Measurement of Information in the Core of Planning and Organization of the New Century

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Abstract
The new century brings companies to transition in a society of information and knowledge; however, traditional organizational and planning tools, such as the organizational chart and the situational analysis, are static and inflexible. This study proposes two tools to measure organizational information. One is used to calculate the maximum planning horizon based on the information available in the environment. The second uses the complex network to measure the entropy increase in the company based on its size and complexity. Both tools provide a new strategic approach that will allow the organization to adapt to an increasingly dynamic and turbulent environment.

Keywords: Complex systems, uncertainty, complex network, entropy

1. Introduction

Adam Smith (1776), in his book *"The Wealth of Nations"*, laid the groundwork for the transition from a primarily agricultural economy to a commercial economy. Since then, labor divisions, specialization and standardization, stood as pillars of organizational business for companies. Today, society is facing a new transition period where companies are forced to continuously adapt to constantly changing markets; which are characterized by instabilities and uncertainties that threaten the usefulness of strategic plans and where technology rises as the main differentiator. Those variables revolve around information management where the generation of new knowledge becomes the main source of wealth for the new economy.

In this new reality, companies cannot be studied as static and closed entities, and the environment cannot be studied through frozen photographs in time, but in a continuous interaction with the company. According to Macintosh and Maclean (1999), organizations move within the spectrum between seasonality and complex adaptability, going through cycles of evolution and revolution.

The traditional theoretical framework tries to avoid, or even ignore, uncertainties; however, uncertainty is a part of today's reality and is an increasingly important element of the environment. This is the main reason why uncertainty must be incorporated in strategic planning. This paper introduces two tools that will allow information management strategies to counter the growing uncertainty in the environment.

2. The Company in an Uncertain Environment

Entropy is a measure of order and chaos; chaos is defined as the lack of information. A growing uncertainty can be translated into growing entropy. To measure environmental entropy, it is necessary to calculate the probability of occurrence of scenarios to project. Based on the *Information Theory* by Shannon (1949), Kolmogorov (1962) provided an indicator, called "Kolmogorov entropy", that measures the storage and information gain of a particular system. Kolmogorov entropy is closely related to the probability of occurrence of an event, this being a measure of the degree of uncertainty of the event. This relationship is quantified by Pons (1992), taking into account that if a system can occupy a set of *N* states with P_i probability to occupy each one of them, the entropy *S* of the system will be:

$$S = \sum_i Pi(\log_2 Pi) \quad (1)$$

The logarithm in base two is used to obtain *bits* as a unit of measurement.

Based on this formula, Kolmogorov entropy can be calculated.

Pons (1992) provided a method for calculating the Kolmogorov entropy from the future path that will follow the system in *state space*. The state space is the set of all possible states in which the system can end. Each point in the state space represents a unique state of a particle, as time goes on, that point moves in the state space forming a curve.

The magnitude of Kolmogorov entropy (K_n) can be calculated using the equation (2) below:

$$K_n = -\sum_{0\ldots n} P_{1\ldots n} \log_2 P_{0\ldots n} \quad (2)$$

P_o represents the probability that the system is located in each of the projected states.

3. Measuring the Planning Horizon

The amount of time designated for planning depends on the extent of available information. The planning horizon is inversely proportional to the uncertainty of the environment, which has been quantified by the entropy of Kolmogorov. According to Prigogine (1997) the *Maximum Planning Horizon*, also called *Lyapunov Time* is calculated by reversing the Lyapunov exponent. Kolmogorov entropy is the result of the sum of Lyapunov exponents. For cases of one-dimensional systems, such as the one studied in this article, the Lyapunov exponent matches the Kolmogorov entropy; therefore, it is possible to calculate the *Maximum Planning Horizon* of the system by reversing the Kolmogorov entropy.

The current business scenario can be used as an example where it is estimated that there is a 90% probability that the market will continue consuming internal combustion vehicles for the next year. The calculated Kolmogorov entropy would be equal to:

$$K = -0.9 * \log_2 (0.9) = 0.137 \text{ bits / year}$$

This shows that 0.137 bits of information a year are lost. The projected maximum time until all system information is lost can be calculated as:

Lyapunov Time = 1 / 0.137 = 7.3 years

Based on the result above, the projected maximum time for loss of current information for any company producing internal combustion vehicles is 7.3 years. Predictions about the scenario will not be reliable beyond this time limit; therefore, any strategy will be useless. In conclusion, the maximum time for long-term projection should be calculated first before studying its reliability.

4. Data Generation to Counteract Entropy

To counteract this loss of entropy, companies generate information continually through market research, database update and forecast analysis. This data generation can be measured by the numbers of elements *N* produced (market research, data analysis or any document that increases the company's knowledge is considered an element). Each new document increases knowledge by *1/N*.

For example, if the company produces 500 elements per month, the next document will increase knowledge to 10% with respect to the prior knowledge. Using the formula, *1/N*, the increase in the precision of the system and the increase in information can be calculated and are shown below:

500 elements*0.1 = 50
$\log_2 (50) = 5.64$ bites

In a more detailed analysis, information can be directly measured by the number of bits provided by each document. If the amount of relevant information generated is less than the entropy of the information lost by uncertainty, then the company is blind and at perpetual risk.

These two elements, however, are not enough to calculate this balance because the company loses information in the process of generating it. To calculate the internal loss, the loss of information during peer communication should be considered. For this purpose, the complex network analysis can be useful as it studies peer-to-peer linkages in a company.

5. The Company as a Complex Network

Rzevski (2015) pointed out that complex systems are formed by independently interrelated entities where a common behavior emerges; therefore, it is likely that a complex system can be represented by a complex network provided that they show the following characteristics:

1. emergent behavior which is the ability to achieve complexity through the integration of relatively simple links; and
2. a scale free distribution in which not all nodes have the same number of connections, forming clumps or clusters of nodes.

According to Aldana (2006), complex networks are sets of connected nodes that interact in some way or another. Nodes of a network, also called vertices or elements, are represented by the symbols *v1, v2, ... vn*, with *n* being the total number of nodes in the network. If a *vi* node is connected to a *vj* node, this connection is represented by the ordered pair (vi, vj). This connection is known as an "edge" within the network. According to Aita (2016), to model a company through a complex network, the traditional organizational chart should be taken as a three-dimensional object which must be observed from a higher perspective rather than in a front perspective. This new view shows vertical relationships where relationships of communication and interaction among each positions are illustrated, forming a complex network instead of a hierarchical structure.

The mechanism for drawing the complex network of a company is given by de Toni and Nonino (2010) in two steps: (1) the nodes are taken from job positions in the organizational chart; (2) the edges are represented as the frequent communication links between peers, and are determined by asking each employee with whom they speak in order to receive information about new issues concerning their work activities.

It should be emphasized that the links between nodes are not casual communication channels; otherwise, all the positions of the company would be connected to each other since anyone can communicate verbally or through mail with any other employee of the company. Those links with continuous exchange of information as part of the company's production process of goods or services are the only ones that must be displayed; while those casual or sporadic interactions must not be included.

De Toni and Nonino (2010) proposed five different kinds of networks which are as follows:

(1) Communication network which is a network of working and non-working information within the organization;
(2) Information network which is a network of working communications within the organization;
(3) Know network which is a network of knowledge within the organization and describes how knowledge and expertise are spread;

(4) Problem solving network which is a network of advice relationships within the organization that solves working issues;
(5) Access network which is a network that allows access to knowledge within the organization.

For this case study, the problem solving network will be studied.

The advantage of regarding the organization as a complex network is that it allows quantitative analysis of information loss between two nodes. An example is the functional organizational chart of an IT company named *eBiz Latin America*. It shows connections between manufacturers and suppliers through a B2B platform (See Figure 1). This chart served as the basis for the construction of the complex network diagram (See Figure 2) following the methodology of de Toni and Nonino (2010).

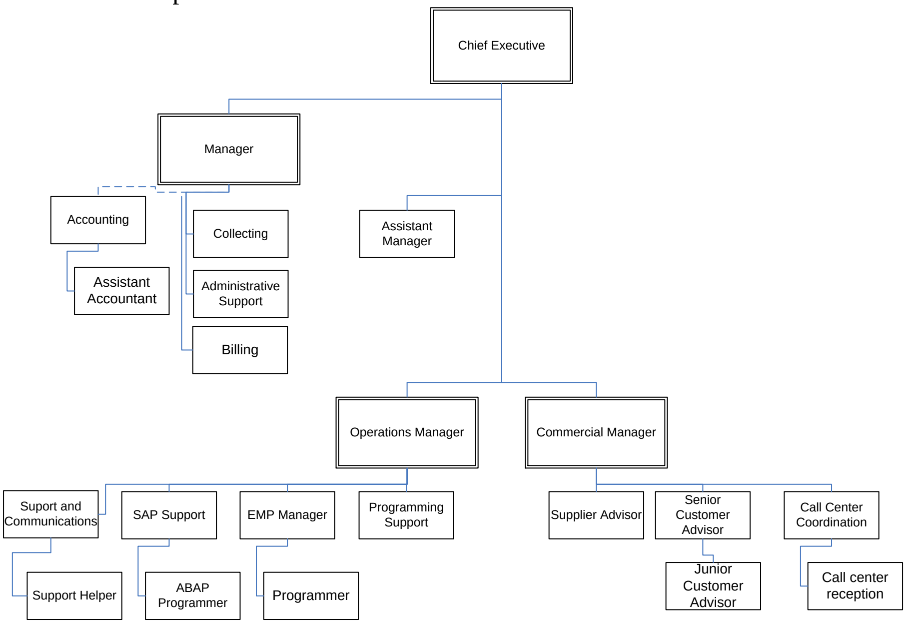

Figure 1: Organizational Chart of eBiz Latin America IT Company

The chart shown in Figure 1 only illustrates the vertical relationships in the organization. In a complex system, this information is insufficient; according to the characteristics previously mentioned, the interrelationships between the components of a complex system are more important than the components themselves. The diagram in Figure 2 shows the complex network of the organization. The connections among each node from the organizational chart are established based on the processes that occur in the company.

The first advantage of this approach is that it allows analysis of the degree of complexity of the organization through the degree of order and disorder within the organization. To measure this complexity, information generation and entropy can be calculated using equation (3) as proposed by Rosvall, Trusina, Minhagen and Sneppen (2005). According to their study, the structure of a complex network is related to its reliability and speed of information propagation. Moreover, network entropy was defined as the degree of difficulty in finding information on the network. In the equation (3) below, $\mathrm{P}[p(i,b)]$ is used to quantify the associated information to locate a specific target in the network; while $\frac{1}{k_i}\prod_{j\in p(i,b)}\frac{1}{k_j-1}$ represents the probability to follow this path in a random choice.

$$\mathrm{P}[p(i,b)] = \frac{1}{k_i} \prod_{j \in p(i,b)} \frac{1}{k_j - 1} \quad (3)$$

Where:
p(i,b) represents the shortest path from vertex i to vertex b
kj represents the degree of vertex j

The resulting product includes all vertexes j in the *p(i,b)* path excluding i and b. The amount of information used in the search to find the shortest path between *i* and *b* can be calculated using equation (4) below:

$$\mathrm{S}(i,b) = -\log_2 \sum_{\{p(i,b)\}} P[p(i,b)] \quad (4)$$

The sum of all the shortest *p(i,b)* paths from *i* to *b* is computed and the total entropy of the organization is calculated as the sum of the entropy generated between all network nodes.

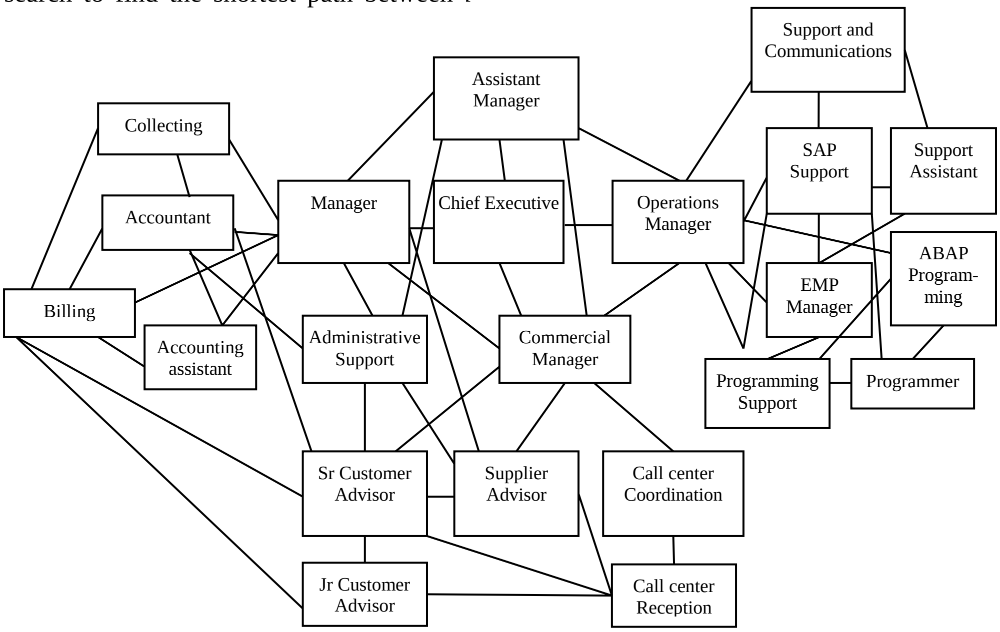

Figure 2: Complex Network Diagram of eBiz Latin America IT Company

As an example, Tables 1 and 2 shows the calculation of the shortest path between the Manager and each of the nodes, and the entropy for the Manager when obtaining information from the rest of the nodes in the system respectively.

Some nodes are directly connected to the Manager; this is the case for the Chief Executive, Assistant Manager, Accountant, Assistant Accountant, Collecting, Administrative Support, Billing, Commercial Manager and Supplier Advisor. The probability to contact them is the inverse of the degree of vertex j, in this case 1/9. For the rest of the nodes, the shortest path between them should be chosen. The probability is the product of the inverse of all vertexes j in the path between the Manager and the selected node. The resulting probabilities are shown in Table 1.

The total entropy lost by the Manager when gathering information is 98.66 bits. The sum of the total entropy of each node needs to be calculated to get the entropy lost by the entire system. The sum of internal entropy and the external loss of information from uncertainty and volatility of the market calculated on the first section is equal to the total loss of information. If the amount of information produced by the company is less than this entropy, then the company will be overwhelmed by uncertainty as many of the companies are experiencing today. Both tools can be used to quantify the amount of information lost in the internal and external entropy. This will help the company estimate if the information being produced is enough to overcome this entropy.

Table 1: Calculation of Shortest Path

From	To	Shortest Path	Probability
Manager	Chief Executive	Direct	= 1/9 = 0.111
Manager	Assistant Manager	Direct	= 1/9 = 0.111
Manager	Accountant	Direct	= 1/9 = 0.111
Manager	Assistant Accountant	Direct	= 1/9 = 0.111
Manager	Collecting	Direct	= 1/9 = 0.111
Manager	Administrative Support	Direct	= 1/9 = 0.111
Manager	Billing	Direct	= 1/9 = 0.111
Manager	Commercial Manager	Direct	= 1/9 = 0.111
Manager	Supplier Advisor	Direct	= 1/9 = 0.111
Manager	Senior Customer Advisor	Manager–Administrative Support Manager–Commercial Manager Manager–Billing Manager–Supplier Advisor	= 1/9*1/4 + 1/9*1/7+ 1/9*1/5+ 1/9*1/4 = 0.093
Manager	Junior Customer Advisor	Manager–Billing	= 1/9*1/5 = 0.022
Manager	Call Center Coordination	Manager–Commercial Manager	=1/9*1/7 = 0.015
Manager	Call Center Reception	Manager–Supplier Advisor	=1/9*1/4 =0.027
Manager	Operations Manager	Manager–Chief Executive Manager–Commercial Manager Manager–Assistant Manager	= 1/9*1/3+ 1/9*1/7+ 1/9*1/4 = 0.08
Manager	Support and Commun.	Manager–Assistant Manager–Operation Manager Manager–Chief Executive–Operation Manager Manager–Commercial Manager–Operation Manager	= 1/9*1/4*1/8+ 1/9*1/3*1/8+ 1/9*1/7*1/8 = 0.01
Manager	Support Assistant	Manager–Assistant Manager–Operation Manager–Support and Comm. Manager–Assistant Manager–Operation Manager–SAP Support Manager–Assistant Manager–Operation Manager–EMP Manager Manager–Chief Executive–Operation Manager–Support and Comm. Manager–Chief Executive–Operation Manager–SAP Support Manager–Chief Executive–Operation Manager–EMP Manager Manager–Commercial Manager–Operation Manager–Support and Comm. Manager–Commercial Manager–Operation Manager–SAP Support Manager–Commercial Manager–Operation Manager–EMP Manager	=1/9*1/4*1/8*1/2 +1/9*1/4*1/8*1/5 +1/9*1/4*1/8*1/3 +1/9*1/3*1/8*1/2 +1/9*1/3*1/8*1/5 +1/9*1/3*1/8*1/3 +1/9*1/7*1/8*1/2 +1/9*1/7*1/8*1/5 +1/9*1/7*1/8*1/3 =0.01
Manager	SAP Support	Manager–Assistant Manager–Operation Manager Manager–Chief Executive–Operation Manager Manager–Commercial Manager–Operation Manager	= 1/9*1/4*1/8+ 1/9*1/3*1/8+ 1/9*1/7*1/8 =0.01
Manager	ABAP Programmer	Manager–Assistant Manager–Operation Manager Manager–Chief Executive–Operation Manager Manager–Commercial Manager–Operation Manager	= 1/9*1/4*1/8+ 1/9*1/3*1/8+ 1/9*1/7*1/8 =0.01
Manager	EMP Manager	Manager–Assistant Manager–Operation Manager Manager–Chief Executive–Operation Manager Manager–Commercial Manager–Operation Manager	= 1/9*1/4*1/8+ 1/9*1/3*1/8+ 1/9*1/7*1/8 =0.01
Manager	Programmer	Manager–Assistant Manager–Operation Manager–Programming Support	=1/9*1/4*1/8*1/4 +1/9*1/4*1/8*1/5

From	To	Shortest Path	Probability
		Manager–Assistant Manager–Operation Manager–SAP Support Manager–Assistant Manager–Operation Manager–ABAP Programming Manager–Chief Executive–Operation Manager–Programming Support Manager–Chief Executive–Operation Manager–SAP Support Manager–Chief Executive–Operation Manager–ABAP Programming Manager–Commercial Manager–Operation Manager–Programming Support Manager–Commercial Manager–Operation Manager–SAP Support Manager–Commercial Manager–Operation Manager–ABAP Programming	+1/9*1/4*1/8*1/2 +1/9*1/3*1/8*1/4 +1/9*1/3*1/8*1/5 +1/9*1/3*1/8*1/2 +1/9*1/7*1/8*1/4 +1/9*1/7*1/8*1/5 +1/9*1/7*1/8*1/2 = 0.009
Manager	Programming Support	Manager–Assistant Manager–Operation Manager Manager–Chief Executive–Operation Manager Manager–Commercial Manager–Operation Manager	= 1/9*1/4*1/8+ 1/9*1/3*1/8+ 1/9*1/7*1/8 =0.01

Table 2: Calculation of Entropy for the Position of Manager

From	To	Entropy
Manager	Chief Executive	= $-\log_2$ (0.111) = 3.16
Manager	Assistant Manager	= $-\log_2$ (0.111) = 3.16
Manager	Accountant	= $-\log_2$ (0.111) = 3.16
Manager	Assistant Accountant	= $-\log_2$ (0.111) =3.16
Manager	Collecting	= $-\log_2$ (0.111) = 3.16
Manager	Administrative Support	= $-\log_2$ (0.111) = 3.16
Manager	Billing	= $-\log_2$ (0.111) = 3.16
Manager	Commercial Manager	= $-\log_2$ (0.111) = 3.16
Manager	Supplier Advisor	= $-\log_2$ (0.111) = 3.16
Manager	Senior Customer Advisor	= $-\log_2$ (0.093) = 3.42
Manager	Junior Customer Advisor	= $-\log_2$ (0.022) = 5.49
Manager	Call Center Coordination	= $-\log_2$ (0.015) = 5.97
Manager	Call Center Reception	= $-\log_2$ (0.027) = 5.17
Manager	Operations Manager	= $-\log_2$ (0.08) = 3.63
Manager	Support and Communications	= $-\log_2$ (0.01) = 6.63
Manager	Support Assistant	= $-\log_2$ (0.01) = 6.58
Manager	SAP Support	= $-\log_2$ (0.01) = 6.63
Manager	ABAP Programmer	= $-\log_2$ (0.01) = 6.63
Manager	EMP Manager	= $-\log_2$ (0.01) = 6.63
Manager	Programmer	= $-\log_2$ (0.009) = 6.71
Manager	Programming Support	= $-\log_2$ (0.01) = 6.63
Total	**98.66 bits**	

5. Conclusions

In a dynamic and uncertain environment, planning and organization should revolve around information management, which is measured through entropy. The new strategic center must focus on producing information to overcome entropic losses.

The organization, as it grows, becomes more complex; the same process of gathering information can produce entropy so the information will be lost in the middle processes and bureaucracy of organization. This loss depends on the complexity of the organization and can be overwhelming if not controlled. It is recommended to measure these losses and manage their reduction. In addition, to measure organizational complexity, it is proposed to calculate the entropy by outlining the organization as a complex network. Moreover, to measure the uncertainty of the environment, it is proposed to use the Kolmogorov entropy to obtain the maximum planning time based on the amount of information currently available.

The tools proposed to calculate the entropy loses in the company should be framed in a wider management theory; one that includes uncertainty as part of the design of the strategic plan. Future researches in this field are suggested to construct this new planning paradigm as a response to current necessities to face market volatility.

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