Identifying Technical Competences of IT Professionals. The Case of Software Engineers.

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Abstract

This paper aims to identify technical competency levels relevant to Software Engineering in a spectrum of professional profiles which are found in Spain's main Software Development companies. The research work presents a combination of three initiatives. The first step constitutes a review of the literature related to the characterization of the labour force in the Software Engineering domain. The subsequent step consists of a qualitative study of the practices of a set of organizations, and lastly, this was followed by a quantitative analysis based on investigative surveys administered to a number of representative professionals.

The professional career is established from seven consecutive profiles. The pyramidal model for professional careers, identifying one single professional track going from Junior Programmer to IT Director, is still present in the organisations subject to this study. Technical excellence is reached in a determined professional profile, in this case "D". From this point onwards, other competencies which are not uniquely characteristic of Software Engineering gain importance, and stimulate professional development towards higher levels.

Keywords: Competences, Competency Levels, Software Engineering, Human Factors, Professional Issues.

1 INTRODUCTION

Human Factors represent one of the most important areas of improvement in Software Engineering (SE). Failure rates in software projects are high, and qualified software engineers pertaining to software development teams are key factors in the software development process and their shortcomings and caveats (Pressman, 2005). More precisely, Boehm points out that "After product size, people factors have the strongest influence in determining the amount of effort required to develop a software product " (Boehm, 1981), and "Personnel attributes and Human Resource activities provide by far the largest source of opportunity for improving software development productivity" (Boehm, Horowitz, Madachy, Reifer, Clark, Steece, Brown, Chulani, & Abts, 2000). Competence at the individual level is required for the creation of core competence, crucial for todays organizations at the organizational level. (Bassellier, Reich & Benbasat, 2001).Individual differences have been identified as one of the paradigms for the research of human factors in software development (Curtis, 2002). Research in this area goes back to the 1960s (Sackman, Erikson & Grant, 1968) and continued actively in the 1980s (De Marco & Lister, 1985). Since the 1990s, productive research investigating the role of human factors in software engineering has emerged (Sommerville & Rodden, 1995), (Turley & Bieman, 1995), (Humphrey, 1998), (De Marco & Lister, 1999), which has continued progressively since the beginning of the 21st century (van Solingen, Berghout, Kusters & Trienekens, 2000), (Constantine, 2001), (Tomayko & Hazzan, 2004).

In order to improve the capability of the workforce, several initiatives, such as SEI's People-CMM (Curtis, Hefley & Miller, 2001), describe an evolutionary improvement path which starts from ad hoc, inconsistently performed workforce practices, and progresses to a mature infrastructure of practices for continuously elevating workforce capability. Level 3,"Defined" of the proposed People-CMM refers to a processing area called "Career Development", which implements the professional career to ensure that individuals are provided opportunities to develop workforce competencies that enable them to achieve career objectives. In order to reach level 3, organisations should determine which different professional careers their employees can undertake, specifying in an explicit way the professional profiles and their corresponding competency levels.

Moreover, competency levels for professional profiles represent one of the fundamental aspects of a professions' maturity level, namely "Professional Development" (Ford & Gibbs, 1996). SWEBOK (Abran, Bourque, Dupuis, Moore & Tripp, 2004), the Software Engineering Body of Knowledge, establishes cognitive levels for each of the components of the 10 knowledge areas. These levels are determined based on levels of apprenticeship described by Bloom's taxonomy (Bloom, 1956). The

typology is made for one single profile, being a Software Engineer with four years of experience. In order to complement the capacity levels introduced by SWEBOK, Bourque, Buglione, Abran, & April (2004) have realised an additional competency description of skill levels which three different profiles of Software Engineers should correspond to at different stages of their professional career: at graduation, after four years of professional experience (already included in SWEBOK), and as an experienced Software Engineer. Nevertheless, the study is not complete, as it has been limited to four areas of knowledge: Maintenance, Management, Processing and Quality. Additionally some other efforts had developed recommendations of knowledge and skills required by software engineering professionals in software industry (Eg. Kitchenham, Budgen, Brereton & Woodall, 2005; Lethbridge, 2000; Callahan & Pedigo, 2002).

Initiatives such as the one mentioned above are difficult to be implemented directly by HR Departments, as they are either limited – they do not cover all of the sector's professional profiles – or too generic, or exclusively specific to other areas of Human Resource Management (Acuña & Juristo, 2004), referring uniquely to a spectrum of knowledge typically associated with a SE stereotype profile. This article will identify a professional career for Software Engineers, described by means of the required competency levels for each of the SE jobs for a specific type of company of significant importance in the software business, as well as a particular geographic area. Specifically, the study has been based on the job profiles identified in actual companies in Spain: large consultancies and software development organisations. In order to define the professional career models as completely as possible, some possibilities were omitted from the research, such as specialisation and dual career paths (technical and managerial).

In order to accurately define the professional careers, Section 2 firstly establishes a professional career and its professional profiles, and analyses appropriate career paths for the companies. Secondly, competency scales of the identified profiles are defined, based on the areas of knowledge established in SWEBOK (Abran, et al, 2004).Section 3 defines the competencies associated with the profiles based on an empirical study.

2. A PROFESSIONAL CAREER PROPOSAL FOR SOFTWARE ENGINEERS

The lack of definitions for professional careers in the field of Information Technology has been highlighted (Lee, 2001). Several studies show the recommendability of making the professional responsible for the planning of his own professional career (Chesebrough & Davis, 1983). However, significant initiatives such as People-CMM (Curtis, Hefley & Miller, 2001) point out the importance of establishing a professional structure with careers which are defined, documented and driven by the organisation.

In this section, a professional career will be defined which can be applied to those Software Engineers who develop their careers in large development and consulting companies in Spain. In order to do so, an analysis will be carried out starting from

three different dimensions. Each dimension contributes to the definition of SE professional profiles within the working field of this paper, with additional reference to geographic area and type of company. From the definitions which result, a professional career will be proposed in Section 2.4, based on the following research sources:

International and local recommendations of professional profiles for Software Engineers (Section 2.1).

Studies on SE job offers in all types of companies, but restricted to the geographic area covered in this paper (Section 2.2).

Professional careers present in a sample of companies corresponding to the profile within the domain of this paper (Section 2.3).

2.1. Technical Literature

There are three principal initiatives within the relevant SE literature: Métrica 3 (MAP, 2001), sponsored by the Spanish government, secondly, suggestions proposed by People-CMM (Curtis, Hefley & Miller, 2001), and thirdly, experiences gained by Construx Software (McConnell, 2003).

The methodology used by MÉTRICA 3 (MAP, 2001) defines profiles of participants in software development projects, and describes a total of 5 different professional profiles: Programmer, Analyst, Consultant, Project Manager and Director.

Secondly, one of the objectives of People-CMM's processing area "Development of Professional Careers" (Curtis, Hefley & Miller, 2001) is to define professional profiles, their competencies and requirements for professional career regularisation. The publication offers an example of gradual professional opportunities, including both technical and managerial competency growth within SE. The description of the professional career is shown in figure 1:

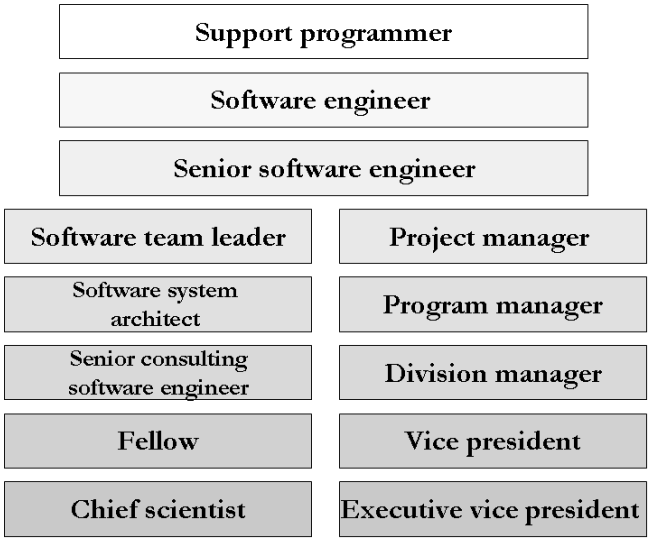

Figure 1. People CMM graduated career opportunities.

The proposal establishes a dual professional career, starting with mainly technical jobs, branching into Software Team Leader and Project Manager, which later on evolve in parallel within the company, depending to the improvement of either technical or managerial competencies.

Finally, the proposal for professional development made by Construx Software (McConnell, 2003) is based on SWEBOK's (Abran et al 2004) ten knowledge areas. Construx attributes to each of those areas four applicable abilities: Introductory, Competence, Leadership and Mastery. In order to provide its personnel with mechanisms for professional career development, the company establishes a scale with seven professional levels, starting with level 9 and ending with level 15. Figure 2 shows the required competencies for each level, according to the knowledge area.

Level 9	Not applicable			
Level 10	**Introductory** All K.A.	**Competence** 3 K.A.	**Leadership** -	**Mastery** -
Level 11	**Introductory** All K.A.	**Competence** 6 K.A.	**Leadership** 1 K.A.	**Mastery** -
Level 12	**Introductory** All K.A.	**Compentence** 8 K.A.	**Leadership** 3 K.A.	**Mastery** -.
Level 13	**Introductory** All K.A.	**Competence** 8 K.A.	**Leadership** 5 K.A.	**Mastery** 1 K.A.
Level 14	Intentionally not defined			
Level 15	Intentionally not defined			

Figure 2. Construx Ladder level requirements via Knowledge Areas.

2.2. Employment Reports in Spain

Spanish employment reports offer a broad range of detailed information on company practices concerning professional careers. The first report which was consulted for the research is issued by the Association of Electronic, IT and Telecommunication Companies. The report is called "Study on Salaries and Labour Policies within the IT Profession" (AETIC, 2004) and has been carried out on a sample of 32.346 employees in the IT field. Out of a total of 22 profiles which have been identified for the technical department, 8 can be applied to Software Engineers: Programmer in training, Junior Programmer, Senior Programmer, Programmer Analyst, Junior Analyst, Senior Analyst, Project Manager and Director.

Another relevant report for analysis is entitled “Infoempleo 2005” (Círculo de Progreso, 2005).The report carries out a review of the Spanish labour market based on 175.362 job offers. The jobs within the IT area which correspond to those performed by Software Engineers are, in order of their position in the hierarchy: Programmer, Programmer Analyst, Functional Analyst, Project Manager, IT Manager or Development Manager and Director.

The last report to be taken into account for definition of the professional career is called “Requirements for Employment within the area of New Information Technologies“ (Sedisi, 2004). This report shows the result of analyses made of job offers published in newspapers with national coverage, focussed on offers towards technical specialists. The following profiles are considered for the current work: Low-level Developers, Medium-level Developers, High-level Developers, Project Managers and Directors.

2.3. Industry Practices in Spain

Industry practices will be analysed based on the professional career exams used by three established companies in Spain, which will be called I, II and III for current research purposes.

Company I is a Spanish IT multinational with over 6.000 employees. Due to its size it has different professional careers, however, only those applicable to Software Engineers will be considered here. This company has the following functions in hierarchical order: Technician IV, Technician III, Technician II, Technician I, Mastery, Expert and Director.

Company II is a division of a US-based multinational, specialised in software development. The pyramidal structure of its professional profiles has seven functions, in the following hierarchy: IT Encoder, Application Programmer, Application Analyst, Systems Analyst, Project Manager, General Manager and Partner.

Finally, Company III is a conglomerate of different European companies which have been merged and acquired. It is currently the most important company in Spain within the business and has a headcount of over 45.000 people worldwide. It has six defined profiles for professional careers related to software, which are in hierarchical order: Programmer, Organic Analyst, Functional Analyst, Project Manager, Business Manager and Director.

2.4. Proposal for Professional Career

The analysis of all the professional profiles identified the previously mentioned sources results in the definition of a professional career that is relevant for the type of development and consulting companies described earlier. The proposal for this professional career is the result of a study of similarity between all of the references

consulted. An analysis has been carried out to extract similarities between definitions for each professional profile in all of the research sources. The result of this analysis and the correspondence between profiles is shown in Table 1.

Table 1 Proposal for professional profiles for Software Engineers

	TECHNICAL LITERATURE			COMPANIES			LABOUR MARKETS		
Proposal	Métrica 3	PeopleCMM	Construx	I	II	III	RENTIC	Infoempleo	S.E.D.I.S.I.
G			Level 9	IT Technician I	IT Encoder				Programmer in training Junior Programmer traditional environments Junior Internet Programmer
F	Programmer	Support Programmer	Level 10	IT Technician II	Application Programmer	Programmer	Low level Developer	Programmer	Senior Programmer traditional environments Senior Internet Programmer
E		SW Engineer	Level 11	IT Technician III	Application Analyst	Organic Analyst	Medium level Developer	Programmer Analyst	Programmer Analyst

									Junior Analyst
D	Analyst	Senior SW Engineer	Level 12	IT Technician IV	System Analyst	Functional Analyst	High level Developer	Functional Analyst	Senior Analyst
C	Project Manager	Project Manager	Level 13	IT Expert	Project Manager	Project Manager	Project Manager	IT Project Manager	Project Manager
B		Program Manager	Level 14	IT Mastery	General Manager	General Manager		IT Manager	
A	Director	Division Manager	Level 15	Director	Partner		Executive	Director	Director of the technical / development department
		Vice-President							

3. COMPETENCY LEVELS FOR THE ESTABLISHED PROFILES

The second step in this study is to define the degree of technical competency with regard to SE, required for each of the professional profiles.

The definition of competency levels within this study, from a professional perspective was considered a very significant factor. Competency studies for Software Engineers (Turley & Bieman, 1995) do not show competency levels, and focus only on the possession of competencies evident in professionals which are relevant for successful job fulfilment. However, during the definition of such competency profiles, distinct professional profiles were not considered, accompanied by the fact that these studies were not performed recently. Therefore, advancement of the profession or shifts in requirements due to the emergence of new paradigms and new technologies have not been considered. Given this current status, it was regarded fundamental to perform a study which analyses the opinions of professionals active in the IT field today. This paper represents an empirical study made in order to support the proposal for competency levels in the previously defined professional profiles. The objective is to establish the professionals' perspective on technical competency levels for each of the professional roles identified. The complete set of competencies correspond to the ten knowledge areas identified by SWEBOK (Abran et al, 2004).

The quantitative study consists of the application of a questionnaire in order to define competencies for the SE professional profiles defined earlier. A Likert (1932) scale with an even number of values was used, ranging from 1 to 4 points. The description of the scale will be generic for all competencies, showing the following order of values and descriptions:

1= Low Level

2= Medium Level

3= High Level

4= Very High Level

3.1. Sample Description

The sample consists of 50 professionals working in software development jobs within large enterprises (over 500 employees) during a period of at least five years. Alongside the assumption that the professionals held the relevant industry experience, they were interviewed *a priori* with the objective of verifying their knowledge of the discipline, as well as determining whether their knowledge was sufficiently adequate for the aims of the study. As a consequence of this process, three subjects were eliminated from the

sample. The distribution of the subjects within the categories identified previously was subsequently established, based on the interviews: 21 “D” (42%), 20 “C” (40%), 5 “D” (10%) y 4 “A” (8%).

The distribution of experimental subjects shows that it was comprised of 6 women (12 %) and 44 men (88 %). The average age was 35.4, with an average experience in the business of 10.32 years.

3.2. Results

Table 2 shows medium scores (m), standard deviations (sd) and modes (mo) of SE technical competencies for the different profiles identified.

Table 2. Medium scores, standard deviations and modes for technical competencies of professional profiles

COMPETENCIES	G			F			E			D			C			B			A		
	m	sd	mo.	m	sd	mo.	m	sd	mo.	m	sd	mo.	m	sd	mo.	m	sd	mo.	m	sd	mo.
Software Requirements	1,32	,587	1	1,98	,820	2	2,96	,605	3	3,74	,487	4	3,32	,844	4	2,34	,982	2	1,84	,912	1
Software Design	1,56	,733	1	2,46	,813	2	3,5	,580	4	3,78	,507	4	2,82	,941	3	1,76	,797	1	1,4	,535	1
Software Construction	2,58	,971	2	3,44	,733	4	3,58	,538	4	3,04	,781	3	2,22	,79	2	1,42	,642	1	1,22	,465	1
Software Testing	2,32	,999	2	3,1	,839	4	3,56	,611	4	3,5	,735	4	2,8	,948	3	1,72	,784	1	1,24	,431	1
Software Maintenance	2,12	,961	2	3	,969	4	3,36	,749	4	3,32	,768	4	2,56	,907	2	1,58	,758	1	1,3	,505	1
Software Configuration Management	1,54	,676	1	2,16	,71	2	3,06	,682	3	3,52	,58	4	3,16	,955	4	2,04	1,16	1	1,54	,762	1
Software Quality	1,64	,693	1	2,38	,855	2	3,16	,71	3	3,58	,673	4	3,4	,782	4	2,52	1,01	3	1,8	,857	1
Software Engineering Management	1,12	,328	1	1,62	,667	1	2,26	,944	3	2,86	,969	3	3,66	,593	4	3,42	,835	4	2,84	1,08	4
Software Engineering Tools and Methods	1,58	,731	1	2,3	,886	2	3,14	,729	3	3,72	,454	4	3,62	,667	4	2,26	,876	2	1,68	,741	1
Software Engineering Process	1,16	,37	1	1,68	,653	2	2,58	,785	3	3,4	,67	4	3,76	,476	4	2,88	,961	2	2,36	1,08	2

The descriptive analysis of competencies does not clarify sufficiently the objectives of the study. Therefore, additional analyses were required, in order to appropriately address the research questions below:

Is there variability between the answers?

Which is the most important technical competency?

What is the professional profile regarded to require most technical competencies?

What is the Evolution of Competencies among profiles?

VARIABILITY OF ANSWERS

Reviewing standard deviations between scores, which are in general lower than 1 (standard deviations greater than 1 have been highlighted in table 2), it can be seen that variability in the sample's answers is low. All 4 cases of significant variability occur in the professional roles "A" and "B", equally distributed and for *Software Configuration Management* and *Software Quality* in case of "B" and for *SE Process* and *SE Management* in case of "A".

MOST IMPORTANT TECHNICAL COMPETENCY

In order to determine the most important technical competency for all professional profiles, table 3 shows a comparison of totals on averages and modes for each technical competency. According to its total average, *Software Quality* is the most important competency, followed by *SE Tools and Methods* and *Software Testing*. The competency to be considered of least importance is *Software Configuration Management*, followed by *Software Maintenance*. However, it is important to point out that values among competencies are very similar, and there is no significant difference among technical competencies.

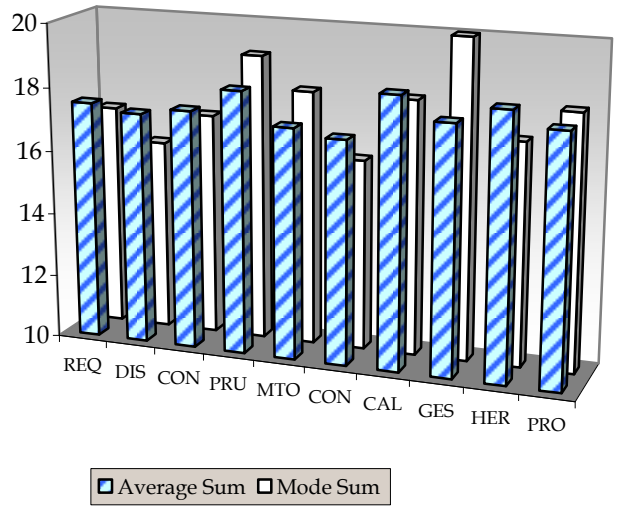

Figure 3. Average and Mode Sums of different technical competencies

PROFESSIONAL ROLE WHICH REQUIRES THE MOST TECHNICAL COMPETENCY

In order to determine the relative importance of SE technical competencies, averages and modes (Figure 4) of technical competencies for each professional profile were summed. “D” shows the highest technical competence, followed by “C” and “E”. Visualisation of the figure suggests a pyramidal approach of competencies. Technical skills increase to a maximum level, in correspondence with profile “D”, from where technical tasks are exchanged for management tasks, often concurring with the professionals’ obsolescence.

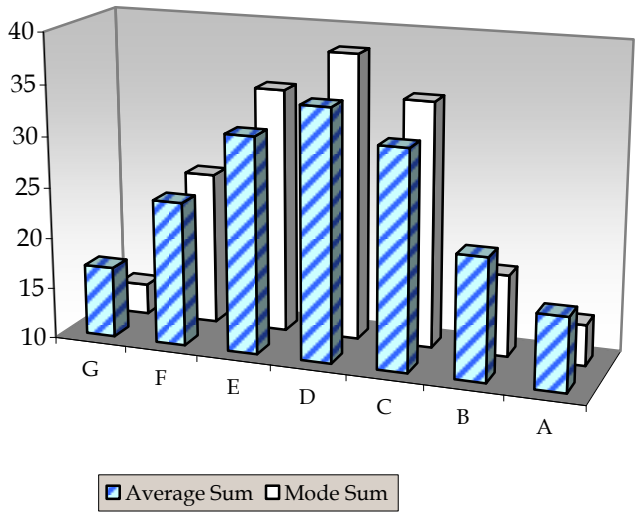

Figure 4. Average and Mode Sums for professional profiles

EVOLUTION OF COMPETENCIES AMONG PROFILES

The establishment of an organisation's competency levels is considered by People-CMM as part of a personal development plan. People-CMM specifically mentions the requirement for a professional to know which competencies he will need for future levels in his career. For this purpose, competency levels - understood as significant differences between scores of technical competencies in related profiles - have been calculated comparing averages by means of Student's T-test for related samples. Comparisons have been made 2 by 2 for each technical competency value, in order to find significant differences which would justify the possible increase, by means of negative T's, or decrease of competencies between related profiles. The results display that significant increases in all of the technical competencies are evident between categories G and F, a similar pattern being visible in the transition between F and E. In the difference between E and D, significant increases in all of the competencies were produced, except with regard to the competency "Software Construction", which held the values $t(49)=4,846$, $p<.05$. Examining C, significant increases in "Software Engineering Management" $t(49)=-5,715$, $p<.05$, and "Software Engineering Process" $t(49)=-3,527$, $p<.05$ were evident, while a significant decrease could be witnessed in the competencies considered more associated with Software Development, and less to Management, that is,, "Software Requirements", "Software Design", "Software Construction", "Software Testing" and "Software Maintenance". A and B, reflecting a similar pattern to the previous one, display significant differences between all of the competencies, except "Software Engineering Management" and "Software Engineering Process".

Table 3 shows the competency level required for each knowledge area and SE professional profile within the type of companies analysed. Competency values have been attributed according to the scores given by the experimental subjects, reflecting competency requirements for different professional profiles. Scores, expressed in a Likert scale ranging from 1 - 4, have initially been assigned by rounding the average scores for different professional profiles. Subsequently, they have been refined according to the competency scales which had been defined previously, in order to finally establish the evolution of competencies of employees in the business environment defined.

Table 3. Competency level per profile

Competency	G	F	E	D	C	B	A
Software Requirements	1	2	3	4	3	2	1

Software Design	2	3	4	4	3	2	1
Software Construction	3	4	4	3	2	1	1
Software Testing	2	3	4	4	3	2	1
Software Maintenance	2	3	4	4	3	2	1
Software Configuration Management	2	2	3	4	3	2	1
Software Quality	2	2	3	4	4	3	1
Software Engineering Management	1	2	3	3	4	4	3
Software Engineering Tools and Methods	2	2	3	4	4	2	1
Software Engineering Process	1	2	3	4	4	3	2

Thus, the previous description of professional profiles can be completed by adding the associated competency levels outlined and described below:

G: Additionally to the previous aspects, this category requires a high competency level with regard to software construction, with notions of design, quality, testing and configuration management.

F: In addition to what was previously mentioned, employees in this category are highly skilled in software construction, which constitutes a major part of their labour efforts. They possess advanced knowledge of design and testing. Employees should have a medium level in other technical competencies.

E: Workers to be found in this category hold a profound knowledge of design, construction, testing and software maintenance, in addition to a high level of knowledge of other SE technical competencies.

D: Employees in category D are top level in technical competencies. They are highly skilled in Requirements, design, testing, maintenance, configuration management, quality, Tools and process. They also hold a high level of knowledge of management and software construction.

C: From this profile onwards, technical competency is less important, except for issues characteristic of management. Nevertheless, employees still show very high competency levels on Quality, Tools and Process, apart from the already mentioned Management skills, and have high skill level on requirements, Testing and Configuration Management features. On Construction, they have a medium level.

B: Additionally to what was mentioned earlier, this profile shows very high Management skills, and competencies with regard to Process and Quality. Such

employees hold medium levels of other competencies, except for Construction, which are of low level.

A: Employees in this category do not focus on technical competencies related to SE, except for managerial aspects, due to commitments to Management and the Software Process.

The most important evidence, shown in Figure 2, is the pyramidal structure of SE professional careers in the targeted companies. The top of the pyramid is represented by profile "D", showing the highest level of technical competency. This characteristic confirms the professional's perception of lesser importance of technical competency in profiles higher up in the hierarchy compared to intermediate profiles, contradictory to the integration and continued competency improvement proposed by Construx (McConnell, 2003) but in the same career path showed by Lannes (2001) in a typical engineering career path.

4 CONCLUSIONS AND FUTURE WORK

In this paper, a professional career and the competency levels related to the professional profiles identified for the organisations subject to this study is proposed, based on the viewpoint of professionals. The professional career is established starting from seven consecutive profiles, giving concrete form to different levels of technical competency. The global importance *of Software Quality* and knowledge of *Tools and Methods* and *Testing* is reflected in the higher levels of competency required for the different professional profiles. On the other hand, *Software Configuration Management* and *Maintenance* are less valued by professionals. The central professional profile, "D", represents higher competency levels in all technical competencies, except for Management.

The pyramidal model for professional careers, identifying one single professional track going from Junior Programmer to IT Director, is still present in the organisations subject to this study. Technical excellence is reached in a determined professional profile, in this case "D". From this point onwards, other competencies which are not typical of Software Engineering gain importance and stimulate professional development towards higher levels. Controversial aspects of these type of professional structures, on one hand, the technical obsolescence in levels higher up in the hierarchy, and on the other hand, the lack of correspondence between improvement of technical competencies and professional progress, are still valid, despite new initiatives which try to define a correspondence between professional development and progress in the career. This can be explained by the company cultures and behavioural inertia of the individuals, heirs of years of tradition of pyramidal professional models.

As future research, we propose definition of competency levels for non-technical competencies, called general competencies, which are common to all professions. This will provide a frame in which the selected companies can establish competency characteristics for the profiles. On this basis, they can create an evaluation model allowing the identification of strengths and weaknesses of the competencies of their employees, referring to the established standards.

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