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Trust in Project Management

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Abstract

The article analyzes trust as applied to program and project management. The concept of trust is reviewed as understood in various disciplines with emphasis on business and engineering settings. The issue is investigated of how trust is affected in an organization's program and project management when various form of dependencies, including more formal vertical (institutional) and less formal lateral or horizontal (peer-to-peer, team-based) business relations exist among entities or actors in both intra- and inter- organizational settings. A trust model is proposed that is analyzed in more detail in a subsequent paper.

1. Introduction

The last few decades brought an increased interest in the concept of trust by researchers in many areas including the behavioral-, social-, organizational sciences as well as psychology and business. Academic and industry research explores trust and its effects on human interactions, interpersonal cooperation, and the value and efficiency of various organizational structures (Blau, 1964; Blomqvist, 1997; Fox, 1975; Grudzewski, Hejduk, Sankowska, Wantuchowicz, 2008; Lewicki and Bunker, 1996; Lewis and Wiegert, 1985; McAllister, 1995; Meyerson Weick, Kramer, 1996; Noorderhaven, 1992; Rousseau, Sitkin, Burt, and Camerer, 1998). With the growing complexity of projects, business management disciplines have refocused their attention to trust as one of the determining factors of any successful business endeavor and consequently named the discipline "trust management" (Grudzewski, Hejduk, Sankowska, 2008; Grudzewski, Hejduk, Sankowska, Wantuchowicz, 2008).

The concept of trust itself has been the subject of transformation in its meaning from the time of enlightenment era with thinkers such as Rousseau and others and it continues to present day. Past understanding of trust as a stand-alone term and enlightenment's social contract has been transformed into an entity with much broader interpretation as societies underwent changes in pre-industrial, industrial, and modern post-industrial times. Schwaner, Harter, and Palla (2013) presented a classification of "conceptual trust formations" with following dominant interpretations within specific time frames: "social trust (interpersonal) (1955-1984), psychological trust (affective) (1985-1995), organizational trust (leadership, workplace) (1996-2003), and diffused trust (knowledge and team based, e-loyalty) (2004-2013)." Thus, according to Schwaner et al. (2013), trust is a function of time and space, a time-space "living organism" that undergoes conceptual and contextual changes reflecting technological advancement of societies. Furthermore, Schwaner et al. (2013) point out that trust as a cultural norm tends only to adapt to technological changes, staying behind socio-technological transformations. As the consequence, Schwaner et al. (2013) reason that this delay of cultural response to change may affect organizational culture and climate by "creating a potential disconnect between management and expectations, leadership and the ability to maintain trusting relationships with personnel, and a climate redefining trust." Trust has been transformed from a narrow stand-alone and interpersonal concept to a broader systemic entity affecting almost all aspects of any business including the project management area.

Model of trust as an interpersonal trust originated in psychology as well as the social and behavioral sciences. These progenitors gave us the cognitive-based (a constituted evidence of trustworthiness (Lewis and Wiegert, 1985)) and affect-based (emotional bond between individuals (Lewis and Wiegert, 1985)) foundations- that were applied to organizations (McAllister, 1995). The concept of trust, and its commonly used synonyms such as competence, credibility, confidence, faith, loyalty, and reliance was narrowed down and described more precisely as used in various disciplines by Blomqvist (1997). In the context of organizational relations, trust can be viewed at personal, departmental (intrafirm), interfirm, district and nationwide levels (Blomqvist, 1997).

In an organization setting, Fox (1975) separates vertical trust (it implies the existing trust between subordinates and superiors) from lateral or horizontal trust (where a similar work situation is shared, i.e., colleagues or peers). Noorderhaven (1992) refers to organizational or routine trust as an "organization's personality" which stems from organizational culture, which makes the organization interact in a particular, "trusting way", which may merge with personal trust.

Since project work plays a critical role in accomplishing organization objectives, trust management found, not surprisingly, its role in the effectiveness of project management processes. Literature provides a few examples of analyses supported by empirical data of trust in project work. Hartman (1999), Edkins and Smyth (2006), Pinto, Slevin, and English (2009), Smyth, Gustafsson, and Ganskau (2010) provide analyses of the role of trust among project managers and clients in inter-organizational type of relations. Recently, Robert (2015) analyzed the effects of trust with respect to the effectiveness of project risk management in engineering projects. The published cases mainly cover the role of trust in an inter-organizational type of engagement between client and consulting firm (Robert, 2015), owners and contractors (Pinto et al., 2009), or customers/buyers and suppliers (Smyth et al., 2010) with assumed partnership based relationships.

In this article we will analyze concept and meaning of trust in the context of business and engineering project work, and provide an overview of the role of trust attributes in project and program management.

2. Project Management

Project management is a relatively new name to the discipline which allowed for the creation of engineering marvels from the dawn of human civilization. Master builders of antiquity had to know how to plan, coordinate or manage, and successfully execute their projects. The modern era brought new challenges of scalability of production, need for increased efficiency, resource allocation, sustainability, increased customer focus, and social responsibility that justified an increased interest in project management as a separate specialized discipline.

According to Larson and Gray (2014), project management is "a results-oriented management style that places a premium on building collaborative relationships among a diverse cast of characters" and it "provides people with a powerful set of tools that improves their ability to plan, implement, and manage activities to accomplish specific organizational objectives." Furthermore, today's project management has a socio-technical nature which combines socio-cultural aspects with technical or formal parts of the process. While technical aspects such as planning, scheduling, and controlling projects consist of "the formal, disciplined, purely logical parts of the process"(Larson and Gray, 2014), the socio-cultural side represents the other vital part of the project environment where building cooperative relationships, trust, leadership, management styles in intra- and inter-organizational settings come into the forefront. Uncertainties and risks were always part of overall planning and execution in any project especially from a managerial perspective. These aspects found their representation in what is now called "risk management."

In the last few decades, especially in the social and organizational sciences, the concept of trust and how it affects the function of the organization and management issues have captured the attention of many researchers. This article focuses on the "socio-cultural" aspect of project management processes related to trust management. The article attempts to answer how, in the realm of trust management, trust is impacted by various affecting factors and what is the significance of individual affecting factors affecting trust irrespective of project organizational models, which can be drawn from a functional organization, dedicated project teams, or matrix models (Larson and Gray, 2014) in an intra- or inter-organizational setting.

3. Program Management

A program, according to Larson and Gray (2014), is "a group of related projects designed to accomplish a common goal over an extended period of time." Usually each project within a program has an individual project manager. Sometimes, however, the program manager acts as project manager for one or multiple of projects, which often happens in the small or medium size companies (Gapinski, 2016B). In this case the reduced level of vertical dependence reduces naturally possible conflicts and increases a personal and direct relational contact which is usually conducive to building a more trusting environment. On the other hand, having separate program manager(s) adds an additional layer in the management structure, thus adding complexity and more indirect contacts which may affect the level of trust among players. Program management entails the management of the program's projects, projects which may be related or interdependent of each other to a various degree, in a coordinated way to meet company objectives within a defined time frame. According to Pietro (2012) a "program management requires a broader, more strategic focus than project management and tighter integration across all elements of the execution process." In practice, the project management office often acts as a program management entity in small to medium size companies which have a more formalized business organization (Gapinski, 2016B). This article addresses the trust issue across organizational structures.

4. What is trust? Trust Models

The concept of trust has been a subject of analyses at various levels of depth by many disciplines such as philosophy, psychology, sociology, behavioral and organizational science, business, engineering, information technology, and economics among others. Many researchers analyzed the trust issue from a variety of perspectives and were able to provide definitions, meanings, and impact on socio-organizational and managerial environments. The nature of human interdependencies in any project management processes suggests areas of social psychology, economics, and philosophy as the most adequate for choosing the definition of trust to match our interest. In the following section we will review the trust concept and proposed models as it applies to the topic of project management as interpreted by the selected disciplines.

Blomqvist (1997) analyzed trust from the perspective of various disciplines such as social psychology, philosophy, economics, contract law and market research. In social psychology, trust is a personal trait of social interpersonal characteristics (Blomqvist, 1997). Namely, according to Blau (1964) "Parties can gradually build trust in each other through social exchange demonstrating a capacity to keep promises and showing commitment to the relationship." Rotter (1967) wrote about trust: "an expectancy held by an individual or a group that the word, promise, verbal or written statement of another individual or group can be relied upon." In these conceptualizations trust is understood as reliance on the other party's honesty, and an increase in trust requires the parties' interaction to be altruistic over an extended time span.

Philosophy in general treated the topic of trust mostly in abstract absolute terms many times as an unconscious, unwanted or forced feature. In antiquity, within the western school of thought, Greek philosophers did not explicitly write about trust per se, but only indirectly in the context of personal traits and virtues of human beings (Blomqvist, 1997). In the context of virtuous attributes, trust was considered as a positive feature and any violation of trust as a negative one.

In psychology, trust is a psychological state according to Rousseau et al. (1998) which has many definitions and meanings depending on the particular studied discipline and area of application. Within this framework the following attribute models for trust were proposed:

- as a psychological state: Rousseau et al. (1998) defines trust as being: "A psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another."
- attitude based trust: Edkins and Smyth (2006) in which they define trust as being: "A disposition and attitude concerning the willingness to rely upon the actions of or be vulnerable towards another party, under circumstances of contractual and social obligations, with potential for collaboration"
- vulnerability based trust: presented by Baier (1986) referenced in Meyerson et al. (1996): "Accepted vulnerability to another's possible but not expected ill will (or lack of good will) toward one" (Meyerson et al., 1996).

The above descriptions contain the existence of vulnerability as Robert (2015) points out which plays an important role in his analysis of the effectiveness of trust in project risk management.

Few authors in literature presented various operational models of trust as it applies to organizational interrelationships. These trust models describe succinctly essential characterizations of relationships of interpersonal trust as it applies to the effectiveness of managerial operations including project activities. The Hartman model (1999) with its integrity, competence, and intuitive trust is based on ethics, belief and emotional aspects and tends to be, it appears, more applicable to inter-organizational relationships (or peer-to-peer or horizontal organizational relation), while the other two models by introduction of formal aspects (economics, legal factor, organizational norms) apply to a more vertical type of organizational interdependence which appear, for example, in supervisor-subordinate relationships. The models by Rousseau et al. (1998) and Lewicki and Bunker(1996) insert the cultural or organizational norms and liability concerns which do not accommodate very well the partner-based relational dependencies present in the client-consulting firm according to Robert (2015). The models by Hartman (1999), Rousseau et al. (1998), and Lewicki and Bunker (1996) are presented below, in Table 1.

Table 1. Trust Models

Authors	Type of Trust	Definition / Context
Hartman (1999)	Integrity Trust	Ethical trust or belief that one party will routinely look after the interests of another party
	Competence Trust	The belief that the other party has the ability to perform the work assigned
	Intuitive Trust	The emotional or "gut feeling" that one party can trust the intentions and actions of the other party.
Rousseau et al. (1998)	Calculus-based Trust	Trust is motivated by self-interest or economic incentives
	Relational Trust	Trust emerging through repeated, direct interactions that spark a comfort level between parties
	Institution-based Trust	The role of legal institutions, cultural and societal norms in promoting trust within a culture or country

Lewicki and Bunker (1996)	Deterrence-based Trust	Parties can be trusted to keep their word in order to avoid sanctions for violation
	Knowledge-based Trust	Parties know each other well enough that their behavior towards each other is predictable
	Identification-based Trust	Mutual understanding is development to the point where parties can act on each other's behalf

Smyth et al. (2010) introduced the concept of value in assessment of trust in business and showed that financial attributes to trust in customer-supplier relation are positive, when trust is high and, negative when there is a lack of trust.

Trust and ethics often play an important role in societies in the form of less or more formalized social contracts between entities offering the services and a public, in general. In the case of professional licensure policies, where individual states within the USA are responsible for setting up and administrating licensing policies, it is assumed that states' policies would ensure well-being of the public (Gapinski, 2016A).

In information technology and computer network security, trust is an implicit ingredient of information assurance and threat assessment (Fisher and Green, 1992; Gapinski, 2014). In general, a security threat in computer networks is assessed via an implemented risk management strategy. Traditionally, computer networks' entities were treated either as "trusted" or "not trusted," a dyadic classification, so effectiveness of mitigation methods were based to a large extent on threat detection or trust violation. New technologies which include wireless communication and the increasing occurrence of threats from cyber-attacks necessitated the re-examining and change of security strategies by organizations and an introduction of a scale for trust assessment, not necessarily a purely dyadic classification (Gapinski, 2014).

5. Trust, Organizational Structure and Project / Program Management

Mintzberg (1979, 1980) investigated the type of organizational structures and the designs of decision making systems. Mintzberg (1979) proposed five types of organizational structure models: 1. a simple structure (little or no techno-structure, middle level line hierarchy, direct supervision) usually of young and small firms; 2. the machine bureaucracy (highly specialized with routine operating tasks, formalized procedures, standardization of work processes) typically of mass production, insurance, telephone companies, government agencies; 3. the professional bureaucracy (techno-structure at minimum, highly trained specialists with operational autonomy) school systems, social work agencies, craft manufacturing firms; 4. the divisionalized form (market-based, little interdependence between divisions, autonomy of inner divisions) of the largest USA corporations; and 5. the adhocracy (little formalization of behavior, quasi-formal authority, extensive horizontal job specialization) of modern process production firms where the professionals are grouped in functional units for specific project work.

Furthermore Mintzberg (1980), in his analysis of the decision making processes, proposed five designs of decision making systems, or decentralization models- (his decentralization: "the extent to which power over decision making in the organization is dispersed among members"), which are either vertical or horizontal or a combination hereof. For more details see Mintzberg (1979, 1980).

Bleicher (1991) describes two opposite approaches to the development of organizational structures. The first one is oriented towards stability and is based on the concept of human as a rational being and the other one underlines the importance of change and informal relations within an organization. Developed trust facilitates an organization of trust ("Vertrauensorganization"), lack of trust creates an organization with mistrust ("Misstrauensorganization") (Bleicher, 1991). The objective of an organization with trust is innovation while an organization with mistrust is focused on eliminating weaknesses associated with human beings through mechanical-technocratic structures (Mintzberg, 1980). Here, a simplified organizational model is based on one proposed by Fox (1975) where the type of subordination in intra- or inter-organizational structure would imply either a vertical or a horizontal model as the dominant one as in Figure 1.

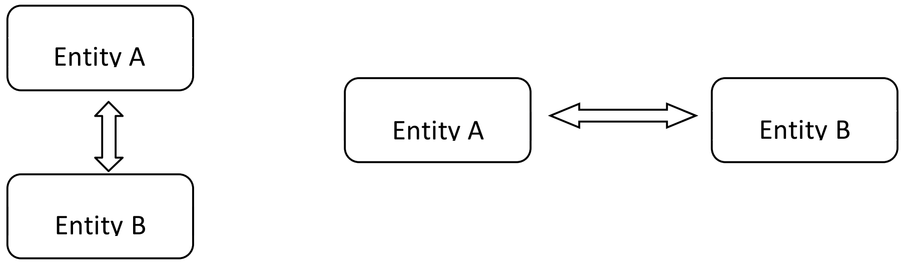

Figure 1. Dominant Vertical vs. Horizontal Relations between entities A & B

Hopej-Kaminska, Hopej, and Kaminski (2014) investigated the relationship between trust and organizational structure assuming the model of Mintzberg (1980), a simple organizational structure model of type 1, which best reflects organizational setups of programs and project works. Hopej-Kaminska et al. (2014) demonstrates with support of empirical data the correlation between the level of trust and the complexity of the organizational dependency among employees. Namely, a higher level of trust in the environment tends to increase the complexity of assigned tasks, and thus lowering the specialization. The decentralization of organizational structures tends to increase the trust level among workers, and in organizations with a high level of trust, more complex and non-routine tasks are assigned (Hopej-Kaminska et al., 2014). Formalization and standardization tends to increase institutional trust, and in the case of a simple organizational structure, the formalization of interdependencies as a promoting mean of trust could be replaced by an organizational culture or value system (Hopej-Kaminska et al., 2014).

In project management like in any other formalized interpersonal collaborations, the interpersonal relations are subject to a developmental process which cannot be downplayed for a successful project result. Consequently, researchers introduced a temporal factor into trust development. Smyth et al. (2010) introduced five stages of trust development:

- Stage 1: Propensity to trust, organizational norms and conditions for trusting
- Stage 2: Trust without existing evidence of behavior
- Stage 3: Zone interpretation
- Stage 4: Tangible and behavioral evidence to build confidence
- Stage 5: Increased expectations due to repeated business.

Robert (2015) in his analysis of the effects of trust on the effectiveness of project risk management considered the influence of a temporal factor by investigating short-term and long-term operational and partnering relationships. His analysis of data and hypotheses testing supports the claim that time duration of building a trusting environment plays a significant role in trust development. His limited time window of trust development, "type-operational environment," contrasts with results of longer periods of partnering, "type-partnering environment," in level of trust and effectiveness of project management. The longer time of interpersonal contacts the better for trust development.

Several authors (McAllister, 1995; Grudzewski et al., 2008; Robert, 2015; Henry, 2012) listed a cultural aspect in trust development which can be rooted in nationality or ethnicity. Authors (McAllister, 1995; Grudzewski et al., 2008; Robert, 2015) reported an increased trust due to cultural homogeneity in organizational structures. Henry (2012) in his analysis of multinational megaprojects (exceeding $1 billion USD) stressed the importance of an ethical corporate culture for successful project completion within an "uncorrupt and sustainable" development environment.

Naturally, the importance of an existing organizational culture cannot be underplayed in any organization's life especially in the realm of management. This is particularly true for companies and project works in high-tech and engineering areas where the development of innovative technologies are crucial to the success of the company. In such a case, Musk, CEO of Tesla (Tribune-Review, 2016) says, "there should be no penalty for failure where it was thoughtful and considered" in a company's overall management strategies and policies. The company should even "embrace failure" (Tribune-Review, 2016) as a necessary factor for overall success.

6. The Proposed Trust Model

The interpretation of trust by Hartman (1999), Rousseau et al. (1998), Lewicki and Bunker (1996), McAllister (1995), Lewis and Wiegert (1985) as it relates to project management processes provide a basis for the proposed model described below. Lewis and Wiegert (1985) proposed an interpersonal trust model established on cognitive-based trust (CBT) (a constituted evidence of trustworthiness) and affect-based trust (ABT) (emotional bond between individuals) foundations as applied to organizational settings. These two principal forms of interpersonal trust: cognition-based and affect-based ones are founded on the belief in others' competence, reliability, responsibility, and organizational formalization for former and interpersonal reciprocated attitude of care, ethical integrity for the latter. The models in McAllister (1995), Pinto et al. (2009), Robert (2015) assumed partner-based relationship among players, susceptibility to vulnerability, and lateral inter-organizational structure. More realistic models in author's view though, should incorporate both types of organizational dependency, vertical and lateral, in either an intra- or inter- organizational relationship. Even in pure horizontal organizational structures, there are some formal dependencies based on supervisor-subordinate relations. Thus, in assessing trust and contributing factors of cognitive-based or the affect-based nature one has to consider the nature of interpersonal relationships implied by the form of the organizational dependence, which motivated the author in proposing the synthesized model - represented in Figure 2. The factors contributing to cognitive-based trust are: competence, responsibility, reliability and organizational formalization and culture, while citizenship behavior, integrity, and cultural affinity are contributing to affect-based trust (see Figure 2).

Consequently, in cases when the relation is dominantly of vertical dependence (DVD), the contribution of attributes of cognitive-based trust provide, based on circumstantial evidence (Gapinski, 2016B), more weight in the overall trust development. This is the case when a systemic, formal, procedural path dependency exists in, for example, a supervisor-subordinate setting, or a firm buying services from another company. On the other hand, in the case of a dominant horizontal type of dependence (DHD) the contribution of factors influencing affect-based trust (ABT), it is hypothesized, carries more significance in the overall trust such as in a peer-to-peer type of relation case. Interestingly, as McAllister (1995) reports, even in peer-to-peer lateral relations (among project managers) "cognition-based trust may be necessary for affect-based trust to develop; people's baseline expectations for peer reliability and dependability must be met before they will invest further in relationships." This fact, after McAllister (1995), is represented by a continuous arrow pointing from CBT to ABT entities in Figure 2. In the case of established relationships, the affect-based trust may contribute to cognitive-based trust either positively or negatively, which is indicated by a dashed arrow pointing from ABT to CBT in Figure 2. Here it is assumed, after McAllister (1995), that actors will undertake either the "needs-based monitoring" (NBM), or "citizenship behavior" (CB), the managing and coping mechanisms to deal with uncertainty in case of cognitive-based trust development, and "control-based monitoring" (CBM) and the "defensive behavior" (DB) approaches to address uncertainty in affect-based trust relations.

The proposed trust model in program and project management depicted in Figure 2 describes trust affected by contributing factors of cognitive-based trust (CBT) such as competence, responsibility, reliability, organizational formalization, and organizational culture, and of affect-based trust (ABT) such as citizenship behavior, integrity, and cultural affinity. The contributions of cognitive-based trust and affect-based trust to cumulative trust (CT) are depicted by a continuous arrow in case of dominant vertical dependence (DVD), and by a dashed arrow for dominant horizontal dependence (DHD) both pointing to cumulative trust (CT) (see Figure 2). Thus, overall trust is the result of the sum of unequal contributions by cognitive-based and affect-based factors depending on formal either vertical or horizontal organizational dependency (Figure 2). It is assumed, after McAllister (1995), that the needs-based monitoring (NBM), citizenship behavior (CB), control-based monitoring (CBM), and defensive behavior (DB), response mechanisms internal to cognitive-based trust and affect-based trust, respectively, are present.

Contributing Factors Type of Trust Cumulative Trust

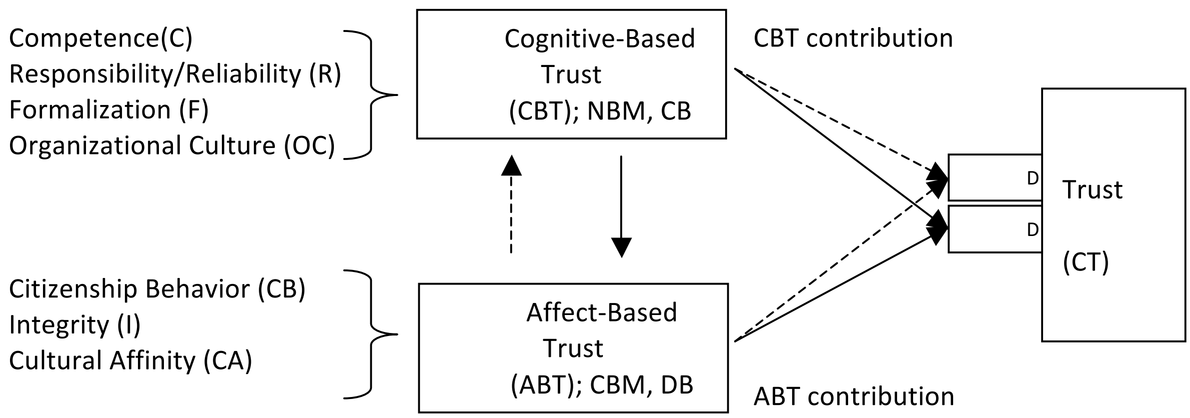

Figure 2. Trust Model in Program/Project Management.
(* DVD = dominant vertical dependence; DHD = dominant horizontal dependence)

One can express the Cumulative Trust (CT) and its value based on contributions of CBT and ABT as:

CBT = f(C, R, F, OC); real-valued f function dependent on C, R, F, OC factors
ABT = g(CB, I, CA); real-valued g function dependent on CB, I, CA factors

$$CT = CBT + ABT \tag{1}$$

where CBT = β CT; β is a CBT contribution coefficient towards CT; ABT = Ψ CT; Ψ is a ABT contribution coefficient towards CT; β and Ψ can be percentages (adding up to 100%), i.e., $\beta = 1 - \Psi$.

The equation (1) which is applicable in all cases may take a following more specific form when investigating trust in business relation when relationship has vertical or horizontal dominant dependence:

$$CT = CBT_D + ABT_D \tag{2}$$

where subscript D denotes dominant dependence either vertical (D = V), or horizontal (D = H). Consequently, it follows that $CBT_D = \beta_D$ CT where coefficient β_D is a CBT_D contribution towards CT and $ABT_D = \Psi_D$ CT where Ψ_D represents the ABT_D contribution towards CT. Since $\beta_D + \Psi_D = 100\%$ (in percent) for D = V or D = H, we have $\Psi_D = 100\% - \beta_D$. The contribution coefficients of cognitive-based trust, β_D, and affect-based trust, Ψ_D, are evaluated based on type of dominant organizational dependence/structure impacting trust.

The equation (1) describes contributions of cognitive-based trust (CBT) and affect-based trust (ABT) and their factors to cumulative trust. The degree of individual contribution of CBT or ABT depends on type of business dependence either vertical or horizontal, which is indicated by subscript D in equation (2), for dependence; where either D = V or D = H for vertical or horizontal dependence, respectively. The CBT and ABT contribution coefficients, β_D and Ψ_D, are subject of evaluation and are determined based on type of dominant organizational relation, either vertical (V) or horizontal (H), impacting trust. The labels C, R, F, OC, CB, I, and CA represent the following factors affecting trust: C – competence, R - responsibility/reliability , F - formalization of structure, OC – organizational culture, CB – citizenship behavior, I – integrity, and CA – cultural affinity, respectively.

In subsequent paper (Gapinski, 2017) the following issues regarding the proposed model of trust in project management are addressed:

1. How do CBT and ABT factors contribute to overall trust in vertical versus lateral dominant dependence?
2. How do project managers assess the actual and the desired contributions of CBT and ABT individual factors (C, R, FA, OC, CB, I, CA) to overall trust in either vertical or lateral type of dependence?
3. How do project managers assess the actual and desired importance of CBT and ABT individual contributing factors (C, R, FA, OC, CB, I, CA) to overall trust in either vertical or lateral type of dependence?

The model's hypotheses are formulated and tested using an anonymous survey distributed among project managers in various industries: manufacturing, mining, high-tech companies, software developers, food processing, architectural/civil engineering, and service sector such as health-care, nursing, IT services in USA, Canada, and elsewhere including firms from Fortune 500 group.

7. Conclusions

The article analyzes trust as applied to program and project management. Trust models were reviewed as reported in the literature by different disciplines. Trust models adopted for trust management and especially project management cases reported in the literature supported by empirical data often assumed partner-based relationships as mostly peer-to-peer, horizontal type of organizational structure, which does not fully reflect realistic and practical dependencies that may have a formalized vertical component. These models assume a vulnerability factor which allows researchers to propose models and hypothesize the role of trust in improvements of effectiveness of the processes. The proposed model takes into account organizational dependency, whether vertical or horizontal as the dominant one affecting trust. The proposed model and associated hypotheses are analyzed and tested in a subsequent article.

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Trust in Project Management: Analysis of the Proposed Model

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Abstract

A model of trust as applied to program and project management is proposed. The proposed model takes into account the dominant business relation dependence either vertical or horizontal, which reflects an often encountered practical business environment. The trust models reported in the literature did not take into account both of the two possible business relationships: either vertical (supervisor-subordinate) and/or horizontal (peer-to-peer), and how they affect trust. This motivated the author to propose the trust model and to analyze its affecting factors and their contributing effects on cumulative trust. To analyze the proposed model and to test the formulated hypotheses the author developed a questionnaire, which was distributed among project managers of various firms representing both industrial and service sectors in the USA, Canada, and elsewhere. The paper uses a survey methodology and statistical analysis to analyze the validity of the anecdotal evidence. Thus, it is the author's belief that the paper addresses the shortcomings of the models previously reported in the literature by taking into account the type of business dependence affecting trust.

1. Introduction

Trust has been a subject of study and empirical investigation by researchers in many disciplines (Blau, 1964; Blomqvist, 1997; Fox, 1975; Grudzewski, Hejduk, Sankowska, Wantuchowicz, 2008; Lewicki and Bunker, 1996; Lewis & Wiegert, 1985; McAllister, 1995; Meyerson Weick, Kramer, 1996; Noorderhaven, 1992; Rousseau, Sitkin, Burt, and Camerer, 1998; Robert, 2015; Rotter, 1967; Gapinski, 2017, etc.). Few authors defined the concept of trust and formulated trust models which were the subject of a few empirical analyses (McAllister, 1995; Robert, 2015). For an extensive review of the trust concept as it applies to various disciplines, especially to program and project management, a reader is referred to McAllister (1995), Pinto, Slevin, and English (2009), Robert (2015), and Gapinski (2017). The investigations of the subject in the literature did not address how the type of the dependency in business relationships affected the trust. The reported empirical models and analyses were performed mostly for peer-to-peer business relationships, thus were limited in scope. More realistic models, in the author's view, should take into consideration both types of possible business relationships: a more formal vertical dependence existing between supervisor and subordinate, and a less formal one, such as peer-to-peer relationship. This fact prompted the author to investigate the subject and to offer the new model which augments the reported models. Consequently, recently, Gapinski (2017) investigated a trust concept with its affecting factors as it applies to program and project management and postulated a model (see Figure 1 below; Gapinski, 2017) which is a subject of this paper.

2. The Proposed Trust Model

The proposed trust model in project management (see Figure 1; Gapinski, 2017) enhances the model reported in the literature (McAllister, 1995). The proposed model allows us to investigate trust in either vertical (supervisor-subordinate) or horizontal (peer-to-peer) dominant dependence with respect to:

- the contribution of cognitive-based trust and affect-based trust factors to cumulative trust,
- the importance of factors affecting trust in either cognitive-based or affect-based trusts.

The proposed trust model incorporates two types of organizational dependency either vertical or horizontal in an intra- and inter- organizational relationship. The investigated factors affecting trust are cognitive-based: competence, responsibility and reliability, organizational formalization and culture, and affect-based such as citizenship behavior, integrity, and cultural affinity (see Figure 1; Gapinski, 2017).

Based on circumstantial evidence (Gapinski, 2016), in cases when the relation in project management is dominantly of vertical dependence, the attributes of cognitive-based trust provide a more significant contribution to overall (cumulative) trust than the affect-based trust attributes. That is the case when a systemic, formal, procedural path dependency exists in, for example, a supervisor-subordinate setting, or a firm buying services from another company. On the other hand, in the case of a horizontal type of dependence as in a peer-to-peer relation, based on anecdotal evidence (Gapinski, 2016), the affect-based trust attributes carry more significance in the overall trust comparing to the effect of cognitive-based trust.

Thus, overall trust is the result of the sum of unequal contributions from cognitive-based and affect-based factors depending on formal business or organizational dependency.

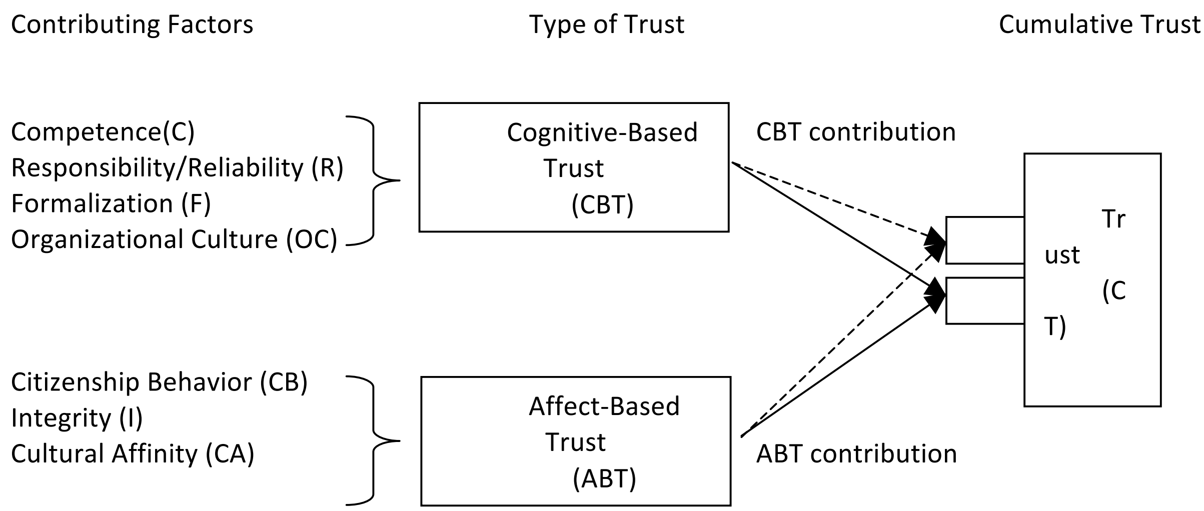

Figure 1. Trust Model in Program/Project Management. (Gapinski, 2017)

(* DVD = dominant vertical dependence; DHD = dominant horizontal dependence)

One can express the Cumulative Trust (CT) and its value based on contributions of CBT and ABT as:

CBT = f(C, R, F, OC); real-valued f function dependent on C, R, F, OC factors

ABT = g(CB, I, CA); real-valued g function dependent on CB, I, CA factors

$$CT = CBT + ABT. \quad (1)$$

The equation (1) which is applicable in all cases takes a following more specific form when investigating trust in business relation when the relationship has vertical or horizontal dominant dependence:

$$CT = CBT_D + ABT_D \quad (2)$$

where subscript D denotes dominant dependence either vertical (D = V), or horizontal (D = H). It is assumed that $CBT_D = \beta_D CT$ where coefficient β_D is a CBT_D contribution towards CT and $ABT_D = \Psi_D CT$ where Ψ_D represents the ABT_D contribution towards CT. Since $\beta_D + \Psi_D = 100\%$ (in percent) for D = V or D = H, we have $\Psi_D = 100\% - \beta_D$.

The contribution coefficients of cognitive-based trust, β_D, and affect-based trust, Ψ_D, are evaluated based on type of dominant organizational dependence/structure impacting trust.

The equation (1) (Gapinski, 2017) describes contributions of cognitive-based trust (CBT) and affect-based trust (ABT) and their factors to cumulative trust. The degree of individual contribution of CBT or ABT depends on the type of business dependence either vertical or horizontal, which is indicated by subscript D, for dependence; where either D = V or D = H for vertical or horizontal dependence, respectively. The contributions of cognitive-based trust (CBT) and affect-based trust (ABT) to cumulative trust (CT) are depicted by a continuous arrow in the case of dominant vertical dependence (DVD), and by a dashed arrow for dominant horizontal dependence (DHD) both pointing to cumulative trust (CT) (see Figure 1). The CBT and ABT contribution coefficients, β_D and Ψ_D, are the subject of evaluation and are determined based on the type of dominant organizational relation, either vertical (V) or horizontal (H), impacting trust. The labels C, R, F, OC, CB, I, and CA represent the following factors affecting trust: C – competence, R - responsibility/reliability , F - formalization of structure, OC – organizational culture, CB – citizenship behavior, I – integrity, and CA – cultural affinity, respectively.

In the model's hypotheses testing the estimates for contribution coefficients β_D and Ψ_D are determined from the responders' surveys. Namely, the responders were asked to report their perceptions of relative importance of the set of CBT and ABT factors using percentages, e.g. 70 %/30%.

The analysis addresses the following question:

- How do CBT and ABT factors contribute to overall trust in vertical versus horizontal dominant dependence based on perceived contributions as assessed by survey responders?

The subsequent article will address the degree of importance of CBT and ABT individual contributing factors and their respective impact on overall trust by answering the following two questions:

- How do project managers assess the actual contributions of CBT and ABT individual factors (C, R, FA, OC, CB, I, CA) to overall trust in either a vertical or horizontal type of dependence?
- How do project managers assess the desired importance of CBT and ABT individual contributing factors (C, R, FA, OC, CB, I, CA) to overall trust in either a vertical or horizontal type of dependence?

3. Model's Hypotheses

In order to test the proposed model and related hypotheses formulated below regarding the influence of the factors affecting trust, the author developed a questionnaire (see Appendix) which was distributed among project managers - representatives of various firms in the industrial and service sectors. The data were collected from representatives of large and medium size companies in manufacturing, mining, high-tech, IT, and the service sector such as architecture/civil engineering, healthcare, banking and financial services (Gapinski, 2016). The firms represented in a survey were from the USA, Canada, England, and Poland. Some of the companies were from the Fortune 500 group. The survey responses were anonymous and collected within a ten-month period from the fall of 2016 to late spring of 2017. A total of forty eight surveys were received. Survey responders were asked to report their perceptions of relative importance of the set of CBT and ABT factors using percentages, e.g. 70%/30%. Since the surveys used self-reported choices the response data can be treated as Likert scale scores justifying the Likert approach. Since the percentages add up to 100%: $\beta_D + \Psi_D = 100\%$ for D=V or H, it is possible to simplify the hypotheses testing. Namely, instead of performing a test of the mean difference between the CBT and ABT percentages, one can directly test the coefficients: β_D and Ψ_D.

The hypotheses are postulated as follows:

Hypothesis 1

In hypothesis 1 the contribution of the CBT factor affecting cumulative trust in a vertical type of dependence is tested. It is hypothesized that the contribution of the CBT factor to cumulative trust in a vertical type of dependence is greater than 50% (i.e. larger than the contribution of ABT).

H_0: $\beta_V = 0.50$

H_a: $\beta_V > 0.50$

Hypothesis 2

In hypothesis 2 the contribution of the ABT factor affecting cumulative trust in a horizontal type of dependence is tested. It is hypothesized that the contribution of the ABT factor to cumulative trust in a horizontal type of dependence is greater than 50% (i.e. larger than the contribution of CBT).

H_0: $\Psi_H = 0.50$

H_a: $\Psi_H > 0.50$

Hypothesis 3

In hypothesis 3 the CBT contribution to cumulative trust in a vertical versus a horizontal dependence is tested.

It is hypothesized that the CBT contribution to cumulative trust in vertical dependence is greater than in horizontal dependence.

H_0: $\beta_V = \beta_H$

H_a: $\beta_V > \beta_H$.

To test the hypotheses the data analysis was performed using t-tests with a significance level of $\alpha = 0.05$.

4. Results of Hypotheses Testing

In this section the results of the hypotheses testing are analyzed. The following hypotheses testing results were obtained using statistical analysis with t-tests (see Table 1):

Hypothesis 1: Hypothesis H_0 is rejected and hypothesis H_a is accepted. Thus, in vertical dominant type of dependence the CBT factor contributes more than 50% to cumulative trust. Namely, the CBT factor (mean $\beta_V = 64.29$ in percent) provides a statistically significant larger contribution to CBT than the ABT factor (mean $\Psi_V = 35.71$ in percent).

Hypothesis 2: Hypothesis H_0 is not rejected. Thus, in a horizontal dominant type of dependence the ABT factor (mean $\Psi_H = 43.1$ in percent) contributes less than 50% to CT. This contradicts the circumstantial assertion that places a more significant role on ABT versus CBT.

Hypothesis 3: Hypothesis H_0 is not rejected. The conclusion is that the contribution of the CBT factor to cumulative trust in vertical and horizontal types of dependence is not statistically different, even though the collected data of the CBT contribution to cumulative trust suggests that the CBT contribution is larger in the vertical dependence (mean β_V = 64.29) than in the horizontal dependence (mean β_H = 56.90).

Table 1. β_D and Ψ_D Data w/ Statistics. β_D & Ψ_D Data in Percent.

	Hypothesis 1	Hypothesis 2	Hypothesis 3	
	β_V	Ψ_H	β_V	β_H
Mean	64.29	43.1	64.29	56.90
Median	70	40	70	60
St. Dev.	15.91	21	15.91	21
Mode	80	40	80	60
Range	40	80	40	80
Min	40	10	40	10
Max	80	90	80	90
n	24	24	24	24
df	23	23	41	
t-Stat	3.35	-1.44	1.22	
p-value	0.002	0.92	0.11	
t-critical	1.77	1.71	1.68	

Since $\Psi_V = (100\% - \beta_V)$ and $\Psi_H = (100\% - \beta_H)$, the testing of the contribution of CBT in a vertical versus a horizontal dependence, $\beta_V = \beta_H$, in hypothesis 3 is equivalent to the testing of the contribution of ABT in vertical versus horizontal dependence, Ψ_V and Ψ_H.

5. Conclusions

The article analyzes trust as applied to program and project management. Trust models adopted for trust management and especially project management cases supported by empirical data often assumed partner-based relationships as mostly peer-to-peer, horizontal type of organizational dependence. These models do not fully reflect practical scenarios, which may often have a formalized vertical component. The model presented here takes into account organizational dependencies, either vertical or horizontal, affecting trust as perceived by parties in an organization. The paper used a survey methodology and statistical analysis to analyze the validity of the anecdotal evidence. The anonymous questionnaires collected from numerous project managers representing various industries and service sectors were analyzed and used for model and hypotheses testing. Thus, the paper enhances the model reported in the literature and brings new light on how the type of business relationships affects trust in business interactions.

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7. Appendix

Trust in Project/Program Management
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Questionnaire

Please fill out each form for one type of dependence if present.
(Type of Dominant Type of Activities' Dependency: Vertical: Supervisor-Subordinate or Lateral: Peer-to-Peer)
What type is your company / organization (manufacturing, material engineering, service, IT, utility, etc.)?

Type of project work (design, manufacturing, software development, mining industry, healthcare, services, etc.):

Company size: (small, medium, large)

Characterize your activities and responsibilities:

Activity Type:	Yes	No
Project Management		
Project work		
Program Management		
Program work		
Intra-organizational (within organization)		
Inter-organizational (collaboration with external organization/entity)		
Collaboration Type:	Blank	Blank
Collaboration has mostly vertical dependence (supervisor-subordinate)		
Explain shortly the dependence:	If vertical, are you a supervisor? Are you a subordinate?	
Collaboration has mostly lateral (horizontal, peer-to-peer) dependence		
Explain shortly the dependence:	If lateral, are you a supervisor? Are you a subordinate?	

Note:
CBT: cognitive-based trust is based on your belief in other party competence, responsibility & reliability, formalized structure (promoting trust), organizational culture (promoting trust)
ABT: affect-based trust is based on belief that other party brings good citizenship, integrity and cultural affinity in work relations.

Evaluate:

1. **Assess** using scale from 1 (strongly disagree), 2 (disagree), 3 (somewhat disagree), 4 (neutral), 5 (somewhat agree), 6 (agree), to 7 (strongly agree) the actual (**Actual Grade**) Cognitive-Based Trust (CBT) and Affect-Based Trust (ABT) attributes within your immediate organization (such as project team, or collaboration with other group on peer-to-peer basis);

2. **Assess** importance (**Importance Scale**) of each attribute using scale from 1(lowest) – 4(highest) for CBT or 1(lowest)-3(highest) for ABT.

Trust & Attributes	**Actual Grade: 1(lowest)-7(highest)**	**Importance Scale: 1(lowest)-4(highest); use each digit only once below**
Cognitive-Based Trust (CBT):		
I believe that the other party is competent. (competence)		
I believe that the other party performs duty responsibly and reliably. (responsibility & reliability)		
I believe that our immediate organization (project group, etc.) has an efficient formalized structure conducive to institutional trust. (formalized structure)		
I believe that our organizational culture is conducive to reaching our goals (organizational culture)		
Affect-Based Trust (ABT):	**Blank**	**Scale 1(low)-3 (high); Use each digit only once below**
I feel that the other party brings good citizenship characteristics to the table. (citizenship)		
I feel that the other party has professional & ethical integrity and it looks for my interests. (integrity)		
I feel cultural affinity to other co-workers. (cultural affinity)		

For Indicated Dependence:

CBT vs ABT

I feel that ______(CBT or ABT) during the project/program work was more important to build trusting relationship.

In my estimation, the contributions of Cognitive-Based Trust (CBT) and Affect-Based Trust (ABT) to overall developed trust can be assessed as (in percent): CBT____; ABT ____ (Example: CBT 70%; ABT 30%).

Gait Lines of Persons with Plantar Fasciitis

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Abstract

Plantar fasciitis is characterized by micro tears, breakdown of collagen, and scarring in the plantar fascia. This study is performed to evaluate and compare the gait and plantar pressure distributions of subjects with and without plantar fasciitis using a high resolution pressure sensor mat during static and dynamic loading conditions. A procedure is reported within outlining data collection procedures and analysis of pressure data through the computation of the Modified Arch Index and the Center of Pressure Excursion Index.

1. Introduction

Plantar fasciitis affects approximately 10% of the US population in their lifetime. There have been a number of studies performed investigating the effect of common treatments for plantar fasciitis on pain (self-assessed) and pressure distribution using pressure mats to measure said distribution [1]. One limitation of the studies which used sensor mats to measure plantar pressure distribution is that the studies do not account for dynamic situations [1]. Another limitation is that the measurements were made while the subjects wore shoes. Thus, not directly measuring plantar pressure distributions. Other studies solve this issue by utilizing in-sole sensors as opposed to sensor mats [2, 3, 4].

To the knowledge of the authors, no study has been performed comparing the gait line of subjects with plantar fasciitis with the gait line of subjects without plantar fasciitis. The purpose of this study is to evaluate and compare the gait and plantar pressure distributions of subjects with and without plantar fasciitis using a pressure sensor mat during static and dynamic load conditions. The objective of this study is to gain a deeper understanding of the difference of the gait and plantar pressure distributions between subjects with and without plantar fasciitis. This can then result in tailoring treatment techniques so that subjects suffering from plantar fasciitis can have similar plantar distributions to subjects without plantar fasciitis.

2. Literature Review

The plantar fascia is the flat band of fibrous tissue connecting the calcaneus to the metatarsals. The plantar fascia consists of three distinct structural components: the medial component, the central component, and the lateral component; with the central component being the largest and most prominent. It supports approximately 14% of the total load of the foot [5], and plays a vital role in affecting the gait. Patients with plantar fasciitis have pain and inflammation of the plantar fascia. It is estimated that 10% of the US population are affected by plantar fasciitis in their lifetime [6], with over a million annually suffering from chronic symptoms [7]. Plantar fasciitis is the third most common injury among runners, behind patellofemoral pain and iliotibial band friction syndrome [8].

The most common cause of plantar fasciitis is thought to be from biomechanical overuse of the plantar fascia from excessive standing or running [9]. Some studies suggest that plantar fasciitis may result when the plantar fascia fails to adapt to different forces which include: compressive, bending, or shear [10]. There are several risk factors which include: long periods of standing, obesity, and increase in exercise.

Since plantar fasciitis is caused by excessive stress on the plantar fascia, treatment is aimed at decreasing the stresses. This can be achieved by decreasing the force or by distributing the force to a larger contact area [11]. There are several treatment options for plantar fasciitis depending on the severity of the injury. Initial treatment includes: rest, application of ice, various foot stretches, and the use of proper shock absorbing footwear. Ongoing treatments include: orthotics, night splints, walking casts, foot wrapping and taping. For more severe or chronic injuries, treatment options include: corticosteroid shots or plantar fascia release surgery.

The use of foot orthotics is one of the most common treatments for plantar fasciitis. When implemented, it aids in preventing overpronation of the foot. Pronation is defined as the inward movement of the foot as it rolls to distribute the force of impact during walking or running [12].

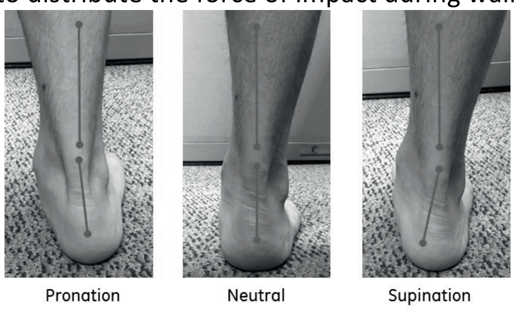

Figure 1 – Foot Functions

Foot roll is measured by the angle that the ankle line makes with the leg line, as shown in Figure 1. The ideal foot roll is approximately 15°. Foot roll over 15° is considered to be overpronation [12]. Studies show that maximum pronation during standing places the greatest amount of strain/stress on the plantar fascia and the medial longitudinal arch of the foot [13]. Thus limiting or reducing pronation, theoretically will reduce strain/stress resulting in a reduction in pain. Several trials have been performed to study the efficacy of both over-the-counter and custom foot orthotics in patients with plantar fasciitis. The results suggest that the use of orthotics decrease foot pain and improve the function of the foot [1].

Figure 2 – Examples of Common Orthotics Used to Treat Plantar Fasciitis

Night splints are another viable treatment option for patients with plantar fasciitis. Night splints help maintain the length of the plantar fascia while the subject sleeps and the foot is at rest. Without the use of night splints, the plantar fascia shortens due to the ankle joint naturally assuming a plantarflexed position when at rest [14]. The sudden stretching of the plantar fascia after long periods of rest would explain the reported pain during the first initial steps.

Foot wrapping and supportive taping are treatment options for subjects with plantar fasciitis. Much like the use of orthotics, foot wrapping and taping may reduce the strain in the plantar fascia during standing or while in motion [15]. Studies have been performed investigating the effects of taping on plantar pressure both on immediate post-application and after a duration of time post-application [16]. While pain was reported to decrease immediately after post-application of taping, the effects were lost after 10 to 20 minute walking sessions [17].

Several options are available for measuring the pressure on the various parts of the foot when attempting to determine the efficacy of various treatments for plantar fasciitis [18]. Some measure the pressure distribution made by the foot using pressure sensor mats [1]. Others use sensors incorporated within the insoles of shoes [2, 3, 4].

Studies have been performed to determine the similarities and differences of the feet of subjects with and without plantar fasciitis. It was determined that subjects with and without plantar fasciitis did not have significant differences in rear foot misalignments [19]. However, subjects with plantar fasciitis or past histories of plantar fasciitis show a significantly more elevated medial longitudinal arch [19]. Another study investigated the effect of reducing pain by reducing the pronation often caused by subjects with plantar fasciitis [16]. Pain was assessed by using a common approach, the visual analog scale (VAS) [1].

One study involved comparing common treatments for plantar fasciitis and their efficacy [1]. There are limitations to some of the studies performed, one being that some of the results are only valid for static weight-bearing instances [1].

Experimental methods of measuring the stresses and/or strains on plantar fascia are very limited. Direct measurements would require invasive methods. Thus, modeling the plantar fascia and other parts of the foot has become an attractive alternate method.

Several published studies have been conducted in an effort to estimate the material properties of tissues [20, 21, 22]. In order to simplify the structure of the foot, researchers would construct the model with fused bone segments [23, 24]. Other boundary conditions, such as the friction between the surface of the skin and the insole of a shoe were estimated using test results [25]. Table 1 outlines the Modulus of Elasticity and Poisson's ratio for modeling the plantar fascia [26].

Table 1 – Material Properties Used for Modeling the Plantar Fascia [26]

Component	Modulus of Elasticity (Mpa)	Poisson's Ratio
Ground	1,000,000	0.1
Insole	0.40	0.2
Fascia	350	---
Ligament	260	---
Soft Tissue	0.15	0.45
Cartilage	1	0.4
Bone	7,300	0.3

Efforts have been made to model the effects of different treatments of plantar fasciitis (different shapes of insoles) on the plantar fascia [26]. In this study [26], a detailed 3D finite element model of a foot was created. The model was calibrated by comparing its results of similar boundary conditions to that of the pressure distribution measurements made from an actual foot. Once calibrated, common orthotic solutions were added as boundary conditions of the model. The shape of the orthotic was optimized, using an iterative process, to minimize the stresses on the medial portion of the foot.

3. Methodology

In gaining a better understanding if there is a difference in gait of subjects with and without plantar fasciitis, experimental data was collected using a high resolution pressure mat and then analyzing the data. The following sections describe data collection and analysis.

3.1 Data Collection

In collecting the data, the foot pressure distribution was measured using a Tekscan Pressure System. All subjects were instructed to be barefoot. The first portion of the test involved measuring the pressure produced by the subject when standing. This was conducted by instructing the subject to sit and relax for a period of five minutes, to minimize any stress on the foot. At the completion of five minutes, the subject was instructed to stand on the pressure sensor mat with both feet, simultaneously. This was repeated to obtain a total of three measurements.

The second portion of the test involved measuring the pressure produced by the subject's feet when walking. The subject was instructed to walk back and forth the length of the room. The mat was placed in a manner which allowed the subject to step on the pressure sensing mat with a different foot for each direction. Several measures were taken in order to ensure that the subject's natural gait was recorded. This included having the subject walk the test area prior to recording, instructing the subject to focus on point above eye level during walking, and conversing with the subject during data collection. Approximately 15 steps for each foot were acquired.

3.2 Analysis

The subject's foot was divided into several regions for analysis purposes, as shown in Figure 3. The main three regions of interest include: the forefoot, arch, and heel.

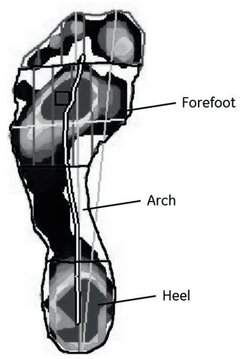

Figure 3 – Foot Regions

Using the results from the standing tests, the foot was individually analyzed in order to calculate its Modified Arch Index (MAI). The MAI was calculated using equation 1, where the pressures are the maximum pressures for each respective region [27]. The regions used for the calculation of MAI consist of the forefoot, arch and heel (shown in Figure 3).

$$MAI = \frac{Pressure_{Arch}}{Pressure_{Forefoot} + Pressure_{Arch} + Pressure_{Heel}}$$

(Equation 1)

Foot posture was defined as planus, rectus, or cavus using Table 2. A planus foot posture is characterized by a exhibiting a low arch. Conversely, a cavus foot posture is characterized by exhibiting a high arch. A rectus foot posture is characterized by a well aligned heel and forefoot [28].

Table 2 – Foot Posture

Foot Posture	MAI Range
Cavus	0 - 0.030
Ractus	0.031 - 0.163
Planus	0.164 - 0.713

The Gait Lines of the subject were plotted using the output of the Tekscan software and analyzed. In order to make an accurate visual comparison, each of the gait lines was normalized using the average gait length of all of the subjects.

Using the results from the walking test, each foot was analyzed to calculate its Center of Pressure Excursion Index. The center of pressure excursion (CPE) is the distance (along the forefoot width line, yellow) between the foot axis (cyan) and the gait line (white), as shown in Figure 4 [27]. This value (CPE) is then divided by the forefoot width (yellow line) in order to calculate the Center of Pressure Excursion Index, as shown in Equation 2.

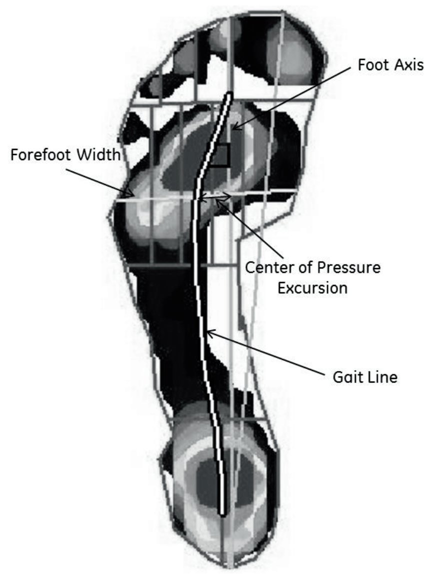

Figure 4 – Center of Pressure Excursion

$$CPEI = \frac{Center\ of\ Pressure\ Excursion}{Forefoot\ Width}$$

(Equation 2)

Foot function was defined as overpronated, normal and oversupinated using Table 3. Overpronation occurs when the foot rolls inward excessively during gait. Conversely, oversupination occurs when the foot rolls outward excessively during gait.

Table 3 – Foot Function

Foot Function	CPEI Range
Overpronated	-25.30 to 7.30
Normal	7.40 - 20.90
Oversupinated	21 - 43.70

4. Summary

A procedure has been developed which provides a mechanism to collect and analyze pressure distribution data of subjects with and without plantar fasciitis. In particular, the procedure outlines the collection of data using a high resolution pressure sensor mat during static and dynamic loading conditions, and how to compute the Modified Arch Index and the Center of Pressure Excursion Index. These indices will be used in comparing subjects with and without plantar fasciitis. Once the differences of gait lines a plantar pressure distribution are established, treatment for the disorder can be tailored for each individual. The treatment may be iterative; solutions can be implemented until subjects have gait lines and plantar distributions similar to individuals without plantar fasciitis.

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Internet of Things: How to Design a Sustainable Product?

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Abstract

The Internet of Things (IoT) is a new paradigm that has used recent advances in wireless communications and enhances everyday objects with techniques such as artificial intelligence to mimic smart behaviors of human counterparts. The aim of this study is to come up with a systematic way to propose a sustainability oriented design of smart, connected products, which should simultaneously incorporate the typical customer expectations. The proposed framework is built upon the Quality Function Deployment (QFD) methodology. We build a comprehensive decision support framework in designing the most suitable IoT product in respect to customer expectations considering quality alongside with sustainability. The proposed framework is applied to end user oriented IoT products, used as a part of home automation and health surveillance. Considering the IoT technology related features of the products, the introduced QFD methodology enables us to come up with a design that highlights how sustainability could be enhanced further. The main contribution of the framework is that it enables organizations to consider different and mostly contradicting issues during product design simultaneously. The approach tries to implement sustainability into IoT offering by considering energy efficiency, resources usage and tries to satisfy typical customer expectations like features, price, security, privacy, etc. To the best of our knowledge, in the related literature, there is not a similar comprehensive framework for designing a sustainability oriented IoT product.

1. Introduction

The Internet of Things (IoT) is a relatively new phenomenon that promises “smart, connected” products (Porter & Heppelmann, 2014). As a disruptive technology, IoT requires that its adopters have to create their own view of the concept. Current IoT solutions are concentrated in areas of assisted living, e-health, enhanced learning, automation, industrial manufacturing, logistics, business/process management, intelligent transportation of people and goods (Atzori, Iera, & Morabito, 2010). We can observe from these diverse views and application areas that companies like Google, General Electric, Amazon, Samsung, etc., are trying to define their individual product families on proprietary platforms without seeking compatibility with other platforms. The main reason for lack of a common platform is that IoT vision requires organizations to come up with new mobile computing scenarios and propose products that should be able to connect with everyday objects and show some level of intelligence to fulfill the promise of “smart” products (Gubbi, Buyya, Marusic, & Palaniswami, 2013). As the first movers in the market seek competitive advantage over their peers, they try to establish a solid framework and license it to potential complementary product/service providers. Herein, commonality of standards is considered less relevant. However, as proposed by Gubbi et al. (2013), in order to obtain a functional

IoT environment: (1) a common view interactions between users and their appliances, (2) software and ubiquitous communication networks to process and relay the contextual information, and (3) data analytics for autonomous and smart behavior, are required. Hence, the design of a successful IoT product does not only depend on its performance, but also necessitates possible integration of information with other products/platforms, which are as now usually treated as independent silos of automation. Consequently, a large amount of data collection, processing and feedback in real-time if possible to the users' of the system remains a challenging task (Ibáñez, Zeadally, & Castillo, 2015). Moreover, designing a product with minimum resources, enhancing the quality of human life and having a social impact and adopt applications/services for public interest are highly sought for features.

In this work, a decision support framework for service providers in designing the most suitable product for their customers and simultaneously considering sustainability to obtain the right product configuration is proposed. Several design considerations and quality of service attributes from the literature are brought together to form customer expectations. This information is transformed into product technical characteristics that should guide service/product providers to shape their offerings. The applicability of the proposed methodology is demonstrated using a wearable IoT solution design.

The remainder of the paper is partitioned as follows: in Section 2 the IoT literature along with the challenges is briefly discussed. Section 3 summarizes the methodologies that are used to build the decision proposed framework. The details of the implementation procedure using a demonstrative example with a wearable IoT product is explained in Section 4. Finally, Section 5 gives concluding remarks and possible future work.

2. Literature review

The Internet of Things literature is rapidly growing and different aspects of the topic are discussed by various researchers. Typical topics include enabling technologies, protocols and possible application scenarios. In their work, Díaz, Martín, & Rubio (2016) defined IoT as "a paradigm based on the Internet that comprises many interconnected technologies in order to exchange information". Their paper presented in detail a survey of integration components: Cloud platforms, Cloud infrastructures and IoT Middleware along with additional integration proposals and data analytics techniques. In their paper, Li, Li, & Zhao (2014) discussed the difficulty to satisfy different quality of service requirements and achieve rapid services composition and deployment in an IoT environment. Their model aimed to optimize the scheduling performance of an IoT network and minimize the resource costs. Research by Mazhelis & Tyrvainen (2014) established a framework for evaluating the IoT platforms from the perspective of how widely they cover the potential needs of the application providers. They evaluated several of the available IoT platforms based on the platforms' features and supporting services. In their work, Flügel & Gehrmann (2009), gave an overview over some of the technical challenges that need to be overcome to build IoT networks, sample applications that have already been realized and necessary technologies that are required by applications in the field of logistics. In their work, Xu, He, & Li (2014) presented key enabling technologies in the field of IoT, major applications in industries, and discussed trends and challenges. In their paper, Viswanath, Yuen, Tushar, & Li (2016) proposed a design for a large-scale IoT system for smart grid application. They implemented their proposed design in a testbed for energy management applications. Stojkoska & Trivodaliev (2017) discussed how to integrate the existing state-of-the-art smart home applications. They proposed a framework consisting of different components to efficiently integrate smart home objects in a cloud-centric IoT based solution. In their work, Wilhelm et al. (2016) presented a platform to allow up to 50,000 students to simultaneously collect and learn from their personal activity, transportation, and environmental data. They defined their goals for the design as: "be low cost; remain powered for the duration of the data collection campaign; robustly sense a wide range of environmental parameters; and be packaged in a form factor conducive to wide-spread adoption and ease of use". Miranda et al. (2106) proposed a design, development, implementation and evaluation of a platform called Common Recognition and Identification Platform. The aim of the platform was defined as supporting caregivers and citizens to manage health routines. They deployed their platform in a real-life setting to demonstrate its effectiveness. In their work, Lee, Kim, Ryoo, & Shin (2016) investigated recent advances in wearable technology and their applications. They defined possible applications of sustainable wearables as: (1) Wellness and healthcare: fitness oriented; aiming to encourage healthy and active lifestyles; etc.; (2) Aid for people with disabilities: help the visually impaired people by giving information about the surrounding environment; allow them to detect obstacles; help them to participate in sports activities using computer vision; etc.; (3) Disaster relief and public protection: devices and clothing for emergency disaster relief personnel; detect fatigue level and presence of life threatening conditions; etc. Their sustainability perspective in an IoT environment is based on the requirements defined for sustainability by UNICEF (Palmer & Gershbein, 2017): be cost effective, low power, rugged and durable, and scalable.

In this work, the sustainability perspective is combined with the design attributes commonly used in the literature for IoT products/services. For sustainability, UNICEF recommendations are followed. The paper differs from Lee et al. (2016), as the former only concentrates on the requirements phase. This paper aims to guide the product/service providers to design their offerings systematically by transforming the requirements into technical product attributes. In this regard, this paper applies the QFD methodology, a popular approach in literature for product design. The requirements defined in this paper is more comprehensive than Lee et al. (2016) as it incorporates additional attributes like security, privacy, reliability, context-awareness, etc..

3. Proposed methodology

3.1. Quality Function Deployment

In this work, QFD is used to guide the product/service providers in shaping their IoT products/services. QFD is a management tool that uses customer expectations and transforms them into the product/service attributes. Hence, the design process incorporates the customers' voice into the product/service before the product/service even reaches its respective customers. It minimizes the correction necessary to the products/service after they are consumed by the customers. The framework is quite comprehensive, but the essential ingredient is customer requirements, the main output is the means to satisfy the requirements. For a comprehensive background on QFD, the reader could refer to Chan & Wu (2005). As depicted in Figure 1, the initial matrix of the QFD methodology, named the House of Quality (HOQ) consists of seven elements:

(1) Customer needs (CNs). These are the customers' phrases where they describe their expectations from the service/product. They are usually called 'voice of the customer'. (2) Product characteristics (PCs). These are the measurable technical/design characteristics. They are usually called 'voice of the company'. They provide the means for achieving the CNs. As the CNs are usually referred to as the WHATs, the PCs are usually referred to as the HOWs. (3) Relative importance of the CNs. Simultaneously handling all of the input coming from the customers is usually quite complicated. Eliminating insignificant CNs is chosen as a solution to this problem. (4) Relationships between WHATs and HOWs. They define to what extent each PC affects each CN resulting in importance values of CNs in terms of PCs. (5) Inner dependencies among the CNs. At this stage, the interactions among the CNs are discovered. The predicted results can be utilized to measure how much and whether or not CNs supports each other. (6) Inner dependencies among the PCs. Similar to the inner dependencies among CNs, the inner dependencies among PCs are calculated and placed in the roof of the HOQ. (7) Competitive analysis. This step incorporates competitors' performances into the decision process of the service

providers when defining improvement directions. (8) Overall priorities and performance values of PCs. The performance values and final ranking are combined to obtain the overall ratings of PCs. The product/service providers will then use these ratings when designing the most appropriate product/service.

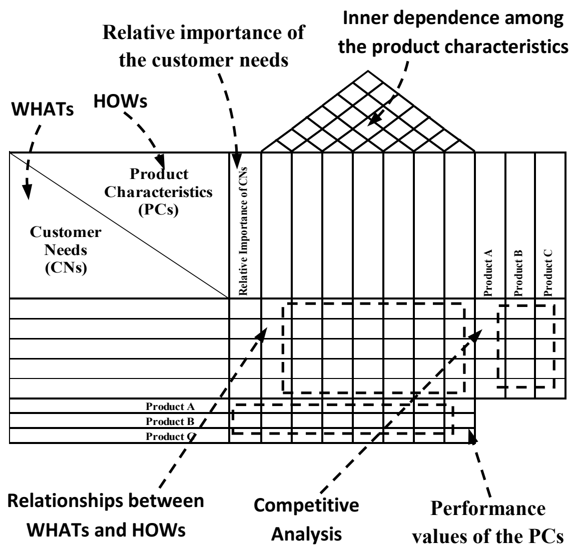

Figure 1. House of quality

3.2. Analytic network process (ANP)

ANP is considered as an extension to the widely used multi-criteria decision making tool, the analytic hierarchy process. AHP separates a complex problem into several levels so that they constitute a hierarchy (Saaty, 1980). Although AHP merges both qualitative and quantitative perspectives into a decision problem, it is not able to handle the interconnections and inner dependencies among decision factors at the same hierarchy level. Hence, ANP discards hierarchies and replaces them with network representations. This change is considered useful when the real life scenario necessitates the consideration of interactions among different elements of the system, which is represented with a network structure in ANP (Figure 2) (Saaty, 1996).

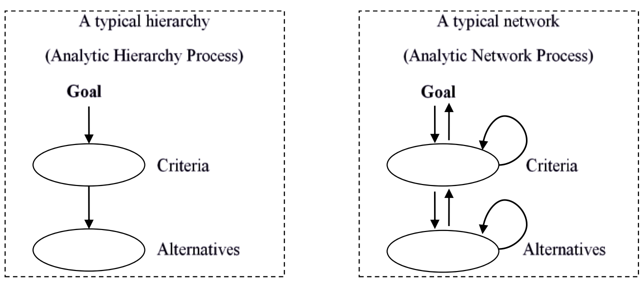

Figure 2. Representation of AHP and ANP structures

3.3. Decision framework

The proposed decision framework evaluates customer satisfaction and suggests improvement directions and is based on the work in Karsak, Sozer, & Alptekin, (2003). The decision framework combines the QFD methodology with ANP. The network representation required by ANP as a matrix is given as:

$$\mathbf{W} = \begin{array}{r} \\ \text{Goal (G)} \\ \text{Criteria (C)} \\ \text{Alternatives (A)} \end{array} \begin{array}{c} \begin{array}{ccc} \text{G} & \text{C} & \text{A} \end{array} \\ \begin{pmatrix} 0 & 0 & 0 \\ \mathbf{w}_1 & \mathbf{W}_3 & 0 \\ 0 & \mathbf{W}_2 & \mathbf{W}_4 \end{pmatrix} \end{array}$$

where $\mathbf{w}_1$ represents the impact of the customer satisfaction goal; $\mathbf{W}_2$ evaluates the impact of the CNs on each of the PCs; $\mathbf{W}_3$ and $\mathbf{W}_4$ represent the inner dependencies of the CNs and PCs, respectively. Initially, the interdependent priorities of the CNs ($\mathbf{w}_C$) are computed by multiplying $\mathbf{W}_3$ by $\mathbf{w}_1$, and similarly the interdependent priorities of the PCs ($\mathbf{W}_A$) are calculated by multiplying $\mathbf{W}_4$ by $\mathbf{W}_2$. The final ratings of the PCs are obtained by multiplying $\mathbf{W}_A$ and $\mathbf{W}_C$.

4. Empirical analysis

The demonstrative example used in this paper aims to establish importance ratings for the technical attributes of a wearable IoT product that should satisfy its customers' expectations and consider sustainability in the design phase. The CNs and the PCs used in this study are based on a comprehensive study of the literature. The main motivation was to establish a comprehensive list of attributes that should enable a design with sustainability and customer satisfaction in mind. As the first step, customers are required to rate the performance of the given cloud product, in respect to the following criteria: Low power usage (CN1), Cost effective (CN2), Rugged/durable design (CN3), Scalable (CN4), Security (CN5), Privacy (CN6), Reliability (CN7), Availability (CN8), Context-aware (CN9), Usability/ease of deployment (CN10), Mobility/portability (CN11) and Interoperability (CN12). Next, the PCs that will be used to satisfy the CNs are determined: Resource discovery (PC1), Resource management (PC2), Data management (PC3), Data integrity (PC4), Data confidentiality (PC5), Data analytics capability (PC6), Event management / Autonomous behaviour (PC7), Embedded information processing (PC8), Service response time (PC9), Delay/latency (PC10), Bandwidth (PC11), Throughput (P12), Programming abstraction (PC13), Service-based architecture (PC14), Distributed architecture (PC15), User/device authenticity (PC16), Recoverability (PC17), Extensibility (PC18), Modularity (PC19), Addressability (PC20) and Sensor fusion capability (PC21).

After defining CNs and PCs, the next step involves determining the relative importance of the CNs by using the following typical question in pairwise comparisons: 'Which customer need should be considered more in establishing the most successful IoT product?'. The importance weights following the pairwise comparisons made for each of the customer needs are given in Table 1.

Table 1. Relative importance weights of customer needs (CNs)

Low power usage (CN1)	0.052	**Reliability (CN7)**	0.045
Cost effective (CN2)	0.119	**Availability (CN8)**	0.045
Rugged/durable design (CN3)	0.031	**Context-aware (CN9)**	0.153
Scalable (CN4)	0.058	**Usability/ease of deployment (CN10)**	0.031
Security (CN5)	0.200	**Mobility/portability (CN11)**	0.052
Privacy (CN6)	0.122	**Interoperability (CN12)**	0.091

Similar to the procedure applied by Karsak et al., all of the remaining matrices are obtained and the necessary matrix manipulation operations carried out. In total, 49 pairwise comparisons are made in order to obtain the matrices. The final ratings for product characteristics are given in Table 2.

Table 2. Final ratings for product characteristics

Resource discovery (PC1)	0.031	**Throughput (P12)**	0.039
Resource management (PC2)	0.047	**Programming abstraction (PC13)**	0.018
Data management (PC3)	0.069	**Service-based architecture (PC14)**	0.082
Data integrity (PC4)	0.065	**Distributed architecture (PC15)**	0.020
Data confidentiality (PC5)	**0.110**	**User/device authenticity (PC16)**	**0.121**
Data analytics capability (PC6)	0.080	**Recoverability (PC17)**	0.012
Event management /Autonomous behavior (PC7)	0.059	**Extensibility (PC18)**	0.029
Embedded information processing (PC8)	0.049	**Modularity (PC19)**	0.032
Service response time (PC9)	0.014	**Addressability (PC20)**	0.015
Delay/latency (PC10)	0.005	**Sensor fusion capability (PC21)**	**0.095**
Bandwidth (PC11)	0.008		

Due to space constraints these pairwise comparisons are omitted in the paper. Based on the empirical results, the most important product characteristics, when a sustainability oriented IoT solution is designed with the typical customer expectations satisfied along the way, should be user/device authenticity, followed by data confidentiality and sensor fusion capacity. As the pairwise comparisons are made to IoT product solution providers and several IoT users, it represents their opinions. Therefore, a more elaborate analysis would lead to results that are more robust. However, based on the feedback of the experts and users, the list of customer needs and product characteristics proved to be effective to denote the most important customer expectations and interrelated product characteristics with them.

5. Conclusion

The Internet of things is a topic which is becoming very popular in the literature. Almost all of the software and hardware industry players are presenting their version of the topic. The players in the market are trying to come up with new ideas to differentiate their products in order to gain a competitive advantage over their rivals and attract their prospective customers. Thus, product/service design proves to be a very challenging task. With these challenges in mind, in this work a framework that incorporates different perspectives simultaneously is proposed. Undoubtedly, a successful IoT product should be able to satisfy its prospective customers in terms of the quality merits it possesses. Sustainability, a relatively new term that simply tries to achieve environmentally conscious and less resource consuming products and services could contribute to the quality of individual life and social public interest. A sustainability point of view could be used to define new roles for IoT applications and guide product/service providers in establishing extended objectives and meanings for their offerings. Hence, sustainability has a potentially contributing effect on user acceptance and IoT framework standardization for developing effective and efficient solutions.

In this work, QFD is applied to a very recent topic. The main reason for selecting this tool is that it provides a very systematic and traceable means to analyze customers' needs and objectively transform customers' own phrases into measurable product attributes. Here the strength of the methodology lies in its ability to handle subjective and objective information encountered during usual design processes. Then, ANP is used for the pairwise comparisons to deal with dependence issues, which are inevitable in such a complex decision problem. Possible extensions of this work could use additional matrices to design/select appropriate middleware structure along with preferences at cloud, network and device layers. Further research may implement fuzzy set theory to deal with vague and imprecise information during the evaluation of CNs, PCs and the relationships among them.

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Development of a Nanoscience Undergraduate Curriculum: Exploring the Societal and Ethical Implications

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Abstract

Nanoscience education presents opportunities to further the growth and development of nanotechnology through creating student awareness and stimulating their interest in the subject matter. In order to increase awareness and interest in nanotechnology and its societal and ethical implications, especially in minority and underprivileged students, an introductory course in nano and bio technology was created at the University of Alabama consisting of instructional modules focused on the three pillars of sustainability: economical, environmental, and societal impact, with additional focus on nanotechnology itself from a scientific standpoint. Emphasis was placed on quality hands-on, technology based activities conducted in a classroom setting, as well as class discussions and trips to see first-hand applications and research techniques related to nanotechnology. The developed course was offered twice during the spring semesters of 2014 and 2015, first opened to only honors students and then offered to all students without restriction. To support class lectures, student learning was enhanced through in-class experiments, many of which were modified from original modules generated by UA's NSF support Math Science Partnership for Nano Bio Science. Learning was also supported through the use of field trips and guest speakers whose work involved nanotechnology. Skype was frequently used to communicate with guest speakers remotely. Virtual access was made available for special class sessions to remote participants. An integrated course curriculum with an authentic learning experience was established. A canned draft version of the course is now available for use and on-going conversations with other institutions such as Bevill State Community College, the University of West Alabama, and Alabama A&M University are taking place to explore the possibility for online offerings at those institutions.

1. Introduction

In the last years, nanotechnology has developed as a practical option for increasing life sustainability through extensive improvements in technology. The importance of educating students on the societal, ethical, commercial, and environmental implications of nano and biotechnology has become essential. Nanoscience educational initiatives first started at Rice University in 1993 by Professor Richard E Smalley. His team's efforts pushed the limits of science and technology and generated the need for other nanotechnology education enterprises (Smalley Institute History, 2008). Since then, great strides have been made in both understanding the science behind nanotechnology and its applicable uses. The trend for technology to become more efficient through the use of nano-sized particles is continually increasing. Therefore, educating undergraduates and the emerging generations on this topic is key to continuing the growth and innovation of the nanotechnology field.

1.1 Project Background and Goals

In 2007, a survey on nanotechnology awareness resulted in only 19% of the 1,850 respondents having previous knowledge of the topic. This study acknowledged the lack of available curricula on the subject and warranted the need for a nanotechnology curriculum in post-secondary learning institutions (Kahan et al., 2007). Hence, the National Science Foundation initiated a Nanotechnology Undergraduate Education (NUE) program to provide an opportunity for students to have an educated perception of nanotechnology as well as to build student's interest in the future of science and technology (Nanotechnology Undergraduate Education in Engineering, 2014). It was through the financial support of NSF's NEU program that this project became a reality. The main goal of our initiative was to develop a new course at the University of Alabama based on the science of nano and biotechnology as well as its ethics, economics, and environmental implications. The five objectives of this project included (1) developing an integrated nano curriculum with opportunities for authentic learning, (2) promoting a multidisciplinary ethical identity of undergraduate STEM students, (3) conducting and evaluating pilot classes using the developed course material, (4) institutionalizing the course for scheduling during the academic year, and (5) disseminating our research outcomes and findings via a distance learning platform. The long term goals of our project are to (1) develop an integrated course curriculum for institutions to implement a nanotechnology course that will allow students the opportunity for genuine learning of nano and biotechnology and (2) develop and promote meaningful research collaboration and relations between the University of Alabama and other education institutions across the United States. Through these goals, our initiative directly addresses the mission of the National Science Foundation by promoting the progress of science (The NSF in a Changing World, 1995).

1.2 Educational Objectives and Outcomes

Preparing students for the future of science and technology is vital to improve the sustainability of our nation's economy. Therefore, a nanotechnology based curriculum (16 weeks, three hours of instruction a week) was developed and implemented to effectively communicate its concepts and applications, and stimulate the learning environment needed to fully educate the students. The specific educational objectives were (1) to introduce students to the concept of nanotechnology and its applications, (2) extend student's knowledge on micro/nanofabrication technologies, and (3) introduce students to the United Nation's pillars of sustainability and impacts of nanotechnology on different aspects of life such as environmental impacts, economical influence, and other societal and ethical implications of nanotechnology. The student learning outcomes that stemmed from these objectives were (1) that students must demonstrate an understanding of the principles and practical applications of nanotechnology, (2) students must be able to interpret how nanotechnology will advance in the future, (3) students must be able to recognize sociocultural and technological issues that could interrupt the progression and acceptance of nanotechnology, (4) students must be able to identify and understand the equipment used to develop materials on the nanoscale, (5) students must understand the societal, economical, and environmental implications of nanotechnology from local and global perspectives, and (6) students must contribute in hands-on and critical thinking activities of nanotechnology applications.

1.3 Authentic Learning

Authentic or real life learning encourages student creation of useful products. A motivational challenge and setting provided by the instructor begins the process of engaging students in a process for learning important problem-solving skill sets. Modules developed followed inquiry based designs such as the 5'E model for instruction. For our project, students were introduced to a new method for understanding how issues or concerns involving nano-biotechnology can be appropriately addressed and solved by using the United Nation's Sustainability Pillars: by balancing in all cases people, place and profit.

2. Project Methodology

2.1 Curriculum Development

In order to build a comprehensive understanding of nanotechnology and its societal implications, the course content was designed around the three pillars of sustainability: economic, environmental, and societal impact, with additional focus initially on nanotechnology itself from a scientific standpoint. This gives students a practical and theoretical understanding of the subject while also fostering discussion and creative thought. To further assist reaching these educational goals, the course material was divided into seven teaching modules. According to a previously conducted nanotechnology undergraduate education study at the University of Central Florida, having educational teaching modules are not enough to engage students in STEM related disciplines as they also need to become actively involved through hands-on activities and field demonstrations (Shabani et al., 2011). To comply with this, guest speakers were invited to discuss their personal experiences with nanotechnology in order to enhance the students' interest in seeking careers in the field. At the same time, it was determined that pairing guest speaker lectures with hands-on demonstrations provided students with a more integral learning experience and allowed them to realize the vast opportunities nanotechnology presents. To permit students to gain a greater understanding, supporting material for each module as well as the guest speakers' lectures were made available on an online platform (i.e. Blackboard Learn) for their access. Figure 1 depicts the sequence of the modules in the developed course curricula. The modules involving the economics and ethics part of the curricula must be taught after the first two modules have been imparted. In the same manner, the modules on the environment and societal issues must be the last in the curricula while the hands-on module, "Seeing is believing" can be taught at any point in the semester.

2.1.1 Module 1: Nanotechnology and Biotechnology:

This module is covered during the first three weeks of classes and introduces students to the concepts of nanotechnology and biotechnology via scientific explanations, practical demonstrations, and exploring some current real-life applications. To enhance the learning experience, students are instructed to research specific applications of nanotechnology and deliver in-class presentations on them. Figure 2 shows the module set-up on Blackboard Learn, which was used to distribute related course media to students digitally.

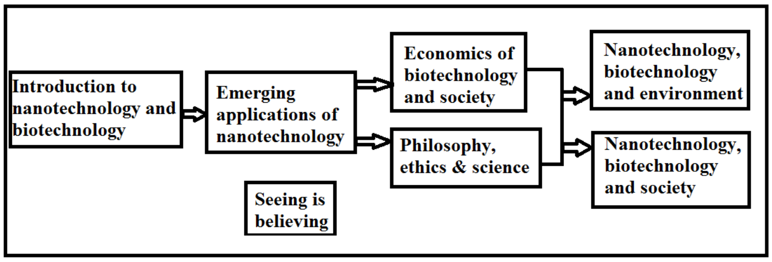

Figure 1. Sequence of Modules

2.1.2 Module 2: Engineering Applications of Nanotechnology:

Once students have learned the fundamentals of nano and biotechnology, further applications of nanotechnology are more deeply explored, with the focus beginning to shift to potential societal, ethical, and environmental implications. During the three weeks dedicated to this module, students were given the task of conducting research on the societal and environmental effects of cerium oxide nanoparticles. As seen in Figure 3, the students were presented with research material to further develop their understanding of nanotechnology and prepare them to successfully complete their research papers on cerium oxide nanoparticles.

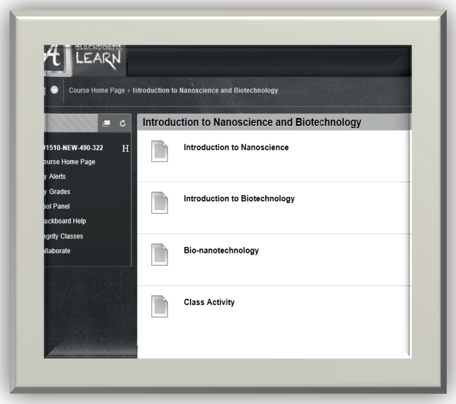

Figure 2. Module 1: Introduction to Nanoscience and Biotechnology

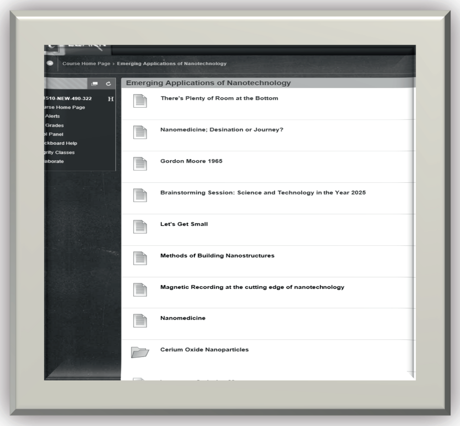

Figure 3. Module 2: Engineering Applications of Nanotechnology

2.1.3 Module 3: Economics of Nanotechnology:

This module discusses the economic implications of nano and biotechnology, with a greater emphasis on the sustainability of the technology. Hands-on activities were conducted to demonstrate economic implications of nanotechnology. During this module, several guest speakers with ample knowledge in the design, development and commercialization of nanotechnology products as well as in overall technology-based entrepreneurship provided students with useful insights on the life cycle cost analysis for nano and bio-based technologies. As mentioned previously, students were given access to guest speakers' presentation materials, shown in Figure 4, to facilitate a better understanding of the experts' domain knowledge.

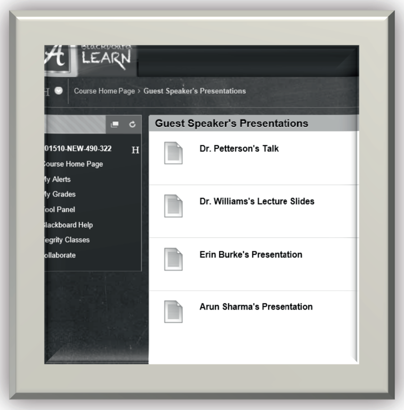

Figure 4. Guest Speaker's Presentation Materials

2.1.4 Module 4: Ethical Implications of Nanoscience:

Six hours of instruction were dedicated to explore different ethical and philosophical view points and assess how ethics and philosophy have impacted scientific advancement. The focus of the class discussions was on both Eastern and Western principles of philosophy and ethics. Case studies on various moral and ethical implications were an important component of these lectures because it allows the students to explore the concepts more in-depth. Students also were challenged with the task of analyzing an ethical dilemma from the scientific literature and relate it to nanotechnology, the three pillars of sustainability, and the theories learned in class. The material provided for this module, along with additional readings to further class discussions, can be seen in Figure 5.

2.1.5 Modules 5 & 6: Societal Implications of Nanoscience & Environmental Considerations:

Module 5: Societal Implications of Nanoscience focuses on the combined impact that nanotechnology and biotechnology have on human lives, both from an individual and societal standpoint. Student team presentations on the development of nanotechnology within a particular application, and related societal implications, were performed. In Module 6, environmental implications were explored, which included discussion of the costs of producing and proliferating new technologies and how to limit environmental harm (see Figure 6).

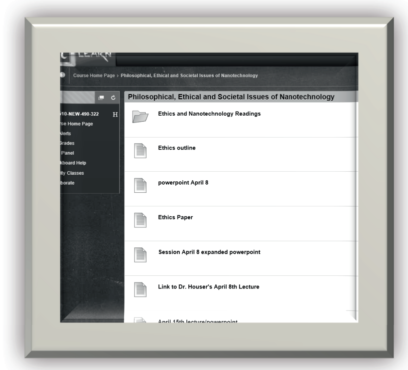

Figure 5. Module 5: Ethical Implications of Nanoscience

Figure 6: Modules 5 & 6: Societal Implications of Nanoscience & Environmental Considerations

2.1.6 Module 7- Seeing is Believing:

Module 7, taught alongside with modules 5 and 6, is designed to enable students to gain direct practical experience and exposure to nanotechnology via hands-on experiments, class demonstrations, and touring state-of-the-art lab facilities. Several field trips were taken to explore specific nanotechnology-related topics. Among the facilities toured are: The University of Alabama's Microfabrication Facility as well as its Central Analytical Facility, University of Alabama at Birmingham (UAB)'s Materials Processing and Applications Development (MPAD) Center, and the Southern Research Institute (SRI) in Birmingham, Al.

2.2. Curriculum Implementation

2.2.1 Spring 2014- Pilot Course Offering:

The nanotechnology curriculum created was initially designated to be offered as a freshman, introductory engineering science elective course, but the desire to market the course to a greater student population prompted a switch to offer it as an undergraduate honors class. The course was successfully taught in the spring of 2014 to a small class of fourteen students. There were a few findings during this initial course trial that needed to be addressed. The subject material was taught in a sequence that was not the most desirable one, pedagogically speaking. Also, a greater emphasis on the scientific and technological aspects of nanotechnology at the beginning of the course was found to be needed to ensure a smooth transition to subsequent discussions of economic, ethical, societal, and environmental implications. Hence, the class instructors collaborated during the summer and fall months of 2014 to restructure the course content, incorporating a preliminary phase before covering topics related to the three pillars of sustainability: economical, environmental, and societal. Such a curriculum change would allow students to understand the broad structure of nanotechnology instead of receiving fragments of it as the course progressed.

2.2.2 Spring 2015 - Final Course Offering:

After the pilot offering, the project's principal investigators -and co-instructors of the course- were able to refine the curriculum implementation strategy to ensure a more enriching learning experience. The desire to reach a more diverse group of students persuaded the project team to offer the class as a New College elective, capped to 17 students, in the spring of 2015. The University of Alabama's New College allows undergraduate students to customize their own particular major, different from all traditional majors offered at the University. New College students are usually regarded as enthusiastic, curious, and open to new ideas and technologies, and according to the University of Alabama's demographic statistics, there is a higher percentage of student diversity in the New College than in the rest of the university community as a whole. Thus, offering the course as a New College elective resulted in reaching a more diverse student population. Nevertheless, teaching nanoscience theory to students from technical and non-technical backgrounds within the same class presented a few barriers. A study completed by a group of investigators at Portland State University found that in order to successfully engage both types of students at the same time, a comfort level between both populations of students had to be established (Morris et al., 2015). Consequently, during the final offering of the created course, group collaborations were encouraged in brainstorming activities, hands-on experiments, and research based projects. This approach proved to help foster class participation and improve the comprehension of the topics taught. Furthermore, after restructuring the content organization, students were able to acquire a thorough foundation of nanotechnology through the understanding and learning of its technical and societal implications more fluidly.

2.2.3 Community Outreach:

During both semesters the course was offered, students were given the opportunity to volunteer for multiple community service projects. Through these projects, students were expected to consider the sustainability pillars learned in class and to assess how their work may benefit the local workforce and community health. Among the projects undertaken by the students are the ones listed below:

- *Create and test nano-bio-materials with engineers at UAB using plants that may be optimally grown for testing in the Greensboro, Alabama Boys and Girls Club greenhouse.*

a) Manufactured and tested composite materials at the University of Alabama Birmingham (UAB) Center for Green Composites.

b) Mentored middle or high school student(s) from Pratt City and/or Greensboro on using the nano-bio-materials for making construction materials for housing.

- *Help program and test bio sensors for Greensboro, Alabama Greenhouse for system automation (e.g., watering plants) and data collection (e.g., temperature, carbon, nitrogen).*

a) Sensors were programmed in Tuscaloosa, Alabama and in Greensboro, Alabama at the Boys and Girls Club. Work was conducted with a practicing environmental and mechanical engineer.

b) Conducted preliminary research on sensors for use in smart materials (e.g., next generation of nano-bio-sensor materials, particularly for homeland defense and healthcare).

c) Mentored middle and high school student(s) on programming and using bio sensors for the Greensboro, Alabama Boys and Girls Club.

- *Program and test a sensor device for biodiversity monitoring. An important part of biotechnology is tools for optimizing species diversity and growth. As one such tool, an environmental sensor was tested* *with a Hale County High School student and a PhD candidate computer scientist via a new virtual mentoring program.*

- *Travel to Greensboro, Alabama Friday afternoons to the Boys and Girls Club to help explain what NUE students learned in class to middle and high school students who are building a greenhouse for growing plants to research for biomaterial properties.*

2.2.4 Related Synergy Activities:

Out of the 17 students taking the course in spring of 2015, twelve were involved in hands-on nano-biotechnology research with the project investigators and other outside collaborators. A weekend session at Alabama Southern Community College in Thomasville, Alabama, provided students with an opportunity to work with Professor Christie Prout in the making of biomaterial pulp at the National Center for Pulp and Paper. A TiO2 nanomaterial was added to the pulp through sonication at a chemistry laboratory (NSF funded) located in the Department of Chemistry and a fiber spinning facility (Department of Defense funded) at the Alabama Institute for Manufacturing Excellence, both on the University of Alabama campus. Some of the pulp generated through this collaborative effort was used to create and test the manufacture of a bioplastic for replacing petroleum based products.

Amended pulp was also used by class students as well as partner investigators from local community colleges at the University of Alabama's Center for Green Composites directed by Dr. Uday Vaidya, professor of Mechanical, Aerospace, and Biomechanical Engineering at UAB, for processing into a household construction material. Dr. Virginia Wimberly, University of Alabama CHES Textiles, served as a project mentor as part of an NSF RII funded Entrepreneurial Internship Program (EIP) with outreach students. The overall goal of this initiative is to research green nano-biomaterials uses in construction applications, particularly examining bamboo and kudzu properties, including seasonal variations. Dr. Rich Martens, associate director of the University of Alabama's Central Analytical Facility, generated ATF and SEM images of the engineered nano material stock for examination by mentors and students participating in the 2015 NUE program. Furthermore, Mr. Jonathan Bonner, Engineering Services Manager for the CFM Group, served as mentor in a project whose end goal was to provide interested students with the opportunity to (1) produce and test nano-bio materials, and (2) discuss elements of the materials, process or project concept with the entire class. UA's DoD's funded fiber spinning facility was used for this endeavor. The students' involvement continued during the summer months as part of a NSF Research Infrastructure Improvement (RII) grant through UA's Entrepreneurial Internship Program. The above mentioned activities enabled the undergraduate students that took part in our nanoscience curriculum to gain hands-on experience in nanotechnology applications.

2.3 Project External Evaluation and Assessment

Dr. Monica Cox, Director of the Pedagogical Evaluation Laboratory at Purdue University, and her team of collaborators developed an assessment and evaluation plan to gauge the effectiveness of the developed course. A series of qualitative and quantitative surveys, interviews, and observations of the students and faculty involved with the teaching of the class were used in the assessment process. The majority of the students' feedback identified strengths that promoted the effectiveness of the course. The students benefitted from (1) the firsthand involvement that the course provided, (2) seeing nanotechnology being used in real world applications via guest speakers and tours of laboratories and (3) having instructors relate nanotechnology to diverse areas and applications.

According to her assessment, the instructors provided students with valuable learning opportunities through various in-class activities and experiments. Also, students were exposed to real-life nanotechnology applications by touring The University of Alabama's Central Analytical Facility, University of Alabama in Birmingham's Materials Processing and Applications Development Center, and

Southern Research Institute. These experiences heightened the students' interest in nanotechnology and allowed them to understand the concepts that were taught through lectures as well as realize the variety of applications that the subject is involved with.

3. Conclusion and Remarks

Nanotechnology education presents opportunities to further the growth and development of nanotechnology through creating student awareness and stimulating their interest in the subject matter. Through an NSF's NUE grant, an introductory course in nanoscience was created at the University of Alabama based on the three pillars of sustainability: economical, environmental, and societal impact. Emphasis was placed on quality hands-on, technology-based activities conducted in a classroom setting, as well as class discussions and field trips. The developed course represents an integral curriculum in nanoscience which provides students with an authentic learning experience that enables them to develop a well-rounded understanding of the fundamentals of nanotechnology, its relationship with biotechnology, as well all its societal and environmental implications.

4. Acknowledgements

The authors want to thank the National Science Foundation for funding this initiative (NSF Grant #1242141). Special thanks are also extended to Dr. Monica Cox and her team at Purdue University for providing valuable feedback and recommendations to improve the effectiveness of the developed nanoscience curriculum.

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Process Improvement for Student Recruitment

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Abstract

Students in the Six Sigma and Applied Statistics course offered by the Electronic System Engineering Technology (ESET) program at Texas A&M University are required to complete a Six Sigma project in the course. Starting in the spring semester of 2016, students taking the course worked on a project to improve the student recruitment process. The goal was to increase the ESET new student enrollment by 30% over the previous year. The student teams followed the DMAIC process to improve the recruitment process. The students took many actions, including designing hand-outs, conducting surveys, visiting academic advisors in other departments and community colleges, and presentation to high school students. The effort in the first semester was followed by another team in the fall semester. As a result, new student enrollment in Fall 2016 was increased by 147% compared with the number for Fall 2015.

1. Introduction

Like many engineering technology programs across the country (Bailey, 2013; Ferrara, 2008; Shull, 2012), the Electronic System Engineering Technology (ESET) program at Texas A&M University faces the challenge of low student enrollment.

There are many possible causes for the low enrollment problem for the ESET program. Many potential students and their parents are confused by the difference between engineering and engineering technology (Land, 2012; Holling, 2003). To make things worse, there are two-year engineering technology programs (Associate degrees) offered by community colleges and four-year engineering technology programs (BS degrees) and people are confused by these programs (Johnson *et al.*, 2017). ESET is one of four small programs within the Department of Engineering Technology and Industrial Distribution at Texas A&M University. There are thirteen faculty members in ESET compared to seventy five faculty members in the Department of Electrical Engineering. ESET is not known to most students at Texas A&M University.

There was one student who graduated after 9 years at Texas A&M, jumping from one program to another until he found ESET.

To address the growing workforce demand in the State of Texas and the USA, the College of Engineering at Texas A&M started the "25 by 25" initiative in 2013 with the goal of increasing the total engineering enrollment from 12,000 in 2013 to 25,000 by year 2025. The total enrollment at Texas A&M has increased from 45,000 in 2006 to 56,000 in 2013 and to 66,000 in 2016. The 25 by 25 initiative is supposed to help ESET enrollment; however, the increase in ESET enrollment was still relatively low compared to other engineering majors.

ESET made a major change in its curriculum to focus on product and system development in 2012 (Porter *et al.* 2012). Six Sigma (Harry and Schroder, 2000; Nonthaleerak and Hendry, 2006; Pande and Holpp, 2002) was added to the curriculum to expose students to different aspects in the product development process (Zhan *et al*., 2009; Zhan and Porter, 2010). This was motivated by other successful adoption of Six Sigma in several engineering programs (Coowar *et al*., 2006; Furterer, 2007; Gore, 2004; Ho *et al*., 2006; Rao and Rao 2007; Scachitti *et al*., 2008).

Students in the Six Sigma and Applied Statistics course (ESET 329) are required to complete a Six Sigma project. Students enrolled in ESET 329 in the Spring and Fall semesters of 2016 chose to worked on increasing the ESET enrollment.

This paper presents the course project carried out by the student teams.

2. Research Methodology

Two different formats were used in the Spring and Fall semesters of 2016. In the Spring semester, there were seven teams of students each consisting of 4 to 5 students. In the Fall semester, one team of 17 students was formed with subgroups consisting of 4 to 5 students. Each subgroup would focus on a different aspect of the project. The student teams followed the DMAIC process (Snee, 2004; Pyzdek, 2003; Wortman *et al*., 2014; Zhan and Ding, 2015) to complete their course projects.

Define

Define is the first step of the Six Sigma process. Students used the affinity diagram and brainstorming to determine the business and performance metric, as shown in Fig. 1.

Affinity Diagram		
Enrollment	Graduation/Job	Enrollment Breakdown
New enrollment	Time to graduation	# transferred out
# of student admitted	ESET students satisfaction levels	# transferred in
# of applicants	Job placement rate	# of change of major
# of inquiries to ESET	Average salary	# of readmits
# of attendants in ESET informationals		# of ETAM applicants

Figure 1. Affinity diagram

The student teams decided that the focus of the project should be in the area of student enrollment increase. Considering that the enrollment number would not be available until next semester, students chose number of students admitted by ESET as the performance metric.

Problem Statement:
The ESET program has not been competitive in the number of students that enroll each semester as compared to other engineering programs at Texas A&M University.

Project Scope:
The total enrollment data will not be available until next semester, therefore, only number of admitted applicants will be considered.

Business Case:

- The low enrollment also has a negative impact on retention rate and time to graduation. Many students wasted years before they found ESET. Some even left the College of Engineering or Texas A&M University. This hurts the retention rate and has a negative impact on the college and university rankings.

- ESET is not making a significant contribution to the 25 by 25 initiatives and education of workforce in general.

Project Sponsor: ESET Program
Resources: Students in Six Sigma class, TA, and a faculty advisor
Project Champion: Dr. Wei Zhan
Performance Metric: Number of applicants admitted to the ESET program
Project Goal: Increase the number of admitted applicants by 30% from Fall 2015
Deliverables: New recruitment process and new recruitment materials
Project Risks: The teams have other duties and responsibilities for other classes, and might not be able to put in a significant amount of time into the project.

Based on the information collected by the teams, the SIPOC diagrams were created. Fig. 2 shows the SIPOC diagram created by one of the student teams. The current process was captured in Fig. 3.

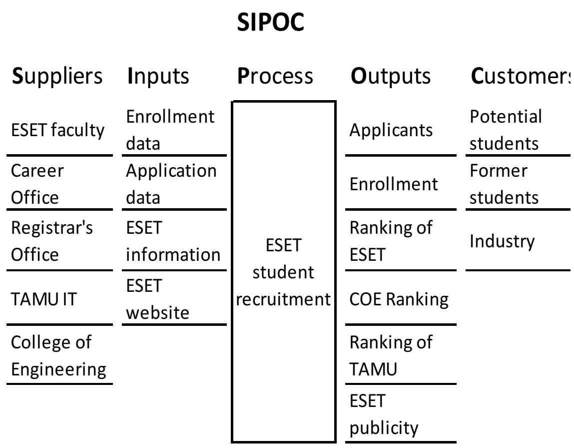

Figure 2. SIPOC diagram

To understand the customer needs and what the team should do to improve the process, a CTQ tree was created, as illustrated in Fig. 4.

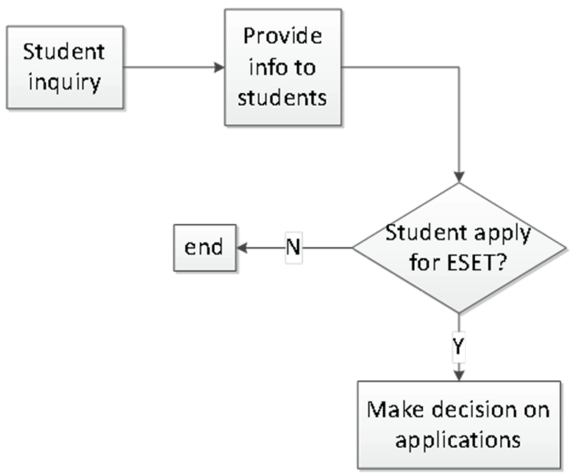

Figure 3. Current process

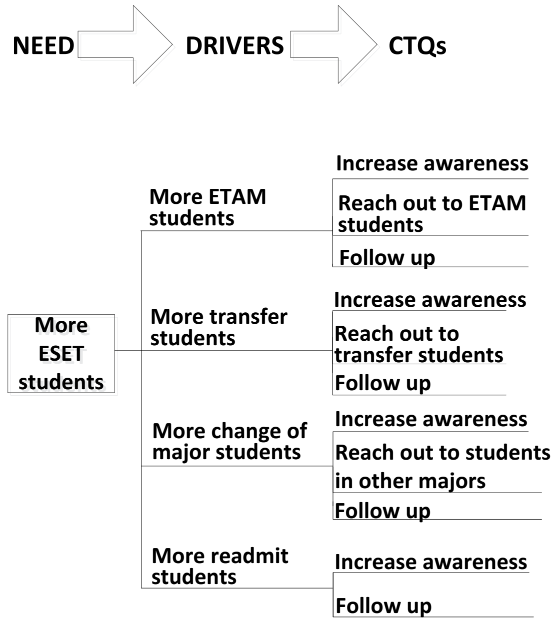

Figure 4. A CTQ tree

<u>Measure</u>

The teams created a survey for Entre To A Major (ETAM) students in the College of Engineering, these are students in their first year in the College of Engineering. After one year, they would be applying for majors in engineering, provided that they have passed certain math and science courses and have a GPA above certain threshold.

The survey result was summarized in Table 1. Among the total of 432 ETAM students surveyed, only 16.44% of the students knew of the ESET major. Eighty three point five-six percent (83.56%) of the students had never heard of the ESET major. Two courses of interest are Chemistry 107 and MATH 152. These are courses typically taken by ETAM students before they apply for their majors.

Eighteen point two four percent (18.24%) of the students surveyed from the CHEM 107 class had heard of ESET, while the percentage of the students surveyed from the MATH 152 class was only 5.88%.

Table 1. Survey data

Class	Yes	No	Total
CHEM 107	58	260	318
MATH 152	1	17	18
Others	12	84	96
Total	71	361	432

Before ETAM students apply for their majors, each program runs an informational meeting to introduce their programs to the students. Numbers of students signed up for these informational meetings is a good indication of how much interest there is among the ETAM students. In the Fall of 2015, a total of five students attended the three ESET Informational meetings.

Table 2 shows the number of students admitted to the ESET program, by categories, in Fall 2015.

Table 2. Fall 2015 Students Admitted

Students admitted	47
ETAM	6
Transfer	20
Change of major	18
Re-admits	3

The total number of new students enrolled in the ESET program in the Fall 2015 semester was 34. The admission to enrollment ratio was 72.34%.

Analyze

Cause-and-Effect diagrams were used by the student teams to find the root causes of the problems with the current process. Fig. 5 illustrates a Cause-and-Effect diagram created by a student team.

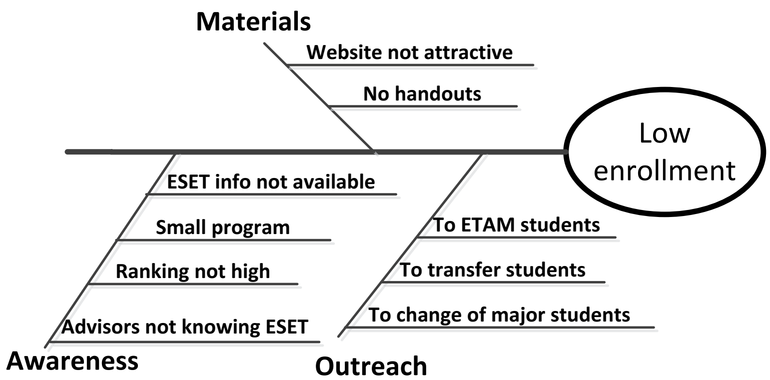

Figure 5. Cause-and-Effect diagram

Based on the measurement data they collected in the Measure stage, the team analyzed the potential causes for low enrollment problem ESET was having. These causes were divided into three categories:

- lack of awareness,
- lack of outreach activities, and
- lack of materials that can provide information about ESET.

Because ESET is a small and less-known program, many students never heard of ESET and would not consider ESET as their major. Many academic advisors in other departments within the College of Engineering did not know about the ESET program either. These advisors would not be recommending ESET to students who are considering a change of major. The ESET program was not doing enough to reach out to students and the academic advisors in other departments. The ESET website was not well-maintained and was not attractive.

Improve

Once the root causes for the problems associated with the current recruiting process were identified in the Analyze stage, improvement ideas were proposed by the student teams. These include:

- Pass out ESET business cards to any students who may be interested in ESET
- Pass out ESET brochures to students who may be thinking about changing majors
- Conduct student survey (ETAM students)
- Recruit from Calculus III, Physics 208, Math 308, where many students find out that they don't like theoretical courses

- Present to community college students
- Present to high school students
- Talk to academic advisors in other departments and provide them with handouts
- Talk to academic advisors in community colleges and provide them with handouts
- Spread by word of mouth (roommates, friends, old classmates)
- Design an ESET T-shirt to be worn by ESET students and given away in recruiting events such as Aggieland Saturday and ESET informational meetings
- Create ESET Facebook, twitter accounts to attract followers

Students brainstormed for information that is of interest to potential students. Figs. 6-7 show the information that was in the ESET brochure designed by the students.

Figure 6. ESET Brochure (Page 1)

- **43%** of all students contribute to faculty research
- **36%** of all students participate in summer internships
- **60%** of all students are engaged in industry projects
- **60%** of all students are active in professional societies

Figure 7. ESET Brochure (Page 2)

The student teams also designed a handout for ESET Informational meetings, as illustrated in Fig. 8.

Job Titles	**For more information contact the er**
Test Engineer	Dr. Zhan (Program Coordinator):
Embedded Software Engineer Magana"	*in email, please include "refe
Network Engineer	
Product Engineer	**Informational Session:** April 12
Technical Sales Associate Thompson Hall	**Location:** Product Innovation C
Electrical Engineer I	**Time:** 6pm
Applications Engineer	*please take brochure to meeti
Development Engineer	
Virtual Systems Engineer	
Project Engineer	
Control Systems Engineer	

Figure 8. Handout for ESET Informational meetings

The ESET recruiting process was modified to include "reach out to potential students", "collect students' contact information", "Follow up", and "Requesting students to tell others about ESET". The flowchart of the proposed improved processes is shown in Figure 9.

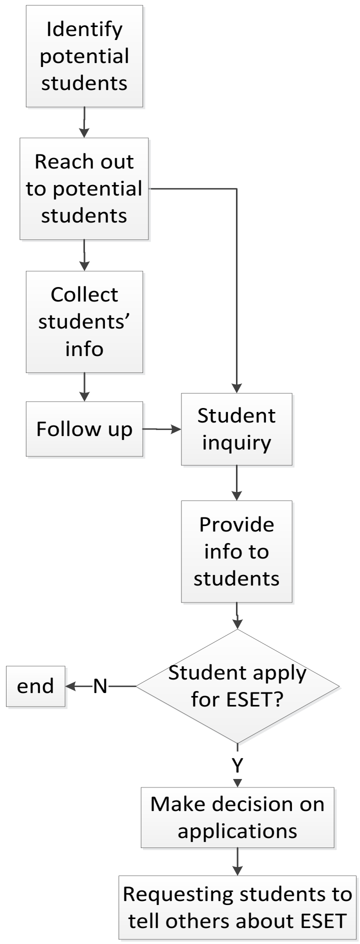

Figure 9. Improved recruiting process

The student teams implemented the improvement ideas they came up with. They visited community colleges in their hometown and Blinn College that is close to Texas A&M University to give presentations to students. They visited academic advisors in these community colleges and provided them with ESET brochures. They handed out brochures and ESET informational meeting handouts to students taking various freshmen Math, Physics, Chemistry, and engineering courses. Each student talked to at least five of their classmates, roommates, and friends about ESET. They created social media accounts such as Facebook, LinkedIn, Twitter, Snapchat for ESET. They also looked at the ESET website and came up with many improvement ideas.

Common sense tells us that the new process should be more efficient than the old process. However, this claim must be validated by data.

Control

After the implementation of improvement ideas, the positive impact could be seen from the increase in number of admitted applications in all categories. As shown in Table 3, the ETAM students admitted increased from 6 to 52. Transfer students admitted increased from 20 to 43. Change of major students increased from 18 to 28. The total admitted students increased from 47 to 129. The improvement of total admitted students was 174%, far exceeding the 30% target established in the project charter.

Table 3. Fall 2016 Application Data

	Admitted
ETAM (2014 cohort)	35
ETAM (2015 cohort)	17
Transfer	43
Change of major	28
Readmits	6
Total	129

The total new ESET enrollment increased from 34 to 84, a 147% increase. (This data was gathered after the semester was over.)

The new recruiting process was approved by the ESET program.

Additional recommendations were made by student teams for continuous improvement:

- Form ESET Ambassadors for recruiting purposes.
- Outreach to high school students.
- Organize robotic competitions for high schools and community college students to increase the awareness of the ESET program.
- Host Makerspace events.
- Continue to conduct student surveys.
- Analyze transfer students and identify key community colleges to focus the recruiting effort on.

3. Discussion and Conclusions

This paper discusses a course project in a Six Sigma course where student teams worked on the improvement of the recruiting process of the ESET program.

Starting in the Spring semester of 2016, students taking the course worked on a project to improve the student recruitment process. The goal was to increase the ESET new student enrollment by 30% over the previous year. Students followed the DMAIC process to first define the project, followed by data collection for current process performance measurement, analyze the root causes of the inefficiency of the current process, propose improved processes, implement the new process, and conduct before-and-after analysis to verify that the process was indeed improved. As a result, the total number of students admitted to ESET was increased from 47 to 129, a 174% increase. The new enrollment was increased from 34 to 84, a 147% increase.

The effort of recruitment improvement was continued in the Spring semester of 2017. The latest enrollment number indicates that there are 91 new students enrolled in the ESET program in the Fall semester of 2017. This is an 8% increase from the Fall 2016 level. In two years, the enrollment was increased by 168%.

This project significantly helped the ESET enrollment situation, it also allowed the students to learn Lean Six Sigma and the DMAIC process. Students worked well as teams. The two different formats in the Spring and Fall semesters provided information about the team dynamics. The one large team format worked more efficiently than the seven small teams. This is something that will be further investigated in the future.

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PREDICTING NON-FERROUS METAL COMMODITY VALUES AS A FUNCTION OF USA AND CHINA GDP

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ABSTRACT

This paper analyzes the relationship of commodity values of major non-ferrous metals (copper, aluminum, lead and tin) with respect to the Gross Domestic Product (GDP) of the United States (US) and China. The research focuses on years 1990 – 2015. It should be noted that China's increased world trade started in the year 1990. Values for non-ferrous metals were collected from the London Metal Exchange (LME) and are at the day rate at the time of reporting. US GDP values were gathered from the US Bureau of Economic Analysis. China GDP values were derived from the Wall Street Journal (Magnier, Wei and Talley). All monetary values are in US dollars based on exchange rate at time of this report. Models were constructed individually for each metal and each GDP value. Outputs suggest a strong association between all metals in relation to both US and China's GDP values. The strength of the association is varying. Due to the results of the models applied, this paper reports a relationship between each non-ferrous metal values and US and China GDP.

TERMS
Non-ferrous metals are metals that do not contain iron.
USA GDP is the Gross Domestic Product of the United States in US Dollars.
China GDP is the Gross Domestic Product of China in US Dollars.

1. Background

The world's current largest economies are the US followed by China. The US GDP was estimated to be $19 trillion United States Dollars (USD) in 2016 (US Bureau of Economic Analysis 2016). In the same year, China's GDP was estimated to be $12 trillion USD (Magnier, Wei and Talley 2016). The gap in GDP between China and the third largest economy (Japan) was approximately $7.7 trillion USD (CNN, 2016). Since 2007 China has experienced a widening decline in growth each year. In 2015 China's economy grew 6.9%, its slowest pace in over 25 years. This decline in momentum is expected to continue in China over the next several years. "China set an economic growth target rate of between 6.5% and 7% for 2016 and an average of at least 6.5% over the next five years, goals that acknowledge slowing momentum in the world's second-largest economy but which still could be difficult to reach" (Magnier, 2016). How this decline in a single country's economy can positively or negatively affect other economies is widely unknown. This lack of knowledge and ability to forecast its effects is largely due to the ever-increasing global economic dependency which is a relatively new occurrence in the interconnected global market. This paper specifically addresses the effects on major commodity prices due to fluctuations that are present in the GDP values of the US and China.

China's growth slowed to a pace in 2015 that it had not experienced since 1990. The China GDP growth rate had grown at a startling rate in the 1990s. However, it began to decrease significantly

2008. This loss of momentum is a concern that was recognized in the entire global economy although its effects have largely not been studied in any major way. This uncertainty over the general conditions of the Chinese economy have reportedly caused global concerns in the international markets. These markets include commodities which are traded globally. "The slipping momentum in China, which reported economic growth of 7.7% in 2013, has reverberated around the world, sending prices for commodities tumbling and weakening an already soft global economy" (Magnier, Wei & Talley 2016).

Appendix A depicts the GDP values used in this study for the US and China between 1990 and 2015. While US growth has remained steady and predictable, such predictability is not without its own fluctuations. The fourth quarter of 2015 revealed signs of a slowdown with the figures reported dangerously close to that of 2009. This suggests that the US may be entering another recession that it was overcoming in 2009. While this trend is a concern for the US, absent the recessional years of 2008 and 2009, the growth median of 2.65% has never had more than a two points variance. This predictable trend in US growth is vastly different from China's large growth.

Metals play an important role in engineering materials in a variety of industries in the US and China. Although there are very many metallic elements it is customary to divide metals and alloys into two major categories, *ferrous* and *non-ferrous* (John 1983). Of all the metallic elements, only a comparatively small number are used in quantity as the basis for engineering materials, although many others are used as alloying elements for specific purposes. The metals used in large amounts are aluminum, copper, magnesium, nickel, titanium and zinc (John 1990). Of direct interest to this study were four major non-ferrous metals- copper, aluminum, lead and tin. These non-ferrous metals are described below:

Copper is "a common reddish metallic element that is ductile and malleable and is one of the best conductors of heat and electricity" (Merriam 2016). Copper is commonly used for its ability to effectively conduct electricity. It is used most commonly in construction and electrical equipment and component manufacturing. Copper is used to manufacture cables, wiring, heating for construction use as well as wiring and circuit boards for electrical goods.

Aluminum is "a bluish silver-white malleable ductile light trivalent metallic element that has good electrical and thermal conductivity, high reflectivity, and resistance to oxidation and is the most abundant metal in the earth's crust where it always occurs in combination" (Merriam 2016). Aluminum is best used for its ability to evade corrosion and primarily consists of bauxite. Due to its anti-corrosive nature, it is frequently used as a material for building construction (Aluminum Flowchart 2016).

Lead is "a heavy, comparatively soft, malleable, bluish-gray metal, sometimes found in its natural state but usually combined as a sulfide, especially in galena" (Dictionary 2016). Lead is a relatively poor conductor of electricity but is dense with high anti-corrosive capabilities. It is used in the manufacturing of automobiles and electric two-wheelers (Kropschot 2011). Eighty percent (80%) of lead is used in the manufacturing of automobile batteries (LME 2016).

Tin is "a soft faintly bluish-white lustrous low melting crystalline metallic element that is malleable and ductile" (Merriam 2016). Tin is commonly used in containers as a protective coating since it does not oxidize when exposed to air or water (Tin 2016). Due to its ability to protect and its natural shine, tin is used to coat finished metals.

Appendix B shows the values of the four major commodities researched in this study from 1990-2015. Supply and demand are the determinants of price. As the world's individual economies become more integrated through increased global trade, changes in price can be the result of changing supply and demand in separate economies. This effect is even more apparent when considering the two largest economies in the world, the US and China. As both economies experience internal fluctuations in domestic demand, these effects may then be felt in the global commodity markets. Considering China's extreme fluctuations from 1990 – 2015 their impact is potentially more strongly represented in the commodities markets. This timeframe is the obvious one to study due to US President Clinton's grant of China to the Permanent Normal Trade Relations (PNTR) in the early 1990s. This entrance encouraged exports from China and resulted in a considerable boom effect in the Chinese economy beginning in the early 1990s.

Commodities are priced internationally. China has been particularly active in the use of metals for construction and manufacturing since 1980 (Goss, 1983). Prices for such commodities such as metals are determined on the commodity exchange. Metals are traded between producers and consumers. Prices are posted daily for both present and future days' value and the commodities are sold at these rates. All prices in this research were obtained from the London Metal Exchange (LME) (LME 2016).

2. Prices, Supply and Demand

Copper prices from 1990 - 2015 rose and fell dramatically. The lowest price per metric ton (pmt) was recorded in 2002 at $1,560.29 pmt. The highest was at $8,823.46 pmt in 2011. For 2015 copper was valued at $5,510.46 pmt. Through the 1970s and 1980s copper gained momentum due to the rise of modern technology. Manufacturing to produce new technological products was fueled by metals, like copper, with its ability to conduct electricity. Prices remained steady throughout the 1990s, but a peak occurred in 2006 when copper broke the $4.00/lb. price for the first time. This climb in price was due to increased demand in China; this increase in demand was fueled by under-investment causing restraints on supply, threats of labor strikes at mines and uncertainty caused by the impending renewal of labor contracts (INN 2015). A dip in 2008 was due to the weakening US economy which caused fluctuations in demand.

Copper is mined in the following order of global production: Chile, Peru, Mexico and Indonesia. Chile hosts the world's nine largest copper mines. Escondido, Chile is home to the world's largest copper producing mine and is one of its ten deepest open-pit mines. It opened in 1990 and has an estimated reserve life of fifty-four years (Mining-technology 2013). Since 1950 copper has been held in reserves. Based on current demand the reserves would supply forty years of demand. "In addition, recycling, innovation and mining exploration continue to contribute to the long-term availability of copper." Copper was one of the first metals used by humans and is estimated to have been first mined over 10,000 years ago (World Factbook Copper 2015).

In the first year of the research (1990), the US was the biggest consumer of **copper,** accounting for 20% of consumption. China, on the other hand, accounted for only 5% of global copper consumption in 1990. China is now the biggest consumer of copper, accounting for more than 42% of global copper consumption (O'Hara 2015). These large shifts in demand and the increase in China's need for non-ferrous metals is assumed to further the metal's price changes as GDP values for the US and China change.

Aluminum was at its lowest in 1993 at $1,139.93 pmt. Aluminum experienced peaks from 2006 – 2008. Thereafter, the US' weakening economy caused a dip in growth. In 2009 the value sunk to $1,669.18 pmt. For 2015 the declining value continued, ending the year at $1,664.68 pmt. Decreasing aluminum prices contributed to a surplus in supply and a worldwide excess of inventories. LME alone currently has a massive 1.7 million tons of aluminum in their registered warehouses around the world as reported in February 2015. Coupled with the cost of aluminum production being relatively equal to the cost of the energy to produce it, there continues to be a decline in the price of aluminum which is expected to continue its downslope in the foreseeable future (Wall Street Daily 2015).

Aluminum compounds are the world's most abundant metal and comprises an estimated 8.2% of the earth's crust. Pure aluminum wasn't discovered until 1825. In 1886 the first process in producing aluminum (i.e. extracting it from aluminum oxide) was discovered. More than a century later the US alone produces over five million tons annually (Harris 2008). In 2014, Australia produced the largest amount of bauxite in the world, followed by China, Brazil, India and Guinea. Figure 1 shows the growth in production over the reported period of 1990-2015.

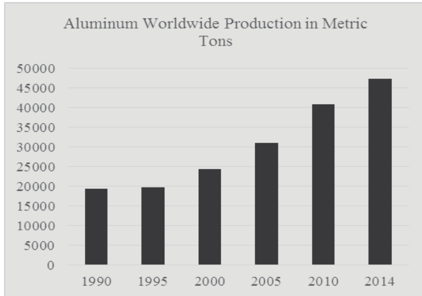

Figure 1 Aluminum Production

Considering its large domestic production of **aluminum,** China is also currently the world's largest consumer of aluminum. China is also the world's largest importer of alumina and bauxite, accounting for more than 40% of global consumption (Aluminum Fact Sheet). Aluminum demand, including production and imports, in North America declined 10.2 percent in 2008 to a total of 22.2 billion pounds (Sapa 2016).

Lead has experienced massive growth from 1990 – 2015. Lead's lowest value in 1993 was $407.34 pmt that then increased by over 80% in 2007 to $2,379.12 pmt. Lead ended 2015 with an average of $1,787.82 pmt. LME reported a record high of lead in October of 2007 when the price reach $3,900; since then the markets for lead have declined. Lead is most popularly used in the manufacturing of lead acid batteries for the automobile industry. As reported in 2008 by The Business Standard, the decrease in automobile demand in the US caused a decrease in production in China, the world's leading consumer of lead (30-35% of world consumption). This along with China's surplus in production ultimately potentially caused a fall in prices (Business Standard 2008).

Lead had been mined for over 8,000 years and was documented in use by the Egyptians circa 5,000 B.C. Top producers of lead in order of production are; Australia, US, China and Canada. Major lead-bearing ore deposits are found in: Mexico, Peru, Russia and Kazakhstan (Lead n.d.). Modern lead mines produce 3 million metric tons of lead annually worldwide.

Reported in early 2015 China is the world's biggest refined **lead** producer and consumer. Slower domestic demand could prompt Chinese smelters to export more metal. Lead is highly dependent on the manufacturing that is done primarily in China due to its natural capabilities of the same. As of 2014, China accounted for over 40% of the global demand of lead. With tightening environmental regulations established in China and other large global economies, the future of lead is unclear (Kropshots, 2016).

Tin's lowest year was 2002 at $4,061.00 pmt. The highest was experienced in 2011 at $26,051.45 pmt. Tin averaged $16,066.63 pmt in 2015 following several years of decline starting in 2009. China is the world's largest consumer of tin. Following China's reduction in inventories, tin has recently reported its lowest price in the past seven years. This leads to major halts in production including from major mines found in China. Demand in 2016 is expected to exceed output by 13,000 tons (The Salt Lake Tribune 2016).

Tin has been used and mined by humans for over 5,000 years. China, Indonesia and Peru are the world's primary producers of tin. The world's economic tin resources currently exceed 7 million metric tons. China is the world's leading producer of tin followed by Malaysia, Brazil, Thailand and Indonesia (Tin Fact Sheet). In 2011 the world produced 11 million metric tons of tin (LME 2016).

Tin's demand is most prevalent in Asia. Compared to the other three metals used in this research, tin is consumed in Asia more than any other metal. Concerning the demand of tin, "Slow global growth is weighing on demand, as is the continual process of miniaturization in the electronics industry". This is especially concerning because solder manufacturers account for 52% of tin's global demand (Adams and Hardcastle 2014).

When comparing the non- ferrous metals, similarities in price fluctuations are detected. From 1990 – 2000 prices were predictable. In 2009 all metals decreased in value. This trend is attributed to decreasing growth in Asian economies, specifically China. The recession experienced by the US in 2008 was another cause in the fluctuating prices. Metal prices are influenced by major national and international events such as wars and recessions. Commodity specific events such as tariff changes or mine strikes can also impact commodity prices (Papp 07).

Supply is dependent on factors influencing the country in which the metal is mined. These factors can include political, environmental and internal events. Government regulations that limit the mining or export capabilities of the metals also cause restraints on supply. In the 25 years used in this research, production for copper and aluminum supply never declined. Tin and lead saw minor declines. When considering the historical mining of all the non-ferrous metals used in the research, the minor increases and decreases in supply appear to be minor indicators of price. The reserves held on all the metals cited further lessens supply as a major determinant of price.

The largest demand for the four non-ferrous metals is found in the two largest economies in the world, the US and China. Commodity prices soared while the two major global economies grew at significant rates, especially China. As Krauss in the New York Times reported in 2016 "For years, China voraciously gobbled up all manner of metals, crops and fuels as its economy rapidly expanded." Further reports concerning commodity demand cite "Now everything has changed. China's economy is slumping. American companies, struggling to pay their debts as interest rates rise, must keep producing" (Krauss 2016). As these two major economies experience shifts in growth, an immediate reaction is felt in the commodity markets. Demand for the four metals is mainly in Asia, and more specifically China (LME, 2016). China is currently the number one consumer of copper, aluminum, lead and tin.

A review of literature was conducted for this research. During this literature review no formal research or models were found that discussed an association between non-ferrous metal values and annual GDP values of US and China. Numerous news articles from sources used in this research (including CNN, The Wall Street Journal and The New York Times) did suggest a potential informal relationship between declining commodity prices as a reaction to declining Chinese economic growth. These news articles were published within the last year of this research (2016). This is due to the recent declining economic growth in China which became more apparent after the reporting of 2015 GDP values.

Price, supply and demand data for years 1990 - 2015 for all the metals were collected from the London Metal Exchange. GDP data was collected from the Bureau of Economic Analysis. Both data sets are readily available through numerous online sources. Individual information on the metals sources and uses was found in research through fact sheets dedicated to education on the specific metals. These fact sheets are listed individually in the references of this paper.

NULL HYPOTHESES:

1. This is no relationship between changing aluminum commodity values and US GDP.
2. There is no relationship between changing copper commodity values and US GDP.
3. There is no relationship between changing lead commodity values and US GDP.
4. There is no relationship between changing tin commodity values and US GDP.
5. This is no relationship between changing aluminum commodity values and China GDP.

6. There is no relationship between changing copper commodity values and China GDP.
7. There is no relationship between changing lead commodity values and China GDP.
8. There is no relationship between changing tin commodity values and China GDP.

ALTERNATIVE HYPOTHESES:

1. There may well be a relationship between changing aluminum commodity values and US GDP.
2. There may well be a relationship between changing copper commodity values and US GDP.
3. There may well be a relationship between changing lead commodity values and US GDP.
4. There may well be a relationship between changing tin commodity values and US GDP.
5. There may well be a relationship between changing aluminum commodity values and China GDP.
6. There may well be a relationship between changing lead commodity values and China GDP.
7. There may well be a relationship between changing tin commodity values and China GDP.

3. METHODOLOGY

Prices for all metals were collected from the London Metal Exchange (LME). The values were all at the time of reporting. The prices for each ending day of each month for the years 1990 – 2015 were collected. An average of all 12 months for individual years was calculated using month end figures. From that average the price per year for copper, aluminum, lead and tin were derived. GDP values were collected from the US Bureau of Economics. Values were collected for the US and China, years 1990 – 2015. These values are reported at year end for each country. These values were then divided by 1,000,000,000 to achieve more understandable outputs. All GDP values are in current US dollar rates. Including the period 1990 – 2015 GDP values were gathered that allow for the identification of trends. This timeframe is important to the study due to US President Clinton's grant of China into the Permanent Normal Trade Relations (PNTR) in the early 1990s. The admittance opened China's trade globally and expanded its manufacturing dramatically. 2008 figures in the reporting of the US economy gives visibility to the effects of the US' recession on the global commodity markets.

Simple regression analysis was used to analyze the relationship between the dependent variable (non-ferrous commodity price) and one independent variable (GDP of the US and China). Y was used to denote the dependent variable; X was used to denote the independent or explanatory variables. Simple regression analysis was calculated using the following values for the dependent and explanatory variables:

- Y = Copper yearly price average; X = China GDP/1,000,000,000
- Y = Aluminum yearly price average; X = China GDP/1,000,000,000
- Y = Lead yearly price average; X = China GDP/1,000,000,000
- Y = Tin yearly price average; X = China GDP/1,000,000,000
- Y = Copper yearly price average; X = US GDP/1,000,000,000
- Y = Aluminum yearly price average; X = US GDP/1,000,000,000
- Y = Lead yearly price average; X = US GDP/1,000,000,000
- Y = Tin yearly price average; X = US GDP/1,000,000,000

4. RESULTS AND DISCUSSION

Using Simple Regression analysis, the models show relatively strong R square values. While R square is a measure of how well observed outcomes are replicated by the model (goodness of fit), it may also provide insight into a potential relationship between a dependent and independent variable. In this case it may indicate that a relationship may well exist between the values of the non-ferrous metals and USA and China GDP (see Figure 2 below). This is seen by observing the primarily robust R square values shown in Figure 3 below. The percent of variation that is explained by the GDP is shown in the independent variables of metal values per column R square. The strongest relationship appears to be between the value of tin and China GDP with an R Square value of 80%. The weakest association is between the value of aluminum and China GDP with an R Square value of only 21%.

	Y Value	Estimated Intercept Coefficient	Estimated Regression Coefficient	T Stat for Estimated Regression	P Value	R Square	Adjusted R Square
China GDP	Copper	2215.999	0.5866	6.663	0.0000	65%	63%
USA GDP	Copper	-2199.424	0.5408	6.967	0.0000	67%	66%
China GDP	Aluminum	1553.345	0.0568	2.513	0.0191	21%	18%
USA GDP	Aluminum	898.890	0.0728	4.125	0.0004	41%	39%
China GDP	Lead	557.202	0.1801	7.093	0.0000	68%	66%
USA GDP	Lead	-773.191	0.1665	7.522	0.0000	70%	69%
China GDP	Tin	4575.151	1.8144	9.674	0.0000	80%	79%
USA GDP	Tin	-7037.974	1.5227	7.142	0.0000	68%	67%

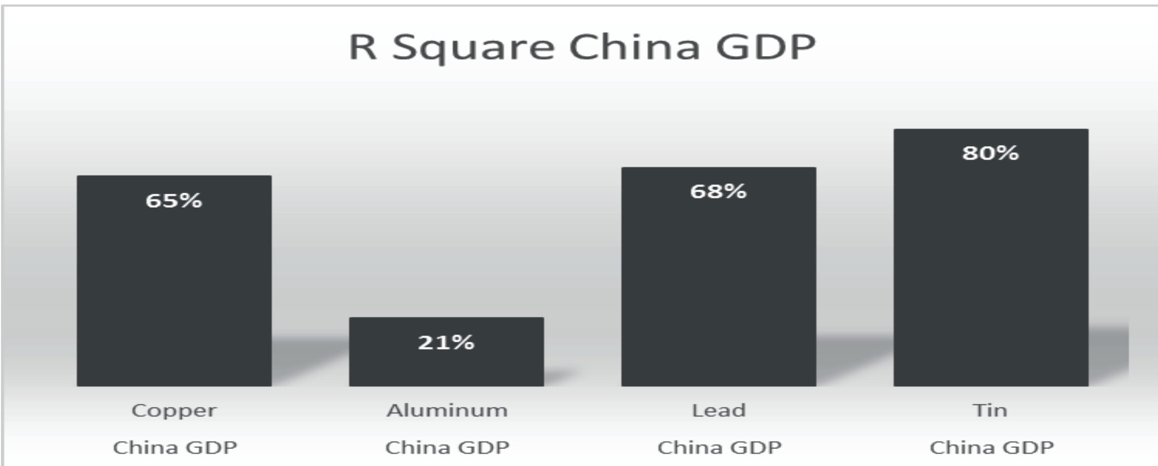

Figure 2 Regression Model Results

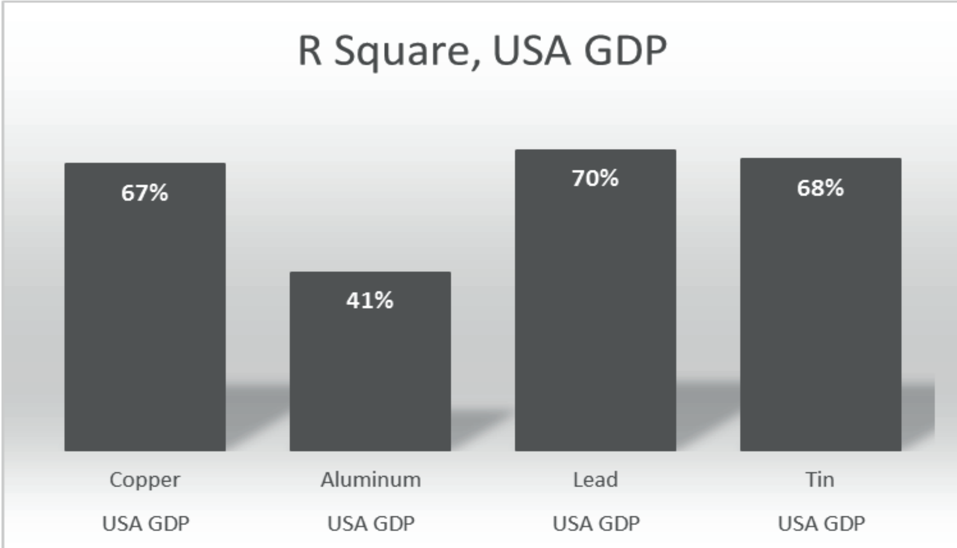

Figure 3 Model Informational Output for the USA and China (R squared)

The models reported in Figure 3 are calculated for the value of the individual metals regressed against the GDP of China and the USA. In these models, lead shows the most strength followed closely by copper and tin. Like the China GDP model, aluminum reflects the lowest relationship. Note that in a simple regression analysis the P Value is equivalent to a significant F. Therefore, the F values are not reported in the above figure to avoid redundancy. P values for all models show values less than .05. All outputs have T statistic values of 2.5 or more. This would indicate that for these models there may well be a positive relationship that exists between all metals studied and GDP values. Thus, the null hypothesis for all models is rejected and it can be inferred that the alternate hypothesis for each model is very likely correct i.e. there may very well be a relationship between the non-ferrous commodity values and both USA and China's GDP.

The model provides regression equations that can be used to predict future commodity values. It should be noted that both the Estimated Intercept Coefficient and the Estimated Regression Coefficients play important roles in each regression equation (i.e. as the Y intercept and slope of each regression line respectively). The P values indicates significance where a P value of less than 0.05 indicates that a relationship exists. R Square is an indication of how much of the variability in the relationship is being explained (above 60% indicates a moderately, strong relationship) The regression equations are as follows:

- Average $ of copper pmt = 2116 + 0.5866 China GDP in current USD/1,000,000,000
- Average $ of aluminum pmt = 1553 + 0.05684 China GDP in current USD/1,000,000,000
- Average $ of lead pmt = 557.2 + 0.1801 China GDP in current USD/1,000,000,000
- Average $ tin pmt = 4575 + 1.814 China GDP in current USD/1,000,000,000
- Average $ of copper pmt = - 2199 + 0.5408 US GDP in current USD/1,000,000,000
- Average $ of aluminum pmt = 898.9 + 0.07282 US GDP in current USD/1,000,000,000
- Average $ of lead pmt = - 773.2 + 0.1665 US GDP in current USD/1,000,000,000
- Average $ tin pmt = - 7038 + 1.523 US GDP in current USD/1,000,000,000

Based on the forecasted 2016 GDP values reported earlier in this research, (US GDP of approximately $19,000,000,000 and a China GDP of approximately $12,000,000), this model would predict the following commodity prices in Figure 4 below. After the Industry, Engineering and

Management Systems (IEMS) Conference in March 2017, figures were released for the actual GDP 2016 values. The US GDP in 2016 in US dollars was $18,562 b; China's GDP was $11,392 b (Knoema, April 2017).

Metal & Country	Estimated Intercept Coefficient	Estimated Regression Coefficient	Forecast GDP/$1,000,000	Forecasted Metal Value in Metric Tns
Copper & China	2116.00	0.5866	12,000	$ 9,155.20
Copper & US	-2199.00	0.0541	19,000	$ -1171.48
Alum. & China	1553.00	0.0568	12,000	$ 2,235.08
Alum. & US	898.90	0.0728	19,000	$ 2,282.48
Lead & China	557.20	0.1801	12,000	$ 2,718.40
Lead & US	-773.20	0.1665	19,000	$ 2,390.30
Tin & China	4575.00	1.8140	12,000	$ 26343.00
Tin & US	-7038.00	1.5230	19,000	$ 21899.00

Figure 4 Regression Model Output

5. CONCLUSIONS

Based on the results of this study the GDP values of the US and China may have a predictive relationship to the values of the metals analyzed (copper, aluminum, lead and tin). Tin shows a strong relationship with both China and US GDP. The values of lead and copper also show a strong relationship with GDP, although slightly lesser than tin. This may be due to copper's strength in electronic manufacturing and lead's overwhelming use in the production of automobile batteries.

Aluminum, with an R square value of 21% and 41% shows the weakest relationship. This may be due to the current pricing structure of aluminum and its natural abundance on earth. With supply that exceeds demand, plus the massive amounts held in reserves, aluminum's price may default to the cost of energy to produce it. This may tend to make it much less susceptible to varying demands evident in GDP values.

6. RECOMMENDATIONS

A sampling of the four most common non-ferrous metals is used in this study along with the GDP figures of the world's two largest economies. It is recommended that further research be focused on collecting data on other metals traded and reported through the London Metal Exchange. Given that the metals in this study are highly used, it would provide further insight when using models to compare rare metals.

Expanding the period of 1990 – 2015 would provide more information on how the growing global economies have affected metal prices in the past. Using the top two global economies of the past 50 years would give insight into how historically these economies affect commodity prices. Given that the values for metals and GDP are easily obtained, further research should not be handicapped by the absence of historical information. This historical information is available through the same cited sources used in this study.

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8. Appendix A China and US GDP figures (1990-2015)

Year	China GDP	USA GDP
1990	392,500,000,000	5,979,600,000,000
1991	411,300,000,000	6,174,100,000,000
1992	490,800,000,000	6,539,300,000,000
1993	616,500,000,000	6,878,700,000,000
1994	562,300,000,000	7,308,800,000,000
1995	732,000,000,000	7,664,100,000,000
1996	860,800,000,000	8,100,200,000,000
1997	958,200,000,000	8,608,500,000,000
1998	1,025,300,000,000	9,089,200,000,000
1999	1,089,500,000,000	9,660,600,000,000
2000	1,205,300,000,000	10,284,800,000,000
2001	1,332,200,000,000	10,621,800,000,000
2002	1,461,900,000,000	10,977,500,000,000
2003	1,649,900,000,000	11,510,700,000,000
2004	1,941,700,000,000	12,274,900,000,000
2005	2,268,600,000,000	13,093,700,000,000
2006	2,729,800,000,000	13,855,900,000,000
2007	3,525,300,000,000	14,477,600,000,000
2008	4,558,900,000,000	14,718,600,000,000
2009	5,059,700,000,000	14,418,700,000,000
2010	6,039,500,000,000	14,964,400,000,000
2011	7,492,500,000,000	15,517,900,000,000
2012	8,461,500,000,000	16,155,300,000,000
2013	9,490,800,000,000	16,663,200,000,000
2014	10,356,500,000,000	17,348,100,000,000
2015	11,384,800,000,000	17,996,820,000,000

9. Appendix B Annual World-Wide Commodity Prices (1990-2015)

Year	Average $ of copper per metric ton	Average $ of aluminum per metric ton	Average $ of lead per metric ton	Average $ tin per metric ton
1990	$2,661.34	$1,639.50	$809.50	$6,085.38
1991	$2,338.50	$1,304.02	$557.80	$5,595.96
1992	$2,284.81	$1,256.27	$543.51	$6,104.09
1993	$1,914.96	$1,139.93	$407.34	$5,167.55
1994	$2,305.53	$1,475.63	$548.72	$5,459.98
1995	$2,932.04	$1,805.02	$629.30	$6,197.36
1996	$2,293.39	$1,506.80	$774.13	$6,158.88
1997	$2,275.19	$1,599.29	$623.06	$5,640.48
1998	$1,653.71	$1,357.57	$526.92	$5,536.23
1999	$1,572.53	$1,359.99	$501.77	$5,391.40
2000	$1,814.52	$1,551.50	$454.17	$5,435.90
2001	$1,580.17	$1,446.75	$476.36	$4,489.44
2002	$1,560.29	$1,351.06	$452.25	$4,061.00
2003	$1,779.36	$1,432.84	$514.21	$4,889.65
2004	$2,863.47	$1,718.51	$881.95	$8,480.94
2005	$3,676.50	$1,900.51	$974.37	$7,385.25
2006	$6,731.35	$2,573.06	$1,288.42	$8,754.90
2007	$7,131.63	$2,639.86	$2,579.12	$14,495.44
2008	$6,963.48	$2,577.92	$2,093.32	$18,466.64
2009	$5,165.30	$1,669.18	$1,719.44	$13,602.69
2010	$7,538.37	$2,173.01	$2,148.19	$20,367.25
2011	$8,823.46	$2,400.64	$2,400.71	$26,051.45
2012	$7,958.93	$2,022.80	$2,063.56	$21,109.36
2013	$7,331.49	$1,846.68	$2,139.75	$22,281.58
2014	$6,863.40	$1,867.42	$2,095.46	$21,898.87
2015	$5,510.46	$1,664.68	$1,787.82	$16,066.63

A Study of the AIAG Measurement System Analysis (MSA) Method for Quality Control

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Abstract

Measurement system analysis (MSA) is an experimental and mathematical examination of the statistical properties of the measurement system, to determine the amount of variation within the measurement data under stable conditions. The measurement data can be variable or attribute data and are taken through multiple measurements. As the quality of the measurement system improves, the quality of the analytic studies that follow improves. The main MSA statistical properties are the bias and the variance. Bias represents the location of a data point from a reference value, while the variance represents the spread of the data. Several approaches have been proposed to evaluate measurement systems in the industrial world. This study aims to provide a broad review of a common method used for MSA; the AIAG analysis method. The focus is to clear some of the discrepancies in results between this method and the ANOVA method. This discrepancy is associated with how the AIAG method uses the calculations of the standard deviation instead of the variance to find the total system variation. The study will provide a detailed comparison of the two approaches and the best practices in applying them; it will also focus on how to interpret the results of these approaches and comment on their differences through a case study.

Keywords: Measurement System Analysis, Gauge, Repeatability, Reproducibility.

1. Introduction

MSA is defined by the Automotive Industry Action Group (AIAG) as "the statistical properties of multiple measurements obtained from a measurement system operating under stable conditions" (Chrysler Group LLC et. Al., 2010). Gauge repeatability and reproducibility (GRR) or gauge capability analysis are terms used to describe the variation in MSA for variable data. Attribute data can also be evaluated through GRR for attributes. Although there is a subtle difference between the analysis techniques used for the two types of data, the common terminology used in MSA remains the same. MSA consists of three main terms: 1) measurements—variable or attribute data that represent a property under study; 2) gauge—a physical device or visual examination that is used to obtain measurements; 3) measurement system—the collection of devices, standards, operators, environment, assumptions, methods, and techniques used to evaluate whether these are valid "quality data" to be used for future analytical studies to improve processes (Measurement Systems Analysis Reference Manual, 2010). In MSA, the data being measured are normally compared with a "reference value" that can hypothetically replicate the "true value" of the measurement, which cannot be known with certainty. Other terminologies are often used to describe the measurement system, such as accuracy, stability, linearity, repeatability, and reproducibility. Accuracy is defined by the distance between the measured data and the "reference value"; the closer the measured value is to the reference value, the more accurate the measurement system is. The stability of the measurement system is its ability to maintain the same amount of bias over time (bias should be at a minimum). Bias changes across all reference values is referred to as gauge linearity. The three aforementioned terminologies are mainly used to describe any location variation of the measured data. Repeatability and reproducibility (R&R) are two important terminologies that should be understood correctly before performing a MSA. R&R is used to describe the width variation—the spread of the data around the mean reference value. The within-system variation that is caused by performing repeated measurements with the same instrument is called repeatability.

Between-system variation, or reproducibility, is caused by performing repeated measurements with the same instrument but with different appraisers (other factors are also involved, such as environment, time, etc.) (ASTM E456-96, 1996). Measurement system repeatability and reproducibility are used to estimate the capability of the system or the measurement variation. Common practice requires the R&R value to be under 10% to consider the measurement system capable. Above 30% variation in the R&R value means that the measurement system is incapable of providing quality analytical studies under the current settings, and corrections should be made to ensure less variation. When the measurement variation is between 10% and 30%, in-depth investigations should be undertaken to determine if the source of variations comes from the measurement equipment, the appraiser (other factors can also be related to appraiser variations, such as the environment, time, etc.), the equipment, or the actual measured parts. In this study, section 2 will survey the literature on MSA. Section 3 will discuss in detail two of the most widely used methods for analyzing the measurement system—the AIAG average and range method and the ANOVA method—and compare the two. Section 4 will present a case study using the two methods, followed by a discussion of the results and some conclusions.

2. Review of relevant literature

MSA is an essential activity that, if not done correctly, will have significant consequences for the primary analytical analysis (Sarkar, Mukhopadhyay & Ghosh, 2014). Manufacturers conduct analyses, such as statistical process control (SPC) and design of experiments (DoE), to monitor and then improve the productivity and quality of processes (Ermer, 2006). Any variation that results from the measurement system itself will eventually mask the variation from the manufacturing processes that the analysis is trying to find. If the measurement system is not providing quality data, a good part may be rejected (Type I error), or a bad part may be accepted (Type II error) (Breyfogle, 2003). This can lead to considerable losses in capital and customer satisfaction. Therefore, it is essential to have a valid and accurate MSA beforehand to ensure that the power of the analysis, such as SPC and DoE, is fully utilized (Ermer & Prond, 1993). In the same vein, MSA is considered to be a powerful tool for isolating the source of variation in the data, whether it stems from an equipment variation, appraiser variation, or part variation (Burdick, Borror & Montgomery, 2003). Before the formation of a standard MSA approach (mainly by the AIAG), process engineers used to validate and ensure that the metrology equipment used to collect data was calibrated and accurate (Little, 2001). A joint effort by a workgroup from Chrysler Group LLC, Ford Motor Company, and General Motors (GM) developed and formulated the well-known gauge R&R method that is widely used in the industry (Knowles, Anthony & Vickers, 2000). This method has been developed and improved to overcome the limitations of using averages and ranges to estimate the standard deviation and to calculate the measurement variation (Ermer & E-Hok, 1997). The analysis of variance (ANOVA) method provides a more detailed analysis using the variance in the measurement system (Quesenberry, 1997). Using statistical process control (SPC) charts, this method also offers an additional graphical representation of the measurement variation which shows the significance of the variation in the measurement system (Murdoch & Barnes, 1986). Following the ANOVA method, a method called evaluating the measurement process (EMP) introduced a detailed graphical representation of the measurement system components using average range control charts and interaction plots (Wheeler & Lyday, 1989). Since the evolution of MSA in the industry, several studies have been published on validating measurement systems using one or more of the mentioned techniques. Table 1 below provides examples of various studies on MSA and gives the object and environment of each study. As noted in the literature, there is still a considerable amount of confusion about the terminology used in MSA and which is the best method to use. Data interpretation is also a barrier to utilizing MSA to its fullest capacity (Smith, Callahan &Strong, 2007).

Table 1: Summary of literature

RESEARCH	OBJECTIVE	ENVIRONMENT	MEASUREMENT APPROACH
Larson (2003)	Multivariate testing with reset and repair	Production	ANOVA – Variable data
Dasgupta and Murthy (2001)	Assessment of MSA to find root cause of measurement errors	Automobile manufacturer	AIAG – variable data
Smith et al., (2008)	Improve visual welding inspection	Welding	AIAG - attribute data
Smith et al., (2007)	Bridge the gap between theory and practice of MSA	General manufacturing	AIAG - variable & attribute data
Potter (1990)	Measurement tools characterization	sub-micron semiconductor manufacturing	AIAG – variable data
Antony et. al., (1998)	Comparison between MSA methods	High resolution microscopes manufacturer	AIAG and ANOVA approaches
Cagnazzo et. al., (2010)	Manage and control business performance	Manufacturing of enamel, stainless steel, and non-stick cookware.	AIAG – variable data
Kaushik & Khanduja (2009)	Application of Six sigma methodology to a process industry	Power plant	ANOVA - variable data
Dasgupta & Murthy (2001)	Root cause analysis for high repeatability and reproducibility	Manufacturing of radiators and gaskets for automobile industry	ANOVA - variables
De Mast et al., (2011)	Binary inspection MSA	General manufacturing	AIAG – Attribute data
Murphy et al., (2009)	Improve library system	Service industry	AIAG- Attribute data
Erdmann et al., (2010)	Study the precision of temperature measurements with an ear thermometer	Healthcare	ANOVA – Variable data
Daricilar & Peters (2005)	Measurement Error of Visual Casting Surface Inspection	Manufacturing	EMP – Attribute data
Raffaldi & Kappele (2004)	Determine out of specification parts using MSA	Manufacturing	AIAG – Variable data

3. Methodology

Quality assurance and process improvement require accurate and precise data. Regardless of whether the measured data is a measurement of the product or a measurement of the process, all data have measurement error. Any measured data (or observed value) (Besterfield, 2004) consists of two values:

the true (or reference) value and error, so that

Measured Value = Reference Value + Measurement Error

Measurement error can be added to the reference value if the measured product/process has variation within it, or if the measurement system has its own variation, so that

Measurement Error = Part/Process Variation + Measurement System Variation

In mathematical expressions, variation in data occurs when a measured value deviates from the mean using the measure of variance σ^2. Thus, $\sigma^2_{meas.} = \sigma^2_{part} + \sigma^2_{meas.syt}$
where

$\sigma^2_{meas.}$= measurement variance/error

σ^2_{part}= part/process variance

$\sigma^2_{meas.syt}$= measurement system variance

The measurement system variance consists of the equipment variance (*EV*) and the appraiser variance (*AV*), so the equation becomes

$$\sigma^2_{meas.} = \sigma^2_{part} + \sigma^2_{E} + \sigma^2_{A}$$

Having no measurement error is not applicable to the real world. Thus, when it comes to validating the measurement system, it is more desirable for measurement error to be a contribution of the part/process variation rather than of the measurement system itself. In this case, one can be assured that the data are accurate for the analysis that will lead to the root cause(s) of the variation in the products or processes. Measurements are usually made using physical devices or visual inspection and can be performed on simple and complex products or processes. Any measurement system consists of the measurement equipment (physical or visual), the appraiser(s), and the measured parts or process (Montgomery, 2005). Performing measurements depends on human experience, judgments, surrounding conditions, and part attributes, which is why it is vital to understand how MSA should be applied and interpreted. According to the AIAG manual (Measurement Systems Analysis Reference Manual, 2010), best practices for conducting a variable gauge repeatability and reproducibility study are at least 10 parts (usually denoted by n), 2 or 3 appraisers (usually denoted by k) measuring for 2 or 3 trials (usually denoted by r). The measurement equipment should be calibrated following a regular routine. Parts should be measured in a random order by each appraiser for the number of trials to be conducted, to ensure linearity. It is also important to identify the attribute of the part/process that is being measured and the correct way to measure it. The data to be collected are then recorded by a fourth person on a data collection sheet. The AIAG GRR published data collection sheet is provided in the Appendix for reference.

3.1 MSA AIAG analysis method

The AIAG manual provides a comprehensive description of analyzing the measurement system for variable data (the manual also discusses attribute data and visual inspection MSA, but those fall outside the scope of this study). The AIAG method (or $\bar{X}$, *R*) bases its calculations on the averages and ranges of the collected data to estimate the variation (represented by the standard deviation, or SD) in the measurement system variables, then finds the percentage of variation of each variable as a function of the total system variation. The measurement system variables are *equipment variation (EV), appraiser variation (AV),* and *part variation (PV)*. All these become a percentage of the *total variation (TV).* Moreover, gauge repeatability and reproducibility (GRR) or R&R is also calculated. In the data sheet in Figure 1 in the Appendix, measurements of the parts/processes should be recorded in rows 1, 2, 3, 6, 7, 8, 11, 12, and13. After recording the measurements, all the remaining values should be calculated using the GRR data report sheet (refer to Figure 2 in the Appendix) . Averages and ranges of the measurements are simply calculated and recorded in rows 4, 5, 9, 10, 14, and 15. Row 16 should be filled with the average of all of the parts' averages from each of the three appraisers and recorded as $\bar{\bar{X}}$. R_p represents the range of part averages among all appraisers. From these calculations, three important values result: 1) $\bar{\bar{R}}$, or the average of all appraisers measurement ranges, which represents the repeatability of the measurement system within each appraiser's range as a multiplication of the number of replicates (trials); 2) R_p, or the part range, which represents the variation within the measured parts; and 3) $\bar{X}_{Diff}$, or the range of the parts averages for each appraiser, which represents the reproducibility of the measurements between appraisers. Using Hartley's constant (d_2) (Caulcutt, 1995), all ranges or means of ranges can be converted to an estimated standard deviation based on the number of subgroups (*g*) and the subgroup size (*m*) using the following equation:

$$\hat{\sigma} = \frac{R}{d_2}$$

For GRR, the value of d_2 is extracted from the d_2 statistical table provided in Table 2 below, which was adapted from Duncan (Duncan, 1986).

Table 2: Hartley's Constant d_2 table

	SUBGROUP SIZE								
NUMBER OF SUBGROUPS	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1.41421	1.91155	2.23887	2.48124	2.67253	2.82981	2.96288	3.07794	3.17905
2	1.27931	1.80538	2.15069	2.40484	2.60438	2.76779	2.90562	3.02446	3.12869
3	1.23105	1.76858	2.12049	2.37883	2.58127	2.74681	2.88628	3.00643	3.11173
4	1.20621	1.74989	2.10522	2.36571	2.56964	2.73626	2.87656	2.99737	3.10321
5	1.19105	1.73857	2.09601	2.35781	2.56263	2.72991	2.87071	2.99192	3.09808
6	1.18083	1.73099	2.08985	2.35253	2.55795	2.72567	2.8668	2.98829	3.09467
7	1.17348	1.72555	2.08543	2.34875	2.5546	2.72263	2.86401	2.98568	3.09222
8	1.16794	1.72147	2.08212	2.34591	2.55208	2.72036	2.86192	2.98373	3.09039
9	1.16361	1.71828	2.07953	2.3437	2.55013	2.71858	2.86028	2.98221	3.08896
10	1.16014	1.71573	2.07746	2.34192	2.54856	2.71717	2.85898	2.981	3.08781
>20	1.12838	1.69257	2.05875	2.32593	2.53441	2.70436	2.8472	2.97003	3.07751

The number of subgroups and the subgroup size in Table 2 depends on the GRR components *n*, *k*, and *r*. For ease of calculation, a set of constants K_1 , K_2 , and K_3 is used in the AIAG manual. K_1 is used to estimate the *EV* from $\bar{\bar{R}}$ and calculated by multiplying $\bar{\bar{R}}$ with $\frac{1}{d_2}$ for the number of trials (2 or 3) if the subgroup size *(n*r)* is >20. K_2 is used to estimate the *AV* from $\bar{X}_{Diff}$ and calculated by multiplying $\bar{X}_{Diff}$ with $\frac{1}{d_2}$ for the number of appraisers (2 or 3) when the number of subgroups is assumed to be one, since the range calculation is done only once. To ensure that the equipment variation is not accounted for twice in the calculation, a fraction of the *EV* should be subtracted from *AV* over the subgroup size *(n*r).* K_3 is used to estimate *PV* from R_p and is calculated by multiplying R_p with $\frac{1}{d_2}$ for the number of parts (2 to 10) when the number of subgroups is assumed to be one (again, there is only one range calculation, so we assume there is only one subgroup). Table 3 summarizes the relation between d_2 and the AIAG *K* constants.

Table 3: Relation between d_2 and the AIAG *K* constants

VARIATION	NUMBER OF SUBGROUPS	SUBGROUP SIZE	AIAG CONSTANT
EV	*n*k*	*r*	K_1
AV	always = 1	*k*	K_2
PV	always = 1	*n*	K_3

Thus, the measurement system variables are calculated as follows:

$$EV = \frac{\bar{\bar{R}}}{d_2} \text{ or } \bar{\bar{R}} * K_1$$

$$PV = \frac{R_p}{d_2} \text{ or } R_p * K_3$$

$$AV = \sqrt{(\frac{\overline{\overline{X_{diff}}}}{d_2})^2 - \frac{EV^2}{nr}} \text{ or } \sqrt{(\overline{\overline{X_{diff}}} * K_2)^2 - \frac{EV^2}{nr}}$$

After calculating all of the system variation, two other important measures are also calculated: the *GRR* and the total variation (*TV*).

$$GRR = \sqrt{EV^2 + AV^2}$$

$$TV = \sqrt{GRR^2 + PV^2}$$

To find the ratio of each system variation to the total variation, AIAG uses a ratio percentage of the *TV* to find *%GRR* (or *%R&R*), *%EV*, *%AV*, and *%PV*. Another performance measure is also calculated in MSA to show the suitability of the measurement system (in terms of discrimination and resolution) to depict different data categories of the measured parts. For example, if data were measured to the nearest thousandths of an inch and had no out of control points on the *R* chart, there might be an out of control point if the data were taken by an instrument that measures to the nearest hundredths of an inch instead. Most of the measured data will be on the lower limit (zero) or outside the upper limit. It would be misleading to start a process improvement project to improve the variability if the problem stems from an unsuitable measurement instrument. The number of distinct categories (*ndc*) is calculated by finding the fraction of the repeatability and reproducibility that is caused by *PV*. If the value is ≥5, then the measurement system has adequate discrimination.

3.2 MSA ANOVA analysis method

The well-known analysis of variance method is another way to analyze the measurement system. It relies on calculations of averages and ranges to estimate the variation (as a measure of the variance) and then to find the percentage of variation of each measurement variable of the total system variation. In addition to providing the calculations for the measurement system variables similar to the AIAG method, ANOVA also provides a measure of interaction between the appraiser and the parts, which can provide an insight into any significant biases incorporated in the measurements. Performing the analysis follows the traditional ANOVA table and can be performed manually but is usually done on computers using various mathematical programs for quicker analysis. The sources column in the ANOVA table consists of the appraiser, parts, appraiser by parts, and the equipment. The degrees of freedom (*DF*), sum of squares (*SS*), mean square (*MS*), and *F-ratio* are calculated following the traditional statistical calculations of the values from the measured data (details on how to perform these calculations can be found in (Montgomery, 2009)). One advantage of employing ANOVA MSA using a statistical software program like Excel or Minitab is the additional graphical representation of the data that can help with interpreting the results. Figures 3 and 4 in the Appendix show an example of the variable *GRR* Minitab results with additional data interpretation. The example used is the one in the case study below.

4. Case study analysis and discussion

To compare MSA using both AIAG and ANOVA methods, a lab experiment was performed as follows: 10 parts were obtained from a lot of hinges for hinges for interior cabinets for airplanes. The feature to be measured was the distance between the two hinge legs with a specification of 0.9000 ±0.0100 inches. Three appraisers were selected to perform the measurements and one recorder to randomize the runs. All appraisers examined a demo part and trained on what to measure with a digital caliper as the instrument. Three trials per appraiser were set for the measurements. After collecting the data points (90 measurements total) the AIAG method was conducted using Excel and the ANOVA method was conducted using Minitab. Table 4 below summarizes the MSA output variables from both methods.

Table 4: Results comparison

MEASUREMENT VARIABLES	AIAG METHOD	ANOVA METHOD
EV	0.00050	0.00050
AV	0.00019	0.00021
R&R	0.00058	0.00055
PV	0.00213	0.00275
TV	0.00220	0.00280
%EV	25.06%	3.23%
%AV	8.57%	0.58%
%R&R	26.49%	3.82%
% PV	96.43%	96.18%
TOTAL	**122.92%**	**100%**

As noticed from the results in Table 4, the measurement variation (SD) is the same for both methods, except for some data rounding discrepancies which do not affect the final results and interpretation of the measurements. However, the total percentage of the variables is different between the two methods, and that is one of the main differences. AIAG relies only on finding the percent of contribution of each measurement variation to the total variation using the SD, while the ANOVA method uses the variance to find the percent of contribution instead. From a mathematical point of view, the ANOVA method is more accurate because, as stated above,

$$\sigma^2_{meas.} = \sigma^2_{part} + \sigma^2_E + \sigma^2_A$$

and mathematically this equation is not equal to

$$\sigma_{meas.} = \sigma_{part} + \sigma_E + \sigma_A$$

Thus, finding the percent of contribution of each variation to the total variation makes more sense if done using the estimation of the variance instead of the SD. Moreover, the summation of the percentage of contribution adds up to 100% using the variance, which makes more sense. For both methods, the interpretation of the data percentages is as follows:

For the value of %*R&R*:

1. If < 10%, the measurement system is acceptable.
2. If > 30%, the measurement system is not acceptable and needs to be improved/modified.
3. If 10 ≤ %*R&R* ≤ 30, a further look at the *EV*% and *AV*% is required:
   a. If the *AV*% is higher, then the variation comes mainly from the appraisers. Additional training, better measurement techniques, improved measurement conditions, or adding fixtures may improve the ability of the appraisers to perform the measurements.

If *EV*% > AV%, the gauge needs maintenance or has to be in a more rigid location, to eliminate vibration, for example.

5. Conclusion

This study has provided a comprehensive review of two well-known methods for analyzing measurement systems for variable data. The AIAG method depends mainly upon estimating the variation of the measurement system as a measure of standard deviation, whereas ANOVA analysis uses the analysis of variance, which, in the case of MSA, makes the data easier to interpret. Moreover, ANOVA analysis provides an additional graphical representation of the measurements that will give more insight into the measurement system and help with pinpointing where improvements need to be applied if necessary. As stated in the literature review, there is another method for MSA that can also be compared with the two methods discussed in the present study, but that has been left as a subject for future research.

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7. Appendix

Gage Repeatability and Reproducibility Data Collection Sheet											
Appraiser /Trial #	PART										AVERAGE
	1	2	3	4	5	6	7	8	9	10	
A 1											
2											
3											
Average											$\bar{X}_a$ =
Range											$\bar{R}_a$ =
B 1											
2											
3											
Average											$\bar{X}_b$ =
Range											$\bar{R}_b$ =
C 1											
2											
3											
Average											$\bar{X}_c$ =
Range											$\bar{R}_c$ =
Part Average											$\bar{\bar{X}}$ = R_p =
([$\bar{R}_a$ =] + [$\bar{R}_b$ =] + [$\bar{R}_c$ =]) / [# OF APPRAISERS =] =											$\bar{\bar{R}}$ =
$\bar{X}_{corr}$ = [Max $\bar{X}$ =] - [Min $\bar{X}$ =] =											$\bar{X}_{DIFF}$ =
* UCL_R = [$\bar{\bar{R}}$ =] × [D_4 =] =											

*D_4 = 3.27 for 2 trials and 2.58 for 3 trials. UCL_R represents the limit of individual R's. Circle those that are beyond this limit. Identify the cause and correct. Repeat these readings using the same appraiser and unit as originally used or discard values and re-average and recompute $\bar{\bar{R}}$ and the limiting value from the remaining observations.

Notes:____

Figure 1. GRR data collection sheet

Gage Repeatability and Reproducibility Report

Part No. & Name: | Gage Name: | Date:
Characteristics: | Gage No: | Performed by:
Specifications: | Gage Type:

From data sheet: $\bar{\bar{R}}$ = | $\bar{X}_{DIFF}$ = | R_p =

Measurement Unit Analysis | **% Total Variation (*TV*)**

Repeatability – Equipment Variation (*EV*)

$EV = \bar{\bar{R}} \times K_1$

= ______ × ______

= ______

Trials	K_1
2	0.8862
3	0.5908

$\%EV = 100\,[EV/TV]$

= 100 [______/______]

= ______%

Reproducibility – Appraiser Variation (*AV*)

$AV = \sqrt{(\bar{X}_{DIFF} \times K_2)^2 - (EV^2/(nr))}$

$= \sqrt{(\_\_\_\_ \times \_\_\_\_)^2 - (\_\_\_\_^2/(\_\_ \times \_\_))}$

= ______

n = *parts* *r* = *trials*

Appraisers	2	3
K_2	0.7071	0.5231

$\%AV = 100\,[AV/TV]$

= 100 [______/______]

= ______%

Repeatability & Reproducibility (*GRR*)

$GRR = \sqrt{EV^2 + AV^2}$

$= \sqrt{(\_\_\_\_^2 + \_\_\_\_^2)}$

= ______

$\%GRR = 100\,[GRR/TV]$

= 100 [______/______]

= ______%

Part Variation (*PV*)

$PV = R_p \times K_3$

= ______ × ______

= ______

$\%PV = 100\,[PV/TV]$

= 100 [______/______]

= ______%

Total Variation (*TV*)

$TV = \sqrt{GRR^2 + PV^2}$

$= \sqrt{(\_\_\_\_^2 + \_\_\_\_^2)}$

= ______

Parts	K_3
2	0.7071
3	0.5231
4	0.4467
5	0.4030
6	0.3742
7	0.3534
8	0.3375
9	0.3249
10	0.3146

$ndc = 1.41\left(PV/GRR\right)$

= 1.41(______/______)

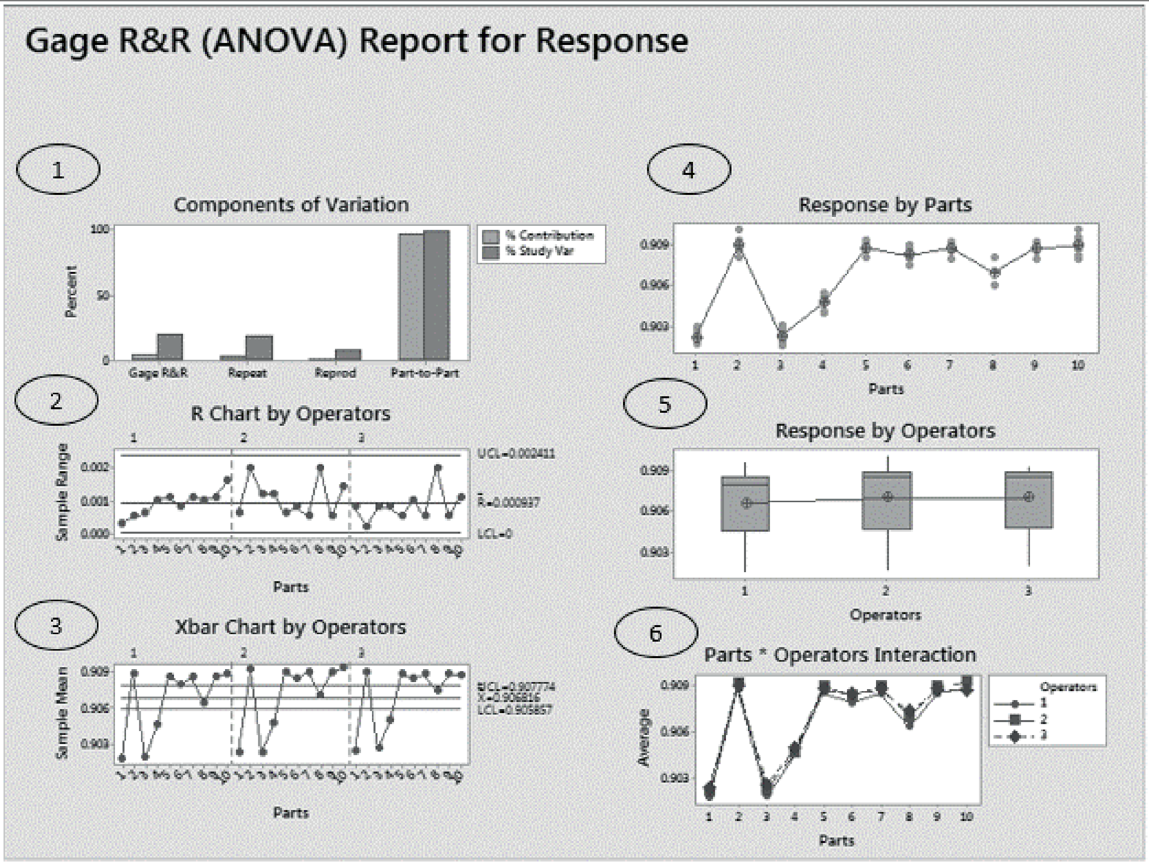
= ______

For information on the theory and constants used in the form see *MSA Reference Manual*, Fourth edition.

Figure 2. GRR data report sheet

```
Gage R&R Study Worksheet

Parts:        10     Operators:    3
Replicates:    3     Total runs:  90


Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source              DF         SS         MS        F      P
Parts                9  0.0006152  0.0000684  649.277  0.000
Operators            2  0.0000033  0.0000016   15.466  0.000
Parts * Operators   18  0.0000019  0.0000001    0.352  0.992  --> No significant interaction
Repeatability       60  0.0000180  0.0000003
Total               89  0.0006383


α to remove interaction term = 0.05


Two-Way ANOVA Table Without Interaction

Source          DF         SS         MS        F      P
Parts            9  0.0006152  0.0000684  268.605  0.000
Operators        2  0.0000033  0.0000016    6.398  0.003
Repeatability   78  0.0000198  0.0000003
Total           89  0.0006383


Gage R&R

                               %Contribution
Source              VarComp     (of VarComp)
Total Gage R&R    0.0000003             3.82   --> (R&R/TV)*%100
  Repeatability   0.0000003             3.23
  Reproducibility 0.0000000             0.58
    Operators     0.0000000             0.58
Part-To-Part      0.0000076            96.18
Total Variation   0.0000079           100.00  --> The higher the better


Upper process tolerance limit = 0.91


                                 Study Var  %Study Var  %Tolerance
Source              StdDev (SD)   (6 × SD)       (%SV)  (SV/Toler)
Total Gage R&R        0.0005480  0.0032877       19.54       51.62
  Repeatability       0.0005044  0.0030267       17.99       47.52
  Reproducibility     0.0002140  0.0012839        7.63       20.16
    Operators         0.0002140  0.0012839        7.63       20.16
Part-To-Part          0.0027507  0.0165041       98.07      259.14
Total Variation       0.0028047  0.0168283      100.00      264.23


Number of Distinct Categories = 7  --> <2; system cannot discriminate
                                       between parts,
Gage R&R for Response                  =2; parts can be divided into high and
                                       low groups
                                       ≥5; the system is acceptable and can
                                       distinguish between parts
```

Figure 3. Minitab ANOVA statistical report



GRAPH #	INTERPRETATION
1	For a good measurement system higher is better for Part-to-Part, lower for the rest
2	The plotted point is the range of each part measurement by appraiser, if measurements are same, range=0, out of control points (UCL) means inconsistency, range is high
3	More variation between parts averages compared to variation between operator measurements averages is desired. So out-of-control averages are desired.
4	The Mean is represented by solid circles; measurements are represented by empty circles. Line represents the average between parts, average should vary enough to show difference between parts
5	All the study measurements arranged by operators. Boxplot for ≥9 measurements otherwise dotes. The desired centerline is to be straight and horizontal between the operators
6	The plotted points grouped tightly together and the lines are parallel is desired, but the parts averages vary enough so that difference between parts is clear

Figure 4. Minitab ANOVA Graphical report

A Usability Assessment of a Statistical Analysis Software Package

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Abstract

The use of software programs to analyze statistical data has great value in engineering applications. The ability to handle large sets, minimize calculation errors, and produce instant results are among the benefits generally expected by users. Several packages with various features and limitations are commercially available. *Usability* is one of the most important criteria for evaluating the quality of software from the users' perspectives. This criteria is utilized to understand the users' experiences and measure their satisfaction. The current paper represents a case study involving a usability assessment of a statistical analysis software package. Scores from the Software Usability Measurement Inventory (SUMI) questionnaire coupled with results from a qualitative analysis of users' written comments reveal valuable insights into their perceptions concerning learnability and portability.

1. Introduction

Despite its importance, quality remains a metric that is difficult to specify and evaluate especially with regards to the end user (Stefani & Xenos, 2007). Although the software industry has yet to adopt a predominant consensus for evaluating software quality; expert reviews, software metrics, and quality models are commonly accepted forms of evaluation (Behkamal et al., 2008). One of the challenges for software developers and experts in human-computer interaction is to design and create software products for e-learning systems (Arh & Blazic, 2008). As software products become increasingly complex, consumers tend to place a higher importance on how easy it is to use the software as a critical measure of the product quality (Jordan, 1997). A product's ease of use is referred to as "*usability*" which has become the main focus of software development.

This paper presents a case study aimed at evaluating usability of the *Statgraphics*® software. The following section represents a brief review of the literature pertaining to software quality and usability assessment tools. Section 3 presents a detailed description of the case study and the steps followed in analyzing the data. Concluding remarks are found in Section 4.

2. Literature Review

The IEEE Standard 610.12 (Institute of Electrical and Electronics Engineering, 1990) defines quality as the degree to which a system, component, or process meets customer or user needs or expectations. As such, software quality refers to the capacity for utilization, and capability of fulfilling users' requirements. Since the 1970s, numerous software quality models have been proposed such as those developed by Boehm et al. (1976), and McCall et al. (1977). In response to a myriad of quality factors and models that caused inconsistencies and confusion in software quality evaluation, the International Organization for Standardization (ISO) began promoting its own internationally recognized model for software quality. ISO/IEC 9126 was published in 1992 and is the most common model used to measure the quality of software products. ISO/IEC 9126 measures software quality in terms of functionality, reliability, usability, efficiency, maintainability, and portability. The primary benefit of ISO/ICE 9126 is its universal applicability across various types of systems including e-learning and e-commerce software. According to the ISO 9241-11 (1998), usability addresses aspects of a software product that pertain to effectiveness, efficiency, and user satisfaction.

The concept of usability derives from research into human behaviors while using technology. Shackel (1991) suggested that a high quality software product must be easy to use and must effectively serve the purpose of a particular set of users, performing particular tasks, within particular environments. He emphasized that usability pertains not only to the objective qualities of a software product, but also to subjective aspects of the end user's perception while operating the software.

Techniques for evaluating software quality have evolved to predict how users will interact with software products. As stated by Jordan (1997), "After all, there is no point in presenting users with technically excellent gadgets … if they cannot use them." Evaluations that include user participation are most useful since the goal of all software products is to meet the needs of the end user (Dumas, 2003). In addition, Holzinger (2005) noted that evaluation measurement involving the end-user is paramount to ascertaining an accurate assessment of a product's usability. Since consumer products are becoming more intricate and complicated, users tend to value and perceive the ease of use as a key indicator of quality. However, measuring usability is not an exact science; much of the confusion about software usability is due to varying perceptions among usability evaluators (Seffah & Metzker, 2004). Usability is subjective by nature. The definition of usability and the output of an assessment depend on the intents of the researcher and the perspectives of the person performing the evaluation (Nielsen, 1993).

Shneiderman (2000) indicated that usability standards that are applicable to all software across the board represent a significant challenge for developers. In order to address the difficulty of creating usable software for a diverse group of users, he proposed that developers should utilize segmentation strategies based on user traits such as values, experience, and temperament.

Throughout the past two decades, usability experts have presented various surveys that are designed to evaluate perceptions of software performance. According to Cavallin et al. (2007), examples of questionnaires have included "the Software Usability Scale (SUS)," "the Computer User Satisfaction Inventory (CUSI)," and "the Questionnaire for User Interaction Satisfaction (QUIS)" as well as "the Software Usability Measurement Inventory (SUMI)." These questionnaires typically consist of up to 70 questions and employ a Likert scale to gather information about users' experience with a software application.

SUMI was developed by the Human Factor Research Group (HFRG) as part of the Metrics for Usability Standards in Computing (MUSiC) project. The questionnaire was published in 1993 to evaluate business applications used in an office environment (Kirakowski & Cierlik 1998). Compared to other methods of usability evaluation, SUMI offers several advantages, and is recognized by ISO/IEC 9126 as an accepted model of assessing user satisfaction.

SUMI is a 50-item user questionnaire that evaluates the usability of a software based on affect, efficiency, learnability, helpfulness, and control (Kirakowski & Corbett, 1993). The questionnaire follows the ISO 9241 standard for assessing a user's level of satisfaction with a software product (O'Malley et al. 2014). The SUMI format consists of statements that use a three-point Likert scale in which a user responds as either agreeing, disagreeing, or making no decision about the item in question. The responses are given a score and evaluated as either a positive reaction or a negative reaction depending on the nature of the item. The questionnaire was originally written in UK English. Currently, SUMI has been translated into 20 different languages including Spanish, Dutch, French, German, Greek, Swedish, and American English.

Additional information and a copy of the questionnaire can be obtained from the SUMI homepage (http://sumi.uxp.ie).

Once the questionnaire is completed, the scores are aggregated and organized using a software program called SUMISCO. This dedicated software is used to score the questionnaire responses and match them against a standardization database. Because SUMI is vastly utilized throughout research in the software industry on a global scale; there are more than 2,000 software evaluations in its commercial database (Kirakowski, 2003). The data is populated based on successful software products and sets a mean score of 50 with a standard deviation of 10. A software that achieves a rank of 40 to 60 is likened to outstanding products in terms of usability. In addition, the survey includes two demographical questions and two open-ended questions. Demographical questions are used to identify the computer skills and knowledge of the evaluator and his or her perception of the importance of the task performed using the software. Open-ended questions solicit user perceptions of the best aspects of the software and suggestions for improvement.

According to Kirakowski (2003), the SUMI model recommends a minimum of 10 to 12 users in order to achieve adequate precision. Arh and Blazic (2008) noted that the SUMI questionnaire typically takes ten minutes to complete unless additional time is needed to acclimate the evaluator to the software and perform benchmark tasks that represent real-world scenarios.

3. Case Study

A usability study of the *Statgraphics*® Centurion XVII from Statpoint Technologies was conducted to measure students' satisfaction, and to obtain a valid measure for comparing competitive products as well as different versions of the software. The SUMI questionnaire (in American English) was administrated to students enrolled in a graduate-level course in Engineering Statistics. A total of 73 graduate students with varying engineering majors participated online. Responses were saved in the SUMI database, compared to existing data, and summarized in a report. The report was generated using SUMISCO at the School of Applied Psychology, Enterprise Centre, in Cork, Ireland. It included a summary of the quantitative scores and a list of written comments from open-ended questions. Also, a global scale was generated, based on responses to 25 items, to represent a single "perceived quality of use" construct. These authors performed a qualitative analysis of all written comments by utilizing SPSS Statistics 17.0 (International Business Machines Corporation, 2007). Both results are represented in the following sections.

3.1 SUMI Report

Results from the questionnaire are presented in Table 1. These results represent the normalized scores on the five attributes of usability and a global score reflecting perceived quality of use. The mean score in the standardized database is 50, with a standard deviation of 10. Because the database contains the ratings of acceptable software, a score in the range 40–60 is comparable in terms of usability to most of these products. A score below 40 would reflect below-average assessment. The results shown in Table 1 suggest that the *Statgraphics*® software is well within the outstanding products in terms of usability. Figure 1 represents the SUMI score profile for the attributes shown in Table 1.

As can be seen, the 95% confidence intervals of estimating the average scores for all attributes exceed the score of 50, except for *learnability* (42.02 to 49.02).

Table 1: Results of the SUMI Questionnaires

	Mean	St Dev	Median	IQR	Minimum	Maximum
Global	58.04	9.70	58.0	16.0	33	74
Efficiency	55.01	10.39	56.0	14.5	23	72
Affect	58.90	10.56	60.0	11.0	23	72
Helpfulness	58.88	8.91	60.0	14.0	36	72
Controlability	55.14	9.91	57.0	13.5	26	72
Learnability	45.52	15.06	45.0	25.5	13	71

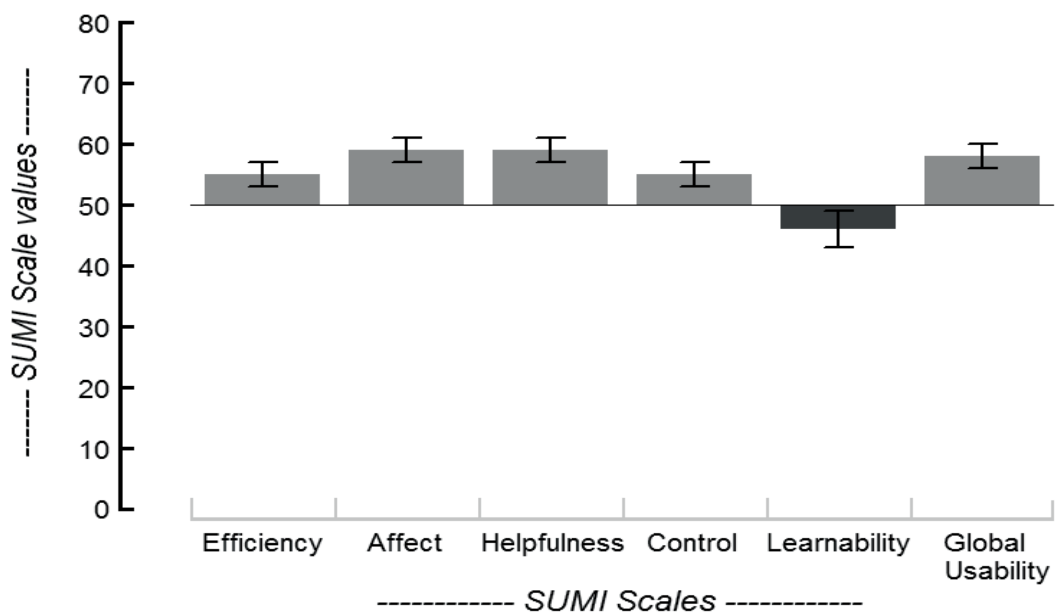

Figure 1: SUMI scale profile: Means with 95% CIs

3.2 Qualitative Analysis

Techniques for qualitative data analysis were utilized in an attempt to gain more insight into students' perceptions of the software usability. Figure 2 presents a pie chart of students' perceptions of their own software skills. As shown, the majority of the students (57%) rated their software skills and knowledge as good, but not very technical. Only 19% of the students rated their skills as very experienced and technical. None of the students reported that they find most software difficult to use.

In response to the question of how important is the type of software evaluated, the majority of students ranked the software as important (57%). About 33% of the students ranked the software as being extremely important, as shown in Figure 3.

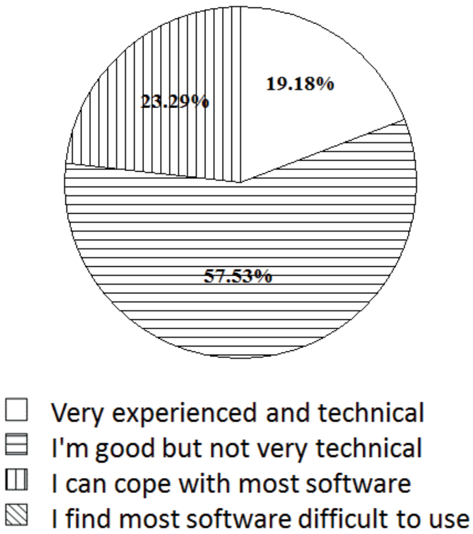

Figure 2: Distribution of software skills

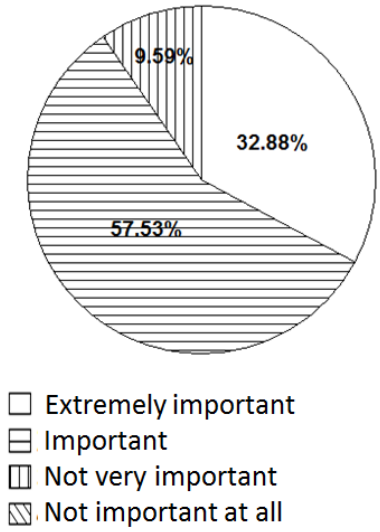

Figure 3: Distribution of perceived importance

ID	Comment
1	evrything works fine
2	help options.
3	make it more fast
4	it may be slightly complicated in the first glance till we get to know the functions if it was made easier it would be great
5	evrything works fine
6	Some of the menus are nested away too far from the menu
7	I do not think it needs improvement
8	Nothing
9	Nothing as of now
69	it needs to be fast
70	every things
71	all the menus should be organised into one
72	n/a
73	Its slow

Figure 4. Partial list of written comments on features to be improved

A list of 73 written comments was also obtained in response to aspects of the software that need to be improved. Part of this list is shown in Figure 4. The list was screened to identify appropriate statements (units) for analysis as defined by Jackson and Trochim (2002). Long statements were divided, while repeated or ambiguous statements (e.g., nothing, I don't know, N/A) were omitted. This resulted in a shorter list of 44 statements. These statements were printed on cards for sorting, and a panel of five graduate students familiar with the study was asked to sort similar statements into piles. The results obtained from each sorter were used to construct a 44 x 44 binary matrix. The cells of the matrix are filled with 1.0 if the statements in the corresponding row and column were placed in one pile by the sorter and zero otherwise. Scores from the five binary matrices were combined into a 44x44 similarity matrix. This final matrix represented the input for multidimensional scaling (MDS) analysis using SPSS. Figure 5 presents the scree plot obtained and suggests that a two-dimensional map could be used to characterize the common space for students' perceptions.

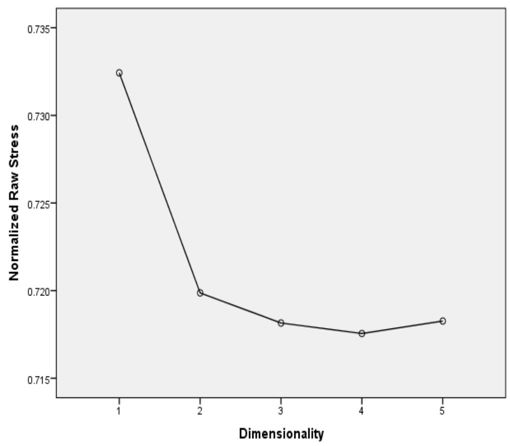

Figure 5. Scree plot and dimensionality

This resulted in the concept map shown in Figure 6. According to Carroll and Wish (1976), a concept map may be analyzed in two ways. One way is to examine the scatters formed on the map and identify the most common themes of perceptions. Only one cluster was obvious as shown in Figure 6.

An examination of the original statements within the cluster indicated the need to improve the degree by which a student can familiarize him or her -self with the functionality of the software. This supports the results of the SUMI report regarding the software learnability. Some of the students suggested offering smart help and simplifying user interface as possible approaches for improving learnability.

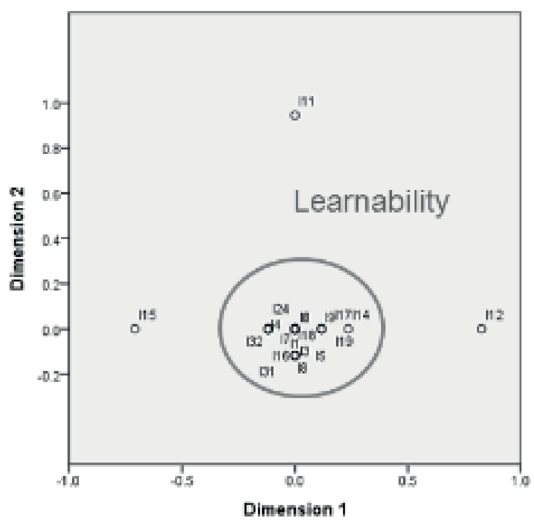

Figure 6. Concept map and cluster analysis

Another method for analyzing the map is to identify appropriate locations and descriptions of the two axes proposed by the scree plot in Figure 5. This type of analysis is typically aimed at discovering dimensions affecting user's perceptions. Because these two axes are not necessarily perpendicular, the process is iterative and requires the examination of meanings of at least two opposing statements along each axis.

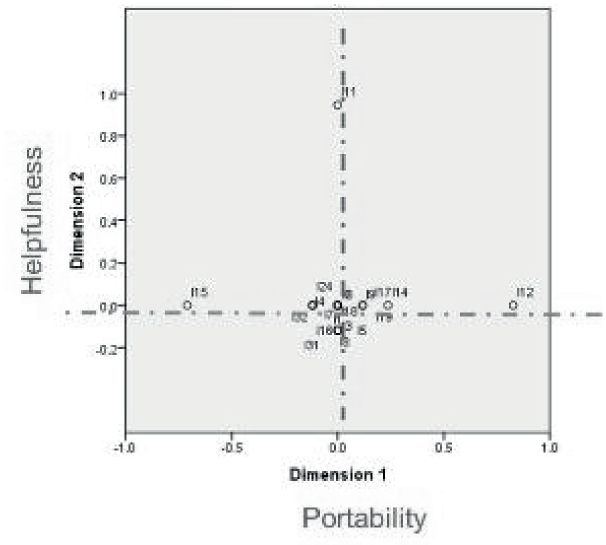

Figure 7. Dimensions of user perceptions

As shown in Figure 7, the scatter appears to be best represented by two perpendicular axes. An examination of the two statements plotted along the horizontal axis (points I15 and I12 in Figure 7) proposed a dimension of portability. Similarly, opposing statements along the vertical axis (points I11 and I8) proposed a dimension of helpfulness. The students suggested that offering a student version for Mac users with built-in tutorials are possible targets for improvement.

A similar analysis of feedback comments regarding the best aspect of the software pointed to the ability of the software to handle large data sets effectively and to visualize the results. This was supported by the high scores on the SUMI report regarding efficiency and affect.

4. Conclusions

Usability plays a major role in satisfying customer needs. In such a highly competitive market, software designers and developers should keep usability as a target for continuous improvement. The main objective of this study was to evaluate the usability of the *Statgraphics*® software. Results indicated a global score of 58 and revealed the most important usability attributes from the students' viewpoint. Both "affect" and "efficiency" scored the highest among the students. However, "learnability" scored the lowest. While SUMI reports are useful, more insight can be gained by analyzing the written comments. All comments made in response to the two open-ended questions were analyzed using MDS on SPSS. Results confirmed the need to improve software "learnability" and suggested improving "portability" and "helpfulness." Software developers should address such important aspects to improve students' satisfaction. These authors strongly recommend that users of SUMI augment the reported results with a similar analysis of written comments for better understanding of users' needs.

5. Acknowledgements

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Optimization of Milk-Run Delivery Issue in Lean Supply Chain Management by Genetic Algorithm and Hybridization of Genetic Algorithm with Ant Colony Optimization: an Automobile Industry Case Study

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Abstract

This paper demonstrates a possible optimal solution for a milk-run delivery issue in lean supply chain (LSC) management. The milk-run delivery issue is studied with the genetic algorithm (GA) approach as well as the hybrid of genetic algorithm with the ant colony optimization approach (HGACO). The objective is to figure out an optimal solution for the transportation distance as well as for managing the transportation of goods in highly complex logistic networks. Using the automobile industry case study (AICS), the designed transport system must visit, from a starting point of a single manufacturing plant facility, numerous supplier facilities as well as various customers only once per run. This problem was previously solved by utilizing improved ant colony optimization (ACO) and mixed integer programming (MIP) approaches in order to minimize the total cost of supply chain. In fact, the optimal transportation distance ensures that the total cost of the entire supply chain is minimized. Additionally, GA, HGACO, and ACO approaches were compared in this work. HGACO is a hybrid meta-heuristic approach that exploits the advantages of both the ACO and GA approaches in order to obtain a more efficient delivery route with fewer iterations. The optimal value obtained with GA was 283.30 km. The results with the GA approach are identical to the results obtained with the HGACO approach, both for the delivery route and the total cost supply chain. However, the results for ACO were not as satisfying in AICS because they did not achieve the optimal value of the GA and HGACO approaches. The results illustrate that the proposed HGACO approach can efficiently and effectively find optimal solutions.

Key words: Lean Supply Chain, Milk-Run, Genetic Algorithm, Ant Colony Optimization and Hybrid Meta-heuristic.

1. Introduction

A lean supply chain (LSC) is a network of integrated organizations in which the capabilities of all entities are aligned with customer demand (Rivera, Wan, Chen & Lee, 2007). The supply chain (SC) is referred to as "lean" when the lean concept is implemented across the entire SC (Ugochukwu, Engström & Langstrand, 2012). Implementing the lean concept is a way to help companies achieve cost reduction as well as quality and efficiency improvement with less effort. Additionally, by identifying and eliminating waste (e.g., of time, effort and materials) through continuous improvement, LSC avoids any processes that do not add value to the customer (Manrodt, Abbott & Vitasek, 2005). Supply chain total costs can include marketability, distribution, production, storage, transportation, operations and the initial expense of setting up a facility (Nguyen & Dao, 2015). The transportation management system can be divided into four categories: direct shipping, milk-run, cross-docking and tailored network (Eroğlu, Rafele, Cagliano, Murat & Ippolito, 2014). To improve the transportation management system, it is recommended to use the milk-run delivery, one of the advanced delivery concepts. The milk-run delivery can be represented as the routing of the supply or delivery vehicle to construct multiple pick-ups or drop-offs on a regularly scheduled basis and at different locations. Having the shortest possible total transportation distance and the lowest cost of milk-run delivery lead to minimize the supply chain total cost. Transport and delivery costs have been considered by Chopra and Meindl (2013) as two cost components in milk-run delivery issue under LSC. Transport cost comes from the delivery route (dr), while the delivery cost is based on the delivery frequency (n) cost in milk-run delivery issue under LSC. Additionally, it has been determined that the milk-run is an important element for an integrated lean logistics strategy (Bowersox, Closs & Copper, 2002). Therefore, the selected model for milk-run delivery must aim to improve vehicle load and minimize transportation distance (optimal delivery route) between facilities with optimizing the entire delivery of goods among the facilities.

The automobile industry case study (AICS) was studied by Zhou and Kelin (2011). They built up a theoretical total cost (TC) model for the milk-run delivery issue in LSC by considering the three factors that most influence the total cost of supply chain: production, delivery and inventory costs. Hence, they developed an equation to minimize TC (Equation (1)) and then solved it by applying the improved ant colony optimization (ACO). Later, Nguyen and Dao (2015) worked on the same case study but with different approaches: mixed integer programming (MIP), along with a hybrid of ant colony optimization (ACO) and tabu search (HAT). They compared their results with those of the original ACO, finding that the MIP results outperformed the previously obtained ACO results as well as the HAT results. Thus, MIP can minimize the total cost of an entire supply chain. The AICS involves only a few facilities (less than 10) making it a small-scale LSC. So, the previous results indicated that the use of MIP is pertinent in a small-scale LSC. However, MIP, HAT and ACO were also tested with random data in large-size LSC (Nguyen & Dao, 2015). The results showed that MIP encounters significant difficulties in such cases. When the number of facilities is greater than 15, the time spent in finding the optimal dr makes MIP all but useless as an industrial application (Nguyen & Dao, 2015). In fact, compared with ACO and HAT, MIP requires a very long processing time when handling a large-scale LSC. When random data were tested with 100 iterations, optimal dr from the HAT was superior to ACO in most cases (Nguyen & Dao, 2015).

In this paper, we will apply both the genetic algorithm (GA) approach as well as the hybrid of the genetic algorithm and ant colony optimization (HGACO) approach to study their advantages and disadvantages compared to each other and to the ACO approach, using the same data from AICS and applying the same TC function (Equation 1) developed by Zhou and Kelin (2011).

$$
\begin{aligned}
Min\ TC = & \sum_{i=1}^{N}\left\{(UIC_s)_i (SI_s)_i + (UIC_m)_i (SI_m)_i + \frac{(UIC_d)_i P_m dr}{VT} + P_m (UPC_s)_i\right\} \\
& + \sum_{j=1}^{K}\left\{UIC'_m \times SI'_m + (UIC'_c)_j (SI'_c)_j + \frac{(UIC'_d)_j (D_c)_j\, dr}{VT} + (D_c)_j (UPC_m)\right\} \\
& + \left(\sum_{i=1}^{N}\{(USC_s)_i + (FOC)_i\} + \sum_{j=1}^{K}\{USC_m + (FOC')_j\} + FDC + UDC \times dr\right) n \\
& + \left(\sum_{i=1}^{N}\left\{(UIC_s)_i P_m \left(1 - \frac{P_m}{2(P_s)_i}\right) + \frac{(UIC_m)_i P_m}{2}\right\} + \sum_{j=1}^{K}\left\{UIC'_m \left((D_c)_j - \frac{((D_c)_j)^2}{2P_m}\right) + \frac{(UIC'_c)_j (D_c)_j}{2}\right\}\right) \Big/ n
\end{aligned}
\tag{1}
$$

A list of the parameters is given below:

D_c: productivity/demand rate from customers;
d_{ij}: transportation distance from facility i to facility j;
dr: total transportation distance for one route;
F: number of facilities;
FDC: delivery start-up cost (1000);
FOC: order fixed cost of parts;
FOC': order fixed cost of finished products;
i: a manufacturing plant /customer/ supplier facility;
j: a manufacturing plant /customer/ supplier facility;
K: number of customers;
N: number of suppliers;
n: delivery frequency;
P_m: productivity/demand rate from a manufacturing plant;
P_s: productivity/demand rate from suppliers;
SI_m: part safety stock quantity of a manufacturing plant;
SI_s: part safety stock quantity of suppliers;
SI'_c: finished safety stock quantity of customers;
SI'_m: finished safety stock quantity of a manufacturing plant;
T: manufacture's production cycle (30 days);
TC: minimum total cost of supply chain;
UDC: unit delivery cost (5 per km);
UIC_d: parts unit inventory cost of in-transit;
UIC_m: parts unit inventory cost of a manufacturing plant;
UIC_s: parts unit inventory cost of suppliers;
UIC'_c : finished product unit inventory cost of customers;
UIC'_d: finished product unit inventory cost of in-transit;
UIC'_m: finished product unit inventory cost of a manufacturing plant;
UPC_m: unit production cost of manufacturing plant;
UPC_s: unit production cost of suppliers;
USC_m: production start-up cost/batch of a manufacturing plant;
USC_s: production start-up cost/batch of suppliers;
V: average speed of delivery vehicle (50 km/h);
W: delivery vehicle capacity (20 tons);
w: weight (mass) of part (kg);
w': weight (mass) of finished product (kg).

2. Specific data and description of automobile industry case study (AICS)

The supply chain in an AICS has just one manufacturing plant facility. This is identified as facility number 1, because the route will always start and end here. Facilities 2, 3, and 4 are considered as suppliers, while facilities 5, 6, 7, 8 and 9 play the role of customers. The geographical location of each AICS facility is listed in Table 1.

Table 1. Geographical location of AICS facilities (adapted from Zhou & Kelin, 2011)

Facility/Location	1	2	3	4	5	6	7	8	9
X-axis	50	26	62	52	40	73	38	86	21
Y-axis	70	95	49	15	80	12	66	97	82

To integrate the supply chain, we need to consider the transportation distance delivery model to minimize the transportation cost between the manufacturing plant, the suppliers and the customers by going to each AICS facilities only once. The goal is to minimize the total cost of the supply chain by applying the following strategy: the shortest delivery route (dr) and the optimal delivery frequency (n). This strategy will have a significant impact on the level of stock and the quantity of goods with regard to the manufacturing plant, suppliers and customers. The supply chain values of the AICS are given in Tables 2 and 3 and will be utilized as input data for Equation (1).

Table 2. Data of manufacturing plant and supplier facilities for AICS (adapted from Zhou & Kelin, 2011)

Facilities/locations	1	2	3	4
$UPC_{m/s}$	50	10	12	15
$USC_{m/s}$	5000	1000	1500	2000
$UIC_{m/s}$	10, 12, 15	10	12	15
UIC_d	-	12	14	18
$SI_{m/s}$	4000	4000	5000	8000
SI'_m	16 000	-	-	-
UIC'_m	50	-	-	-
FOC	-	100	100	100
W(kg)	-	2	1.5	1.5
W'(kg)	5	-	-	-
$P_{m/s}$	12 600	134 000	135 000	138 000

Table 3. Data of customer facilities for AICS (adapted from Zhou & Kelin, 2011)

Facilities/process	5	6	7	8	9
FOC'	200	200	200	200	200
UIC'_c	50	50	50	50	50
UIC'_d	60	60	60	60	60
SI'_c	2200	2000	1800	2000	1800
D_c	22 000	20 000	18 000	20 000	18 000

2.1. Objective function

The main objective here is to minimize the transport distance between the facilities, which can be modelled as the sum of the distances to all of the facility locations in just one route.

$$Minimize\ dr = \sum_{i=1}^{F} \sum_{j=1}^{F} d_{ij} x_{ij} \tag{2}$$

2.2. Constraints

1) Ensure that each customer/supplier is serviced/supplied only once and included in one route:

$$x = \begin{cases} 1 \text{ if vehicle travels from i to j} \\ 0 \text{ otherwise} \end{cases}$$

2) Ensure that a route is fully connected and that there is no sub-route:

$$\sum_{i,j \in F} x_{ij} = |K| - 1 \quad K \subset i, 2 \leq |K| \leq F - 2$$

K is the set of all transportation distances in one route.

3) Ensure that the vehicle starts and ends at the same facility. As shown below, [1] means facility number 1, which is both the start and the end of the same route:

Route = [1]: [F+1]

However, the path from the second facility [2] to the last facility [F] is random:

Random route= [2]: [F]

Mathematically, we can obtain the minimum n and the minimum TC by the following equations:

- delivery frequency (Nguyen & Dao, 2015):

$$n = \sqrt{\left(B + (D \times dr)\right)/C} \tag{3}$$

- total cost (Nguyen & Dao, 2015):

$$Min\ TC = A*dr + B*n + C*n*dr + D/n + E \tag{4}$$

where:

$$A = \sum_{i=1}^{N}\left(\frac{(UIC_d)_i P_m}{VT}\right) + \sum_{j=1}^{K}\left(\frac{(UIC'_d)_j (D_c)_j}{VT}\right)$$

$$B = \sum_{i=1}^{N}\left\{(USC_s)_i + (FOC)_i\right\} + \sum_{j=1}^{K}\left\{USC_m + (FOC')_j\right\} + FDC$$

C = *UDC*

$$D = \sum_{i=1}^{N}\left\{(UIC_s)_i P_m\left(1 - \frac{P_m}{2(P_s)_i}\right) + \frac{(UIC_m)_i P_m}{2}\right\} + \sum_{j=1}^{K}\left\{UIC'_m\left((D_c)_j - \frac{((D_c)_i)^2}{2P_m}\right) + \frac{(UIC'_c)_j (D_c)_j}{2}\right\}$$

$$E = \sum_{i=1}^{N}\left\{(UIC_s)_i (SI_s)_i + (UIC_m)_i (SI_m)_i + P_m (UPC_s)_i\right\} + \sum_{j=1}^{K}\left\{(UIC'_m) SI'_m + (UIC'_C)_j (SI'_c)_j + (D_c)_j (UPC_m)\right\}$$

3. Proposed meta-heuristic approaches

3.1. Genetic algorithm (GA)

The GA approach is a type of optimization algorithm which is used to find the ideal solution(s) for a given computational problem that maximizes or minimizes a function (Gonen, 2011). The GA approach represents one branch of the area of study that is called evolutionary computation. This is based on the principles of natural genetic and natural selection to find the fittest solutions. Like in evolution, many of the genetic algorithm processes are random and feature factors such as selection, crossover, and mutation. After encoding the solution in an appropriate way, GA works iteratively, evolving to obtain the global optimum. In addition, the individuals in a population are manipulated by the genetic operators to improve their fitness values while searching for global optimum solutions. This optimization technique allows one to set the level of randomization. The following section lists the seven steps of GA (Potvin, Duhamel & Guertin, 1996):

1) Initiate: Randomly create the initial population of the chromosome.
2) Evaluate the fitness function: Evaluate the fitness of each chromosome in the population.
3) Create a new population of chromosomes: Repeat the process of reproduction with the following sub-steps (a, b, c) until an optimal solution that satisfies the optimization criteria is obtained:
   a. Selection: select chromosomes depending on each chromosome's fitness function score. The better a chromosome's fitness, the more likely it is to be chosen. Various techniques can also be used to pick the best chromosomes' fitness, such as a roulette wheel selection.
   b. Crossover: Perform the crossover to produce new chromosomes, which are off-springs by exchange between two chromosomes at the crossover point. There are many types of crossovers. In this study, an order one crossover has been used to produce off-springs.
   c. Mutation: After off-springs are produced, perform the mutation, which is the modification of a few randomly chosen genes in off-springs to produce a new off-spring. However, the primary advantage of genetic algorithm comes from the crossover operation.
4) Re-evaluate the fitness function: Evaluate the fitness of each off-spring that has been produced to find out the best fitness.
5) Replace: Replace the worst random fitness chromosomes of population with off-springs.

6) Return processes: Repeat processes 2 to 5 until the conditions are satisfied.
7) Stop: Terminate the process.

3.2. Hybrid of genetic algorithm and ant colony optimization (HGACO)

GA and ACO algorithms are population-based search algorithms capable of wide applications for solving hard and complex problems across various branches of science and engineering. These algorithms can be hybridized with other algorithms (Zukhri & Paputungan, 2013). The first ACO was used through focussing on the conduct of real ants (Dorigo, Birattari & Stutzle, 2006). In the ACO algorithm, artificial ants search a graph probabilistically and with the guidance of the pheromone, in order to create candidate solutions. These solutions are then evaluated and used for pheromone updates. Various versions of the ACO have been developed, but they all follow the same idea of solution construction guided by pheromone levels (Qiu & Xie, 2012). Many attempts have been made to hybridize these algorithms in order to improve the quality of the solutions. Based on previous studies, hybrid of genetic algorithm and ant colony optimization (HGACO) provides acceptable solutions in a reasonable time (Lee, 2004). This is because several meta-heuristic approaches work together in order to benefit from the best characteristics of each. In view of the foregoing, we propose a hybrid of genetic algorithm and ant colony optimization to solve the milk-run delivery issue in LSC management for AICS.

4. Work performed with meta-heuristic approaches

4.1. Genetic algorithm

GA is proposed to find the best solution for the shortest route in a complicated logistics network. In this study, the steps defined by Potvin et al. (1996) and presented at section 3.1 have been used as illustrated in Figure 1. GA is first applied on data from the transportation distance matrix d of AICS, as shown in Table 4. Each facility is given a unique integer value index from 1 to F, and every chromosome is designed to represent a solution for the problem, keeping in mind that the route must not repeat facilities. The length of the chromosome, which is one delivery route (dr), is selected to be equal to the number of facilities of AICS.

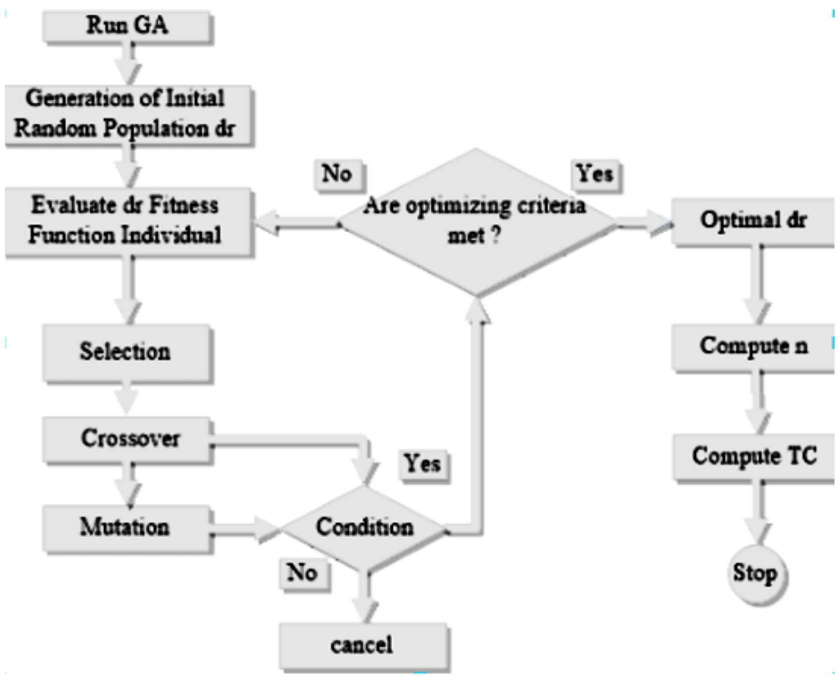

Figure 1. Flow chart of proposed GA for optimizing route distance (dr)

4.1.1. Encoding: Permutation encoding can be used in ordering problems and it can also be used in this problem. In permutation encoding, every chromosome is a string of numbers that randomly represents the number of facilities. The number of facilities in each chromosome is fixed. From AICS data, as mentioned previously, there are nine facilities: a single manufacturing plant, three suppliers and five customers. The optimal dr is calculated from (1, 2, 3, …, F, 1). Different routes are based on the same geographical location of facilities (Table 1) with different transportation distances defined by Equation (5) and presented in Table 4:

$$d_{ij} = \sum_{i}^{F} \sqrt{\left(x_i x_j - 1\right)^2 + \left(y_i y_j - 1\right)^2} \tag{5}$$

Table 4. Transportation distance matrix d among facilities of AICS

d_{ij} =

0.00	34.66	24.19	55.04	14.14	62.39	12.65	45.00	31.38
34.66	0.00	58.41	84.12	20.52	95.38	31.38	60.03	13.93
24.19	58.41	0.00	35.44	38.01	38.60	29.41	53.67	52.63
55.04	84.12	35.44	0.00	66.10	21.21	52.89	88.77	73.82
14.14	20.52	38.01	66.10	0.00	75.58	14.14	49.04	19.10
62.39	95.38	38.60	21.21	75.58	0.00	64.35	85.99	87.20
12.65	31.38	29.41	52.89	14.14	64.35	0.00	57.14	23.35
45.00	60.03	53.67	88.77	49.04	85.99	57.14	0.00	66.71
31.38	13.93	52.63	73.82	19.10	87.20	23.35	66.71	0.00

4.1.2. ***Identification of the optimal dr:*** The optimal dr is obtained by the following steps, which have been adapted for this study. They are illustrated in Figure 1:

1) Find all possible solutions (F-1)! where F=9 is the number of facilities.
2) Set random permutation for (9-1)! that contains the number of all different facilities.
3) Choose 9 random chromosomes (routes) as the initial population from the data of transportation distance matrix d of AICS.
4) Check the validity of the routes (all facilities ≠ 0, no sub-route).
5) Compute fitness function (optimal route dr) for each route with Equation (2).
6) Select the best 4 chromosomes (routes) by roulette wheel selection. The selection is based on current population fitness (dr value) by probability of selection (Rao, 2009).
7) Randomly create 2 off-spring populations from 4 existing chromosomes (routes) by applying an order one crossover operator. In this case, each group of 2 chromosomes (routes) produces one off-spring. Two crossover points will be chosen randomly from the third gene (facilities) and seventh gene (facilities) for the first chromosome. This part is then transferred to the off-spring (new route). After that, the genes (facilities) which are not in the off-spring are copied from the second chromosome (route) to the off-spring (new route). This last step is done by starting from the right of the cut point of the part of the first chromosome (route) and by using the order of the second chromosome (route), which is wrapped around at the end.
8) Mutate randomly by choosing 2 genes (facilities) in the off-spring and by switching them. However, if the new off-spring (new route) value is bigger than the old off-spring (old route), the mutation is canceled.
9) Compare the 2 off-springs (new route value dr) with the old chromosome (old route dr).
10) Continue to check other possible values of the route until all successive GA iterations no longer produce better results.

11) Stop when the optimal dr is found.

In summary, GA checks all possible dr to identify the optimal dr. Afterwards, the delivery frequency (n) is computed as well as the total cost of the supply chain (TC) (Figure 1).

4.2. Hybrid genetic algorithm and ant colony optimization

Hybrids of genetic algorithm and ant colony optimization are used to obtain the best result in terms of the optimal route (dr) by using transportation distance matrix d of AICS as shown in Table 4. In the ACO approach, artificial ants probabilistically search a graph, with the guidance of pheromone, in order to create candidate solutions. Candidate solutions are then evaluated (dr) and pheromone updates are repeated until the stop condition is met (9 iterations). This can be achieved by following a temporary memory or tabu list before being selected as the initial population for GA approach. The alternative is selecting random initial population and then following the stages as in the previous GA approach, including identifying optimal n and TC. The framework is used as a guide to find the optimal route (dr) for hybrid genetic algorithm and ant colony optimization. All of the codes were written and implemented in MATLAB 2015.

1) Set the parameters and assign the initial pheromone value on each path to the same constant value.
   β=1: Heuristic Exponential Weight M=9: Number of Ants (Population Size)
   α=1: Pheromone Exponential Weight E=0.05: Evaporation Rate Q=1: constant value
2) Solution Construction. Each ant begins at a start facility and constructively builds a solution based on the pheromone values. Ants choose to move from the facility (i) to facility (j) based on a probabilistic decision $p_{ij}^{k}(t)$, and then onto a facility that has not yet been visited, as shown in Equation (6) (Dorigo et al., 2006):

$$p_{ij}^{m}(t) = \begin{cases} \dfrac{[T_{ij}(t)]^{\alpha} \cdot [\eta_{ij}]^{\beta}}{\sum_{m \in allowed_m} [T_{ij}(t)]^{\alpha} \cdot [\eta_{ij}]^{\beta}} & \text{if } m \in allowed_m \\ 0 & otherwise \end{cases} \tag{6}$$

   where:

   m_i is the feasible neighborhood of facility (i). The neighborhood of facility (i) is the set of all facilities that an ant can move to when at facility (i).

   T_{ij} is the pheromone value between facility i and j.

   η_{ij} is a heuristic value, η_{ij} =1/d_{ij}.
3) Update Pheromone. Once all ants have finished constructing their routes, the pheromone trails are updated. This is done first by lowering the pheromone trails by a constant factor (evaporation) and then by allowing the ants to deposit pheromone on the transportation distance they have visited.
4) The solution construction and pheromone update are repeated until the stop condition is met by the selected first 9 iterations.
5) The best four chromosomes (routes) are then selected by a roulette wheel from the first 9 iterations of ACO, becoming the initial population for GA and then following the same stages as the previous GA approach, including identifying optimal n and TC.

5. Results

The main results obtained from this study is the optimal delivery route which is illustrated in Figures 2 and 3 and Table 5. As can be seen from the results, the proposed genetic algorithm starts from facility

1 and then does a full array equation cross of other facilities to find the optimal value. As can be seen in figure 2, the optimal value is 283.30 km after 18 – 36 iterations. This optimal solution is the optimal delivery route which is 1-5-2-9-7-4-6-3-8-1 presented in Table 5. However, HGACO shows superior performance when compared to other existing meta-heuristic by getting the best optimal route (dr) with slightly fewer iterations than GA. A comparison between the three approaches (GA, HGACO and ACO) is presented in Figures 2 and 3. As shown, HGACO and GA have obtained the same optimal dr (283.30 km) which is slightly better than ACO (286.22 km) as presented in Table 5.

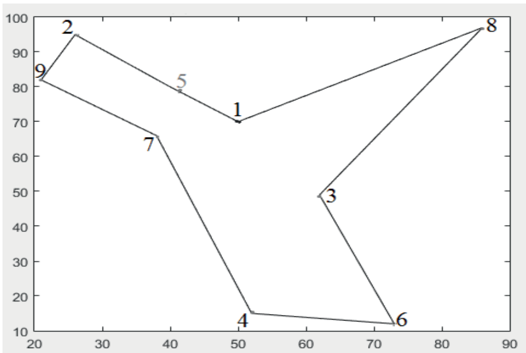

Figure 2. Optimal dr (283.30 km) with GA and HGACO

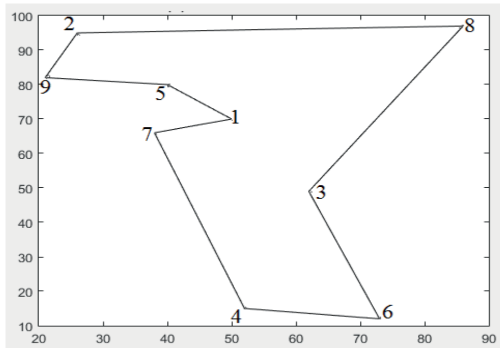

Figure 3. Optimal dr (286.22 km) with ACO

Table 5. Optimal dr from GA, HGACO and ACO

Approaches	dr (km)	Best route
GA	283.30	1 - 5 – 2 – 9 - 7 – 4 – 6 – 3 – 8 - 1
HGACO	283.30	1 - 5 – 2 - 9 - 7 – 4 - 6 - 3 – 8 - 1
ACO	286.22	1 - 5 – 9 - 2 - 8 – 3 - 6 – 4 – 7 - 1

However, because this optimal route does not meet the vehicle capacity by delivering to allof the facilities in one delivery route distance, it needs to be divided into two sub-route distances, as follows: (dr_1) is 1-8-3-6-4-7-1 and (dr_2) is 1-9-2-5-1. With these sub-routes, the dr becomes 295.94 km. Once again, the two sub-routes obtained from GA are the same as those obtained from HGACO (Table 6). Equations (3) and (4) were then used to calculate the delivery frequency (n): for dr_1 and dr_2, the delivery frequency is equal to 30 (Table 6). The total cost of the supply chain (TC), as calculated with Equations (3) and (4) is found to be 14,265,635.58 $ (Table 6). With the same sub-routes, GA also has the same TC as HGACO.

Table 6. Optimal dr with two sub-routes found from GA, HGACO and ACO

Approach	dr (km)	Best sub-Route	n	TC ($)	Note
GA	295.94	dr_1 = 1 – 8 - 3 – 6 – 4 – 7 - 1 dr_2 = 1 – 9 - 2 – 5 - 1	30 30	14, 265, 636.58	Optimal TC
HGACO	295.94	dr_1 = 1 – 8 – 3 – 6 – 4 – 7 - 1 dr_2 = 1 – 9 – 2 – 5 - 1	30 30	14, 265, 636.58	Optimal TC
ACO	301.75	dr_1= 1 – 5 – 9 – 2 – 8 - 1 dr_2= 1 – 7 – 4 – 6 – 3 - 1	19 19	14, 766, 546.00	

6. Conclusion

In this paper, the integrated optimization of the supply chain management — lean supply chain management —is used in order to improve the relationships between the various facilities. In addition to being more effective, responsive and flexible, the approach seeks to gain a sustainable competitive advantage through high quality and cost minimization. This study confirms that the genetic algorithm approach (GA) along with the hybrid of genetic algorithm and ant colony optimization approach (HGACO) for the design of a logistic distribution network is effective in achieving an optimal solution. HGACO gives encouraging results that can be obtained by using fewer iterations than the GA approach. In addition, since GA and HGACO have superior performance compared to ACO, these approaches seem quite promising for industrial applications. However, they would first have to be applied in larger-scale problems to confirm the trend. The work can be further extended to solve this problem using the other hybrid meta-heuristics.

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