Development of a Competence Management System: an algebraic approach

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Abstract: The complexity in engineering processes of high technology companies needs to carefully and efficiently manage the human resources competences dedicated to the related activities. Focus on an Italian aerospace company, Alenia Aeronautica, the paper wants to illustrate the use of set theory in order to represent objects, rules and indexes of the competence management methodology. This mathematical formalism allows to easily represent the complexity of this context and to guide the implementation of a future competence management system (CMS).
In addition, the use of an algebraic approach allows the implementation of a competence management information system that may be customized to any industrial context. In addition, this flexible structure can be easily modified to respond to a continuously changing competence scenario related to the business environment.

Keywords: Aerospace industry, Engineering competences, Competence Management System, Set theory.

1 Introduction

The increasing competition, the need to reduce the time to market and to increase innovation require to continuously adapt the organization and its behavior to respond to this dynamically changing context [Hr06]. In this situation, competence-based management is becoming an object of growing interest. The human resources and specially their competences are considered strategic assets to achieving the companies objectives [Ct07]. The continuous monitoring of resources and competence gaps, and the definition of actions aimed to fill them, become fundamental organizational capabilities. The management of competences requires the definition of several entities and principles leading the implementation of a whole system that can be translated in an information system. In fact, studies of effects and challenges related to computer-aided competence

management are also present in literature [Ln04; HM05; LB07]. As part of a human resource management system, information technology (IT)-supported strategic competences management can be a driver of relevant benefits such as experts and talents location and allows to increase the objectivity in the evaluation of human resource.
An efficient way to implement a complete competence management tool, which have a flexible structure related to the enterprise context, is to explicit a mathematical formalization supporting a valid understanding of competence management. Several studies have been focused on the use of analytic mathematical model adapted to the theoretical basis concerning the competence management system [Hr06; Pt07; Rn07] but no one is based on the representation of the complexity of engineering competences in aerospace sector.
In this perspective, the paper treats the case of a leading Italian aerospace company, Alenia Aeronautica, especially of the CTO (Chief Technical Officer) departments, very careful to have a clear view about the competences available and very interesting to search and continuously improve its competence management system. Alenia Aeronautica is a large Italian aerospace company, part of the Finmeccanica group which operates in the aerospace sector and is involved in several programs (e.g. "C27J," "ATR," "Eurofighter Typhoon," and "Boeing 787 Dreamliner") with different levels of responsibilities and risks sharing. Its CTO department has a purposeful competences management methodology and web-based application [Cr10] that need to be improved in order to optimize the evaluation and allocation of resources. By means of the set theory using sets, relationships and mappings between sets, the main concepts of the competence management methodology are defined to allow further and easily improvements with the aim to optimize the identification, development, and scouting of competences required in design, manufacturing, and testing activities through the realization of a new system. The paper wants to underline the utility of a mathematical approach to overcome linguistic divergences between semantically equivalent concepts concerning a competence management methodology. Moreover, a mathematical model permits to lead an easier development of a related IT system. The sets formalism allows to generalize the methodology and to support further and most directly changes both for the company internal use and for the application in other companies.
The remainder of the paper is organized as follows. In Section II, some theoretical definitions and previous studies are briefly reviewed in order to outline the background of the proposed approach. In Section III, the research design approach is described. Section IV illustrates the paper results based on the representation by set theory of all the objects related to an improved competence management methodology for the company that will be used to realize a CMS. Finally, Section V draws conclusions, limitations, and future research.

2 Theoretical Framework

A competence can be defined as a set of intrinsic attributes correlated with the performance in executing one or more defined tasks [SS92; By82].
A competence is thus a standardized requirement to properly perform a specific job and it typically encompasses a combination of knowledge, skills and behavior utilized to improve performance.

Competences of individual actors have also a strong organizational relevancy, being the overall performance of the actor strongly related to his/her behavior, work or understanding skills [BL03].
The human competencies have to be specified considering a strong connection with the tasks performed and thus, the competence diagnosis and competence gap analysis have to be lead by the normal working tasks [Ly08].
Skills and competence management systems (CMSs) can help organizations to improve the effectiveness of the employees allocation and performance. CMSs are aimed to identify those processes or tasks that are critical to achieving results, design task knowledge and supervisor observation, inventory training resources and align the right resources to the right task, group processes into job families, align jobs with organization units.
Several studies have adopted a analytic mathematical model to structure and to formalize the concept of a competence management methodology. In general, this approach is presented for the development of competence management information systems to enable company's competence management at all business control levels (i.e., strategic, tactical, and operational) [Hr06].
In other studies, the analytic mathematical model is adopted to respond to precise aims, i.e. to develop a model for a effective and efficient assignment of employees to workplaces [Pt07] or to evaluate the strategic competence of senior leaders in enterprises [Rn07].
Previous studies explore the methodology at the base of CMS in aerospace companies [Lw97; Cr10], but no one translates the theoretic concept in mathematical formalism. The study of Lewis [Lw97] shows a successful application of a method based on the definition of competences, resources, processes in an Aerospace Composite Technologies company. The study of Corallo et al. [Cr10] is instead focused on the optimization of the competence management process in the Alenia Aeronautica company.
The present paper wants to translate a competence management methodology of an aerospace company in algebraic terms for leading the related IT system reengineering.

3 Research Design

The study is based on an action research based on an inductive approach in which problems and solutions have been derived through an observation of the organizational practices [BB07; Th06; Ob01]. This action research is based on the contributions coming from the direct observation and use of the methodology and system available inside the company by a team of engineers of Alenia Aeronautica and researchers of University of Salento. During the period of observation, the need of improvements in the competence management methodology and of a new CMS, with new functionalities and further indicators, has emerged to optimizing the decision making process related to actors allocation, scouting and improvement.
In Corallo et al. [Cr10], the methodology and web-based application used in Alenia Aeronautica are described. This paper wants, instead, to algebraically represent a most powerful and reliable methodology solving the weakness of the previous approach and leading a reengineering of the CMS.

The Alenia Aeronautica approach to competence management is rich of concepts and linkages among concepts and the use of set theory allows to easily represent this complexity providing an immediate and complete view on objects, rules and indexes.
The problem of managing engineering competences is a very pressing issue in engineering processes aimed to produce complex products and systems. In those processes, a large number of elements interact dynamically both in physical aspects and in the transfer of information. Each interaction is, in fact, rich and influences all the others elements [Cl98]. Specially, aerospace products are complex ones, they are composed by many parts and demands several and varies engineering competencies related to sophisticated technologies, innovative materials and knowledge-intensive processes.
In this paper the mathematical model has been considered the most adequate choice to represent a competence model that reflects the complexity of the aerospace context and provides further developments and adjustments.
The following proposed results are flexible and easily adaptable to other context characterized by high complexity in the engineering process, such as automotive and naval.

4. Competence Management in Algebraic Terms

4.1 Key points definition of Alenia's Competence Management System

This section defines and describes schematically all objects constituting the current competence management methodology adopted by Alenia. Using the set theory, a representation of objects is made at a given time t.
The main concept of the competence, at the base of the Alenia's methodology, is tightly related to the work activities. Following there is a description of the system entities.

Human resource	A person who operates within the Chief Technical Office (CTO) which can be an internal or an external employee. $P = \{p_1, p_2, \dots, p_m\}$
Competence Area	Set of activities that requires similar knowledge and skills to be performed. The activities that belong to a competence area can not take part of another area. $\mathrm{M} = \{\mathrm{M}_1, \mathrm{M}_2, \dots, \mathrm{M}_s\}$
Activities	Tasks or jobs performed by a human resources in order to achieve the goals of their competence area. $A = \{a_{1,} a_{2,} \dots, a_n\}$

Tab. 4.1.1: System entities of Alenia's methodology.

In order to better describe and evaluate the activities executed within the CTO department and to allow a set of useful analyses, the activities of each area are classified according to their complexity. Index and rules are presented in the following table.

Complexity Index	This index measures the complexity of an activity due to its technical difficulty and its interaction level. It is expressed by a numerical value that varies from 1 ("low") to 5 ("very high"). $K = \{\tilde{k}_a\}\ con\ \tilde{k}_a{}^1 \in\ \bar{K} = \{1, 2, 3, 4, 5\}$
Competence	This parameter represents the human capability to perform a particular activity. Every person, with reference to an activity, can actually perform it or not and, if not, he/she could be potentially able to do that. The competence is expressed whit numerical values 1, 0, -1. $C = \{c_{pa}\}\ con\ c_{pa}{}^2\ \in\ \bar{C} = \{-1, 0, 1\}$ If we consider the person p_1 and the activity a_2, the competence c_{12} is associated with these two elements. Consequently, the person p_1 may: - Not be able to carry out the activity a_2 ($c_{12} = 0$); - Potentially be able to carry out the activity a_2 ($c_{12} = -1$); - Know how to carry out the activity a_2 ($c_{12} = 1$).
Competence Level	Given an activity, this level represents the assessment make by the head of discipline, the responsible of the evaluated person, expressed by a numerical value from 0 to 4, according to the degree of competence possessed by a particular person, independently if it performs or not the activities. $L = \{l_{pa}\}\ con\ l_{pa}{}^3\ \in\ \bar{L} = \{0, 1, 2, 3, 4\}$ If we consider the previous case, the person p_1 is able to perform the a_2? There may be five cases that correspond to five competence levels: 0: no, p_1 doesn't perform, actually or potentially, the activity a_2 ($l_{12} = 0$); 1: yes, p_1 perform, actually or potentially, a_2 with inconclusive results ($l_{12} = 1$); 2: yes, p_1 perform, actually or potentially, a_2 with satisfactory results ($l_{12} = 2$); 3: yes, p_1 perform, actually or potentially, a_2 with good results ($l_{12} = 3$); 4: yes, p_1 perform, actually or potentially, a_2 with excellent results ($l_{12} = 4$).
Role	Within a competence area, the role is a set of activities. The activities belong to a role on the strength of a certain weight v_{ar}[4] that represents the competence level required by the activities of this role. Within the same competence area an activity may belong to several different roles. Every person belongs to a role and can perform tasks that belong to that role with a competence level l_{pa}. $R = \{R_1, R_2, \ldots, R_t\}$ $V = \{v_{ar}\}\ con\ v_{ar}\ \in\ \bar{V} = \{1, 2, 3, 4\}$ A competence area can include multiple roles, but different competence areas have different roles.
Advisor role	For each activity belonging to a given role, there is an ideal figure with the competence level required by the activities of this role, v_{ar}.
Competence index of advisor role	For each role, it is the numerical value given by the sum of the product of: - the competence level required by the activities of this role, v_{ar}; - the complexity index of activities, $\tilde{k}_a$.
Role index	It measures the ability of the resource to carry out the activities belonging to a

[1] The subscript "a " indicates that the complexity "$\tilde{k}$" is related to "a " activity.

[2] The subscript "pa " indicates that the competence "c" is possessed by "p " person to carrying out the "a " activity.

[3] The subscript "pa " indicates that the competence level "l" is possessed by "p " person to carrying out the "a" activity.

[4] The subscript "pa" indicates that the competence level "v" is required by the activity "a" in that role "r".

	given role in relation to competence level of advisor role. Considering all activities of a role, it is obtained as the sum of the product of: - the competence level possessed by a person. For each activity of the role, this value mustn't exceed the competence level of advisor role; - the complexity index of the task.
Competence level of a person relative to a role	This value is important to evaluate the competence gap between people and role and to determinate the main important actions to mitigate the gap, as supply a training course or make a better resources allocation.For each resource, this value is calculated as the ratio between the "Role index" and the "Expertise index of advisor role".

Tab. 4.1.2: Index and rules of Alenia's methodology.

4.2 An algebraic design of the CMS

Given the previous definitions, this section summarizes the main concepts leading the future CMS that has to be developed. Supposing to be within a single well-defined competence area M_1, the following elements may be defined as:

Element	Formalism
Set of people	$P = \{p_1, p_2, \dots, p_m\}$
Set of activities	$A = \{a_{1,} a_{2,} \dots, a_n\}$
Vector (1xn) of complexity	$K = [\tilde{k}_1 \quad \tilde{k}_2 \dots \quad \tilde{k}_n] \;\; with \; \tilde{k}_a \in \bar{K} = \{1, 2, 3, 4, 5\}$
Matrix (mxn) of competences	$C = \begin{bmatrix} c_{11} & c_{12} \cdots & c_{1n} \\ c_{21} & c_{22} \cdots & c_{2n} \\ \vdots & \ddots & \vdots \\ c_{m1} & c_{m2} \cdots & c_{mn} \end{bmatrix} \;\; with \; c_{pa} \in \bar{C} = \{-1, 0, 1\}$
Matrix (mxn) of competence level	$L = \begin{bmatrix} l_{11} & l_{12} \cdots & l_{1n} \\ l_{21} & l_{22} \cdots & l_{2n} \\ \vdots & \ddots & \vdots \\ l_{m1} & l_{m2} \cdots & l_{mn} \end{bmatrix} \;\; with \; l_{pa} \in \bar{L} = \{0, 1, 2, 3, 4\}$
Set[5] of roles	$R = \{R_1, R_2, \dots, R_t\}$
Matrix of weight (nxt) with the activities are associated to a role	$V = \begin{bmatrix} v_{11} & v_{12} \cdots & v_{1t} \\ v_{21} & v_{22} \cdots & v_{2t} \\ \vdots & \ddots & \vdots \\ v_{n1} & v_{n2} \cdots & v_{nt} \end{bmatrix} \;\; with \;\; v_{ar} \in \bar{V} = \{1, 2, 3, 4\}$

Tab. 4.2.1: Summary of the concepts.

The definitions given above can be formalized as follows:

[5] It is a set of nonempty subsets disjointed: $R = \{Ri \mid i \in \{1, .., t\}\} \ni' R = \cup Ri \;\; e \;\; Ri \cap Rj \neq \emptyset \; with \; i \neq j$.

Definition	Formula
Competence and Competence level	$\forall p_k \in P, with\ k \in \{1,\dots,m\}\ results$ $c_{ki} = \bar{f}(a_i) = \begin{cases} 0 \\ 1\ with\ i \in \{1,\dots,n\} \\ 2 \end{cases}$ $if\ c_{ki} = 0\ then\ l_{ki} = g(c_{ki}) = 0$ $if\ c_{ki} = \{1,2\}\ then\ l_{ki} = g(c_{ki}) = \begin{cases} 1 \\ 2 \\ 3 \\ 4 \end{cases}$
Role expressed as a set of activity with a certain weight	$\forall j \in \{1,\dots,t\}\ results\ R_j = \tilde{f}(a_i, v_{ij})$ $with\ i \in \{1,\dots,n\}\ e\ v_{ij} \in V$
Competence index of advisor role	$\forall\ R_j\ with\ j\ \in \{1,\dots,t\}, \forall a_i \in M_1\ with\ i \in \{1,\dots,n\}$ $results\ \ AdvR_j = \sum_{i=1}^{n} \tilde{k}_i \times v_{ij}, with\ v_{ij} \in \{0,1,2,3,4\}$ $that\ is\ AdvR = K \times V$
Role index	$\forall\ i\ \in \{1,\dots,t\}, define\ \widetilde{L}_{i,b}$[6] $= [\tilde{l}_{i,b}] = [min(l^T{}_{i,k}, v_{i,\tau})]$ $where\ b = m + t, k \in \{1,\dots,m\}\ and\ \tau \in \{1,\dots,t\};$ $\forall p_k \in P\ with\ k \in \{1,\dots,m\}, \forall\ R_j\ with\ j\ \in \{1,\dots,t\},$ $\forall a_i \in M_1\ with\ i \in \{1,\dots,n\}\ results\ \ IR_{kj} = \sum_{i=1}^{n} \tilde{k}_i \times \tilde{l}_{ib}$ $that\ is\ IR = K \times \widetilde{L}$
Competence level of a person relative to a role	$\forall p_k \in P\ with\ k \in \{1,\dots,m\}, \forall a_i \in M_1\ with\ i \in \{1,\dots,n\}$ $results\ \ LR_{kj} = \frac{IR_{kj}}{AdvR_j},\ \ with\ j\ \in \{1,\dots,t\}$ $that\ is\ \ LR$[7] $= diag(IR) \times (diag(AdvR_1 \mid \dots \mid AdvR_k))^{-1}$

Tab. 4.2.2: Sintax and semantics of the method.

The presented formulas allow to provide an easy to understand representation of the competence management indexes and rules available in the current improved methodology.

The indexes represented in Tab. 4.2.2 can permit to get a complete CMS that visualizes an as-is competence scenario, specifically to:

- analyze both competency gaps and resources experience currently available in the company;
- monitor several parameters, like the resource seniority;
- evaluate the potential of internal resources growth;

[6] The columns of this matrix, $\widetilde{L}$, are the minimum value calculated between the competence level of i-th person for all n activities (columns of L^T) and the weight of j-th role for the same activities (columns of V). The size of $\widetilde{L}$ is $n \times b\ where\ b = m + t$.

[7] Where the matrix: $diag(AdvR_1 \mid \dots \mid AdvR_k)$ is constituted by the repetition of the vector AdvR k-th time as it is the number of people to evaluate.

- improve the process for managing the internal competences, allowing also a cross-functional management;
- simulate the competencies asset by removing the resources that will not be available anymore in the near future (retirement, contract expiring, transferring, etc.).

Formulas can be used to implement a new software since they can be translated in software language in a fast and clear way. The formulas are also very flexible to any required changes that could emerge using the developing system.

An interesting application of the formalism presented above is given for example by a linear programming problem for searching the optimal allocation of the resources.

Indeed, if you consider the roles index matrix for a set of activities belonging to Competence Area and you want allocate the resources in order to obtain the maximum productivity inside the Competence Area, it is enough to resolve a linear system which coefficients are the role indexes and the unknown quantity are the time consuming (expressed in percent) of each resource.

5 Conclusions, limitations, and future research

This paper proposes the utility of the use of an algebraic method for the representation of the entities and rules guiding the competence management inside a complex enterprise context, such as an aerospace company, Alenia Aeronautica. This approach allows to provide a design easy to understand and flexible for further improvements that includes in a simple set of formulas all the most important rules useful to re-engineer the CMS.

The used representation is thus very flexible since can be adequate to further improvements and also applied in other companies through easy adjustments to the formulas.

Moreover, the development of software based on an algebraic design is easier for the use of a common and complete representation of the objects and linkages and allows to reduce the developing time.

Further development of this approach will be useful to test the appropriateness and eliminate emerging errors. In fact, future researches are based on the re-engineering of the actual competence management system based on the proposed algebraic representation. The implementation will improve the results and the soundness of the approach.

Actually, a competences dictionary and new assessment parameters as the time-work and work-load are under evaluation. Besides, the algebraic representation is under-testing of the research team that is working on apply the formulas to some key company cases in order to better define company scenario and evaluate lacks to be improved. Further developments will be also emerged from the test and will be used to improve the whole representation.

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