4-2016

A preliminary study of the relationship between complexity, motivation, and design quality.

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A PRELIMINARY STUDY OF THE RELATIONSHIPS BETWEEN COMPLEXITY, MOTIVATION, AND DESIGN QUALITY

By

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B.S., University of Louisville, 2015

A Thesis
Submitted to the Faculty of the
University of Louisville
J. B. Speed School of Engineering
as Partial Fulfillment of the Requirements
for the Professional Degree

MASTER OF ENGINEERING

Department of Mechanical Engineering

April 2016

A PRELIMINARY STUDY OF THE RELATIONSHIPS BETWEEN COMPLEXITY, MOTIVATION, AND DESIGN QUALITY

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ACKNOWLEDGEMENTS

First and foremost, I would like to thank my parents, Robin and Stella Mountain, for always supporting and encouraging me. Secondly, I would also like to thank Dr. Matt Bohm for encouraging me to pursue a thesis, allowing me to work on these topics, and being a life-changing mentor and friend. I would also like to thank Dr. Thomas Berfield and Dr. Jason Saleem for serving on my committee.

THEIS PUBLICAITON OPTION

Sections of this thesis have been submitted for publication in relevant engineering conference proceedings and have been treated in the style utilized by these publications. Pages 12 – 45 have been prepared in the style required by the ASME International Mechanical Engineering Congress & Exposition. Pages 47 – 74 have been prepared in the style required by the ASME International Mechanical Engineering Congress & Exposition. The remaining pages have been prepared in accordance with the University of Louisville's Speed School of Engineering thesis specifications.

ABSTRACT

This collection of work comprises a preliminary study of the relationships between product complexity, design motivation, and design quality. Complexity, as it relates to the design process, is largely undefined and there exists no generally accepted method of measurement. This study applies an independent data set to a complexity measurement technique and develops complexity measurements at the pre and post design stages. Pre design is considered when design ideas are in formation and customer needs are being addressed. Post design is considered when a functional prototype is realized, manufacturing and assembly processes have been considered, and the product design is considered finalized. Developing complexity measurements for both stages of design are critical to realizing lean design development. Additionally, this study investigates the effects of personal motivation on design quality outcomes. Taking from the field of sociology, a survey tool is utilized to gauge an individuals' motivation toward design as a serious leisure activity. Serious leisure is considered an activity in which participants glean an internal reward, pleasure, or satisfaction from participation. Utilizing a proposed design quality survey, this study determines quality metrics based on customer needs, manufacturability, serviceability, and product fit and finish, and considers quality to be the ultimate measure of a design. The intersection of complexity, personal motivation, and design quality is of particular interest in this study, as it may provide insight into engineering team dynamics as it relates to design outcomes.

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INTRODUCTION

The first paper, "Evaluation of Techniques to Describe Complexity in Pre and Post Design Stages," presents the current state of product complexity and utilizes a prominent complexity metric to evaluate an independent data set. The second paper, "A Preliminary Study: The Effects of Personal Motivation on Design Quality," investigates motivation of designers, assessment of design quality, and the intersection of individual designer motivation and design quality outcomes.

EVALUATION OF TECHNIQUES TO DESCRIBE DEVICE COMPLEXITY IN PRE AND POST DESIGN STAGES

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ABSTRACT

Electro-Mechanical device complexity exists in everyday items from cell phones to automobiles to vacuum cleaners. Generally, product complexity is one of the least quantifiable characteristics in the design cycle with arguably some of the greatest implications. A high level of device complexity carries a negative connotation and is usually considered an attribute a designer should attempt to mitigate. Alternatively, a low level of device complexity may induce designers and marketers to question a product's usefulness. Whether complexity is a necessary aspect of a design or a hindrance needing to be minimized or eliminated, depends upon how complexity is framed. Some instances in literature attempt to measure complexity yet there is no unified measure that captures the complexity of a product or system during design phases or upon product/system realization. Complexity is defined in many ways, at different levels of abstraction, and different stages of design therefore, becoming highly contextual and subjective at best. An established and repeatable methodology for calculating complexity of existing products in the marketplace is necessary. Once a measure of complexity is agreed upon at the post design stage we can look to earlier phases in design to see whether insights are observable. Identifying complexity early in the design cycle is paramount to strategic resource allocation. This study considers the Generalized Complexity Index (GCI) measure put forth by Jacobs (Jacobs, 2013) and expands upon it to include functional modeling as a key component in determining an indicative complexity metric. Functional modeling is a method used to abstract system or product specifications to a general framework that represents a function based design solution. Complexity metrics are developed at the functional and completed design levels and used for comparison. Thirty common household products retrieved from an online design repository ("Design Engineering Lab - Oregon State University," 2015) as well as seven senior capstone design projects were evaluated using the GCI. A modification to the GCI equation is proposed and to gain a relative scale of complexity within the data, a ranked complexity metric was developed and utilized. The magnitude of the ranked complexity metric was only indicative of hierarchical status of a product within the data set and therefore is not comparable to GCI values. Though Jacobs GCI worked well in his study, the GCI does not represent a meaningful complexity measure when applied to the data in this study. This study is an initial attempt to apply an independent data set to Jacobs GCI model with perhaps greater implications, with respect to products, that complexity is multifaceted and is not accurately represented by only interconnectedness, multiplicity, and diversity.

1. INTRODUCTION

As the market place remains competitive, companies are looking to shorten the product design cycle. Designers are constantly searching for ways to quickly assess initial ideas and determine product feasibility before precious time and resources are devoted to development. Traditionally, designs are progressively refined, prototypes are realized, and products are evaluated. Design tools, such as functional modeling, can be utilized in the early stages of design while the project requirements or customer needs are being determined and refined. Functional modeling allows design teams to systematically represent a design within a universal framework (Miles, 1972). Functional modeling is widely used (Blanchard et al., 1990; Cross, 2008; Dieter et al., 2009; Dym et al., 2004; Gibson et al., 2007; Miles, 1972; Nagel et al., 2015; Nise, 2007; Otto et al., 2001; Pahl et al., 2013; Technology, 1993; Ullman, 2015; Ulrich, 2003; Voland, 2004) and allows complex problems to be abstracted into a form that is easily solvable. When utilized in a capstone design course, functional modeling equips student designers with an objective method of representing complex systems based on the functions they will perform.

Product portfolios are becoming increasingly diverse and complexity becomes paradoxical, because it is necessary yet unwanted in product design. Consider the following example where complexity meets function. A customer indicates the desire for an artifact with which they can write and erase. The image of a pencil is prevalent with respect to these customer needs. A basic wood pencil consists of wood pieces, a lead core, a metal sleeve, and an eraser. It could be argued that a wooden pencil has the necessary number of components to make it a functionally viable product with respect to the customers' needs. Therefore, the wooden pencil is necessarily complex. Now consider a mechanical pencil. The mechanical pencil consists of a plastic body, an eraser, a clip, a retaining nozzle, and internal components (such as a lead guide, mechanical actuation components, etc.). Both the wooden and mechanical pencil satisfy the same functional requirements (writing and erasing) but the mechanical pencil is traditionally thought to be a more "complex" product. "Complex" here means that the mechanical pencil likely requires greater design effort, more detailed manufacturing and assembly processes, and higher per-unit cost. However, complexity cannot simply be affirmed based on perceived design effort, manufacturing and assembly procedures, and cost. A complexity metric must be defined in an objective manner and must be directly measurable. So the question becomes, in general, "what are the characteristics that make a product complex and are they measureable?"

Complexity of a system or product conjures many understandings. Commonly thought to have a negative effect (Blackenfelt, 2001; Pasche, 2008; Suh, 2005), understanding complexity in the design process is critical to efficient system and product design. Although some instances in literature attempt to measure complexity (Braha et al., 1998; Hölttä et al., 2005; Jacobs, 2013; Minhas, 2002; Novak et al., 2001; Summers et al., 2010), there is no unified measure that captures the complexity of a product or system during the early design phase or upon product/system realization. Understanding complexity of a product can be beneficial in the early stages of design as an indicator of future design complexity. As designers and managers seek to mitigate complexity, having early indicators are paramount to keeping project costs low. An important aim of this research is to determine whether a complexity metric derived at the functional model level will be predictive of a complexity metric at the completed product level. Utilizing functional complexity to forecast product complexity will enable designers, managers, and organizations to be better informed and take proactive measures in managing and mitigating unnecessary complexity in the design cycle. This paper reports the findings on developing a systematic approach to predicting design complexity outcomes based on functional model representations. A proposed framework and measurement metric for the GCI proposed by Jacobs (Jacobs, 2013) are examined.

2. BACKGROUND

This section outlines current literature on complexity in section 2.1, functional modeling in section 2.2, and Design Structure Matrices (DSMs) in section 2.3.

2.1 Complexity

In literature, complexity is discussed in domain specific contexts and primarily focused on the modeling, management, and negation of complexity of products in supply chains, product portfolios, manufacturing and assembly, and organizations as a whole (Abbasi, 2008; Adamsson, 2007; Alamoudi, 2008; Calinescu, 2002; Chalidabhongse, 1999; ElMaraghy et al., 2012; Kim, 1999; Maier et al., 2000; Marti, 2007; Minhas, 2002; Summers & Shah, 2010; Tomiyama et al., 2007). Novak et. al view complexity as a measure of product variations within a product family with respect to the supply chain (Novak & Eppinger, 2001). They claim product complexity has three main elements: "(1) the number of product components to specify and produce, (2) the extent of the interactions to manage between these components (parts coupling), and (3) the degree of product novelty" (Novak & Eppinger, 2001). They apply a simultaneous equations model to data gathered from the luxury-performance segment of the auto industry. The model takes into account the degree of vertical integration (a percent of the system components produced in-house), quality (defined according to Consumer Report Reliability Reviews), and complexity. Complexity was measured by developing key characteristics of a system then having industry experts rate statements which were translated into a 0–1 measure; 0 being low complexity and 1 being high complexity. They produce a robust methodology however; it is specific to the auto industry.

Pasche claims (Pasche, 2008), complexity is context dependent, which seems to be supported by Novak et. al and Sum et. al (Novak & Eppinger, 2001; Sum et al., 1993) who define complexity measures specific to their needs. Where Sum et al. (Sum et al., 1993) are focused on complexity's impact on lot sizing, this study concerns how they define complexity. They consider product structure complexity to be characterized by three parameters; the number of items, number of levels, and commonality index. The number of items is indicative of product structure size and as the number of items increase so does the complexity of the product structure. The number of levels indicates depth of a product structure and as the number of levels increase greater effects are possible within the product structure. The commonality index, proposed by Collier (Collier, 1981), measures the average number of immediate parent items per component item where increases in interactions across product levels makes lot sizing more complex. Yu et al. consider complexity to be associated with the resources and variables required to develop and launch a product (Hagel, 1998; Yu et al., 2010). Considering relative and absolute measures, Summers et al. (Summers & Shah, 2010) frame complexity in the mechanical engineering design process to be a function of size, coupling, and solvability.

Complexity is defined in many ways, at different levels of abstraction, and different stages of design (Blackenfelt, 2001; Braha & Maimon, 1998; Hölttä & Otto, 2005; Jacobs, 2013; Maier & Rechtin, 2000; Summers & Shah, 2010) therefore, becoming highly contextual and subjective at best (Jacobs, 2013). The issue of generality rampantly exists in literature when considering complexity, because each methodology defines complexity to exist only within its realm of investigation. Complexity may be necessary for product success in certain cases though, traditionally is viewed as unfavorable. It can also be viewed as a hindrance if unnecessary functions or attributes are added to the product. Such unnecessary functions or attributes could lead to more involved design efforts, greater manufacturing or assembly work, and higher production costs. Developing product requirements or customer needs is an effective way to explicate significant product functions and mitigate useless ones. Functional modeling allows designers to transform these requirements into a universally understood framework (Nagel et al., 2012). Functional models enable designers to determine the key flows of material, energy, and signal information that are necessary to meet the project requirements or customer needs. When considering complexity in a product development manner, it is generally considered to have an adverse effect on product performance, quality, and manufacturability (ElMaraghy et al., 2012). However, it is unclear exactly what complexity is and how it can be measured on a general scale.

The starting point for this study will be Jacobs' Generalized Complexity Index (GCI) (Jacobs, 2013). The GCI requires scrutiny of three factors; 1.) multiplicity, 2.) diversity, and 3.) interconnectedness. Multiplicity is defined as the number of variants or versions of a product or the number of suppliers if evaluating at the supply chain level (Bozarth et al., 2009; Closs et al., 2008; Closs et al., 2010). Diversity refers to the degree of dissimilarity seen across the elements and can be quantified by comparing the number of unique elements to the total number of elements within a system. Interconnectedness is a ratio of the number of connections within a system and the total number of possible connections. The degree of interconnectedness can be illustrated and derived through the use of a Design Structure Matrix (DSM) (English et al., 2008; Hommes et al., 2003; Otto, 2001; Otto & Wood, 2001; Pahl & Beitz, 2013). For the GCI, Jacobs prescribes a simple mathematical formula to calculate complexity (Equation 1). Table I on the next page provides an explanation of the variables in Equation 1.

$$GCI = V\left(1 - \frac{U}{T}\right)\left(\frac{A}{M}\right) \tag{1}$$

TABLE I

DESCRIPTION OF VARIABLES IN THE GENERALIZED COMPLEXITY INDEX.

Variable	Description
V	Number of Variants
U	Number of unique elements
T	Total number of elements
A	Number of connections
M	Maximum number of connections

2.2 FUNCTIONAL MODELING

Functional modeling presents a graphical description of what a system should do based on customer needs, target specifications, objectives, and constraints. Models are generated at two levels of abstraction: a black box model and a sub-functional model. Black box functional models are stand-alone functional models abstracting a high-level transformation intended for the product to complete and are generated based on the system design requirements. A functional model decomposes the overall functional black box into specific flow transformations. Flow transformations define the operations required of the system such that the identified input flows do become the identified output flows through the operation of the system. Stone et al. (Stone et al., 2000) develop the general framework for functional modeling and Nagel et al. (Nagel et al., 2012) develop an algorithmic approach to teaching functionality. The Nagel et al. approach uses a series of grammar rules to assemble function chains from a list of enumerated functions desired of the final product. Function chains are then aggregated into a complete functional model which represents a system or product. Creating a functional model consists of three primary steps; Black box model, chains, and the aggregated functional model. Nagel et al. (Nagel et al., 2012) produce an example of a black box model, chains, and an aggregated functional model show in Figure 1, 2, and 3, respectively (Nagel et al., 2015).

FIGURE 1: BLACK BOX MODEL. (NAGEL ET AL., 2015)

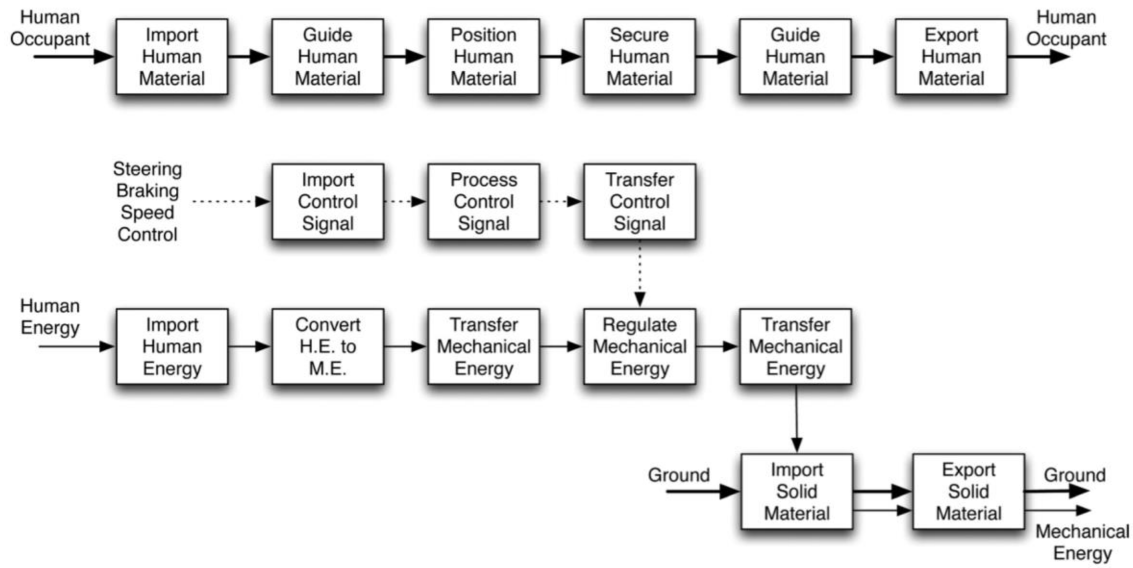

FIGURE 2: FUNCTIONAL MODELING CHAINS. (NAGEL ET AL., 2015)

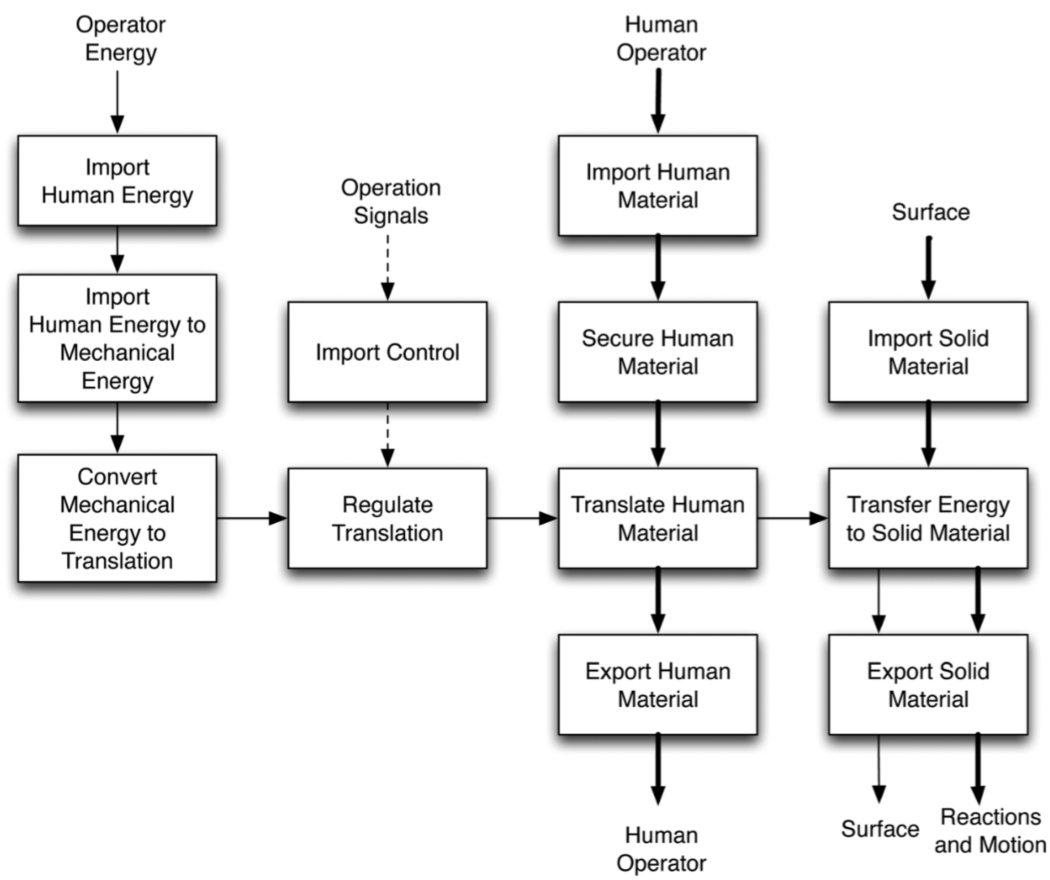

FIGURE 3: FUNCTIONAL MODEL. (NAGEL ET AL., 2015)

Utilizing the framework and teaching methodologies of functional modeling, functional models are created and analyzed. Functional models are a key factor of this study's approach to complexity analysis as variable values are derived directly from analysis of functional models. This study considers functional modeling to be a pre design stage activity.

2.3 DESIGN STRUCTURE MATRIX

The Design Structure Matrix (DSM) is a compact and visual representation of a system, project, or artifact in the form of a square matrix (Eppinger et al., 2012). DSM's have been used in aerospace, manufacturing, and software engineering industries as well as research and academia (Ahmadi et al., 2001; Farid et al., 2006; Guenov et al., 2005; Lambe et al., 2012; Makins et al., 2000; Sullivan et al., 2001). Example DSM applications are estimation of product development time, definition of complex system interactions, and determining system modularity (Carrascosa et al., 1998; Eppinger & Browning, 2012; Sullivan et al., 2001). DSM's are widely used because of their ease of readability even when mapping becomes complex. DSM's are constructed by listing system elements in a square matrix then noting the interactions between elements with a value. Whole numbers, dots, or even probabilities are utilized to signify element interactions. This study will utilize whole numbers to signify element interactions. A simple DSM of elements A – E are listed in Table II (on the next page) where a single element connection is signified by placing "1" in the respective cell.

TABLE II

SIMPLE DSM.

	A	B	C	D	E
A					
B	1				
C	1	1			
D			1		
E	1	1	1		

The simple DSM indicates element B is connected with element A. Similarly, C is connected with A and B, D is connected with C, and E is connected with A, B, and C.

3. METHODOLOGY

Building upon Jacobs' move toward an empirical measure of complexity, thirty common household products and seven capstone projects are considered. The approach here differs from Jacobs in that product variants (V) are not considered therefore; multiplicity is disregarded as an influencing factor of complexity. The reason for disregarding the multiplicity factor is that each product analyzed presents only one variation therefore, the number of variants, V, would not influence the GCI and this variable becomes obsolete. Jacobs' GCI equation as well as modifications deemed necessary are considered. As Jacobs' original equation stands, holding interconnectedness (A/M) constant, a low diversity (U/T) value will translate to a high complexity metric. This study argues that low diversity should lead to low complexity because this implies part reuse within a system or product is favorable to obtaining low complexity. The proposed GCI equation is presented below.

$$Proposed\ GCI = \left(\frac{U}{T}\right)\left(\frac{A}{M}\right) \tag{2}$$

After investigating two sample products, a door handle and a lawnmower carburetor, as baseline measures, a larger sample size of 30 common household products are considered. The thirty products were retrieved from a repository ("Design Engineering Lab - Oregon State University," 2015) previously created by Bohm et al. (Bohm et al., 2006; Bohm et al., 2005) where preexisting functional models and product design structure matrices were readily available. Eventually, seven senior capstone design projects are evaluated to determine if complexity is accurately measured in prototypes. Capstone groups ultimately produce a functional prototype as a culmination of semester long projects. The functional prototypes will be analyzed as final products. As will be explained in detail in the next sections, functional models are analyzed and quantified to produce a complexity metric at the functional abstraction level of design. Similarly, DSM's are utilized to quantify a complexity metric at the post design stage or product level. This study aims to produce a functional model complexity metric which will be indicative of final product complexity. The implications of this study would be a method to derive final product complexity from functional modeling complexity analysis.

3.1 RANKED COMPLEXITY

Consider two products from the repository: a vegetable peeler and an induction cooktop. The vegetable peeler is molded plastic with a stamped metal part used to peel the skin off vegetables. It is intuitive to assume that the vegetable peeler would have low complexity. In stark contrast to the vegetable peeler, the induction cooktop utilizes special materials, novel technology, and complex functions. The cooktop could be considered to have high complexity. Because complexity of a product is highly dependent on the context in which it is analyzed, a ranking method was used to produce a low to high complexity scale for the data set. Having a ranked complexity metric is helpful because it provides a general spectrum of low to high complexity for the products analyzed. The thirty products from the design repository cover a wide array of mechanical and electro-mechanical devices. To gain a ranked measure of product complexity a 9-point Likert scale questionnaire was utilized. Ranked complexity questionnaires were completed by graduate students with backgrounds in mechanical engineering and exposure to industry based cooperative educational experiences. Questionnaire statements were worded such that a high score would indicate a product to have high complexity. The five statements were:

1) This product is difficult to manufacture.
2) This product is difficult to assemble.
3) This product utilizes novel technology.
4) This product requires major design effort.
5) This product is highly complex.

Agreeing to all of the statements (choice of 9) indicates the highest possible complexity. The five ranking questions were chosen as they represent elements that have traditionally thought to influence complexity during a product lifecycle (Adamsson, 2007; Alamoudi, 2008; Bozarth et al., 2009; Braha & Maimon, 1998; ElMaraghy et al., 2012; Eppinger & Browning, 2012; Hölttä & Otto, 2005; Jacobs, 2013; Marti, 2007; Minhas, 2002; Summers & Shah, 2010; Tomiyama et al., 2007). Ranked complexity metrics are bound between 0 and 1, not comparable to GCI values, and only indicative within the repository and capstone project data sets. To obtain a final ranked complexity metric for each product, each answer was divided by 9 to obtain a fraction of agreeability, multiplied by an equal weight of 0.2 (1/5 questions), summed over all evaluators, and divided by the total number of evaluators. The ranked complexity equation can be seen below (Equation 3).

$$Cplx_{Ranked} = \left(\frac{Question\ 1_{average}}{9} * \left(\frac{1}{5}\right)\right) + \left(\frac{Question\ 2_{average}}{9} * \left(\frac{1}{5}\right)\right) + \ \dots + \left(\frac{Question\ 5_{average}}{9} * \left(\frac{1}{5}\right)\right) \tag{3}$$

3.2 EXPLANATION OF VARIABLES

When considering function or design structure matrices, the four parameters previously introduced in Table 1 are used to produce a complexity metric. The total number of elements are represented by the variable *T* and the unique number of elements are represented by the variable *U*. Variable *M* is the maximum number of element connections and is calculated by

$$M = \frac{(T^2 - T)}{2} \tag{4}$$

and *A* is the actual number of connections with in a matrix. Variables *A* and *M* are obtained by constructing a function or design structure matrix at the functional or completed product level of design. The ratio *U*/*T* represents the diversity of a design whereas ratio *A*/*M* represents the connectivity. Probabilistic values are not considered here and only the number one is used if a connection is present. Complexity metrics from either Equation 1 or 2 are bound between 0 and 1, where 1 is the highest possible complexity. The abbreviation FSM for Function Structure Matrices and DSM for Decision Structure Matrices will be observed. FSM's were analyzed using two distinct methods, MES and FLOW methods. MES stands for Material-Energy-Signal, as they are the primary function-flow pairs of functional modeling. FLOW method indicates use of single distinct flows of material, energy, or signal through the functional model. MES and FLOW methods will be referred to as method 1 and 2, respectively. The Total number of elements (T) will be the same for both method 1 and 2 however, unique number of elements (U), will differ. Two examples below explain the procedures and quantification in each method (FSM and DSM).

3.3 FUNCTION STRUCTURE MATRIX (FSM) – AN EXAMPLE

At the function level obtaining values for A and M are similar among evaluation methods and will be demonstrated first considering a door handle (Table III on the next page – a snippet of a full DSM). Functions are listed in a column then transposed to a row to create a square matrix. Counting the total number of functions (*import hand, import human energy, import door frame ... export door*) yields 15 ($T = 15$). The number of connections (A) is determined by summation of the matrix and division by two, or simply counting the number of ones on either side of the matrix diagonal. The maximum number of connections (M) is obtained utilizing Equation 4. For the door handle example $M = 105$. As mentioned before, when considering functional model complexity there are two methods used to obtain the unique number of elements (U). Each method will be presented separately below.

TABLE III

FUNCTION STRUCTURE MATRIX (FSM) – DOOR HANDLE SNIPPET.

Door Knob - FSM	import hand	import human energy	import door frame	import door	import lock/unlock signa	guide hand	convert HE to PE	guide frame	guide door	export hand	...
import hand	0					1					
import human energy		0					1				
import door frame			0					1			
import door				0					1		
import lock/unlock signal					0						1
guide hand	1					0				1	
convert HE to PE		1					0	1			
guide frame			1				1	0	1		1
guide door				1				1	0		1
export hand						1				0	
...					1			1	1		...

3.3.1 FSM – METHOD 1 – THE MES METHOD

First, method 1, the MES method, will be reviewed. In viewing the functional model representation of the door handle (Figure 4 on the next page), each action or block of the functional model represents an element. As found before, the total number of elements are 15 (T = 15). Method 1 states that an element is considered to be unique only if it appears once, at the highest level of abstraction, in the functional model. For example, “Import Hand”, “Import Door Frame”, and “Import Door” are all individual elements, yet not unique. All three elements can be described by the phrase “Import Material.” “Hand”, “Door Frame”, and “Door” are all considered a material in the functional modeling context. Even though three separate elements exist, they can be described by a single phrase and therefore constitute one unique element. Classifying unique elements with respect to method 1 is defined as “verb – noun” or “verb – MES” (Material–Energy–Signal). Another example of this classification is seen when considering three elements “Guide Hand”, “Guide Frame”, and “Guide Door”. Each individual element contains the verb “guide” and again “hand”, “frame”, and “door” are considered materials. Therefore, these three individual elements comprise a single unique element “Guide Material.” Using method 1 to classify unique elements leads to a number of 9 ($U_1 = 9$) for the door handle example.

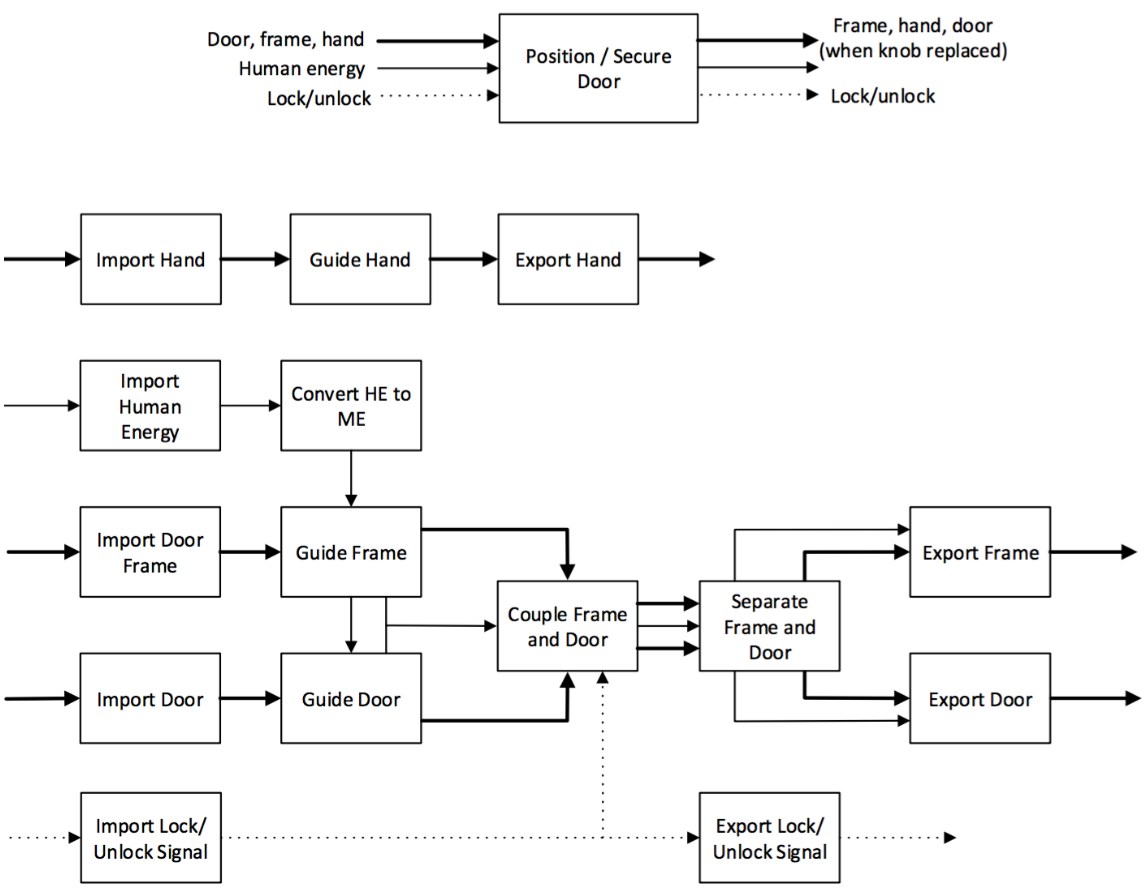

FIGURE 4: FUNCTIONAL MODEL – DOOR HANDLE.

3.3.2 FSM – METHOD 2 – THE FLOW METHOD

Method 2, the FLOW method, follows material, energy, and signal flows through the functional model. Method 2 focuses on noun words such as "Hand", "Human Energy", "Door Frame", and "Door Lock/Unlock Signal." Therefore, a single FLOW represented in Figure 4 is "Import Hand – Guide Hand – Export Hand." Each FLOW represents a unique element and we can conclude that using method 2 for the door handle functional model in Figure 4 yields five unique elements (U_2 = 5). Table IV provides a summary of each variable, value, and method utilized at the function level.

TABLE IV

FUNCTION STRUCTURE MATRIX (FSM) VALUES.

Method	A	M	A/M	T	U	U/T
1	14	105	0.13	15	9	0.60
2	14	105	0.13	15	5	0.33

3.4 DESIGN STRUCTURE MATRIX (DSM) – AN EXAMPLE

An important aim of this research is to determine whether a complexity metric derived at the functional model level will be predictive of a complexity metric at the completed product level. Continuing to use the door handle example, complexity analysis at the completed product level is explored. A bill of materials (*BOM*) can be seen in Table V on the next page for the door handle and is an important starting point for creation of the DSM.

TABLE V

BILL OF MATERIALS (BOM) – DOOR HANDLE.

Total Assembly – 38 parts

Item No.	Quantity	Description			
1	1	Front latch housing	16	1	Lock button cover
2	1	Face plate	17	1	Snap ring
3	1	Latch spring	18	1	Frame (non-lock side)
4	1	Retainer	19	1	Frame cover (no holes)
5	1	Rear latch housing- Left	20	1	Lock shaft
6	1	Rear latch housing- Right	21	1	Handle connector
7	1	Slide	22	2	Threaded inserts
8	1	Catch	23	1	Lock mechanism housing
9	1	Bolt	24	1	Lock spring retainer
10	1	Bolt bracket	25	1	Lock catch
11	2	Knob	26	1	Snap ring (w/ key)
12	1	Frame (lock side)	27	1	Knob return spring
13	1	Frame cover (w/ holes)	28	1	Striker plate
14	2	Knob Insert	29	1	Privacy key
15	1	Lock button	30	2	Machine screws (handle)
			31	4	Wood screws (striker & latch)

Variables *U* (Unique number of elements) and *T* (Total number of elements) can be derived directly from the BOM. Summation of the "quantity" column yields a total of 38 parts. Unique number of elements, 31, can be observed from the BOM. DSM's are created by listing the unique number of parts in a column then transposing them to an additional row. DSM creation differs from FSM creation as DSMs utilizes the unique number of parts to create the matrix and FSMs utilize the total number of elements to create the matrix. Table VI (on the next page) illustrates the DSM constructed for the door handle at the completed product level. DSM values for A and M, are enumerated in a similar way to FSM values with one minor change. Since the DSM lists only unique components in the matrix, the maximum number of possible connections, M_{DSM}, is calculated with the following equation (Equation 5).

$$M_{DSM} = \frac{(U^2 - U)}{2} \tag{5}$$

When determining the number of connections (A) in a DSM, utilizing a BOM and an exploded part view is beneficial because they show which parts are connected. Utilizing a BOM and an exploded part view allows for non-subjective analysis and consistent DSM creation. Table VII provides a summary for each variable obtained from the DSM.

TABLE VI:

DESIGN STRUCTURE MATRIX (DSM) SNIPPET – DOOR HANDLE.

Door Handle - DSM	front latch housing	face plate	latch spring	retainer	rear latch housing	slide	catch	bolt	bolt bracket	...
front latch housing	0	1		1	1			1	1	
face plate	1	0						1		
latch spring			0		1			1		
retainer	1			0		1		1	1	
rear latch housing	1		1		0	1	1			
slide				1	1	0	1			
catch					1	1	0			
bolt	1	1	1	1				0	1	
bolt bracket	1			1				1	0	
...										...

TABLE VII

DESIGN STRUCTURE MATRIX (DSM) VALUES.

	A	M	A/M	T	U	U/T
DSM	51	465	0.11	38	31	0.82

Both functionally derived complexity and product level complexity for the door handle example can be calculated from Tables IV and VII. As another baseline indicator, a lawnmower carburetor was analyzed and results are shown in Table VIII on the next page. For reference, Jacobs M1 designates Jacobs' original equation (Equation 1) and method 1 were used for this complexity metric. Jacobs M2 designates the original equation and method 2 were used for this complexity metric. Proposed M1 designates the proposed equation (Equation 2) and method 1 were used for this complexity metric. Proposed M2 designates the proposed equation and method 2 were used for this complexity metric. Example calculations for the door handle example can be seen in Table IX on the next page. Functional model illustrations were utilized to create FSM's, as they did not already exist in the repository. However, DSM's did already exist in the repository and after minor formatting adjustments they were used directly for analysis. Capstone students produced a functional model relevant to their project before concept generation began. Each capstone group submitted a final report that included a BOM and an exploded view of the final product. These final reports were utilized to construct a DSM.

TABLE VIII

COMPLEXITY METRICS AT FUNCTION AND PRODUCT LEVEL – BASELINE EXAMPLES.

	FSM				DSM	
Product	Jacobs M1	Jacobs M2	Proposed M1	Proposed M2	Jacobs	Proposed
Door Handle	0.052	0.287	0.078	0.043	0.726	0.090
Carburetor	0.015	0.121	0.168	0.061	0.014	0.105

TABLE IX

CALCULATIONS AT FUNCTION AND PRODUCT LEVEL – DOOR HANDLE.

Function Level (FSM) Calculations

$$Jacobs\ M1 = (1 - 0.13)(0.6) = 0.052$$
$$Jacobs\ M2 = (1 - 0.13)(0.33) = 0.015$$
$$Proposed\ M1 = (0.13)(0.6) = 0.078$$
$$Proposed\ M2 = (0.13)(0.33) = 0.043$$

Product Level (DSM) Calculations

$$Jacobs = (1 - 0.11)(0.82) = 0.726$$
$$Proposed = (0.11)(0.82) = 0.090$$

4. RESULTS AND DISCUSSION

This section presents results of the study for ranked complexity in section 4.1, for function and product level in section 4.2, and discussion in section 4.3.

4.1 RANKED COMPLEXITY

The door handle and carburetor examples covered in the previous sections provide a baseline for understanding complexity at functional model and completed product levels. Microsoft Excel for Mac 2011 Version 15.6 was used for all matrix manipulation, calculations and analysis. Ranked complexity data for the thirty repository products had relatively low coefficients of variation (Table X) for each question, indicating agreeable evaluations from the graduate students.

TABLE X

COEFFICIENTS OF VARIATION FROM RANKED COMPLEXITY QUESTIONNAIRE – REPOSITORY AND CAPSTONE DATA.

Data Source	Q. 1	Q. 2	Q. 3	Q. 4	Q. 5
Repository	0.34	0.38	0.44	0.30	0.29
Capstone	0.47	0.47	0.37	0.39	0.40

For the products form the design repository there is greater variation of answers to question 3. Larger variation in question 3 could be explained as evaluators may not have known the specific technologies used in each product. Pearson correlations were utilized per question and at every evaluator combination to determine agreeability. Higher disagreement among evaluators was seen in questions 2 and 3 (Pearson's Correlation from 0.13 to 0.26) whereas higher agreement was observed on question 5 (Pearson's Correlation from 0.68 to 0.78).

The capstone project data coefficients of variation were higher than repository data on all questions except question 3. A potential explanation is that evaluators knew they were evaluating capstone projects, therefore had the perception that each project utilized novel technologies, ultimately leading to less variation in their responses. Higher coefficients variation in the capstone data could be explained in that the products being evaluated were not in finalized product form. Evaluators needed to estimate what manufacturing processes would take place, how the part would be assembled, and what kind of design effort would be needed to produce a finalized product. Ranked complexities in order from low to high, left to right, are illustrated in Figure 5.

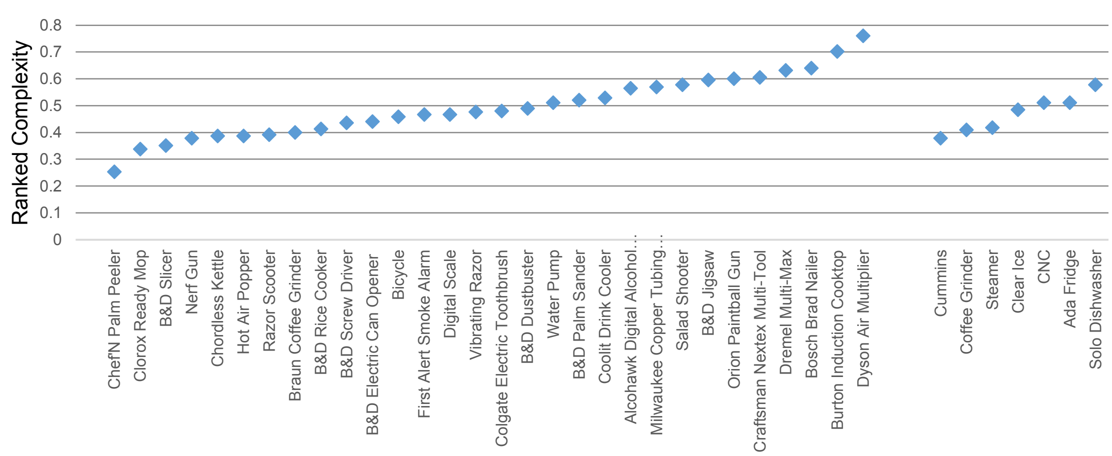

FIGURE 5: RANKED COMPLEXITIES (LOW TO HIGH, LEFT TO RIGHT) – REPOSITORY AND CAPSTONE DATA.

4.2 FUNCTION AND PRODUCT LEVEL COMPLEXITY

Utilizing ranked complexity in increasing order is insightful because it provides a guide to compare GCI calculated complexities and as such, x-axes on Figure 6 and 7 remain unchanged from Figure 5, as ranked complexity is taken to be the ultimate measure. It is important to reiterate that the numerical value of ranked complexity has only an indicative value with in the data set and is not comparable to Jacobs or the proposed GCI metrics. Functional and product level complexities are graphically represented in Figures 6 and 7, respectively on the next page. Recalling that complexity values are expected to increase for products listed from left to right on the x-axis, functional level complexity does not increase, indicating no correlation was present. Product level complexity, derived from either Equation 1 or 2, and illustrated in Figure 7, was expected to follow a general trend of increasing complexity. Visual inspection of the repository and capstone data shows that equated product complexity do not follow a general increasing trend. Linear regression analysis confirms very poor correlations for repository data with respect to ranked complexity. Jacobs and the Proposed equations yield trend-line R^2 values of 0.00603 and 0.00612, respectively. Considering only capstone project data, linear regression shows improvement (Jacobs R^2 = 0.396 and Proposed R^2 =0.0239) yet remains undesirable.

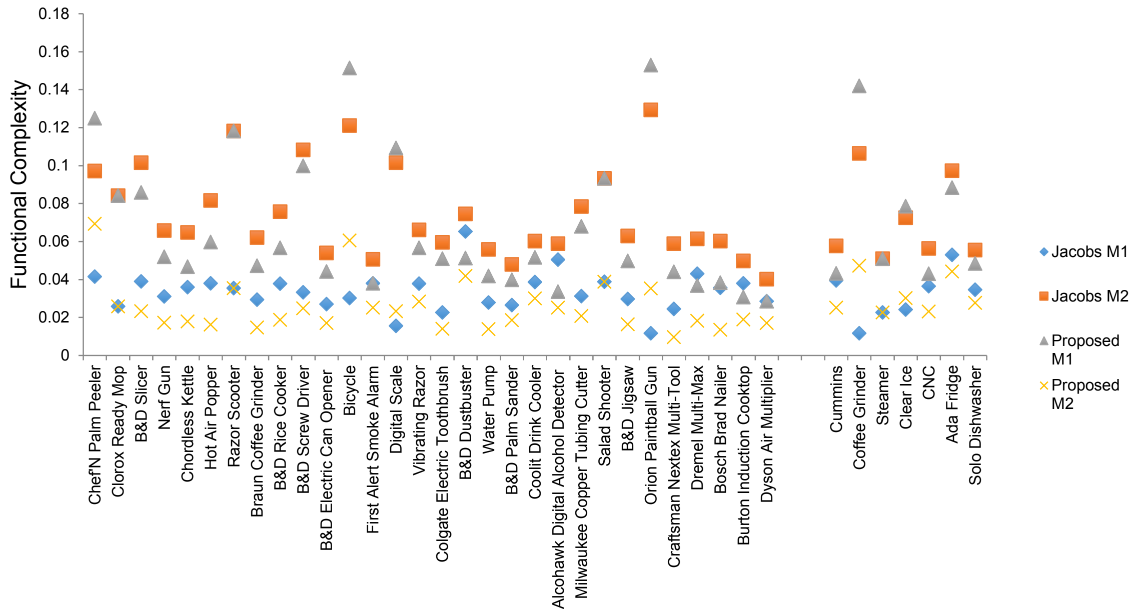

FIGURE 6: FUNCTION LEVEL COMPLEXITY – REPOSITORY AND CAPSTONE DATA.

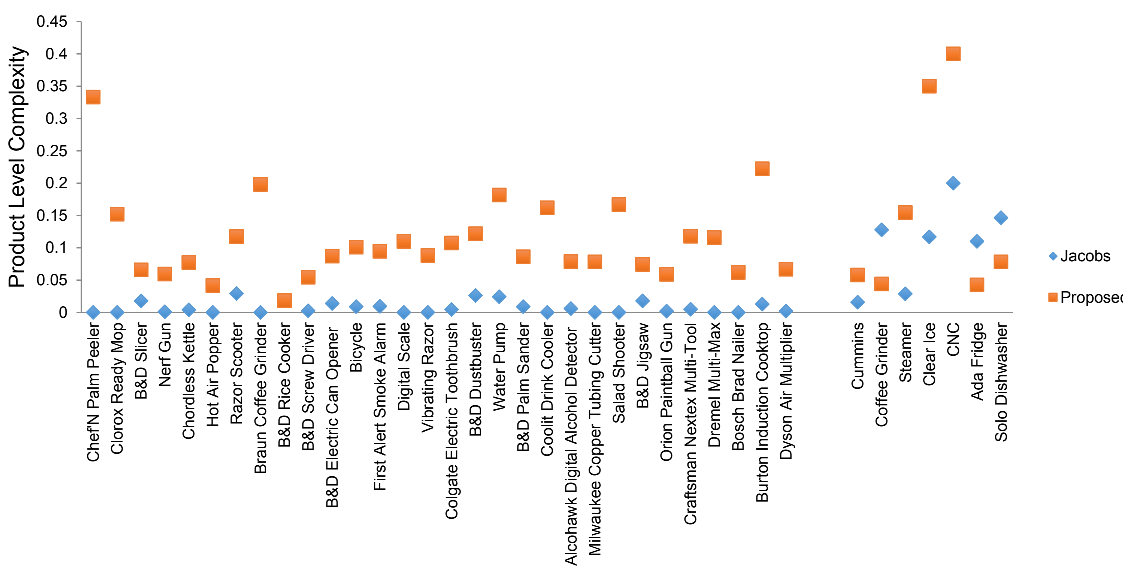

FIGURE 7: PRODUCT LEVEL COMPLEXITY – REPOSITORY AND CAPSTONE DATA.

When considering ranked complexity as the ultimate measure, observation of no general increasing trends in Figure 6 or 7 indicates that Jacobs and the proposed complexities, from Equation 1 and 2, do not accurately represent overall product complexity with respect to ranked complexity. Figures 8a and 8b illustrate scatter plots of equated complexities at both function and product level. There is no general agreement among data and as trend line slopes were approximately horizontal. Complexity at the function level is not suggestive of product level complexity as calculated with the GCI.

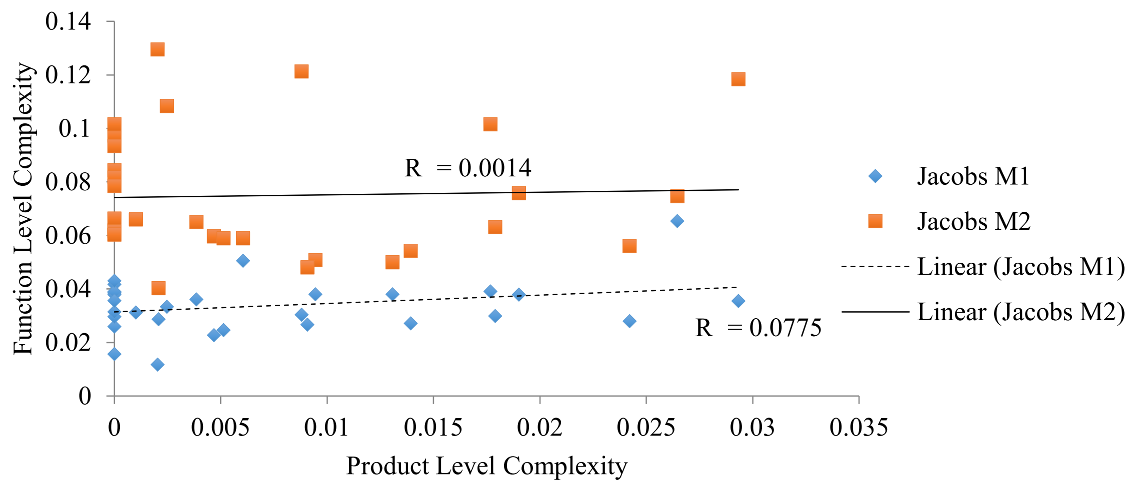

FIGURE 8A: JACOBS COMPLEXITY (EQUATION 1) – PRODUCT VS FUNCTION LEVEL.

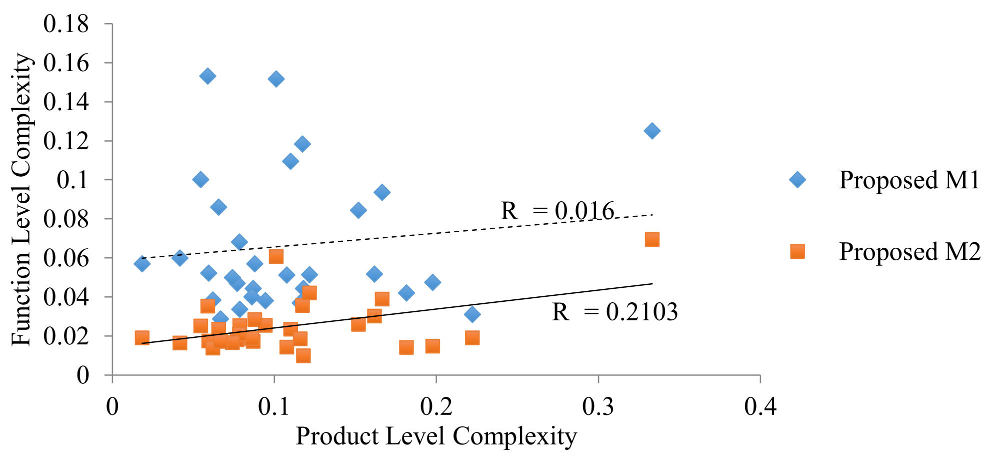

FIGURE 8B: PROPOSED COMPLEXITY (EQUATION 2) – PRODUCT VS FUNCTION LEVEL.

4.3 DISCUSSION

Since the ranked questionnaire use generalized questions, there is concern when using ranked complexity as the ultimate guide. To increase reliability of ranked complexity as the ultimate guide, incorporating objective measures directly from Design for Manufacturing and Assembly (DFMA) (Boothroyd, 1994), such as number of assembly procedures, and determining less subjective measurement criteria would provide a more consistent and objective method of ranking complexity. Although ranking complexity was necessary for this study to provide a general scale with which to measure against, ideally a measure of complexity will be non-subjective. Measuring complexity by consideration of only three factors (multiplicity, diversity, and interconnectedness) may not be sufficient to capture product complexity on a generalized scale because other factors such as manufacturing, assembly, novel technology, and design effort are likely to significantly influence product complexity. Therefore, capturing a multitude of factors in an objective manner is imperative to creating a meaningful generalized complexity metric.

When considering major sources of variation, DSM's obtained from the online repository are of concern. DSM's are prefabricated and downloaded directly from the repository. As a result, there is uncertainty in the specific method of part deconstruction and mapping as it may have been different than was outline in section 3.4. Additionally, some DSM's were composed using all unique components leading to a unique issue. When utilizing eqn1, having all unique components leads to the ratio U/T being 1 and ultimately complexity equal to 0. This phenomenon can be seen on the y-axis of Figure 8a. Figure 8b shows promise with the fitted equation having a slight positive slope. Low

R^2 values, indicating poor trend line fit to the data, are an indication that the equation derived using the proposed GCI and method 2 is an inaccurate predictor or completed product complexity.

Complexity may easily be represented by interconnectedness, multiplicity, and diversity when supply chains are considered however, when considering product-based design, a complexity metric needs to consider manufacturing, assembly, technological novelty, and design effort. Generalized complexity is an elusive subject as there is no absolute measure that currently exists. A need still remains for proposing and validating a general complexity metric. Through empirically supported research it may be possible to derive a generalized complexity metric. This study estimated product complexity by ranking thirty products and seven capstone projects and using the ranked complexity as an ultimate measure. Complexity values calculated from Jacobs GCI model were expected to follow in a similar increasing trend as ranked complexities. No similar trends were found to exist. Assuming ranked complexity to be the ultimate measure, Jacobs GCI and the proposed version of Jacobs GCI do not accurately represent the product data to which they were applied. This study is an initial attempt to apply an independent data set to Jacobs GCI model with perhaps greater implications that complexity is multifaceted and is not accurately represented by only interconnectedness, multiplicity, and diversity, when considering product-based designs. With respect to product-based design, building upon Jacobs's claim of complexity, indicators of great importance, such as interconnectedness, multiplicity, diversity, manufacturability, assembly, technological novelty, and design effort, need to be considered when defining and measuring complexity on a general scale.

5. FUTURE WORK

Future investigation upon this study would limit the source of variability of product data by utilizing documented and consistent methods of part deconstruction leading to accurate DSM representations. Due to time and resource limitations, a sample size of thirty products and seven capstone projects were analyzed. Gathering of a larger sample size, with consistent data collection methods, would build upon this study and possibly form an empirical relationship between function level and product level complexity. The need for a multifaceted complexity measure on a generalized scale has been demonstrated. Developing objective measures of what this study indicates are complexity's core components (interconnectedness, multiplicity, diversity, manufacturability, assembly, technological novelty, and design effort) and incorporating them into a unified framework, would be a next step toward a generalize complexity metric.

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BRIDGE

The previous paper investigated complexity and proves it to be a nuanced subject. The focus of this study shifts from function and product complexity analysis to the process of design, specifically what motivates designers and how can product quality be evaluated. The second paper in this work titled "A Preliminary Study: The Effects of Personal Motivation on Design Quality," investigates personal motivation effects on design quality. Sociological surveying techniques are used to extract participant motivation levels and a design quality survey is used to measure design quality outcomes of various senior mechanical engineering capstone projects.

PAPER 2: A PRELIMINARY STUDY: THE EFFECTS OF PERSONAL MOTIVATIONS ON DESIGN QUALITY

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ABSTRACT

The ultimate goal of most design projects or endeavors should be to create a product with high quality as it typically leads to higher customer satisfaction and brand retention. Product design teams are usually comprised of a group of engineers with varying backgrounds, personalities, and motivational drives. This paper presents an initial study on how motivation of individuals affects the quality of their resulting designs. The overarching hypothesis of this research is that highly motivated individuals and teams produce better quality designs when compared with designers whom possess lower levels of motivation. Initial data for this study stems from a senior level capstone design course in a mechanical engineering program and takes the form of design quality and motivational inventory surveys. Design quality is measured by a group of engineering faculty and industry representatives utilizing a proposed design quality rubric which scrutinizes factors such as customer satisfaction, manufacturability, and product fit and finish. Motivational factors are measured using the Serious Leisure Inventory and Measure (SLIM) short form, a 9 point Likert style questionnaire. The goal of this research is to identify teaming strategies such that a group of designers will achieve the

level of design quality desired of a specific product or project. Findings in this study indicate that teams, comprised of individuals largely motivated by group aspects, or conversely demotivated by personal aspects, tend to realize better design quality outcomes.

1. INTRODUCTION

Ultimately a design aims to create a product or system with high quality leading to high customer satisfaction. Product quality is often assessed during the prototype stages or perhaps even later in the design cycle, which leaves organizations at risk of lost time if a design fails to meet customer needs and quality specifications. As product design cycles shorten and customer demand increases, accurately measuring design quality is imperative. Design quality has been linked with greater customer satisfaction, lower production costs, and better product performance (Bai et al., 2008; Fine, 1986; Keating, 2000); therefore, consideration of design quality is critical for project success. Several researchers have proposed and piloted methods to assess design quality within a variety of disciplines and settings (Bansiya et al., 2002; Davis et al., 2007; Davis et al., 2006; Davis et al., 2009). Much of the research concerning design assessment focuses on the processes, steps, and learning that occurs throughout the design project. This study utilized a proposed design quality measurement survey to assess design quality which scrutinizes factors such as customer satisfaction, manufacturability, and product fit and finish.

Design teams are generally composed of individuals from a broad range of backgrounds, with varying personalities, and motivational drives. Individual designers in a career environment may be motivated by organizational incentives such as expected performance level, financial compensation, etc. However, in a leisure environment, individual designers may be motivated by personal incentives such as self-enrichment, self-actualization, etc. Individuals are motivated in many different ways to participate in a wide variety of activities and hobbies. Intrinsic and extrinsic motivations play a large role in why individuals choose to participate in a particular activity. Intrinsic motivation arises from rewards gleaned from participation in an activity whereas extrinsic motivation focuses on processes apart from participation for its own sake.

Leisure consists of discretionary participation in activities expected to result in pleasure and/or satisfaction. The Serious Leisure Perspective (SLP) (Robert A Stebbins, 2007) is an especially influential theoretical framework wherein individuals orient toward a leisure activity in three ways: casual, serious, and project-based. Serious leisure pursuits tend to be goal directed as an individual strives to improve performance outcomes. It is argued that motivation for serious leisure stems predominantly from the intrinsic challenge of the activity, yet strong self-identification with the activity as well as seeking prestige and social connection within a social world have much in common with integrated and external forms of extrinsic motivation, respectively. This study focus' on individual leisure motivation and the effect it has on design quality.

2. BACKGROUND

This section will explore background literature related to design quality, motivation, and leisure.

2.1 Quality

Several researchers have proposed and piloted methods to assess design quality within a variety of disciplines and settings. Bansiya and Davis (Bansiya & Davis, 2002; Davis et al., 2009) proposed a framework for assessing software design quality. The authors state that functionality, effectiveness, understandability, extendibility, reusability, and flexibility are quality attributes. They do offer a word of caution when discussing quality attributes "just like overall quality, these are abstract concepts and therefore not directly observable." Stone-Romero et al. (Stone-Romero et al., 1997) coin the term "perceived quality" and argue that it is a valid measure of product quality as it takes into consideration the consumers view. Perceived quality consists of flawlessness, durability, appearance, and distinctiveness. They offer a note that perceived quality focus' on product quality and not service quality.

In an industry-based publication, Keating (Keating, 2000) observes that "[computing] *chips continue to get larger and more complex and as they do, design quality continues to become more difficult* [to measure]." Arguing that quality must be designed and is measured by observing design complexity, Keating assesses complexity, and therefore quality, through four factors: 1) the number of modules at each level of hierarchy, 2) the number of levels of hierarchy, 3) the number of interfaces per block, 4) complexity of the interconnect between blocks. Keating asserts that chips ought to be easy to design correctly so that quality is designed, not tested, in the chip. While proposing a specific method of measuring complexity and quality of computing chips, Keating calls for further research of measuring quality to "*tame the enormous and rapid growth of design complexity.*"

A NSF funded study (DUE 0404924) focuses on assessing performance areas in capstone design courses (Davis et al., 2007; Davis et al., 2006). The work centers on assessment in four areas: personal capacity, team processes, solution requirements, and solution assets. Of the four areas, solution requirements and solution assets are the most related to examining design quality whereas personal capacity and team processes are more focused on growth and personal interactions. The authors propose a scoring rubric for personal growth assessment, but do not propose a similar rubric for solution requirements or solution assets. Their research has expanded into TIDEE (Transferable Integrated Design Engineering Education) Assessment Model (Davis et al., 2009). Key to the TIDEE Assessment Model is a set of scoring rubrics that help to give the evaluation more meaning and context. For example, an assessment of concept generation processes asks team members to rate the team on implementation of the basic steps in the concept generation process (Wilson, 1980). Other studies employ methods of protocol analysis, where the process of team concept generation and problem solving is described in finely grained detail (Zainal Abidin et al., 2009). In one longitudinal study investigating how an engineering design course influences how students think about and practice design, protocol analysis was used to characterize students' design thinking (Christopher B Williams et al., 2010; C.B. Williams et al., 2011).

A number of different metrics for assessing design problems have been used to evaluate conceptual (non-physical) designs (Bouchard Jr, 1969; Van der Lugt, 2002). Shah et al. developed a set of metrics specifically for the evaluation of engineering idea generation techniques including quantity, quality, novelty, and variety of ideas (Shah et al., 2000; Shah et al., 2003). Quality, as defined by Shah, et al., (Shah et al., 2003) is a measure of a product solution's feasibility and how well it meets design specifications. They note the fact that engineering design concepts must meet a particular need and function and thus require an expanded set of measures. For engineering, a unique idea is not useful if it is not technically feasible.

Much of the research concerning design assessment focuses on the processes, steps, and learning that occurs throughout the design project. In a review of design assessment tools, Moazzen et. al (Moazzen et al., 2013) prescribe three key features required of an assessment tool. They state that a 'good' assessment tool should be systematic, flexible, and efficient. Systematic refers to the consistency and reliability of the tool, flexibility refers to the breadth and context in which a tool can be applied, and efficiency refers to the time and costs required to perform the assessment.

2.2 Motivation

Humans have basic psychological needs that are critical for growth and psychosocial well-being (Ryan et al., 2000); psychological needs are often fulfilled via leisure directly (Tinsley et al., 1995) and may serve as mediators between leisure and well-being (Gunnell et al., 2013; Leversen et al., 2012; Rodríguez et al., 2008). Developmental psychologists have developed numerous theories on how needs germinate behavioral motivations (Beard et al., 1983; Maslow, 1982). For example, Self Determination Theory (SDT) posits that autonomy, competence, and relatedness fuel self- motivation, and acknowledges that motivations may be enhanced or blunted by social context (Ryan & Deci, 2000). Intrinsic motivation stems from rewards gleaned from participation in the activity, and is often regarded as " . . . the prototypic manifestation of the human tendency toward learning and creativity . . . " (Ryan & Deci, 2000), and there is empirical backing for the assertion (Amabile et al., 1994). Others have subdivided intrinsic motivation into motivation to know, to accomplish, and to experience stimulation (Pelletier et al., 1995; Vallerand et al., 1992; Weissinger et al., 1995). Evaluation theory – housed within the broader SDT – takes the position that forces external to the individual shape intrinsic motivation by raising or lowering levels of perceived competence toward the activity (Deci et al., 1985).

In contrast, extrinsic motivation focuses on processes apart from participation for its own sake. There are several types of extrinsic motivation under SDT (Ryan & Deci, 2000): (1) integrated motivation concerns situations when the individual so internalizes an activity that it becomes a core part of their self and/or social identity; (2) identified motivation occurs when the individual believes participation is in her best interest; (3) introjected motivation stems from internalization of obligation; (4) external motivation stems from recognition or prizes that might accrue from participation, or conversely, the possibility of punishment for nonparticipation. The motivational terrain is nuanced by additional considerations. There is debate as to the extent to which motivations should be treated as fairly malleable situational states (Guay et al., 2000; Harter, 1981) or relatively stable – though not immutable – psychological traits (Amabile et al., 1994; Manfredo et al., 1996), with the latter position holding sway. Although "global" motivations exist, researchers have also developed specific motivational inventories toward a wide range of activities, such as paid work (Beard & Ragheb, 1983), academics (Vallerand et al., 1992), sport (Pelletier et al., 1995) and leisure (Manfredo et al., 1996; Weissinger & Bandalos, 1995), and religion (Hoge, 1972).

2.3 Leisure

Much of leisure research has centered on why individuals participate in certain leisure activities (Dannefer, 1981; Kelly, 1978; Kuehn et al., 2006; Ruddell et al., 2006; Zarnowski, 2004), whether they persist or not when faced with constraints (Auster, 2008; Barnett, 2006; Brehm, 2013; Bryan, 1977; Carini et al., 2015; Kuentzel et al., 2006; Schulte, 2015; Weber et al., 2012), and how leisure may confer a variety of personal and social benefits (Brown et al., 2008; Bryan, 1977; Joudrey et al., 2009; Kelly, 1978; Lareau, 2002; Palmer et al., 2007; Robert A Stebbins, 2008; Van Ingen et al., 2009; Wood et al., 2007). Sociologists studying leisure have long been interested in leisure-work nexuses (Rapoport et al., 1974; Veblen, 1899). Others have emphasized processes of socialization that facilitate participation, as well as socialization that occurs through leisure itself (Atkinson, 2008; Robert A Stebbins, 2001), i.e., leisure has the potential to change our attitudes, preferences, and behaviors via participation (Kleiber et al., 2011; Shinew et al., 2004; Son et al., 2007). Sociologists often focus on the meanings attached to leisure and its place in our lives (Cohen, 1984; Conley, 2009; Cunningham, 1961). Further, theories on motivation have been used to understand psychological antecedents toward leisure involvement in social contexts (Caldwell, 2005; Gage et al., 2012; Stone et al., 2008; Witt et al., 1970). Importantly, leisure motivations often shape the perceived quality of leisure outcomes (Lee et al., 2013; Manfredo et al., 1996; Shupe et al., 2016). The field of leisure studies, and in particular, the social psychology of leisure, may offer key insights into the motivations of contestants in crowdsourced design competitions, e.g., how incentives may shape their motivations, the meanings they attach to their participation, and how specific types of leisure motivations/incentives may shape design outcomes and maximize learning opportunities

Although scholars continue to debate the nuances of how leisure should be defined, there is broad agreement that, at a minimum, leisure consists of discretionary participation in activities expected to result in pleasure and/or satisfaction (Blackshaw, 2010; Churchill et al., 2007; Gunter et al., 1980; Robinson et al., 2010; R.A. Stebbins, 2005; Wilson, 1980). Personal freedom to sample and become more deeply involved with a leisure activity may be tempered and constrained by personal, social, organizational, and/or cultural factors (Kay et al., 1991; R.A. Stebbins, 2005). Leisure may hold aspects of obligation, yet obligations should not be perceived as overly burdensome by participants (Robert A Stebbins, 2000; R.A. Stebbins, 2005).

2.4 Categorizing Leisure

Scholars have made attempts in recent decades to reduce complexity inherent in the universe of leisure activities by creating typologies or categorizations (Cottrell et al., 2005; Kelly, 1983). The Serious Leisure Perspective (SLP) is an especially influential theoretical framework wherein individuals orient toward a leisure activity in three ways: casual, serious, and project-based forms (Robert A Stebbins, 2007, 2014). Serious leisure is characterized with six distinguishing qualities: (1) perseverance to overcome performance obstacles or leisure constraints (McQuarrie et al., 1996); (2) development of a “leisure career” in the activity; (3) considerable effort that invokes specialized knowledge, training, experience, and/or expertise; (4) accrual of a host of personal and social benefits (e.g., self-actualization, self-enrichment, self-expression, regeneration or renewal even after intense focus, feelings of accomplishment, improved self-image, social interaction and belongingness, social recognition, products of the activity, fulfillment, and financial returns); (5) a unique ethos concomitant with the activity, such that values, norms, and symbols are shared to the extent that a "social world" is formed (Unruh, 1980); and (6) strong identification with the activity such that it becomes a "central life interest" due to strong affective investment (Dubin, 1979). Stebbins identifies three types of serious leisure: amateurs, hobbyists, and volunteers. Makers/tinkerer are a subtype within amateurs, who participate in fields that have professional counterparts to emulate (Robert A Stebbins, 2007).

Serious leisure pursuits tend to be goal directed as the individual strives to successively improve performance outcomes (R.A. Stebbins, 2005), and competitive events serve as a means to assess skill development within a comparative schema (Yoder, 1997). It is argued that motivation for serious leisure stems predominantly from the intrinsic challenge of the activity (Stebbins 1981), yet strong self-identification with the activity as well as seeking prestige and social connection within a social world have much in common with integrated and external forms of extrinsic motivation (Ryan & Deci, 2000), respectively. In terms of the benefits of serious leisure, self-enrichment, self-gratification, and self-actualization typically rank one through three in importance, respectively (Robert A Stebbins, 2007). Further, psychological flow is more likely to occur when individuals pursue serious leisure over casual leisure pursuits (Robert A Stebbins, 2007). Flow can be characterized as a form of temporary self-transcendence in that the self – and even one's sense of time – is submerged during all-encompassing absorption in a challenging activity, only to be reappear in an elevated state after the activity ceases (Csikszentmihalyi et al., 1992). Flow results in deeply fulfilling leisure experiences and is sought after as an important reward by serious leisure enthusiasts (Csikszentmihalyi & Csikszentmihalyi, 1992). Although a number of benefits are possible in serious leisure, Stebbins (Robert A Stebbins, 2007) cautions against confounding the benefits of serious leisure participation with motivations to participate in it.

This paper presents an initial study on how motivation of individuals with respect to serious leisure affects the quality of their resulting designs. The overarching hypothesis of this research is that, with respect to serious leisure, highly motivated individuals and teams produce better quality designs when compared with designers whom possess lower levels of motivation. The next section will outline methods used to collect and analyze data. The following sections will outline results of the study, discuss the results, and outline potential future work.

3. METHODOLOGY

Data for this study stems from a senior level capstone design course in a mechanical engineering and takes the form of design quality and motivational inventory surveys. Capstone projects have four distinct milestones in which physical artifacts are presented; proof of concept one (POC 1), proof of concept two (POC 2), alpha prototype (ALPHA), and beta prototype (BETA). POC 1 and 2 are considered early stage designs and often great changes are seen between these iterations. Greater changes in early stage design are seen because teams are considering how to maximize design potential to meet customer needs while working within project constraints. The purpose of milestone presentations are to assess "how well" the project meets the customer needs. To evaluate quality in the early stages of design, specifically POC 1 and POC 2, the professor and students rated presentation of designs on three parameters; progress, value, and style. Some factors of the proposed Design Quality Survey (Figure 1) do not apply to early stage designs therefore; the survey was not utilized for POC 1 and 2. Quality measurements at POC 1 and 2 were averaged to form a single measurement of early stage design quality for each project.

Data was collected over two consecutive semesters and as this paper concluded before the second semester ended, quality data for ALPHA and BETA milestones are not considered for the second semester. ALPHA/BETA quality measurements were analyzed for the first semester only, effectively reducing the sample size from 59 to 27. After early stage design phases, quality was measured by a group of engineering faculty and industry representatives utilizing the proposed design quality survey (Figure 1) which scrutinizes factors such as customer satisfaction, manufacturability, and product fit and finish. No orientation or training was provided to evaluators for rubric use as the rubric utilized precise language and instructions. The goal was to demonstrate that the proposed rubric could be utilized without training to objectively evaluate quality.

Design Quality Survey		
Customer Needs Assessment:		
Original Customer Needs Statement:	Ranking (0-5)	Instructions:
1. CN 1 Statement	CN-R1	0 - Need not addressed, 1 - Need addressed poorly, 2 - Need somewhat addressed, 3 - Need moderately addressed, 4 - Need mostly addressed, 5 - Need fully satisfied
2. CN 2 Statement	CN-R2	
...	...	
n. CN n Statement	CN-Rn	
Average:	Avg(CN-R1:CN-Rn)	
Manufacturability:		
Major/Critical Components	Ranking (0-5)	Instructions:
1. Component 1	M-R1	0 - Component must be fully redesigned to be manufacturable, 3 - Component requires some redesign to be manufacturable, 5 - Component is ready for manufacture
2. Component 2	M-R2	
...	...	
n. CN n Statement	M-Rn	
Average:	Avg(M-R1:M-Rn)	
Maintenance/Serviceability:	Ranking (0-5)	Instructions:
Overall product servicability	S	0 - Product must be fully redesigned to allow serviceability, 3 - Product requires some modification for serviceability, 5 - Product requires no modification to allow for serviceability
Fit and Finish:	Ranking (0-5)	Instructions:
Overall product fit and finish	F	0 - Product is poorly constructed and is not appealing, 3 - Product is moderately constructed and somewhat appealing, 5 - Product is constructed well and is very appealing
Overall Design Quality:	**Avg(Avg(CN-R1:CN-Rn),Avg(M-R1:M-Rn),S,F)**	
	out of 20 points possible	

FIGURE 1: PROPOSED DESIGN QUALITY SURVEY.

Motivational factors were measured using the Serious Leisure Inventory and Measure (SLIM), a 9 point Likert style questionnaire. Broadly, the SLIM questionnaire reveals an individual's motivation with respect to serious leisure. Motivational categories consist of personal and group motivators which can be broken down in to 18 sub-sets.

Personal motivators account for 14 of the 18 sub-sets while group motivators account for the remaining four. Personal motivators indicate an individual's motivation for personal reasons, while group motivators indicate an individual's motivation for group reasons. Some personal motivators include effort, financial return, self-image, and personal enrichment. Group motivators include unique ethos, group maintenance, group accomplishment, and group attraction. A complete table of motivation qualities and descriptions can be seen in Table I on the next page. In a study involving both a convenience sample of university students in leisure education classes and a purposive sample of adventure racers, trail runners, and paddle sports participants, confirmatory factor analysis of the SLIM short form demonstrated excellent model fit (RMSEA=0.04 and CFI=0.95) (Gould et al., 2008). Overall, the instrument displayed acceptable convergent validity (factor loadings above 0.707 for all but five items and average variance explained in indicators by each of the 18 sub-scales generally exceeded 50 percent) and discriminant validity (factor correlations constrained to unity exhibited significant differences in model chi-squares). For the present study, Cronbach's alphas were 0.978, 0.969, and 0.945 for the serious leisure summative index, personal, and group motivation indexes, respectively, for those who participated in design as leisure. For the 18 sub-scales, internal consistencies ranged from 0.699 (self- actualization) to 0.954 (self-image). The SLIM survey was administered early in the semester before quality measurements were assessed and as such, motivation was considered an independent variable, with quality a potential depended variable.

TABLE I

MOTIVATION QUALITIES AND DESCRIPTIONS.

	Motivator	Description
Personal	Effort	Willingness to exert considerable effort and practice to become more competent in design-related leisure.
	Financial Return	Financial compensation or monetary benefits drive participation in design-related leisure.
	Career Contingencies	Certain defining moments and events have influenced and shaped involvement in design-related leisure.
	Self-Image	Design-related leisure has enhanced and improved individual self-image.
	Identity	Devotion to, and identification with, design-related leisure defines an individual's identity.
	Perseverance	Persistence in overcoming obstacles and adversity in design-related leisure.
	Self-Actualization	Personal potential is realized when utilizing talents for design-related leisure.
	Self-Gratification - Satisfaction	Design-related leisure is intensely gratifying and provides a profound sense of satisfaction.
	Self-Gratification - Enjoyment	Design-related leisure is enjoyable and fun.
	Re-creation	A feeling of renewal, revitalization, and invigoration follow design-related leisure participation.
	Career Progress	Improvements and progression have been realized since beginning design-related leisure.
	Self-expression of Individuality	Expression of individuality is realized through design-related leisure.
	Self-expression of Abilities	Design-related leisure is a way to display and demonstrate skills and abilities.
	Personal Enrichment	Design-related leisure experiences have led to personal enrichment.
Group	Unique Ethos	Sentiments and ideals are shared among design-related leisure group individuals.
	Group Maintenance	Development and unification of design-related leisure group is of high importance.
	Group Accomplishments	A sense of group accomplishment is important to participation in design-related leisure.
	Group Attraction	Affinity to seek, interact, and associate with other individuals who are devoted to design-related leisure.

Three variations of analyzing the data were considered. First, on an overall summative basis, an individual's survey score was totaled. Each question was worded such that a high scoring answer (selection of 9) indicated the individual was highly motivated with respect to that question. This study refers to the first variation of analysis as the major summative score. The maximum major summative score is 495. Second, personal and group motivation was considered. Personal motivation is comprised of 14 individual motivators where group motivation is comprised of four individual motivators. This study refers to the second variation of analysis as personal and group scores. Maximum scores of 414 and 81 are possible for personal and group motivation, respectively. Lastly, each motivator was considered individually. Since each motivator score is defined by three survey question answers, a maximum total score for each motivator is 27 (selection of 9 all 3 times). This study refers to the 18 sub-set motivators on an individual basis, which can be seen in Table I on the previous page.

4. RESULTS AND DISCUSSION

Results and discussion of the results are presented in this section.

4.1 Quality and Motivation Scores

All quality measurements were designed to have a maximum of 20 points. For semester 1 and 2, POC average design quality ranged from 14.1 to 19.1 as can be seen in Table II on the next page. Using the proposed Design Quality Survey, ALPHA/BETA average quality ranged from 13.9 to 17.8. With respect to POC 1 and 2, the average quality score for semester 1 and 2 was 16.91 with a standard deviation of 1.45. With respect to ALPHA/BETA, the average quality score for semester 1 was 15.88 with a standard deviation of 1.31. Pearson correlations were computed on the design quality survey responses as a form of interrater reliability and ranged from 0.51 to 0.88, indicating moderate agreeability. Considering the diverse backgrounds and experience level of evaluators, and that there was no training provided, the Pearson correlations are considered relatively strong.

TABLE II

AVERAGE QUALITY SCORES BY SEMESTER AND DESIGN PHASE.

	Team	Average POC	Average ALPHA/BETA
Semester 1	1	17.11	13.95
	2	15.42	16.23
	3	18.11	16.93
	4	17.08	16.23
	5	18.67	17.85
	6	16.92	15.31
	7	18.89	13.95
Semester 2	8	16.00	
	9	15.12	
	10	16.15	
	11	19.07	
	12	19.00	
	13	16.60	
	14	17.98	
	15	15.90	
	16	16.33	
	17	15.76	
	18	14.17	

With respect to motivation scores, a maximum major summative score of 481 and minimum score 145 were seen over semesters 1 and 2. Personal motivational scores ranged from 124 to 364, where group motivational score ranged from 6 to 107. The 18 sub-set motivational indicator scores ranged from 1 to 27. Regression analysis, performed in Minitab 17.2.1, indicated that of the three methods of analysis (major summative, personal-oriented, and group oriented) only personal-oriented motivation was statistically significant (P = 0.020) to design quality outcomes. Incomplete data was ignored in the analysis, reducing sample size from 72 to 60 observations. The relationship between design quality and personal-oriented motivation was negative with an adjusted R^2 of 0.252.

4.2 Quality and Motivation Intersection Trends

Only motivation scores that were deemed statistically significant from regression analysis results will be presented graphically. No trends were seen utilizing the major summative or group-oriented motivational scores. Figure 2 depicts design quality in an increasing manner from left to right on the secondary vertical y-axis while person-oriented motivation scores and their associated standard deviation error bars are plotted on the primary y-axis. Average personal-oriented motivation was negatively correlated with design quality indicating that teams consisting of individuals who are less personally motivated produce higher quality designs. A possible social explanation of this phenomenon, is that teams who reported lower levels of personal-oriented motivation toward design as a serious leisure activity, were individuals motivated by group activities. Though analysis of group-oriented motivation was not statistically significant (P = 0.294) to design quality, with a larger sample of data this could change. As this study was of preliminary data, findings for personal-oriented motivation were considered respectable.

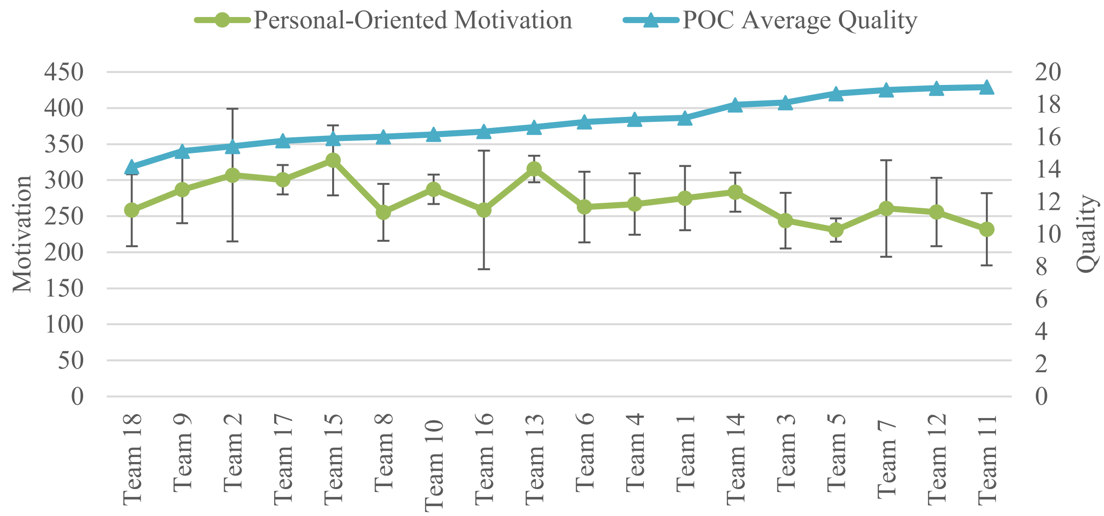

FIGURE 2: TEAM AVERAGE PERSONAL-ORIENTED MOTIVATION, DESIGN QUALITY SCORES, AND STANDARD DEVIATION ERROR BARS.

Though found to be statistically insignificant in regression analysis, group-oriented motivation displayed unique trends. Again, keeping quality on the secondary y-axis in increasing order, Figure 3 indicates standard deviation by team, for group-oriented motivation, decreases as design quality increases. This finding suggest that teams comprised of individuals whom have similar group-oriented motivation scores, tend to produce better quality designs. As decreased team variability leads to higher levels of group cohesion, a lower emphasis of individually-achieved outcomes could be realized by design groups as a whole.

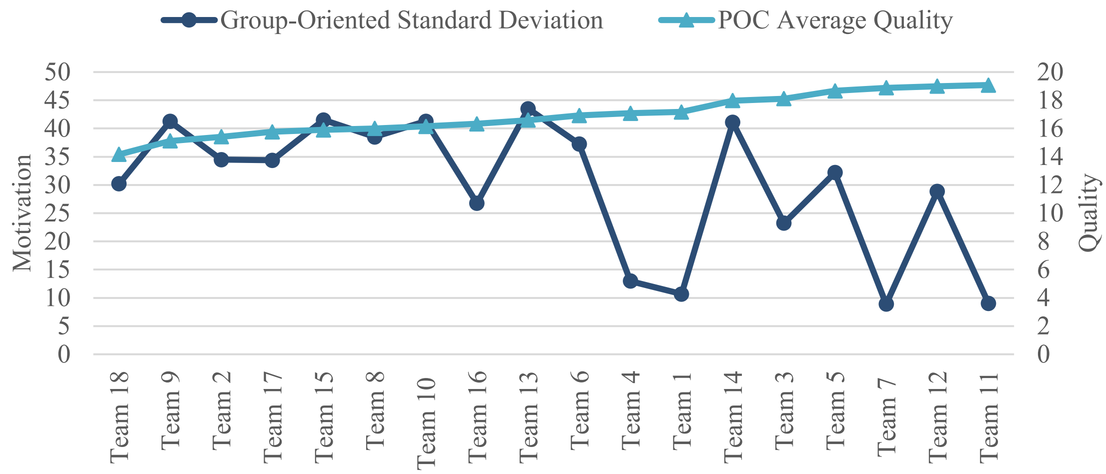

FIGURE 3: GROUP-ORIENTED MOTIVATION STANDARD DEVIATION BY TEAM.

Utilizing the SLIM survey scores in a major summative manner produced no insight with respect to design quality. Of the 18 sub-set motivators non were found to be significant with a 95% confidence level. Personal-oriented motivation was found to be statistically significant and negatively correlated with design quality outcomes. As group-oriented motivation standard deviation decreased by team, design quality increased, indicating teams with greater and similar group-oriented motivation qualities produce better quality designs. As teams were comprised of three to five individual members and motivational survey participation was voluntary, some teams reported incomplete data. Reasonable Pearson correlations provided preliminary validity to the proposed design quality survey. Findings in this study indicate that teams largely motivated by group aspects or conversely demotivated by personal aspects, tend to realize better design quality outcomes. The information in this study could be of particular interest to engineering educators, sociologist, or team managers as a means to leverage design quality outcomes in a team based environment.

5. FUTURE WORK

As this study works with preliminary data findings, sample size is of concern for statistical validity. However, this study does indicate observed trends in the preliminary data, which can be further analyzed in subsequent studies containing greater sample sizes. The researchers aim to utilize the observed trends in the preliminary data with subsequent studies. The researchers intend to continue utilization of the design quality survey in subsequent semesters and increase sample size to substantiate statistical validity of the survey.

ACKNOWLEDGEMENTS

The authors would like to thank all the students for their voluntary participation in the study.

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CONCLUSION

While the first paper revealed complexity to be a highly nuanced subject, the second paper uncovered a relationship between personal motivation and design quality. Jacob's Generalized Complexity Index adequately represented complexity in supply-chain designs however, when applying the measurement method to a diverse product dataset, nonsensical results were observed. A sociological motivation survey provided valuable insight to personal motivations toward the design process. Specifically, that design teams composed of individuals who exhibit high personally-oriented motivation, tended to realize lower quality designs. Alternatively, design teams composed of individuals with similar and high group-oriented motivations, tended to realize higher quality designs. This study reported on findings with respect to a low sample size preliminary dataset. Upon additional data collection, the observed trends of this study are expected to remain largely unchanged for a larger sample size. Though it is evident that a great deal of work is needed in order to define and measure product complexity at both pre and post design stages, the preliminary findings suggest the interaction of complexity, motivation, and design quality is nontrivial. With respect to complexity, future enhancements of this study would include framing complexity in a categorical versus a generalized method. Comparing products or systems of a similar category may produce meaningful complexity results. This study brought to light a preliminary understanding of the relationships between complexity, motivation, and design quality. It is crucial that scientists, educators, and managers understand the influential and impactful factors in a group oriented design environment to achieve project success. This study brings together two fields of study that are seldom-conjoined, resulting in a mix of novel insights and research products. While complexity, motivation, and design quality have been explored individually, interconnections between these variables have rarely – if ever – been explored in combination. There is great significance in knowing how complexity and motivation effect design quality. In both academia and industry, complexity, motivation, and quality are factors that can be used to manage design expectations, assemble effective design teams, and predict design success.

VITA

Philip Mountain was born September 4th, 1989 in Vryheid, South Africa. After immigration to the United States in 2000, Philip attended a cooperative educational school in which he excelled at mathematics and science. Upon relocation to Louisville Kentucky in 2007, Philip attended the University of Louisville's College of Business where he received his Bachelors of Science in Business Economics in 2011. Philip enrolled in the University of Louisville's Speed School of Engineering in the Fall of 2015. After completing his Bachelors of Science in Mechanical Engineering, he extended his tenure at the Speed School of Engineering in pursuit of a master's degree in Mechanical Engineering completed in May 2016.