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Testing Baron and Kenny's Preliminary Conditions for Mediating or Moderating Variables in Structural Equation Modeling

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Abstract

A common misnomer in statistical analysis is the identification of intervening variables as either moderating or mediating as a result of placement of another latent construct or variables between exogenous and endogenous variables in a Structural Equation Model (SEM). However, placement does not determine variable status. Determination of variable status requires the application of Baron and Kenny's preliminary conditions and analysis for determining whether a variable is moderating, mediating, or in fact, intervening. This procedure aids in statistically representing the actual strength and direction of variables in order to improve reporting predictor results on outcomes. An SEM was developed using the results of the analysis of the Biomedical Engineering Interdepartmental (BEI) Survey conducted in 2011. This document illustrates the application of Baron and Kenny's method to the BEI survey SEM model.

Key Words: Intervening Variables; Moderating Variables; Mediating Variables; Regression Analysis; Structural Equation Modeling

INTRODUCTION

Statistical terminology used to describe the relationship between study variables (e.g., mediating, moderating, or intervening) are often inappropriately applied or incorrectly used interchangeably. The major cause of these misnomers can be attributed to the lack of application of fundamental methods that determine the true variable relationship status. Consequently, this analysis will apply the preliminary conditions for a mediating or moderating variable status set forth by Baron and Kenny (1986) to the results of the 2011 Biomedical Engineering Interdepartmental (BEI) Survey. The following will 1) provide BEI Survey background information using Structural Equation Modeling statistical study results, 2) define and demonstrate the conditions of a mediating variable, 3) define and demonstrate the conditions of a moderating variable, 4) identify and demonstrate the characteristics of an intervening variable, and 5) summarize current variable analysis results.

BACKGROUND

The BEI Survey instrument was designed a priori by Fiedler (2011) using the Tailored Design Method (Dillman et al., 2009) and conventional analysis protocols (DeVellis, 2003; Flynn, Schroeder, & Sakakibara, 1994) to assess the inter-professional perspective of hospital quality as viewed by the biomedical engineering technician, a medical equipment maintenance occupation of Clinical Engineering. The 39 questionnaire items are associated with three latent constructs from Donabedian's Triadic relationships between structure, process and outcome

(Donabedian, 1989, 1988, 1980, 1966). Donabedian's model was linear in nature and could be illustrated SàPàO. However, the BEI Survey hypothesized a non-linear relationship demonstrated by the following:

Process Adequacy=f (Structural Complexity) and Level of Quality=f (Structural Complexity + Process Adequacy) as shown in Figure 1.

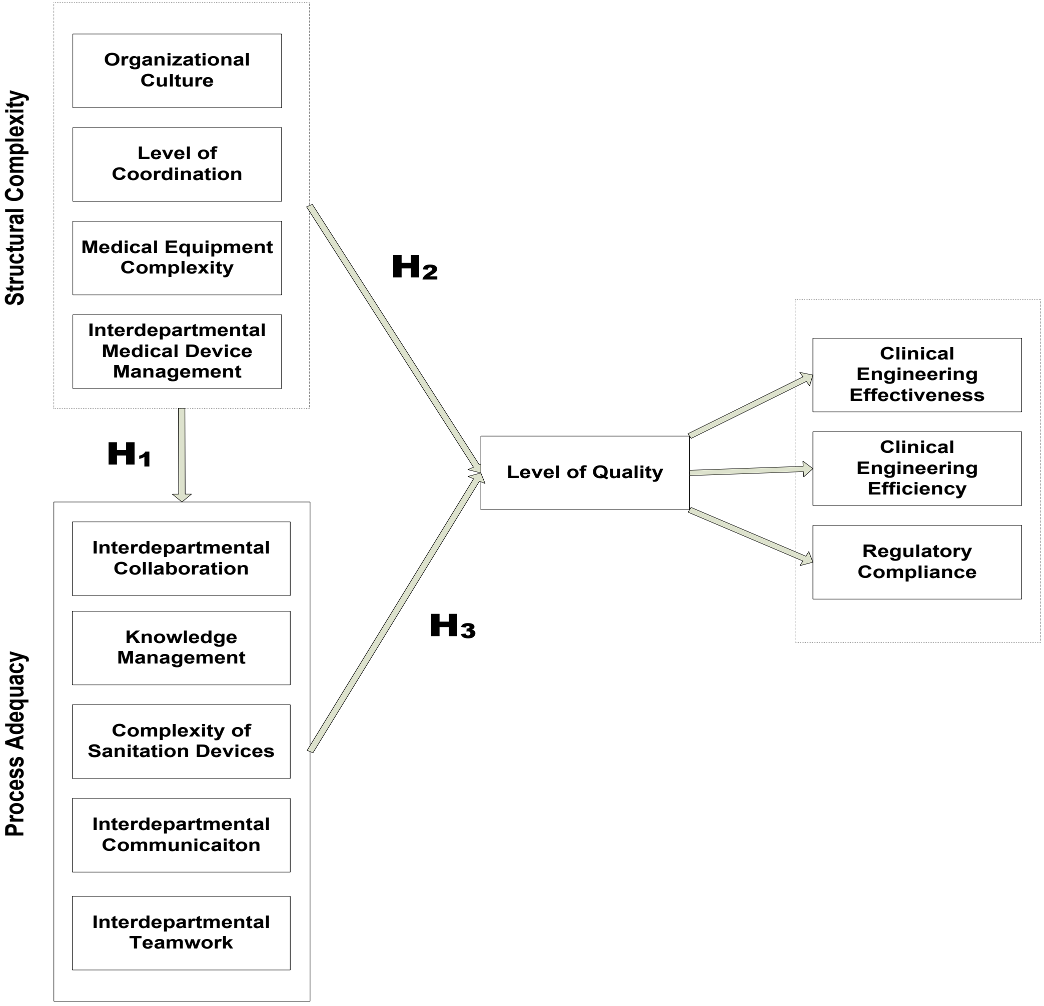
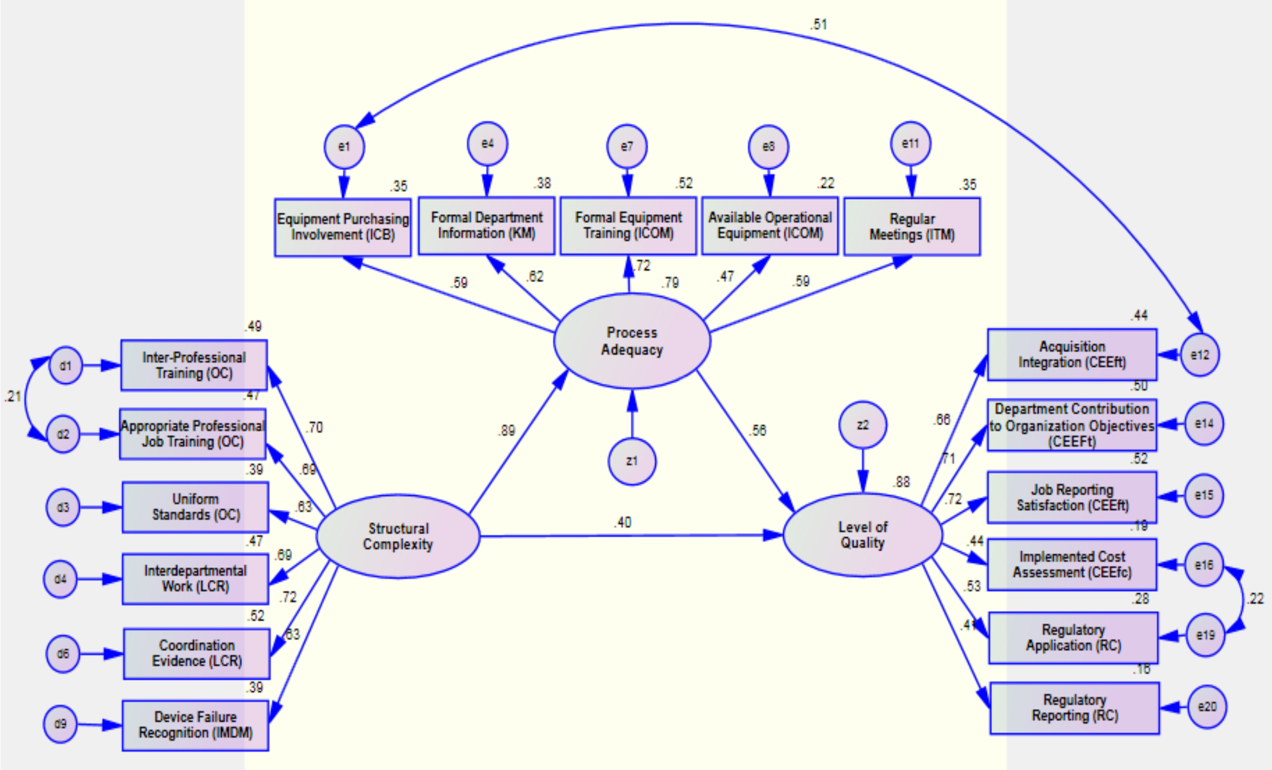


Figure 1. Unconditioned Conceptual Analytic Model with Three Latent Variables Indicating Hypothesized Relationships among Predictor Variables and the Level of Quality in Clinical Engineering as Measured by the Contributions of the Biomedical Engineering Technician

Respondents were asked to use a 5-point Likert scale (1=strongly agree, 2=agree, 3=neither agree or disagree, 4=disagree, 5=strongly disagree) on three questions for each initial indicator of Structural Complexity and of Process Adequacy and four questions for each indicator of the endogenous study variable of Level of Quality (Appendix Tables A1 to A3).

The application of the BEI Survey to the sample population of biomedical engineering technicians study met validity requirements as results from PASW statistical analysis software confirms normally distributed data. The results also demonstrated internal consistency in Item-Total Statistics analysis and Reliability Item Descriptive Statistics. The Cronbach α coefficient for each latent construct ranges from 0.718 (Process Adequacy) to 0.831 (Structural Complexity). Overall Cronbach α = 0.905, N=317, 17 survey items after data cleansing.



Note: Organizational Culture (OC), Level of Coordination (LCR), Interdepartmental Device Management (IMDM), Interdepartmental Collaboration (ICB), Knowledge Management (KM), Interdepartmental Communication (ICOM), Interdepartmental Teamwork (ITM), Clinical Engineering Effectiveness (CEEft), Clinical Engineering Efficiency (CEEfc), and Regulatory Compliance (RC).

Figure 2. Structural Equation Model of the Biomedical Engineering Interdepartmental Survey, 17 Items Listed with Equivalent Subscales on Major Constructs

The SEM model of the BEI Survey is shown in Figure 2 utilizing Analysis of Moment Structures (AMOS) v.18 graphical statistical software. Table 1 indicates the results of the unstandardized and standardized regression weight analysis and provide statistical support for the hypothesized study relationships as shown in Table 2.

Table 1. Final Structural Equation Model for BEI Survey Without Control Variables

	URW Estimate	SRW Revised	Standard Error	t	P
Process Adequacy ← Structural Complexity	.647	.889	.089	7.248	***
Level of Quality ← Process Adequacy	.504	.563	.161	3.136	.002
Level of Quality ← Structural Complexity	.262	.402	.106	2.469	.014
Structural Complexity X_{1-6}					
Interdepartmental Work← Structural Complexity[1]	1.000	.687			
Uniform Standards ← Structural Complexity[2]	1.414	.627	.141	10.062	***
Inter-Professional Training ← Structural Complexity[3]	1.171	.701	.106	11.091	***
Coordination Evidence ← Structural Complexity[4]	1.161	.723	.101	11.445	***
Appropriate Professional Job Training ← Structural Complexity[5]	1.134	.685	.105	10.850	***
Device Failure Recognition ← Structural	.992	.627	.099	10.065	***

	URW Estimate	SRW Revised	Standard Error	t	P
Complexity[6]					
Process Adequacy Y_{1-5}					
Available Operational Equipment ← Process Adequacy[7]	1.000	.469			
Regular Meetings ← Process Adequacy[8]	1.850	.590	.264	7.009	***
Equipment Purchasing Involvement ← Process Adequacy[9]	1.670	.593	.237	7.036	***
Formal Equipment Training ← Process Adequacy[10]	1.576	.719	.205	7.678	***
Formal Department Information ← Process Adequacy[11]	1.225	.618	.171	7.172	***
Level of Quality Y_{6-11}					
Regulatory Application ← Level of Quality[12]	1.000	.531			
Acquisition Integration ←Level of Quality[13]	2.166	.660	.259	8.371	***
Job Reporting Satisfaction ← Level of Quality[14]	2.026	.722	.231	8.785	***
Department Contribution to Organizational Objectives ← Level of Quality[15]	1.737	.709	.200	8.702	***
Implemented Cost Assessment ← Level of Quality[16]	1.294	.441	.179	7.226	***
Regulatory Reporting ← Level of Quality[17]	1.139	.406	.191	5.976	***

***<0.001 (2-tailed) significance level;

Note: URW=Unstandardized Regression Weight; SRW=Standardized Regression Weight.

Notes: Scale[1-17]: 1) I receive and/or provide interdepartmental input in order to successfully complete work, 2) Standards are applied equally across all departments, 3) The organization values contributions to other staff members' professional development, 4) Interdepartmental coordination has resulted in visible positive benefits, 5) I have been provided clear training to perform my job function, 6) I receive and/or provide advice on new equipment purchases, 7) I receive and/or provide clean, operational equipment in a timely fashion, 8) Nursing and biomedical engineering conduct regularly scheduled meetings on equipment issues, 9) I receive and/or provide advice on new equipment purchases, 10) I receive and/or provide training on the proper way to operate equipment,11) I have access to formal knowledge within the department, 12) Biomedical engineering is able to apply medical equipment regulatory policy, 13) Biomedical engineers are integrated in the medical equipment purchasing process, 14) Biomedical engineers are satisfied with reporting authorities, 15) Biomedical engineers set and achieve department goals based on organizational objectives, 16) Biomedical engineering measures cost using generally accepted metrics, and 17) All departments have access to hospital acquired infection data.

Table 2. Summary of the Statistical Evidence in Support of Study Hypotheses

Hypotheses Statements	Summary of Statistical Evidence	Results
Hypothesis$_1$: Structural complexity positively affects process adequacy in the hospital environment of care.	PA←SC: $p<0.001$ level (2-tailed); $\beta=.889$, $t=7.248$, $t>1.96$ on all factors; $R^2 = 79\%$.	Supported
Hypothesis$_2$: Structural complexity positively affects the level of quality in the hospital environment of care.	LOQ←SC; $p=0.014$ level (2-tailed); $\beta=.402$, $t=2.469$, $t>1.96$ on all factors; $R^2 = 16.2\%$.	Supported
Hypothesis$_3$: Process adequacy positively affects the level of quality in the hospital environment of care.	LOQ←PA: $p=.002$ level (2-tailed); $\beta=.563$, $t=3.136$; $t>1.96$ on all factors; $R^2 = 31.2\%$.	Supported

Abbreviation Notes: SC=Structural Complexity, PA=Process Adequacy, LOQ=Level of Quality, ← = direction of the relationship between constructs.

The SEM data analysis indicates strong, positive relationships between constructs as statistically significant (2-tailed) with normal distribution: 1) Structural Complexity and Process Adequacy, 2) Process Adequacy and Level of Quality, and 3) Structural Complexity and Level of Quality. Translation of these findings into an equation form as follows:

Level of Quality = .889 Structural Complexity + .563 Process Adequacy

The study finds several determinants of quality derived from structural complexity including 1) uniform standards, 2) inter-professional training, and 3) coordination evidence. In addition, the intervening effect of process adequacy comprising regular meetings, equipment purchasing involvement, formal equipment training across departments, and formal department information on the level of quality is supported. In order to determine the actual role of the latent construct Process Adequacy, Baron and Kenny's (1986) causal step approach methodology was applied to the final revised SEM model.

DEMONSTRATING CONDITIONS OF A MEDIATING VARIABLE

A mediation variable is defined in classic terms as an external organism or mechanism that intervenes between a stimulus and a response. Processes that occur between the predictor input and the output response may also demonstrate mediating characteristics. (Baron & Kenny, 1986; Woodworth, 1928).

Baron and Kenny's (1986) causal step approach methodology to determine mediation requires manipulation of the final revised SEM model in three stages. First, eliminate the variable under consideration (Process Adequacy) in the SEM model. Second, determine the direct relationship between the independent variable (Structural Complexity) and the dependent variable (Level of Quality) using regression analysis (Figure 3). Third, determine if there is no longer statistical significance between the predictor and the outcome variables (Table 3).

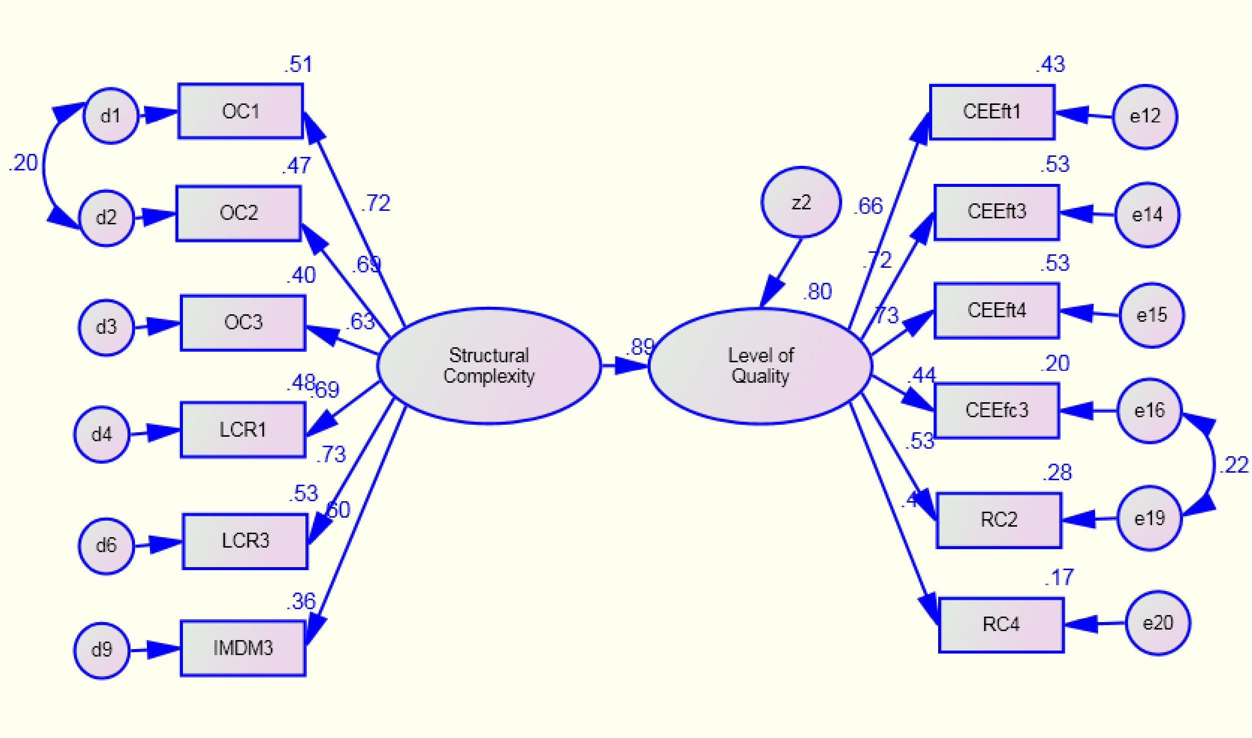


Figure 3. Results of the Final Structural Equation Model with Proposed Mediating Construct Process Adequacy, Removed for Illustrative Purposes

Elimination of the Process Adequacy term indicates a strong relationship of .89 between Structural Complexity and Level of Quality at t>1.96, p<0.001 (2-tailed). Since the relationship is significant without the Process Adequacy construct, the preliminary conditions of mediation did not occur. Consequently, it was unnecessary to perform the causal steps interpretation of the Beta coefficient in the structural equation model for the stimulus-response effect on the linear regression equations under the historically accepted maximum likelihood-based method (Hayes, 2009; Baron & Kenny, 1986).

Table 3. Structural Equation Model with Proposed Mediating Variable Removed

Predictors	URW Estimate	SRW	Standard Error	t	P
Level of Quality← Structural Complexity	1.061	.894	.108	9.841	***

***<0.001 (2-tailed) significance level

Abbreviation Notes: URW=Unstandardized Regression Weight; SRW=Standardized Regression Weight

Review of the results of the complete regression analysis in Table 1 compared to the results of the direct variable relationship between Structural Complexity and the Level of Quality in Table 3 reveals two interesting conclusions. First, isolated structural changes may only have a marginal impact on quality. This conclusion is indicated by the interpretation of the unstandardized regression weight which shows that for each instance of improvements in structural complexity, a marginal increase of level of quality will occur in the ratio of 1:1.061. Second, the combined effects of structural complexity and process adequacy can result in increased levels of quality. For example, Acquisition Integration can positively impact the Level of Quality at the ratio of 1:2.166 indicating that for every instance of the biomedical engineering technician inclusion on purchasing, the rate of return will be more than twofold. Hence, having a structural reference is vital, but following the rule by completing the process is where the greatest level of benefits is achieved.

DEMONSTRATING CONDITIONS OF A MODERATING VARIABLE

Moderating variables can be either qualitative (e.g., urban, profession, non-profit) or quantitative (e.g., pay scale, budget allocation, days in hospital). Their function is to interact as a third variable between the exogenous variable and an endogenous outcome study variable in an SEM and other statistical methods (e.g., ANOVA, Analysis of Variance) in such a way that impact the strength and/or direction of the predictor-outcome relationship. (Baron & Kenny, 1986).

A preliminary consideration to determine moderation under desirable conditions requires that the "moderators and predictors are at the same level in regard to their role as causal variables antecedent or exogenous to certain criterion effects" (Baron & Kenny, 1986, p. 1174). Reviewing the hypothesized and final relationships in Figures 1-2 illustrates that this study does not consider the intervening variable of Process Adequacy on the same level as Structural Complexity since Process Adequacy has been established as both an exogenous and endogenous variable (e.g., Process Adequacy is endogenous to Structural Complexity; Process Adequacy is exogenous to Level of Quality).

Correlation analysis also plays a factor in statistically establishing a moderator variable. A preliminary consideration to determine moderation under desirable conditions indicates that the "moderator variable be uncorrelated with both the predictor and the criterion (the dependent variable)" (Baron & Kenny, 1986, p. 1174).

Table 4. Spearman Correlation Coefficients of Structural Complexity and Process Adequacy, N=317

Process Adequacy	Equipment Purchasing Involvement	Formal Department Information	Formal Equipment Training	Available Operational Equipment	Regularly Scheduled Meetings
Structural Complexity					
Inter-professional Training	.379**	.336**	.393**	.217**	.332**
Appropriate Professional Job Training	.351**	.375**	.406**	.225**	.316**
Uniform Standards	.262**	.295**	.342**	.231**	.394**
Inter-Departmental Work	.367**	.331**	.445**	.264**	.331**
Coordination Evidence	.397**	.375**	.424**	.329**	.324**
Device Failure Recognition	.273**	.362**	.461**	.335**	.394**

**Correlation is significant at the 0.01 level (2-tailed).

Table 4 shows multiple positive statistically significant relationships at p=.01 (2-tailed) between Structural Complexity and Process Adequacy, ranging from .217 to .461. The largest relationship is between Formal Equipment Training and Device Failure Recognition. The smallest relationship is between Available Operational Equipment and Inter-Professional Training. Formal Equipment Training also correlates with three other variables >.4. They are Appropriate Professional Job Training (.406), Inter-Departmental Work (.445), and Coordination Evidence (.424).

Table 5. Spearman Correlation Coefficient Table of Process Adequacy and Level of Quality, N=317

Level of Quality	**Acquisition Integration**	**Department Measures Tied to Organizational Goals**	**Job Reporting Satisfaction**	**Implement Cost Assessment**	**Regulatory Application**	**Regulatory Reporting**
Process Adequacy						
Equipment Purchasing Involvement	.688**	.389**	.440**	.305**	.313**	.277**
Formal Department Information	.331**	.363**	.385**	.169**	.283**	.219**
Formal Equipment Training	.433**	.428**	.416**	.356**	.378**	.230**
Available Operational Equipment	.155**	.247**	.281**	.172**	.289**	.219**
Regularly Scheduled Meetings	.459**	.349**	.421**	.346**	.239**	.184**

**Correlation is significant at the 0.01 level (2-tailed).

Correlation coefficients were calculated for the intervening variable Process Adequacy and the endogenous variable Level of Quality. The results shown in Table 5 indicate that Process Adequacy and Level of Quality indicators are positively associated, ranging from .155 to .688. The largest relationship is between Acquisition Integration and Equipment Purchasing Involvement. The least relationship occurred between Available Operational Equipment and Acquisition Integration.

Correlation is demonstrated between Structural Complexity and Process Adequacy (Table 3) and between Process Adequacy and Level of Quality (Table 4). Hence, the preliminary conditions of moderation were not met.

SUMMARY

In summation, the preliminary conditions of mediation and moderation have not been met under Baron and Kenny's (1986) causal path methodology for the Process Adequacy construct in the 2011 BEI Survey.

Consequently, Process Adequacy is an intervening variable. An intervening variable is defined as one that may affect the causal path relationship between an exogenous and an endogenous variable but does not meet the specific statistical conditions of a mediating or moderating variable.

As demonstrated in the case of the BEI Survey results, the exogenous variable of Structural Complexity had some direct impact on the endogenous study variable of Level of Quality. But, the greatest impact on the Level of Quality was the result of the interaction between Structural Complexity and Process Adequacy. The intervening process action was necessary to enhance the rules or accepted methods embedded in the organizational structure.

One additional item must be noted. If the variable of Process Adequacy had met these preliminary criteria, further analysis of mediating or moderating conditions would be required to determine the complete statistical significance of the causal path relationships.

Baron and Kenny's methods are not without critics. Other researchers have recently provided other methodologies that were not performed in this analysis which may be used to provide alternative methods for testing.

In fact, several researchers suggest that these new analysis methods may improve on the causal steps approach which may have reduced power (Hayes, 2009; MacKinnon et al., 2007; Bauer et al., 2006).

They suggest an alternative testing sequence such as the Sobel test (Sobel, 1982, 1986 as cited in Hayes, 2009), which analyzes the standard error in the direct relationship between the predictor and the outcome that may in part account for the intervening effect. But Hayes (2009) and MacKinnon et al. (2007) indicate that each potential replacement struggles with weaknesses that require further examination before a new method can gain mainstream acceptance in the statistical community.

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