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The Network Entropy as a Measure of a Complexity for Project Organizational Structures

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Abstract

The selection of an organizational structure is one of the most important decisions to make when executing a project. The form of the structure will define the authority, the relationships between the members of the project, where each member is located, the lines of coordination, control, etc. There exists a wide array of quantitative metrics that may be used to measure the complexity of a project organizational structure and that are borrowed from other fields. In this paper, we adopt a metric developed from Shannon's information entropy, the network entropy, which is a useful metric to measure the complexity of a project organizational structure linking the complexity of the structure to its functional role. The measure is applied to the project organizational structure of an international company dedicated to the development, construction, and operation of renewable energy projects in Europe, Asia, and America. Additionally, and for comparative purposes, alternative organizational structures are considered for the company. Our results show that adopting an organizational structure different from the structure that the company is currently using, the company would reduce its complexity and improve its structural agility and performance.

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Keywords: Network Entropy; Project Management; Project Organizationas Structures

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1. Introduction

Measuring the complexity of project organizational structures may be a complicated process for several reasons. The ability to measure this complexity is itself defined by the model chosen, by the information not known or even unknowable about the project, and some aspects that are ambiguous or not understood can also be difficult to be modelled. In fact, there are problems in defining a complexity measure for organizational management in general and for project organizational structures in particular. In organizational theory, for example, complexity has been interpreted as an objective, characteristic of either the structure or behaviour of an organization [1, 2]. Eppinger [3] defines five fundamental elements that a complexity measurement for organizations, processes, and products should address: (*i*) Number of decomposed elements (components, tasks, or teams); (*ii*) Number of interactions managed across these elements; (iii) Uncertainty of the elements and their interfaces; (*iv*) Patterns of the interactions across the elements (density, scatter, clustering, etc.); and (*v*) Alignment of the interaction patterns from one domain to another. Organizational complexity measurement should also consider factors such as diversity, ambiguity, interdependence, flux, and human factors such as sociality, behaviour and cognition, since these factors mainly differentiate organizations from non-living and non-human systems [4].

The selection of an organizational structure is one of the most important decisions to make when executing a project. The form of the structure will have a significant impact on the successful completion of the project. What is the number of specializations? Who are the project participants? What are the contractual relationships and interrelatedness among these participants? How is the organizational structure adapted by project managers? How is the coordination and control? These are only some of the questions that may arise when selecting an organizational structure.

In this paper, we use a metric developed from Shannon's information entropy, the network entropy, which is a useful metric to measure the complexity of a project organizational structure, linking the complexity of the structure to its functional role. The organization of the paper is as follows. In the next Section, we develop the complexity measure, the network entropy. In Section 3, the metric is applied to the organizational structure of an international company dedicated to the development, construction, and operation of renewable energy projects in Europe, Asia, and America. For comparative purposes, the real project organizational structure and three alternative structures are also considered for the company. Finally, there is a concluding section with the main findings of the paper.

2. The Network Entropy

There exists a wide array of quantitative metrics that may be used to characterize the structure of an organization and that are borrowed from other fields such as Graph theory [5-7], Physics [8], and Information theory [9]. However, studies that measure the complexity of a project organizational structure remain scant. Research is needed to measure the complexity of this type of structures and that can help to evaluate aspects such as its structural agility or performance, and even to identify the factors that are the main cause of complexity in projects and prevent them from being effective. Daft [10] defines complexity in organizations as the number of activities within the organization measurable by three dimensions: vertical complexity, quantifiable by the number of levels in the organization hierarchy; horizontal complexity, represented by the number of job titles or departments across the organization, and spatial complexity, expressed by the number of geographical locations. Baccarini [11] describes organizational complexity using two dimensions, interdependence and differentiation, which can either be expressed in form of horizontal differentiation, referring to division of labor, or in form of vertical differentiation, referring to the depth of hierarchical structure. Backlund [12] defines a complex organization as an organization whose behaviour, inner structure, and processes are complex. Lane et al. [13] see complexity in globalized organizations as a four dimensional concept consisting of multiplicity, interdependence, ambiguity, and flux. Similarly, Steger's organizational complexity elements are diversity, interdependence, ambiguity and flux [14].

In this paper, we use a metric developed from Shannon's information entropy, the network entropy [15, 16], which can be a useful metric to measure the complexity of a project organizational structure linking the complexity of the structure to its functional role. Considering that a structure has L different levels and amongst these levels are M

organizational units, the number of units at the l^{th} level of the hierarchy will be given by M^l. Thus, the number total of units in the structure, M, will be:

$$M = \sum_{l=1}^{L} M^l \tag{1}$$

The sum of the entropy contribution within levels is referred to as the vertical entropy, defined as S_V and given by:

$$S_V = -\sum_{l=1}^{L} M^l \ln P^l \tag{2}$$

where $P^l = (M^l/M)$. Since each unit at the l^{th} level reports to a specific unit at the l+1 level, the number of units reporting to the u^{th} department at the l+1 level is given by M_u^l. Thus, the number of units at the l^{th} level of the hierarchy, M^l, will be

$$M^l = \sum_{u} M_u^l \tag{3}$$

The entropy contribution produced by variations across levels are referred to as the horizontal entropy, defined as S_H and given by

$$S_H = -\sum_{l=1}^{L} \sum_{u} M_u^l \ln P_u^l \tag{4}$$

where $P_u^l = (M_u^l/M^l)$. Finally, the total entropy of the project structure will be the sum of the horizontal and vertical entropy:

$$S_{tree} = S_H + S_v \tag{5}$$

These two different contributions, horizontal and vertical entropy, mean that two different structures can look quite different and still have the same organizational entropy. In general, the horizontal entropy is maximal when units within each level are populated with the same number of individuals. Also, the vertical entropy is maximal when the population at each level remains the same. A high ordered, low entropy project structure, would be a very hierarchical structure with strict lines of connection and perfect ordering of reports. Different areas of expertise are each contained within the main organizational units. On the contrary, in a low ordered, high entropy structure the regularity of the structure is disrupted by the variability of the reporting structure with loose lines of communication. Different areas of expertise with comparable authority are also mixed across units.

3. Application

In this section, the complexity measure developed above will be applied to the organizational structure of an international company dedicated to the development, construction, and operation of renewable energy projects in Europe, Asia, and America. Fig. 1 shows the current structure of this company, which has 23 units in total, 1 managing director, 16 managers at the second and third levels and 6 staff units at the fourth and last level.

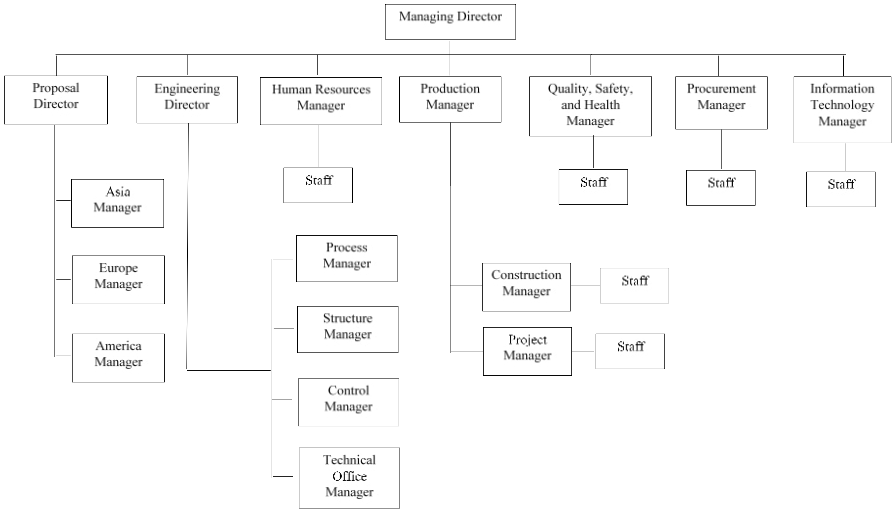

Fig. 1. Current project organizational structure.

Let us consider that the company under study has the possibility to adopt the three organizational structures more commonly used in the literature, namely, functional, pure project and matrix organizational structure. Our aim is to compare the complexity of the organizational structure that the company is currently using with these three alternative project organizational structures, which are shown in Figs. 2, 3, and 4.

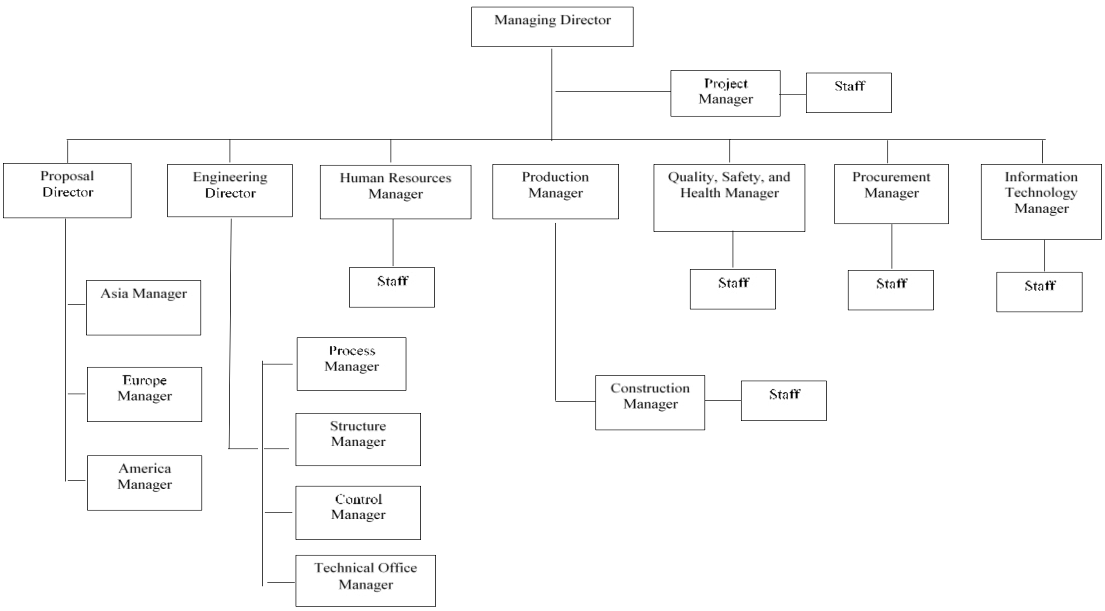

Fig. 2. Functional project organizational structure.

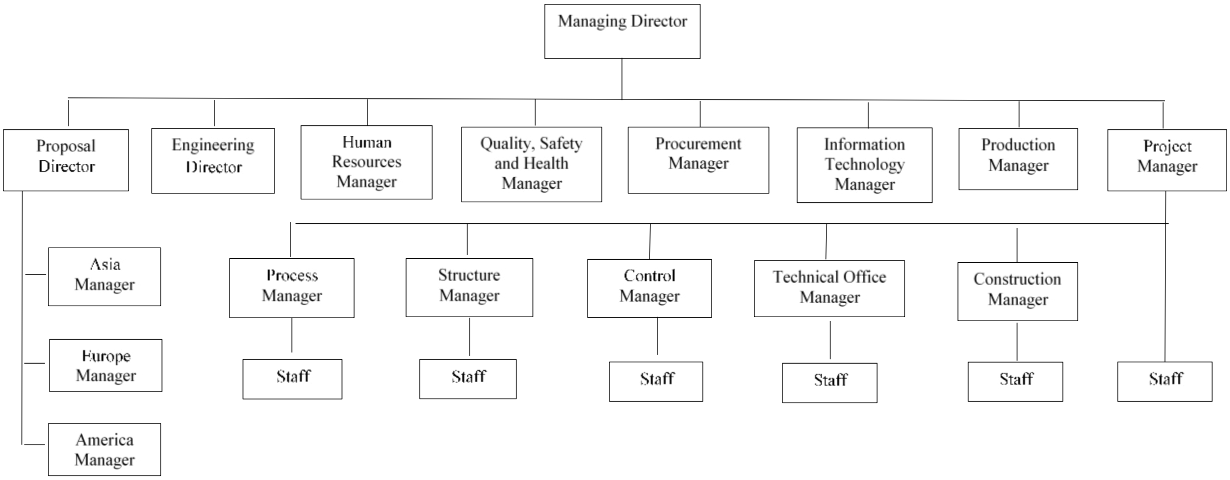

Fig. 3. Pure project organizational structure.

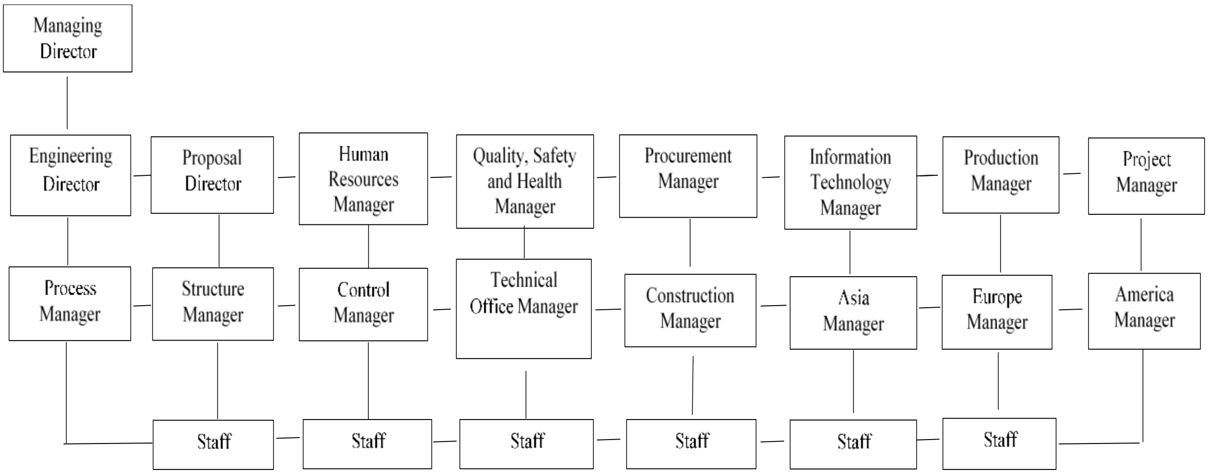

Fig. 4. Matrix project organizational structure.

Tables 1, 2, 3, and 4 show the results from applying Eqs. (1)-(5) to the project organizational structures shown in Figs. 1, 2, 3, and 4. The network entropy associated to the real project organizational structure (Figure 1) is 48.268. Whereas in the real case, the project manager is located at the third level of the hierarchy, adopting the functional organizational structure (Fig. 2), the Project Manager is located at a higher level, acting as staff between the managing director and the different managers located at the second and third levels of the hierarchy. The network entropy associated to this case is 49,654, slightly higher than in the real case. If the company adopts the pure project organizational structure (Fig. 3), the project manager has a high level of authority but also the full responsibility for the performance of the project. This is the case, in which the network entropy is the lowest, with a value of 44,138.

Finally, under the matrix organizational structure (Fig. 4), which is a combination of a functional project structure and line-and-staff structure, the project manager shares responsibility with program unit managers and must work closely with other team members, sometimes competing for the same resources. The network entropy associated to this case is 168. 630, by far the highest of all the cases considered.

Table 1. Network entropy associated to the current project organizational structure.

Level	M^l	S_V	Mu^l	S_H	S_T
4	1	3.135	1	-	-
3	7	8.448	7	-	-
2	9	8.448	9	5.293	-
1	6	8.062	6	10.751	-
Total		28.095		16.043	48.268

Table 2. Network entropy associated to the functional project organizational structure.

Level	M^l	S_V	Mu^l	S_H	S_T
5	1	3.135	1	-	
4	1	3.135	1	-	-
3	7	8.327	7	-	-
2	8	8.448	8	7.795	-
1	6	8.062	6	10.751	-
Total		31.109		18.545	49.654

Table 3. Network entropy associated to the pure project organizational structure.

Level	M^l	S_V	Mu^l	S_H	S_T
4	1	3.135	1	-	-
3	8	8.448	8	-	-
2	8	8.448	8	5.293	-
1	6	8.062	6	10.751	-
Total		28.095		16.043	44.138

Table 4. Network entropy associated to the matrix project organizational structure.

Level	M^l	S_V	Mu^l	S_H	S_T
4	1	3.135	1	-	-
3	8	8.448	23	8.448	-
2	8	8.448	23	67..587	-
1	6	8.062	23	64.499	-
Total		28.095		140.535	168.630

4. Conclusions

Studies that measure the complexity of a project organizational structure remain scant. In this paper, we have adopted and applied a complexity measure, the network entropy, to the project organizational structure of an international company dedicated to de development, construction, and operation of renewable energy projects in Europe, Asia, and America. Alternative structures have also been considered and compared to the real case. Although the network entropy of the organizational structure that the company is currently using is not the most complex structure of all the cases considered, adopting the pure project organizational structure the company would reduce its complexity, which could improve its structural agility and performance. Despite the value of the network entropy associated to the functional and pure project organizational structures is very similar, it is worth noting that the functional organizational structure implies more levels within the organization and hence more complexity because it affects the movements of personnel in and out of the project and within the staff units.

Design and operate the right organizational structure for the type of project under execution will improve its structural agility and communication and coordination among the members of the project. Further research is needed to develop and apply different metrics that can be employed to reduce the complexity of this type of structures and that can help to evaluate aspects such as its structural agility or performance, and even to identify the factors that are the main cause of complexity in projects and prevent them from being effective.

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