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Self-Organizing Maps for Competitive Technical Intelligence Analysis

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***Abstract*: This study examines how the Self-Organizing Map (SOM) technique can be used to identify key competitors and determine key technical attributes of electronic products. A novel SOM display named Attribute Variance Matrix (AV-Matrix) was presented and applied to the background colors of the corresponding SOM nodes. The cell phone industry was selected as the example and a certain number of cell phones and their technical attribute data were collected and trained by the SOM algorithm. The cell phone SOM display was projected into the space constructed by the key technical attributes and the advantages and disadvantages of competitors were explored.**

***Keywords*:** Self-Organizing Map, Attribute Variance Matrix, Competitive technical intelligence, Cell phone

I. Introduction

Competitive intelligence (CI) is an important kind of activities for enterprises to make appropriate decisions and hold a competitive edge in the market. It provides the knowledge about the current competitive position, historical performance, strengths and weaknesses, and specific future intentions [21]. In the electronic industry, enterprises' competitiveness usually heavily depends on their research and development (R&D) activities. Thus competitive technical intelligence (CTI), which is defined as competitive intelligence with a strong emphasis on science and technology and their impact on research and development activities [3], is indispensable and worth studying.

In recently years, the demand for cell phones has grown very rapidly in the Chinese market, where more and more cell phone manufacturing firms are emerging. Among the numerous competitors, not all of them are competitive to the same extent. Cell phone manufacturing firms need to target their key competitors and track the competitors' technical development. With the intense competition, in addition to the basic functions such as talking and short messages, more and more advanced functions and technologies have been developed and applied to cell phones. However, whether these functions and technologies are all important and how they are implemented by different competitors is unknown. Comparing and analyzing different cell phones is a difficult and time-consuming task by means of traditional statistical methods, for a cell phone may consist of a great number of technical attributes. Therefore, a dimension reduction and visualization method is required.

The objective of this study is to employ a visualization technique (SOM) to investigate the key competitors and important technical attributes of cell phones, and explore the advantages and disadvantages of competitors.

II. Related research

A. Self-organizing map

Self-Organizing Map (SOM) is one of the most prominent artificial neural network models introduced by Kohonen [9]. In this model, objects in a high-dimensional signal space are trained in an unsupervised learning paradigm and visualized in a low-dimensional display [14]. One of the important attributes of this display is that it preserves the topological properties of the input space. Similar items are projected onto nodes in close vicinity [1]. As a result, the dimensionality of the input space is reduced, assisting users in viewing the configuration of objects in a convenient and intuitional way.

The principles and basic algorithms of SOM have been addressed in abundant literatures [10][11][12], which provide useful references for the understanding of SOM. In general, there are two main learning algorithms, i.e. sequential (also online, stochastic, or incremental) algorithm and batch algorithm. In the former algorithm, the weight

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vectors are updated shortly after each input vector is presented while in the latter the weight vectors associated with the SOM nodes are updated after all the input vectors are processed. Thus the batch algorithm is much faster compared with the sequential algorithm. A thorough comparison between the two algorithms was conducted in [5][6]. The results show that the batch algorithm has the advantages of computation simplicity, efficient training time, better final distortion, omission of the tuning adaptation parameter, and deterministic results. Some researchers also argued that the batch algorithm does not suffer from the convergence problems caused by a changeable learning rate α [1]. However, the batch algorithm also suffers from the worse organization and visualization, and less balanced classes than the sequential algorithm. In addition, the batch algorithm shows a strong dependence on the initialization.

The SOM layout is determined by the values of weight vectors associated with SOM nodes. Because the weight vectors are multi-dimensional, the differences between the weight vectors cannot be reflected in the SOM display. Thus the concept of Unified Distance Matrix (U-matrix) was proposed in [24]. The Euclidean distances between the weight vectors were computed and assigned to the elements of the U-matrix. The U-matrix display is determined by the comparative values of weight vectors. The length or width of the U-matrix is 2n-1 where n is the length or width of the SOM display. The odd rows of the U-matrix store the distances between horizontal neighbors in the SOM display. The units in even rows and odd columns store the distances between vertical neighbors while those in even rows and columns store the distances between diagonal neighbors. Later, a different definition of U-matrix was proposed in [22], in which the value in each unit equals to the sum of the distances to all immediate neighbors normalized by the largest occurring value. The second definition of U-matrix has the advantage of sharing the same length and width with the SOM display so that it is easier and more convenient for users to observe.

SOM has been widely used in many fields, such as visualization of machine states, fault identification [17], feature extraction, computer vision [13], exploratory data analysis, and knowledge discovery in databases [15]. It was reported that the development speed of SOM application was about 15 per cent each year [17].

B. Competitive technical intelligence research

Competitive technical intelligence (CTI) is increasingly an important research field of competitive intelligence (CI). It assists the CI analysts in determining the strategic impact of technologies and allows enterprises to anticipate future technological trends with the early identification of modifications or changes in technology platforms due to developments and discoveries in the underlying applied and pure sciences [4].

The CTI process is similar to the CI cycle. It starts from intelligence needs and anticipates future changes, between which there are six stages, i.e. process planning, evaluation of information sources, information collection, analysis, results delivery and process evaluation [19]. Among the six stages, information collection and analysis are the most important and difficult parts, in which some significant studies have been done. [7] examined how database tomography could be used to derive technical intelligence for professional literature in the technical field of research impact assessment. [2] presented how the combination of free patent databases (i.e. esp@cenet) and dedicated software made it possible to perform easily and rapidly tests on new ideas, the automatic benchmarking of an enterprise's activity and the stimulation of innovative thinking. [18] summarized some of the useful analytical techniques of CTI, including technology prospecting, technology scouting, patent analysis, bibliometrics, technology forecasting, scenario analysis and S curve analysis.

As some researchers pointed out, it is notable that in most educational institutions (e.g. universities), especially those in developing countries, many researchers are research oriented and do not have the capability to promote their R&D knowledge to develop business or new projects in association with local or national industries or institutions [8]. Thus, they developed a model which was rooted within Indonesian constrains and led to a general guideline to introduce CI in industries and institutions in most developing countries. [19] investigated how the intelligence unit in a Mexican steel manufacturer analyzed the main directions of research and competitive actions in the steel market. This study enabled this company to redefine their R&D portfolio.

In summary, while much work has been done in information analytical techniques and the establishment of CTI process in industries, the technical status quo of electronic industries is seldom studied. The information source of CTI usually comes from publications and literature databases. Most of the analytical techniques are task oriented and not specific enough. Thus, the CTI research needs to be not only research oriented, but also capable of being applied in industries.

In this study, several typical competitors in cell phone markets were selected and a number of technical attributes of their products were analyzed with the SOM technique. A novel SOM display named Attribute Variance Matrix (AV-Matrix) was proposed and applied to the background colors of the corresponding SOM nodes. A comprehensive CTI analytical method was presented and showed how key competitors and important technical attributes were identified, upon which the advantages and disadvantages of different competitors were summarized. The findings of this study can reveal the technical status quo of the cell phone industry. The research method can also be applied to other electronic industries.

III. Research method description

A. Cell phone attribute description on the Younet

The data source in this study comes from the Younet (http://www.younet.com), which aims to provide comprehensive and latest information service to cell phone customers. Seventy-two technical attributes were identified for each cell phone and organized in six groups. See Table 1.

B. Construction of the SOM input matrix

The SOM algorithm requires an m*n input matrix. The rows (m) of the matrix represent objects which are visualized in the SOM space and the columns (n) of the matrix define attributes of the objects. In this study, two SOM input matrix were constructed. The first input matrix (M1, see Equation

(1)) has m rows and n columns. c_{ij} (i=1,2,…,m, j=1,2,…,n) stands for the element at the i^{th} row and the j^{th} column of the matrix. It is defined as the j^{th} attribute value of the i^{th} cell phone.

$$M1=\begin{pmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ \cdots & & & \\ c_{m1} & c_{m2} & \cdots & c_{mn} \end{pmatrix} \quad (1)$$

The second input matrix (M2, see Equation (2)) has n rows and m columns. d_{ij} (k=1,2,…,n, l=1,2,…,m) stands for the element at the k^{th} row and l^{th} column of the matrix. It is defined as the k^{th} attribute value of the l^{th} cell phone normalized by the largest occurring value in all the cell phones in terms of their k^{th} attributes. Thus, the value of d_{ij} ranges between 0 and 1.

$$M2=\begin{pmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ \cdots & & & \\ d_{n1} & d_{n2} & \cdots & d_{nm} \end{pmatrix} \quad (2)$$

Table 1. Technical attributes of cell phones

No.	Attribute Type	Attribute No. and Name
1	Specifications and parameters	(1) product time, (2) weight, (3) stand-by time, (4) talk time, (5) interior display color, (6) interior display pixel;
2	Multimedia entertainment	(7) game, (8) memory, (9) multimedia card extension, (10) micro hard disk, (11) USB flash drive, (12) Java extension, (13) camera, (14) video play, (15) realtime stream media, (16) mp3 player, (17) radio, (18) electronic book;
3	Basic functions	(19) QWERTY keyboard, (20) recorder, (21) chord ringing tones, (22) mp3 ringing tones, (23) incoming call ringing tone identification, (24) incoming call image identification, (25) incoming call video identification, (26) encryption, (27) stand-by image, (28) image menu, (29) subject mode, (30) file manager, (31) touch screen, (32) hand-writing input;
4	Communication functions	(33) Chinese message, (34) message firewall, (35) group message, (36) EMS message, (37) long message, (38) multimedia message, (39) voice tone, (40) voice dialing, (41) voice menu, (42) voice answering, (43) voicemail, (44) minute beep, (45) electronic name card, (46) contact group, (47) incoming call firewall, (48) hands-free speaker, (49) flight mode;
5	Web and data transfer	(50) instant message, (51) WAP browser, (52) WWW browser, (53) infrared interface, (54) bluetooth interface, (55) data cord interface, (56) wireless modem, (57) GPS navigation chip, (58) WIFI, (59) E-mail;
6	Personal assistant	(60) electronic dictionary, (61) alarm clock, (62) calculator, (63) timer, (64) stopwatch, (65) notepad, (66) memo, (67) calendar, (68) automatic power on/off, (69) automatic keyboard lock, (70) world time, (71) unit conversion, (72) currency conversion.

C. U-matrix and its rationale

As discussed in Section II (A), two kinds of definitions of U-matrix were presented [22][24]. However, both of them are limited to the two-dimensional SOM display and thus suffer from the "border effect", i.e. the nodes on the border or at the corner of the SOM display have fewer neighbors than those in the middle. [16] stated that the border effect reduces the accuracy as well as causes the SOM more difficult to converge. To solve this problem, [23] extended the definition of U-matrix to the toroid SOM space. The high values of the U-matrix represent borders between clusters and the low values represent the cluster itself. The values of the U-matrix are applied to determine the background colors of corresponding SOM nodes. Thus the similarities among input data can be intuitively observed.

D. Attribute Variance Matrix and its application

While U-matrix can reveal the cluster structure of the input data, people may wonder which attributes contribute the most to the differences among the input samples. To attain this goal, we propose a novel SOM display named Attribute Variance Matrix (AV-Matrix).

Assume a rectangular SOM display S with p rows and q columns in Equation (3),

$$S=\begin{pmatrix} s_{11} & s_{12} & \cdots & s_{1q} \\ s_{21} & s_{22} & \cdots & s_{2q} \\ \cdots & & & \\ s_{p1} & s_{p2} & \cdots & s_{pq} \end{pmatrix} \quad (3)$$

where s_{ij} (i=1, 2, …, p, j=1, 2,…, q) represents the weight vector associated with the corresponding node. Each weight vector contains m elements, where m is the number of attributes of input matrix M2. The elements of s_{ij} are denoted by w_{ij1}, w_{ij2}, …, w_{ijm}.

The AV-Matrix with p rows and q columns is depicted in Equation (4),

$$\mathrm{AVM} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1q} \\ a_{21} & a_{22} & \dots & a_{2q} \\ \dots & & & \\ a_{p1} & a_{p2} & \dots & a_{pq} \end{pmatrix} \quad (4)$$

where each element is represented by a_{ij} ($i=1, 2,\ldots, p, j=1, 2,\ldots, q$).

The element a_{ij} indicates the variance of all the elements of s_{ij} as defined in Equation (5),

$$a_{ij}=\frac{\sum_{k=1}^{m}\left(w_{ijk}-\frac{\sum_{k=1}^{m}w_{ijk}}{m}\right)^2}{m} \quad (5)$$

The high values in the AV-Matrix signify large variance of the weight vector elements associated with the corresponding SOM nodes and the low values indicate small variance. If the AV-Matrix is applied to the SOM display which is generated upon the input matrix M2, the technical attributes of cell phones which are projected onto the high-value areas in the AV-Matrix signify those who contribute a lot to the differences among individual cell phones and the technical attributes of cell phones which are projected onto the low-value areas indicate those who contribute a little to the differences among the cell phones. The values of the AV-Matrix are used to produce the background colors for the corresponding SOM nodes. The background colors help people identify the key attributes that contribute the most to the differences among cell phones.

E. Analysis method

To deal with the high dimensional attributes of cell phones, the SOM technique was utilized to visualize the input data in a low-dimension space. When the input matrix M1 is used, the cell phones that are projected onto the same or neighboring nodes in the SOM display have similar technical attributes. Although many competitors may exist in the market, only those with similar characteristics are key competitors. Thus, the competitors whose products are projected onto the same nodes in the SOM display for many times are key competitors.

In this study, seventy-two attributes are identified for each cell phone, which described multiple technical aspects of cell phones. The development of specific technologies is different, some of which are so basic and mature that a majority of cell phones are highly similar in terms of the corresponding attributes. However, some technical attributes are novel and complementary functions so that only a minority of cell phones adopts them. The self-defined AV-Matrix is calculated and applied to the background color of the SOM display generated upon input matrix M2. The key technical attributes can be identified according to their AV-Matrix values. The SOM display generated upon input matrix M1 is projected onto the space constructed by the key technical attributes. Then the development status of various technologies and the characteristics of individual competitors in terms of the key technical attributes are analyzed and summarized.

IV. Data analysis and discussion

A. Data description

The data source of this study came from Younet (http://www.younet.com). Four brands were selected for analysis and denoted by N, S, L and D. Twenty-eight latest cell phone models were collected for each competitor. Thus, there were 112 samples in total, each of which involved 72 attributes. The input data was a 112*72 matrix. Nearly for all the attributes, the higher values represented better performance, except that the lower values of weight represented higher performance.

B. Key competitor identification

The SOM Toolbox for the Matlab was utilized to train the input matrix M1. As the different attributes (columns) had different value ranges, the input data was first normalized with the 'var' method [20], in which normalization process is linear and the variances of the variables are normalized to 1 in case some large variables dominate the organization of the map.

Batch learning was chosen because it has the advantages described in Section II (A). The learning process was described in [12], where no changeable learning rate α is needed and the weight vectors are updated after all the input vectors are processed. The toroid shape was chosen to eliminate border effect [23]. The SOM Toolbox utilizes a heuristic formula to determine the number of SOM nodes, which is exponentially related to the number of samples. Thus a 9*6 SOM grid was created.

The U-matrix was applied to determine the background color of the SOM display. Each cell phone was labeled with its brand and serial number. For example, N5 represents the 5^{th} sample of brand N. The SOM display in a tiled display is shown in Figure 1, where the upper edge is actually connected with the bottom edge and the left connected with the right edge. The color bar provides reference for the U-matrix cell values. For example, the red color represents high values and the blue color represents low values.

The similarity among cell phones was reflected by their geometric vicinities in the SOM display. In Figure 1, the cell phones were scattered on the SOM grids based on their similarity. It is believed that the cell phones that are situated in the same node are the most similar, the ones that are located in the adjacent nodes are less similar, and those that are placed far away from each other are quite different. In the resulting configuration, observe that some cell phones were clustered in the same nodes, such as N25 and S11. On the whole, all the brands are mixed together, which suggests that there is no significant difference among the four brands and they are competing severely. The clusters of cell phones in a single node and corresponding competitors were summarized in Table 2.

Although four brands were selected in this study, not every two of them are key competitors. Severe competition usually happens in similar products. Thus, the more frequently two brands co-occur in the same node, the more likely they become key competitors. The frequencies of each competitor pair were calculated and ranked in a descending order in Table 3.

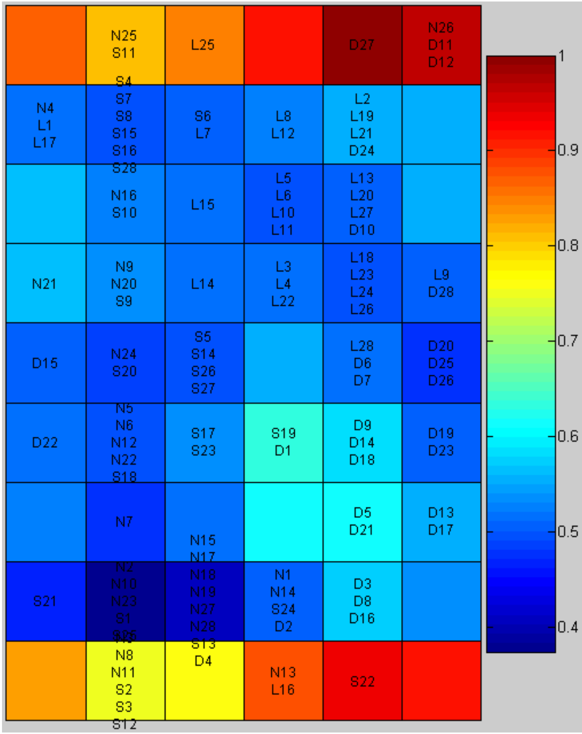

Figure 1. The SOM display of cell phones

Table 2. Cell phone clusters in a single node

Cluster No.	Label	Brand	Cluster No.	Label	Brand
1	N4,L1,L17	N,L	17	S19,D1	S,D
2	N25,S11	N,S	18	N1,N14,S24,D2	N,S,D
3	S4,S7,S8,S15,S16,S28	-	19	N13,L16	N,L
4	N16,S10	N,S	20	L2,L19,L21,D24	L,D
5	N9,N20,S9	N,S	21	L13,L20,L27,D10	L,D
6	N24,S20	N,S	22	L18,L23,L24,L26	-
7	N5,N6,N12,N22,S18	N,S	23	L28,D6,D7	L,D
8	N2,N10,N23,S1,S25	N,S	24	D9,D14,D18	-
9	N3,N8,N11,S2,S3,S12	N,S	25	D5,D21	-
10	S6,L7	S,L	26	D3,D8,D16	-
11	S5,S14,S26,S27	-	27	N26,D11,D12	N,D
12	S17,S23	-	28	L9,D28	L,D
13	N15,N17,N18,N19,N27,N28,S13,D4	N,S,D	29	D20,D25,D26	-
14	L8,L12	-	30	D19,D23	-
15	L5,L6,L10,L11	-	31	D13,D17	-
16	L3,L4,L22	-			

Table 3. Frequency of competitor pairs

Competitor pair	Frequency
N,S	9
L,D	4
S,D	3
N,D	3
N,L	2
S,L	1

Table 3 shows that brand N and S compete the most severely, brand L and D are in the next place, brand S (N) and D compete ordinarily and brand S (N) and L compete slightly. Thus, brand N and S are key competitors for each other. The same is true for brand L and D.

The background color also helps reveal the similarity among cell phones. In general, the U-matrix values of the "upper" and "bottom" edge are much higher than those of the "middle" nodes, which indicates that the cell phones that are projected onto the "upper" and "bottom edge" are quite different from those that are projected onto the "middle" nodes.

C. Key technical difference

Although 72 attributes were identified for each cell phone, not all of them were of the same importance. For some attributes, different cell phones have similar values while some other attributes vary in a wide range with different cell phones. The attributes which can best differentiate cell phones represent key technical difference among cell phones and thus are important. To attain this goal, the input matrix M2 was trained by the SOM technique and the AV-Matrix was applied the SOM display. See Figure 2. The labels in the SOM display represent the attribute No., for example, v36 refers to the 36th technical attributes of cell phones (See Table 1), i.e. EMS message.

According to the definition of the AV-Matrix, the attributes which were projected onto the red area in Figure 2 are the key attributes which contribute the most to the differences among cell phones while the attributes which were projected onto the dark blue area are the ordinary attributes which contribute the least to the differences among cell phones. Thus, the key attributes were identified according to their AV-Matrix values and summarized in Table 4.

It is observed in Table 4 that the key attributes which contribute the most to the differences among cell phones can be categorized into the following attribute types,

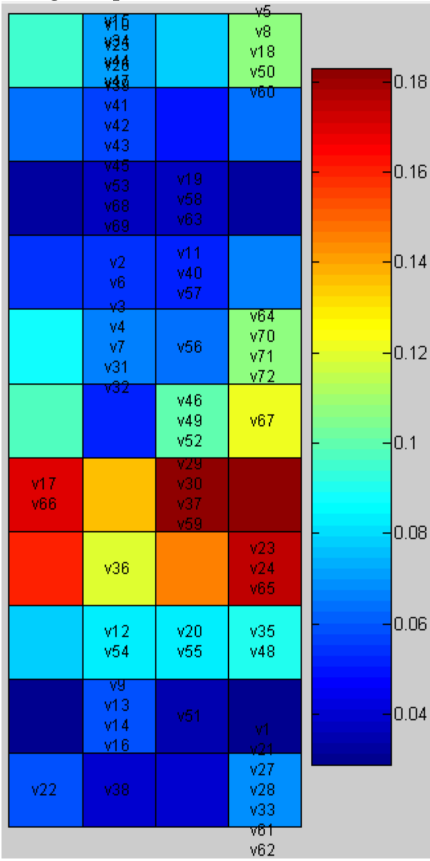

Figure 2. Attribute Variance Matrix

Table 4. Key attributes identified by their AV-Matrix values

AV-Matrix Value (color)	Attribute No. and Name
Very High (Red)	v29_subject mode, v30_file manager, v37_long message, v59_E-mail
	V23_incoming call ringing tone identification, v24_incoming call image identification, v65_notepad
	V17_ radio, v66_ memo
High (Yellow)	v67_ calendar
	v36_ EMS message
Medium(Green)	V5_interior display color, v8_memory, v18_electronic book, v50_instant message, v60_electronic dictionary
	v64_stopwatch, v70_world time, v71_unit conversion, v72_currency conversion
Low (Cyan and blue)	Others

1) Basic functions: v29_subject mode, v30_file manager, v23_incoming call ringing tone identification, v24_incoming call image identification,

2) Communication functions: v37_long message,

3) Web and data transfer: v59_E-mail,

4) Personal assistant: v65_ notepad, v66_ memo,

5) Multimedia entertainment: v17_radio.

To reveal the technical characteristics of the cell phone clusters in Figure 1, three axes were constructed using the key attributes of the first three attribute types, i.e. the X axis represents v29, v30, v23 and v24, the Y axis represents v37, and the Z axis represents v59. Then the SOM display of cell phones in Figure 1 was projected into the space constructed by the three axes. See Figure 3.

The high values at the X (Y or Z) axis indicate that the cell phone cluster has high values in the corresponding key attributes and the low values at an axis suggest that the cell phone cluster has low values in the corresponding key attributes. For example, many cell phones of brand N were projected onto the positions with high values at X and Z axes. It indicates that these cell phones of brand N have high values in terms of v29, v30, v23, v24 and v59.

In the same way, two axes were constructed using the key attributes of the other two attribute types, i.e. X axis represents v65 and v66 and Y axis represents v17. Also, the SOM display of cell phones in Figure 1 was projected into the plane constructed by the two axes. See Figure 4.

For the same reason, the high values at the X (Y or Z) axis indicate that the cell phone cluster has high values in the corresponding key attributes and the low values at an axis suggest that the cell phone cluster has low values in the corresponding key attributes. For example, many cell phones of brand L were projected onto the positions with low values at the X and Y axes. It indicates that these cell phones of brand L have low values in terms of v65, v66 and v17.

The key technical characteristics of the four brands can be observed in Figure 3 and Figure 4 and summarized in Table 5.

It is seen in Table 5 that brand N has significant advantages in most key technical attributes. The advantages of brand S lie in basic functions and multimedia. Unfortunately, brand L exhibits obvious disadvantages in most key technical attributes while brand D exhibits no significant advantages or disadvantages in any key technical attributes.

V. Conclusion

This paper presented a novel approach to analyze CTI in the cell phone industry. By training cell phones and their technical attributes, it can identify the key competitors. A novel SOM display named Attribute Variance Matrix (AV-Matrix) was presented and applied to the background colors of the corresponding SOM nodes to reveal the key technical attributes which contribute the most to the differences among cell phones. The cell phone SOM display was projected into the space constructed by the key technical attributes to reveal the technical characteristics of cell phone clusters. Although a limited number of cell phone samples and their technical attributes were investigated in this study, an effective approach to analyze CTI was established and systematically elaborated. More competitors, samples and technical attributes could be studied and the approach could be applied to other electronic products.

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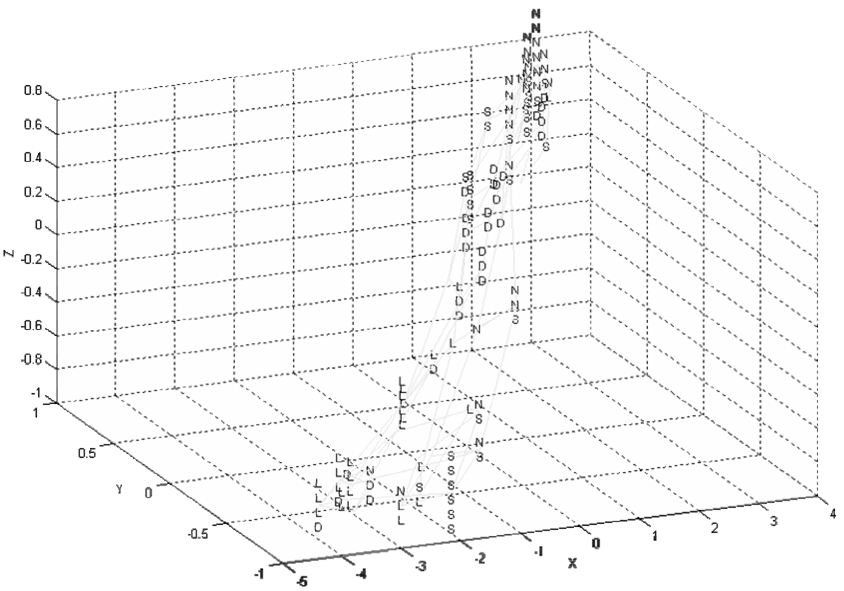

Figure 3. *Key Attribute Projection (I)*

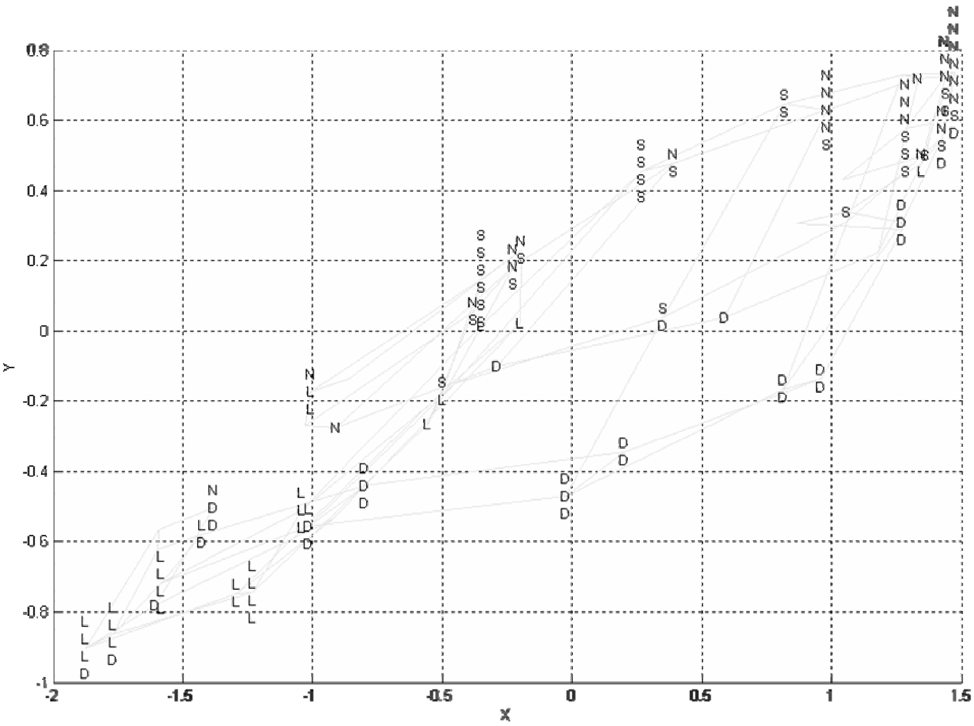

Figure 4. Key Attribute Projection (II)

Table 5. Advantages and disadvantages of individual competitors

Attribute Type (Attribute No.)	**N**	**S**	**L**	**D**
Basic functions (v29,v30,v23,v24)	Mainly high	Mainly medium and high	Mainly low	Cover the whole range
Communication functions (v37)	Mainly high	Mainly high or low	Mainly low	Cover the whole range
Web and data transfer (v59)	Mainly high	Mainly high or low	Mainly low	Cover the whole range
Personal assistant (v65, v66)	Mainly high	Mainly medium	Mainly low	Cover the whole range
Multimedia entertainment (v17)	Mainly high	Mainly medium and high	Mainly low	Cover the whole range
Key technical characteristics	Significant advantages in most key technical attributes	Advantages in basic functions and multimedia entertainment	Obvious disadvantages in most key technical attributes	No significant advantages or disadvantages

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