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AXIOMATIC DESIGN BASED VOLATILITY ASSESSMENT OF THE ABU DHABI HEALTHCARE LABOR MARKET: PART I - THEORY

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ABSTRACT

The progress of a developing nation is often measured by the advancement of its infrastructure. While "hard" infrastructure such as water, power and transportation are often easy to assess, "soft" structures such as healthcare systems are often more challenging. Furthermore, the quality and reliability of a nation's healthcare system is often driven by the number and diversity of its healthcare professionals. Unfortunately many developing nations often suffer from very constrained segments in their highly skilled labor market and hence must "import" this human capital. Volatility in key healthcare professions can threaten reliable and sustainable healthcare delivery. In this two-part paper, the Axiomatic Design large flexible system modelling framework is used to assess healthcare delivery capability in Abu Dhabi, United Arab Emirates. Part I provides the methodological developments. Here, each profession type is modelled as a functional requirement and the physical hierarchy is modelled at three levels of decomposition: individuals, healthcare facilities, and regions. The associated knowledge base is filled with the associated number of professionals of a given type provided by the corresponding design parameters. The knowledge base is then evolved on a yearly basis as professionals enter, stay and ultimately leave. In Part II, the Abu Dhabi case study shows results indicative of significant volatility in the healthcare labor market. The work demonstrates that Axiomatic Design Theory as applied to large flexible systems can be applied to data-centric methods in human resources management in the context of skills shortages and high attrition rates.

Keywords: healthcare system, Axiomatic Design, large flexible system, human resource management, degrees of freedom, reconfiguration process, reconfigurability.

1 INTRODUCTION

The progress of a developing nation is often measured by the advancement of their infrastructure. While "hard" infrastructure such as water, power & transportation are often easy to assess, "soft" infrastructure [Niskanen, 1991] such as healthcare systems are often more challenging. Fundamentally, healthcare is a labor-intensive system whose quality and reliability is driven by the number and diversity of its healthcare professionals. Therefore, ensuring a nation's development can be seen to equally depend on the retention of knowledge-based healthcare professionals as it does on the maintenance of water, power, and transportation capital.

Moving from a macroeconomic scale to a microeconomic scale, recent research has shown the critical role of knowledge workers in the strategic development of organizations [Grant, 1996; Spender, 1996; Pettigrew *et al.*, 2006]. This is due in large part to the workers' possession of tacit knowledge [Nonaka and Nishiguchi, 2001; Nonaka and Takeuchi, 1995] which has received much attention in the context of the resource-based view [Barney, 1991; Wernerfelt 1995] competence-based competition [Nonaka and Takeuchi, 1995; Leonard-Barton, 1992], dynamic capabilities [Spender, 1996; Teece *et al.*, 1997; Brown and Eisenhardt, 1998], and the knowledge-based view [Grant, 1996; Sveiby 2001].

The strategic importance of knowledge workers has subsequently led to supporting human resources management (HRM) practices. In one work, the impacts of HRM practices are studied from an operations management perspective [Pathirage *et al.,* 2007]. In another, experienced and well-trained police and fire personnel made fewer mistakes and performed faster in the delivery of their critical services [Taylor III *et al.*, 2006]. Such results are likely extensible to first-response healthcare professionals. HRM has also shown to be central to the development of a leadership-centric business vision [Roepke *et al.,* 2000]. Recent work has also shown the importance of HRM to the knowledge management of an organization [Whelan and Carcary, 2011] and its criticality in the development of learning organizations [Lee-Kelley *et al.*, 2007] especially as it develops key capabilities in corporate social responsibility and sustainability [Nicolopoulou, 2011].

Unfortunately, many nations suffer from very constrained segments in their highly skilled, knowledge-centric labor market [Jin and Li-ying, 2003]. Given the relative ease of attrition and relative difficulty to train, the HRM literature has given a great deal of attention to IT professionals [Roepke *et al.* 2000; Ang and Slaughter, 2004; Zheng and Hu 2008]. One author also highlights the critical service role of IT professionals in the healthcare sector [Boland, 1998]. Similarly, HRM research has addressed the challenges of maintaining a capable R&D staff [Han and Froese, 2010] including the needs posed by its female members [Servon and Visser, 2011; Cuny and Aspray, 2002]. The retention of Army officers is also a particularly interesting workforce segment given that their practical field experience represents decades of tacit knowledge [Dabkowski *et al.*, 2011]. Similarly, HRM practices have recognized the important role of senior workers [Armstrong-Stassen and Schlosser, 2011; Wong and Kimura, 2009]. Finally, there is growing recognition that knowledge workers also includes skilled manual labor in manufacturing [Zheng *et al.,* 2008; Foy and Iwaszek, 1996] and construction [Clarke and Herrmann, 2007; Gow *et al.* 2008].

These human resources challenges are particularly exacerbated in developing and emerging economies where either human capital has not had a chance to accumulate or where the growth rate of the economy outstrips efforts at human capital development [Beulen, 2009; Kapoor and Sherif, 2012]. Geography specific studies have addressed the large scale issues found in China and India [Zheng *et al.,* 2008; Beulen, 2009; Kapoor and Sherif, 2012; Doh *et al.* 2011]. In similar studies, Horowitz shows the lingering impacts of centrally planned political economies on HRM in Eastern and Central Europe [Horwitz, 2011] while Zheng & Hu describe the effects of economic restructuring in Singapore & Taiwan [Zheng and Hu 2008]. Further attention has been given to Gulf Cooperation Council (GCC) countries where the absence of well-established indigenous human capital combined with fast economic and population growth has led to dramatic needs in human resources management [Doh *et al.,* 2011; Horwitz, 2011].

Given these exacerbated conditions in the GCC, and the importance of retaining knowledge-centric healthcare professionals to a nation's development, this paper specifically seeks to assess the volatility and the retention of healthcare HRM practices in the United Arab Emirates. Section 2 provides the methodological background to this study in terms of existing HRM research methods and the relevant aspects of Axiomatic Design. Section 3 then provides a methodological contribution by describing how an Axiomatic Design knowledge base can be used to model the healthcare labor pool as a large flexible system. Section 4 concludes the work and introduces Part II of this two-part paper.

2 BACKGROUND

In this Section, the methodological background for the study is provided. Existing human research management methods are first reviewed so as to be contrasted to how an Axiomatic Design based approach can be applied.

2.1 EXISTING HUMAN RESOURCE MANAGEMENT RESEARCH METHODS

In the context of this discussion, human resources management research methods have centered around two broad classes of research questions 1.) what are the causal factors driving an individual's decision to join and stay within an organization? [Afifi, 1991; Ang and Slaughter, 2004; Budhwar et al. 2009; Ghosh & Sahney 2010; Armstrong-Stassen & Schlosser 2011) 2.) what HRM strategies can be implemented to prolong the retention of this individual in an organization [Lockwood and Ansari 1999; Finegold *et al.,* 2005; Kaliprasad, 2006; Chew and Chan, 2008; Beulen, 2009]? In the majority of this work, the research methods relied on semi-structured interviews and surveys to study the attrition *intention* of currently employed individuals. Such a research methodology presents two biases. First, it is not clear if the intention to resign is fleeting or if it is severe enough to be actionable. Second, the individuals who have already resigned are not included in either the interviews or surveys. From the perspective of continuous improvement, these individuals present the greatest learning opportunities.

In contrast, some of the more recent research has taken the strategy of directly studying organizations' human resources databases [Zheng and Hu, 2008; Holtbrugge *et al.,* 2010; Dabkowski *et al.*, 2011). Such a research methodology resolves the two previously mentioned concerns. Furthermore, it allows for rigorous diagnostic capabilities based upon data mining techniques [Dabkowski *et al.*, 2011; Chien and Chen, 2008]. For example, recent work has proposed the usage of GIS technology to study the impact of location on human resources retention [Hanewicz, 2009]. Other work presents the development of work flexibility to manage the disturbances caused by worker attrition [Fry *et al.*, 1995]. These types of practices lend themselves to the knowledge base-centric capabilities assessments used in the Axiomatic Design of large flexible systems.

2.2 AXIOMATIC DESIGN THEORY FOR LARGE FLEXIBLE SYSTEMS

The Axiomatic Design of large flexible systems provides a natural extension to the data-centric trends in HRM research methods. Suh defines large flexible systems as systems with many functional requirements that not only evolve over time but also can be fulfilled by one or more design parameters. In this case, Suh uses the large flexible system design equation notation:

$$\begin{aligned} &FR_1 \$ (DP_1, DP_2, DP_3) \\ &FR_2 \$ (DP_2, DP_3) \\ &FR_3 \$ (DP_3) \end{aligned} \quad (1)$$

to signify that FR_1 can be realized by design parameters DP_1, DP_2, or DP_3 [Suh, 2001]. Here, it is implicit that the set of functional requirements and design parameters is at a specified level of decomposition. Nevertheless, it may be necessary to describe the functional requirements and design parameters higher up in the functional and physical hierarchies respectively. Previous work has mathematically described aggregation as binary operation denoted by * [Farid, 2007]. Given an arbitrary element $s_j \in S$, an arbitrary parent group $\underline{s}_k \in \underline{S}$, and a binary aggregation matrix A whose elements a_{kj} equal 1 if $s_j \in \underline{s}_k$, then

$$\underline{S} = A * S \quad (2)$$

is equivalent to:

$$\underline{S}(k) = \bigcup_j A(k,j) \cdot S(j) \quad (3)$$

For the purposes of recursively representing the Axiomatic Design functional and physical hierarchies,

$$\begin{aligned} \underline{FR} &= A_F * FR \\ \underline{DP} &= A_P * DP \end{aligned} \quad (4)$$

Previous work reinterprets Equation (1) in terms of a matrix equation using a boolean knowledge base matrix J_S [Farid and McFarlane, 2008].

$$FR = J \odot DP \quad (5)$$

The A ⊙ B operation represents the Boolean equivalent of matrix multiplication

$$C(i,k) = \bigvee_j A(i,j) \cdot B(j,k) \qquad (6)$$

where $\bigvee_j$ is the array-OR operation similar to the familiar sigma (summing) notation for real numbers [Farid and McFarlane, 2008].

The same work demonstrated that in production systems if the set of functional requirements is taken as the set of production processes and the set of design parameters taken as the value-adding and material handling resources, then the non-zero elements in the knowledge base J can be interpreted as the production system's degrees of freedom [Farid and McFarlane, 2008). This work and others [Baca *et al.,* 2013; Viswanath *et al.*, 2013) seek to generalize this result for all large flexible systems that follow the Axiomatic Design definition. A generalized definition of a large flexible system's degrees of freedom is:

$$DOF = \sum_i^{FR} \sum_j^{DP} J(i,j) \qquad (7)$$

From this, it follows that the redundancy R_i of the ith functional requirement is:

$$R_i = \sum_j^{DP} J(i,j) \qquad (8)$$

and the flexibility of the j^{th} design parameter is:

$$F_j = \sum_i^{FR} J(i,j) \qquad (9)$$

This work was extended to allow the possibility for a system architecture that changes in time through a reconfiguration process [Farid and Covanich, 2008]. Given a reconfiguration process $\mathcal{R}$ that occurs over a time interval T, the resulting discrete time difference equation describes the time evolution of the knowledge base

$$J(t+T) = \mathcal{R}(J(t)) \qquad (10)$$

Given that J represents independent degrees of freedom, it is valid to vectorize it with the vec() operator [Abadir and Magnus, 2005) as is typically implemented in MATLAB with the (:) operator. It follows that the knowledge base differential ΔJ caused by a reconfiguration process **R** is given by:

$$\Delta J = (\mathcal{R} - 1) vec(J(t)) \qquad (11)$$

These measures are applied to the development of a healthcare human resources knowledge base in the following section.

3 METHODOLOGY: MODELING HEALTHCARE SYSTEMS WITH AXIOMATIC DESIGN

In this section, the Axiomatic Design knowledge-based models are applied to data-centric human resources management of healthcare professionals.

The functional and physical hierarchies are established as follows. The set of functional requirements is defined as the set of healthcare professions: **FR**={Healthcare Professions}. The functional domain is only addressed at this level of hierarchy as it is important to be able to distinguish between these individual healthcare function throughout the analysis. In contrast, the physical domain can be analysed at three levels of hierarchy. At the lowest level, the set of design parameters is the set of individuals' names e.g. **DP**={IndividualNames}. Further analyses can be conducted if each individual belongs to a healthcare facility. **<u>DP</u>**={Healthcare Facilities}. Finally, these healthcare facilities can be viewed in terms of the geographic regions in which they are located. **<u>DP</u>**={Regions}. The resulting Axiomatic Design dual hierarchy is pictured in Figure 1.

The relationships between the healthcare professions in the functional hierarchy and the various aggregations of the physical system can be captured in the healthcare human resources knowledge base. At the lowest level, J is the binary map between the i^{th} healthcare profession and the j^{th} individual name. At a higher level of aggregation, J_P is defined as an integer knowledge base whose elements equals the number of individuals with a given profession at a given healthcare facility, then it follows that

$$J_P = J \cdot A_P^T \qquad (12)$$

Equation (12) may be used recursively for the regional analysis.

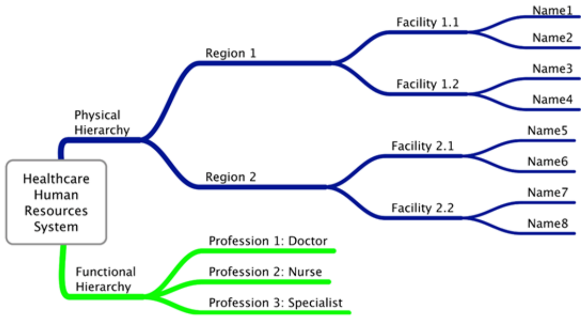

Figure 1. Axiomatic Design Dual Hierarchy for Healthcare Human Resources System

The calculation of the number of healthcare human resources degrees of freedom follows straightforwardly from Equation (7). It represents the total number of healthcare professionals in the system at a given time. The redundancy R_i of the i^{th} healthcare profession is given by Equation (8) or in the special case that all healthcare professionals work for a single healthcare facility or region then:

$$R_i = \sum_k^{DP} J_P(i,k) \qquad (13)$$

Similarly, Equation (9) gives the functional flexibility F_j of the j^{th} design parameter. It represents the number of professions for which an individual is licensed. Typically, this is only 1. The functional flexibility F_k of the k^{th} healthcare facility exhibits the same form provided that J_P is taken in binary rather than integer form.

$$F_j = \sum_i^{FR} bi\left(J_P(i,k)\right) \qquad (14)$$

The healthcare system properties of profession redundancy and facility flexibility are particularly important system properties. The former is often related to a healthcare system's quality of service especially when normalized by the size of the patient population (e.g. # of doctors/patients). The latter is often related to a healthcare facility's convenience, in that if a particular profession is present at a given facility then it eliminates the need of a patient to go elsewhere. Such a convenience measure addresses patient conditions that are time critical one-offs (e.g. emergency services) as well as more routine services (e.g. the neighbourhood pharmacist).

In this context, human resources management recruiting practices that counter natural rates of professional attrition can be modelled as reconfiguration processes acting upon the system knowledge base. Given a recruiting (reconfiguration) process $\mathcal{R}_R$ and an independent attrition (reconfiguration) process $\mathcal{R}_A$ that occur over a time interval T, the healthcare human resources knowledge base evolves by a differential:

$$\Delta J = (\mathcal{R}_R - \mathcal{R}_A)J(t) \quad (15)$$

If the recruiting and attrition processes are taken to be time invariant processes that occur over successive time intervals, then Equation (15) can be rewritten as a familiar first order differential equation.

$$\dot{J} = \frac{(\mathcal{R}_R - \mathcal{R}_A)}{T} J \quad (16)$$

The efficacy of human resources management practices can then be measured in terms of the time constant matrix ($\mathcal{R}_R$-$\mathcal{R}_A$)/T. In a sense, Equation (16) describes the rate of change of the healthcare human resources system architecture and that its control are the region's aggregate human resources practices. The rate of change is also particularly important in the context of rapid population growth as the normalization by population is closely linked with quality of service.

4 CONCLUSIONS & FUTURE WORK

This paper represents Part I in a two-part paper on the application of Axiomatic Design to the human resources management of the Abu Dhabi Healthcare system. It specifically addresses the necessary methodological contributions. After an extensive review of existing human resources, it was found that existing HRM research is trending towards data analysis intensive techniques. In this regard, the Axiomatic Design Knowledge base provided an effective tool for organizing the data. The concept of degrees of freedom previously applied to other large flexible systems was used to quantify the system architecture, and the concept of a reconfiguration process was used to develop a differential equation of the long-term evolution of the system architecture. Finally, the rate of change of the system architecture was proposed as a measure of the efficacy of human resources retention. In Part II of this two-part paper, these developments are applied to the Abu Dhabi healthcare system [Khayal and Farid, 2013]. Much effort is devoted to determining the effective time constants of the healthcare human resources knowledge base evolution over the span of 1967-2012.

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