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A Structural and Evolutionary Approach to Change Management

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Abstract

Organizational change management is concerned with realizing strategies using models, methods and prescriptions that seek to guide the three key elements of strategic management process: *strategic analysis* (what is our current configuration?), *strategic choice* (what is our desired configuration?) and *strategic implementation* (how to realize the desired configuration?). To address these strategic management issues, this paper presents an evolutionary and structural approach that uses a classification technique (cladistics) and a method from algebraic topology (q-analysis) to identify and understand different organizational configurations, along with the relationships and connectivity (change route) between a current and desired configuration. A simple example data set is used to introduce and describe the cladistic and q-analysis methods. This is followed by an application of the technique to a data set from the automotive assembly industry.

Keywords: change management, q-analysis, cladistics, manufacturing systems, evolutionary model

1. Introduction

One reason why organizations change is because they are open and evolving systems influenced by alterations in their environmental (internal or external) conditions. It is this ability to evolve that contributes to the difficulty of understanding and managing organizational change. In fact, the preceding characteristics indicate that organizations are not rational, mechanical and deterministic systems. The latter, along with accounts from previous change management projects, suggest therefore that success in implementation tends to be patchy (Grover, 1999; Redman, 1999; Alpander and Lee, 1995; Siegal et al., 1996).

At the micro level, all organizations are unique, but at the macro level it is possible to aggregate organizations into distinct groups of configurations, each sharing common characteristics (e.g. resources, routines and capabilities). These organizational configurations or 'prescribed formats' (Greenwood and Hinings, 1996; Hinings and Greenwood, 1988) are best thought of 'not as a loosely coupled clustering of structural properties, but as overall gestalts' (Hinings and Greenwood, 1998, p. 9). They are argued to form the target of the change management process, which involves achieving change within a configuration, or more rarely, the movement from one configuration to another. This latter shift is considered to be primarily dependent on the attitudes, values, beliefs and mindsets, the so-called 'interpretive schema', of senior managers acting in their design roles as organizational architects and leaders (Tranfield and Smith, 2002).

Therefore, we argue that appreciating organizations as evolving configurations is potentially helpful to understanding the change management process. Such a view requires a systematic approach to the classification of 'prescribed formats' to facilitate scholars and practitioners in understanding and ordering the evolving nature and diversity of configurations. Classification of this type would offer models from which ideas for alternative configurations might be developed and then realized in practice. Systematically understanding the "organizational specie" in the fields that influence the 'interpretive schema' of managers, could be immensely valuable in aiding understanding and facilitation of both the mimetic change and mutational change processes. However, so far, the identification and application of a valid and reliable approach to this problem has proved elusive and thus provides a key motivation for this research.

To help address this problem, a structural and evolutionary approach to change management using the cladistic and q-analysis methods is developed and presented. Cladistics permits systematic analysis and classification of organizational diversity (the classification result is called a cladogram), and acknowledges that organizations, while essentially dynamic, achieve short-term periodic stability through consistent patterning among organizational characteristics. The area of algebraic topology known as q-analysis provides a method and parameters to determine how distant a current configuration is from a desired configuration. In combination, cladistics and q-analysis offer an approach that is capable of providing information that will help address the three key elements of strategic management process: strategic analysis (what is our current configuration?), strategic choice (what is our desired configuration?) and strategic implementation (how to realize the desired configuration). In addition, the application of q-analysis and cladistics to change management is consistent with the 'quantum view' (Miller and Friesen, 1984) or "coarse-grained" approach (Gell-Mann, 1994; Sherman and Schultz, 1998) and relates to the earlier work of Pugh et al. (1969) and Mintzberg (1979), who emphasized the importance of patterning in structural elements to produce typologies and taxonomies of organizations.

This paper is organized as follows: A description of the underpinning theoretical constructs of cladistics and q-analysis is first given through a simple worked example that is provided to demonstrate the methods. Then a data set from the automotive assembly industry is used to apply cladistics and q-analysis for a change management process on a larger scale. Finally, a discussion about potential benefits that change management planning could derive from an evolutionary and structural approach is given with special emphasis on its ability to classify and determine the path and distance between strategic change options.

2. Introduction to Cladistics and q-Analysis

Organizational theory accepts that organizations evolve, but one of key differences between biological and organizational evolution is that managers use their decision-making capability to influence this evolution. Thus, organizations can modify their configuration in an attempt to ensure future and current survival, and this manifests various changes over time. This evolutionary change can be assembled into a study of organizational forms based on resultant configurational variety (Mckelvey, 1982; Hannan and Freeman, 1989; McKelvey, 1994).

There are two basic perspectives to studying the evolutionary process and its impact on organizational existence and change: the *ecological* approach (Aldrich, 1986, 1999; Hannan and Freeman, 1989; Baum, 1999) and the *systematic* approach (classification) (McKelvey, 1982; Ulrich and McKelvey, 1990). The ecological view focuses on the transformation processes (e.g. converting an idea or need into a marketable product), and the interactions and mechanisms that accompany an organization's response to environmental conditions. It was this view that primarily identified the organizational evolutionary processes of variation, selection, retention and struggle (Campbell, 1969; Aldrich, 1999). The systematic view examines organizational diversity to help create or contribute to a theory of differences (*taxonomy* is the theory and practice of delimiting and classifying different kinds of entities). The resulting classification is a system or scheme for arranging configurations into *taxa* (hierarchical groups or classes), based on the characteristics or theory identified from the taxonomic process.

The cladistic school of classification acknowledges both the ecological and systematic perspectives, as it involves identifying and using shared and derived organizational characteristics to construct common ancestry relationships between entities. The groups or configurations of the classification are generated through the creation of the common ancestry relationships.

2.1. The Cladistic Classification Process

The development and application of the cladistic classification method to organizations was first explored by McKelvey (1978); who argued that the management research community could learn valuable lessons from biological classification techniques. Motivated by this work, McCarthy (1995) and McCarthy et al. (1997) created pilot cladistic classifications of manufacturing organizations based on classic biological approaches to cladistics. This was followed by McCarthy and Ridgway (2000) who presented a methodology for constructing a cladistic classification. A summary of the relevant stages of the methodology are described in the simple example that follows. This method has since been applied to the concept of benchmarking (Fernandez et al., 2001), strategies in the hand tool manufacturing industry (Leseure, 2002) and facilities management organizations (Lord et al., 2002). This paper extends earlier work by exploring the utility of cladistics in addressing the three key elements of strategic change management and by using q-analysis to help identify and measure the relationships and connectivity (change route) between a current and desired configuration.

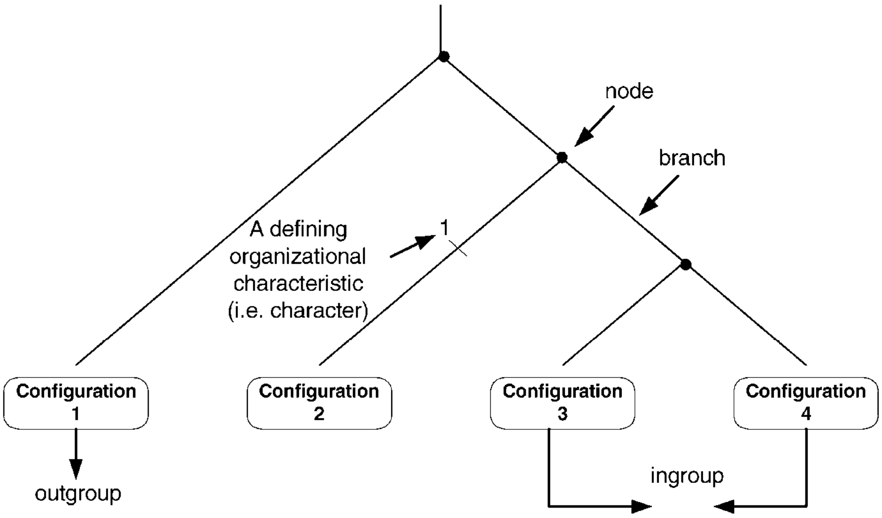
Table 1. Example data.

	Characters									
Configurations	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
F1	0	0	0	0	0	0	0	0	0	0
F2	0	0	0	0	0	0	0	0	1	1
F3	0	0	0	0	0	0	1	1	1	1
F4	0	0	0	0	0	1	1	1	1	1
F5	0	0	1	1	1	1	1	1	0	1
F6	1	1	1	1	1	1	1	1	1	1

To explain the cladistic and q-analysis methods, the following sections use a simple and hypothetical example. The data for the example is shown in Table 1. It is binary coded, assumed to be resolved and is used specifically to explain how a cladogram is constructed in stage 4 of the example. The example data contains six organizational forms (configurations) labeled F1 through to F6, and ten organizational characters (characteristics) labeled C1 through to C10.

Before describing the cladistic classification process, it is necessary to introduce the system that is used to represent a cladistic classification (the cladogram) and briefly discuss the principles of *phylogeny*, *congruence* and *parsimony*. The philosophical foundations of cladistics focus on the search and selection of shared and derived characters that are used to identify the common ancestry relationships between different configurations. The construction of these relationships produces a cladogram (see figure 1) that orders different configurations as a hierarchical system (the classification) based on common ancestry (phylogenetic analysis). Thus, a cladogram is a branching diagram assumed to be an estimate of the relationships between the configurations under study and the final output of a cladistic analysis. It represents the succession of changes that organizational configurations experience i.e. the phylogeny. The principle of congruence states that a classification should provide internal consistency i.e. the characters used for a classification should provide one unique phylogenetic relationship, assuming that the configurations are derived from a common ancestor. Finally, the principle of parsimony requires that *ad hoc* assumptions should be minimized as far as possible when explaining natural phenomena. Thus, from all the theoretical possible cladograms, the simplest one is chosen, i.e. the one with the minimal number of nodes (evolutionary changes).

Stage 1: Select the Manufacturing Clade. The starting point is to define the clade or study group to be classified. In this case, it is a simple and made up study group with generic labels given to the organizational configurations and characteristics (See Table 1). An actual study would select a group of organizational configurations that satisfy certain research objectives or business interests. Classifications based on industry and competitor similarities are widely used and accepted and are difficult to ignore when beginning a cladistic classification. Hence, the definition and boundary of the study group focused on organizational



Outgroup - The ancestral configuration used to help resolve the polarity of characters.
Ingroup - A set of configurations considered to be more closely related to each other than any are to the outgroup.
Node - A branch point on a cladogram representing a speciation event
Branch - A line connecting a branch point (node) to a terminal point

Figure 1. A cladogram.

entities that compete and are involved in resource exchange and transformation of a similar nature.

Stage 2: Determine the Characters. Once the clade has been defined, a number of different types of configuration automatically appear to be a member of that clade. For instance, if the study group were based on automotive assembly plants, then configurations such as mass production, lean production, agile, craft, job shop etc. would be candidates. At this stage, complete membership of a clade and the defining characteristics of each configuration are not always known. To develop the membership, existing classifications can be used to validate, enhance and expand such knowledge. In addition, the initial group of configurations is considered a polytomy, because the relationships between the entities have not yet been identified (see figure 2).

With the generic example data provided, it is not possible to provide a contextual explanation of the process of determining characters, but it is possible to describe the key tasks which are a form of historical excavation involving character search and character selection. This is where evidence is sought to suggest the possible existence of a particular type of configuration. Often, such evidence tends to be in the form of published material or archives, which detail the existence of new strategies and organizational forms, along with a description of their operations and defining characteristics, the location where it exists/existed and a date when it was first discovered or evolved. For a detailed discussion of the character search and selection process the reader is referred to McCarthy et al. (2000).

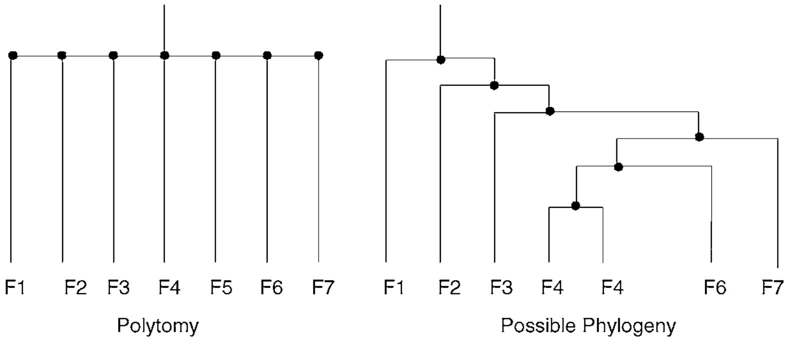


Figure 2. Polytomy and phylogeny.

The key aim of the character search and selection process is to identify the existence of a particular type of organizational characteristic (a synapomorphy) that indicates a natural and parsimonious grouping. Synapomorphies are characters that have a derived (advanced) state and are shared by two or more configurations and thus indicate common ancestry (evolutionary similarity). This data collection phase is also vital for the q-analysis process, which depends on the coherence of the hierarchical aspect of the data set (Atkin, 1980; Johnson, 2000).

Stage 3: Character Coding and Polarization. Once a set of characters has been identified, along with a set of configurations that are an outcome of these characters, the relationship between the characters and the configurations is examined to identify phylogenetic relationships and thus begin construction of the cladogram. The result is a matrix of data, which in this case is the data presented in Table 1.

The character data in Table 1 reveals relationships, because it exhibits three properties: direction, order and polarity, (Swofford and Maddison, 1987). It is the coding (in this case binary) of a character that represents these properties and facilitates the processing of the character set. Ordering is that property of a character that refers to the possible character change sequences that can occur, whilst direction refers to the transition between character states. When the direction of transformation for a character has been determined, the character is said have a polarized state.

Crucial to the cladistic method is the task of identifying and using shared and derived organizational characteristics to construct common ancestry relationship. Determining whether a character is derived or ancestral is a process of understanding the *character state*. The method of revealing character states is called *character polarization* or *character argumentation* (Wiley et al., 1991) and is based on *a priori* arguments of an "if, then" deductive nature and of the methods proposed by Henning (1966). These methods include the outgroup comparison method which is discussed in the next stage.

Stage 4: Construct Cladogram. Once the characters have been selected, polarized and coded (i.e. Table 1 has been produced), the next stage in the cladistic process is to construct cladograms. According to Lipscomb (1998), the key method for constructing cladograms is the Henning Argumentation method (Henning, 1966) and using the example data in Table 1, it is possible to manually show how this method is used to construct a cladogram. However, when the data set is larger and more complex it is usually processed using phylogenetic software that examines the evolutionary relationships within and between groups. Recommended software tools include: PHYLIP (Felsenstein, 1989, 1993), PAUP (Swofford, 1998) and MacClade (Maddison and Maddison, 1992).

The Henning Argumentation method is based on the inclusion/exclusion rule. This rule states that if the information available allows for either complete inclusion or complete exclusion of groups, then an hypothesis of relationships can be generated. The method analyzes the character information one by one and is described using the following example:

- The matrix (Table 1) contains a set of character data consisting of ten characters; and six configurations, one of which (F1) is the outgroup. Until processed, the data is considered a polytomy (figure 3—step 1).
- Characters C1 and C2 have a derived state, found only in configuration F6, and are thus defined as “uniquely-derived” i.e. only found in configuration F6 (figure 3—step 2).
- Characters C3, C4 and C5 have derived states, shared by configurations F5 and F6, and thus defined as “shared and derived” characters that unite F5 and F6 (figure 3—step 3).
- Character C6 has a derived state and is shared by configurations F4, F5 and F6, and is thus defined as a “shared and derived” character that unites F4, F5 and F6 (figure 3—step 4).
- Characters C7 and C8 have derived states, shared by configurations F3, F4, F5 and F6, and are defined as “shared and derived” characters that unite F3, F4, F5 and F6 (figure 3—step 5).
- Characters C9 and C10 have a derived state, shared by configurations F2, F3, F4, and F6, and are defined as a “shared and derived” characters that unite F2, F3, F4, and F6 (figure 3—step 6), but C10 is also present in F5, but C5 is not and this is indicated by −9 (a character conflict) on F5.

In the example described above, constructing the cladogram is a relatively simple process. However, in a real study, significantly more characters and configurations are involved, sometimes creating numerous conflicts in the relationships among the configurations. Also, with larger sets of characters, many different hypothetical cladograms can be constructed. Potential cladograms are then validated according to the principles of parsimony and congruence using three descriptive statistics (tree length, consistency index and retention index) that show the level of similarity from independent evolutionary change achieved by the cladogram.

The tree length of a cladogram is the number of times that characters change from 0 to 1 or vice versa. The cladogram with the minimum length is considered to have fewer independent evolutionary changes and, as a consequence, to be the best (most parsimonious) cladogram. To illustrate tree length, the final cladogram shown in figure 3—step 6 is considered along with another possible tree for the example data (see figure 4). The cladogram on the left requires eleven character state changes (tree length = 11), as each character changes once in the cladogram apart from character 9 that changes twice, whereas the cladogram on the right requires 18 character state changes (tree length = 18). Hence, based on the tree length

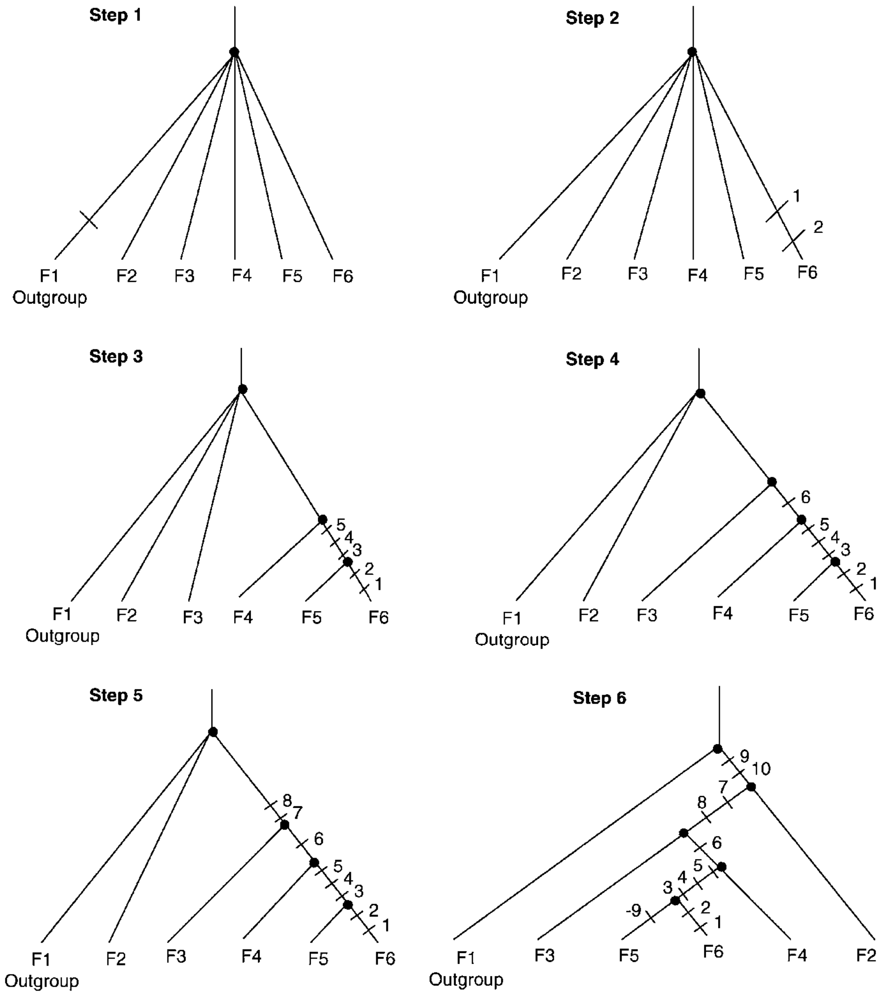


Figure 3. Constructing a cladogram.

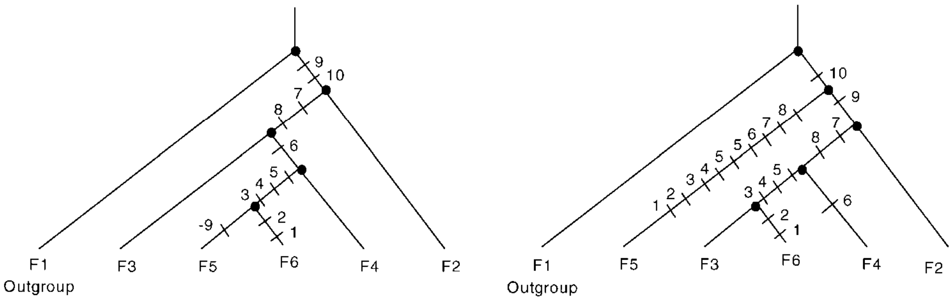


Figure 4. Tree length.

only, it is concluded that the left tree is the most parsimonious and as a consequence offers a better hypothetical representation of the example configurations.

The consistency index (CI) serves to measure the level of difficulty in fitting a data set to a cladogram (CI). Where M is the total number of character changes expected from the data set and S is the actual number of changes that occur in the cladogram (i.e. the tree length) the CI is calculated with the formula:

$$\mathrm{CI} = \frac{M}{S} \tag{1}$$

For instance, in the example depicted in figure 3—step 6, there are ten characters with two states and assuming that they change only once $M = 10$. With the tree length ($S = 11$), the consistency index is thus $10/11 = 0.90$. A consistency index of 1 indicates a perfect fit between the data and the cladogram under analysis.

Finally, the retention index (RI), measures the proportion of synapomorphy (shared and derived characters) in a cladogram. In other words, the retention index is a measure of the proportion of similarities in a cladogram (Farris, 1988). Where M and S are the same variables used by the CI, and where G is the total number of configurations with state 1 or 0 (which ever is smaller), the retention index is calculated using the formula:

$$\mathrm{RI} = \frac{(G - S)}{(G - M)} \tag{2}$$

To illustrate how the RI is obtained, the example data set is developed (see Table 2). The retention index is calculated as:

$$\mathrm{RI} = (17 - 11)/(17 - 10) = 0.85.$$

The closer the RI is to 1 the better the tree is considered to be.

In summary, a cladistic analysis consists of three inextricably interlinked processes: the search and selection of characters and configurations; the character coding; and the

Table 2. Retention index calculation.

	Characters									
Configurations	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
F1	0	0	0	0	0	0	0	0	0	0
F2	0	0	0	0	0	0	0	0	1	1
F3	0	0	0	0	0	0	1	1	1	1
F4	0	0	0	0	0	1	1	1	1	1
F5	0	0	1	1	1	1	1	1	0	1
F6	1	1	1	1	1	1	1	1	1	1
Max steps (g)	1	1	2	2	2	3	2	2	1	1
									$G = \Sigma g = 17$	

determination of the best cladograms (i.e. the cladogram that best explains the relation between characters and entities).

2.2. *The q-Analysis Method*

To analyze the mathematical structure of the data, assumptions and relationships within a cladogram, the q-analysis method is used as an elicitation technique that provides further understanding of a priori knowledge, but cannot be used to build the data set (i.e. select characters and cases). The example data in Table 1 is used to introduce and describe q-analysis. The same example is used to explain the three q-analysis parameters (i) structure vector, (ii) eccentricity measures, and (iii) complexity measure.

The q-analysis method provides structural interpretations of a cladogram that could assist organizations in resolving strategic management issues about changing from one configuration to another. Pioneered by Ron Atkin (Atkin, 1980), q-analysis is a combination of geometric and algebraic tools for studying the relationships and connectivity among entities in a complex system. The method has been used in social science (Cullen, 1983; Atkin, 1980; Macgill, 1985; Seidman, 1983) political science, industrial relations (Atkin, 1980), community studies (Jacobson and Yan, 1998), planning (Johnson, 1981; Macgill and Springer, 1986) and supply chain management studies (Rakotobe-Joel, 2000, 2001; Houshmand and Rakotobe-Joel, 2001).

The q-analysis method provides a description of complex systems in terms of a relatively static backcloth (i.e. the layers of structure that contain the data) that supports a dynamic traffic of system activities (Johnson, 1990). Using this approach, social communities have been described where the static element consists of community members against the traffic of influences and issues that pattern the system (Cullen, 1983; Atkin, 1980; Mcgill, 1985; Seidman, 1983). In industrial relations, planning and management systems have been described in terms of their relations with the systems members, such as supply chain elements or manufacturing system elements (Singh, 2002; Rakotobe-Joel, 2001; Houshmand and Rakotobe-Joel, 2000, 2001; Johnson, 1981, 2000; Macgill and Springer, 1986). In summary, q-analysis describes a number of data representations between two entities or sets and seeks to elucidate their meaning by computing various relational parameters (structure vector, obstruction vector and eccentricity measures), providing therefore a better insight into the structural configuration of the connections.

2.2.1. Data Representations. The study of the relationship λ between two sets of entities (figure 5), called the simplex set and vertex set, is the foundation of q-analysis. In regard to the application of q-analysis to an organizational cladogram, the simplex set is the set of organizational configurations and the vertex set is the set of associated organizational characteristics. Thus, the data contained in Table 1 is equivalent to the relationship λ. From this data, an incidence matrix $\Lambda = [x(j, k)]$, defined mathematically as:

$$x(j,k) = \begin{cases} 1 & \text{if } (A(j), B(k)) \in \lambda \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

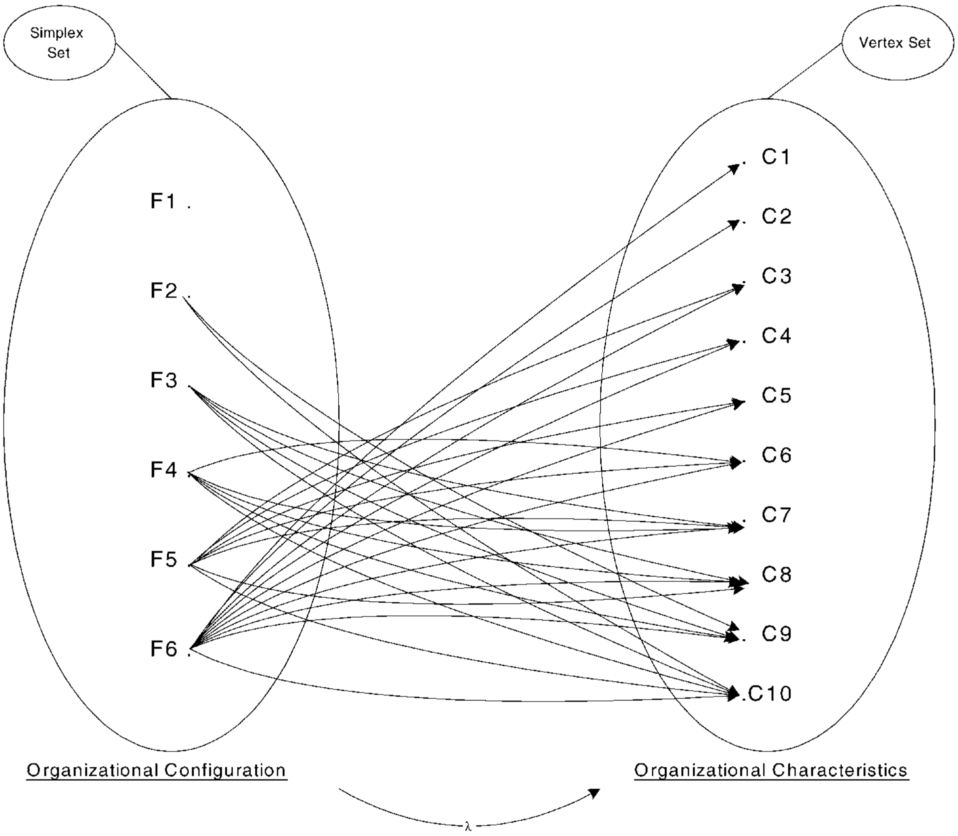


Figure 5. Relational structure of organizational configuration.

In applying this relation to the cladogram example, the configurations are associated with their individual characteristics according to the resolved data given in Table 1. This data indicates alternative known strategies, their defining characteristics and resulting configurations. As the codification used is binary (i.e. 1 if the characteristic is present and 0 if not), a simple change management process could use this data to identify an organization's current configuration and a potential desired configuration, along with difference in defining characteristics. Even though this approach is simple, and logical, it could mislead a change manager, as moving from one configuration to another requires an understanding of the relationships between characteristics as well as the relationships between alternative configurations.

Each configuration can be represented by a relational structure, expressed as an n-dimensional polyhedron σ (See Table 3), that is based on the results of the membership function. Each configuration is represented by the set of characteristics that make define it.

Table 3. Relational structure of organizational configurations.

Configuration F1: σ(F1)	⟨–⟩
Configuration F2: σ(F2)	⟨C9, C10⟩
Configuration F3: σ(F3)	⟨C7, C8, C9, C10⟩
Configuration F4: σ(F4)	⟨C6, C7, C8, C9, C10⟩
Configuration F5: σ(F5)	⟨C3, C4, C5, C6, C7, C8, C10⟩
Configuration F6: σ(F6)	⟨C1, C2, C3, C4, C5, C6, C7, C8, C9, C10⟩

2.2.2. The q-Analysis Parameters. The q-analysis parameters (structure vector, obstruction vector and eccentricity measures) provide the key descriptions of the data sets and are computed using an algorithm developed by Atkin (1980) and furthered by Johnson (1990) according to the assumption that if the simplices σ(A) and σ(B) are q-connected, then they are also $(q - \sigma)$ connected at $\sigma = 1, \ldots, q$. This means that if two simplices are connected at a given higher level, then they are also connected at all lower levels. Applying this concept to analyze the data in a cladogram suggests that if two organizational configurations have shared and derived characteristics, then they should have the same ancestral organizational configuration. These parameters therefore describe the complexity of change for a given data set and are determined using the following method:

(1) Form $\Lambda\Lambda^T$ (an $m \times m$) matrix, where Λ was previously defined as the incidence matrix.
(2) Evaluate $\Lambda\Lambda^T - \Omega$, where Ω is an $m \times m$ matrix with all entries equal to 1.
(3) Retain only the upper triangle part (including main diagonal) of the symmetric matrix $\Lambda\Lambda^T - \Omega$. This is the shared-face matrix, as shown in Table 4. This matrix indicates the dimension of the faces shared by the simplices. For example, it can be deduced, that configuration F3 and configuration F5 share three characteristics (i.e. C7, C8, and C10).

The above three-step approach was used to obtain the values in Table 4, which represents the upper triangle portion of the symmetric matrix $\Lambda\Lambda^T - \Omega$. This matrix is used to compute the q-analysis parameters.

Table 4. Symmetric matrix.

	F1	F2	F3	F4	F5	F6
F1	**−1**	−1	−1	−1	−1	−1
F2		**1**	1	1	0	1
F3			**3**	3	2	3
F4				**4**	3	4
F5					**6**	6
F6						**9**

2.2.2.1. Structure Vector. The structure vector (Q) provides a summary of the overall organization of the relationship λ (Atkin, 1980). In terms of a cladogram and change management it provides a representation of the connectivity within for the total classification and information about the interactivity between various configurations and their shared characteristics. It is also a parameter that helps to verify the evolutionary changes experienced by the different configurations. For data given in Table 4, the structure vector is represented as followed:

$$Q = \{\overset{-1}{1}, \overset{0}{2}, \overset{1}{2}, \overset{2}{2}, \overset{3}{2}, \overset{4}{2}, \overset{5}{2}, \overset{6}{2}, \overset{7}{1}, \overset{8}{1}, \overset{9}{1}\}$$

The norm of the structure vector is a measure of the complexity of the structure of the total set of configurations given in Table 2. To remove any bias from the number of characters used, it is better to divide the norm of Q by the norm of the unit vector of the same dimension. This ratio provides a comparison of the complexity levels for the different classifications (e.g. different sectors).

2.2.2.2. Obstruction Vector. The obstruction vector (Q^*) is derived from the structure vector and represents the level of stability at the branching level i.e. the degree of freedom of each structure vector component has. In terms of cladistics and change management, the obstruction vector indicates the level of difficulty for one configuration to change into another. The higher the obstruction vector, the more difficult it is to change. If the obstruction vector is zero, then this indicates that no bifurcation points exist within a cladistic classification, and thus the organizational change from one configuration is along the same branch and is relatively simple. If the obstruction vector is not zero, this indicates the existence of branching points and thus any organizational change is constrained by path dependency. Some changes are not possible unless some characters are reversed to go back to the closest ancestral state that would allow such a change. In other words, the norm of the obstruction vector is a direct measure of the existence of path dependency in an industry, and thus, a direct measure of the resistance to change that organizations may encounter. Table 5 shows the various configurations that share common numbers of characteristics with the associated obstruction Q^* at each level.

By applying q-analysis to change management, we argue that the relationship between the structure vector and the obstruction vector provides insightful information about the level of fitness or adaptability for a given organizational configuration. This concept of fitness relates to the degree of obstruction that preserves a configuration to its position on the cladogram and thus prevents it from changing into other forms. Equally, the ability of a configuration to overcome the level of obstruction at a given branching would indicate its level of fitness.

2.2.2.3. Eccentricities. To further the analysis of relationships between configurations, a measure of eccentricity is used in q-analysis. There are two types eccentricity measures: *eccentricity* (Ecc) provides a measure of the distance between alternatives, while the *eccentricity* (Ecc$'$) measures the level of isolation of a given alternative to the overall cladogram structure.

Table 5. Structure vector (Q), obstruction vector (Q^*), and equivalence classes.

q	Q	Q^*	Equivalence class
9	1	0	{F6}
8	1	0	{F6}
7	1	0	{F6}
6	2	0	{F6}, {F5}
5	2	0	{F6}, {F5}
4	2	1	{F6, F4}, {F5}
3	2	1	{F6, F4, F3}, {F5}
2	2	1	{F6, F4, F3}, {F5}
1	2	1	{F6, F4, F3, F2}, {F5}
0	2	1	{F6, F4, F3, F2}, {F5}
−1	1	0	{F6, F5, F4, F3, F2, F1}

Note. q-level "−1" is the outgroup.

Mathematically, (Ecc) measures the extent to which the simplex σ shares vertices with the simplex most highly connected with it, while (Ecc′) measures the extent to which the simplex σ shares vertices with all the simplex that are connected to it. Therefore, (Ecc′) depends on all the other simplices that are connected to it, while (Ecc) depends only on the closest simplex that is connected to it. With the following variable

- $\hat{q}$ as the dimension of the simplex σ
- q^* as the highest dimension at which σ joins another simplex in an equivalence class
- q_i are each q-level at where σ appears
- σ_i as the number of elements in its equivalence class at level q_i
- $q_{\max}$ as the maximum q-level of the complex (in our study example it is 9)

Ecc and Ecc′ are calculated as follows:

$$ecc(\sigma) = \frac{\hat{q} - q^*}{q^* + 1} \tag{4}$$

and

$$ecc'(\sigma) = \frac{2\sum_i \frac{q_i}{q}}{q_{\max}(q_{\max} + 1)} \tag{5}$$

The two types of eccentricities provide information on the relationship of an individual configuration to its nearest connected configuration and all the forms that are connected to it. Practically, (Ecc) provides the "distance" between two closest organizational configurations, while (Ecc′) indicates the relative level of integration of the organizational configurations

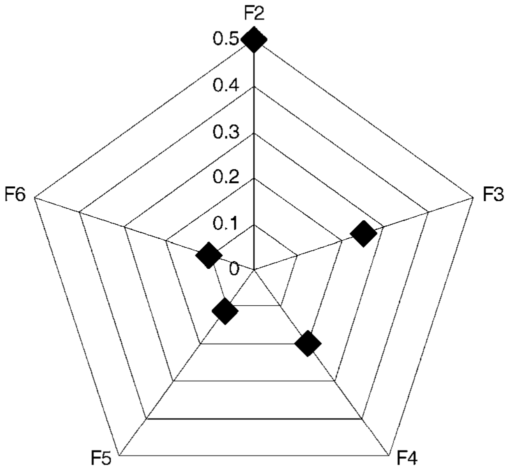


Figure 6. Eccentricities (Ecc).

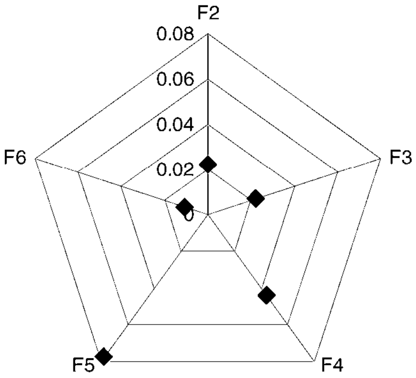


Figure 7. Eccentricity (Ecc′).

in the entire population. Figures 6 and 7 provide the illustrations of these ideas as it pertains to the data in Table 1.

A summary of the eccentricity analysis for all the configurations can be found in Table 6.

Table 6. Eccentricities.

Alternative configurations	Eccentricity (Ecc)	Eccentricity (Ecc′)
F1	–	
F2	0.500	0.022
F3	0.250	0.022
F4	0.200	0.044
F5	0.111	0.078
F6	0.100	0.011

Table 7. List of automotive assembly configurations.

F1.	Ancient crafts systems	F9.	Just in time systems
F2.	Standardized crafts systems	F10.	Intensive mass producers
F3.	Modern crafts systems	F11.	European mass producers
F4.	Neocraft systems	F12.	Modern mass producers
F5.	Flexible manufacturing systems	F13.	Pseudo lean producers
F6.	Toyota production systems	F14.	Mass producers à la Fordism
F7.	Lean producers	F15.	Large scale producers
F8.	Agile producers	F16.	Skilled large scale producers

3. The Automotive Data Set

This section introduces an automotive data set (See Tables 7 and 8) taken from McCarthy et al. (1997) and determines the corresponding structure vector, obstruction vector and eccentricity measures. From the 16 configurations and 53 characteristics given, a coded and polarized matrix is presented, along with the resolved and best-fit cladogram (Table 9 and figure 8). The relationship between the configurations and their respective characteristics is then used to generate the relational structure information in Table 10.

This data and the results provide a focus for a discussion that will examine the relevance and value of cladistics and q-analysis in understanding how certain configurations can adapt to other configurations. i.e. what level of connectivity represents the most probable area where change will occur and how might a configuration resist change or open to opportunities?

3.1. *Results and Discussion*

As per step 3 of the q-analysis method the upper triangle part (including main diagonal) of the symmetric matrix $\Lambda\Lambda^T$-Ω is retained (Table 11). This matrix indicates the dimension of the faces shared by the simplices and is used to compute the values of the q-analysis parameters. The structure vector (Q) and the obstruction vector (Q^*) for each level (q) of the automotive data set is represented by Table 12. The eccentricity values for the automotive data set are shown in figures 9 and 10 and Table 13.

To consider the value and relevance of the information represented by a cladogram, a section of the automotive cladogram is presented in figure 11. This cladogram and its network of branches provide a map that indicates an organization's current configuration and the history of its configuration. It also presents information about possible paths (the arrowed lines) from the current configuration to known and unknown/emerging configurations (dashed branches) i.e. either mimetic change or future mutational change. The character information represented by the cladogram branches and the identified paths between configurations is crucial to the strategic analysis and strategic choice aspects of change management. It is also important to recognize that evolution like competitiveness is a relative and

Table 8. List of manufacturing systems characteristics.

C1. Standardization of parts
C2. Assembly time standards
C3. Assembly line layout
C4. Reduction of craft skills
C5. Automation (Machine paced shops)
C6. Pull production system
C7. Reduction of lot size
C8. Pull procurement planning
C9. Operator based machine maintenance
C10. Quality circles
C11. Employee innovation prizes
C12. Job rotation
C13. Large volume production
C14. Mass sub-contracting by price bidding
C15. Exchange of workers with suppliers
C16. Training through socialization
C17. Proactive training programs
C18. Product range reduction
C19. Automation
C20. Multiple subcontracting
C21. Quality systems
C22. Quality philosophy
C23. Open book policy with suppliers
C24. Flexible, multi-functional workforce
C25. Set-up time reduction
C26. Kaizen change management
C27. TQM sourcing
C28. 100% inspection/sampling
C29. U-shape layout
C30. Preventive maintenance
C31. Individual error correction
C32. Sequential dependency of workers
C33. Line balancing
C34. Team policy
C35. Toyota verification of assembly line
C36. Groups vs. teams
C37. Job enrichment
C38. Manufacturing cells
C39. Concurrent engineering
C40. ABC costing
C41. Excess capacity
C42. Flexible automation for product versions
C43. Agile automation for different products
C44. In-sourcing
C45. Immigrant workforce
C46. Dedicated automation
C47. Division of labour
C48. Employees are system tools
C49. Employees are system developers
C50. Product focus
C51. Parallel processing (in equipment)
C52. Dependence on written rules
C53. Further intensification of labour

co-evolving process, and thus a cladogram provides a parsimonious snapshot of the landscape of configurations.

With the current and future configurations identified, a cladogram provides transparent and parsimonious information (i.e. the shortest path between configuration) about the assumptions and characteristics that differentiate one configuration from another. In addition, a cladogram indicates those characteristics that an organization should remove or devolve to achieve a desired configuration. For instance, if we consider that an organization with the current configuration (Lean Producers) wishes to innovate and create a new configuration (unknown/emerging configuration A), the strategic analysis and strategic choice steps reveal that the characters X, Y and Z should be acquired, but also that characters 29, 23 and 15 should be removed first. This is because; these characters define the current configuration and are likely to be in conflict with the characters in the desired configuration, and a

Table 9. The resolved binary data matrix.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16
C1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C2	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C3	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
C4	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0
C5	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0
C6	0	0	0	0	1	1	1	1	1	0	0	1	1	0	0	0
C7	0	0	0	0	1	1	1	1	0	0	0	0	1	0	0	0
C8	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
C9	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
C10	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0
C11	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
C12	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
C13	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
C14	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0
C15	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
C16	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
C17	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
C18	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
C19	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
C20	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0
C21	0	0	0	0	1	1	1	1	1	0	0	0	1	0	0	0
C22	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
C23	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
C24	0	0	0	0	1	1	1	1	0	0	0	0	1	0	0	0
C25	0	0	0	0	1	1	1	1	0	0	0	0	1	0	0	0
C26	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
C27	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
C28	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
C29	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
C30	0	0	0	0	1	1	1	1	1	0	0	1	1	0	0	0
C31	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
C32	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
C33	0	0	0	0	1	1	1	1	0	0	0	0	1	0	0	0
C34	0	0	0	0	1	1	1	1	0	0	0	0	1	0	0	0
C35	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
C36	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
C37	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
C38	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0

(*Continued on next page.*)

Table 9. (*Continued*).

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16
C39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C40	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
C41	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
C42	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
C43	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
C44	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
C45	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
C46	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0
C47	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C48	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
C49	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
C50	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
C51	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
C52	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0
C53	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0

Table 10. Relational structure of organizational configurations.

F2: ⟨C1⟩

F3: ⟨C1, C2, C47⟩

F4: ⟨C1, C2, C47, C13, C48, C50⟩

F5: ⟨C1, C2, C47, C13, C48, C50, C3, C16, C32, C4, C5, C41, C31, C30, C28, C26, C22, C21, C19, C17, C10, C6, C42, C40, C38, C37, C36, C34, C33, C29, C25, C24, C9, C7⟩

F6: ⟨C1, C2, C47, C13, C48, C50, C3, C16, C32, C4, C5, C41, C31, C30, C28, C26, C22, C21, C19, C17, C10, C6, C42, C40, C38, C37, C36, C34, C33, C29, C25, C24, C9, C7, C8, C11, C12, C27, C35, C49⟩

F7: ⟨C1, C2, C47, C13, C48, C50, C3, C16, C32, C4, C5, C41, C31, C30, C28, C26, C22, C21, C19, C17, C10, C6, C42, C40, C38, C37, C36, C34, C33, C29, C25, C24, C9, C7, C8, C11, C12, C27, C35, C49, C15, C23⟩

F8: ⟨C1, C2, C47, C13, C48, C50, C3, C16, C32, C4, C5, C41, C31, C30, C28, C26, C22, C21, C19, C17, C10, C6, C42, C40, C38, C37, C36, C34, C33, C29, C25, C24, C9, C7, C8, C11, C12, C27, C35, C49, C15, C23, C43, C51⟩

F9: ⟨C1, C2, C47, C13, C48, C50, C3, C16, C32, C4, C5, C41, C31, C30, C28, C26, C22, C21, C19, C17, C10, C6⟩

F10: ⟨C1, C2, C47, C13, C48, C50, C3, C16, C32, C4, C5, C14, C46, C52, C45, C53, C18, C44⟩

F11: ⟨C1, C2, C47, C13, C48, C50, C3, C16, C32, C4, C5, C14, C20, C46, C52, C45, C53⟩

F12: ⟨C1, C2, C47, C13, C48, C50, C3, C16, C32, C4, C5, C14, C20, C46, C52, C6, C30⟩

F13: ⟨C1, C2, C47, C13, C48, C50, C3, C16, C32, C4, C5, C14, C20, C46, C52, C6, C30, C7, C21, C24, C25, C33, C34⟩

F14: ⟨C1, C2, C47, C13, C48, C50, C3, C16, C32, C4, C5, C14, C20, C46, C52⟩

F15: ⟨C1, C2, C47, C13, C48, C50, C3, C16, C32, C4⟩

F16: ⟨C1, C2, C47, C13, C48, C50, C3, C16, C32⟩

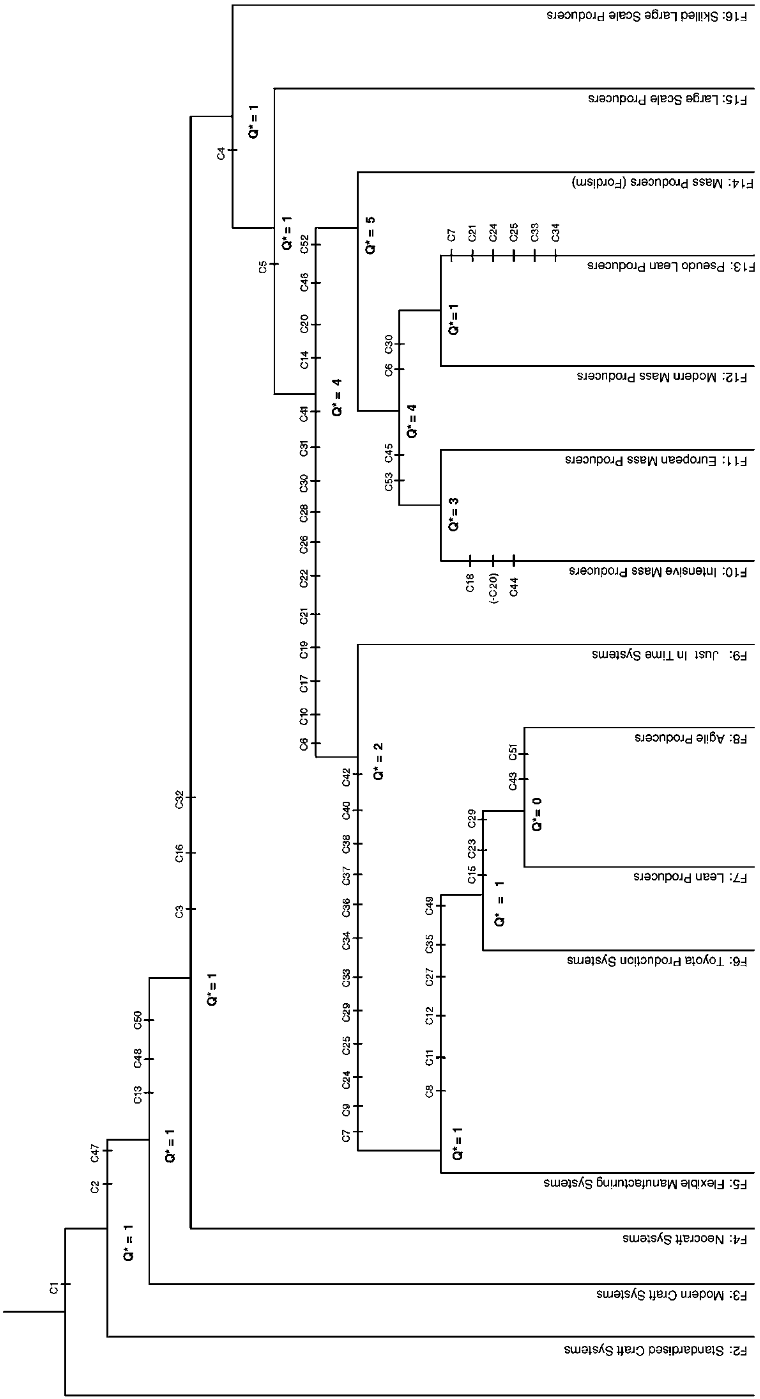


Figure 8. Automotive cladogram.

Table 11. Symmetric matrix $\Lambda\Lambda^T$-Ω.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16
F1	**−1**	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1
F2		**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F3			**2**	2	2	2	2	2	2	2	2	2	2	2	2	2
F4				**5**	5	5	5	5	5	5	5	5	5	5	5	5
F5					**33**	33	33	33	21	10	10	12	18	10	9	8
F6						**39**	39	39	21	10	10	12	18	10	9	8
F7							**41**	41	21	10	10	12	18	10	9	8
F8								**43**	21	10	10	12	18	10	9	8
F9									**21**	10	10	12	13	10	9	8
F10										**17**	15	13	13	13	9	8
F11											**16**	14	14	14	9	8
F12												**16**	16	14	9	8
F13													**22**	14	9	8
F14														**14**	9	8
F15															**9**	8
F16																**8**

reluctance to remove conflicting current characters can lead to an increase in change inertia. This information is important for the strategic implementation aspect of change management.

The value and relevance of q-analysis is that it provides parameters that can be used to evaluate the mathematical structure of a potential change program. If we consider figure 8, the integration of the obstruction vectors at each branching point shows further indications of potential hindrance for movements from one branch to another. Thus, it can be hypothesized that stability in one part or another of the cladogram depends on the level of the obstruction vector. If the normal obstruction is considered to be $Q^* = 1$, then the higher the obstruction—the greater resistance observed for a given region of the cladogram. This hypothesis is summarized in Table 14.

Overall, the following observations may be drawn from the elicitation of the cladogram (figure 8) using q-analysis:

- The configuration F8 (Agile Producers) is located at the lower part of the cladogram and within the context of evolutionary analysis could be interpreted as the most recent (i.e. the most evolved) configuration within the automotive data set. Equally, figure 8 shows that the configuration F1 (Ancient Craft Systems) is the common ancestor (also defined as the outgroup) to all the configurations within the classification.
- The highest level of obstruction is located at connectivity levels $q = 11, 12, 13, 14$ where the obstruction vector (Q^*) has a component 5. This indicates that the configurations that

Table 12. Structure vector (Q), obstruction vector (Q^*), and equivalence classes.

q	Q	Q^*	Equivalence classes
43	1	0	{F8}
42	1	0	{F8}
41	1	0	{F7, F8}
40	1	0	{F7, F8}
39	2	1	{F6}, {F7, F8}
38	2	1	{F6}, {F7, F8}
37	2	1	{F6}, {F7, F8}
36	2	1	{F6}, {F7, F8}
35	2	1	{F6}, {F7, F8}
34	2	1	{F6}, {F7, F8}
33	2	1	{F5}, {F6, F7, F8}
32	2	1	{F5}, {F6, F7, F8}
31	2	1	{F5}, {F6, F7, F8}
30	2	1	{F5}, {F6, F7, F8}
29	2	1	{F5}, {F6, F7, F8}
28	2	1	{F5}, {F6, F7, F8}
27	2	1	{F5}, {F6, F7, F8}
26	2	1	{F5}, {F6, F7, F8}
25	2	1	{F5}, {F6, F7, F8}
24	2	1	{F5}, {F6, F7, F8}
23	2	1	{F5}, {F6, F7, F8}
22	2	1	{F5, F6, F7, F8}, {F13}
21	3	2	{F5, F6, F7, F8}, {F9}, {F13}
20	2	1	{F5, F6, F7, F8}, {F9}, {F13}
19	3	2	{F5, F6, F7, F8}, {F9}, {F13}
18	3	2	{F5, F6, F7, F8}, {F9}, {F13}
17	4	3	{F5, F6, F7, F8}, {F9}, {F10}, {F13}
16	5	4	{F11}, {F5, F6, F7, F8}, {F9}, {F10}, {F12, F13}
15	5	4	{F11}, {F5, F6, F7, F8}, {F9}, {F10}, {F12, F13}
14	6	5	{F11}, {F5, F6, F7, F8}, {F9}, {F10}, {F12, F13}, {F14}
13	6	5	{F11}, {F5, F6, F7, F8}, {F9}, {F10}, {F12, F13}, {F14}
12	6	5	{F11}, {F5, F6, F7, F8}, {F9}, {F10}, {F12, F13}, {F14}
11	6	5	{F11}, {F5, F6, F7, F8}, {F9}, {F10}, {F12, F13}, {F14}
10	4	3	{F5, F6, F7, F8, F9}, {F10, F11}, {F12, F13}, {F14}
9	2	1	{F5, F6, F7, F8, F9, F10, F11, F12, F13, F14}, {F15}
8	2	1	{F5, F6, F7, F8, F9, F10, F11, F12, F13, F14, F15}, {F16}
7	2	1	{F5, F6, F7, F8, F9, F10, F11, F12, F13, F14, F15}, {F16}
6	2	1	{F5, F6, F7, F8, F9, F10, F11, F12, F13, F14, F15}, {F16}
5	2	1	{F4}, {F5, F6, F7, F8, F9, F11, F10, F12, F13, F14, F15, F16}
4	2	1	{F4}, {F5, F6, F7, F8, F9, F11, F10, F12, F13, F14, F15, F16}
3	2	1	{F4}, {F5, F6, F7, F8, F9, F11, F10, F12, F13, F14, F15, F16}
2	2	1	{F3}, {F4, F5, F6, F7, F8, F9, F11, F10, F12, F13, F14, F15, F16}
1	2	1	{F3}, {F4, F5, F6, F7, F8, F9, F11, F10, F12, F13, F14, F15, F16}
0	2	1	{F2}, {F3, F4, F5, F6, F7, F8, F9, F11, F10, F12, F13, F14, F15, F16}

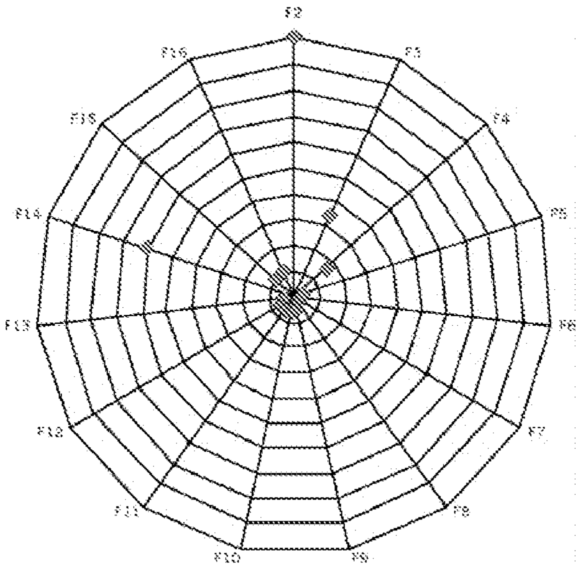


Figure 9. Eccentricity (Ecc).

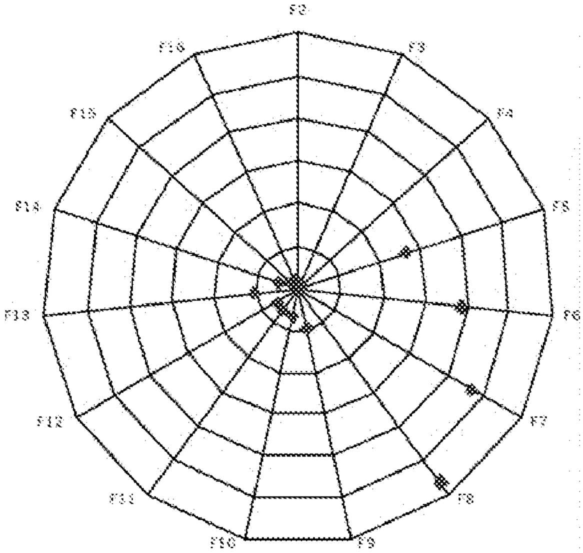


Figure 10. Eccentricity (Ecc′).

belong to the mass producers clique (F10, F11, F12, F13 and F14) could be relatively more stable and thus more difficult for other configurations to emulate. Equally, a stronger resistance to change appears to exist at this section of the classification. The particularities of the configuration F13 (pseudo-lean) is for instance characterized by a reduction in lot

Table 13. Summary of configuration eccentricities.

	Ecc	Ecc′
F1	–	–
F2	1.000	0.000
F3	0.333	0.002
F4	0.167	0.006
F5	0.029	0.267
F6	0.025	0.383
F7	0.024	0.468
F8	0.023	0.558
F9	0.045	0.092
F10	0.056	0.065
F11	0.059	0.059
F12	0.059	0.059
F13	0.043	0.104
F14	0.600	0.051
F15	0.100	0.024
F16	0.111	0.019

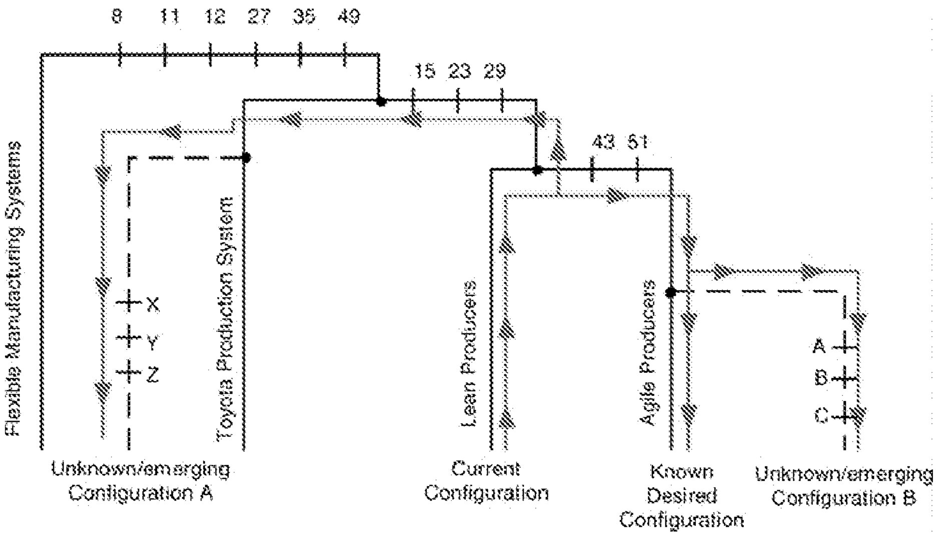


Figure 11. Change management and cladistic mapping.

sizes (C7), improved quality systems (C21), a flexible and multi-functional workforce (C24), reduced set-up time practices (C25), line balancing (C33) and a policy for team work (C34). Such characteristics set the F13 configuration apart in relation to the other configurations and could explain the high level of obstruction at their level. Perhaps, this

Table 14. Obstruction value and configuration response to changes.

$Q^* < 1$	$Q^* = 1$	$Q^* > 1$
High instability	Normal flexibility to changes	Increasing resistance to changes
Very sensitive to changes	No major obstruction to changes	Often involve organizational forms that have highly integrated corporate cultures
Example: Lean Producers (F7) and Agile Producers (F8)		Example: The groups of mass producers F10, F11, F12, F13, F14

suggests that such phenomena lies at the heart of structural inertia theory (Hannan and Freeman, 1979; Baum, 1999).

- In contrast, the lowest level of obstruction within the population is at the level of configurations F7 (Lean Producers) and F8 (Agile Producers), where the obstruction vector has a component of 0. A tentative explanation could reside in the relative recent emergence of these configurations, therefore creating instability and vulnerability to changes. In fact, these two organizations are sometimes confused with each other, along with the F6 configuration (Toyota Production Systems) (Womack et al., 1990). Practically, these configurations could be expected to respond to changes easily and quickly adopt different prescribed formats.

The above results and observations indicate that an evolutionary and structural approach to change management offers insights on the resistance or inertia associated with one configuration relative to others in the classification. The classification and parameters produced from a cladistic and q-analysis study not only provides the necessary contextual information concerning the acquisition or removal of certain organizational characteristics, but it also signifies the levels of obstruction and instability for each configuration relative to other configurations, which can be plotted as a landscape (figure 12).

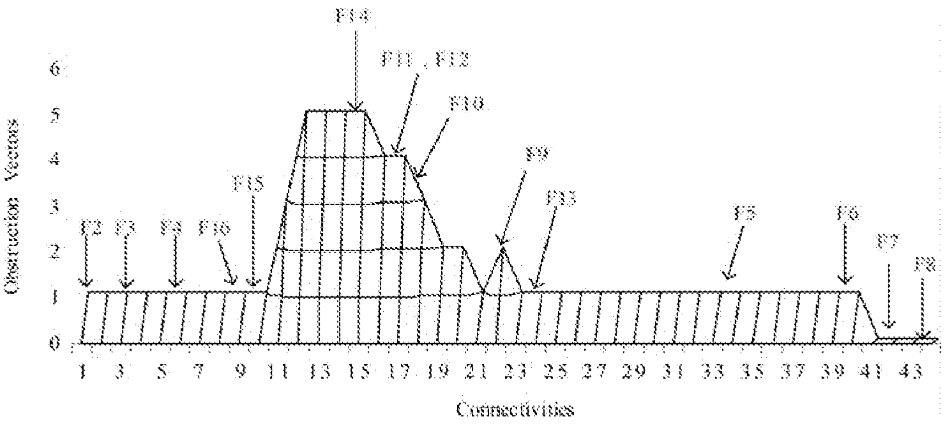


Figure 12. Landscape of automotive configurations.

4. Conclusion

In practice, change management programs will always manifest emergent and unpredictable properties, but it is the managers' responsibility to insure that decisions related to future survival of their organizations such as change management will involve some form of rational planning and identification of alternative configurations, and potential impediments. The use of cladistics and q-analysis allows the development of such decision process as it examines and maps organizational diversity through a visual and mathematical representation of the connectivity between such change options. This information is a determining factor for successful organizational change, in that it reveals the potential obstacles and opportunities for change, along with the prescriptive information associated with the change. The result is a theoretical system of information that could aid understanding and management of the three key issues of change and strategic management process: *strategic analysis* (what is our current configuration?), *strategic choice* (what is our desired configuration?) and *strategic implementation* (how to realize the desired configuration?).

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