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The Structure of Manufacturing Flexibility: Comparison Between UK and Malaysian Manufacturing Firms

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Abstract: This research identified the basic structure of manufacturing flexibility based on literature of previous researches and examined the fitness of this theoretical structure. The identified theoretical structure of manufacturing flexibility consists of four flexibility dimensions: Volume, variety, process and material handling. Data collection from the UK and Malaysian manufacturing firms was conducted to test whether the theoretical structure of manufacturing flexibility was fulfilled. A confirmatory factor analysis was performed and the results showed that the existing structure of manufacturing flexibility fits the theoretical structure. A comparison was made between the UK and Malaysian samples and the results showed that there was no significant difference in the existing structure and they confirmed the theoretical structure. The structure of manufacturing flexibility could be used by both researchers and managers as a framework to clarify the concept of manufacturing flexibility, so that the issue could be better understood and managed.

Key words: Manufacturing flexibility, dimension, measurement, structure, confirmatory factor analysis, UK, Malaysia

INTRODUCTION

Flexibility receives a particular attention by managers in order for manufacturing firms to respond to uncertain external environment. Cumulative effects have been seen in the sector by the changes in customer requirements, global competition and technological advancement. Manufacturing flexibility is usually referred as the ability of manufacturing organisations to manage their resources in order to cope with environmental uncertainties and to be able to produce variability in product outputs. According to Zhang *et al*. (2003) manufacturing flexibility is the ability of the organisation to manage production resource and uncertainty to meet various customer requests.

Many manufacturing flexibility studies have been done in the scope of classification and measurement. Beach *et al*. (2000) give an extensive review of the literature to examine the issues surrounding the concept of manufacturing flexibility, including the taxonomies and measurement of flexibility. Among the early flexibility classification in 1984 consists of eight dimensions of flexibilities. These are machine, process, product, routing, volume, expansion, operation and production flexibility.

The classifications and definitions of the constituent elements of flexibility might use various terms, including types, dimensions and kinds. Taking into consideration this difficulty, Ramasesh (2000) suggests a distinction between manufacturing flexibility types and manufacturing flexibility dimensions. According to him, manufacturing flexibility types refers to a few aggregate broader concepts or the aggregate notions of manufacturing flexibility. Whereas, manufacturing flexibility dimensions applies to a large number of specific, more narrowly defined types of flexibility, or the specific attributes or constituent notions of manufacturing flexibility. Therefore, the discussion in this research will refer to the constituent elements of manufacturing flexibility as manufacturing flexibility dimensions, although various researchers use different terminology.

The measurement of manufacturing flexibility suggested in the literature can be classified into three attributes. First, the number of options or range at a given time (Gerwin, 1993; Upton, 1994; Koste and Malhotra, 1999). Second, the mobility or the ease with which the organisation moves from one state to another (Upton, 1994; Koste and Malhotra, 1999). Mobility attribute uses both time and cost of making changes as an assessment because of the interrelatedness of these two elements. Third, the uniformity or the similarity of performance outcomes within the range (Upton, 1994; Koste and Malhotra, 1999).

This study will identify the most appropriate constituent to be used. The selection of the appropriate flexibility dimensions for this study involves two steps. First, it reviews the examined dimensions from recent research on manufacturing flexibility. Second, it considers

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Table 1: Flexibility dimensions studied in recent empirical research

Flexibility dimensions	Reasons for choosing dimensions	Research
Volume, variety, process and material handling	Parsimonious set of primary dimensions for manufacturing flexibility	D'Souza and Williams (2000)
Machine, labour, mix, new product and modification	Chosen for two primary reasons. First, flexibility dimensions frequently discussed in flexibility research. Second, appear to be most relevant to automotive industry	Koste and Alhotra (2000)
Volume	Key competitive dimension	Jack and Raturi (2002)
Machine, process, product, routing, volume, expansion and layout	Combination of dimensions proposed in literature	Petroni and Bevilacqua (2002)
Machine, labour, material handling, routing, volume and mix	Machine, labour, material handling and routing flexibility represent flexible manufacturing competence. Volume and mix flexibility represent flexible manufacturing capability	Zhang *et al.* (2003)

the constituents that have the most comprehensive definition and measurement, based on work from previous research. To select the flexibility dimensions to be used in this study, recent empirical research involving manufacturing flexibility found in the literature (D'Souza and Williams, 2000; Koste and Malhotra, 2000; Jack and Raturi, 2002; Petroni and Bevilacqua, 2002; Zhang *et al*., 2003) was analysed. The flexibility dimensions and reasons for choosing them are as shown in Table 1.

Four dimensions of flexibility: Volume, variety, process and material handling flexibility, appear to be popular dimensions. According to D'Souza and Williams (2000), they are a parsimonious set of primary dimensions for manufacturing flexibility. One of the dimensions, i.e., volume flexibility, is considered as key in a competitive strategy (Jack and Raturi, 2002). These four dimensions were also among the flexibility dimensions proposed by researchers, as discussed in the previous section. The operationalisation of the four dimensions has been developed by D'Souza and Williams (2000). They used (Gerwin, 1993) taxonomy as the starting point to define the flexibility dimension. For the flexibility measurement, they used Gupta and Somers (1992) research.

The flexibility dimensions suggested by Gerwin (1993) are: Mix, modification, volume, changeover, rerouting, material flexibility and flexibility responsiveness. Mix, modification and volume flexibility are externally-driven flexibility. The uncertainty associated with these dimensions is either from market or customer demand, in terms of product varieties, innovation and quantity. Changeover, rerouting and material are internally-driven flexibility. The uncertainty associated with these dimensions is either from the production input or production environment, in terms of product specification, machine downtime and materials' characteristics.

According to D'Souza and Williams (2000), mix and modification flexibility dimensions represent two perspectives on an underlying dimension that represents the variety of new and existing products that a manufacturing system can produce. In addition, changeover and rerouting flexibility reflect characteristics of the manufacturing process itself and are seen to represent a broader dimension of process flexibility. Regarding flexibility responsiveness, they recommend that this dimension is an element or sub-dimension of all manufacturing flexibility dimensions. Therefore, they suggest that while the flexibility responsiveness dimension is embedded in the other six dimensions, these six can be parsimoniously represented in four: Volume, variety, process and materials handling flexibility. The four flexibility dimensions of volume, variety, process and material handling flexibility are either component flexibilities or system flexibilities, representing primary dimensions, rather than aggregated flexibility or secondary dimensions. At the level of manufacturing function, it is important for the study to focus on the primary dimensions and not cloud the analysis with overlapping secondary dimensions (D'Souza and Williams, 2000).

The selection of the constituent to be used in this study is based on four justifications:

- They are a parsimonious set of primary dimensions for manufacturing flexibility (D'Souza and Williams, 2000)
- Process and material handling flexibility represent internally-driven flexible manufacturing capability
- Volume and variety flexibility represent externally-driven flexible manufacturing capability
- They are among dimensions proposed in literature and frequently discussed in flexibility research.

The suitable manufacturing flexibility constituent comprises four flexibility dimensions. In this study, there are two attributes emphasised as the manufacturing flexibility measurements. The first is the number of range or options at a given time and the second is the mobility or the ease with which the organisation moves from one state to another. These attributes were chosen because they were the most common measurement approach in practice. Gupta and Somers (1992) review of the literature on manufacturing flexibility will be examined to identify and select the suitable measurement representing these two attributes for each dimension of flexibility.

Definition and measurement of four manufacturing flexibility dimensions: The definition of four flexibility dimensions: Volume, variety, process and material handling flexibility will be discussed here.

Volume flexibility: This dimension of flexibility is defined as the ability of the manufacturing system to change the volume or output of a manufacturing process (Sethi and Sethi, 1990). This ability is related to the ability to increase and decrease production to fulfil upward and downward demand quantity required by customers (Gerwin, 1993).

Variety flexibility: This is the ability of the manufacturing system to produce many different products simultaneously and to incorporate new design. Variety flexibility represents mix flexibility and modification flexibility in taxonomy. While, mix flexibility is the ability of the system to produce many different products during the same planning period, modification flexibility is the ability of the system to incorporate design changes into a specific amount (Gerwin, 1993). Other researchers such as Sethi and Sethi (1990) and Upton (1994) regard variety flexibility in other terms, e.g., product flexibility is defined as the ability to change over to produce new products.

Process flexibility: This is the ability of the manufacturing system to adapt to changes in the production process. Examples of changes in the production process are machine breakdowns, changes in the production schedules and changes in the sequence of steps through which the product must progress. This definition suggests that in order to adapt to these changes, there should be alternative routes to produce a part through the system. Process flexibility is comprised of changeover flexibility and rerouting flexibility in (Gerwin, 1993) taxonomy.

Material handling flexibility: Material handling flexibility is the ability of the material handling system to transport different materials between various processing centres over multiple paths (Sethi and Sethi, 1990). Sethi and Sethi (1990) suggest the ratio of the number of paths the material handling system can support to the total number of paths.

The measurement of these four flexibility dimensions is shown in Table 2.

Table 2: Definition and measurement of flexibility dimensions

Flexibility dimension	Flexibility measurement
Volume	We can run a range of production volumes (volume range)
	We can economically increase or decrease our production volume (volume cost)
	We can quickly increase or decrease our production volume (volume time)
Variety	We can produce a wide variety of products simultaneously (Variety range 1)
	We develop new products each year (variety range 2)
	We can economically change from producing one product to another (variety cost)
	We can quickly change from producing one product to another (variety time)
Process	We can use many different routes to produce a part type (process range)
	We can economically change sequence of steps in production process (process cost)
	We can quickly change sequence of steps in production process (process time)
Materials handling	Material handling system can handle different part types (Material handling range 1)
	Material handling system can link different processing centres (material handling range 2)
	Material handling changeovers between parts are economical (material handling cost)
	Material handling changeovers between parts are quick (Material handling time)

MATERIALS AND METHODS

Population and sample: The United Kingdom (UK) and Malaysian electronic and electric manufacturing companies were chosen as a focus for the research. This industry has demonstrated a high degree of market uncertainty in recent years that makes them suitable subjects for the study of manufacturing flexibility achievement (Lau, 1999). The electronics industry in the UK and Malaysia is recognised as among the most important industries (Driffield and Girma, 2003; Ismail, 2001). The selection of a population representing the UK manufacturing firms was done by using the Financial Analysis Made Easy (FAME) database. For Malaysia, the researchers had to produce a company list from various databases included Standards and Industrial Research Institute of Malaysia (SIRIM) 1999 database, The Federation of Malaysian Manufacturers (FMM) online directory, Malaysia Manufacturers online and Malaysia Business online directory.

The UK sample was obtained by identifying firms that fall into three Standard Industrial Classification (SIC) codes: SIC 2971 (electric domestic appliances), SIC 3162 (other electrical equipment not elsewhere classified) and SIC 3230 (TV and radio receivers). With regard to the Malaysian sample, the researchers needed to find manufacturing companies that fall under the electrical and electronic category. Stratified random sampling was used as the sampling design for both populations. The underlying idea in using the stratified random sampling is due to its available information on the population and to divide it into groups, such that the elements within each group are more alike than are the elements in the population as a whole. In this technique, the UK sampling frame is divided into three groups according to the manufacturing industry, namely SIC 2971, SIC 3230 and SIC 3162. As suggested by de Vaus (1996), this sampling frame has already been divided into three strata. For consistency, the same strata system is applied to the Malaysian sampling design.

Survey procedures and responses: Since the study involves two countries, the UK and Malaysia, the survey started with data collection from the UK companies, followed by the Malaysian companies. For the UK part, the process went through three data collection phases. The first phase involved pilot study. Fifty companies were taken from the UK sampling list. The questionnaire was addressed to the production manager. Six responses were received after one month. Slight modifications were made to the questionnaire, mainly in the background information section. The second phase was on a larger scale, 550 amended questionnaires were distributed. The data collection in Malaysia was done by one of the researchers in person. The same set of questionnaires was used as in the UK. Though Malay is the national language in Malaysia, English is very widely used, especially in private firms. The process in Malaysia, which took a month, was divided into two phases. The first phase involved 400 Malaysian manufacturing companies. The second phase involved distribution of a follow-up letter, followed by redistribution of questionnaires to non-replying companies. According to de Vaus (1996), a common way of calculating the response rate is with the formula:

$$\text{Response rate} = \frac{\text{No. of returned}}{\text{N in sample} - (\text{Ineligible} + \text{Unreachable})} \times 100$$

Using the formula, the response rate is 18.51% for the UK sample, whereas, 19.75% for the Malaysian sample. The Malaysian sample's response rate is slightly better than the response rate in the UK. The data collection process in the UK involved 600 companies and was able to collect 105 usable responses. Meanwhile, the Malaysian survey involved 400 companies and was able to collect 78 usable responses. The sizes of UK and Malaysian samples are reasonable to make a comparison study. More companies have been involved in the UK sample due to the fact that the size of the electronic and electric sector is bigger in the UK than in Malaysia.

Confirmatory factor analysis (CFA): CFA uses structural equation modelling that allows for a statistical test of the goodness-of-fit for the proposed confirmatory factor solution (Hair *et al*., 1995). AMOS 5.0 (Arbuckle and Wothke, 1999), a program for structural Eq. modeling techniques, was used to evaluate how well the specified models adequately described the data and to examine the significant difference in the model pattern across two samples. According to Schumacker and Lomax (1996), a given model is properly specified if the true model, the one that generated the data, is considered consistent with the given model. The difference between the given and true model may be due to errors of omission and/or inclusion of any variable or parameter. There are a number of procedures available for the detection of specification errors, so that modification can be made to find a more properly specified subsequent model. The procedures include examining modification indices and parameter change that represent an improvement over the first-order partial derivatives (Schumacker and Lomax, 1996; Sharma, 1996; Loehlin, 1998).

Given the significant lack of consensus present in the literature for preferred indices of fit (MacCallum *et al*., 1996; Arbuckle and Wothke, 1999) it was decided that χ^2 and multiple goodness-of-fit indices would be used to assess model fit (Sharma, 1996). The indices used included the χ^2 to df ratio, the goodness-of-fit index (GFI), the adjusted goodness-of-fit index (AGFI), the relative goodness-of-fit index (RGFI), the relative adjusted goodness-of-fit index (RAGFI) and the root mean square error of approximation (RMSEA).

The likelihood-ratio Chi-squared statistic (χ^2) is the most fundamental measure of overall fit, but it is too sensitive to sample size differences, especially with more than 200 cases (Hair *et al*., 1995). Therefore, Marsh *et al*. (1996) have suggested the use of χ^2/df ratio as a measure of fit, that represents the minimum discrepancy divided by its degrees of freedom. GFI is the squared residuals from prediction compared with the actual data, which represents the overall degree of fit and the value ranges from 0 (poor fit) to 1.0 (perfect fit) (Hair *et al*., 1995). AGFI is an extension of the GFI, adjusted by the ratio of degrees of freedom for the proposed model to the degrees of freedom for the null model. RMSEA is the square root of the mean of the square residuals between observed and estimated input matrices of the population approximation. It represents the goodness-of-fit that could be expected if the model were estimated in the population, not just the sample drawn for the estimation (Hair *et al*., 1995).

According to Sharma (1996), GFI and AGFI are affected by sample size and the number of observed variables. Maiti and Mukherjee (1990) have derived the approximate sampling distribution for GFI under the assumption that the null hypothesis is true. See Sharma (1996) for the approximate expected value for GFI and AGFI. Sharma (1996) suggests researchers use a relative goodness-of-fit index (RGFI) and relative adjusted goodness-of-fit index (RAGFI).

RESULTS AND DISCUSSION

Table 3 shows the result of demographic analysis. The principal products manufactured by the participating organisations in this study include electrical equipment, electronic components, home appliances and communication equipment. Table 3 shows the breakdown of the participating manufacturing organisations by the number of employees, which might indicate the organisation size. In the UK sample, many participating organisations (41.90%) were reported in the third category, i.e., organisation with number of employees from 100 to 249. In the Malaysian sample, the distribution is more scattered across the six categories. The percentage of participating organisations with more than 500 employees is higher in the Malaysian sample (39.74%) than in the UK sample (13.33%).

The manufacturing flexibility structure was initially tested on the UK sample. The size in this sample is slightly bigger than the Malaysian one, therefore, the test to identify the well-fitted structure was based on the UK sample. A single sample is used because the comparison (using multiple samples) in the second objective requires a well-fitted model based on one of the samples, which will serve as the basis for the comparison.

Manufacturing flexibility is hypothesised as a four-factor model consisting of three to four indicator variables (Table 2). (1) volume flexibility: volume range, volume cost and volume time. (2) variety flexibility: variety range1, variety range 2, variety cost and variety time. (3) process flexibility: process range, process cost and process time. (4) material handling flexibility: material handling range 1, material handling range 2, material handling cost and material handling time.

The assumptions of confirmatory factor analysis involve multivariate normality and absence of outliers. AMOS provides the normality assessment by presenting the skewness and kurtosis measurements for each item. Absolute skewness values of above 1.00 suggest the presence of univariate and multivariate non-normality (Hair *et al*., 1995). Skewness values ranged from -1.16 to -0.19 and -1.48 to 0.14, for each of the UK and Malaysian samples. Multivariate normality and outliers were evaluated using the square Mahalanobis distance for all cases, by comparing the maximum value to a critical value (Pallant, 2001). This resulted in 8 cases with values in excess of critical value being deleted from each of UK and Malaysian sample data.

As mentioned previously, the fitness of the hypothesised four-factor model will be assessed using the χ^2, df, χ^2/df ratio, GFI, RGFI, AGFI, RAGFI and RMSEA statistics. The results for the models and the suggested optimal values are presented in Table 4. The results indicate that the hypothesised model for UK sample, which comprises four flexibility dimensions, was reasonably fit for the data but should be modified. The statistics are: χ^2 (df = 71, n = 97) = 186.169,

Table 3: Background analysis of manufacturing organizations with No. of employs on UK and Malaysia

	UK		Malaysia	
Principal product	Frequency	%	Frequency	%
Electrical equipment	30	28.57	14	17.95
Electronic components	8	7.62	17	21.79
Home appliances	15	14.29	3	3.85
Communication equipment	13	12.38	9	11.54
Automotive industry equipment	10	9.52	10	12.82
Office equipment and computers	10	9.52	5	6.41
Electrical components	7	6.67	8	10.26
TV and radio	6	5.71	8	10.26
Other	6	5.71	4	5.13
Total	105	100.00	78	100.00
No. of employees				
1-49	14	13.33	6	7.69
50-99	18	17.14	5	6.41
100-249	44	41.90	19	24.36
250-499	15	14.29	17	21.79
500-1000	10	9.52	14	17.95
More than 1000	4	3.81	17	21.79
Total	105	100.00	78	100.00

Table 4: Summary of Goodness-of-Fit indices

Model	χ^2	df	χ^2/df	GFI	RGFI	AGFI	RAGFI	RMSEA
Optimal	-	-	<3.0[a]	>0.90[b]	>0.90[b]	>0.80[b]	>0.80[b]	<1.0[c]
UK sample								
Hypothesised four-factor model	186.169	71	2.622	0.808	0.892	0.716	0.833	0.125
Respecified model	111.347	66	1.687	0.880	0.966	0.809	0.942	0.081
UK and Malaysian samples								
Respecified model	183.060	66	2.774	0.881	0.931	0.811	0.886	0.099

[a]Carmines and McIver (1981), [b]Sharma (1996), [c]Browne and Cudeck (1993)

Table 5: Modification indices

Covariances[a]	Modification indices (MI)	Parameter change (ParC)
e_4 and e_1	18.630	0.556
e_{12} and e_{11}	22.371	0.391
e_9 and e_{14}	9.095	-0.168
e_{10} and e_{14}	11.708	0.202
e_8 and e_1	8.500	0.518
e_8 and e_4	11.562	0.557

[a]represents error term of the item, e.g. e 4 is error term for item 4

χ^2/df ratio = 2.622, GFI = 0.808, RGFI = 0.892, AGFI = 0.716, RAGFI = 0.833 and RMSEA = 0.125. A close examination of the standardised residual covariance matrix and the modification indices was made in examining misspecification, so that specified subsequent models may be evaluated by Schumacker and Lomax (1996).

Model respecification and results: The modification procedure was performed. The aim is to modify the original model in the search for a model that is 'best fitting' in some sense and yields parameters having practical significance and substantive meaning (Schumacker and Lomax, 1996). It revealed large covariances between six pairs of error terms. The modification indices (MI) and parameter change (ParC) are given in Table 5.

Any model modification or respecification should be well grounded in theory (MacCallum *et al*., 1996; Sharma, 1996), hence, no modification will be made regarding the third covariance, as it is not theoretically justified. The model will be modified by including covariances between five pairs of error terms from the original model. According to Aish and Jöreskog (1990), measurement error covariances may derive from characteristics of either the items in question or the respondents. For example, error term correlations between two items may indicate item content redundancy, that they measure the same concept (Simon and Tovar, 2004). In examining Material Handling range 1 (ability of the material handling system to handle different part types) and Material Handling range 2 (ability of the material handling system to link different processing centres), it was clear they were attempting to measure the range of material handling. e_{11} and e_{12} represent the error term of Material Handling range 1 and Material Handling range 2, respectively. Therefore, the high correlation between e_{11} and e_{12} implies item content redundancy between material handling range 1 and Material Handling range 2. The theoretical considerations guiding the other 4 error correlations are based on the fact that the 4 flexibility dimensions were measured using two attributes: Range and mobility.

Post hoc model adjustments were made in order to develop a better fitting model. Modification was based on five covariances in the hypothesised model. The results show reasonable and statistical model fit over Model 1, χ^2 (df = 66, n = 97) = 111.347, χ^2/df ratio = 1.687, GFI = 0.880, RGFI = 0.966, AGFI = 0.809, RAGFI = 0.942 and RMSEA = 0.081. Before examining the sample difference in the respecified model, the model was evaluated using both the UK and Malaysian samples to examine if a bigger sample size impacts on the model fitness. The results indicate that the respecified model, was a fairly good fit for the data: χ^2 (df = 66, n = 167) = 183.060, χ^2/df ratio = 2.774, GFI = 0.881, RGFI = 0.931, AGFI = 0.811, RAGFI = 0.886 and RMSEA = 0.099.

Equality of factor structure across UK and Malaysian samples: The results for multiple group analysis to identify the structure equality are presented in Table 6.

They indicate that both unrestricted and equal loadings models fit the data fairly well. The statistics for unrestricted loadings are: χ^2 (df = 132, n = 167) = 338.838, χ^2/df ratio = 2.567, GFI = 0.799, RGFI = 0.880, AGFI = 0.681, RAGFI = 0.807 and RMSEA = 0.097. The second model of equal loadings produces these statistics: χ^2 (df = 142, n = 167) = 351.367, χ^2/df ratio = 2.474, GFI = 0.795, RGFI = 0.910, AGFI = 0.696, RAGFI = 0.827 and RMSEA = 0.095. The more restricted equal loadings model fits the data slightly better than the original model, in which the factor loadings are allowed to vary across the UK and Malaysian samples. The model comparison test to compare the sample difference is shown in Table 7.

The results from this model comparison [χ^2 (df = 10, n = 167) = 12.529, sig. = 0.251] suggest that imposing the additional restrictions of four equal factor loadings across the two samples of manufacturing firms did not result in a statistically significant worsening of overall model fit. Therefore, there is no significant difference in the factor structure of manufacturing flexibility between the UK and Malaysian samples.

Table 6: Equality of structure results

Model	χ^2	df	χ^2/df	GFI	RGFI	AGFI	RAGFI	RMSEA
Unrestricted loadings	338.838	132	2.567	0.799	0.88	0.681	0.807	0.097
Equal loadings	351.367	142	2.474	0.795	0.91	0.696	0.827	0.095

Table 7: Nested model comparison statistics

Model	df	χ^2	Sig.
Equal loadings	10	12.529	0.251

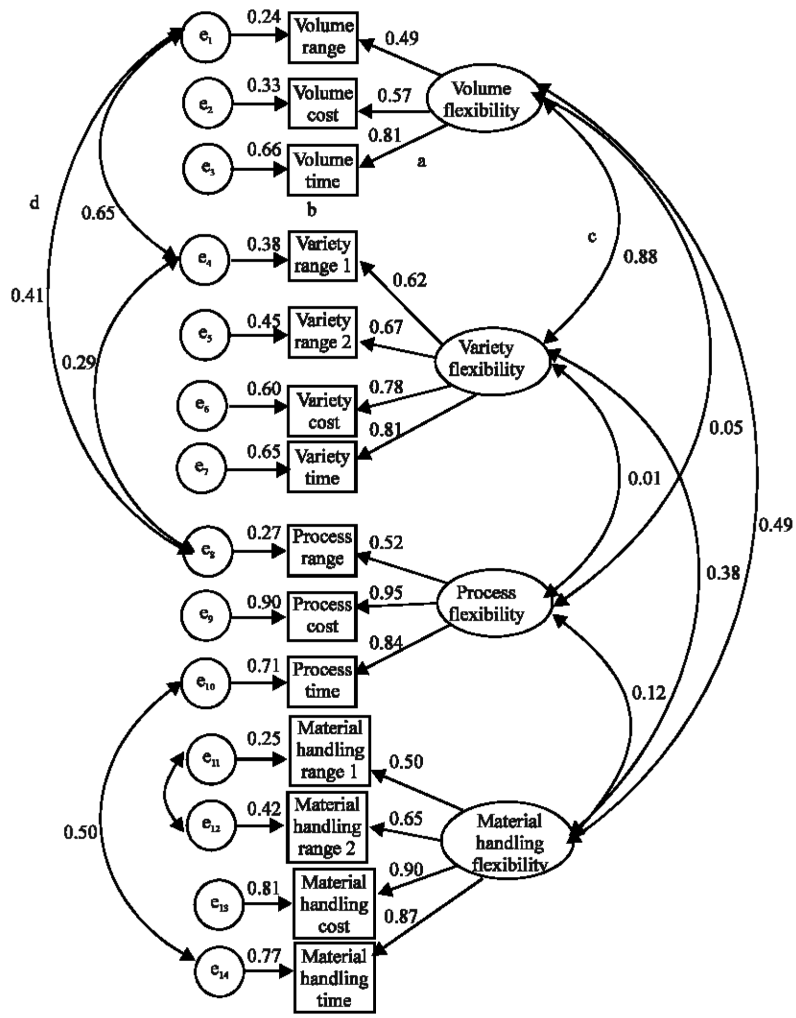

Fig. 1: Equal loadings standardised estimation for UK Sample. (a) standard item loading, (b) multiple correlation, (c) correlation between construct and (d) correlation between error

The final model for each sample, including standardised item loadings, squared multiple correlations, correlation value between constructs and correlation value between error terms are shown in Fig. 1 and 2. The factor loadings indicate they are reasonably and statistically significant. In the UK sample, standardised items loadings (as loadings in exploratory factor analysis) range from 0.49 to 0.81 for volume flexibility, 0.62 to 0.81 for variety flexibility, 0.52 to 0.95 for process flexibility and 0.50 to 0.90 for material handling flexibility. The loadings range from 0.40 to 0.68 for volume flexibility, 0.56 to 0.80 for variety flexibility, 0.69 to 0.96 for process flexibility and 0.51 to 0.98 for material handling flexibility, in the Malaysian s ample. The squared multiple correlations

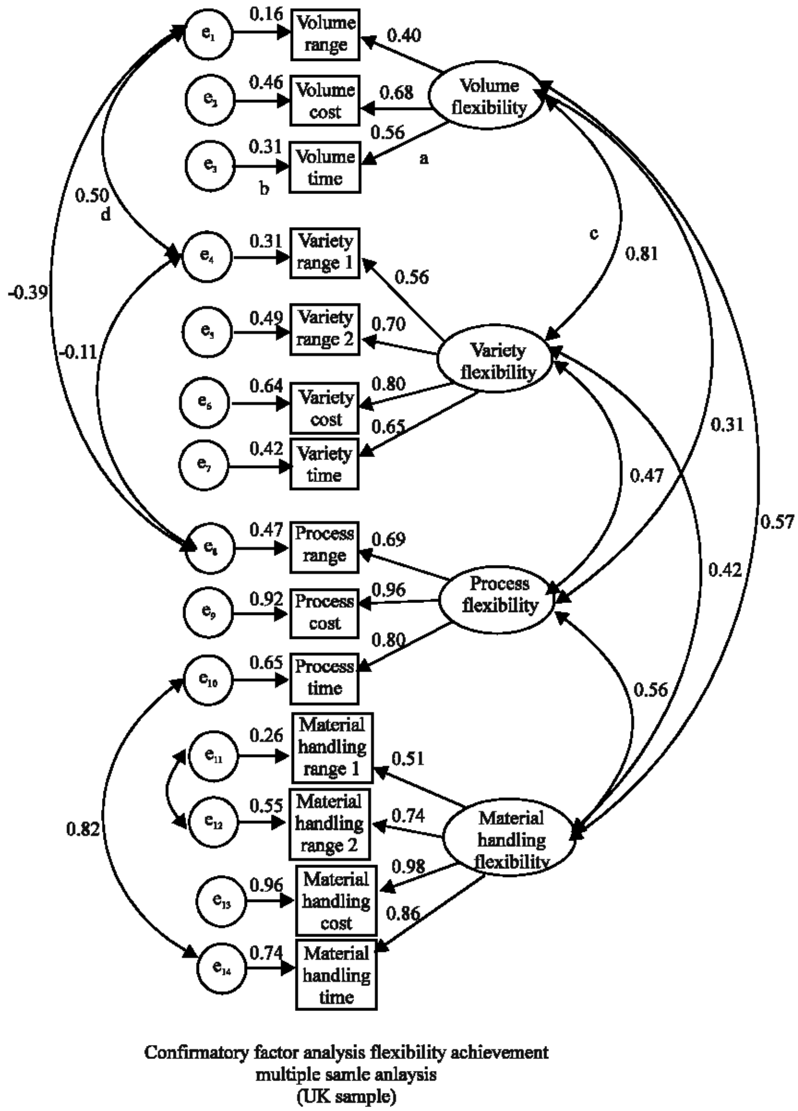

Fig. 2: Equal loadings standardised estimations for Malaysian sample. (a) standard item loading, (b) multiple correlation, (c) correlation between construct and (d) correlation between error

(as R^2 in regression analysis) represent the percentage of variance explained by each observed variable (Holmes-Smith and Rowe, 1994). In the UK sample, only three out of fourteen observed variables show values below 0.30 (less than 30% of the variance is explained by that variable): Volume range, process range and material handling range 1. Consistently, volume range and material handling range 1 show low values in the Malaysian sample. Therefore, for most of the observed variables, a high percentage of the variance is explained by them.

Three pairs of manufacturing flexibility achievement constructs were found to be significantly correlated (as correlation value in correlation analysis) in the UK sample, between volume and variety (high correlation), variety and material handling (moderate correlation) and volume and material handling flexibility (moderate correlation). Except for the correlation between volume and process flexibility, all pairs of manufacturing flexibility achievement constructs were found to be significantly correlated in the Malaysian sample. Three pairs, between volume and variety, variety and process and volume and material handling flexibility indicate high correlation. The other two, between variety and process and variety and material handling flexibility signify moderate correlation. All the considered correlations between error terms were found significant in the UK sample. The correlation values range from 0.29 to 0.56 and indicate moderate to strong correlation between error terms. In the Malaysian sample, correlations between e_4 and e_8 and e_{11} and e_{12} indicate insignificant estimation. The values for significant correlations range from -0.39 to 0.82 and also indicate moderate to strong correlation between error terms.

As shown in Fig. 1 and 2, all observed variables except volume range (factor loading of 0.49) have factor loading above 0.50 in the UK sample. Similarly, volume range is the only observed variable with factor loading below 0.50 (exactly 0.40) in the Malaysian sample. According to Garson (2004), a finding that observed variables have high loadings on the predicted factors indicates convergent validity. In general, the values signify convergent validity for the data. The correlation values for manufacturing flexibility achievement constructs were shown in Fig. 1 and 2. Regarding volume and variety constructs, their high correlation in both samples may indicate that the managers in these samples did not distinguish volume from variety flexibility achievement. This may mean that they feel their volume flexibility levels are constrained and tied by variety flexibility achievement and vice-versa. This also might mean that volume and variety flexibility represent one construct, as the finding leads the researcher to think the two factors overlap conceptually. As suggested by Peláez and Ruiz (2001), the level of volume and variety flexibility can be measured in an integrated way. The researchers believed that the integration is supported by the relationship existing between them (Boyer and Pagell, 2000). In any regard, the linkage of the constructs suggests a need for research on whether production managers see them as an integrated concept or a separated one.

Significant correlations between volume and material handling and variety and material handling flexibility, were also found in both samples. As regards volume and material handling flexibility, this means that the achievement of material handling flexibility and volume flexibility are related. Insufficient consideration of the material handling system, according to Hutchinson (1991), can constrain the benefits of flexible manufacturing systems in terms of product variety and production volume. Flexible material handling is required to prevent paths from becoming bottlenecks which starve downstream stations. Consistently, Sethi and Sethi (1990) argue that variety flexibility depends on various factors, including material handling flexibility. From these arguments, it is also expected to find a significant correlation between variety and material handling flexibility in both samples.

Significant correlations between variety and process and process and material handling flexibility were found in the Malaysian sample, but not in the UK one. Variety flexibility, according to Sethi and Sethi (1990), depends on process flexibility. In addition, process flexibility of a system derives from the flexibility of the material handling system composing the system (Sethi and Sethi, 1990). The difference in the finding might be due to different organisational characteristics in the samples. The percentage of large organisations is higher in the Malaysian than in the UK sample. Larger organisations are more likely to invest in technology and automation, including machine and material handling systems. One significant benefit of increasing the degree of automation in process technology is reducing variability in the operation (Slack *et al*., 1995). The availability of a flexible material system in these organisations improves process flexibility and, consequently, variety flexibility. No significant correlation was found between volume and process flexibility. This finding, according to Hair *et al*. (1995) indicates that there may be weak support at best only at the 0.10 significance level in the Malaysian sample) for believing that volume and process flexibility are correlated. The finding might suggest that the relationship between volume and process flexibility is not as strong and significant as, for example, between volume and variety flexibility.

As discussed earlier, the re-specified model considers the covariance between five pairs of error terms. As a result, the final model displays five correlations between error terms. The justifications for inclusion were based on item content redundancy and the use of standardised range and mobility attributes in measuring flexibility achievement. The correlation between errors e_{12} and e_{11} reflects the content redundancy in the two items in measuring the range of material handling. The correlations between errors e_4 and e_1, e_8 and e_1 and e_8 and e_4 reflect the relationship between the two items representing different flexibility dimensions but using the same measure for range attribute. Similarly, the correlation between errors e_{10} and e_{14} reflects the commonality between two items in using the same measure for mobility attribute (time). The significant negative correlation between errors e_1 and e_8 in the Malaysian sample is an interesting finding which needs closer examination. This might mean that the variance due to volume and process range has an inverse relationship. Many of the relationships between variables found in the confirmatory factor analysis suggest further examination in future research.

CONCLUSIONS

Confirmatory factor analysis was conducted in this study with two aims. First, to test the hypothesis corresponding to prior theoretical notions of the manufacturing flexibility structure and second, to examine the equality of factor pattern matrices across the UK and Malaysian samples. The proposed four-flexibility-dimensions model of manufacturing flexibility achievement consisting of 14 indicator variables reasonably fits the data from a sample of the UK manufacturing firms. The flexibility dimensions were volume, variety, process and material handling. A respecified model which allows five pairs of error terms to covariate was proposed as a better fitting model for the UK sample. The model also gave a reasonably good fit for the data from both UK and Malaysian samples. The relative goodness of fit indices were also used besides the conventional indices of GFI and AGFI, due to the influence of sample size and the number of observed variables on the fitness measures (Sharma, 1996).

The results suggest that it was appropriate to presume manufacturing flexibility achievement behind these four flexibility dimensions. This finding provides empirical evidence that the parsimonious set of primary dimensions for manufacturing flexibility developed by D'Souza and Williams (2000) are reliable and valid for determining the achievement of flexibility. The finding is important in the study because the flexibility dimensions were used in Regression Analysis as independent variables, to examine the contribution of management initiatives to flexibility achievement in the UK and Malaysia.

A model comparison test was conducted to examine the factor structure of manufacturing flexibility achievement in the UK and Malaysian samples. The result suggests no significant difference between the samples in the fit of the identified model to the data. Therefore the factor structure of manufacturing flexibility between the UK and Malaysian samples is equal. This finding lends some support that the proposed four-flexibility-dimensions model of manufacturing flexibility achievement is valid and reliable across the two samples (Schumacker and Lomax, 1996). This finding also provides evidence for replication in two samples (May, 1997) as the model was consistent in both the UK and Malaysian samples. The structure of manufacturing flexibility could be applied by both researchers and managers as a global framework to clarify the concept of manufacturing flexibility in order to help them understand and manage the important competitive weapon in the market.

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