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MULTIDIMENSIONAL IMPORTANCE METRICS IN MONITORING, MARKETING AND ASSESSING QUALITY VIA EXAMPLES FROM DIFFERENT ENGINEERING DISCIPLINES

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Abstract: The paper presents an advanced comparative method for exploring the role of quantitative indicators and various criteria measures in studying their mutual inter-relationship on quality as a whole system. This method was found to be a unique and universal way for assessing quality on a quantitative level in different disciplines such as Manufacturing Industry, Production/Design and Archaeometallurgy. Author found that when qualitative issues such as observations are combined with quantitative observations the results provide a broader tool for evaluating quantity. This can be a useful tool for evaluating quality in terms of quantity in other areas such as ethnographic research and / or phenomenology.
Key Words: indicators, interpretation, importance level, quality, quantity, measures

1. INTRODUCTION TO INTERPRETATION AND ANALYSIS OF QUALITY

Quality of goods and services that are available to people influence the standard of living in a society. The quality itself is a term that includes variety of criteria about aesthetic measures, performance measures and economic measures. These criteria are mutually linked and have different importance when compared each against others. Therefore, quality is a complex system of a quantitative significance. Unfortunately, the word quality became so popular and taken for granted that people at different levels have a tendency to ignore, underestimate and/or overlook the role of various criteria measures on the quality when judging the object, item, person, or service as a whole. Such approaches result in lack of precision with which the term 'quality' is interpreted. This is not beneficial in qualitative research which has a tendency to be descriptive rather than critically quantitative. People are often concerned about quality and more or less about assessment, interpretation and analysis of quality.

Quality is a combination of symptoms, specialities and properties separating one object, item, person or phenomenon from others. Quality as a whole can be represented by a variety of criteria, functions, and statements which are mutually linked and have different quantitative weights (levels of importance) when compared each against others. These criteria and functions represent together a complex combination of qualitative characteristics reflecting the ability of product, item or person to fulfil a role for which they are selected. The assessment of quality is a continuous process between a person and an object of his or her interest. It is therefore a matter of taste, opinion, mood, constrains (environmental, ethical, financial), and a level of knowledge of assessor(s). Hence, assessment is a relationship between a person and a product of interest. As such, assessment is a continuous process which is finished when the intelligence accumulated for a given purpose is satisfactory to make the final judgements about the product. However, such judgements are only prognoses which need to be verified when making an objective judgement. The product, item or person can be judged objectively when doing the job for which they were made, trained or selected. At the end of each assessment there is a new image of quality.

Freshwater and Avis [1] suggested that there is a similarity in ways by means of which different researchers accumulate evidence to develop and test their theories. They suggested that "*there may exists an universal process for analysing and interpreting evidence, irrespective of whether the evidence has been generated through qualitative enquiry, scientific investigation, or reflection on individual experience*".

This is quite a revolutionary idea. If this is correct it appears that it may be possible to create a powerful 'generalized' methodology for analysing quality in different disciplines. This would ask one to ignore distinctions between methodological and hypothetical differences within qualitative research traditions when identifying process, items, product, object or person in "critical reflection" on evidence [1]. Since evidence itself is based on quality and quantity of intelligence accumulated about the system to be evaluated, the greater the evidence the stronger the argument. However, the increases in a number of quantities and differences in the level of their importance could make the whole system to be too difficult and confusing. This complexity can, however, be fully or partially eliminated when employing "analysis" as a tool for reducing the evidence to its basic units. Breaking a complex system into casual and meaningful criteria allows the evidence to be reduced to its most fundamental aspects.

In this paper a comparative method for determining quantitative weights of individual criteria when assessing quality of a system as a whole from quantitative point of view will be described and discussed. This will be followed by practical examples of using this method for analyses of various quality measures from different disciplines.

2. PROPOSED METHODOLOGY TO DETERMINE AND COMPARE QUANTITATIVE INDICATORS OF QUALITATIVE MEASURES

The Section 2 is structured into two sub-Sections 2.1 and 2.2. Sub-Section 2.1 is aimed on determining quality of a system as a whole via quantitative indicators of various qualitative measures belonging to one group. Sub-Section 2.2 is focused on comparing quality of two systems via differences in quantitative indicators of their common qualitative measures.

2. 1. ASSESSMENT OF QUALITY OF A SYSTEM AS A WHOLE

Quality, Q, is a complex system of various qualitative measures, Q_i, each having different quantitative weight(s), q_i, with i ranging from 1 to n, depending on a number of qualitative measures in the system, see Equation 1.

$$Q = \sum_{i=1}^{n} Q_i . q_i \tag{1}$$

The accuracy of this method is dependent on the quality and quantity of information gained about the system. It should be mentioned that some of qualitative measures are measurable and quantitative while others are qualitative and descriptive, as for example in any other fields of art, ethnography, and/or phenomenology. The quantitative weight of each individual criterion determines both the level of importance of the criterion against others and its position in the hierarchy of total quality of system as a whole. As such a quantitative weight indicator represents the factor of relative importance of each individual criterion in the system. Therefore it determines the outcome of the calculations, however they express the importance assigned by a user of this method.

The relative importance, q_j, is the product of the individual importance indicator, D_j, and the sum indicator of the quality, $D = \sum_{i=1}^{n} D_i$, see Equation 2.

$$q_i = \frac{D_i}{D} = \frac{D_i}{\sum_{i=1}^{n} D_i} \tag{2}$$

The D_i represents the individual importance indicator for each qualitative criterion (Q_1, Q_2, Q_3, Q_i ... Q_n) and can be calculated as a sum of statistical significance numbers in a row for each criterion, as shown in Table 1. In this table the symbols 0, 1 and 2 are used to indicate the perceived importance of one criterion against another. Thus, 0 is used whenever a criterion (Q_1, Q_2, or Q_3) from column 1 has less perceived importance than the 'header' criterion, 1 is used to indicate that both criteria from 'column and header' are of equal importance, and 2 is used to indicate that the 'column' criterion has better importance than the 'header' criterion.

Table 1. A key to determine statistical significance by mutual comparison of one criterion against other criteria, An example.

	Criterion 1	Criterion 2	Criterion 3	D_i	q_i
Criterion 1 (=Q_1)	----	1	2	3	0.5 (=3/6)
Criterion 2 (=Q_2)	1	----	0	1	0.16 (=1/6)
Criterion 3 (=Q_3)	0	2	----	2	0.33 (=2/6)

Symbols: 2 greater importance; 1 equal importance; 0 lesser importance.

From data in Table 1, the individual importance indicator, D_i, from the most significant to the less significant, has its quantity of 3 (=1+2) for criterion 1(=Q_1), 2(=0+2) for criterion 2(=Q_2), and 1 (=1+0) for criterion 3(=Q_3). The sum indicator of quality in this case is $D = \sum_{i=1}^{n} D_i$ =3+1+2 = 6. The quantitative weight (*ie* relative importance), $q_i = (D_i/D)$, from the most significant to the less significant, has its quantity of 0.5(=3/6), 0.33(=2/6) and 0.16(=1/6) for criterions 1(=Q_1), 3(=Q_3) and 2(=Q_2), respectively. This means that criterion 1 with its 50% quantitative weight (q_i=0.5) is deemed more important than criterion 3 (q_i=0.33 or 33%), and/or criterion 2 ((q_i=0.16 or 16%). For all criteria, *i* ranging from 1 to n, the sum of the relative importance, q_i, must be equal to 1 (*ie* 100%) for overriding importance/significance.

2. 2. Quantitative Comparison of Qualitative Differences Between two Systems

Quantitative comparison of qualitative differences between two systems is possible for cases that have the same qualitative measures, hence for each various Criteria 1, 2, 3 ...*i* ...*n* it is possible to calculate corresponding quantities q_1, q_2, q_3... q_i ... q_n., as shown earlier in Table 1 in Sub-Section 2.1. Because the quantitative weights q_1 to q_n are the same for both systems their qualitative weights are also equally valid for both systems *ie* $q_i\big|_{i=1}^{n}$ from System 1 are equal to $q_i\big|_{i=1}^{n}$ from System 2. However, differences are between qualitative measures that are measurable and therefore quantitative *ie* (Q_1 to Q_n) of System 1 differs from Q_1^* to Q_n^* of System 2. As a result the total quality, Q1, of System 1 differs from total quality, Q2 of System 2, see Equations 3 and 4.

System 1
$$Q1 = \sum_{1}^{n} Q_i . q_i \tag{3}$$

System 2
$$Q2 = \sum_{1}^{n} Q_i^* . q_i \tag{4}$$

Differences between total qualities Q1 and Q2 of Systems 1 and 2 respectively can be calculated as a sum of positive and negative quantitative differences between the real features and requested features as shown in Equations 5 and 6.

$$Q12 = \sum_{i=1}^{n} q_i . \left(\frac{Q_i - Q_i^*}{Q_i} \right) \tag{5}$$

$$Q12 = \left[q_1 . \left(\frac{Q_1 - Q_1^*}{Q_1} \right) \right] + \left[q_2 . \left(\frac{Q_2 - Q_2^*}{Q_2} \right) \right] + ... + \left[q_n . \left(\frac{Q_n - Q_n^*}{Q_n} \right) \right] \tag{6}$$

3. PRACTICAL EXAMPLES FROM USING THE METHODOLOGY FOR DIFFERENT DISCIPLINES

The methodology proposed in Section 2 was used by Audy J [5] and Audy K [18] in various fields of authors' interest, namely: Manufacturing Industry [5], Production/Design 5, 18] and Archeometallurgy [18]. The results are shown and discussed in sub-Sections 3.1 to 3.3. The examples in this article were used to do both develop and prove the methodology. Variations in customer perception being incorporated into this methodology are minimised by scientific evidence – facts used in individual approaches when developing and/or categorising the qualitative criterions and their individual and mutual significance measures.

3. 1. THE USE OF COMPARATIVE METHOD IN ANALYSING THE MOST SUITABLE APPROACHES AND MEASURABLE PARAMETERS FOR CONTROLLING THE METAL MACHINING PROCESS PARAMETERS

It has been long recognized that performance of machining operations can be assessed by various technological and economic performance measures. From the published information it became clear that research concentrated on technological performance measures was aimed on: chip formation [2 to 4] and chip flow [2 to 4], the forces [2 to 6] and power [2 to 5], the tool wear [4, 5, 7 to 10] and tool life [2, 4, 5, 7 and 8], as well as the component surface roughness [5 and 8] and dimensional accuracy [5 and 8], while the research work concentrated on economic performance measures associated with the time per component [2], and cost per component [2]. According to different sources [2 to 13] increases in tool wear were reported to be responsible for increases in component surface roughness [5, 8 and 13] which affected forces [2 to 5, 7, 8, 11 to 13], power [2 to 5], vibrations [5, 8 and 13] and acoustic emission [5 and 13]. Consequently, dimensional changes in tool shape due to wear affected the economic performance of machining [2]. Thus, tool wear is a factor of some economic significance. Bearing this in mind it has been recognized that in order to optimise the metal machining processes, a reliable approach is required to monitor the state and conditions of cutting tools (in terms of wear, chipping and therefore approach to failure) by real time measurement of 'the most suitable' in-process phenomena [5 and 8]. Literature sources suggested that there are five major methods, namely electrical [2 to 5, 7, 8, 12 and 13], optical [5, 7 and 14], radioactive [15], holography [16], and pneumatic [17] that can be possibly used for 'suitable' monitoring of tool wear. However, the results and conclusions, published by world-wide researchers, and their opinion on the possibility of using these methods in practical applications for indirect measuring tool wear phenomena (cutting forces, machining power, tool temperature, vibrations *etc*) and for controlling the cutting process in the machining industry, are different.

Consequently, a comparative method, for assessing the importance of published results on machining process, has been used to elaborate upon the theory with focus on turning process [5]. The accuracy of this statistical method is dependant on the time and on the quantity and the quality of the gained information about the tracked process.

Table 2. The relative importance of possible methods for controlling cutting process parameters by indirect monitoring of tool wear [5].

	Electrical	Optical	Radioactive	Holographic	Pneumatic	D_i	q_i
Electrical		2	2	2	2	8	0.4
Optical	0		2	2	0	4	0.2
Radioactive	0	0		0	0	0	0
Holographic	0	0	2		0	2	0.1
Pneumatic	0	2	2	2		6	0.3

Symbols used in Table 2 were:

0	The first method has less possibility for controlling the cutting process than the second method.
1	Both methods are equally suitable for controlling the cutting process
2	The first method used for controlling the cutting process is better than the second method
q_i	The relative importance of individual methods used to control the cutting process
D_i	The individual pointer of the quality of the method used to control the cutting processes
D	The statistic pointer of the sum quality

Table 2 shows the relative importance of five methods, namely Electrical, Optical, Radioactive, Holographic, and Pneumatic, to be possibly used for controlling the cutting process by measurement of the tool wear.

Table 3 shows the relative importance of variables developed in metal cutting, to be possibly used as the critical factors in the mathematical model to control the cutting process.

Table 3. The relative importance of possible cutting process phenomena for controlling the cutting process [5].

	Tool Temperature	Machining Power	Cutting Forces	Tool Wear	Machined Surface	Vibrations	Tool Length Changes	Acoustic Emission	D_i	q_i
Tool Temperature		1	0	1	0	0	1	0	3	0.05
Machining Power	1		0	0	0	0	1	0	2	0.04
Cutting Forces	2	2		1	2	2	2	2	13	0.24
Tool Wear	1	2	0		1	0	1	0	5	0.09
Machined Surface	2	2	0	1		0	1	0	6	0.11
Vibrations	2	2	0	2	2		2	0	10	0.18
Tool Length Changes	1	1	0	1	1	0		1	5	0.09
Acoustic Emission	2	2	0	2	2	1	2		11	0.2

Symbols used in Table 3 were:

0 The first variable used as the critical factor in the mathematical model has less possibility for controlling the machining than the second variable

1 Both variables are suitable for creating the mathematical model and for controlling the cutting process

2 The first variable used as the critical factor in the mathematical model tor controlling the cutting process has better properties than the second variable

q_i The relative importance of the individual variables used as the critical factor in the mathematical model for controlling the cutting process

D_i The individual pointer of the quality of the critical factors, used to control the cutting processes

D The statistic sum pointer of the quality of factors used to control the cutting processes

It is apparent that there are many theories concerning the methods and variables which are important in the selection of variables for controlling the state of metal machining operations. From Table 2 it is clear that the electrical method (with the highest q_i= 0.4) would probably be the best method for controlling the cutting process by the indirect measurement of the tool wear.

From Table 3 it is clear that the forces acting on the tool during cutting (with the highest q_i= 0.24), are probably the most suitable variables for controlling the cutting process, and can be used as the critical factors in the mathematical model. The acoustic emission (with q_i= 0.2) and the vibrations acting on the tool during cutting (with q_i= 0.18) have a slightly lower suitability as the cutting forces (q_i=0.24), and require to use a special expensive measurement technique.

Experimental Verification

Extensive experimental work based on the results of the comparative study was carried out. It has been shown that it is possible indirectly and continuously monitor tool wear by evaluating dynamic changes during the cutting process [5]. It has been established that measurements based on piezoelectric devices and force measurements are accurate enough for these purposes and results gained can be used for prediction of the real time state of the tools and in research information to assist better tool design life [5 and 8]. An example is shown in Figure 1 that depicts the trends obtained for thrust and torque in drilling with respect to outer corner flank wear for uncoated 6.35mm diameter high speed steel (M1 grade) general purpose twist drills. The results are plotted as a function of the number of holes drilled into a Type S1214 steel work-piece material at a cutting speed of 35m/min and a feed rate of 0.4m/min.

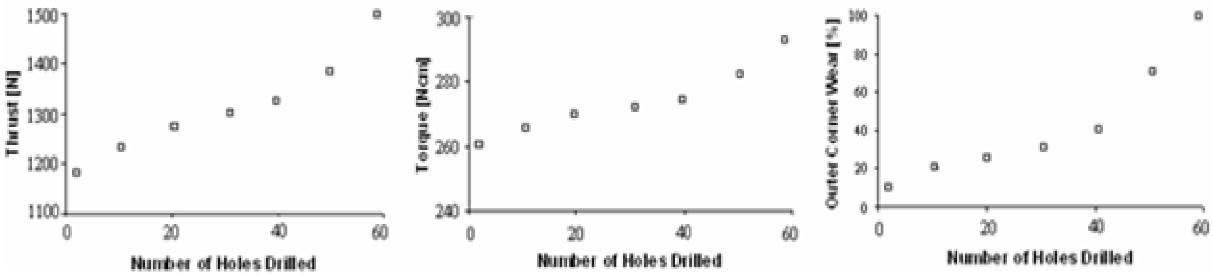


Figure 1. Graphs showing the thrust, torque and outer corner wear as a function of the number of holes drilled.

From Figure 1 it is evident that the results showed a definite pattern in which thrust and torques increased with the tool wear and the number of holes drilled. Hence the methodology described in sub-Section 2.1 was able to select the most suitable - electrical - method and – force – phenomena for measuring, controlling and predicting tool conditions via indirect monitoring of tool wear [4, 5, 8, 12 and 13]. It has also been shown experimentally that this choice can also be used for other practical operations such as drilling, tapping and milling [4].

3.2. THE USE OF COMPARATIVE METHOD IN ANALYSING THE MOST SUITABLE APPROACHES AND IMPORTANT MEASURABLE PARAMETERS FOR DESIGNING BELLS AND ASSESSING THEIR PERFORMANCE

Audy [18] conducted an extensive literature survey and found that the results and conclusions published by bell makers, historians and researchers world-wide, and their opinions as to the possibility to find a simple relationship between the sound, bell design features and bell material composition are in conflict. Consequently she aimed a part of her study on investigating the key features of bell making process and effect of individual operations on final quality of bells. From the literature survey she found that seven qualitative measures, namely material, sound level, decoration, design, life, historical importance and qualitative appearance could possibly be used to determine the perceived quality of church bells.

The results of her survey indicated that:

(1) Material properties depend on mechanical properties, microstructure, hardness, chemical composition, porosity, and nature of internal phases in microstructure.
(2) Sound level can be described in terms of level, note, tone and decadence.
(3) Decoration depends on number, size and position of decorative ornaments.
(4) Life can be measured as time representing the useful performance of a particular bell.
(5) Qualitative Appearance includes visible faults, surface roughness, and type of decoration.
(6) Design is influenced by the weight of bell and shape of its profile.
(7) Historical Importance reflects origin, country, bell maker and the use of bell.

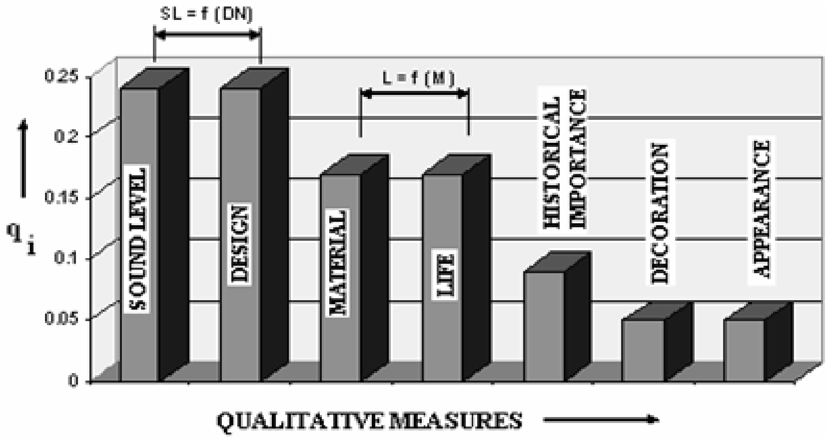


Figure 2. The relative importance of qualitative measures in describing the final quality of church bells [18]

She stated that some of these qualitative measures are measurable and quantitative (1, 2, 4, and 6), others (3, 5 and 7) are qualitative, as in any other art work. To try to provide a basis for comparison of the relative perceived importance of published information on criteria 1 to 7 and to analyse this information for purposes of her experimental programme she used the comparative approach described in sub-Section 2.1 that was adopted from study [5]. The results of her analysis are shown in Table 4 and Figure 2.

Table 4. The perceived relative importance of factors/variables for determination of the quality of a bell [18].

	Material	Sound Level	Decoration	Life	Qualitative Appearance	Design	Historical Importance	D_i	q_i
Material		0	2	2	1	0	2	7	0.17
Sound level	2		2	1	2	1	2	10	0.24
Decoration	0	0		0	1	0	1	2	0.05
Life	0	1	2		2	1	1	7	0.17
Qualitative Appearance	1	0	1	0		0	0	2	0.05
Design	2	1	2	1	2		2	10	0.24
Historical Importance	0	0	1	1	2	0		4	0.09

Symbols: 2 greater importance; 1 equal importance; 0 lesser importance

From the above analysis she concluded that the sound emitted and bell construction material are prime variables for determining quality of the bells. This is clearly indicated in Figure 2 which suggests a close dependence of the sound level on the bell design / profile, and the bell's life on the bell material.

Experimental Verification

Extensive experimental work followed based on the rationale drawn from this comparative study. It embraced a number of interrelated aspects – bell design, sound development / characteristics, fabrication technology, alloy type – composition, constitution and properties. Such information was sought with particular reference to church bells in Australia. In addition, European bell making technology was studied through metallographical and chemical analyses of samples taken from bells cast from the 15th to 20th century. A similar analysis was carried out on bell materials derived from a number of bells exported to Australia from England, Ireland, Italy, Scotland and Bohemia. Analysis of the sound quality of bells from various Adelaide churches was conducted and the data evaluated inter-relation to the design and material features of those artefacts. The results were compared with similar information derived from the European bells. The results and conclusions obtained from these experiments provided design data which were used for preparing moulds and to allow the casting of a number of bells for subsequent characterisation and analysis. The sound qualities of these bells were evaluated in relation to the microstructure, chemical composition and design and confirmed relationship between these qualitative measures predicted earlier using comparative methodology.

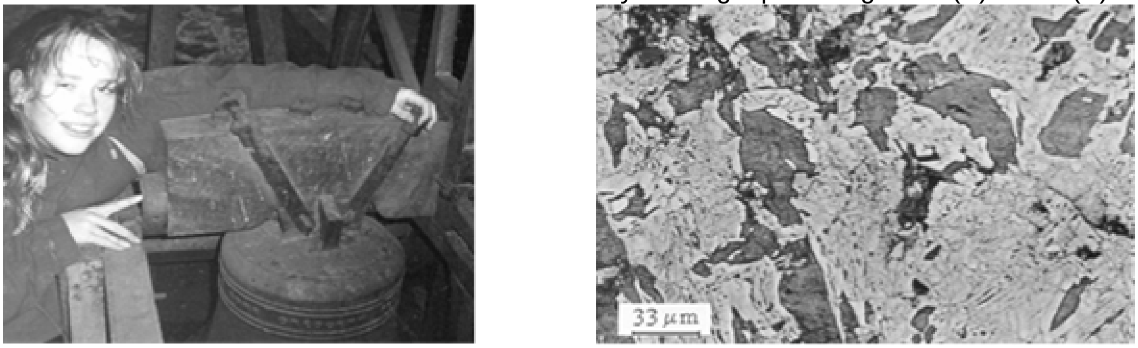
Moreover the same author [18] employed this method successfully for calculating the relative importance of alloying and trace elements in bell material and predicting their effect on cast ability and cast quality. Again the effectiveness of these predictions was verified experimentally firstly by casting a set of experimental bells and analysing their quality from quantitative point of view, and secondly by evaluating quality of existing bells with respect to their composition, microstructure and material features.

Finally the method was successfully used for quantitative comparison of quality of two bells imported to Australia from England. The information was drawn from source [18], see sub-Section 3.3.

3.3. THE USE OF COMPARATIVE QUALITATIVE METHOD FOR QUANTITATIVE COMPARISON OF QUALITY OF TWO BELLS CAST IN THE SAME FOUNDRY

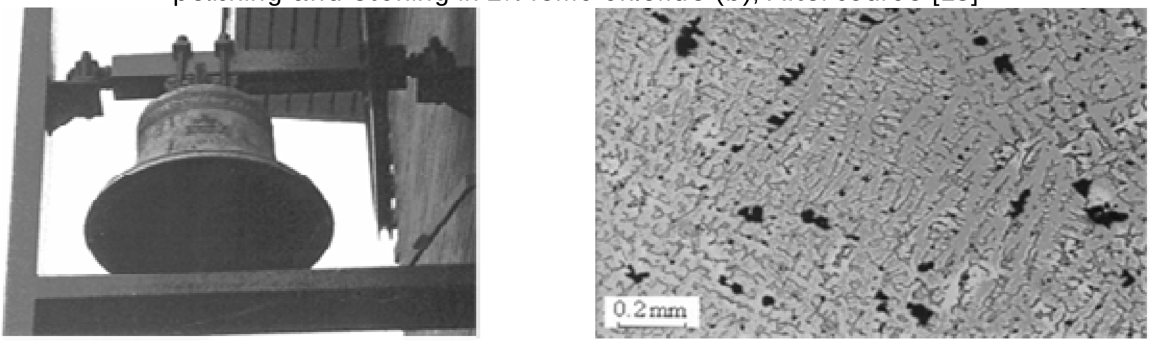
Two bells - one from Scottish Church in Adelaide, see Figure 3(a), and second one from the St. Jude Church in Brighton, see Figure 4(a), were originally cast by "John Warner and

Sons" company in London in 1857 and 1862, respectively. The bells have almost the same decoration and very similar dimensional parameters, and they were both selected for investigation of variations in their qualitative factors characterised by the sound decadence, accuracy of a given tone and microstructural features of a particular bell-material. The microstructure of both these bells is documented by micrographs in Figures 3(b) and 4(b).



(a) (b)

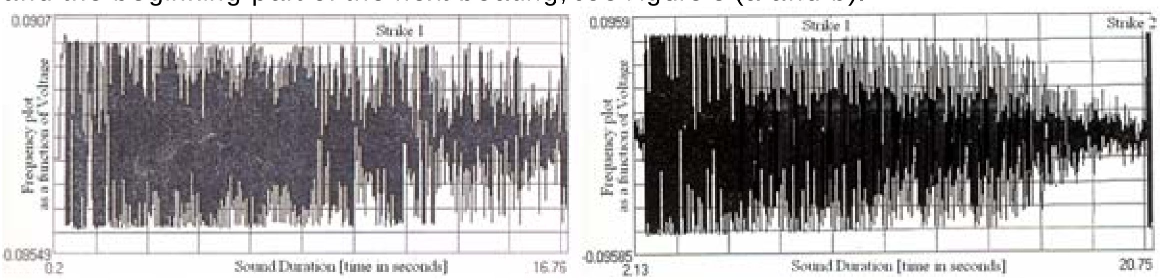
Figure 3. The bell from the Scottish Church in Adelaide City (a), and its microstructure after polishing and etching in 2% ferric chloride (b), After source [18]



(a) (b)

Figure 4. The bell from the "St. Jude's Anglican Church' in Brighton, in Adelaide City (a), and its microstructure after polishing and etching in 2% ferric chloride (b), After source [18]

The sound of the two bells was recorded on a tape recorder and the sound frequencies were analysed using a computer equipped with Types Snap Master and Math-Cad softwares. The patterns were plotted in a way to allow recognising one whole complete sound signal and the beginning part of the next beating, see Figure 5 (a and b).



(a) (b)

Figure 5. The out-put frequency/sound charts of two geometrically similar bells cast of different bell-materials

The frequency charts are presented in a pattern of voltage out-put/time graphs to give *firstly* overall information about the tone decay (sound duration) and *secondly* to plot the real width of frequency sound charts. Comparison of plots 5 (a) and 5 (b) shows that the sound decay between these two bells, for one stroke, differed by 2.06 seconds i.e. 18.62sec – 16.56 sec; or (20.75-2.13) – (16.76-0.2).

Table 5 sets out the most important variables associated with the dimensional parameters, rough chemical composition and hardness data of these two bells with respect to their tone sound decay and metallurgical features.

Table 5. The most important data describing particular features of two different bells from one foundry. After source [18]

Bell Location	Bell Diameter	Sound Decadence	Microhardness	Chemical Composition 'Rough data' in [wt%]		
Adelaide	[mm]	[seconds]	[$HV_{(0.002)}$]	Cu	Sn	Pb
Scottish Church in the City	620	9.4	296	73.6	23.2	balance
St. Jude Church in Brighton	680	10.9	299	72.2	24.9	balance

The comparative method described earlier in the sub-Sections 2.1 and 2.2 was used to determine the quantitative levels of qualitative criteria of these two bells. Chemical composition, hardness data, bell diameter and sound decadence were four major variables considered. Two variables, namely chemical composition and hardness data belonged to the material criterion and had the quantitative weight of q_i equal 0.17, see data in Table 4. Bell diameter feature belonged to the design criterion and had the quantitative weight of q_i equal 0.24, see data in Table 4. The sound decay values belonged to the sound level criterion and had the quantitative weight of q_i equal 0.24, see data in Table 4. Consequently, all these criteria were of very high statistical significance. Differences in total qualities Q1 and Q2 of Bell 1 and Bell 2 were calculated using data in Table 5, Equation 6 and methodology described in sub-Section 2.2. The calculation is shown in Equation 7, below.

$$\begin{aligned} Q12 &= \left[0.24x\left(\frac{680-620}{680}\right)\right]+\left[0.24.\left(\frac{10.9-9.4}{10.9}\right)\right]+\left[0.17.\left(\frac{299-296}{299}\right)\right] \\ &+\left[0.17.\left(\frac{72.2-73.6}{72.2}\right)\right]+\left[0.17.\left(\frac{24.9-23.2}{24.9}\right)\right]+\left[0.17.\left(\frac{2.9-3.2}{2.9}\right)\right] \end{aligned} \tag{7}$$

$$Q12 = 0.0211+0.033+0.0017+(-0.0033)+0.011+(-0.0176)=0.0459 \cong 4.6[\%]$$

This calculation showed that the qualitative level of the bell in Scottish Church was some of 4.6 percent lower than that of the bell in the St. Jude Church. The differences in the qualitative indicators of these two bells developed mainly due to higher hardness and sound decay of the second bell. Moreover, the microstructure of the bell in the Brighton, Figure 4 (b), exhibited smaller grains of alpha phase (copper) and (α+δ) eutectoid (tin) which resulted in higher hardness and better sound decay. It also suggested that different forming mixtures were used for mould preparation. The one used for casting the bell in Scottish Church was less porous so the cooling rate was slow and the diffusion time longer allowing grains to grow bigger and making the structure to be softer.

The results from sub-Section 3.3 confirmed the validity of comparative methods for quantitative comparison of qualitative differences between two different products. This knowledge was beneficial and useful in designing and analyses of experiments associated with Product Design and Archeometallurgy [19 and 20]. Most recently, this method was successfully used for qualitative comparison of efficiency of teaching methods at Surf Science and quantitative evaluation of students' perceptions about surfboard fin design features and performance measures [21 and 22].

Finally it should be mentioned that this methods is a very efficient in calculating quality in terms of quantity from economical point of view. The practical examples are not shown in this paper but are available on written request to the corresponding author.

4. CONCLUSIONS

The main conclusions to be drawn from this study are summarised as follows:

- The quality as a whole can be described by qualitative measures that are measurable and quantitative and others that are purely qualitative. Investigations described in this paper showed that when qualitative measures from observations are combined with quantitative observations the results provide a broader tool for evaluating quality from the quantitative point of view. It has also been shown in this paper that such approach can be a useful tool for evaluating quality in terms of quantity in other areas such as phenomenology where the majority of data is qualitative or descriptive.

- A statistical comparative methodology was presented and described in the ways that allow determination and comparison of quantitative indicators of various qualitative measures in a system to be evaluated, and enable to compare quantitatively differences in quality of two different systems. The methodology was verified experimentally for different disciplines and found to be a universal 'highly flexible' tool for assessing quality in terms of quantity.

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