GIS Maturity and Integration

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1. Abstract

This paper discusses the concept of maturity in the use of GIS and then formulates a computational method for measuring an organisations maturity level from the construction of a surrogate indicator. Generation of this model is made under the proposition that maturity is linked to the level that GIS has been integrated and utilised on an organisation wide basis in day to day activities. The research focuses on New Zealand local government and incorporates parallel studies of conventional information technology (IT) with recently collected data to provide support for the concepts and techniques used. It is postulated that due to similarities of function found in other local authorities, that the model has the potential, with further research for wide application.

2. Introduction

In New Zealand as in other parts of the world, Geographic Information Systems (GIS) have become a firmly established production tool in many areas of regional and local government. New Zealand local authorities have traditionally possessed large amounts of spatial and non-spatial data (Fraser and Todd, 1994; and Anderson and Benwell,

1992) and GIS is increasingly being used as a tool for data management and analysis (Marr and Benwell, 1996a). For most organisations GIS offers a variety of benefits both tangible and intangible over more traditional and less automated methods (Mackaness, 1989; Dickinson and Calkins, 1988).

The majority of GIS implementations in New Zealand have occurred in the last three years, but some date back prior to 1988 (Marr, 1996). This situation has occurred over a period of major technological improvement, enhancing the computational functions and abilities of GIS. In addition, there has been a rapid increase in the amount, availability, and quality of digital data (Marr and Benwell, 1996a). These factors over time have led to contrasts in the way GIS has been implemented among different organisations. The proposition is made that trends observed in the local authorities represent an identifiable maturity process from which a principle component is the organisation wide integration of data resources.

3. Maturity and Integration

Some organisations consider the development of a totally integrated information system as the logical process of increasing organisation wide overall efficiency (Marr and Benwell, 1996b). The result of organisation wide data integration may be that GIS becomes less of a standalone system, and more of an incorporated tool responsible for spatial problem solving (Mayr, 1995; Zwart, 1992).

Although not regarded as authoritative, "GIS maturity is defined as the degree to which systems are actually used, which in turn relates to the number of users" (Mayr, 1995, p30).

Figure 1 lists some of the benefits that may be achieved if organisation wide integration is attained. It is suggested that where an organisation is found to have widely integrated its data resources, the relative level of maturity will be high in the use of those resources. As levels of integration increase, the number of users for which use of the new system would be advantageous also potentially increase resulting in a higher maturity level inline with the definition by Mayr.

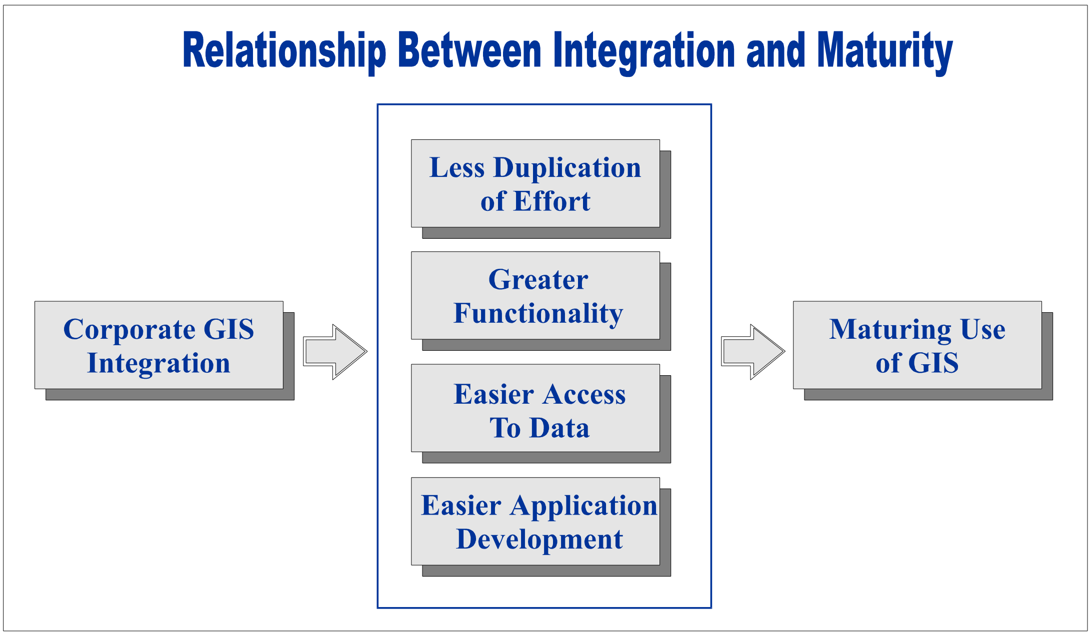

Figure 1 - Relationship Between Integration and Maturity
from Lopez and John (1993)

The effects of corporate integration were analysed based on both New Zealand and Australian local government surveys carried out between 1992 and 1995. The 1995 survey was carried out and reported on by Marr (1996). The survey was conducted on all New Zealand local government organisations, and resulted in a response rate of

74.4%. Of this response, 70% of the organisations indicated they had GIS. While most organisations perceived corporate integration as desirable, most were far from such a reality. Related to the integration of data resources is the inherent need for GIS analysis to be generally available within an organisation. Typically in the past, GIS implementation has focused on a particular application and therefore a related department of the organisation. As GIS management moves to a corporate role, there is often a need to re-engineer internal processes to cope with the changes which commonly see GIS control move to the information services department or equivalent (Marr and Benwell, 1996a).

To illustrate this trend, Figure 2 shows the primary activity of the person most responsible for managing GIS in the organisation based on the returned responses.

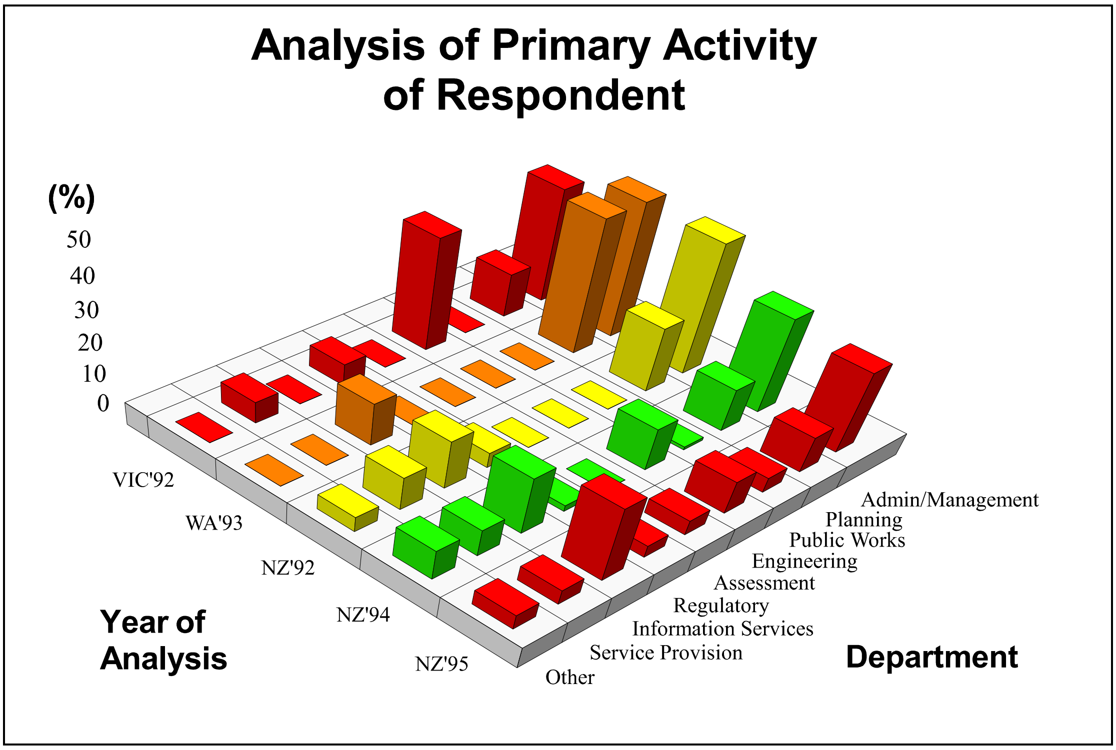

Figure 2 - Analysis of Primary Activity of Respondent
from Marr (1996)

The trends suggest that the role of the information services department in managing the corporate resources is increasing while the role of more traditional departments such as administration/management and planning is decreasing. These trends are further corroborated by the analysis of Figure 3.

This graph shows the department responsible for GIS within the organisation through the successive studies.

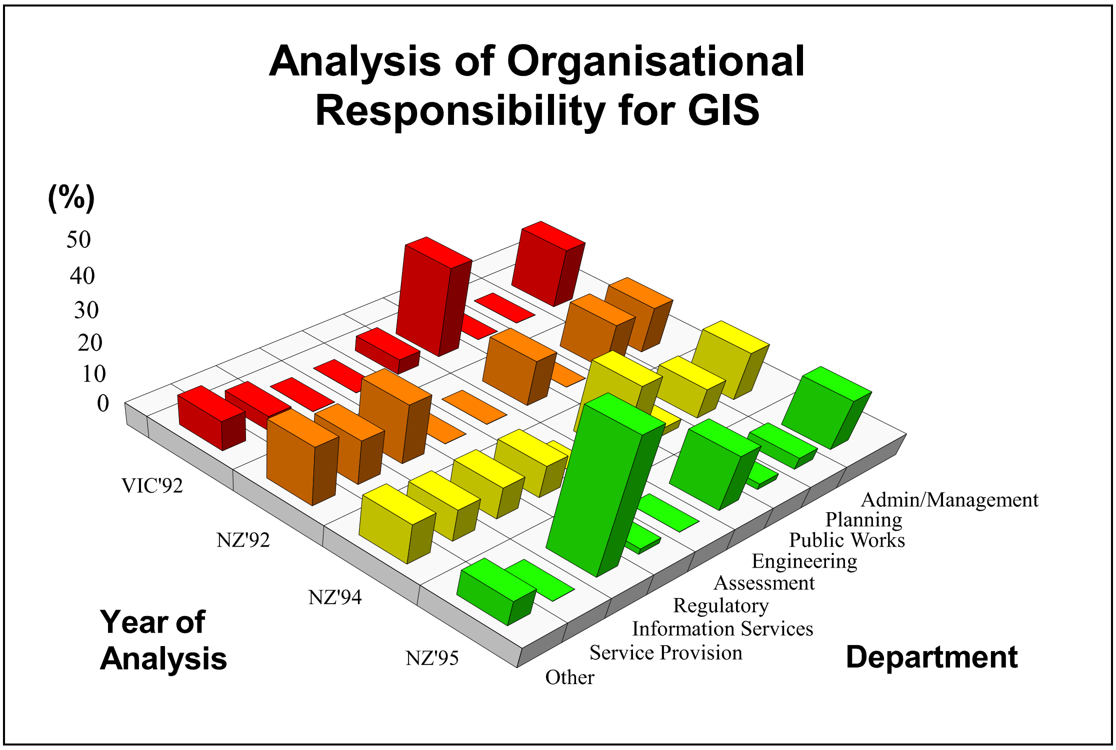

Figure 3 - Analysis of Organisational Responsibility for GIS
from Marr (1996)

There appears to be a marked increase in the percentage of information services departments assuming responsibility for GIS in the organisation.

4. The Nolan Model

There exists a very close relationship between the technologies of GIS and other forms of IT. Indeed, organisations with a policy of corporate integration find that it eventually becomes difficult to differentiate GIS from other IT. Total integration would see this differentiation disappear altogether with the development of generic tools for spatial manipulation and analysis.

Among most local government organisations in New Zealand and probably elsewhere, GIS implementations may be regarded as immature and not fully developed. However extensive research has been carried out into conventional IT where greater development has had time to occur. Some of the more fundamental work has evolved in the form of the 'Nolan Model' shown in Figure 4 which suggests the components of an IT maturing process (Nolan, 1979; Nolan, 1977; Gibson and Nolan, 1974; Nolan, 1973). The development of the model and associated management guidelines are widely considered to be the most comprehensive research in this area (Sprague and McNurlin, 1993; Jackson, 1986; Benbasat *et al*., 1984).

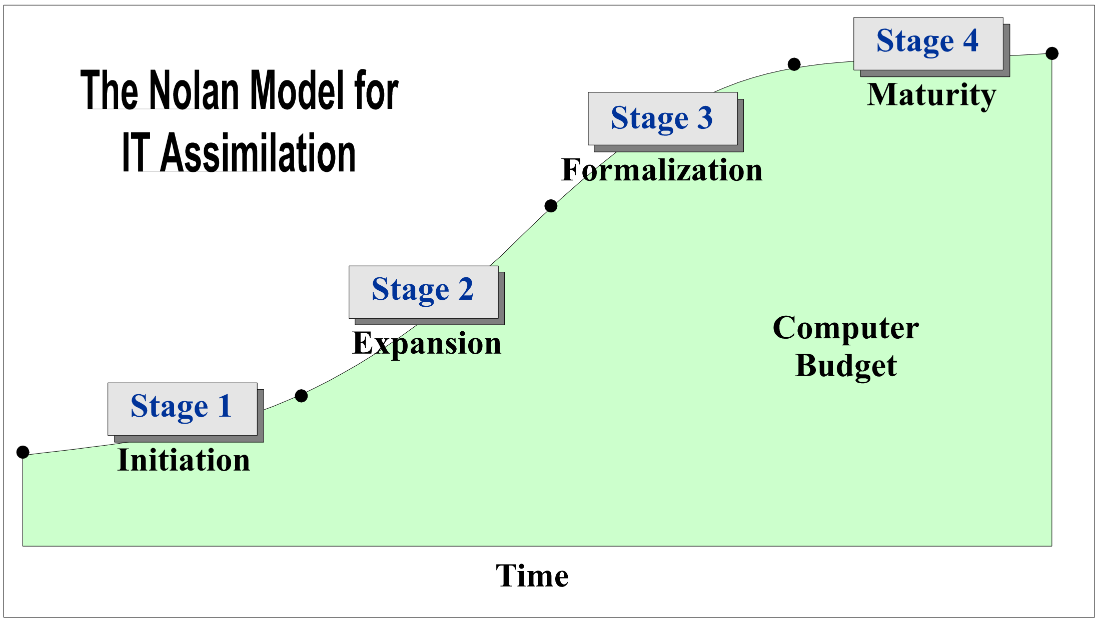

Figure 4 - The Nolan Model for IT Assimilation
From Gibson and Nolan (1974)

Based on the observation of a number of organisations, Nolan hypothesised that the IT implementation could be identified to pass through a series of stages beginning with initiation and ending with maturity. These stages were identified based on the analysis of computer budget expenditure for each organisation and plotted as a curve (Figure 4). It was suggested by Gibson and Nolan (1974) that the curve, represented the growth of applications, the growth of personnel specialisation, and growth of formal management techniques. From the analysis of the organisations it was postulated that the further through the stages an organisation was, the greater the efficiency achieved in its use of IT (Nolan, 1979; Nolan, 1977; and Gibson and Nolan, 1974). This is attained through the integration, standardisation, and dispersal of IT throughout the organisation.

The assertion that the computer budget may used as an surrogate indicator for a number of aspects relating to IT management has been disputed on several occasions (King and Kraemer, 1984; Drury, 1983; and Lucas and Sutton, 1977).

Whilst acknowledging its limitations, the appeal of the model is its simplicity and logical progression. Most IT managers can relate their organisation to a position on the development model and therefore may take advantage of the management policies suggested by Nolan for each stage. These policies attempt to facilitate innovation and development while restricting cost overruns. While Nolan (1973) acknowledges that the use of this indicator is less than ideal, the point is made that few alternatives exist for the convenient verification of the assertions made.

5. Maturity and Integration with GIS

Organisations identified as having a higher level of maturity, appear to be integrating their GIS with conventional IT (Marr and Benwell, 1996b). It is therefore suggested that the Nolan model provides a suitable basis for the development of a parallel GIS model. New Zealand local government organisations were asked to determine their relative position on a development line similar to that shown in Figure 5. The line is not intended to represent a linear relationship, but more a general progression of development. Respondents in the survey were asked to indicate via the addition of a vertical line, the position they felt their organisation had reached. By the inclusion of an arbitrary scale on the X axis, their response could be measured numerically.

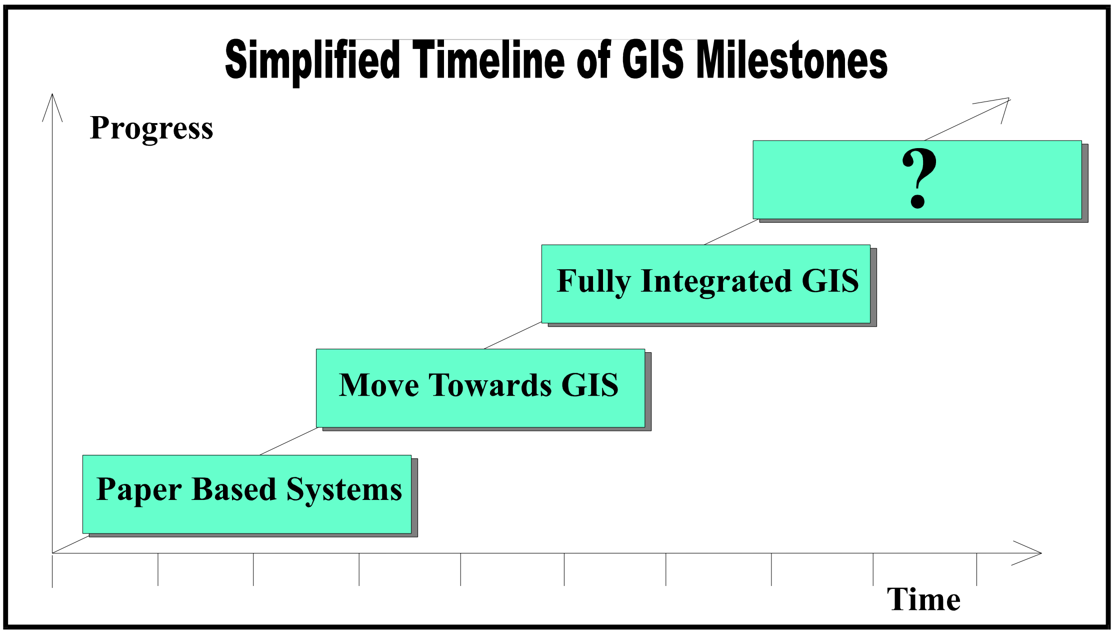

Figure 5 - Simplified Timeline of GIS Milestones
From Marr (1996)

The definition of '*Paper based systems*' is where primary operation in the organisation is undertaken using new and existing paper plans, documents, and microfiche. *'Move towards GIS*' describes the situation where initial GIS purchase, both hardware and software has been made, and electronic data capture is in progress, resulting in some limited functionality. When 100% of the data capture is complete (or very close), and the GIS is fully operational achieving original objectives, it is described as being at the '*Fully Integrated Stage'*.

The respondents were also asked to name the fourth unidentified stage. This was designed to illicit the response of 'Integration of Corporate Data Resources'. This is where all organisational data is integrated as a corporate resource. Based on the response to the question 56% of the respondents correctly identified this stage. This suggests that while for most organisations the GIS implementation process is far from complete, there is clear focus on the end objectives. The timeline is highly simplified and subjective, but it is believed that most organisations with GIS would relate to the general concept shown. The respondents were provided the opportunity to comment on the model. Comments were made on the length of time required during the data capture phase, and some raised the issue as to whether corporate integration would ever be achieved. While these points are acknowledged, none of the respondents dismissed the model outright, leading to the confidence that the model and resulting responses are appropriate.

The graph not only represents a general progression of development, but is also indicative of a rise in the maturity level in the use of GIS in the organisation. This is founded on the assertion that as integration increases, the number uses and users also increase. This is inline with maturity definition by Mayr (1995). Although a numerical indicator is created, it suffers in accuracy from the subjective and continuous scale from which it is derived.

The remaining portion of this paper is devoted to the formulation of a computational method for measuring an organisation's maturity level based on the analysis of discrete data. It is suggested that such a method would provide an improved model, that was free from bias, from which to perform cross-organisation comparison.

6. A Computational Indicator of Maturity

Six individual variables (Table 1) believed to be potentially related to GIS maturity by the authors, were identified from the survey and a correlation matrix (Table 2) produced using SPSS software (Norušis and SPSS Inc., 1993). In addition, the variable POS was also included in the matrix representing the maturity level identified for each organisation from the development line. The assumption was made that variables achieving high correlation coefficients in relation to the POS variable, could be regarded as significant in the construction of a maturity indicator. POP and AGE were the only unconstrained variables, the others related only to the options provided. The effect of this aspect with regards to the creation of a generic indicator of maturity is to provide standardisation.

ID Code	Description of Variable
ACCEPT	The Degree of Acceptance of GIS in the Organisation
DEPT	The Department Responsible for GIS
NUMD	The Number of Departments in the Organisation Using GIS
NUMUSE	The Number of the Uses which GIS is Assisting
POP	The Population Base of the Local Government Organisation
AGE	The Age in Years of the GIS Implementation

Table 1- Description of the Selected Maturity Variables
Marr and Benwell (1996b)

	ACCEPT	AGE	DEPT	NUMD	NUMUSE	POP	POS
ACCEPT	1	0.0360	0.0684	0.3075	0.3291	0.0525	0.1586
AGE		1	0.1286	0.4865	0.4329	0.2877	0.3132
DEPT			1	0.1564	0.1528	0.1774	0.0400
NUMD				1	0.4979	0.2226	0.3613
NUMUSE					1	0.2763	0.5314
POP						1	0.0610
POS							1

Table 2- Coefficients of Possible Maturity Variables
From Marr and Benwell (1996b)

The highest three correlation matrix values in relation to POS were NUMUSE, NUMD, and AGE with 0.5314, 0.3613, and 0.3132 respectively. To further analyse the relationship between each variable and POS, Chi square tests (χ^2) were performed (Daniel, 1990). This additional statistical analysis was used to show that each variable and POS are dependant and further justify the variables selected. The values for each variable were categorised in matrix form against the POS value for each organisation. When required, real values on the boundary of categorisation, were rounded up to the nearest integer. Associated with the Chi square test is the Cramér statistic value which used to determine the strength of an identified relationship (Table 3). The results confirm the use of these variables as significant

ID Code	X^2	χ^2	Deg. of Freedom	Cramér Value
NUMUSE	18.402	16.812	6 (to 0.99)	0.50
NUMD	37.457	21.666	9 (to 0.99)	0.62
AGE	N/A	N/A	N/A	N/A

Table 3 - Statistical Analysis of Maturity Variables
From Marr and Benwell (1996b)

In the case of AGE, the average expected frequency failed to obtained the minimum of 2.0 recommended by Daniel (1990). This would have introduced uncertainty in any resulting statistics if followed through. Still, a relationship clearly exists as shown in Table 2.

Although some circularity and inter-variable dependence is likely to exist, it is considered unavoidable since the assumption has been made that all the variables combine to form an approximate maturity level of GIS use. Observation of organisations with GIS suggests that no single variable is capable of being used as an appropriate indicator of maturity.

To create the required surrogate indicator of maturity in GIS use, there is a need to incorporate the values of the three variables (NUMUSE,NUMD, and AGE) to form one new computational indicator of maturity. One method of achieving this in diagrammatic form is shown in Figure 6. Each organisation may be represented in three-dimensional space based on the value of the three variables identified above. The variables form the three axis of the model. An extended line is drawn from the origin, through an axis represented by the corresponding values for each variable on the correlation matrix (Table 2). Values on the line are then taken to represent the level of integration and thus a surrogate measure for maturity of GIS use. This technique has previously been used by Lilburne (1996) to show the inter-relationships of interface, data, and functionality in systems integration.

The position of an organisation on the integration line is determined by computing the shortest distance between the (X,Y,Z) of the organisation and the line itself. The imaginary line from each point forms a 90º angle with the line of integration. The standard algebraic equations to analyse these are shown in Figure 7, and may be incorporated in any spreadsheet package. Also shown is the formula to compute the length of a point on the line from the origin. This distance then becomes the amalgamated indicator of maturity.

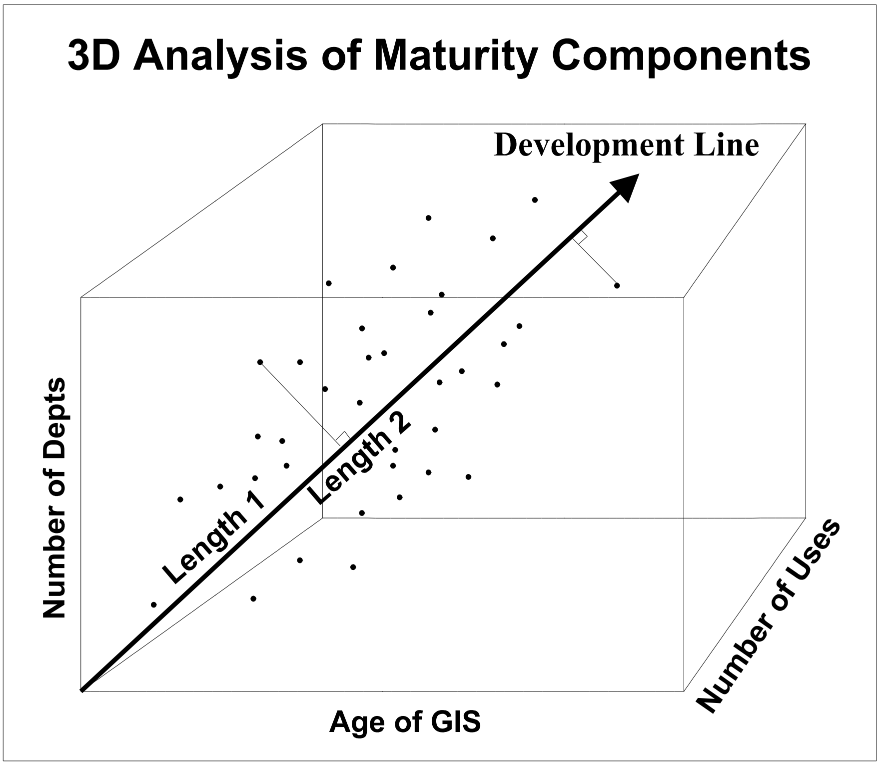

Figure 6 - 3D Analysis of Maturity Components with Two Examples
from Marr and Benwell (1996b)

To test this concept, a correlation matrix was produced to assess the relationship between the derived maturity value from the model and the position of the responding organisation as indicated in Figure 5. This resulted in a positive correlation coefficient of 0.5233. In addition, the Chi-square test was also performed. This resulted in X^2 of

24.598 which is greater than χ^2 of 13.277 with 4 degrees of freedom. The Cramér statistic produced a value of 0.577 indicating a very strong relationship. For additional analysis the values for each organisation derived from the integration model were plotted against the POS values indicated by each respondent. The resulting graph (Figure 8) shows a positive relationship between the two values for each organisation as expected.

Where

$\underline{n} = (n_1,n_2,n_3)$ = coefficients(*numuse, numd, age*)

$\underline{a} = (a_1,a_2,a_3)$ = (*NUMUSE, NUMD, AGE*)

$\underline{z} = (z_1,z_2,z_3)$ = *Standardised Position Vector*

Then

$$\underline{\hat{n}} = \frac{\underline{n}}{|\underline{n}|} = \frac{1}{\sqrt{n_1^2 + n_2^2 + n_3^2}}(n_1,n_2,n_3)$$

Position Vector = (Z_1, Z_2, Z_3) =

$$(\underline{a}.\underline{\hat{n}})\underline{\hat{n}} = \left(\frac{a_1n_1 + a_2n_2 + a_3n_3}{n_1^2 + n_2^2 + n_3^2}\right) \times (n_1,n_2,n_3)$$

$$\text{Distance } |\underline{Z}| = \sqrt{Z_1^2 + Z_2^2 + Z_3^2}$$

Figure 7 - Equations for Position Determination

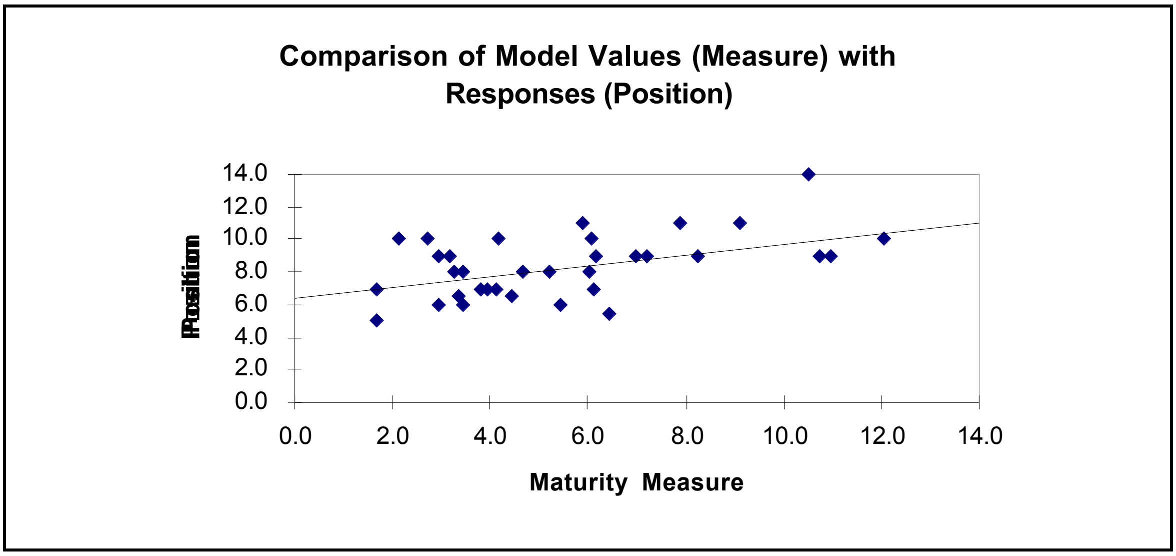

Figure 8 - Comparison of Model Values and Response Values
From Marr and Benwell (1996b)

The graph and the previous statistical analysis suggest that the number of uses of GIS, the number departments using GIS and the age of the GIS, can be used in combination to form an approximate measure of GIS maturity in New Zealand local government. While potential problems have been acknowledged such as circularity and inter-dependence, the model represents a serious attempt to map an organisation's effective GIS development. The development of the indicator draws on previous research in this field relating to general IT. It is suggested that the Nolan model forms a suitable foundation, due to the observed parallel nature of the two technologies, particularly in those perceived to be at a more mature level of operation. The model uses data identified as being related to maturity (Mayr, 1995), but also encompasses the concept that the differences between maturity of use and integration appear minimal.

7. Conclusion

The aim of this paper was first, to discusses the concept of maturity in the use of GIS and second, formulate a computational method for measuring an organisation's maturity level from the construction of a surrogate indicator. From the accumulated data and discussion it has been found that the process of a maturing GIS can be mapped empirically with some degree of confidence. With the use of statistical analysis techniques, a comparison has been made as to which organisations have the greater level of GIS maturity based on the variables NUMUSE, NUMD, and AGE. This model can be used to assess an organisation's progress in relation to other comparable authorities. It is also suggested that with more testing, the model concept may possibly apply to other organisations outside local government.

8. References

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