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OPERATIONAL COMPLEXITY IMPACT ON PERFORMANCE OF ELECTRICAL AND ELECTRONCIS INDUSTRY IN MALAYSIA

Nasuha Lee Abdullah[1], Khairur Rijal Jamaludin[2] and Hayati Habibah Abdul Talib[2]
[1]School of Computer Sciences, Universiti Sains Malaysia, Malaysia
[2]Razak School of Engineering and Advanced Technology, Univeristi Teknologi Malaysia, Malaysia
E-Mail: nasuha@cs.usm.my

ABSTRACT

The electrical and electronics (E and E) manufacturing industry is one of the most complex, challenging and dynamic industry. In order to maintain competitiveness, companies need to learn how to manage and leverage on the increase of complexity in their operations. This study seeks to understand the relationship between operational complexity and operational performance of E and E industry in Malaysia. This survey-based study registered a response rate of 17.8% with 111 usable data. Partial Least Square Structural Equation Modelling (PLS-SEM) technique was applied to analyze the data. Operational complexity consists of two dimensions, namely, complicatedness and uncertainty. Meanwhile, operational performance has four dimensions of cost, quality, delivery and flexibility. Both variables are multi-dimensional and modeled as formative second order in PLS-SEM. Results of structural model reveal that operational complexity has a positive impact on operational performance which indicate that the higher the operational complexity, the better the performance. Based on Complex Adaptive System (CAS) in complexity science literature, the relationship between performance and complexity is an inverse U shape curve. This implies that, high operational complexity needs to be managed so as not to reach the threshold of a chaotic stage, which will affect performance. The finding provides insights for managers to cope with increasing operational complexity and to improve performance in the current fast-moving business environment. It also contributes to knowledge in complexity science.

Keywords: operational complexity, electrical and electronics, manufacturing, operational performance

INTRODUCTION

The electrical and electronics (E and E) manufacturing industry is a complex, challenging and dynamic industry. In Malaysia, E and E is the leading manufacturing sub-sector contributing substantially to the Malaysia's economy (MIDA, 2014). Thus E and E is identified as one of the 12 National Key Economic Area (NKEA) that is under the Economic Transformation Programme to propel Malaysia into a developed nation by year 2020 (PEMANDU, 2014). E and E alone is projected to contribute 56, 800 high-income jobs in 2020 (PEMANDU, 2014). In order to maintain competitiveness, Malaysian companies need to understand the impact of operational complexity and learn how to manage and leverage on the increase of complexity in their operations to improve performances.

The manufacturing industry consists of two types of businesses, namely, original equipment manufacturer (OEM) and contract manufacturer (CM). OEMs are those who outsource some of their processes while CM are those that run the processes for the OEMs (Mucha, 2008). In essence, CMs exist due to outsourcing trend in the global manufacturing industry (Brown and Wilson, 2005). In Malaysia, OEMs generally are multinational companies (MNC) that outsource some of their processes to the local CMs consist of small and medium size enterprises (SME). The growth of local CMs was spurred by the rapid development of the E and E industry and continued to play a major role in E and E industry ecosystem (MIDA, 2007). The Malaysia's contract manufacturing industry consists of both foreign and local companies (MIDA, 2007). Some of the foreign prominent CMs are Flextronics, Jabil and Plexus. Meanwhile, homegrown CMs are BCM Electronics, Globetronics, Unisem, AIC offering services of integrated circuit and semiconductor packaging, surface mount technology, printed circuit board and assembly (MIDA, 2007).

In manufacturing outsourcing, the CM would perform the manufacturing activities according to a plan, customised specification or design with varying details determined by the OEM (Sousa and Voss, 2007), (Webster *et al.*, 1997). A company that produces 'off the shelf' and standardised component and then supplies it to the OEM is not a CM as there is no customization involved (Sousa and Voss, 2007). In this case, it is known as a supplier. Meanwhile, OEM are companies that do not perform any manufacturing activities for a third party. The OEM has full control over its entire operations including all the design processes (Sousa and Voss, 2007). Sousa (2003) and Sousa and Voss (2007) posited that OEM and CM can be compared using the following operational characteristics: extent of control over product design, rate of new production introduction, influence of customer over operational decisions, intensity of exchange of information with customer, internal item variety and type of manufacturing process (Sousa and Voss, 2007). Upon comparison, CM has a much higher operational complexity than OEM (Sousa and Voss, 2007). With the current fast changing business environment, ability to quickly adapt to the increase in complexity is crucial to

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ensure sustainable business (Schwandt, 2009). The review in manufacturing complexity literature indicated a growing interest in managing complexity. However, research conducted in Malaysia is scarce. It is hoped that by understanding the impact of complexity on performance, Malaysia's E and E manufacturers would be able to learn from this study and take proactive steps to leverage on the increase in operational complexity to their advantages.

LITERATURE REVIEW

Operational complexity

Complexity has been studied in various fields including manufacturing, information technology (IT), organisational, physical science, engineering, and management resulting in various broad ranges of definitions and terms (Bozarth *et al.*, 2009), (Vachon and Klassen, 2002). The seminal work by Galbraith's (1973) information-processing model where complexity of an organisation is directly linked to the information processing needs is one of the major streams in manufacturing complexity literature (Vachon and Klassen, 2002), (Flynn and Flynn, 1999), (Galbraith, 1973). Galbraith (1973) defined complexity as the consequence of uncertainty. Uncertainty is the difference between the amount of information required to perform the task and the amount of information already possessed by the organisation. The higher the uncertainty the more information that needs to be processed and eventually leads to complexity (Galbraith, 1973). Hence, Frizelle and Woodcock (1995) defined complexity as the variety and uncertainty associated with a system and further classified it into static and dynamic complexity. Static complexity is the variety embedded in a static system while dynamic complexity is associated with uncertainty of a dynamic system (Frizelle and Woodcock, 1995). Sivadasan *et al.* (2002) extended the concepts and used the term operational complexity to measure complexity in supplier-customer system. In another study, Borzath *et al.* (2009) defined supply chain complexity as the level of complexity exhibited by the products, processes and relationships that constitute a supply chain and further classify complexity into detail and dynamic complexity. Detail complexity is the distinct number of components or parts that form a system while dynamic complexity refers to the uncertainty of a system's response. A closer look at the definitions indicated that there is no standard term to describe complexity in manufacturing and hence, the term operational complexity is chosen for this study since the variable is derived from the operational characteristics of the organisations.

Operational performance

Review from the manufacturing literature showed that performance of an organisation could be assessed using single or multiple dimensions of financial, operational performance or customer satisfaction (Valmohammadi and Roshanzamir, 2015), (Mahmud and Hilmi, 2014), (Fotopoulos and Psomas, 2010). In this study, the traditional operational variables of cost, quality, delivery and flexibility (Zhang *et al*., 2012) are chosen to be the performance dimensions. The main reason is that once operational performance improved, it would in turn affect the other dimensions such as customer satisfaction and financial performance (Sousa and Voss, 2008). It is also to heed the proposal by scholars in the field of operational management that special attention should be given to operational performance compared to other dimensions since the main focus of the field is to create prescriptive knowledge in increasing operational performance of organisations (Sousa and Voss, 2008). The four traditional operational dimensions of cost efficiency, conformance to quality, delivery dependability and flexibility or speed in model change were one of the most prominent contributions from Skinner (1966)'s seminal work as cited in (Ferdows and De Meyers, 1990). Acquiring the four capabilities should be the mission and long-term competitive strategy of any manufacturer in order to outperform their competitors (Ferdows and De Meyers, 1990). These four dimensions are now commonly known as cost, quality, delivery and flexibility.

Related works in operational complexity and performance relationship

As organisations tried to be more flexible in their operations in order to cope with dynamic and aggressive competitions, it also created decision-making complexity in the operations that may eventually affect performance if it is not properly controlled (Calinescu et al., 1998). Frizelle and Woodcock (1995) measured manufacturing complexity using mathematical model derived from the logic in algorithmic complexity with the intention to improve operational strategy (Frizelle and Woodcock, 1995). Hence, once complexity was measured, it would aid to develop operational strategy to reduce the complexity. Later, Flynn and Flynn (1999) investigated the relationship of manufacturing environment complexity with manufacturing performance based on Galbraith's (1973) information-processing model. The empirical findings strongly supported Galbraith's (1973) model and suggested that reducing the sources of complexity would lead to the reduction in overall complexity and eventually improve manufacturing performance. In another study, Vachon and Klassen (2002) proposed a two dimensional framework to conceptualise the degree of complexity embedded in a supply chain along two dimensions: technology and information processing. The study set out to investigate the effects of supply chain complexity on delivery performance. Their results showed that increase in complexity especially in product or process complicatedness and uncertainty of management system led to a decrease in delivery performance. In 2009, Borzath *et al.* extended the previous work in manufacturing complexity by Flynn and Flynn (1999).

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Their empirical study found that all complexity adversely impacted plant performance. In short, all the findings above indicated that complexity negatively relate to performance.

METHODOLOGY

Research framework

In this study, the two main variables are operational complexity (OC) and operational performance (OP). OC is the independent variable and OP is the dependent variable. Both variables are modeled as second order constructs. OC consists of two dimensions of complicatedness and uncertainty while OP has four dimensions of cost, delivery, quality and flexibility. The study hypothesized that OC negatively relate to OP (H1). The framework is as shown in Figure-1.

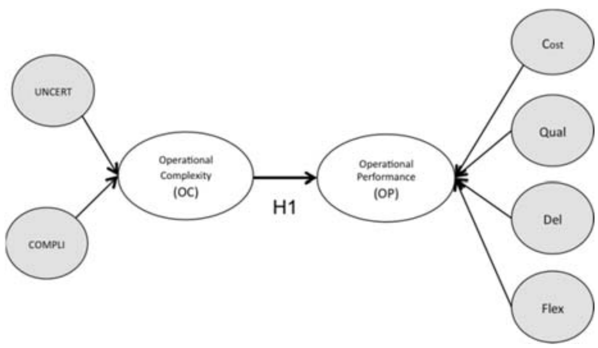

Figure-1. Research framework.

Operationalization of operational complexity

Having reviewed the complexity variables across studies in manufacturing industry and based on the distinct operational characteristics between CM and OEM, OC can be modelled as having two dimensions, which are complicatedness (COMPLI) and uncertainty (UNCERT). The proposed model is adapted from the supply chain complexity model by Vachon and Klassen (2002) as mentioned in the section above. In this study, complicatedness refers to the intensity and variety of components that are present in the manufacturing system including extent of human resource skills and knowledge required (Vachon and Klassen, 2002), (Bozarth *et al.*, 2009). Meanwhile, uncertainty refers to the level of accuracy and predictability of a system outcome including the lack of information or change in information to perform a given task (Vachon and Klassen, 2002).

Operationalization of operational performance

The four dimensions of operational performance can be operationalized as follows: -

- Cost is the expenditure incurred to manufacture a product. It is measured by unit cost of manufacturing. It includes the cycle time from raw material to delivery as well as inventory turnover *(Schroeder et al*., 2002), (Zhang *et al.*, 2012).
- Delivery refers to the sending of product to the customers. It is measured by how often deliveries are made in full on time to the customers and how fast it can be delivered (Zhang *et al.*, 2012), (Terziovski, 2006), (Samson and Terziovski, 1999).
- Quality refers to the conformance of product specification. It is measured by both internal and external performances. Examples of internal quality performance are scrap rate, pass yield. An example of external quality performance is the number of customer complaints (Arumugam *et al.*, 2008), (Fotopoulos and Psomas, 2010).
- Flexibility refers to how fast can the company responds to the request in change of model or volume of production (Schroeder *et al.*, 2002), (Zhang *et al.*, 2012).

Sampling and data collection

The sampling frame for this study was the list of E and E manufacturer in Malaysia. A total of 858 companies were identified based on compilation from the online database of Malaysia External Trade Development Corporation (MATRADE) and directory of Federation of Malaysian Manufacturers (FMM) (MATRADE, 2014), (FMM, 2011). This study has adopted the probability sampling design since the list of E and E manufacturing companies was available. Hence generalisability may be possible (Sekaran, 2007). Disproportionate stratified random sampling technique was used to ensure every state in Malaysia is represented.

Data collections were conducted using a questionnaire which has been pretested and confirmed to be valid and reliable. All the questions are either adopted or adapted from the literature. The development of the questionnaire also included some procedural remedies as suggested by Podsakoff *et al*. (2012) to prevent common method bias. For example, the questions measuring OC were using 7 point scale while those measuring OP were using 5 point scale. The respondents were executives or managers representing the E and E manufacturers. Company was the unit of analysis and data collection method included sending out the questionnaire electronically, through friends and by mail.

Analysis technique

The analysis of the research model which included the testing of hypothesis was carried out using Partial Least Square structural equation modeling (PLS-SEM) technique via a software, smart PLS 2.0 *(Ringle et al.,* 2005). Meanwhile, descriptive statistic and analysis of the profile of respondents were conducted using SPSS version 20. PLS-SEM is favored over other techniques mainly because the data in this study was non normal, both OC and OP were modeled formatively in the second order, sample size obtained was small and the structural model

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was complex. The conditions met the rule of thumb suggested by Hair *et al*. (2014) on when to use PLS-SEM.

RESULTS

A total of 652 questionnaires were distributed and 116 responses were received. However only 111 were usable. The data collection period lasted about five months. The 17.8% response rate was considered as average when compared to previous studies in Malaysia manufacturing industry whereby Shaari (2010) reported the response rate of 18%, Islam and Karim (2011) reported 14.4% and Ahmad *et al*. (2012) reported 21.9%.

Profile of respondents

A fairly distributed data were obtained where 40.6% of the respondents were in the OEM type of business, 34.2% of them were CM and 25.2% consisted of CM cum OEM. Half of the respondents or 53.2% were from foreign own companies, 35.1% were local and 11.7% were joint venture. The majority or 64% of the respondents were large companies with employees of more than 150, while the rest were SMEs. About 90% of the respondents have been in operations for more than 5 years. The types of products in the E and E industry were very diverse and ranged from components to complete products. It can be categorised under electrical or electronics. About 51.4% of the respondents were manufacturers of electronics products, 29.7% were electrical and 18.9% were producing both electrical and electronics products. Finally, majority or 61.3% of the respondents held the position of ‘manager and above’ indicating the relative importance of the survey to the company. This indicated that those who were capable of having the information needed for the survey actually responded to the survey. The profile is summarized in Table-1.

Table-1. Profile of respondents.

Descriptions	Categories	Percentage
Types of businesses	CM	34.2
	OEM	40.6
	CM cum OEM	25.2
Types of ownership	Local	35.1
	Foreign	53.2
	Joint venture	11.7
Number of employees	< 50	18
	51-150	18
	> 150	64
Types of products	Electronics	51.4
	Electrical	29.7
	Electrical and Electronics	18.9
Number of years in operations	1-5 years	9
	> 5 years	91
Position in the company	Owner/Managing Director	8.2
	General manager/ Director	10.8
	Senior Manager/ Manager	42.3
	Senior Executive/ Executive	38.7

Measurement model

The assessment of measurement model was conducted using confirmatory factor analysis (CFA) available in SmartPLS software. First, assessment of first-order constructs consisting of reflective indicators was carried out. Subsequently, assessment of the second-order constructs, which consisted of formative relationship with the first-order constructs, was carried out.

Assessment of first-order constructs

The assessment was to evaluate the reliability, convergent validity and discriminant validity of the scales (Hair *et al.*, 2014). The focus was on the value of loadings of the indicators with first-order construct, value of Average Variance Extracted (AVE), Composite Reliability (CR) for first-order constructs. These values were obtained from the report in SmartPLS under quality criteria. Indicators that did not meet the threshold were deleted and the algorithm was rerun until all the criteria were met. As shown in Table-2, all indicators with loadings of more than 0.708 were retained.

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Table-2. Psychometric properties for first-order constructs.

1st order constructs	Indicators	Loadings	CR	AVE
COMPLI	COMPLI_1	0.669	0.550	0.859
	COMPLI_2	0.683		
	COMPLI_3	0.760		
	COMPLI_4	0.781		
	COMPLI_5	0.807		
UNCERT	UNCERT_1	0.737	0.546	0.783
	UNCERT_4	0.780		
	UNCERT_5	0.698		
Cost	OPC_1	0.826	0.734	0.892
	OPC_2	0.883		
	OPC_3	0.860		
Delivery	OPD_1	0.940	0.878	0.935
	OPD_2	0.934		
Quality	OPQ_1	0.860	0.803	0.891
	OPQ_2	0.932		
Flexibility	OPF_1	0.946	0.903	0.949
	OPF_2	0.955		

Meanwhile, COMPLI_1, COMPLI_2, UNCERT_5 with loadings of 0.669, 0.683 and 0.698 were retained since the AVE and CR values have met the threshold of more than 0.50 and 0.708 (Nunnally and Bernstein, 1994), (Hair et al., 2014). The AVE and CR values for COMPLI were 0.550 and 0.859, and for UNCERT were 0.546 and 0.783. Overall, two indicators were deleted, UNCERT_2 and UNCERT_3. These reflective indicators were deleted because the loadings were less than the required threshold value of more than 0.4 (Hair *et al.*, 2014). In addition, the deletion would not cause the construct to lose its theoretical essence.

In order to assess discriminant validity of the measurement model, the square root of AVEs was calculated. In Table-3, the values highlighted in bold, exceeded the intercorrelations of the construct with other constructs in the model, thus ensuring discriminant validity (Hair *et al.*, 2014). In conclusion, the measurement model for first-order construct was therefore acceptable with evidence of adequate reliability, convergent validity and discriminant validity.

Table-3. Discriminant validity.

	COMPLI	UNCERT	OPC	OPD	OPQ	OPF
COMPLI	**0.742**					
UNCERT	0.528	**0.739**				
OPC	0.358	0.497	**0.857**			
OPD	0.315	0.291	0.537	**0.937**		
OPQ	0.176	0.328	0.531	0.518	**0.896**	
OPF	0.308	0.292	0.417	0.506	0.221	**0.950**

Note: Diagonals represent the square root of AVEs while off-diagonals are correlations between constructs

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Assessment of second order constructs

Formative measurement criteria were used to assess the second-order construct of operational complexity and operational performance. There were three steps in the assessment. First, the validity assessment followed by checking for collinearity issues and finally the significance and relevance of the indicators (Hair *et al.*, 2014). For the first step, the study has adopted the suggestion by MacKenzie *et al*. (2005) that discriminant validity assessment for formative construct be assessed by intercorrelation between the constructs to be less than 0.71. The second step was to verify that all the indicators (in this case, the first-order constructs) did not have high collinearity issues, which could be assessed by VIF value of less than 5.0. The final step was to assess whether all the first-order constructs had significant t value. The validity assessment for operational complexity was based on intercorrelation between COMPLI and UNCERT. Based on Table-3, the intercorrelation was 0.528. As for operational performance, the intercorrelation for OPC and OPD was 0.537, OPC and OPQ was 0.531, OPC and OPF was 0.417, OPD and OPQ was 0.518, OPD and OPF was 0.506, finally OPQ and OPF was 0.221. All the values are less than 0.71 and met the criteria as stated. The assessment results for collinearity and t value are shown in Table-4. There is no collinearity issue for all the construts as the VIF value are less than 5. Meanwhile the results also showed that the construts are significant at 5% when the t values are more than 1.96.

Table-4. Psychometric properties for second-order formative constructs.

2nd order construct	1st order construct	Weights	t value	VIF
OC	COMPLI	0.735	18.918	1.471
	UNCERT	0.393	10.81	1.668
OP	OPC	0.424	15.134	1.926
	OPD	0.329	16.743	1.883
	OPQ	0.254	7.346	1.461
	OPF	0.276	9.011	1.598

Structural model

The structural model consists of the hypothesized relationship between OC and OP. Bootstrapping procedure (500 samples) was used to generate the path coefficient. The results are as shown in Figure-2.

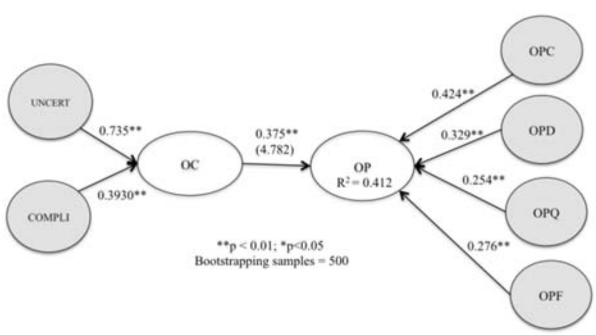

Figure-2. Structural model.

Figure-2 shows all path coefficients (beta value) of the model and the value in parentheses for OC -> OP is the t value. All path are significant at $p<0.01$. The coefficient of determination, R^2 is 0.412 implicating that 41 percent of the variance in OP can be explained by the model. The significant positive relationship between OC -> OP indicated that hypothesis H1 is not supported.

DISCUSSIONS

The results showed that operational complexity, OC has a significant positive effect (path coefficient = 0.375) on operational performance, OP. Contrary to H1, high operational complexity level enhanced operational performance. The finding was surprising because there were consistent findings in the manufacturing literature that complexity inversely affected performance as discussed in the section above. Nevertheless this interesting finding had led to the linking of literature in complexity science, which was drawn from theory in natural sciences. Based on complexity science perspective, the behavior of an organisation can be viewed as a Complex Adaptive System (CAS) (Schwandt, 2009), (Carlisle and McMillan, 2006). CAS was derived from the natural sciences but its findings have many implications in managing organisations (Carlisle and McMillan, 2006), (McKelvey, 1999). In essence, it was about organisations (consist of people) that would adapt to environment change through self organize, learning, experiment and exploration (Carlisle and McMillan, 2006). When an organisation faced change, whether it has to implement new initiatives or sudden unpredictable situations, it would disrupt the normal routine of its operations. Hence, there would be interruptions to the existing system in which complexity would occur (Tsai and Lai, 2010). Based on CAS, those affected would then attempt to self- organize, learn and adapt to the change. The stage where complexity

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occurred was also known as the 'edge of chaos' (Carlisle and McMillan, 2006), (Tsai and Lai, 2010). According to McKelvey (1999), performance was optimum when the organisation was at the stage of 'edge of chaos' where complexity increased with performance. However, the view also suggested when complexity reached a threshold it would turn into the chaotic stage which would affect performance. The relationship was an inverse U shape curve as shown in Figure-3 (Schwandt, 2009), (McKelvey, 1999). The chaotic stage occurred when system behavior could not be predicted (Tsai and Lai, 2010). This implied that when there was a positive relationship between operational complexity and operational performance, the organisation was going through change, self-organisation, learning and adapting. However, if this stage (complexity) was not managed well, it would lead to chaotic condition where performance would be affected drastically.

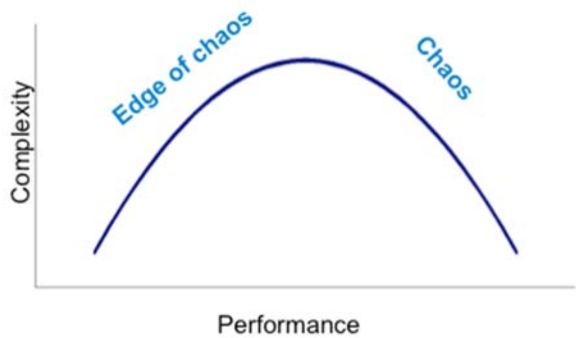

Figure-3. Edge of chaos.

CONCLUSIONS

The result imply that managers should take caution and be aware of an impending chaotic stage, when performance improved with the increased in operational complexity. Therefore, level of complexity still needs to be managed. With this knowledge, managers will be able to take full advantage by surfing at the edge of chaos in the current fast changing business world. Hence, managers especially in Malaysia E and E industry should not be intimidated by complex operations. Instead, they should take up the challenge and continue to learn new skills in managing complexity. Future work may look into specific method of managing complexity that is suitable for Malaysia perspective.

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