Application of hybrid structural interaction matrix to quality management

S.A. Oke*

Department of Mechanical Engineering,
University of Lagos,
Lagos, Nigeria
E-mail: sa_oke@yahoo.com
*Corresponding author

M.K.O. Ayomoh

Department of Systems Engineering,
University of Lagos,
Lagos, Nigeria
E-mail: mikeayomoh@yahoo.com

O.G. Akanbi and F.A. Oyawale

Department of Industrial and Production Engineering,
University of Ibadan,
Ibadan, Nigeria
E-mail: engrakanbi@yahoo.com
E-mail: festwale@yahoo.com

Abstract: This paper applies the concept of Hybrid Structural Interaction Matrix (HSIM) to the management of quality in a manufacturing organisation. The application is motivated by the need to evolve alternative prioritisation tools in quality management. A process, which could be used to analyse a specific situation, was presented by showing how Structural Interaction Matrix (SIM) and Hierarchical Tree Structure Diagram (HTSD) could be used to create a model. The result indicates the feasibility of applying the model in a specific situation in some useful insight into the problem solution. This research has serious implications for management in manufacturing organisation in that it saves tremendous energy and cost that could be expended on alternative prioritisation techniques due to minimisation of time expended in seeking expert of opinion on the issue. This paper is new in that it shows a new dimension about thinking on quality management..

Keywords: Hybrid Structural Interaction Matrix; HSIM; quality management; decision sciences; manufacturing organisation; prioritisation; structured approach.

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Biographical notes: S.A. Oke graduated in Industrial Engineering from the University of Ibadan, Nigeria, with Bachelor and Master's degrees in 1989 and 1992, respectively. He worked for the IDM Services Limited as a Consultant. He presently Lectures in the Department of Mechanical Engineering, University of Lagos and has also reviewed papers for international journals.

M.K.O. Ayomoh is a Lecturer in the Department of Systems Engineering, University of Lagos, Nigeria. His research interests include manufacturing system investigation.

O.G. Akanbi is a BS, an MS and an MBA. He is a Former General Manager of a Manufacturing Plant in Ibadan. Lectures in the Department of Industrial and Production Engineering, University of Ibadan and has published extensively.

F.A. Oyawale is a BS, MS (Western Michigan) and a PhD (Benin). He is a Member of the Nigerian Institute of Industrial Engineers. He is also a registered Engineer and specialises in Production Engineering. Currently, he is the Post-graduate coordinator in the Department of Industrial and Production Engineering, University of Ibadan. He has published books for undergraduate courses. He has several years of teaching and research experience.

1 Introduction

Over the past few decades, quality has become very significant in production systems since enormous pressure is placed on businesses to achieve efficiency and effectiveness (Ahire et al., 1996; Patti et al., 2001). Quality has been extended from the production floor to service systems in such areas as maintenance, marketing, purchasing, project management and environment (Karatzas et al., 2003; Lillrank and Kujala, 2006; Pramod et al., 2007; Tat and Jantan, 2006). However, improvement methodologies such as fuzzy logic, neural networks, artificial intelligence, information management, etc. have also been integrated into the quality paradigm (Flynn et al., 1994; Mahapatra and Khan, 2007). With the proper application of quality, organisation have been able to achieve improvement in the delivery service of products, shorter lead-times, perfect quality and reliability of products, lesser price, greater flexibility, better communication, greater manufacturing control and better coordination with suppliers and customers (Beatty, 2006; Middleton et al., 2007; Oakland and Tanner, 2006; Reid, 2006; Zailani et al., 2007).

Quality expresses the underlying attributes of a production system in terms of quality of material usage, the skill competency and the know-how of its technical staff, the efficient layout of its production system, energy availability and usage, fund availability and its disbursement and the quality of information that is available to the system all the time. The perfection in product quality is revealed in such diverse phenomena as:

1 the level of quality assurance of the product

2 degree of attainment of zero defect quality level.

While most researchers have concentrated on the traditional perspectives of quality, a new host of variables exists to which quality could relate. One of these variables is goal programming. Goal programming is not a new star, but new in its applied form in the concept of quality. A survey of the quality literature within the field of quality management establishes that there are virtually no references to the phenomenon that is subject of this paper (Saraph et al., 1989). Studies on quality in totality gives a comprehensive understanding of all aspects of the system thus, we advocate an integration of the existing methodologies to our current approach.

The structure of this paper is as follows: Introduction, the Goal Programming Quality Management (GPQM) paradigm, the Hybrid Structural Interaction Matrix (HSIM) matrix, prioritising the Quality Management Factors (QMFs), model formulation, case example, conclusion and future directions. The introduction provides the motivation to understanding the subject of this paper. This is supported with references to justify the research. Section 2, the GPQM paradigm, explores the GPQM. Section 3, the HSIM matrix, discusses the supporting structure for HSIM. In Section 4, the framework for prioritising the QMFs is discussed. Section 5 focuses on the model formulation, which integrates Sections 2–4. Section 6 discusses a case example. In Section 7, the concluding remarks and future directions are given.

2 The GPQM paradigm

The GPQM paradigm refers to a framework that explains the structure of the GPQM technique that is developed based on goal programming principles. This refers to a multiobjective structure that combines various attributes of the system into a whole. This is the basis for the development of the GPQM wheel. The various factors have interacting behaviours. The holistic presentation of the GPQM wheel makes the focus of this study achieve a concise and practically-useful structure. The model structure on which the GPQM hinges could be visualised as consisting some 13 factors (see Figure 1). The importance and the impact of each factor on the production system are as follows:

1 *Quality of raw materials*: the quality of the raw materials for production determines the quality of the finished product; low quality raw materials have high potentials of producing low quality finished goods and vice-versa.

2 *Technical know-how of workers*: the ability of the workers to take qualitative decisions during production, decide on real technical issues of high level risk, project likely production mishap, etc. depends largely on their professionalism. Low technical skilled workers are liabilities to the management of a company while highly skilled workers are assets.

3 *Facility layout of production system*: poorly-laid production facilities may result in leap-frogging of the production process that is, skipping off some vital processes required to enhance quality due to job fatigue, boredom and low working morale hence, limiting the quality of the end product. A poor layout of facilities is usually associated with processing delays that should be avoided. It may also result in accidents.

4 *Production process*: the steps involved in production and the types of technology adopted add or reduce the quality of the finished products. While a standardised production process has a high potential to improve on the final product of a low quality raw material, an obsolete production process results in poor quality products.

5 *Equipment type in use*: the equipment in use has a significant role to play in determining the eventual quality of the product. Low quality equipment produces low quality products while qualitative production equipment assists the workers through technological advancement.

6 *Energy availability*: energy is important in production systems since its availability encourages automation in production. Products with high level of precision need to be processed with automated systems, which requires energy availability. Some raw materials can be processed only at certain temperatures either extremely higher or lower than the room temperature.

7 *Manpower availability*: technology has not completely eliminated man from the production process despite its sophistication. Enough capable hands are needed to carry out maintenance of the production machines, carryout inspection on product quality, operate machine and monitor the production process with the utmost objective of enhancing the quality of the final product.

8 *Staff training programme*: there may not be skill acquisition without periodic organisation of staff training programmes. All class of workers stand to benefit each time a training programme is organised. This factor is indirectly related to improving the technical know-how of crafts. It may help in stimulating new quality improvement ideas, creates confidence and gives a sense of professionalism to the workers with an utmost goal of improving product quality.

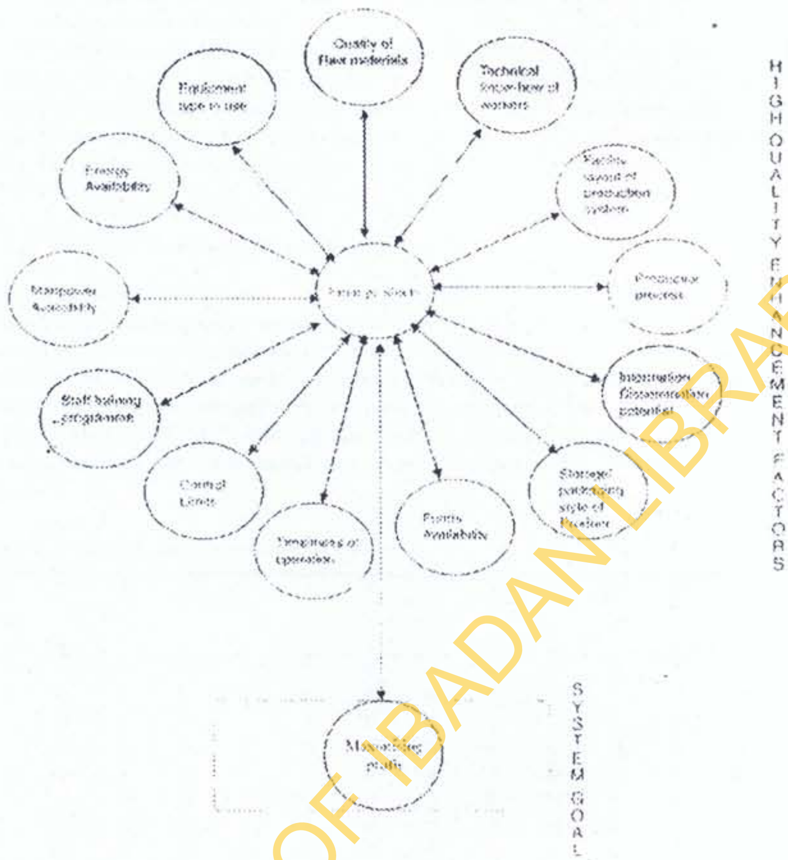
9 *Product quality control limits*: every product has standards and specifications to ensure better quality. The extent of deviation of a product from these standard may have a significant effect on its quality. The control limits are described respectively as upper and lower control limits. Outside this, a product is considered defective.

10 *Fund availability*: without an adequate disbursement of fund, the concept of quality may remain a mirage. Barely all the factors discussed so far, requires fund to be executed. With all technicalities in place, quality attainment may remain impossible without proper funding. Fund availability is the heart of qualitative operation.

11 *Storage/packaging style of product*: high quality finished product may soon begin to deteriorate if the method of packaging or preservation is bad. To sustain quality, packaging and storage must be properly assessed and convincingly accepted.

12 *Information dissemination potential*: the efficiency with which information is disseminated or reports made within a production system could make or mar the desired product quality. The flow of information from the management (supervisors) to the subordinates (crafts) or vice versa, if not properly coordinated could deter quality attainment.

Figure 1 GPQM wheel



3 The hybrid structural interaction matrix

This is a matrix that helps in relating one factor to the other. The problem of prioritising factors has been approached using a number of research methods. This section presents a methodology termed the Structural Interaction Matrix (SIM) that incorporates the Hierarchical Tree Structure Diagram (HTSD) (Ayomoh and Oke, 2006; Oke and Ayomoh, 2005). Given a set of elements in a system, we may be interested in the interaction among them. Here, we develop a matrix that considers all elements for pairwise comparison. A given element pair may interact in several ways. However, only an interaction according to some particular contextual relationships is relevant to the problem under consideration. Contextual relations often consider an orientation that exists among factors influencing a system of study. A matrix, called SIM, could be used since it has orientation and direction association with it. Then, we have a subordination matrix in which a special form of transitivity is present such that if $e_{ij} = 1$, then of necessity $e_{ji} = 0$. If there is a relevant interaction between elements i and j, then there cannot be a relevant interaction between elements j and i. The subordination matrix may therefore represent an hierarchy.

The contextual relationship used to develop the SIM is thus: 'does QMF i depend on $(QMF)_j$ for its actualisation?' In another form it goes thus; 'is element i subordinate to element j?' A response of 'no' by the decision maker after a pairwise relation attracts a '0' in the specified elemental space while a 'yes' attracts a '1' in the specified elemental space. The contextual relation mathematically could be written as thus:

$$e_{ij} = \begin{cases} 1 \text{ if } i \text{ is subordinate to } j \\ 0 \text{ if } i \text{ is not subordinate to } j \end{cases}$$

It should be noted that $e_{ji} \neq e_{ji}$.

HTSD is used to display the prioritisation order of a set of components or factors in a hierarchical manner. It relies on the results obtained from (SIM) and is described as a tree since its structure is such that line segments or edges join a set of elements or vertices. There can be one and only one path between every pair of vertices.

The structure of SIM showing the pairwise comparison of the QMFs (Table 1). We also showed the hierarchical tree structure diagram for the problem at hand in Figure 4.

Table 1 HSIM pairwise comparison framework

i \ j	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
1	0	1	0	0	0	0	0	1	0	0	1	0	0
2	0	0	0	0	0	0	0	1	0	0	0	0	0
3	0	1	0	1	1	0	0	1	0	0	0	0	0
4	0	1	0	0	0	0	0	1	0	0	0	0	0
5	0	1	0	1	0	0	0	1	0	0	1	0	0
6	0	0	0	0	0	0	0	0	0	0	1	0	0
7	0	0	0	1	1	0	0	0	0	0	1	0	0
8	0	0	0	0	0	0	0	0	0	0	1	0	0
9	1	1	0	1	1	0	0	0	0	0	0	0	0
10	0	1	1	1	1	0	1	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1	1	0	1	1	0	0	1	1	0	1	0	0
13	0	1	0	0	0	0	0	0	0	0	1	0	0

Figures 2–4 are illustrative of the procedural implementation of the approach. This consists of a flow chart of HSIM development (Figure 2), diagram detailing the HTSD framework (Figure 3) and the hierarchical tree structured diagram for the QMFs (Figure 4). These Figures 2–4 are mutually dependent and are integrated into a whole. The procedure for the development of HSIM consists of ten main stages (Figure 2). The HSTD flow chart framework consists of six stages (Figure 3), while the final hierarchical diagram for HTSD has seven stages (Figure 4). For Figure 2, the first step relates to obtaining QMFs that affect the study, which are numbered serially. This is to enable the establishment of a contextual relationship among the factors (Step 2). Further advancement of the HSIM development is aided by drawing a square matrix of dimension $(n + 1)$, where n represents the total number of factors considered in the study.

From the drawn square diagram, a diagonal is drawn that divides it, where *i* is inserted at the lower half and a *j* at the upper half of the box. This segregates the row from column elements. The row and column elements are then numbered from 1 to *n*. Pairwise comparisons are made to determine what cell is to be labelled 0 or 1. This is done until all classification is achieved. Basically, Figure 3 deals with subordination of one factor to the other. It compares pairs of factors and used experience to prioritise them by placing one factor above the other. This is done by comparing all possible factors in order to conclude at a prioritised scale which is achieved in Figure 4.

Figure 2 A flow diagram for HSIM development

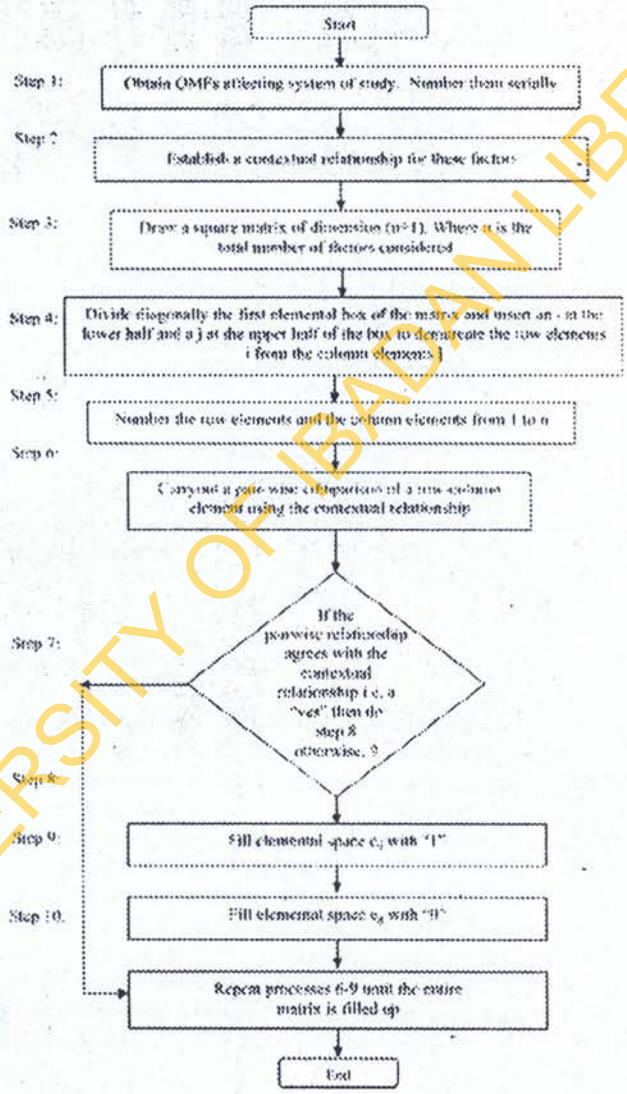
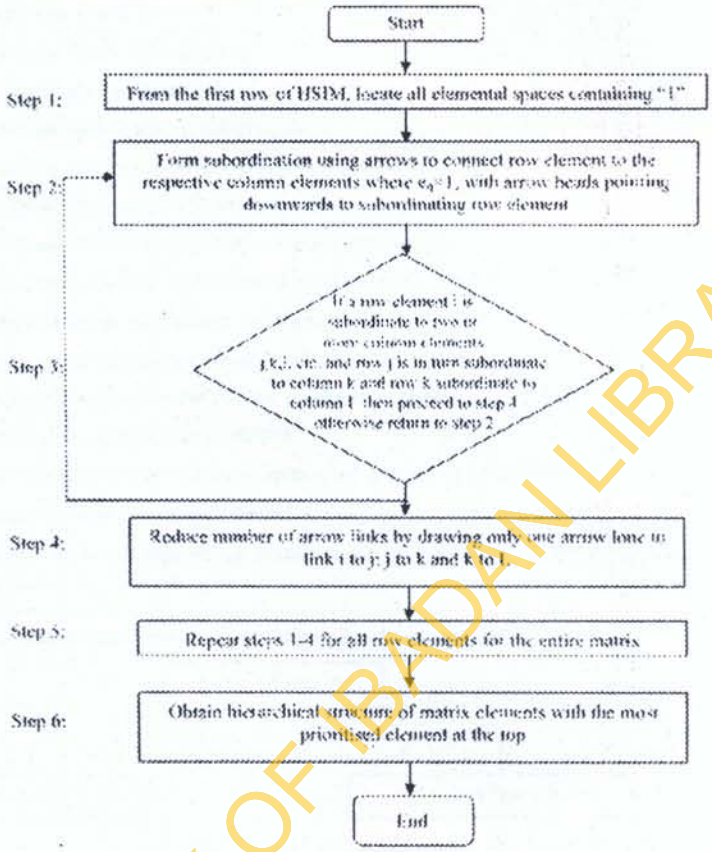


Figure 3 A flow diagram showing HTSD framework



4 Prioritising the QMFs

A number of prioritisation studies have been conducted using the alternative technique of Analytical Hierarchy Process (AHP) in diverse areas (Eifvengren et al., 2007; Mishra et al., 2007). In many endeavours, the limitation of resources has motivated the need for prioritisation in the execution of projects. The prioritisation discussed here relates to QMFs. However, this work utilises the SIM pairwise comparison framework and the HTSD structure applied to quality management using 13 factors, which are prioritised into seven levels. From the analysis, 'Funds Availability' has the highest priority attached hence it is at level 1. This is indicated in the HTSD framework above. Further investigation revealed that at level 2, we have two prime factors – 'Energy Availability' and 'Staff Training Programme'. The implication is that they are attached to the same priority rating. By observing closely, the frameworks presented here, we would see a distribution of 1, 2, 1, 3, 1, 3 and 2 factors at levels 1, 2, 3, 4, 5, 6 and 7, respectively.

Arising from this could be the definition of our goals for the system under consideration. Our prioritised goals are:

1 maximise funds availability
2 maximise energy availability
3 maximise staff training programmes
4 maximise the technical know-how of workers
5 maximise the quality of raw materials
6 maximise the usage of modern production process
7 maximise information dissemination potential
8 maximise usage of modern equipment
9 minimise deviation of control limits from the mean
10 maximise facility layout for the production system
11 maximise manpower availability
12 maximise the usage of better packaging and storage facilities
13 maximise timeless of operations.

From this, a goal programming problem for the model could be established in tabular form as shown in Table 2.

Figure 4 Hierarchical tree structure diagram for the critical QMFs

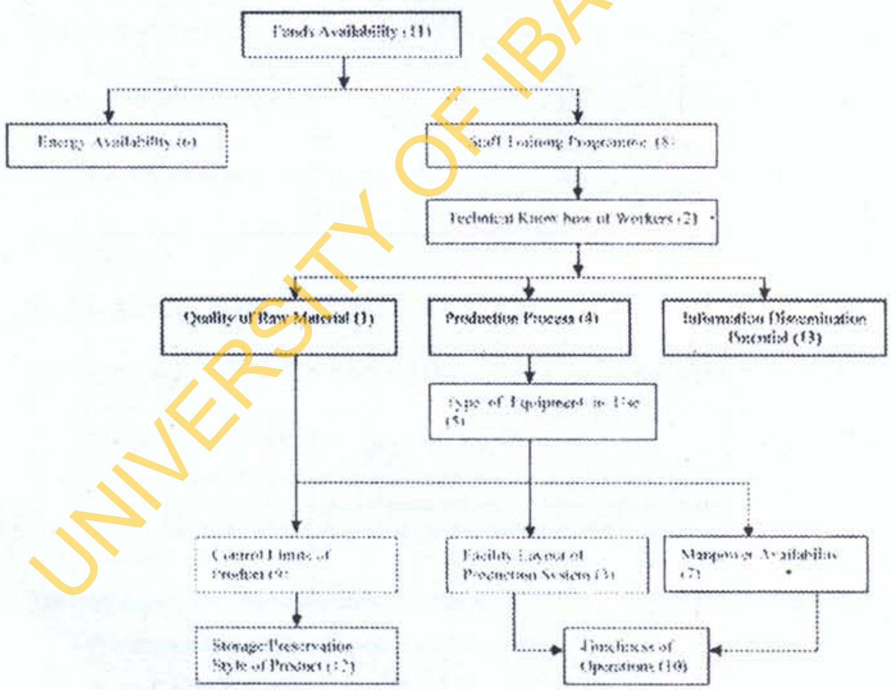


Table 2 The goal programming framework applied in quality management

Quality management factors (i)	*Decision variables (X_j)*				*Constraint on QMFs availability (C_i)*
	1	*2*	*n − 1*	*N*	
Funds availability	X_1	X_2	X_{n-1}	X_n	C_1
	a_{11}	a_{12}	$A_{1(n-1)}$	a_{1n}	
Energy availability	X_1	X_2	X_{n-1}	X_n	C_2
	a_{21}	a_{22}	$a_{2(n-1)}$	a_{2n}	
Staff training programme	X_1	X_2	X_{n-1}	X_n	C_3
	a_{31}	a_{32}	$a_{3(n-1)}$	a_{3n}	
Production process	X_1	X_2	X_{n-1}	X_n	C_4
	a_{41}	a_{42}	$a_{4(n-1)}$	a_{4n}	
Information dissemination potential	X_1	X_2	X_{n-1}	X_n	C_5
	a_{71}	a_{72}	$a_{7(n-1)}$	a_{7n}	
Equipment type in use	X_1	X_2	X_{n-1}	X_n	C_8
	a_{81}	a_{82}	$A_{8(n-1)}$	a_{8n}	
Control limits of product	X_1	X_2	X_{n-1}	X_n	C_9
	a_{91}	a_{92}	$a_{9(n-1)}$	a_{9n}	
Facility layout of production systems	X_1	X_2	X_{n-1}	X_n	C_{10}
	a_{101}	a_{102}	$a_{10(n-1)}$	a_{10n}	
Manpower availability	X_1	X_2	X_{n-1}	X_n	C_{11}
	$a_{11,1}$	$a_{11,2}$	$a_{11(n-1)}$	a_{11n}	
Storage/packaging style of product	X_1	X_2	X_{n-1}	X_n	C_{12}
	$a_{12,1}$	$a_{12,2}$	$a_{12(n-1)}$	a_{12n}	
Timeliness of operations	X_1	X_2	X_{n-1}	X_n	C_{13}
	$a_{13,1}$	$a_{13,2}$	$a_{13(n-1)}$	a_{13n}	

5 Model formulation

The model presented would work if and only if the following assumptions are valid:

1. the sum of all the resources allocated to the decision variables of a particular QMF cannot be greater than the available total
2. all data types are to be converted to a dimensionless parameter by making them a proportion (%) of the original values for homogeneity during optimisation after which they could be reconverted to the original data units.

The following model notations are also helpful

P_i = preemptive priority factors such that

$$P_i >> P_{i+1} >> P_{i+2} >> P_{i+n-1} >> P_{i+n}$$

d_i^- = negative deviation from c_i

d_i^+ = positive deviation from c_i

X_j = decision variable

c_i = associated right-hand side value or target value

a_{ij} = percentage proportion of resource allocated from (QMF)$_i$ to decision variable j.

The generalised model is as follows:

Objective function:

$$\text{Min } Z = \sum_{i=1}^{n} P_i\left[\left(d_i^- + d_i^+\right), d_i^-, d_i^+\right]$$

For all the QMFs, only one of these three generalised deviational quantities in the model for the objective function holds.

Constraints:

$$\text{s.t. } \sum_{i=1}^{i}\sum_{j=1}^{n} a_{ij}X_j \le C_i$$

$$\sum_{i=1}^{i}\sum_{j=1}^{n} a_{ij}X_j \le d_i^- - d_i^+ = C_i; \quad X_j, d_i^-, d_i^+, C_i, a_{ij} \ge 0 \quad i = 1,\ldots,I; \; j = 1,2,\ldots,n-1,n$$

If both the negative and positive deviations of a particular QMF is to be optimised, its objective function is given as: $\text{Min } Z = \sum_{i=1}^{n} P_i(d_i^- + d_i^+)$.

However, if only the negative deviation is to be optimised, its objective function becomes: $\text{Min } Z = \sum_{i=1}^{n} P_i d_i^-$.

While the optimisation of its positive deviation results in an objective function given as: $\sum_{i=1}^{n} P_i d_i^+$.

In addition, factors having the same hierarchical order are given equal treatment from the objective function by enclosing them in the same priority bracket as stated thus:

1 Equally prioritised factors whose negative deviations are to be optimised yields:

$$P_i\left(d_i^- + d_{i+1}^- + d_{i+2}^- + \cdots + d_{i+n-1}^- + d_{i+n}^-\right)$$

2 **Equally prioritised factors whose positive deviations are to be optimised are characterised by:**

$$P_i\left(d_i^+ + d_{i+1}^+ + d_{i+2}^+ + \cdots + d_{i+n-1}^+ + d_{i+n}^+\right)$$

3 Equally prioritised factors whose negative and positive deviations are to be optimised results in:

$$P_i\left(d_i^- + d_i^+ + d_{i+1}^- + d_{i+2}^+ + d_{i+2}^- + d_{i+2}^+ + \cdots + d_{i+n-1}^- d_{i+n-1}^+ + d_{i+n}^- + d_{i+n}^+\right).$$

6 Case example

In order to demonstrate the applicability of the model developed in this work, we present a case which incorporates the seven levels of the HTSD framework. The objective function is as described:

Objective function:

Min Z =

$$\left[P_1 d_1^-, P_2\left(d_1^+ + d_3^-\right), P_3 d_4^-, P_4\left(d_5^- + d_6^- + d_7^-\right), P_5 d_8^-, P_6\left(d_9^- + d_9^+ + d_{10}^- + d_{11}^-\right), P_7\left(d_{12}^- + d_{13}^-\right)\right]$$

Constraint (s.t.)

$$P_1: a_{11}X_1 + a_{12}X_2 + \cdots + a_{n-1}X_{n-1} + a_n X_n + d_1^- - d_1^+ = C_1$$
$$P_2: a_{21}X_1 + a_{22}X_2 + \cdots + a_{2(n-1)}X_{n-1} + a_{2n}X_n + d_2^- - d_2^+ = C_2$$
$$P_2: a_{31}X_1 + a_{32}X_2 + \cdots + a_{3(n-1)}X_{n-1} + a_{3n}X_n + d_3^- - d_3^+ = C_3$$
$$P_3: a_{41}X_1 + a_{42}X_2 + \cdots + a_{4(n-1)}X_{n-1} + a_{4n}X_n + d_4^- - d_4^+ = C_4$$
$$P_4: a_{51}X_1 + a_{52}X_2 + \cdots + a_{5(n-1)}X_{n-1} + a_{5n}X_n + d_4^- - d_5^+ = C_5$$
$$P_4: a_{61}X_1 + a_{62}X_2 + \cdots + a_{6(n-1)}X_{n-1} + a_{6n}X_n + d_6^- - d_6^+ = C_6$$
$$P_4: a_{71}X_1 + a_{72}X_2 + \cdots + a_{7(n-1)}X_{n-1} + a_{7n}X_n + d_7^- - d_7^+ = C_7$$
$$P_5: a_{81}X_1 + a_{82}X_2 + \cdots + a_{8(n-1)}X_{n-1} + a_{8n}X_n + d_8^- - d_8^+ = C_8$$
$$P_6: a_{91}X_1 + a_{92}X_2 + \cdots + a_{9(n-1)}X_{n-1} + a_{9n}X_n + d_9^- - d_9^+ = C_9$$
$$P_6: a_{10,1}X_1 + a_{10,2}X_2 + \cdots + a_{10(n-1)}X_{n-1} + a_{10n}X_n + d_{10}^- - d_{10}^+ = C_{10}$$
$$P_6: a_{11,1}X_1 + a_{11,2}X_2 + \cdots + a_{11(n-1)}X_{n-1} + a_{11n}X_n + d_{11}^- - d_{11}^+ = C_{11}$$
$$P_7: a_{12,1}X_1 + a_{12,2}X_2 + \cdots + a_{12(n-1)}X_{n-1} + a_{12n}X_n + d_{12}^- - d_{12}^+ = C_{12}$$
$$P_7: a_{13,1}X_1 + a_{13,2}X_2 + \cdots + a_{13(n-1)}X_{n-1} + a_{13n}X_n + d_{13}^- - d_{13}^+ = C_{13}$$

$$X_i, d_i^-, d_i^+, a_{ij}, C_i \geq 0 \quad i = 1, \ldots, I, \; j = 1, 2, \ldots, n$$

The linear GPQM model developed is primarily aimed at the attainment of an optimal distribution of the limited quality management resources attributed to the different QMFs within the production system for actualisation of the desired high quality products in order to attain the utmost goal of profit maximisation. An adopted procedure to enhance this, is the specification of some optimisation variables to which these resources are to be allocated bearing their availability constraint. As earlier depicted, a_{ij} is the (%) proportion of resource availability from (QMF) i to optimisation variable j within the constraint C_i. The results obtained from optimisation of the decision variables considered are rather used as a guide to verify whether or not the allocation proportion of resource a_{ij} to the optimisation variables $X_j, \ldots, X_{j..n}$ needs to be augmented, considered normal or reduced. Consider an instance where a decision variable $X_i = 1$.

The model interpretation is that the allocated resources to variable X_i are normal for quality attainment amidst of the constraint. A case where a variable $X_i = 3$, means the allocation needs to be tripled for quality attainment. The optimisation results of the decision variables with respect to this paper are seen as multiplicative indicators for the proportion of resource allocations and not size, numbers, duration, etc. Though ranging from X_1 to X_n, it is important to note that all the decision variables considered in a study may not be assigned to a particular QMF. For instance decision variables X_1, X_2 and X_4 may be assigned to (QMF) *i* while decision variables X_1, X_2 and X_3 may be assigned to $(\mathrm{QMF})_{i+1}$. The assignment of decision variables to QMFs usually is based on the fact that there is an interconnectivity between the concerned QMF and the decision variables. The assignment of these variables to the different QMFs should be carried out by proficiently-skilled hands within the system of study or experts in the study area. Though, yet to be validated with the use of data, the purported data type required is discussed in advance. It is obvious that the QMFs as earlier described are characterised with heterogeneous data units such as population (persons), cost ($), duration (hr), etc.

The model demands homogeneity in the units of the sourced data for the purpose of validation. The desired methodology to establish data homogeneity is by obtaining the percentage proportion of all the available data, which may be converted after optimising to the initial data unit. It is obvious that most of the QMFs do not actually have direct numerically generated data for optimisation. An easy way of establishing this is by noting the desired attainment for these categories of factors and making a comparison with the actual or available operational level, which leads to the establishment of percentage proportions.

7 Conclusions and future directions

Thus far, we have presented a new way of thinking about quality through the introduction of HSIM in prioritising the quality goals of a system (Elangovan et al., 2007; Maguire and Hope, 2006). This could be helpful in understanding and exploring the potentials of production systems and adding long lasting value to it. For the robustness of the model, further computational experience and experimentation needs to be gained (Giloni et al., 2006). Future researchers may clarify issues on possible subjectivity in HSIM to improve on its robustness and acceptability. Potential contributors to the quality-goal programming problem could explore the robust concept of expert systems development. An immediate follow on effort is needed to make the expert system developed here more useful to all the stakeholders in the system. An intelligent system that is based on both the consumer and producers perspective could be developed. The resulting software should be comprehensive, automated and useful as a management tool. It should centre on the quality-goal programming model structure.

The development of the software from both the producers and consumers' perspectives is essential. The relevant dimensions from producers' perspective are accuracy, capability, features, completeness, conformance, flexibility, serviceability, stability and structure. From a consumer perspective, relevant dimension include capability, communication, completeness, conformance, features, flexibility, simplicity and stability. However, by utilising the software, we have permanent records in a database that can be manipulated to provide specific product cost and reliability information. Report can be electronically transmitted to a database. An interesting dimension in the software development could be the ability for system users to access data entry screen, reports and data submission modules through an internet browser. A CD-ROM software could be put in place, and its functionality ported over to a server, enhanced and made available at a website (i.e. www.quality-total.model.com). It could be developed such a way that no special software would be required and the operator can access the system from anywhere on the internet.

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