Universitat Politècnica de Catalunya
Department of Management

PhD Thesis

A methodology for the strategic staff planning in public universities

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Barcelona, September 2015

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Printed in Barcelona by Fotocòpies Diagonal
First Print, September 2015

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola de Doctorat

Curs acadèmic:

Acta de qualificació de tesi doctoral

Nom i cognoms

Programa de doctorat

Unitat estructural responsable del programa

Resolució del Tribunal

Reunit el Tribunal designat a l'efecte, el doctorand / la doctoranda exposa el tema de la seva tesi doctoral titulada ____ ____.

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Abstract

The number of public universities worldwide has been increased substantially in the last decades. In Europe, such growth has been accompanied of several regulatory changes in regard of different aspects such as: the Bologna process, the European Credit Transfer System (ECTS), new mechanisms for resource management, growing interests in patents and entrepreneurship and the increasing emphasis on university-industry relationship, among others. Accordingly, universities should adopt new management strategies; otherwise, they would face problems around weak financing, personnel management (from both academics and administration departments) and treatment of talent, amongst others.

The strategic staff planning consists in determining the long term quantity and type of required resources according to a set of restrictions (e.g. personnel, academic and economic policies). The lack of a strategic planning could be translated into an increment in personnel costs, an inadequate determination of workforce size to the actual university needs, and an inadequate workforce composition in regard of various aspects such as: the generational renewal, experience, expertise in diverse knowledge fields and an adequate balance between teaching and research profiles.

The determination of a methodology, which includes the mathematical modeling by means of a Mixed Integer Linear Program, for the strategic planning of public universities, is the main object of the present thesis. The optimization of the strategic planning addresses various aspects such as: i) policies on personnel hiring, firing and promotion; ii) workforce heterogeneity (set of categories); iii) and the adoption of an optimization criterion, in

this case based not only on economics, but also on other aspects such as the required service level and the achievement of a workforce composition according to a preferable one. The optimization model, and the corresponding analyses in regard of diverse study cases on different personnel, academic and economic policies, are the main contributions of the present thesis.

The contents of the thesis are divided into 7 principal chapters. Chapter 2 offers a state of the art on knowledge intensive organizations (KIOs) and the strategic capacity planning, also particularizing for the case of universities. Next, Chapter 3 identifies the most relevant characteristics of KIOs in general, and of universities in particular. This chapter gives rise to the development of a methodology for the determination of the strategic staff planning, which is stated in Chapter 4. This methodology consists of different phases, each one treated in the following chapters: the characterization of the problem (Chapter 5), the mathematical formulation of the optimization model for the strategic planning (Chapter 6) and the evaluation of the optimization model in different study cases (Chapter 7). Finally, the conclusions of the previously mentioned analyses and the potentiality of the proposed tools are summarized in Chapter 8.

The main conclusions of the thesis indicate, among others, that the proposed optimization model successes in obtaining a close composition to a preferable one taking into account constraints associated to budget and required service level, as well as others affecting personnel (hiring, firing and promotions) and academic policies. In this sense, the model contributes to decision making processes on strategic staff planning, thus facilitating the sustainable development of public universities.

Resum

El nombre d'universitats públiques ha crescut considerablement en les últimes dècades en el món. A nivell europeu, aquest creixement s'ha vist acompanyat de nombrosos canvis de regulació en l'àmbit de l'ensenyament com el procés de Bolònia, les reformes de l'Espai Europeu d'Investigació (ECTS), nous mecanismes de gestió de recursos, interès en les patents i l'emprenedoria, i el creixent èmfasi en les relacions universitat/empresa, entre d'altres. Amb tot això les universitats que no adoptin noves estratègies de planificació o no considerin aquests canvis, s'enfrontaran a problemes tals com finançament dèbil, i relacionats amb la gestió de personal (tant docent com administratiu) i el tractament del talent, entre d'altres.

La planificació estratègica de personal consisteix en determinar a llarg termini la quantitat i tipologia dels recursos de personal d'acord a un conjunt de criteris (polítiques de personal, acadèmiques i econòmiques). La falta d'un pla estratègic es podria traduir en un increment del cost de personal, una inadequació del volum del mateix a les necessitats reals de la universitat, i una composició poc adequada en referència, per exemple, al relleu generacional, experiència, capacitats en diversos àmbits de coneixement, balanç entre perfils docents i investigadors.

La determinació d'una metodologia, que inclou la formulació i resolució d'un model matemàtic d'optimització, pel pla estratègic per al cas de les universitats públiques és l'objecte principal d'aquesta tesi. L'optimització del pla estratègic té en compte diversos aspectes tals com: i) polítiques referents a la contractació, acomiadament i promoció de personal; ii) l'heterogeneïtat dels treballadors (conjunt de categories); iii) i l'adopció d'un criteri d'optimit-

zació, en aquest cas basat no només en mètriques econòmiques, sinó també d'acord amb altres aspectes tals com el nivell de servei requerit i la consecució d'una composició de la plantilla de treballadors d'acord a un ideal. Aquesta eina d'optimització, així com les anàlisis al voltant de diversos casos d'estudi avaluant diferents polítiques de personal, acadèmiques i econòmiques, són les contribucions principals d'aquesta tesi.

Els continguts de la tesi es divideixen en 7 capítols principals. El Capítol 2 ofereix un estat de l'art sobre les organitzacions intensives en coneixement (KIOs en anglès), i la planificació estratègica de la capacitat, particularitzant en el cas de les universitats. Complementàriament, el Capítol 3 identifica les característiques rellevants de les KIOs en general, i de les universitats en particular. Aquest capítol dóna peu al desenvolupament d'una metodologia per a la determinació del pla estratègic de personal, tractat al Capítol 4. Aquesta metodologia consta de diferents fases, cadascuna de les quals és tractada en els següents capítols: la caracterització del problema (Capítol 5), la formulació matemàtica d'un model d'optimització per al pla estratègic (Capítol 6) i l'avaluació d'aquesta eina d'optimització d'acord a diferents casos d'estudi (Capítol 7). Finalment, les conclusions d'aquestes anàlisis s'ofereixen al Capítol 8.

Les conclusions principals de la tesi indiquen, entre d'altres, que el model d'optimització proposat determina satisfactòriament una composició de la plantilla de personal a llarg termini i d'acord a un ideal, considerant diversos aspectes o restriccions relacionades amb el pressupost, nivell de servei requerit i d'altres afectant polítiques de personal (contractacions, acomiadaments i promocions) i acadèmiques. En aquest sentit, el model s'esdevé com una eina que pot contribuir a la presa de decisions al voltant del pla estratègic –a llarg termini– de personal, facilitant el desenvolupament sostenible de les universitats públiques.

Acknowledgements

This thesis would not be possible without the help of the following people:

My parents Manuel and Araceli, for their love and unconditional surrender during my whole life. My life partner Francisco for his support, understanding and assistance during these years.

My thesis advisors Manel Mateo and Amaia Lusa, for all they have taught me and help me during the last four years.

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1 Introduction, objectives and scope

The strategic capacity planning consists in determining the long term resource requirements (both in type and quantity) for an organization, according to a set of criteria, to satisfy the demand. For the case of Knowledge Intensive Organizations (KIOs) in general, and universities in particular, the strategic capacity planning consists, basically, in determining the size and composition of the workforce. To do so, not only the economic criteria should be considered, but also other aspects related to the nature of the organization activity.

The number of public universities has increased considerably in the last decades. This growth has been accompanied by changes in the European higher education (European Credit Transfer System - ECTS), an increasing concern about the quality of university tasks (teaching, research, technology and knowledge transfer, etc.) and financial problems. Moreover, the latter has been accentuated by the global economic crisis.

Apart from the external changes, there have been several substantial changes in the structure of the university during the last years. One of the most relevant changes has been the importance given to the research and the knowledge and technology transfer tasks, apart from the teaching tasks. This, obviously, has a great influence on the definition of the best structure of the university (composition of the workforce and, in particular, of the academic staff).

Thus, strategic staff planning in public universities is a hot topic and very timely, as it will require changes in current funding policies, human resources policies and academic policies. Literature works argue that the use of strategic planning allows universities a better use of their resources, and therefore they achieve greater institutional success (internationalization, creating a better and innovative academic environment, etc.). The author of the present thesis contributes arguing that the required long training periods for highly qualified workers, as those configuring the academic workforce, demand the university to determine mid and long term personnel policies, so to adopt a strategic planning. This would permit the university to achieve the best workforce structure.

Surprisingly, to the best of our knowledge, a formalized procedure for the strategic staff planning in universities, taking into account regulations on personnel policies as well as other relevant characteristics for universities, was not addressed in the literature. These characteristics are such as workforce heterogeneity and the need of considering other optimization criteria apart from that purely economic.

Accordingly, the *scope of the present thesis* is to design the strategic staff planning in universities, including the formulation of a mathematical model for optimization, and taking into account aspects such as:

- personnel policies on hiring, firing and promotion;
- workforce heterogeneity;
- optimization criteria based on economics, required service level and the achievement of a preferable workforce composition.

This tool, and the practical implications and problem insights that arise from the resolution of different study cases, are the main contributions of the thesis. The *main objective* of the present thesis is to design and develop a methodology for the strategic staff planning in KIOs, and to adapt it to the particular case of the Spanish public university. The main objective is to be accomplished adopting the following *specific objectives*:

- To characterize KIOs, addressing the principal characteristics affecting staff capacity and planning.
- To design a general methodology for the strategic staff planning in KIOs.
- To address the principal characteristics of the public university sector to adapt the methodology for staff planning to this type of organizations.

- To design and formulate a deterministic procedure, or mathematical model, for the strategic staff planning in the public university sector.

- To exploit the designed mathematical model to evaluate different managerial insights around staff planning in the public university sector.

This thesis is organized in seven principal chapters. Chapter 2 offers a state of the art review on literature on three topics directly related with the thesis: Knowledge Intensive Organizations, strategic capacity planning and strategic planning in universities.

Chapter 3 deeps in the identification of principal characteristics for KIOs. Moreover, the factors affecting the strategic capacity planning for KIOs in general and for universities, in particular, are defined. Concluding, the Chapter establishes the basis for the formulation of an optimization model for strategic planning in universities, work to be presented in Chapter 6.

Chapter 4 presents a methodology to deal with the problem of the strategic capacity planning in universities. The methodology covers from the problem characterization to the evaluation of the results.

The problem characterization is offered in Chapter 5. In there, the optimization criteria, as well as the capacity decision to make in the strategic planning (e.g. personnel hiring, firing and promotion) are discussed. The problem characterization also includes the definition of objectives for each of the three proposed study cases for exploiting the optimization model. Such definition of objectives is located in this first phase of the methodology, as it precisely affects the model's formulation and the collection of the required data for analysis, which are developed in subsequent Chapters of the thesis.

Chapter 6 presents a mathematical model for the strategic staff planning in universities. The data, variables, objective function and constraints are presented and discussed. The first basic model formulation is then adapted to the scope of each of the three study cases for analysis. The optimization criteria for the model are to achieve a preferable academic staff composition under service level constraints while also minimizing the associated economic expenditures considering a long term horizon. The model is applied to a real case and validated by means of a computational experiment considering several scenarios, in further chapters of the thesis. For such analyses, the required data are also introduced here.

Chapter 7 presents the results yielded by the optimization model for staff planning previously introduced, and according to the scope of the three study cases for analysis. For each one, numerous computational experiments are proposed, to evaluate the impact of various strategic decisions on academic and personnel policies. The obtained results show how accurate the model is in determining workforce while under different optimization criteria and other externalities.

Finally, Chapter 8 summarizes the main conclusions of the thesis and proposes further research.

2

State of the art

Summary.- This Chapter offers a state of the art review on literature regarding Knowledge Intensive Organizations, strategic capacity planning, and strategic planning in universities. The contributions of the thesis are placed in the intersection of the above mentioned three knowledge areas, so this literature review is worth including at this point of the dissertation. The analysis of the literature indicates that, to the best of the knowledge of the author of the present thesis, there are no works in the scientific literature that propose tools for solving the problem of staff planning in public universities, taking into account the regulations on hiring, firing and promoting as well as other relevant characteristics such workforce heterogeneity and optimization criteria as defined here. In particular, for the present thesis, the optimization criteria for staff planning is not based solely on economics, as usually considered, but also addressing the required service level and the achievement of a preferable staff composition.

2.1 Introduction

Knowledge-Intensive Organizations (KIO) are those organizations where knowledge is regarded as critical and strategic resource and a key core competence, such as universities, consulting firms or high-tech and engineering firms [Robertson and Swan 2003]. As presented in previous Chapters, the thesis tackles the problem of the strategic staff planning in KIOs, and particularly in public universities, developing a formalized procedure for solving such planning.

Accordingly, this Chapter offers a state of the art review on previous related works. In particular, the review covers the following topics, as related to the topic of the thesis:

- **Knowledge Intensive Organizations**. Specific contents are included so as to cite previous works on the definition and characterization of this kind of organizations, in which universities are included.

- **Strategic capacity planning**. The second part of the Chapter presents the strategic capacity planning concept, and deals with the review of literature on the strategic capacity planning, mostly emphasizing in KIOs.

- **Strategic capacity planning in universities**. Finally, the third part of the Chapter notes specific literature on strategic capacity planning practices in universities.

The reviewed literature works can be schematically organized per topic as presented in Figure 2.1. According to this representation, the contributions of the thesis will be placed in the intersection of the three thematic areas: KIOs, strategic capacity planning and strategic planning in universities.

The rest of the Chapter is organized as follows: Section 2.2 introduces the concept of Knowledge Intensive Organizations. Section 2.3 defines the strategic planning, also noting specific works for KIOs. Section 2.4 reviews specific works on strategic planning in universities. Finally, the last section lists the final remarks of the Chapter.

2.2 Knowledge Intensive Organizations (KIOs)

As previously noted, this section includes relevant contributions to the definition and characterization of KIOs. The characterization presented here will be further discussed in Chapter 3. The contents here serve as a reference point necessary for the proper understanding of the rest of the concepts presented in the Chapter.

According to [Makani and Marche 2010], Knowledge Intensive Organizations are intended as those which principal activity is knowledge intensive; the main production factor is the knowledge; and to this aim, workers are highly qualified. Thus, the services offered by KIOs are tightly related to the personnel, information flows and knowledge. [Makani and Marche 2010] note that for cataloging an organization as KIO, it is necessary to globally evaluate its activity and its worker's characteristics. As examples of KIOs we

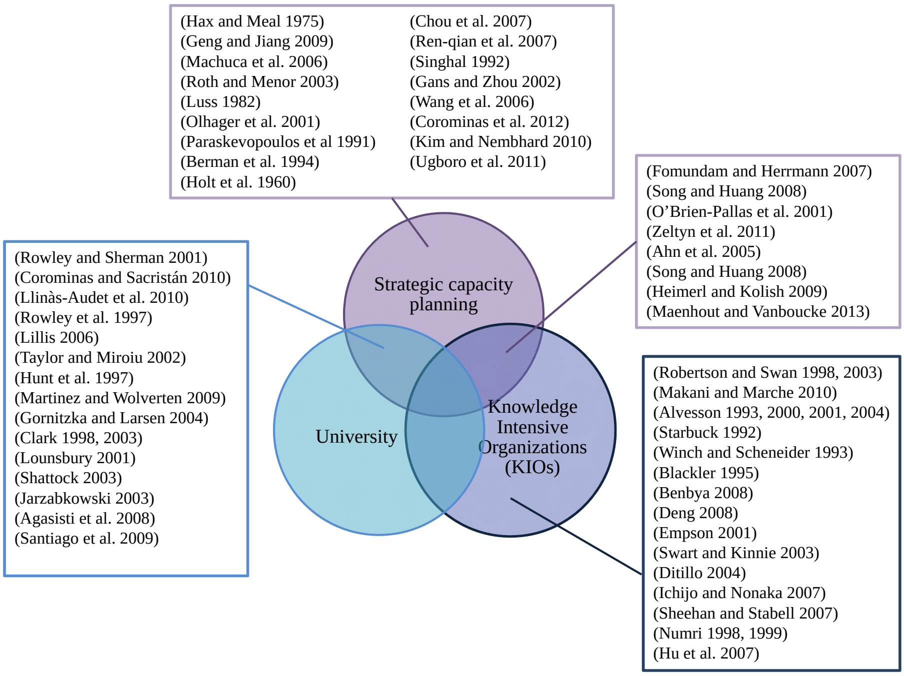


Figure 2.1: Graphical thematic classification of the reviewed literature.

note banks, advertising agencies, architecture firms, engineerings and IT services, legal, accounting and management services, medical centers, research institutes and universities.

KIOs have increased in recent years [Alvesson 1993], [Kärreman 2010], even though there is still a lack of consensus on the definition of KIOs [Makani and Marche 2010].

[Starbuck 1992] was the first to present the term Knowledge Intensive Organization. In this work, KIOs are defined as organizations in which at least one third of total workforce should be composed by experts, i.e. experienced personnel holding a PhD or similar. According to the author, the principal and defining characteristics for KIOs are: the principal activity is knowledge intensive; the processes, routines and projects are organized function of workers experience and knowledge; and the successes and failures of the organizations are, as well, specially attributed to workers. As examples of KIOs, this work included consultancies and law firms.

[Winch and Scheneider 1993] defined KIOs as those principally relying in worker's experience and expertise to deploy their commercial activity. The principal and defining characteristics for these organizations are: the product is intangible; the principal resource is the personnel, usually answering to skilled professionals, actively contributing technical solutions; and the core activity of the organization is usually related with innovation. As examples for KIOs, the authors included advertising agencies, consultancies and architecture firms. [Blackler 1995] complemented the definition from [Winch and Scheneider 1993], presenting KIOs as experienced consultancies in solving singular and innovative projects, thanks to high skilled workers. This paper was principally inspired in software consultancies.

[Robertson and Swan 1998], [Benbya 2008] and [Deng 2008] defined KIOs as those organizations in which knowledge acquires principal relevance and the success greatly depends on personnel skills. According to the authors, the differential factors with respect to other organizations are: core activities are knowledge intensive; it is fundamental to include high skilled personnel in workforce (holding PhD or similar); and career aspirations for workers are prioritized. Finally, the unique example of KIOs explicitly cited in the above mentioned works is the consultancy.

[Nurmi 1998] presented KIOs as organizations in which knowledge is the main product, which in turn is translated into services for customers. According to the author, the principal characteristics are: KIOs require less capital than manufacturer companies (considering the same business volume); KIOs require more skilled workers than for other companies in the service sector; knowledge is considered as a product for the company; and workforce structure is highly hierarchical. Examples of KIOs are consultancies, architecture firms, as well as research institutes.

The definitions proposed by literature [Alvesson 1993], [Alvesson 2000], [Alvesson 2001], [Alvesson 2004], [Empson 2001], [Swart and Kinnie 2003], and [Ditillo 2004] are all based on that provided by [Blackler 1995]. These authors included in KIOs law firms, accounting and management services, consultancies, engineerings, advertising agencies and manufacturers on high-tech products. [Ichijo and Nonaka 2007] and [Sheehan and Stabell 2007] also based their work on [Blackler 1995] and included among KIOs, consultancies, research centers, pharmaceutics, medical centers, law firms, advertising companies, architecture firms, minerals and oil producers, executive recruitment companies, design studios and investors. Such broad definition of KIOs contrasts with other studies like [Hu et al. 2007], which constrained such type of organizations to universities and high-tech producers.

In conclusion, the literature analysis presented so far, reveals that the definition and characteristics of KIOs can vary in the views of the different consulted literature works. Table 2.1 succinctly summarizes the main characteristics of such organizations identified so far.

Table 2.1: Characteristics in KIOs literature

Characteristics	Literature
Workforce is composed by high qualified and experienced personnel	[Starbuck 1992, Starbuck 1993], [Blackler 1995], [Robertson and Swan 1998], [Alvesson 2000, Alvesson 2001, Alvesson 2004], [Empson 2001], [Swart and Kinnie 2003], [Ditillo 2004], [Ichijo and Nonaka 2007], [Sheehan and Stabell 2007], [Benbya 2008], [Deng 2008]
Routines and projects are organized function of workers experience and knowledge	[Starbuck 1992, Starbuck 1993]
Workforce structure is highly hierarchical	[Nurmi 1998]
Workers promotion is prioritized	[Robertson and Swan 2003], [Benbya 2008], [Deng 2008]

2.3 Strategic capacity planning

Conventionally, the capacity planning in organizations –also including Knowledge Intensive Organizations– is addressed adopting a three-tier hierarchical approach, based on the classification proposed by [Hax and Meal 1975]. Each of the above mentioned tier levels is introduced in the following. Further, Figure 2.2 offers a graphical representation of such hierarchical approach for capacity planning.

- **Strategic level**. This level builds up the top of the organizational pyramid. This level establishes, at least in the fundamental, the organizational strategies and management philosophy. That is, long term decisions in regard of workforce sizing and composition are addressed in this level.

- **Tactical level**. This level develops the organizational strategies defined in the strategic level of the pyramid. In this level, concrete actions in the mid term are scheduled in the time and place to achieve the organizational strategy objectives. In particular, decisions such as the length of the working day, workers location, as well as workers assignation to working groups according to capacity requirements are defined here.

- **Operating level**. This level corresponds to the base of the organizational pyramid. Here, the short term capacity needs are adjusted. In particular, the decisions to be addressed in this level are those related to the assignment of specific tasks to be developed for each worker in the short term, so as to fulfill the organizational plan defined in the tactical level.

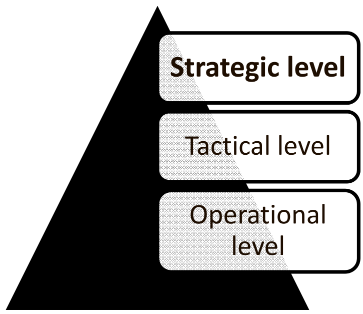


Figure 2.2: Three-tier hierarchical approach for capacity planning.

According to [Geng and Jiang 2009], the strategic planning aims to define the sequence and timing of the purchase, sale and replacement of goods according to multicriteria decisions which include economic aspects, as well those in regard of the performance, risks and the production rate of the organization. The strategic planning can be also referred as the expansion capacity plan, the plan resource requirements and the inventory management definition. In this way, the strategic capacity planning consists in determining the long term resource needs according to a set of criteria. Even though the strategic capacity planning is considered crucial for the design and viability of an organization, there are few procedures in literature for its determination.

The strategic capacity planning in the services sector has been addressed from the queuing theory [Fomundam and Herrmann 2007]. This theory results adequate to model relatively simple systems under restrictive assumptions (e.g. defined temporal trends in demand and externalities), but few organizations can be seen under such circumstances. Other approaches suggested to address the problem of the strategic capacity planning from methods barely formalized, at best, based on generation and comparison of alternatives.

So far, formalized procedures in the literature concentrate on manufacturing industry, and these could be extrapolated to simple organizations in the services sector (e.g. supermarkets, workshops, and etc.) The adaptation of such procedures to KIOs is not trivial at all. At the end of the day, and as pointed out by [Machuca et al. 2006], [Roth and Menor 2003] and [Ernst et al. 2004], there is a gap between the increasing importance in the management of services in organizations and the number of studies carried out so far. Further, an additional problem with the strategic planning in the service sector is the widespread inability to implement its plan, once it is developed and approved by the institutional government [Rowley and Sherman 2001].

Strategic capacity planning is extremely important for every company [Luss 1982], [Olhager et al. 2001], [Geng and Jiang 2009]. For manufacturing industries and some types of services (such as telecommunications, transport, electricity distribution, water distribution, etc.) companies have to invest huge amounts of money in tangible assets with long payout times [Paraskevopoulos et al. 1991], and sometimes these decisions are irreversible or the assets invested have insignificant resale value [Berman et al. 1994]. For this reason, most of the developed capacity planning tools are focused on organizations that have significant expansion costs. In our study we will focus in service organizations for which the main expansion cost is related to personal and the workforce planning constitutes a major problem.

Since the early production planning model of [Holt et al. 1960], which considered hiring and firing of personnel in a very simple way, few authors have dealt with similar problems, mainly addressing manufacturing industry [Wang et al. 2006], [Chou et al. 2007], [Ren-qian et al. 2007], and [Geng and Jiang 2009].

Service organizations differ from manufacturing industries in a number of ways. One of the most important differences is that an important amount of service facilities exist in a restricted local market, so that service product cannot be shipped to other markets and it cannot be stocked to meet fluctuations in demand. Second, the economies of scale in service industries are often considerable less than for manufacturing or process industries [Berman et al. 1994]. Also, the service industry is very broad and businesses are different.

Knowledge-Intensive Organizations represent a specific case in the service industry, for which capacity depends on the size and composition of the workforce. Moreover, knowledge differs from other resources in being immaterial and ambiguous [Alvesson 1993]. The principle of organization of knowledge-creating work may differ significantly from the traditional organization of physical work. At the end of the day, the strategic planning for a KIO implies the determination of the long term staff capacity addressing the specificities of this type of organizations. Specificities such as those presented in Table 2.1 in Section 2.2, which are around workforce expertise and organizational structure. But also, it is necessary to consider other factors such as the financing of the organization, the plan horizon, the evaluation criteria for the strategic plan, and the forecasting methods to estimate the demand and / or other externalities. Recently, the problem of determining the staff planning in Knowledge Intensive Organizations has received an increasing research interest as the world is moving from an industrial-based to a more service-based and information-based economy [Song and Huang 2008]. In fact, service sector has been experiencing an increasing importance in developed economies in recent decades, both in production as in employment. Also, service activities are being incorporated more and more into manufacturing companies. However, the relevance of the services sector in developed countries has not been reflected in the importance given to Operations Management research. As [Machuca et al. 2006] pointed out, despite the importance of service organizations little attention is still paid to service operations research in the Operations Management field. Regarding KIOs, there are not almost works in Service Operations Management research. Some literature on strategic capacity planning in KIOs is presented in the following.

[O'Brien-Pallas et al. 2000] presented an analysis on the aspects of the labor market that can affect the demand in the medical sector, and in what extent these aspects could potentially affect the staff planning of such organizations. Moreover, this work also discussed on the necessity of developing tools for the strategic capacity planning in the medical sector. Methods or tools that permit to determine the long term capacity of organizations considering the variability in demand.

Also in the medical sector, [Zeltyn et al. 2011] addressed the different levels of the capacity planning in a hospital, i.e. the strategic, tactical and operative levels. The study principally concentrated on the operative and tactical levels –the plan horizon did not exceed one month–, aiming to determine the capacity of the personnel under eventualities such as unscheduled and sudden variations in demand and / or other aspects. Moreover, the authors addressed how to adjust workforce under substantial changes in the location of one the facilities of the hospital. In this regard, several dynamic simulations are carried out evaluating the time needed for personnel to move between the different areas of use within the hospital and the time for patients between their arrival and leaving from the hospital, all modeling the processes carried out in the different areas of use. The evaluation of the results based on the above mentioned indicators serve to validate the suitability of the proposals on the strategic staff planning for the hospital.

[Corominas et al. 2012] developed a mathematical model for solving, in an aggregated manner, the staff planning, also including hiring and firing rules, learning periods as well for workers. This work left out other aspects such as workers' internal promotions and the achievement of a preferable or ideal workforce composition.

[Singhal 1992] adapted the initial work carried out by [Holt et al. 1960] to be suitable for application in large problems, since it proposes an easy and efficient non-iterative quadratic cost function instead of the iterative linear cost function proposed in the former paper. Further, some authors as [Gans and Zhou 2002] dealt with similar problems in simple service sector systems by proposing a hiring and firing model with constrains related to the turnover and the training process in new workers. Based on this, [Song and Huang 2008] presented a model for KIOs with homogeneous workers in different units in which the main optimization criterion is to minimize the personnel cost. [Ahn et al. 2005] and [Huang et al. 2009] proposed new models, but considering heterogeneous workers. Also considering workforce heterogeneity, [Kim and Nemhard 2010] addressed the improvement in the functioning of organizations with high skilled workers through strategic plans, also considering workers training and other business oriented policies.

2.4 Strategic capacity planning in universities

Universities are Knowledge Intensive Organizations in which having academic staff with certain knowledge and expertise may require several years (workers, which are highly qualified, are not easily replaced) [Starbuck 1992]. Having the right academic staff size and composition in the university, as in other organizations, depends on decisions that must be taken in advance enough (for example, to have a certain amount of professors in a certain year is possible only if staff with the right profile is hired some years before and trained and promoted progressively from lower categories). Without an accurate strategic planning the available academic staff may not be appropriate for the requirements of the university, both regarding teaching capacity (teaching hours), research and knowledge transfer activities. Thus, it is essential to have tools that enable an adequate planning for long term (strategic) academic staff size and composition. This is especially important for public universities, where there are normally strict regulations that do not permit to adjust easily the staff composition.

In most countries, universities have been growing (both in number and size) as the education level of the population was becoming higher. The size of the academic staff in public universities has been increasing while the economic situation of countries was good and the demand for university courses was high. Generally, the academic staff was growing, but without the result of an analytical planning procedure and only as the result of short-term decisions taken normally with a reduced horizon (without considering for example future retirements). As [Rowley et al. 1997] pointed out the planning of the workforce in universities is mostly short-sighted, or motivated from the need of solving punctual problems. This conclusion is in line with those achieved by [Llinàs-Audet et al. 2010]. This work presents an analysis about the state of strategic planning in the Spanish universities. The authors discuss on the effectiveness of the management tools implemented to date. They state that "there are not definitive standard formalized procedures to guide higher education institutions in this process". In line, [Corominas and Sacristán 2010] note that "in the literature predominates outline and repeated proposals that frequently are not a result of a rigorous analysis of reality or are unreasoned". In addition, [Lillis 2006] claimed that available literature does not provide a standardized methodology to determine the effectiveness of strategic capacity planning neither a procedure for measuring and analyzing the organizational learning of the process.

The lack of an accurate planning may cause a too high cost of the staff, a shortage or a surplus of academics with certain knowledge and/or category in some areas or departments or an inappropriate staff composition. Note that, as [Maenhout and Vanboucke 2013] state, in a university, where knowledge plays an important role, not only the economic criteria are necessary to be considered for determining a staff composition. Moreover, the different types of tasks and responsibilities of academic staff must be taken into account (for example, several academics in some departments can teach but without enough knowledge or expertise to do a high level research or knowledge transfer).

Thus, in the university, where knowledge plays an important role, not only the economic criteria are necessary to be considered for determining a staff composition. Moreover, the different types of tasks and responsibilities of academic staff must be taken into account (for example, several academics in some departments can teach but without enough knowledge or expertise to do a high level research or knowledge transfer).

Thus, if staff strategic planning is an important activity for any organization (its performance may depend on this), this is especially true for public universities, because of two main reasons: first, the flexibility to correct the size or the composition of the staff in the medium or short term is very limited; and second, because the available budget to use on staff decisions (hiring, firing, promotions, etc.) is tight, especially in situations of economic crisis like the present, with public funding becoming lower and lower. Resources have to be used in an efficient way, and this means leading to the best academic staff size and composition (taking into account the future demand and the different tasks that the academic staff performs) in the best possible way (planning in advance and in a correct way the hiring, the firing and the promotions). Besides, it is important to note that the staff planning in universities is also a very relevant problem for other reasons, such as the competition to attract the best professors, pupils and research funding [Taylor and Miroiu 2002]. In this line, [Hunt et al. 1997] pointed out that the strategic staff planning would permit universities to optimize their resources, thus achieving greater institutional success (greater international projection, better academic environment, etc.). Also, [Martínez and Wolverten 2009] noted that considering those multiple changes in higher education the universities are facing, universities would have to adopt new management strategies; otherwise, they would not be ready to apply changes in academic and financial policies when necessary. Further, [Gornitzka and Larsen 2004], and [Santiago et al. 2009] assure that an efficient strategic staff planning could solve the problem of autofinancing for universities.

During the last decades, universities, or High Education Institutions (HEIs) in general, have been adapting some management strategies inspired in business world. These strategies propose to determine, in a long term horizon, the quantity and type of resources for an organization considering not only economic criteria but also other aspects of different nature. Although the strategic capacity planning is regarded as a key element in the design and viability for an organization, so far formalized procedures are just focused in manufacturing industry, noting very few cases for the service sector (e.g. supermarkets, call centers and so on). The conducted studies in HEIs as

[Clark 2003], [Lounsbury 2001], [Shattock 2003] and [Agasisti et al. 2008] indicate that the number of strategic practices is increasing and diversifying. This evolution has been influenced as a response to external pressures for a better accountability, which in strategic terms imply answering strategic problems, as well as teaching and research quality. However, and as noted in several studies [Clark 1998, Clark 2003], [Lounsbury 2001], [Shattock 2003], [Agasisti et al. 2008] and [Jarzabkowski 2003], this positive change in the tendency is constrained by the academic and institutional regulations in universities.

Anyhow, the problem of determining the strategic planning in universities is still shortly considered in literature. This is explicitly reported in [Gornitzka and Larsen 2004], noting the scarcity of literature around strategic planning for both European and also North American universities.

[Gornitzka and Larsen 2004] addressed the problem of determining the strategic staff planning, by examining the evolution of the profile of personnel from administration department in the last 20 years. The study differentiates between directives and the rest of administrative staff. The authors identify an increasing specialization of administrative staff, and based related strategic staff planning proposals on the above mentioned staff profile study.

Not explicitly mentioning the university case and proposing approaches fully applicable to universities, [Song and Huang 2008] formulated a model addressing hiring and firing rules for workers. This work also concerns transfer of workers between different units of the organization and the optimization criteria for staff planning is based on purely economic metrics. Further, it is important to note that in this work a homogeneous workforce was considered, i.e. all workers offer the same capacity and skills. Improving the modeling, [Ahn et al. 2005] and [Heimerl and Kolisch 2010] do consider the heterogeneity of workforce for staff planning, not adopting an strategic vision but tactical (short-term) one.

More literature, such as the works by [Agasisti et al. 2008], [Clark 2003], [Lounsbury 2001], [Shattock 2003] also addressed the problem of determining the staff planning for universities. However, as for all above mentioned works, no one concerns the achievement of a preferable staff composition as an optimization criterion. In this regard, and as a first approximation, [Ugboro et al. 2011] aimed to develop a guide for the adoption of strategic planning practices in public organizations in the sector services, considering aspects such as the personnel division in units and their localization.

Finally, other studies such as that developed by [Titova and Shutov 2014], presented a predictive model for the workforce size considering aspects as the quality of the educational services, the level of development of research activities, the public image of the university as well as the financial issues.

2.5 Chapter remarks

This Chapter presented an state of the art around three main topics: i) the definition of KIOs; ii) the strategic capacity planning in KIOs; and iii) the strategic capacity planning in universities. These contents serve as a background information for the development of following Chapters of the thesis.

As a conclusion of the literature review, and to the best of our knowledge, there are no works in the scientific literature that propose tools for solving the problem of determining the size and composition of the academic staff of a public university and at the same time taking into account the regulations on hiring, firing and promoting, optimization criteria and relevant characteristics for this kind of organization as well. These characteristics are such as the heterogeneity of the workforce and the need of considering other factors apart from those purely economic, as the required service level, while determining a preferable staff composition (in size and expertise).

Such vision is adopted in the present thesis, and so far this has been just partially considered in a few papers as previously discussed. Not explicitly addressing universities, [Corominas et al. 2012] proposed a model for an aggregate planning problem that includes the hiring and firing of workers considering a learning period, but the transfers between categories (promotions within a given pathway) nor the staff composition criteria are included there. In the same line [Song and Huang 2008] presented a model for KIOs for hiring, firing and transferring employees (who are considered homogeneous, i.e with the same capacity and skills) among different units and the main optimization criterion is to minimize the personnel cost. Such problem was also addressed in [Ahn et al. 2005], but considering heterogeneous workers in this case.

3

Classification scheme for strategic capacity planning in KIOs. The university case

Summary.- This Chapter deeps in the identification of principal characteristics for KIOs and presents all of them in terms of the impact they have in the strategic capacity planning of the organization. The first part of the Chapter concludes with a summary table, that succinctly typifies and classifies all identified relevant factors for KIOs in strategic planning. The second part of the Chapter, and from the previous general classification of KIOs' characteristics, tackles the specific and differentiating aspects for universities. This second part of the Chapter also finishes with a summary table, clearly highlighting relevant factors for universities in strategic planning. The conclusions of the present Chapter will establish the basis for the formulation of an optimization model for strategic planning in universities, work to be presented in subsequent Chapters of the thesis.

3.1 Introduction

As introduced in Chapter 2 the problem of determining the strategic capacity planning for an organization refers to the determination of the quantity and type of the required resources in a long term, and according to certain criteria. Therefore, it determines, for instance and among other aspects, the required long term plant machinery in a manufacturing industry or the long term workforce composition in a Knowledge Intensive Organization (KIO).

The term KIO was first introduced in [Starbuck 1992]. Examples of KIOs are consultancies, universities, banks, advertising agencies, medical centers and research institutes. In regard of workforce, KIOs are characterized by the fact that workers are not easily replaced because of the required long training periods and high expertise. In these organizations, the strategic capacity planning, which mainly refers to the determination of staff composition, should include not only economic aspects, i.e. cash management and available budget for staff costs, but also training activities and workforce expertise, among others, as decision variables, thus hindering decision making. The concerned strategic decisions are mainly personnel hiring, firing, promotions between categories, interdepartmental personnel transfers, as well as decisions on investments for increasing the amount of promotable staff. Finally, the evaluation criteria of the strategic planning could be diverse. For instance, it could be based on economic metrics; on the offered service level (estimating, for instance, the ability of the organization for deploying its core activity); or on the adjustment of the planned workforce composition to a preferable one.

The present Chapter, from previous contents in Chapter 2, deeps in the definition and description of KIOs. The aim is to clearly identify and typify the principal characteristics of these type of organizations to facilitate the formulation of a mathematical model for strategic planning purposes in universities, which is to be deployed in further Chapters of the thesis. Accordingly, following contents firstly discusses on each of the principal characteristics potentially affecting the strategic staff planning in KIOs. Secondly, the particular and differentiating aspects for universities are also reviewed.

3.2 General classification scheme for KIOs in regard of strategic capacity planning

3.2.1 Organizational structure

According to [Robbins and Judge 2012], the organizational structure defines how personnel is divided, grouped and formally coordinated to deploy different tasks. There are six basic elements that managers must address when designing the organizational structure: the labor specialization, the departmentalization, the chain of command, the span of control, the centralization and decentralization, and the training.

Thus, to determine the organizational structure for a company, agency and any kind of institution in general, consists of arranging the required personnel resources to ensure the proper deployment of the activities of the organization for the achievement of its objectives. The organizational structure for a KIO is particularly relevant, because among the different types of resources for any kind of organization (i.e. human, material, financial and technological), human resource is precisely the principal one. Thus, the organizational structure can be intended as the infrastructure with which an organization carries out its activities and as noted by [Van der Merwe 2002], it greatly influences the sensitivity of the organization to externalities of different nature.

There are different types of organizational structures addressing the adaptability requirements of the organization and the specialization of personnel. In the case of KIOs, the staff could be organized like some of the organizational structures proposed by [Robbins and Judge 2012], i.e. by function (tasks); by product or service; according to the processes and/or projects developed; and depending on a geographical criterion. For KIOs, a departmental (organizational) structure according to the product or service provided, promotes workers' expertise in different areas of knowledge. Conversely, an departmental structure based on the processes and/or projects carried out, promotes personnel specialization in the particular topics under investigation in the projects. The above-presented succinct introduction on the most common organizational structures for KIOs are further developed in the following.

- Organizational structure based on the *functions or tasks* performed. The aim is to let groups of workers to deploy together similar or related tasks, thus promoting personnel synergies and optimizing human and material resources. For instance, usually hospitals propose a workforce organizational structure based on deployed functions, would involve to group workers in terms of tasks such as management, research, medical attention, etc.

- Organizational structure based on the main *product or service*, i.e. the "leitmotiv" for the organization. For a KIO, in which the main product or service is the knowledge, workforce would be organized in departments and each department is in charge of a particular knowledge field. Each department offers its knowledge expertise to the customers, for instance, in the legal advice case, the workers are usually divided in: payroll and retirement advice, business management services, etc.

- Organizational structure according to *processes and / or projects*. In this case, each unit (or department) of an organization would be specialized in a specific type of productive process or project. The staff could work in parallel on several projects and participate on several working groups though. Ideally, such kind of organizational structure permits to segment the different phases of a process / project, and also maximize the utilization of resources through methodology standardization. For instance, in the case of an engineering, workforce would be divided in different groups, tackling the diverse tasks or phases of a project.

- Organizational structure according to *geographical* criteria. The departments or units of an organization can be organized geographically, addressing customers with similar needs and geographical proximity. For instance, the location a hospital could be determined according to the population or the emergency requirements in the area.

- Organizational structure based on combinations of any of the above presented criteria would lead a *hybrid structure*. An example of those are the software development companies, in which case although the workforce is organized based on the different products, the sales department could be structured geographically.

3.2.2 Personnel categories

According to [Makani and Marche 2010], workforce in KIOs usually is built up by highly skilled workers (holding a master degree, PhD or equivalent), with prolonged experience, creative, innovative and independent. Given this professional profile, it is common to organize workforce into different categories according to their expertise level and merits.

It is assumed that members belonging to the same category are capable of performing the same type of tasks. In principle, activities that are associated to a certain category can only be performed with the desired quality by the workers in such or in an upper category. However, in organizations concerning cross training –specific training on a discipline in which it is possible to include contents from others disciplines–, a task performed in principle by workers in a particular category can also be carried out by the staff from other categories. Further, it is also considered that the professionals who belong to a high category (i.e., one in which personnel is supposed to have prolonged experience and expertise) can perform highly specific tasks with better performance than that offered by staff in low categories.

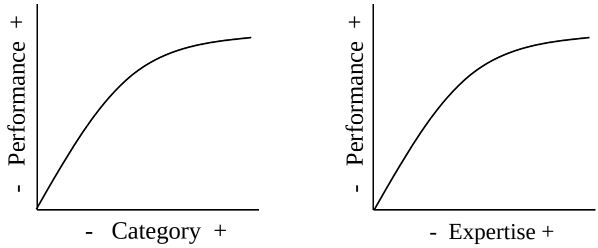


Figure 3.1: In the left subplot: relationship between staff performance and category. In the right subplot: relationship between staff performance and required degree of specialization.

Figure 3.1 shows the correlation between categories and staff performance, and the staff performance and the required degree of specialization for developing a particular task. It is interesting to note here that in KIOs the promotion to a higher category supposes more expertise and specialization in a particular knowledge field.

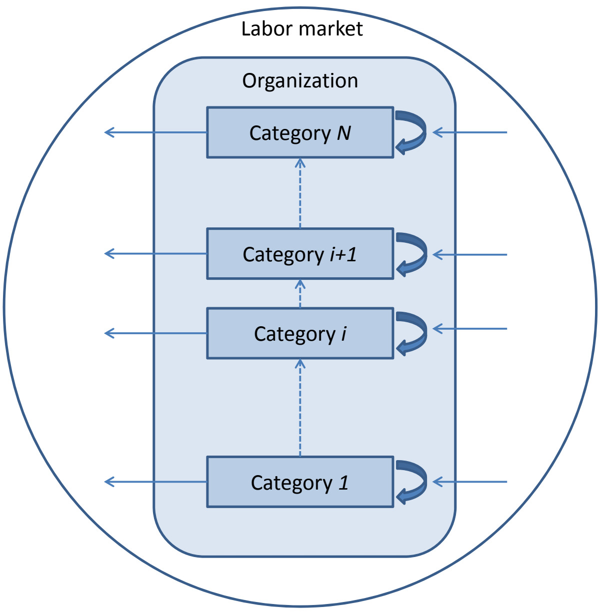


Figure 3.2: Relationship between different categories in an organization.

Figure 3.2 shows a diagram with the different categories for the staff in an organization where *Category 1* corresponds to the lowest category, while

Category N corresponds to the highest one. In general, it can be assumed that the access to a category is possible if there is an available spot, the candidate has the required merits for accessing and/or passes an access test. Therefore, it is possible for a candidate, even having the required merits, not to access to a higher category. It is also possible for a candidate to remain in the same category (even satisfying all requirements) provided that the available spot in a higher category results occupied by a new worker from the labor market. When a worker is hired or promoted to a new category, there may exist a learning period during which the performance of the worker may result diminished.

According to Figure 3.2, it is assumed that a person can access to a category from the immediately below category or from the labor market. However, depending on the organizational structure personnel transfer may be more complex than those presented in the Figure.

So, workers can be classified in terms of their capacity, expertise and skills, but also in terms of other metrics such as:

- Age. Jobs in the highest categories of the workforce pyramid are usually occupied by senior workers since these are supposed to have more skills than young personnel.
- Staff (or category / unit) turnover rate. In organizations where turnover rates for workers are projected to be high, it is necessary to allocate an important percentage of annual budget for the usually required long term training processes for new workers.

3.2.3 Capacity decisions

The capacity to face the demand for a KIO depends basically on the size and composition of the staff. The capacity decisions mainly include workers' hiring, firing, promotions and transfers (from one department or project to another). For personnel promotions and transfers, training periods may be necessary, thus temporarily diminishing workforce capacity. All above mentioned capacity decisions are discussed in the following.

Decisions on hiring and firing workers, as for internal promotions, are affected by the need of creating and removing a spot into the organization. For instance, for a worker to be promoted it may be necessary to create a new spot in the category she or he opts to occupy. The creation of a new spot may be also motivated by the recruitment of new staff from labor market to fulfill the capacity requirements, and thus to achieve the objectives for a department, project and / or process. Similarly, removing a spot may also be due to eventual capacity excess of workers with similar knowledge expertise. For the university, workers' hiring are carried out by adopting limitations on renewing fixed-term or temporary contracts, or directly through contractual dismissals. Finally, it is worth noting that decisions on replacing a worker by someone else (that is, firing a worker to contract another one to occupy the resultant free spot) are not considered as capacity decisions.

The decisions on workforce training could affect internal promotions. It is usual for KIOs in general, and universities in particular, to gain the required merits for promoting, and some of these merits are directly related to training activities (e.g. to attend to courses, seminars, workshops, and etcetera). Such training activities may be in turn constrained by available budget, thus affecting the achievement of merits for workers. For the university case, the provision of enough economic resources for personnel training results even more relevant than for other types of organizations, due to the great amount of training activities workers have to carry out to promote.

In regard of decisions on personnel transfer between departments of an organization it is important to envisage required training activities for workers. Under such circumstances, the performance or capacity for workers may be temporarily compromised. The impact of training periods in workforce capacity depends on the adopted organizational structure. For instance, in case of organizational structures based on processes or projects, the decisions on personnel transfer could have less repercussion than in other structures such as those based on functions or hybrids (see Section 3.2.1). This is because in structures based on processes or projects, workers are intended to participate in different activities at the same time. So they could still carry on with part of their duties while training for deploying particular processes or projects.

Apart from the above mentioned decisions affecting the capacity for an organization, it is usual to also consider other factors (related to tactical level) in strategic planning such as eventual subcontracting and overtime. Further, sometimes capacity decisions could be also affected by available facilities and equipment. For instance, investing in new infrastructures for an organization could boost workforce capacity.

3.2.4 Capacity requirements (demand)

The required capacity is greatly, but not only, determined by the demand for an organization. Other factors determining the required capacity are the required service level, workers' capacity reduction (e.g. due to absenteeism), and the difficulty in matching the required capacity with available one (e.g.

due to timetable) [Corominas et al. 2012]. Following contents discusses on the relationship between required capacity and the aforementioned factors.

General theories dealing with required *capacity scheduling* in the educational field are: the human capital theory [Schultz 1971], [Becker 1983], the theory of credencialism [Collins 1979] and the theory of social demand [Lareau 1987]. With the objective of determining the principal affecting factors for required capacity in high education institutions, [Mora 1989] presented a review of empirical studies presented so far. According to the study, such affecting factors can be grouped in: demographic factors, economic (including both public and private resources), social and family-related factors, as well as individual and institutional aspects.

The required *service level* determines the minimum required quality for the service offered by the organization. Thus, the definition of this metric is diverse and depends on the core activity of the particular organization under consideration.

Finally, in regard of the *required capacity* for an organization, it is usually constrained by the quantity of available resources for the organization. In principle, the higher the available resources, the higher the demand the organization could cope with.

To sum up, the capacity decisions affecting the required capacity are those affecting (directly or not) the aforementioned three aspects: required capacity scheduling, the capacity of available resources and the required service level for an organization. Capacity decisions affecting any of the above mentioned three aspects are usually addressed in the very top level of the capacity planning pyramid. For instance, examples on capacity decisions affecting the demand for an organization are the portfolio or catalog of products offered and the main markets to focus on.

3.2.5 Service level

Apart from being considered as a limiting demand factor, the service level is one defining characteristic for a KIO, and as such it is introduced in the following.

As previously noted, the quality of customer service in organizations in the service sector is quantified by the aforementioned service level. This indicator can be quantified in very different ways depending on the organization and its core activity. In general terms, the service level can be quantified as the percentage of required capacity to be satisfied taking into account the capacity of the organization.

The service level is one the principal factors to be considered in the strategic capacity planning, since workforce is precisely designed so as to satisfy the demand according to the quality standards set in terms of this indicator. The required service level could further complicate the strategic planning, since it should consider aspects such as agreed delays in satisfying the demand for calculation. For instance, a consulting can delay the starting of a project; instead, a university cannot delay or stop the course.

3.2.6 Workforce costs

The workforce costs to be considered in strategic planning may include salaries, hiring, firing and training, equipment as well. If from a given number of workers it is necessary to open a new site (or increase the available space) and, possibly, to hire complementary staff (for example, for administrative and IT tasks), the corresponding costs can be assigned to the workforce. In this case though, the relation between the number (and type) of workers and the costs usually is not linear.

Independently of such exceptional circumstances, the costs associated to workforce depends directly on its structure. It is quite important to identify the organizational structure to maximizing the profitability of the capabilities of workforce in an organization, and this would facilitate to minimize workforce costs.

3.2.7 Finance

Financial planning decisions are also relevant for the strategic staff planning. The expansions or reductions in workforce size may lead to financial needs that cannot be faced by the organization, forcing it to getting loans from a bank, with the consequent costs this implies. Also, in high income periods, benefits could be invested in different ways (e.g. in financial products, goods, equipments and infrastructures). Thus, budget constraints should be considered together with capacity decisions for staff planning.

3.2.8 Uncertainty

Uncertainty may affect many factors such as capacity requirements (demand), economic externalities, workforce turnover, and etcetera. The uncertainty can be faced by solving several deterministic scenarios, in which the sensitivity of the system under parameter variations can be evaluated, or by means of a stochastic approach.

3.2.9 Planning horizon

Strategic capacity planning is also known as long term capacity planning. Depending on the type of organization (how changing are the conditions), the planning horizon can be more or less long (e.g. from one year up to twenty years). The length of the planning horizon may affect the kind of decisions to be included in the planning (for example, to include or not tactical decisions, how to consider financial issues, etc.) and, also, the importance of the uncertainty regarding some parameters. The planning horizon could be also determined in terms of the type of organization. For instance, for an engineering the planning horizon is much shorter than for a medical center or a university (for which the planning horizon could comprise up to twenty years). This is because capacity decisions are usually addressed from processes duration, and these, for consultancies and engineerings do not last for more than one year, while the minimum typical process length in universities comprises 4 years at least (i.e. the time needed to complete a degree).

3.2.10 Evaluation criteria

Several strategic capacity planning solutions may be generated or designed, and there are different criteria that can be used to evaluate them and choose the best one. The economical one (for example, the profit) is probably the most used one, but there are other regarding the service level (for example, to get a capacity as close as possible to the desired one) or the composition of the staff (for example, to have a workforce whose composition is as close as possible to an ideal one).

The evaluation criteria for strategic planning depend on the type of service offered by an organization. The following contents relate examples of KIOs with evaluation criteria for staff planning:

- Economic criteria. By adopting these criteria, the objective is to maximize economic benefits or minimize costs. Examples of KIOs adopting the economic criteria for staff planning are profit organizations such as consultancies and legal auditing services providers. For non-profit organizations, the economic criteria could affect the strategic planning or even complement the optimization criteria, but these last should not be solely based on economic metrics.

- Service level. The objective is to determine a workforce size and composition with as close as possible capacity to the required one (the demand). For instance, for medical centers one metric for service level is the ratio patients / doctor. The required service level is comprised to more or less extent in all types of organizations because, obviously, all companies, being profit or non-profit, want their customers to be satisfied with the service offered.

- Workforce composition according to an ideal. Here the objective is to minimize discrepancies between the ideal workforce model for an organization (e.g. in terms of personnel age and category) with the planned workforce. Such vision could be adopted for different ends: to ensure the long term survival of the organization, to achieve an equilibrium between the share or importance of the different categories composing workforce, and etcetera. This way, examples of organizations that would be willing to adopt this strategy as an evaluation criteria for staff planning could be universities and research institutes.

The different criteria can be considered in a hierarchical way or can be combined into an evaluation function.

Previous ideas presented throughout the Chapter lead to the classification of KIOs' characteristics shown in Table 3.1. Even though not all combinations may have sense, the scheme gives rise to a high number of variants.

3.3 The university case: characteristics

The previous section has introduced the principal characteristics for KIOs affecting the strategic capacity planning. These characteristics are related to several aspects such as organizational structure, personnel categories, capacity decisions (workers hiring, firing, promotions and interdepartmental transfers), demand, finance and workforce costs, amongst other aspects. The present section relates to specific characteristics affecting the strategic capacity planning in a particular type of KIO: the public university.

The functioning of public universities in general, and for the strategic planning in particular, is greatly affected by the pertinent regulatory framework. These regulations define aspects such as the main duties for faculties, colleges and universities, as well as their autonomy, the requisites and conditions for their creation, scientific recognition, operation and legal regime. Examples of such regulations are, for the particular case of Spanish universities, the regulations [BOE 307 2006] "Ley orgánica de universidades 6/2001" and [BOE 89 2007] "Ley orgánica de universidades 4/2007". The organizational structure, i.e. the categories for workers, as well as their rights and

Table 3.1: A classification scheme for strategic capacity planning in KIOs

Issue	Characteristic	Options
Organization	Organization structure	Functions Products or services Processes or projects Geographical Hybrid
Workforce	Categories	Dedicated categories Cross-training
	Age of workers	Relevant Not relevant
	Learning effect	Relevant Not relevant
	Workforce turnover	Relevant Not relevant
Capacity decisions	Hiring and firing	Unlimited Limited
	Workers promotion	Unlimited Limited
	Transfers	Allowed Not allowed
	Training	Included Not included
	Tactical decisions	Included (overtime, outsourcing) Not included
Demand	Capacity requirements	Demand planning Current available capacity Service level
Service level	Actual capacity	% of requirements, without delays % of requirements, with delays
Costs and finance	Workforce costs	Linear Not linear
	Financial planning	Included Not included
Uncertainty	Stochastic variables	Considered Not considered
Planning horizon	Term	Medium (1-5 years) Long ($\geq$ 5 years)
Goal	Evaluation criteria	Economic Service level Staff composition

duties, are also typified by such regulations. Moreover, the regulatory framework could be region specific, determining for instance particular rules for hiring and firing workers. An example in this regard is the regional law for Catalan universities [DOGC 3826-20.2.2003]. Further, the operation of the university could result constrained by regulations eventually set by governs, due to the economic environment and / or other reasons of different nature. For instance, an example of such actuations could be a decree bounding the hiring of temporary personnel in public administration, thus affecting the personnel from administration department in public universities. In fact, currently in Spanish universities and due to the economic crisis, hirings for personnel in public administration should not overcome 50% of the retirements.

The regulatory framework for universities is an example of the aspects to be specifically addressed while determining the characteristics that affect the strategic decisions in universities. With the aim of formulating a new tool for the strategic staff planning in universities, these aspects should be firstly determined and are precisely addressed in the following subsections. In particular, the organizational structure for public universities is presented in Section 3.3.1; the personnel categories and capacity decisions are introduced in Section 3.3.2; aspects on demand and service level for the university are introduced in Section 3.3.3; aspects related to finance are listed in Section 3.3.4; and a brief presentation on evaluation criteria for the strategic planning in universities is offered in Section 3.3.5.

3.3.1 Organizational structure

As previously presented, the structure of public universities could be region dependent. As an example, and adopting the Spanish case, public universities can be comprised by schools, faculties, departments and research institutes, apart from those necessary structures for the proper deployment of their duties [BOE 89 2007]. Moreover, the universities could create other centers or structures provided that the activities carried out in there do not lead academic titles not included within those considered as official or institutionally recognized [BOE 89 2007].

Universities are usually organized in departments. These are intended as teaching and research units, which are in charge of one or various knowledge fields. The department, as an entity, should support the activities, as well as the teaching and research initiatives, impulsed by the professors building up department workforce. The department should also perform any other functions determined by the statutes of the university. However, the creation, modification and suppression of a department is usually competence of the university. Finally, it is important to note that personnel within a department can be located in one or various centers of the university.

A kind of combination frequently observed for universities is proposing organizational structures based on *product / service* and *processes / projects* criteria. As said, the professionals are organized into departments according to their specialty, and participate in projects in collaboration with other departments. For example: a university campus can hold different departments, which participate collaboratively in different projects and / or activities.

3.3.2 Personnel categories and capacity decisions

In regard of personnel categories, for universities, the workforce pyramid is usually more rigid and hierarchical than for other KIOs. This is because the required professional profile for workers is quite specific and different –in terms of experience and academic merits–, for each of the categories of workforce pyramid, so much so that for workers it is necessary to obtain an accreditation from an external organism for accessing / promoting. Such accreditation is also necessary for new workers from the labor market to be contracted by the university. Later in the section, accreditation related processes are described.

Considering the selection process, it is usual for personnel within a determined category to present a comparable academic profile (in regard of experience and academic merits). Therefore, work capacity for all workers within a category is considered to be equal. Figure 3.3 presents a basic sample categories chart for a university. The particular case of the Spanish universities is adopted.

As presented, workforce in the Spanish universities can follow two contractual pathways: one labeled as contractual pathway, and the other named permanent public / tenure pathway. The main difference between the two types of categories is that workers within public pathway cannot be fired. Workers under contractual categories can be fired, provided an economic compensation though.

The salaries for workers under contractual categories proceed from public fundings, which are managed by universities. Within contractual pathway, there exists categories in which workers hold permanent contracts (i.e. full professor, tenured assistant professor, associated professor), and workers contracted temporarily (assistant lecturer and tenure-track lecturer). Conversely, all workers in public / tenure pathway hold permanent contracts and

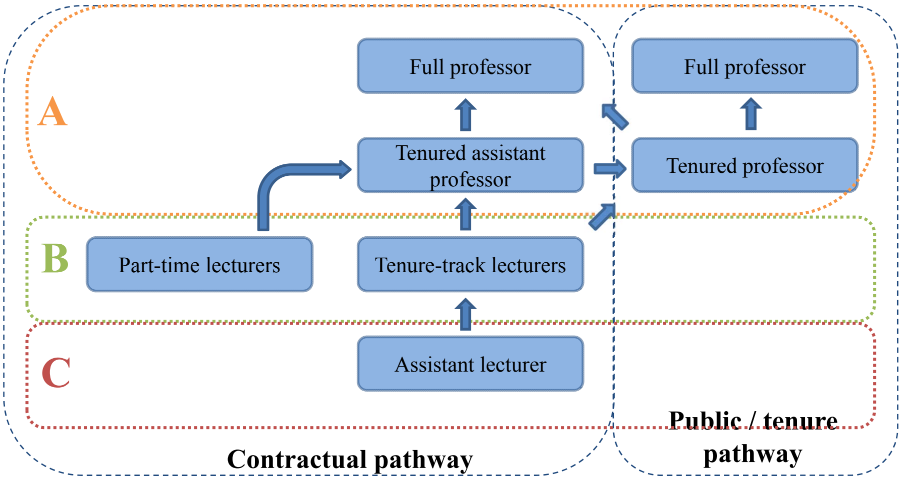


Figure 3.3: Personnel categories according to the current regulatory framework for Spanish universities.

for gaining one of those, workers should win a public tender. As presented in Figure 3.3, the categories in public pathway hold full professors and tenured professors.

All considered categories has been divided into three main blocks (A, B and C, see Figure 3.3). Categories within the group A are those at the top of workforce pyramid, that is, full professors (both under the public or contractual pathways), tenured professor and tenured assistant professor. Categories within the group B are those in the middle of the workforce pyramid, i.e. associated professor and tenure-track lecturers, so categories within the group C correspond to those at the bottom of the pyramid (assistant lecturer).

For the university, the staff decisions to consider in strategic staff planning are mainly those related to personnel hiring, firing, promotions, and interdepartmental transfer, being this last one the least frequent. However, such interdepartmental personnel transfer can be an economical alternative against hiring new workers from the labor market while experiencing budget constraints. The following contents describe capacity decisions around workforce, building up the personnel categories previously presented.

As previously noted, to access to any of the categories (any other than the one at the bottom of workforce pyramid, i.e. assistant lecturers, to be precise), for teaching and research academic staff it is necessary to obtain an accreditation from an external organism or agency. The aim of these agencies is to certify the achievement of the required merits for accessing / promoting to a determined category, and according to the particular regulatory framework in universities. This is a way to ensure the required expertise and knowledge for workers. The number of certifying agencies can be diverse and region dependent. As an example, Table 3.2 summarizes the agencies for the particular case of Spain.

Table 3.2: Agencies for personnel accreditation in Spain

Region	Agency
Spanish state	"Agencia Nacional de Evaluacin de Calidad y Acreditación" (ANECA)
Andalusia	"Agencia Andaluza de Evaluación de la Calidad y Acreditación Universitaria", "Unidad para la Calidad de las Universidad Andaluzas" (UCUA)
Aragon	"Agencia de Calidad y Prospectiva Universitaria de Aragón"
Balearic Islands	"Agència de Qualitat Universitària" (AQUIB)
Basque Country	"Agencia de Evaluación y Acreditación de la Calidad del Sistema Universitario"
Canary Islands	"Agencia Canaria de Evaluación de la Calidad y Acreditación Universitaria" (ACECAU)
Castile and León	"Agencia para la Calidad del Sistema Educativo Universitario"
Castile-La Mancha	"Agencia de Calidad Universitaria de Castilla-La Mancha"
Catalonia	"Agència per la Qualitat del Sistema Universitari" (AQU)
Galicia	"Axencia para a Calidade do Sistema Universitario de Galicia" (ACSUG)
Valencia	"Comisión Valenciana de la Acreditación y Evaluación de la Calidad"

Personnel accreditation is unavoidable for workers to be hired (with except to young workers aiming to start a career in teaching and research as an assistant lecturer). Workers (both already working in the university or new workers from labor market) should access to a public tender, which should be properly announced and with enough anticipation. Personnel selection should be in accordance with institutional principles on equality, merit and ability. An example of the aspects evaluated to obtain an accreditation to act as tenure-track lecturer according to the Spanish agency ANECA is offered in Table 3.3. Please note that for accreditation, the candidate should reach 55 points out of 100 at minimum.

Table 3.3: Aspects addressed for the accreditation of tenure-track lecturers [ANECA 2014].

Aspect evaluated	Orientative maximum punctuation
Experience in research	
Scientific publications	30 points
Books and book chapters	12 points
Research projects	5 points
Congresses, conferences, workshops	9 points
Other merits	4 points
Academic CV, teaching and other professional experience	
Doctoral thesis, European doctorate, grants, seminars and complementary training, other titles	12 points
Stages in other universities	9 points
Teaching experience	9 points
Other professional experience	5 points
Other merits	5 points

The share or percentage of total workforce size in each category can be bounded by regulatory framework, so this also affects capacity decisions on hiring, firing and promotions. For instance, and according to the particular case of Spanish universities [BOE 89 2007], teaching and research personnel under contractual pathway should not overcome the 49% of total workforce.

Moreover, personnel under temporary contracts should not overcome the 40% of total workforce. The contract for *assistant lecturers* (i.e. those workers building up temporary categories at the bottom of the workforce pyramid in Figure 3.3) is normally annually renewed, with a maximum of a few years (e.g. five years for the Spanish universities). For the computation of this maximum period of time, eventualities such as temporary disability and maternity may not be computed. Professionals admitted to doctorate programs or in conditions to do so are candidates to work as assistant lecturers.

The requirements for workers to be hired as *tenure-track lecturers* are higher than for assistant professors. In this case, only professionals holding a PhD could be hired, and they also need to be accredited by the pertinent agency or organism. While assistant professors are hired to support teaching and research activities but with limited dedication (it is supposed that most of the time assistant professors should be working on their PhD), tenure-track professors are hired to work at full-time in teaching and research related activities. Nevertheless, tenure-track professors are also hired under temporary contracts and as for assistant professors, they can be contracted for a maximum of a few years. For example, for the particular case of Spanish universities, such professionals can work as tenure-track lecturers for eight years, at maximum.

Tenured assistant professors and *full professors* are personnel holding a PhD and with the required academic merits determined by the pertinent agency or organism for accreditation. As previously noted, tenured assistant professors are hired to conduct, in a full time basis, teaching, research and technology and knowledge transfer related activities. As a difference with the rest of academics within the contractual pathway discussed so far (i.e. assistant lecturers and tenure-track lecturers), tenured assistant professors hold permanent contracts.

Professionals hired as tenured assistant professors can come from the labor market, from categories holding tenure-track professors or from categories holding *part-time lecturers*. Part-time lecturers are professionals accrediting experience and activity outside the university in a particular knowledge field. For these workers, the contract is temporary and requires part-time dedication. The duration of the contract would be quarterly, biannual or annual, and could be prolonged in time provided that the external professional activity continues.

The duties and competences for *tenured professors* and *full professors* under public / tenure pathway are the same of for *tenured assistant professors* and *full professors* under contractual pathway. The main difference is that personnel in public pathway cannot be fired, and this is because workers could have preference to go for this public pathway instead of choosing the contractual one. As for the rest of the categories presented for the contractual pathway, professionals aiming to win a spot as *tenured assistant professor* and *full professor* should to obtain an accreditation from an external agency, as well as win a public tender. The reason underpinning all these accreditations and public tenders is to guarantee the quality in the selection processes for teaching and research personnel.

To sum up, Table 3.4 presents the main tasks developed by workers in the above mentioned categories of workforce pyramid. The table also lists the required professional profile for workers. It is important to remark that the scope of the present thesis only includes teaching and research academic staff, so personnel within administration departments are not considered.

Finally, and as a general comment, it is usual for regulatory frameworks to prevent workers from accessing to a category prior remaining in the immediately below for a determined period of time.

Table 3.4: Summary of main tasks for workers in each group of categories

Category group	Tasks
Group A (full professor, tenured assistant professor, tenured professor). This group of categories is composed by high experienced workers in all aspects of teaching and research. Workers have also skills in project management, and well as scientific project leading.	*i)* Lead projects / processes; *ii)* conduct research; *iii)* provide strategic vision for projects in research and technology transfer, as well as for the strategic objectives for the department; *iv)* publish scientific results from research; *v)* teach professionals in lower categories; *vi)* teach students.
Group B (associated professor and tenure-track lecturer). This group of categories is composed by professionals with high capacity for carrying out teaching and research activities. Workers have more expertise and knowledge than those in Group C.	*i)* Collaborate in the management of projects and processes; *ii)* execute projects required high degree of specialization; *iii)* conduct research; *iv)* publish scientific results from research; *v)* teach young researchers; *vi)* teach undergraduate and master students.
Group C (assistant lecturer). This group of categories is composed by workers starting their career and thus, they are still in training processes for teaching and research purposes.	*i)* Participate in research and technology transfer projects; *ii)* execute projects under the advise of colleagues in upper categories; *iii)* support teaching activities.

3.3.3 Capacity requirements (demand) and service level

In the case of the university, the demand results constrained by factors such as the capacity of classrooms, since these limit the number of pupils that can course a particular subject, and the number of professors. It is worth noting here that, bearing in mind that the main objective of the present thesis, is to design a tool for the determination of the workforce size and composition in the university, we consider the volume of professors as a principal limiting factor for demand. Accordingly, it is assumed that the admissible number of pupils coursing a particular subject increases proportionally to the number of professors.

The number of pupils per classroom, or the number of pupils per professor among other metrics, determine in turn the service level offered by the university. The required service level is, in fact, another limiting demand factor for any organization in general, and for the university in particular, since a minimum standard for such indicator should be guaranteed. Thus, for the university, a minimum service level should be considered also in the strategic staff planning and as such is considered in the present thesis.

For the purposes of the present thesis, the required capacity (demand) directly refers to teaching demand, as this can be properly quantified from the number of pupils for each of the subjects offered. This implies that for workforce determination purposes in the strategic planning, only teaching demand will be considered. Duties for workers such as research activities and technology and knowledge transfer will be considered indirectly.

3.3.4 Finance in the university

The universities, as any other organization, should dispose enough economic resources for the basic deployment of their services and processes. As public entities, available economic resources for universities are established governmentally. Regulatory framework [BOE 89 2007] may lead universities to propose multi-annual financing programs for approval by governmental administration. For evaluation, such administrations should consider aspects like budget consistency with objectives and the scope of the project presented by the university.

The budget of the university should be public, single and balanced, and should consider all incomes and expenditures of the organization. In particular, budgets, among other aspects, should include: transfers for current and capital expenditures; incomes due to the offered academic services and other rights legally established; incomes due to compensations corresponding to exemptions and reductions; incomes due to teaching activities, courses for specialization and other activities; incomes due to transfers from other public and private entities; incomes from equity investments and other economic activities; incomes from collaborations with other organizations; treasury surpluses and any other income. It is worth noting that the current economic environment is affecting the budget of Spanish universities, thus resulting quite tight and even insufficient.

3.3.5 Evaluation criteria

Universities may adopt as criteria for the staff planning determination, all three criteria previously presented for KIOs, as general. These three aspects were: the economic viability of the organization (i.e. minimize personnel costs or maximize economic benefits), the fulfillment of a determined service level and the achievement of a workforce as similar as possible to a preferable one.

As previously introduced, metrics for quantifying the service level for universities could be the pupils/professor ratio and/or the pupils/capacity classroom ratio. Finally, one example in regard of the preferable staff planning could be to ensure a minimum percentage of doctors per category, so as to intensify research activities.

All three aspects are precisely adopted in the present thesis as optimization criteria for strategic capacity planning in universities.

As for the case of KIOs in general in Section 3.2, and considering the contents presented so far in this Section 3.3, the main characteristics of universities affecting the strategic staff planning are summarized in Table 3.5.

3.4 Chapter remarks

This Chapter presents a classification scheme for the strategic capacity planning in KIOs, a problem that, as discussed in Chapter 2, has not been previously dealt with (or, at least, no formalized solving procedures have been proposed). The work presented will serve to design and formulate a mathematical model for solving the strategic capacity planning in public universities, being this the main contribution of the thesis. The analyses offered in the present Chapter depict the great number of aspects influencing staff planning. Aspects are multiple ranging from the adopted organizational structure, personnel categories, and demand, to finance aspects and those related to uncertainty and the adopted evaluation criteria. The main

Table 3.5: A classification scheme for strategic capacity planning in universities

Issue	Characteristic	Options
Organization	Organization structure	Departments
Workforce	Categories	Chain Network Tree
Staff decisions	Creation of new spots	Only through promotion Through promotion and hirings from labor market
	Workers firing	Contract dismissal Contract non-renewal
	Workers promotion	Limited Non limited
	Workers training	Included Not included
	Interdepart. transfer	Included Not included
	Internal promotions	Prioritized Not prioritized
Demand	Capacity requirements	Demand planning Current available capacity Service level
Service level	Capacity-demand ratio	Included Not included
Costs and finance	Workforce costs	Only personnel Personnel + equipment, infrastructures, and etcetera.
	Financial planning	Included Not included
Uncertainty	Stochastic variables	Considered Not considered
Planning horizon	Term	Medium (1-5 years) Long ($\leq$ 20 years; $\geq$ 5 years)
Goal	Evaluation criteria	Economic Service level Staff composition

conclusion of the Chapter is succintly presented in Tables 3.1 and 3.5, summarizing the main characteristics and their variants around strategic staff planning in KIOs, in general, and in universities, in particular.

4 Methodology

Summary.- This Chapter proposes a methodology to deal with the problem of the strategic staff planning in universities. The methodology consists in four phases, covering from the problem's characterization, the formulation of a mathematical model for optimization of the strategic planning, the data collection for analysis and the evaluation of the results from model solving. The methodology is stated as general enough to facilitate its applicability to other KIOs apart from public universities.

4.1 Introduction

This chapter states the methodology for solving the problem of the strategic staff planning in public universities, taking into account the characteristics of the university as defined in Chapter 3.

The proposed methodology includes preliminary definitions of strategic decisions to consider, but also addresses other aspects related to the practical implementation of the strategic planning. In particular, the preliminary definitions refer to the optimization criteria for the staff planning, as well as to the academic and personnel policies (e.g. personnel hiring, firing and promotion) to address. Conversely, in regard of the practical implementation, the methodology contemplates the formulation, resolution and analysis of a mathematical optimization model for strategic planning, and these concern various phases of the methodology.

For the university, the proposed methodology could help to:

- Determine the long term personnel needs (including size and workforce structure) under different possible scenarios.

- Evaluate future impact of strategic decisions at the time of defining the strategic planning. Strategic decisions such as: staff stabilization plans; collective firings; the acquisition, sale or rent of a building; variations in the required level of service; among others.

Each of the phases in the methodology are firstly stated in Section 4.2. In addition, this chapter deploys the first of the phases of the methodology, based on the contents included in Chapter 3, and this is presented in Section 5.1.

4.2 Methodology for the strategic staff planning in public universities

The methodology for the strategic staff planning in public universities is graphically introduced in Figure 4.1.

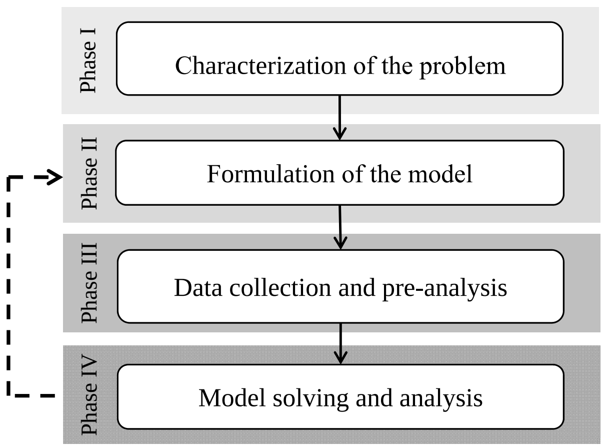


Figure 4.1: A methodology scheme for the strategic staff planning problem in universities.

As can be noted, it comprises four phases, from the problem's characterization to the discussion of the obtained results. Each of the phases is briefly introduced in the following:

- **Phase I: Problem's characterization**. Schemes of the most relevant characteristics of the strategic staff planning in Knowledge Intensive Organizations in general, and for universities in particular, were presented in Chapter 3. According to the identified different characteristics (organizational structure, workforce, capacity decisions, demand, service level, costs associated to the capacity decisions, financing, uncertainty, planning horizon, and evaluation criteria), the problem gives rise to different variants. The first step is to identify the variant, describing the specific characteristics of the problem while applied to the particular case or public university adopted for study. Despite the fact that most public universities present common characteristics, some are particular for each organization. For example, the characteristics of the university can vary in regard of the location or country. Another example could be that related to the different economic and social policies for each region, affecting, in a long term basis, the functioning of the university. Further, the characteristics of the problem should be particularized here to the objectives of the study, i.e. the specific aspect around the definition of the strategic planning to concentrate on. The present thesis proposes three particular study cases evaluating the performance of the proposed tool for the strategic staff planning. The scope of each study case should also be defined in this first phase of the methodology. This phase is presented in Chapter 5.

- **Phase II: Model's formulation**. Once the problem has been characterized, next phase consists in designing a mathematical optimization model. Each characteristic of the problem carries an associated set of variables and constraints, which are properly formulated here. Moreover, the formulation of the model is adapted to the objectives of the particular study case, as presented in the first phase of the methodology. This phase is deployed in Chapter 6.

- **Phase III: Data collection and pre-analysis**. The objective of this phase is to define the sources of information for each type of data, and process the information as required by the model. The data could be provided by the universities as public information in their websites or can be obtained directly from requests to human resources' department. Also, data around personnel policies can be obtained by consulting experienced academics. The processing of the information is a critical task since data should be standardized and tabulated for usage. For instance, workers can be contracted as part time or full time lecturers, or the university could evaluate different criteria for the required service level. All these specificities should be considered and analyzed while tabulating data. This phase is also deployed in

Chapter 6.

- **Phase IV: Model solving and analysis for each study case**. In this phase the aim is to solve and analyze the results of the mathematical optimization model for staff planning. The implementation and testing of the model according to the objectives of each study case are included in this phase. This phase is deployed in Chapter 7.

4.3 Chapter remarks

This Chapter presents a methodology to deal with the problem of the strategic staff planning in universities. The methodology states four phases covering from the problem's characterization to the discussion of the obtained results. The methodology is defined as general and could be applied for solving the problem of the strategic staff planning in other types of organizations, apart from universities. The different phases of the methodology are deployed in further Chapters of the thesis.

5 Problem characterization

Summary.- As stated in the previous Chapter 4, the first phase of the methodology deals with the characterization of the problem of the strategic staff planning in universities, and this is developed in this Chapter. This step is an unavoidable phase prior to the formulation of the optimization model for staff planning in universities in Chapter 6, being this the object of the second phase of the methodology. The problem characterization makes use of previous analyses in Chapters 2 and 3. Moreover, this first phase of the methodology includes the definition of objectives for each of the three proposed study cases for exploiting the optimization model. Such definition of objectives is located in this first phase of the methodology as it affects the model's formulation and required data for analysis.

5.1 Introduction

For modeling purposes, the problem of determining the strategic capacity planning should be properly characterized considering the particular case of public university adopted for study. The identified problem characteristics will be translated into the constraints and objective function of the optimization problem. Accordingly, this section succinctly summarizes the main characteristics of the problem, based on previous contents in Chapter 3. In addition, the scope of the three proposed study cases for the evaluation of different aspects around strategic planning in universities are also presented here.

5.2 Problem's characterization oriented to modeling

Strategic staff planning may involve many kinds of decisions. Some of them (for example, the number of people to hire, dismiss and promote) can be taken by applying a formalized planning procedure (for example, based on a mathematical model, as it is proposed here), and others (such as deciding the kind of staff pyramid that is appropriate for a given university) would require other kind of procedures, probably not so formalized and more qualitative. The concrete strategic staff planning problem here addressed consists of determining, for each period of a long term horizon, the size and the composition of the academic staff for a public university. The university is supposed to be organized in units (for example, schools, faculties or departments) and each member of the academic staff belongs to one and only one unit. Transfers between units are not considered since such decisions are quite singular and require dedicated analyses. This way, the capacity decisions considered for strategic planning are those related to personnel hiring, firing and promotions.

In regard of the required capacity (demand), it is supposed to directly refer to teaching demand, as this can be properly quantified from the number of students for each of the subjects offered. This implies that workforce determination in the strategic planning will consider teaching demand requirements. In addition, other duties for workers such as research activities and technology transfer will be indirectly addressed by concerning a preferable staff composition.

Each academic belongs to a category, being possible to change from one category to another/s during the planning horizon, according to the established rules, which in public universities are normally clear and rigid. It is possible for a person to promote to a higher category once the required merits (for the upper category) are reached and, of course, if a job position in that upper category has been created or is available.

In most public universities there are part time lecturers, which are hired only for teaching purposes and provide students with real world experience thus complementing their education. The proportion hold by these workers in university may be bounded by the government or by the university.

Of course the exact career pathway depends on the country/university legislation, but it can be considered that most public universities have common characteristics. In all of them there are temporary categories (this means that if after a certain time the person has not changed to an upper category, he/she is dismissed) and permanent categories. The academics that are needed for a certain category can come from a lower category (an internal promotion) or from the labor market. So, two types of categories for workforce are considered for modeling: temporary and permanent. In temporary categories, just after a member of the staff obtains his/her graduate and PhD, it is mandatory to follow a path of a certain duration. In these categories, the contracts are typically renewed each year. On the other hand, staff in permanent categories may follow two possible pathways: contractual and public/tenure. Personnel in contractual pathway can be dismissed, but on the other hand, the progression is not as hard as in the public pathway is. Besides, there can be part-time lecturers.

The main differences between categories are the cost (salaries), the number of teaching hours per person, the responsibilities that can undertake and the productivity and quality of tasks regarding research and knowledge transfer. The latter are not easily quantified, while the salary and the amount of teaching hours are usually well specified and, of course, objective.

Since teaching is the first mission of a public university, the academic staff is usually sized according to the expected teaching needs (which are supposed to be known), normally allowing an oversizing to face reductions in real capacity (unexpected problems, discounts of teaching hours to people in charge of other responsibilities like head of the department, etc.) and to take into account that, due to courses timetables, it is not usually possible to perfectly adjust capacity to requirements.

If minimizing the cost while ensuring teaching hours was the main driver, a staff with a high number of members with a low category (or even part time lecturers) would be probably the result of a planning process. However, even if cost minimization and budget constraints must be taken into account, a public university cannot forget research and knowledge transfer. So, it has to ensure that the number of professors in the academic staff can undertake these tasks with a high level, leading research teams and projects. To take this into account, a preferable staff composition (or pyramid), which is a strategic issue that has to be determined by the government of the university (or even the region), can be considered. In some universities or countries there is a high number of assistants, who teach for a lot of hours, and a low number of professors supervising them; in others, the situation is almost the opposite. Different pyramids or university models may have different advantages and disadvantages –this is going to be specifically addressed in one of the proposed study cases for model's evaluation–. Addressing the discussion, the thesis aims to give tools for planning the academic staff size and composition according to, among others, the criteria of getting a composition similar to a preferable one.

To sum up, below, the characteristics of the problem are summarised:

- The initial size and composition of the staff are known.
- Forecasted layoffs are known.
- Each member of the academic staff belongs to one unit (e.g., department) and category.
- The maximum number of annual teaching hours for each category is known.
- There is a forecast of the number of teaching hours that will be required for each unit (e.g. department) and year. The capacity (measured in teaching hours) must not be less than the required one multiplied by a coefficient that can be positive (a surplus is desired), zero or negative (a shortage would be allowed).
- The academic pathway is known, and also there is a forecast on the proportion of people from a category that acquire the merits to promote to another category, which gives an upper bound of the number of people that can pass from one category to another.
- Decisions to be taken include the number of people to hire, to dismiss and to promote.
- The preferable composition of the staff, in terms of categories, is given by the government of the university.
- The objective is to minimise a function that contains the cost of the staff (salaries and dismissals) and the discrepancy between the composition of the staff and the desired one.

The mathematical model to be developed in the second phase of the methodology (see Chapter 4, Figure 4.1) is proposed to be exploited in various study cases, whose scope should be previously defined in this first stage.

5.3 Scope of the study case I. Basic performance evaluation and around managerial insights for the model

The scope for the first study case is to perform a basic performance evaluation of the model. This work serves to prove the validity of the model while aiming to optimize the staff planning according to the adopted optimization criteria. As previously presented, the optimization criteria is to plan a workforce composition as close as possible to a predefined preferable academic staff composition under service level constraints, while also minimizing the associated economic expenditures considering a long term horizon.

The performance of the model is further evaluated by giving some managerial insights that come from a computational study and the application of the model to a real case (the Universitat Politècnica de Catalunya, in Barcelona, Spain). Such managerial insights are according to the variation of some input data as workforce size, cost and structure.

5.4 Scope of the study case II. Evaluation of the impact of strategic decisions in the university

After the basic performance evaluation for the model carried out in the study case I, this second study case exploits the model to evaluate the impact of strategic decisions in the university workforce.

The strategic decisions that mostly affect the workforce are: i) those related to academic policies that influence the demand of teaching hours (for example, creating or eliminating courses or studies, assigning students to small or big groups), as the number of workers is sized according to these requirements; and ii) personnel policies (e.g. staff budget, promotions and types of contracts), because the permanence and the expertise career of the workers depend on them. Finally, we consider important to establish a preferable university model (in composition and size) to ensure the service quality and the continuity and improvement of the educational model. These three aspects (academic policies, personnel policies and preferable composition) have effect in the setting up process of the strategic staff planning of the university. In the present thesis, personnel policies are evaluated allowing or not the firing of permanent workers; by acting on the ratio for internal promotion for workers, and by varying personnel budget. On the other hand, the academic policies are tested through the impact of different temporal trends in demand.

Several scenarios are used, based on real data from the Universitat Politècnica de Catalunya (Barcelona, Spain). The results show how the planned staff composition is adjusted to a preferable workforce composition through the available mechanisms (worker firing, hiring and internal promotions).

For analysis, different preferable workforce compositions are considered. These are derived from a survey addressed to experienced academics. The different workforce structures can prioritize skilled workers with enough experience to lead technology transfer projects and research teams, or, for instance, hold an important proportion of young researchers, so as to ensure the future sustainability of the organization. Figure 5.1 graphically summarizes the scope of the second study case.

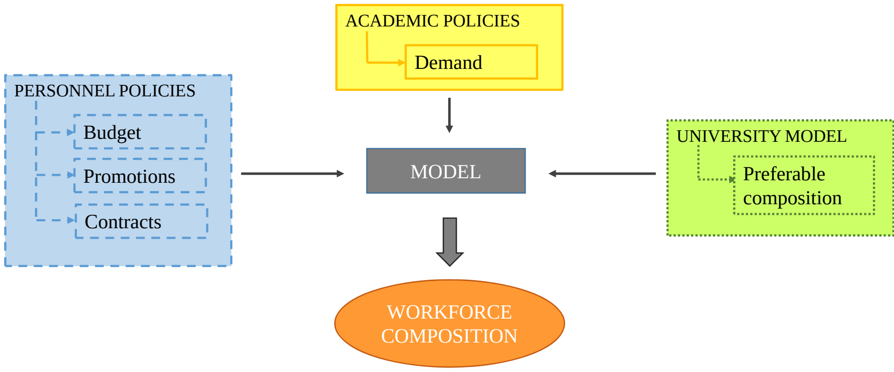


Figure 5.1: Graphical summary of the study case II. Evaluation of the impact of strategic decisions in the university workforce.

5.5 Scope of the study case III. Specific evaluation on the impact of strategic decisions around personnel promotions

As previously stated, strategic decisions regarding workforce are mainly hiring, firing and promotions. This problem is challenging per se, but it results particularly difficult for the case of the university, because of the several specificities to take into account (i.e. workforce heterogeneity, promotion rules, as well as the achievement of a preferable staff composition, the required service level and the minimum cost as optimization criteria).

As discussed in the study case II, one of the key strategic decisions so as to achieve the preferable workforce composition in public universities –and thus to fulfill the required objectives in research and technology transfer amongst others–, is the personnel promotion. In fact, since decisions on hiring and firing are usually more restrictive and expensive than promotions due to associated costs, they are intended as the first tool for achieving a preferable workforce structure.

For workers, progressing through categories is a long process challenged by the need of progressively achieving the required academic merits. In turn, the achievement of academic merits is constrained by the economic resources provided by the university: for instance, training, research and dissemination activities. In the previous study cases, such additional expenditures for workers' promotion were not explicited. Now, in this third study case, the admissible number of promotions –which are deduced in the optimization problem by an admissible promotion ratio for workers–, is not a parameter anymore as in the previous study cases, but a decision variable for the model for optimization. This means that the model will include the number of workers that can be promoted per unit, category and time period of the considered time horizon. Thus, the maximum number of workers that may promote are not bounded by a predetermined admissible promotion ratio anymore, and the above mentioned additional expenditures for promotions should be considered, since they can result important in magnitude. Accordingly, this third study case specifically addresses the relationship be-

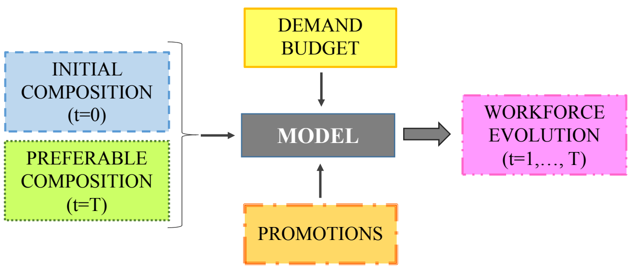


Figure 5.2: Graphical summary of the study case III. Evaluation of the impact of strategic decisions around personnel promotions.

tween the required economic resources to help workers' promotion to each of the categories of workforce pyramid, and the preferable staff composition pursued in strategic staff planning for universities. This analysis also considers external factors, such as several trends in demand and available budget, as well as different initial and preferable staff compositions. In regard of the latter, and as in the study case II, different preferable staff compositions will be defined, from the desired weight of temporary categories composed by young researchers, or permanent categories at the top of workforce structure. However, as a difference with the study case II, the initial staff compositions will not exactly represent the current composition of any department of the Universitat Politècnica de Catalunya, UPC, (Barcelona, Spain). Instead, different initial staff compositions for a department will be adjusted to the predetermined preferable ones. This way, one can also evaluate the impact that different initial and preferable combinations for staff composition have in the solution of the optimization problem, i.e. in the staff planning for the university.

So in conclusion, this third study case specifically addresses personnel policies on promotions. For the sake of clarity, the scope of the third study case is graphically depicted in Figure 5.2.

5.6 Chapter remarks

The first phase of the methodology (as introduced in Chapter 4) is presented here. It states the problem's characterization taking into account the specificities of KIOs in general and universities in particular (see Chapter 3). The first stage also includes the definition of the different study cases exploiting the tool for staff planning developed in the thesis, comprising the second phase of the methodology. Such definition of objectives is located in this first phase of the methodology as it affects the deployment of the subsequent phases (i.e. model's formulation and data collection).

The proposed study case I permits to firstly evaluate the validity of the model for optimization of the staff planning in universities. After this basic performance evaluation, the second study case assesses the impact of different strategic decisions related to academic and personnel policies in the strategic staff planning. The analyses performed in this study case II (and also in the first one) are based on real data from the Universitat Politècnica de Catalunya (Barcelona, Spain). This work contributes to evaluate how the planned staff composition results adjusted to a preferable workforce composition through worker's firing, hiring and internal promotions, while under different computational scenarios. Finally, the study case III further deeps in academic policies, specifically addressing the required economic resources for workers' promotion, while pursuing different preferable staff compositions and under various externalities. This third study case goes a step forward in complicating the problem for optimization, since admissible worker's promotion is not bounded based on historic data as in the previous study cases, but treated as a decision variable. Also, this third study case evaluates the impact in considering different initial workforce compositions, and while pursing different preferable ones. Altogether yield a valuable set of analyses from which derive the main conclusions of the thesis, both in terms of the performance of the proposed models for optimization, and in terms of the impact that academic and personnel policies have in staff planning.

6 Modeling

Summary.- This Chapter presents a model for dealing with the long term staff composition planning in public universities. University academic staff is organized in units (or departments) according to their field of expertise. The staff for each unit is distributed in a set of categories, each one characterized by their teaching hours, cost and other specificities. Besides the use for planning (and updating a plan), the model can be used to assess the impact that different strategies may have on the personnel costs and the structure of a university. The proposed model is formulated generally, so it can be applied to different types of universities attending to their characteristics. The optimization criteria for the model is to achieve a preferable academic staff composition under service level constraints while also minimizing the associated economic expenditures considering a long term horizon. The model will be applied to a real case and validated by means of a computational experiment considering several scenarios, in further chapters of the thesis.

6.1 Introduction

The first phase of the methodology for the staff planning in public universities, as presented in Chapter 4, clearly characterizes the problem, so as to the identified characteristics can be translated into a mathematical model for optimization.

Such mathematical model is presented in this Chapter and is a formalized procedure for tackling the problem of strategic staff planning in universities. The formulation of the model corresponds to the phase II of the methodology (see Chapter 4). The model, which results in a Mixed Integer Linear

Programming (MILP) tool, is one of the main contributions of the thesis. In the model, several university characteristics are considered, especially those regarding the planning criteria (such as achieving a certain composition) and those regarding hiring, firing and promoting possibilities (category pathways). The model is firstly presented as general, and then adapted to the scope of each of the presented study cases in Chapter 5. Such adaptation, as well as the required data for model's solving, are also introduced in this Chapter.

6.2 Basic model formulation

The basic structure of the optimization model is presented below. This includes the definition and notation for: required data and model parameters, decision variables and other model variables, objective function in terms of optimization criteria, and the set of constraints for optimization. As a reminder, the model just considers teaching and research staff for strategic staff planning. Personnel from administration departments is not included in the model.

6.2.1 Data

Table 6.1 lists and describes the required data for modeling purposes.

6.2.2 Parameters

Table 6.2 lists and describes the required parameters for the model.

6.2.3 Decision variables

Table 6.3 lists and describes the decision variables for the model.

6.2.4 Other variables

Table 6.4 lists and describes additional variables for the model.

6.2.5 Objective function

The main application for the model is as a tool for determining the long term staff composition and size for an organization. In the present thesis, the main criteria defining the workforce composition and size are:

Table 6.1: Data description

Data	Description
T	Set of periods.
U	Set of units.
K	Set of categories.
KT	Set of temporary categories (for modeling purposes each temporary category is divided into as many temporary categories as years a person can belong to that category).
KP	Set of permanent tenure categories.
KC	Set of permanent contractual categories.
Γ_k^+	Set of categories to which it is possible to access from the category k [$\forall k \in K$].
Γ_k^-	Set of categories from which it is possible to access to the category k [$\forall k \in K$]. Note that for temporary categories represented by the year number j ($j > 1$) this set has only the category representing the year number $j - 1$ of the same category.
c_{kt}	Cost in [mu/worker] associated to the category k in period t [$\forall t \in T$; $\forall k \in K$].
cf	Cost in [mu/worker] associated to firing staff (an average value is considered).
v_t	Cost in [mu/hour] associated to part time lecturers in period t [$\forall t$].
C_{ut}	Required teaching hours for the unit u, in period t [$\forall t$; $\forall u$].
h_{kt}	Teaching hours associated to each worker in the category k in period t [$\forall t$; $\forall k \in K$].
L_{ukt}	Expected personnel layoffs (for instance, due to retirement or to previously agreed firings) in the unit u, category k, in period t [$\forall t$; $\forall u$; $\forall k \in K$].
r_{uskt}	Proportion of workers in unit u that can promote, as maximum, from the category s to the category k, in period t [$\forall t$].
UW_{ukt}^+	Maximum number of workers that can be hired in unit u, category k and period t.
B_t	Planned budget for the cost of the academic staff for the period t [$\forall t$].

Table 6.2: Parameters of the problem

Parameter	Description
UP_{kt}, LP_{kt}	Preferable bounds for the proportion of academic staff that belongs to the category k in the period t. This condition is not hard, but non-compliance is penalized.
α_{ut}	Excess of teaching hours that should have, at least, the unit u in the period t [$\forall t$]. Note that, even if it is not usual, this parameter could be negative if a shortage in the capacity was allowed; this would mean a worsening in the service level (for example, because the number of students in a teaching room is too high). This parameter is expressed in per unit, as a proportion of required teaching hours.
γ	Maximum bound for the number of workers that can be fired.
φ	Maximum capacity assigned to part-time lecturers. This value is determined by the regulations and expressed in per unit.
λ_{kt}	Penalty associated to the discrepancy between the preferable and the planned composition of academic staff in the category k, in the period t [$\forall t$].
μ_t	Penalty associated to the maximum discrepancy between the preferable and the planned composition of the academic staff, in the period t [$\forall t$].
ω	Penalty associated to the maximum discrepancy between the preferable and the planned workforce.
US_{ut}, LS_{ut}	Admissible bounds for the size of the academic staff in period t and unit u.

Table 6.3: Decision variables of the problem

Variable	Description
$w_{ukt} \in \mathbb{Z}^+$	Indicates the number of workers of the unit u, category k and period t [$\forall t$; $\forall u$; $\forall k \in K$].
$A_{ut} \in \mathbb{R}^+$	Indicates the capacity assigned to part time lecturers in the unit u in period t [$\forall t$; $\forall u$].
$Q_{uklt} \in \mathbb{Z}^+$	Indicates the number of workers who access to the category l from the category k, in the unit u, in the period t [$\forall t$; $\forall u$; $\forall k \in K$; $\forall l \in \Gamma_u^+$].
$w_{ukt}^+ \in \mathbb{Z}^+$	Indicates the number of workers who are hired from the labor market for the unit u and category k, in the period t [$\forall t$; $\forall u$; $\forall k \in K$]. Note that for categories representing the year number j ($j > 1$) of a temporary category usually this variable should be 0. However, this is not constrained in the model because in some cases it might be possible to hire people for a temporary category with a contract of less years than the maximum permitted (for example if the person has already worked in that category during almost one year in another university).
$w_{ukt}^- \in \mathbb{Z}^+$	Indicates the number of fired workers (excluding the previously forecasted) in the unit u and the category k, in the period t [$\forall t$; $\forall u$; $\forall k \in K$].

Table 6.4: Other variables of the problem

Variable	Description
δ^+_{ukt}, $\delta^-_{ukt} \in \mathbb{R}^+$	Positive and negative discrepancies, respectively, between the preferable and the planned composition of the academic staff in the unit u, category k, in the period t [$\forall t$; $\forall u$; $\forall k \in K$].
$\delta_{ut} \in \mathbb{R}^+$	Maximum discrepancy (positive or negative), between the preferable and the planned composition of the academic staff in unit u and all the categories in period t (i.e. $\delta_{ut} = \max_k(\delta^+_{ukt}, \delta^-_{ukt})$) [$\forall t$; $\forall u$].
$\Delta_t \in \mathbb{R}^+$	Maximum discrepancy between the preferable and the planned composition of the academic staff in period t ($\Delta_t = \max_u(\delta_{ut})$) [$\forall t$].

- The economic criterion, that is, to maximize the economic profit for the organization, or to minimize personnel costs (in the case of the university, the latter is normally more appropriated). Variable costs for the strategic planning, salaries, hiring, firing and teaching related expenditures are included. Moreover, apart from the abovementioned costs, which are proportional to the number of workers for the organization, there are also other fix costs related to the size of workforce, which are usually calculated as piecewise-linear. These are derived from the water service, electricity service, maintenance contracts, and others.

- The workforce composition is according to a preferable one. Adopting this optimization criterion for the strategic planning, the objective results in minimizing the discrepancies between the ideal or preferable workforce composition and the determined one. Preferable or ideal workforce composition could be defined in terms of the desired expertise for the workers building up each of the categories of the organization.

- The required level of service. Adopting this criterion, the objective is to ensure a workforce size with enough capacity, even oversized to some extent, with respect to the required capacity (the demand). Doing that, the organization could have enough capacity to front eventualities such as worker's temporary disabilities and/or other incidents.

> The service level of the university can be evaluated through different metrics such as number of students per professor and/or classroom.

The adopted optimization criteria could consider just one or various of the above listed criterion. In the case of considering a multicriteria optimization it is necessary to establish a weighting system to give less or more importance to each singular objective. Non-priority optimization objectives could be included as constraints of the model, while priority objectives should serve to build up the objective function of the model. For instance, in case of prioritizing the economic criteria, the objective function of the model would be in terms of costs minimization or profit maximization. Thus, the criteria of achieving a preferable workforce composition and that ensuring a proper service level could be represented as economic penalizations, included in either the objective function or as constraints.

Conventionally, for universities, the principal optimization criterion is based on personnel costs minimization. As previously noted, these costs mainly comprise salaries. However, and considering the heterogeneity of workforce in terms of expertise and work capacity, it is necessary to also consider the achievement of a preferable workforce composition in the strategic planning. Addressing such heterogeneity, the proposed model for staff planning optimization includes, in its objective function, an economic penalization associated to the discrepancy between the determined workforce composition and the preferable one. Further, the criterion of ensuring a proper service level is also taken into account in the model. In this case, though, it is included as a constraint.

To sum up, the objective function of the model is presented in the following:

$$
\begin{aligned}
[\text{MIN}]\, z = & \underbrace{\sum_{\forall u,t}\left[\sum_{\forall k}(w_{ukt}\cdot c_{kt}) + A_{ut}\cdot v_t\right] + \sum_{\forall u,t,k\in KC}\left(cf\cdot w^{-}_{ukt}\right)}_{\text{Personnel costs}} \\
+ & \underbrace{\sum_{\forall u,k,t}\lambda_{kt}\cdot(\delta^{+}_{ukt}+\delta^{-}_{ukt}) + \sum_{\forall u,t}\mu_t\cdot\delta_{ut} + \omega\cdot\sum_{\forall t}\Delta_t}_{\text{Costs associated to discrepancies between preferable and planned composition}}
\end{aligned}
\tag{6.1}
$$

As noted in equation (6.1), the objective function aims to minimize the costs associated to: i) the salaries of the workers per each category k, unit u and time t; ii) penalties for hiring staff; and iii) those costs associated to discrepancies between the preferable and the planned composition in academic staff.

6.2.6 Constraints

The constraints corresponding to the fulfillment of required capacity (demand C_{ut}) include the parameter α_{ut}, which specifies the minimum desired capacity level for the university, and this can be higher than the demand.

$$\sum_{\forall k} w_{ukt} \cdot h_{kt} + A_{ut} \geq (1 + \alpha_{ut}) \cdot C_{ut} \quad \forall u, t \tag{6.2}$$

In addition, the capacity of the organization depends on the following balances or constraints. These are expressed in terms of: the number of workers in the unit or department u, category k and period t, w_{ukt}, the number of retirements L_{ukt}, and the proportion of workers that can promote from a category s to a category k, also for each unit u and period t, r_{uskt}. The balances further determine the number of workers actually promoting from a category k to a category l, Q_{uklt}, the number of workers hired from the labor market w^+_{ukt}, the dismissals or firings w^-_{ukt} and the capacity assigned to part-time lecturers $A_u t$.

$$w_{ukt} = w_{ukt-1} - L_{ukt} + \sum_{s \in \Gamma^-_k} Q_{uskt} - \sum_{l \in \Gamma^+_k} Q_{uklt} + w^+_{ukt} - w^-_{ukt} \quad \forall u, t; \forall k \in (KC \cup KP) \tag{6.3}$$

$$w^-_{ukt} \leq \gamma \cdot w_{ukt} + 1 \quad \forall u, t; \forall k \in KC \tag{6.4}$$

$$w_{ukt} = w^+_{ukt} + \sum_{s \in \Gamma^-_k} Q_{uskt} \quad \forall u, t; \forall k \in KT \tag{6.5}$$

$$Q_{uskt} \leq r_{uskt} \cdot w_{ukt-1} \quad \forall u, t; \forall s \in K | \Gamma^+_s \neq \{\emptyset\}; \forall k \in \Gamma^+_s \tag{6.6}$$

$$A_{ut} \leq \varphi \cdot C_{ut} \cdot (1 + \alpha_{ut}) \quad \forall u, t \tag{6.7}$$

Equation (6.3) is the balance for workers concerning categories under KC and KP. Equation (6.4) bounds the maximum dismissals for workers under contractual categories, attending to university regulations. The balance for workers in KT is expressed in equation (6.5). Equation (6.6) ensures that only workers that were already in a category k in period $t-1$ can be promoted to other categories in period t. Equation (6.7) bounds the maximum capacity assigned to part-time lecturers in unit u and period t.

To make the workforce composition as close as possible to the preferable one, the following set of constraints are included in the model. In there, variables δ^+_{ukt} and δ^-_{ukt} weights the positive and negative discrepancies between the preferable and the planned composition, being LP_{kt} and UP_{kt} the preferable bounds for the proportion of academic staff in the category k and period t. Finally, Δ_t corresponds to the maximum discrepancy for a unit in each period t. The maximum discrepancies (apart from the sum of discrepancies for each category and period) are added to avoid, insofar as possible, that the discrepancy between preferable and planned composition concentrates on particular periods or categories. It is preferable to obtain a regular distribution for the discrepancy throughout the considered time horizon.

$$\sum_{\forall u} w_{ukt} \geq \left(LP_{kt} \cdot \sum_{\forall u,k} w_{ukt} \right) - \delta^-_{ukt} \quad \forall u, t; \forall k \in K \tag{6.8}$$

$$\sum_{\forall u} w_{ukt} \leq \left(UP_{kt} \cdot \sum_{\forall u,k} w_{ukt} \right) + \delta^+_{ukt} \quad \forall u, t; \forall k \in K \tag{6.9}$$

$$\delta_{ut} \geq \left(\delta^+_{ukt} + \delta^-_{ukt} \right) \quad \forall u, t; \forall k \in K \tag{6.10}$$

$$\Delta_t \geq \delta_{ut} \quad \forall u, t \tag{6.11}$$

An additional balance or constraint is added to limit the personnel costs associated to salaries in the university budget for period t, B_t.

$$\sum_{\forall u} A_{ut} \cdot v_t + \sum_{\forall u,k} (w_{ukt} \cdot c_{kt}) \leq B_t \quad \forall t \tag{6.12}$$

Further, the academic staff of the university per each time period t is bounded by a maximum number of workers US_t and by the minimum LS_t.

$$LS_{ut} \leq \sum_{\forall k} w_{ukt} \leq US_{ut} \quad \forall u, t \tag{6.13}$$

Also, the number of workers that can be hired per each unit u, category k and time period t is bounded by UW^+_{ukt}.

$$w^+_{ukt} \leq UW^+_{ukt} \quad \forall u, k, t \tag{6.14}$$

Finally, the model is completed by defining all decision variables as non-negative; some of them are integer values and the rest are float values.

$$w_{ukt},\ Q_{uskt},\ w^+_{ukt},\ w^-_{ukt} \in \mathbb{Z}^+ \quad \forall u, t; \forall k \in K \tag{6.15}$$

$$A_{ut},\ \delta^+_{ukt},\ \delta^-_{ukt},\ \delta_{ut} \in \mathbb{R}^+ \quad \forall u, t; \forall k \in K \tag{6.16}$$

Completing the basic model formulation, Table 6.5 associates the problem characteristics, as defined in Chapter 5 with the above presented balances or constraints.

6.3 Model adaptation to the objectives of study

The optimization model presented in Section 6.2 should be adapted (e.g. complemented with additional constraints and/or new terms in the objective function) to the objectives of the different study cases proposed in the present thesis. Model adaptations are accordingly described in the present section.

6.3.1 Study case I. Basic performance evaluation and around managerial insights for the model

For the purposes of the study case I, no modifications are required to the equations presented so far in the Chapter. The model neither requires additional constraints for completeness, nor modifications in the variables.

6.3.2 Study case II. Evaluation of the impact of strategic decisions in the university

There are universities that prioritize promotions over foreign contracting due to policies aiming to return the investment in personnel training and for motivating the staff. In order to represent these policies in the model, a binary variable y_{uskt} is defined. This is an auxiliary variable for modeling the condition of prioritizing the promotion of the current workers from the category s to the category k above hiring workers from the labor market, in the unit u and period t. The introduction of the binary variable y_{uskt} permits to define constraints (6.17) to (6.19):

Table 6.5: Problem characteristics associated to the balances (constraints) of the model

Problem	Characteristic	Equation / Variable
Type of organization	Organizational structure	All variables are defined for each department u of the organization.
Workforce	Category / age / turnover	All variables are defined for each category k of the organization.
Decisions on workforce capacity	Creation of new spots / job shedding / promotions / training / interdepartmental transfer of personnel /	Balances of planned workforce capacity. These are in terms of hiring, firing and personnel promotion related decisions.
Required capacity (demand)	Capacity requirements	Balance of required capacity (demand). It refers the capacity of the university to the required service level.
Service level	Planned capacity	Balance of required capacity (demand).
Costs and financing	Personnel costs / financial plan	Budget constraint and objective function.
Uncertainty	Deterministic scenarios	-
Time horizon	Length	All variables of the model are defined for each time period t of the considered horizon.
Objective	Optimization criteria	The objective function is defined in terms of the economic optimization of the strategic planning, but also so as to achieve a preferable staff composition.

$$y_{uskt} \in \{0,1\} \quad \forall u,t; \forall s \in K | \Gamma_s^+ \neq \{\emptyset\}; \forall k \in \Gamma_s^+ \tag{6.17}$$

$$Q_{uskt} \geq r_{uskt} \cdot w_{uk,t-1} - r_{uskt} \cdot \left(\frac{C_{ut} \cdot (1+\alpha_{ut})}{h_{kt}} \right) \cdot y_{uskt} - 1 \\ \forall u,t; \forall s \in K | \Gamma_s^+ \neq \{\emptyset\}; \forall k \in \Gamma_s^+ \tag{6.18}$$

$$w^{+}_{ukt} \leq \left(\frac{C_{ut} \cdot (1+\alpha_{ut})}{h_{kt}}\right) \cdot (1 - y_{uskt}) \quad \forall u,t; \forall s \in K | \Gamma^{+}_{s} \neq \{\emptyset\}; \forall k \in \Gamma^{+}_{s} \tag{6.19}$$

Equations (6.18) and (6.19) force variable w^{+}_{ukt} equal to zero if the number of workers promoted to a category k is shorter than the upper bound.

6.3.3 Study III. Specific evaluation on the impact of strategic decisions around personnel promotions

With the objective of encouraging workers' promotions –and therefore research and technology transfer–, the university contemplates mechanisms to help workers to gain required merits for promotions. These mechanisms can be, for instance, economic resources for attending conferences, grants for scholarships in other universities, and others. In this study case, such economic resources are specifically addressed. In particular, these are intended to be proportional to workers' salary (e.g. planned resources for an experienced worker are higher than for a young PhD researcher) and for modeling purposes, such expenditures are weighted as a proportion θ_k of a worker's salary in each category k. The additional expenditures will be incurred proportionally to the difference between the resultant effective promotional ratio r_{ukt} –which in this case is not any more a parameter for the model, but a variable to be determined by the optimization–, and the predetermined proportion of workers that can promote, as maximum, without incurring in more expenditures r_{ukt_min}.

As a result, the objective function of the optimization problem previously presented in equation (6.1) is complemented with a new term associated to the costs for workers' promotion:

$$\sum_{\forall u,k,t} \left[\theta_k \cdot c_{ukt} \cdot (r_{ukt} - r_{ukt\_min})\right]$$

This way, the objective function for this study case III results as:

$$\begin{aligned} z = & \sum_{\forall u,t}\left[\sum_{\forall k}(w_{ukt} \cdot c_{kt}) + A_{ut} \cdot v_t\right] + \sum_{\forall u,t,k \in KC}(cf \cdot w^{-}_{ukt}) \\ & + \sum_{\forall u,k,t} \lambda_{kt} \cdot (\delta^{+}_{ukt} + \delta^{-}_{ukt}) + \sum_{\forall u,t} \mu_t \cdot \delta_{ut} + \omega \cdot \sum_{\forall t} \Delta_t \\ & + \sum_{\forall u,k,t} \left[\theta_k \cdot c_{ukt} \cdot (r_{ukt} - r_{ukt\_min})\right] \end{aligned} \tag{6.20}$$

The promotional ratio r_{ukt} is bounded in terms of the maximum and minimum reachable values but also in terms of admissible increments or decrements over time. This is to prevent the optimization model to determine unrealistic temporal trends in r_{ukt}. Such boundaries and limitations are represented by equations (6.21) to (6.23).

$$r_{ukt\_min} \leq r_{ukt} \leq r_{ukt\_max} \quad \forall u,k,t \tag{6.21}$$

$$r_{ukt} - r_{ukt-1} \leq \Delta r \quad \forall u,k,t \tag{6.22}$$

$$r_{ukt-1} - r_{ukt} \leq \Delta r \quad \forall u,k,t \tag{6.23}$$

$$\Delta r \leq Ur \tag{6.24}$$

Since r_{ukt} is now a variable, constraint (6.6) results non-linear, as it multiplies variables r_{ukt} and w_{ukt-1}. Thus, to formulate a linear model it is necessary to linearize this constraint. Constraint (6.6) is replaced by the following set of equations. Tables 6.6 and 6.7 include the description of the associated parameters and variables.

$$\begin{gathered} Q_{uskt} \leq \sum_{i=1}^{NR}\sum_{j=1}^{NW}(vr_i \cdot vw_j \cdot yrw_{ijuskt}) \\ \forall u,t; \forall s \in K|\mathit{\Gamma}_s^+ \neq \{\emptyset\}; \forall k \in \mathit{\Gamma}_s^+ \end{gathered} \tag{6.25}$$

$$\sum_{i=1}^{NR} yr_{iukt} = 1 \quad \forall u,k,t \tag{6.26}$$

$$r_{ukt} = \sum_{i=1}^{NR}(vr_i \cdot yr_{iukt}) \quad \forall u,k,t \tag{6.27}$$

$$\sum_{j=1}^{NW} yw_{jukt} = 1 \quad \forall u,k,t \tag{6.28}$$

$$w_{ukt} = \sum_{j=1}^{NW}(vw_j \cdot yw_{jukt}) \quad \forall u,k,t \tag{6.29}$$

$$\begin{gathered} 2 \cdot yrw_{ijuskt} \leq (yr_{iukt} + yw_{just-1}) \leq (1 + yrw_{ijuskt}) \\ \forall u,t; \forall s \in K|\mathit{\Gamma}_s^+ \neq \{\emptyset\}; \forall k \in \mathit{\Gamma}_s^+; \forall i \in NR; \forall j \in NW \end{gathered} \tag{6.30}$$

Table 6.6: Parameters associated to the linearized model

Parameter	Description
θ_k	Factor weight in additional expenditures associated to personnel promotions per each category k.
r_{ukt_min}	Minimun proportion of workers in unit u that can promote to the category k, in period t, without incurring in additional expenditures.
r_{ukt_max}	Maximum proportion of workers in unit u that can promote to the category k, in period t, incurring in additional expenditures.
Ur	Maximum value for variable Δr.
NR, NW	Number of values that r_{ukt} and w_{ukt} can adopt respectively.
vr_i	Discretized value for the promotional ratio r_{ukt}. $[i = 1..NR]$.
vw_j	Discretized value for the number of workers w_{ukt}. $[j = 1..NW]$.

Table 6.7: Decision variables associated to the linearized model

Variable	Description
$r_{ukt} \in \mathbb{R}^+$	Proportion of workers in unit u that can promote, as maximum, to the category k, in period t. This is representative of the workers that actually promote to category k, unless its value results bounded by the limits r_{ukt_min} and r_{ukt_max}.
Δr	Increment or decrement in promotional ratio r_{ukt} over two consecutive time periods.
$yrw_{ijuskt} \in \{0,1\}$	Boolean variable that equals $\{1\}$ in the case $r_{ukt} = vr_i$ and $w_{ukt-1} = vw_j$. $[\forall u,k,t;\ i = 1..NR;\ j = 1..NW]$.
$yr_{iukt} \in \{0,1\}$	Boolean variable that equals $\{1\}$ in the case $r_{ukt} = vr_i$. $[\forall u,k,t;\ i = 1..NR]$.
$yw_{jukt} \in \{0,1\}$	Boolean variable that equals $\{1\}$ in the case $w_{ukt} = vw_j$. $[\forall u,k,t;\ j = 1..NW]$.

As noted in equation (6.25), the product between variables r_{ukt} and w_{ukt-1} in equation (6.6) is replaced by the product of the binary variable yrw_{ijuskt} and the parameters vr_i and vw_j, thus yielding a linear equation. The value for variable yrw_{ijuskt} is computed from variables yr_{iukt} and yw_{just} in equation (6.30) and these are, in turn, determined in equations (6.26) to (6.29). Equations (6.26) and (6.28) indicates that for each unit u, category k and period t there is one and only one pair of indices i and j for which yr_{iukt} and yw_{just} respectively, equal 1. This way, the product between vr_i and yr_{iukt}, as well as vw_j and yw_{just}, determines the value of r_{ukt} and w_{ukt} in equations (6.27) and (6.29) respectively. Then, r_{ukt} and w_{ukt} can be used in other equations in the model.

6.4 Chapter remarks

This Chapter presents a mixed linear mathematical programming model for determining the size and composition of the academic staff of public universities under a long term planning horizon and taking into account the category structure and a preferable composition, while minimizing the associated costs. The problem, which is relevant and very important for the performance of any public university, is too difficult to be solved without an adequate and formalized procedure and powerful tools and techniques.

The presented optimization model, along with the real data from a Spanish university, the UPC, is going to be exploited in the following Chapter, discussing around the results obtained for each of the three proposed study cases.

7 Results

Summary.- This Chapter discusses on the results determined by the optimization model for staff planning in public universities, as presented in Chapter 6 and according to the scope of the three study cases for analysis in Chapter 5. For each study case, several computational scenarios are considered so as to evaluate the impact of different strategic decisions related to academic and personnel policies in the staff planning. Also, different quantitative metrics for evaluation are defined.

7.1 Introduction

The optimization model previously developed in Chapter 6 is exploited in this Chapter to evaluate different aspects around staff planning in public universities.

The principal capacity decisions considered in the present problem are personnel hiring, firing and promotions. The strategic decisions in the optimization of the staff planning can be affected by several factors such as demand, available personnel budget and the preferable staff composition aiming to achieve. For instance, under increasing temporal trends in demand, personnel hirings are expected to also increase. Another example is that under reductions in personnel budget, the objective of achieving a preferable workforce composition could result compromised, since those workers with the best ratio between work capacity per salary are expected to be prioritized, no matter their category.

So, this Chapter discusses on such capacity decisions, as presented in the scope of the three study cases for analysis considered in the present thesis.

Since both the scope and the modeling were presented in previous chapters, this Chapter presents required data for analysis and tackles the discussion on obtained results for each of the study cases. To do this, Section 7.2 firstly presents the formulation of metrics to evaluate the results. Then, Sections 7.3 to 7.5 discuss on the results for each study case. Each discussion includes the definition of computational scenarios for analysis.

7.2 Metrics

The performance of the model is evaluated by defining a set of metrics. Metric RC_{ukt} is the proportion of staff over the whole staff of the unit u at period t belonging to category k (resulting from the solution of the model), computed as:

$$RC_{ukt} = \frac{w_{ukt}}{\sum\limits_{k=1}^{K} w_{ukt}} \qquad \forall u, k, t \tag{7.1}$$

Let PC_k the preferable weight of category k in the university workforce composition. Using RC_{ukt}, the Global Discrepancy GD_{ut} is computed by the discrepancies of all the categories k, between PC_k and the workforce obtained per each period t and unit u:

$$GD_{ut} = \sum_{k=1}^{K} |PC_k - RC_{ukt}| \qquad \forall u, t \tag{7.2}$$

Since the index GD_{ut} accumulates the aforementioned discrepancy associated to each category, the obtained value can exceed 1 p.u. (i.e 100%).

With a higher level of aggregation, the Global Discrepancy GD_{ut} can be averaged for all units or departments of the university. This leads to a third metric defined for each period t, the Average Global Discrepancy $\overline{GD}_t$, which is computed as:

$$\overline{GD}_t = \frac{\sum\limits_{u=1}^{U} GD_{ut}}{U} \qquad \forall t \tag{7.3}$$

In addition, the metric Z_t computes the cost for each period t related to personnel management, i.e. salaries and firing costs. This metric is defined as:

$$Z_t = \sum_{\forall u} \left[\sum_{\forall k} (c_{kt} \cdot w_{ukt} + c_{kt} \cdot w^{-}_{ukt}) + A_{ut} \right] \qquad \forall t \tag{7.4}$$

And finally, metric R computes the total additional costs during the considered time horizon for personnel promotion. This metric is defined as:

$$R = \sum_{\forall u,k,t} \theta_k \cdot c_{ukt} \cdot (r_{ukt} - r_{ukt\_min}) \tag{7.5}$$

7.3 Study case I. Basic performance evaluation and around managerial insights for the model

This section presents the required data and obtained results for the study case I, which carries out a first performance evaluation and around managerial insights for the model. The scope and model's formulation for the following analyses were presented in Chapters 5 and 6 in the corresponding sections.

7.3.1 Data

For the study cases I and II, information is taken from a real university, the Universitat Politècnica de Catalunya (UPC). UPC, created in 1971, is one of the top 10 universities in Spain; the academic portfolio of this public university offers 68 degrees and masters, mainly in the field of engineering, altogether hosting more than 30,000 students in 23 schools and faculties. The academic workforce exceeds 3,000 people distributed in 42 units ($u = 42$) or departments.

The UPC concerns two types of categories for workforce: temporary and permanent. Regarding temporary categories KT, it is mandatory for a member of the staff to progress to a higher category once a certain period of time is completed (otherwise, the worker loses his or her job position). In these categories work contracts are annually renewed and workers are in a training period, so their capacity (teaching hours) is low in comparison with the workers in permanent categories.

Regarding permanent categories, workers can follow two different career paths: contractual and public/tenure. The main difference between them, for strategic decisions, is that only workers following the contractual path KC can be fired, although financial compensation is paid. On the other hand, promotion in the tenure path KP is harder than in the contractual one, because fewer new posts are available. Furthermore, although non-conventional, it is worth noting that workers can switch between contractual and public paths by horizontal or vertical promotion. The total number of categories for the UPC is $k = 15$. The first 8 categories comprise subset

KT, thus leaving 7 permanent categories. Amongst them, 3 correspond to subset KC and 4 are within subset KP. Figure 7.1 includes a chart with the evolution of academic staff through the different categories in UPC.

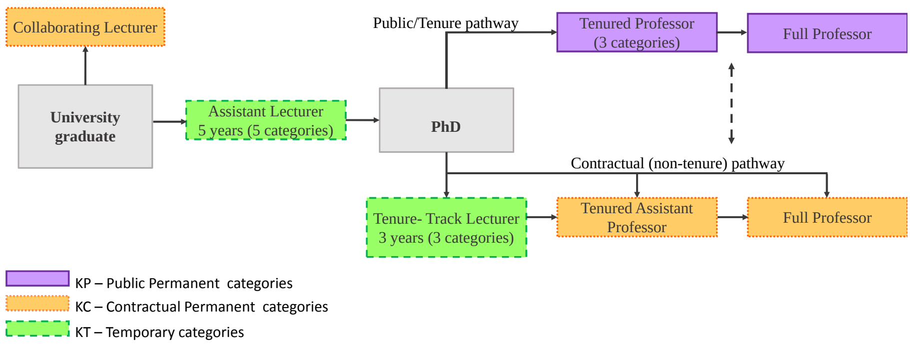


Figure 7.1: Categories in the UPC and the evolution of the academic career.

For solving the model, and addressing the specificities of the UPC, several data are needed on economic costs, regulations, promotions and retirements, among other factors. These aspects are summarized in the following. For the sake of clarity, most of the data are tabulated and presented in the Appendix B.

- The costs associated to the staff for the different categories (c_{kt}, v_t), have been estimated from the university public information [UPC 2014], and are listed in Table B.1, in the Appendix B, for the sake of clarity. The presented costs can be considered constant or variable throughout the considered time horizon for analysis, depending on the objectives of analysis in the different study cases.

- In the same way, the teaching capacity of workers h_{kt} for each category and period is public information, and this is presented in Table B.2, in the Appendix B. As for personnel costs, the capacity in the table can be varied during the considered time horizon addressing the objectives of the study cases.

- The required capacity (demand) for each unit or department is deduced from the number of students for the subjects offered by each department of the university [UPC 2014] (see Table B.3, in the Appendix

B). The demand can be modified in the study cases for addressing the impact of different academic policies on the determination of the strategic staff planning.

- The expected personnel retirements L_{kt} and internal promotions r_{uskt} are computed from historical data [ANECA 2014], [AQU 2014] and [Ministry 2014]. Data for L_{kt} and r_{uskt} are presented in Tables B.4 and B.5, in the Appendix B. In addition, the minimum required excess of capacity for each category α_{ut}, is accepted around 15% (according to [UPC 2014]). This capacity over sizing is due to the reduction in the effective workers' capacity for addressing management tasks. Further, the capacity that part-time lecturers can hold is bounded by regulations and in this case has been considered as $\varphi = 0.4$.

- The sets of categories Γ_k^+ and Γ_k^- derive from the regulatory framework applied to public universities [AQU 2014], [ANECA 2014] and [Ministry 2014], and these are presented in Figure 7.2. Dismissals of workers within KC are also bounded by regulations. In the model, this is regulated by the parameter γ, and this is set to 0.5.

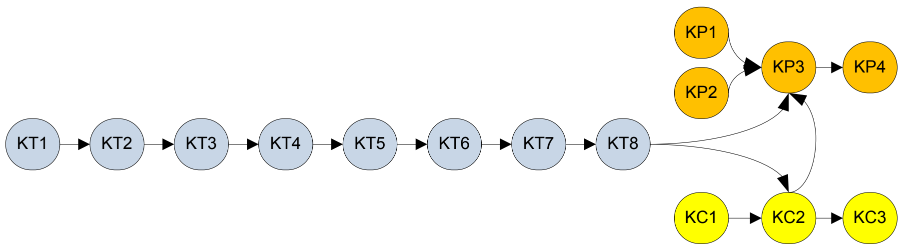


Figure 7.2: Categories to which workers can promote, for the particular case of the UPC.

- The budget B_t for the university is estimated from public information on the website of the university [UPC 2014]. This is estimated around 129 M€/year.

- The university policies establish that the maximum length of time (consecutive years) a professor can be rector is eight years (two consecutive four year periods). Also, eight years is the required time for achieving a tenure position. Hence, it seems appropriate to consider an eight-year horizon for the UPC staff planning.

- The number of workers per each of the 42 units or departments of the university and for each category, at the beginning of the time horizon for analysis, are presented in Tables B.6 to B.9, in the Appendix B.

All these data would allow the execution of the proposed model, but just considering economic aspects, so avoiding those aspects referred to the preferable composition of the workforce. In the following, those parameters for including the preferable composition criteria are introduced.

In order to achieve the preferable workforce composition, and for modeling purposes, UP_{kt} and LP_{kt} are introduced as preferable bounds for the proportion of each category in the academic staff. In the current case, parameters UP_{kt} and LP_{kt} permit a deviation of up to 25% for the percentage of each category within KT, KC and KP. The addressed study cases II and III consider 3 different preferable compositions, which are deduced from a survey addressed to experienced academics. These preferable compositions refer to different strategic visions for the university such as generational replacement, workforce training, the vocation to develop technology transfer, among other aspects. The definition of these 3 university models, –named hereinafter as Models A, B and C–, will be introduced in the present Chapter in the corresponding section. For the time being, just note that each of the university models imposes different preferable proportion of workers in group of categories KT, KC and KP.

To include the personnel costs and the deviations from a preferable staff composition in a single objective function, the latter have been penalized in an economic terms. Penalty λ_{kt} is the annual salary per each category and worker, whilst penalty μ_t is computed as a proportion (around 5%) of the annual average budget of a department and ω, as a proportion (around 1%) of the annual budget for the entire university. The aforementioned penalties have been considered constant throughout the considered time horizon.

For evaluating the capacity, it is worth noting that only tasks related to teaching are considered. Nevertheless, the capacity of a worker can be minored depending on the attributions of other duties (e.g. research and management tasks) apart from teaching. Thus, the staff requirements are calculated according to the capacity in number of hours per worker and category. The remaining tasks are taken into account in an indirect way according to the composition of the academic staff.

7.3.2 Results of the basic tests

The following results show the performance of the proposed model for the optimization of the workforce composition of the UPC considering a time horizon of 8 years. The model formulated in 6 was solved in IBM ILOG CPLEX Optimization Studio software (version 12.2), with the variables, constraints and execution time summarized in Table 7.1.

Table 7.1: The CPLEX Optimization Studio solution report

Real var.	Integer var.	Binary var.	Constraints	Execution time
14,197	20,370	1,344	43,268	1000 sec.

Table 7.2 shows the average global discrepancy $\overline{GD_t}$ for each period t, and the comparison of the two consecutive values of $\overline{GD_t}$ throughout the considered temporal horizon. The maximum discrepancy (i.e., Δ_t variables) is depicted. It is clear from Table 7.2 that the global discrepancy is being progressively reduced throughout the time horizon, from a value of 0.974 down to 0.329. The major reduction in global discrepancy is in the first periods of the considered time horizon. In the rest of the periods the improvement is relatively small, since the staff composition gets closer to the preferable one.

Table 7.2: The CPLEX Optimization Studio solution report

t	0	1	2	3	4	5	6	7	8
$\overline{GD_t}$	0.974	0.641	0.541	0.433	0.4	0.362	0.345	0.335	0.329
$\overline{GD_t}$ - $\overline{GD_{t+1}}$	0.333	0.1	0.108	0.033	0.038	0.017	0.01	0.006	
Δ_t	25.00	14.70	10.70	8.10	7.80	3.80	2.80	2.50	2.25

Figure 7.3 plots $\overline{GD_t}$, the average index GD_{ut} for the 42 units of the university, as well as the maximum and minimum values between $t = 0$ and $t = 8$. As it can be observed, the proposed procedure for the strategic capacity planning reduces progressively along the time horizon the discrepancy between preferable and planned workforce compositions. Most of the changes are applied in the early years of the horizon (this also means that from the results point of view an eight-year horizon is appropriate). The discrepancy has been reduced for all 42 units, without any exception.

As a result of the optimization procedure, the final workforce composition is much similar to the preferable composition than the initial one, as

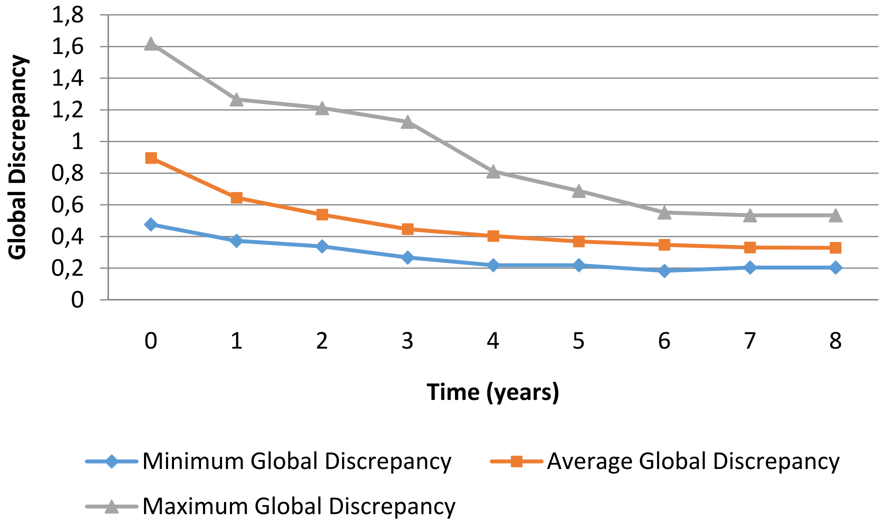
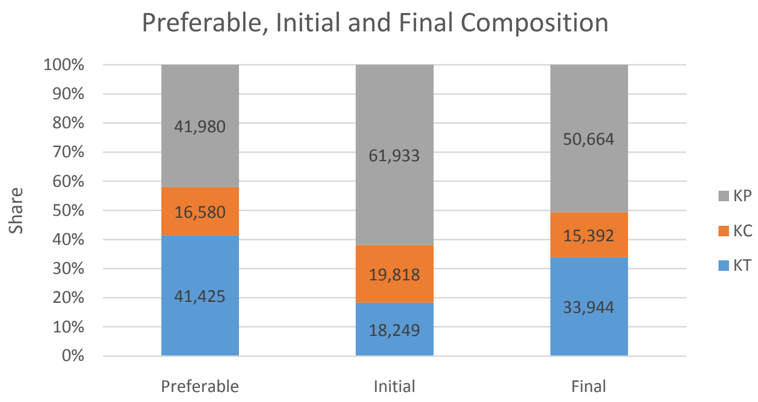


Figure 7.3: Evolution of the global discrepancy GD_{ut} (mean, maximum and minimum values) in a time horizon of 8 years.

plotted in Figure 7.4 i). As shown, categories within subset KC hold minor changes as they were initially closed to the preferable composition. On the other hand, categories within KT and KP have been substantially modified. Further, and as shown in Figure 7.4 ii), it is important to remark that the optimization results lead a substantial reduction in the total number of workers of the university, which also shows that the academic workforce was too oversized.

Complementing the performance evaluation of the optimization procedure, the following results give details for the subsets of categories KT, KC and KP. Each one of them is influenced by the singularities of that particular subset affecting strategic decisions, so this incentivizes separate studies which results are graphically plotted in Figures 7.5, 7.6 and 7.7. These figures present the Global Discrepancy GD_{ut} for each subset of categories and for each unit and time, in order to evaluate the evolution of the index influenced by the specificities of each subset. The mean results are given in Tables 7.3 and 7.4.

Figure 7.5 plots index GD_{ut} for the subset KT (the temporary academic staff). As a figure of merit, the discrepancy GD_{ut} has been reduced for the 95% of the units considering categories in KT. As a reminder, employment contracts for workers in categories within KT are renewed annually; so, this



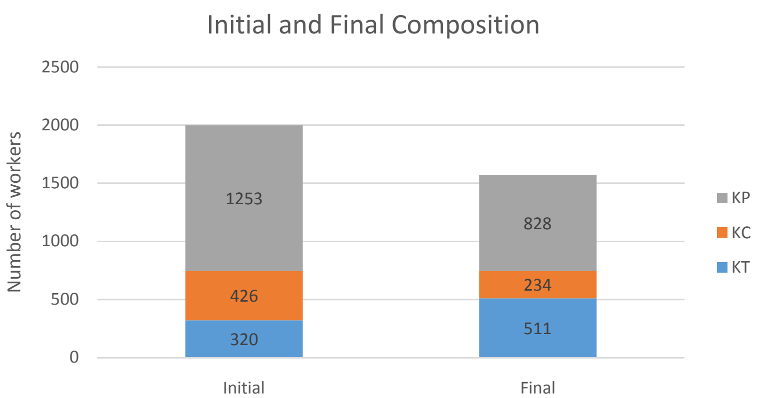


Figure 7.4: Comparison between the preferable, the initial and the final compositions and the initial and the final number of academic workers in the UPC.

Table 7.3: Average Global Discrepancy $\overline{GD}_t$ for subsets KT,KC and KP in a time horizon of 8 years

t	0	1	2	3	4	5	6	7	8
Subset KT	0.297	0.276	0.230	0.179	0.159	0.142	0.140	0.133	0.133
Subset KC	0.192	0.061	0.055	0.053	0.065	0.060	0.059	0.061	0.052
Subset KP	0.485	0.304	0.256	0.201	0.176	0.160	0.146	0.141	0.144

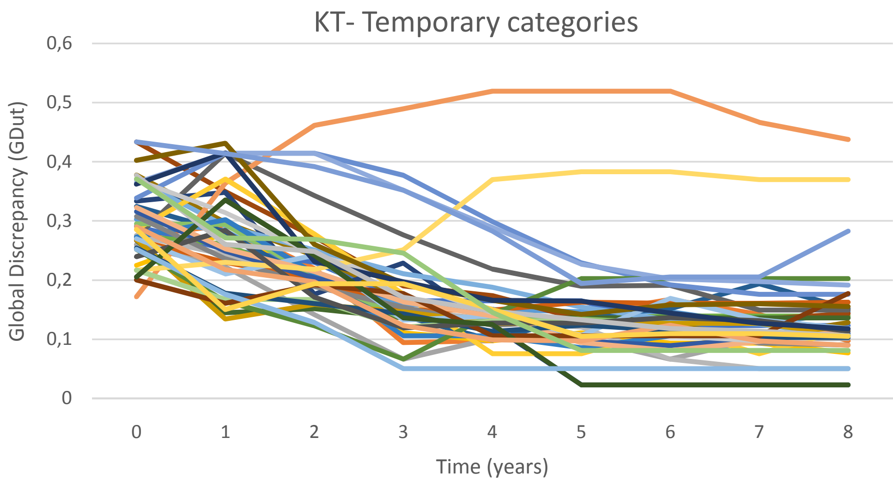


Figure 7.5: Evolution of the Global Discrepancy GD_{ut} in subset KT per unit and period.

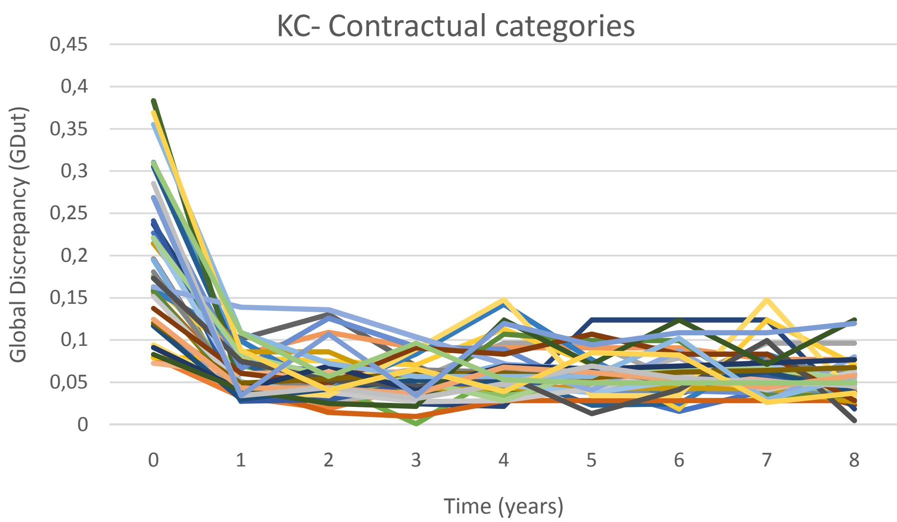


Figure 7.6: Evolution of the Global Discrepancy GD_{ut} in subset KC per unit and period.

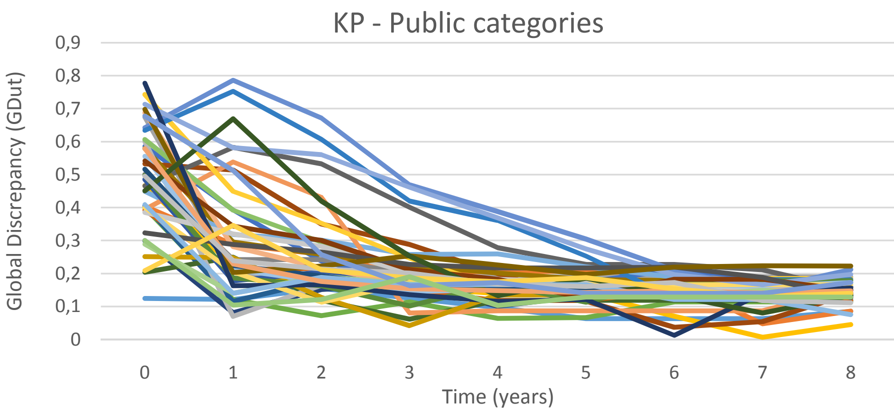


Figure 7.7: Evolution of the Global Discrepancy GD_{ut} in subset KP per unit and period.

Table 7.4: Difference of Average Global Discrepancy $\overline{GD}_t - \overline{GD}_{t+1}$ for subsets KT, KC and KP in a time horizon of 8 years

t	0	1	2	3	4	5	6	7
Subset KT	0.021	0.046	0.051	0.020	0.017	0.002	0.007	0.000
Subset KC	0.131	0.006	0.002	-0.012	0.005	0.001	-0.002	0.009
Subset KP	0.181	0.048	0.055	0.025	0.016	0.014	0.005	-0.003

permits high flexibility while determining workforce composition –note the high variability of GD_{ut} in Figure 7.5, also numerically summarized in the first row of Table 7.3–. Further, and bearing in mind that most workers in these categories are in training periods, they offer reduced capacity and economic yield. These factors lead strategic decisions concerning subset KT subordinated to some extent to those decisions taken for workforce composition of permanent categories. The effects of such subordination can be also observed in Figure 7.5, focusing on the increasing Global Discrepancy GD_{ut} for subset KT in some units. Capacity for these units surplus the demand and workers are mostly in categories within KP, so they cannot be fired. As a result, workforce composition is very constrained and it is only driven by promotions and layoffs. Given that contracts are annually renewed for KT and penalizations associated to a preferable composition are lower than for categories within KP and KC, it seems reasonable to expect minor adjustments for KT versus the rest of the categories.

Figure 7.6 plots the index GD_{ut} for the subset KC (permanent staff that can be fired with economic penalty). As it is shown, most of the strategic decisions are taken in the very beginning of the considered time horizon. From this point on, the workforce composition becomes almost steady. As a result, the discrepancy GD_{ut} has been reduced in 97% of the units considering KC. Adjustments are influenced by the fact that strategic decisions within KC are subjected to penalties due to discrepancies between preferable and actual composition as well as those associated to the cost of firing. Note that workers in KC hold permanent contracts. The second row of Tables 7.3 and 7.4 supports graphical results on categories within KC.

Finally, Figure 7.7 presents the index GD_{ut} for the subset KP (permanent staff that cannot be fired) and the third row of Tables 7.3 and 7.4 gives the associated values $\overline{GD}_t$ and its temporal variation. The workforce composition in KP for all units has been improved, as at the time horizon it results closer to the preferable in comparison to the initial. Opposite to the case of subset KC, strategic decisions towards preferable composition are not concentrated at the very beginning of the horizon, but they are distributed throughout most of the considered time. This is because strategic decisions are restricted by the fact that workers hold permanent contracts and cannot be fired. If the weight of these categories at the beginning is too high (compared to the preferable one) as in this case, the managers should wait for the worker's promotion and the scheduled retirements.

7.3.3 Performance of the model and managerial insights

The previous sections introduce the problem of the strategic staff planning in universities, propose a model and apply it to a real case. Complementary, this section aims to prove the performance of the model under different scenarios considering the university size as well as to give some managerial insights according to the variation of some input data.

7.3.3.1 Performance of the model

This section presents the performance of the model under different university sizes. To do so, a set of experiments have been designed. Each one considers universities with different number of departments or units, as well as different number of categories. In particular, the number of departments is $|U| = \{20, 60, 100\}$, while the number of categories is $|K| = \{5, 10, 15\}$, altogether affecting the size and complexity of workforce structure. These assumptions are translated into 9 different scenarios for optimization. The model is, in turn, executed 10 times for each scenario varying input data as the budget and parameters UP_{kt} and LP_{kt} (which correspond to the preferable bounds for the proportion of academic staff that belongs to the category k in the period t). The set of periods in the horizon are $T = 10$ in this part of the study. A total execution time of 10,000 seconds was given to solve each instance, i.e. 167 minutes.

A synthetic view of the obtained results is presented in Table 7.5: for each of the 9 scenarios, the minimum (in any of the 10 executions), average (of the 10 executions) and maximum (in any of the 10 executions) gap given by the software at the end of the execution time and the minimum (in any of the 10 executions), average (of the 10 executions) and maximum (in any of the 10 executions) time needed for achieving the given final solution.

As can be noted, the maximum gap to the optimal solution has been bounded to 2.08%, which can be considered very good, taking into account that a strategic long term problem is being solved. The time needed to reach an admissible gap and the gap magnitude both are increased with the considered number of units and categories but, overall, both can be considered small enough.

7.3.3.2 Managerial insights

This section aims to study the model sensitivity under variations of different characteristic parameters. In particular, the analyses are concentrated in three main aspects: workforce structure, worker capacity per subset of

Table 7.5: Computational results (gap and time to obtain the final solution) for the model performance in the 9 scenarios

			Gap (%)			Time (minutes)		
Scenario	$\|U\|$	$\|K\|$	Min	Mean	Max	Min	Mean	Max
1	20	5	0	0	0	13	13	13
2	20	10	1.17	1.20	1.21	39	40	42
3	20	15	1.05	1.06	1.07	69	69	75
4	60	5	0.58	0.64	0.65	32	33	36
5	60	10	1.43	1.45	1.46	34	46	48
6	60	15	1.71	1.76	1.77	95	96	98
7	100	5	0.86	0.90	1.02	39	41	41
8	100	10	1.86	2.04	2.06	120	127	131
9	100	15	1.74	2.03	2.08	144	155	167

categories and personnel costs. For each issue, several scenarios are studied. The scenario #0 is the basic one, i.e. that was already considered in Section 7.3.2. The total number of computational experiments carried out is 11 (3, 3 and 5 experiments respectively for the three mentioned aspects). The obtained results are below presented according to each input data.

Workforce structure The number of temporary categories KT, public permanent categories KP and contractual permanent categories KC has been varied, which gives different ratios between temporary and permanent contracts. The total number of categories is always 15. There are 3 new scenarios. In scenario 1 the number of categories within KC is left constant and there are less temporary categories. Scenario 2 has the same number of categories within KP and proposes that the number of categories within KC is increased. Scenario 3 suggests a different number of categories within KC and KP, with same initial temporary categories.

The summary of the main results for the considered scenarios at the end of the time horizon ($t = 8$) are presented in Table 7.6: the personnel costs, the number of workers for groups of categories and the Global Discrepancy $\overline{GD}_8$.

The minor difference in number of workers per subset of categories and Global Discrepancy in comparison to scenario 0 is obtained in scenario 3. Furthermore, in this scenario, personnel costs are the lowest. The greater number of categories within the graph of KC and KT provides the system with flexibility for firing workers (as a reminder, workers in KP cannot be

Table 7.6: Sensitivity analysis concerning workforce structure in $t = 8$ for the different scenarios

Sc.	KT	KC	KP	Total costs (k€)	$\sum_{u,k} w_{uk8}$, $\forall u,k \in KT$	$\sum_{u,k} w_{uk8}$, $\forall u,k \in KC$	$\sum_{u,k} w_{uk8}$, $\forall u,k \in KP$	$\sum_{u,k} w_{uk8}$, $\forall u,k$	$\overline{GD}_8$
#0	8	3	4	98,990	462	254	844	1560	0.329
#1	6	3	6	99,974	416	249	941	1606	0.235
#2	6	5	4	99,824	415	390	800	1605	0.233
#3	8	5	2	97,809	454	255	824	1533	0.337

fired) and the university workforce barely diminishes (from 1560 to 1533 workers) and, as a consequence, the total personnel costs.

Major differences can be observed comparing scenarios with 8 temporary categories (scenarios 0 and 3) to the ones with only 6 ones. If the number of temporary categories decreases (scenarios 1 and 2) decisions must be taken in a more rigid environment than in scenario 0. This rigidity comes from the fact that more workers' firing is now subjected to an economic penalization and they cannot be fired if they are included in permanent categories KP. As a result, the total number of workers (and the total personnel costs) is greater in scenarios 1 and 2 than in the rest, because of the resilience of the system to reduce the number of workers in permanent categories.

Workforce capacity (teaching hours) Workforce capacity h_{kt} is a parameter that directly affects the number of workers in each of the categories of the university, in order to fulfill demand requirements. Intuitively, one can expect that the lower the ratio c_{kt}/h_{kt} (i.e. the specific cost per capacity unit for a worker in the category k and period t), the higher the number of workers to be hired towards the cost minimization. This is successfully predicted by the model, as presented in Table 7.7.

In the three new scenarios, the number of teaching hours (initially h^0_{kt}) corresponding to one of the group of categories has been doubled, $h_{kt} = 2h^0_{kt}$. For the sake of clarity, we only indicate the multiplying factor between the worker capacity in scenario 0 and the new scenarios. As it can be noted, comparing the results for scenarios 1 to 3 versus scenario 0, an increment in the capacity in all of the category subsets is clearly translated in a reduction of personnel costs for the university. It is interesting to note that if the capacity of workers within KT is doubled (scenario 1) the hiring of such workers is favoured and thus the achievement of the preferable workforce

Table 7.7: Sensitivity analysis concerning workforce capacity in $t = 8$ for the different scenarios

Sc.	h_{KT}	h_{KC}	h_{KP}	Total costs (k€)	$\sum_{u,k} w_{uk8}$, $\forall u,k \in KT$	$\sum_{u,k} w_{uk8}$, $\forall u,k \in KC$	$\sum_{u,k} w_{uk8}$, $\forall u,k \in KP$	$\sum_{u,k} w_{uk8}$, $\forall u,k$	$\overline{GD}_8$
#0	h^0	h^0	h^0	98,990	462	254	844	1560	0.329
#1	$2h^0$	h^0	h^0	88,467	579	223	675	1468	0.282
#2	h^0	$2h^0$	h^0	85,411	404	245	688	1337	0.332
#3	h^0	h^0	$2h^0$	74,129	304	148	660	1152	0.408

composition (as a reminder, 41% of university workforce should be sustained by workers in categories within KT in this case, see Figure 7.4). This is translated in a reduction of the Global discrepancy compared to that for scenario 0. On the other hand, the higher capacity of workers in permanent categories (scenarios 2 and 3) compromises the achievement of the ideal workforce composition. Since these categories were initially oversized, an increment in workers capacity does not facilitate the downsizing.

Workforce cost Finally, variations in workforce cost c_{kt} are studied through five new scenarios, in which the cost per worker is increased for one or two of the subsets of categories respect to the scenario 0, c^0_{kt}. As presented in Table 7.8, results do not provide a very clear picture of the effect neither in workforce composition nor in total personnel costs for the university. However, comparing scenarios 1 to 3 versus the scenario 0, it is remarkable that an increment in the salary for workers within a particular subset of categories is associated to a reduction in the number of workers in that subset. For instance, in the base case categories within KT hold 462 workers, whose number is reduced to 435 in scenario 1; it is also the minimum for workers within KT compared to the rest of scenarios. Finally, if the salary for workers within permanent categories increases, but not for temporary ones (i.e. scenario 5), the number of workers within KT is greater than in scenario 0 and the number of workers within KC and KP is slightly reduced.

Table 7.8: Sensitivity analysis concerning workforce capacity in $t = 8$ for the different scenarios

Sc.	c_{KT}	c_{KC}	c_{KP}	Total costs (k€)	$\sum_{u,k} w_{uk8}$, $\forall u,k \in KT$	$\sum_{u,k} w_{uk8}$, $\forall u,k \in KC$	$\sum_{u,k} w_{uk8}$, $\forall u,k \in KP$	$\sum_{u,k} w_{uk8}$, $\forall u,k$	$\overline{GD}_8$
#0	c^0	c^0	c^0	98,990	462	254	844	1560	0.329
#1	$1.25c^0$	c^0	c^0	102,209	435	259	850	1544	0.339
#2	c^0	$1.25c^0$	c^0	102,635	465	230	863	1558	0.331
#3	c^0	c^0	$1.25c^0$	113,299	480	262	832	1574	0.321
#4	$1.25c^0$	$1.25c^0$	c^0	105,962	443	237	865	1545	0.341
#5	c^0	$1.25c^0$	$1.25c^0$	117,313	487	251	837	1575	0.316

7.4 Study case II. Evaluation of the impact of strategic decisions in the university

This section presents the required data, scenarios and results for the study case II. According to the objectives of the study case, exhaustive analyses for evaluating the impact of different strategic decisions regarding personnel policies, academic policies and a preferable workforce composition are performed here. The scope and model's formulation for the following analyses were presented in Chapters 5 and 6 in the corresponding sections.

7.4.1 Data

Data for the Study Case II is the same as those adopted for the Study Case I, as presented in subsection 7.3.1.

7.4.2 Description of scenarios

As previously explained, the performance for organizations in services is not mainly evaluated from economic metrics but also considering other factors. It is necessary to establish other criteria according to strategic decisions. In the case of the university, these factors are the achievement of a workforce structure according to an ideal, and a proper service level, which would be defined by the strategic policies of university government also ensuring a proper quality in the offered services. This section proposes several scenarios for analyzing the effect that different strategic policies (such as those related to personnel, academic-type and the adopted university model) can have in the definition of the long-term capacity planning.

7.4.2.1 Personnel policies

The aim of personnel policies is to support and enable the construction of a university model, once defined a regulatory framework. Amongst them:

- Types of contracts and hiring and firing rules. There is the possibility that policies bound the workers' firing in some categories. For instance, workers within permanent tenure categories KP cannot be fired, opposed to workers within categories in subsets KT and KC.
- Promotions and retirements. Promotion ratios for workers while progressing in their career pathways are defined and the minimum age for workers retirement. Also, these policies can establish preferences for promoting internal workers over hiring new workers from labor market.
- Personnel budget and salaries. Bounding workforce size and structure, the personnel budget is a key driver for the progression of the university. The salaries for the academic staff in the different professional categories of the organization are determined here, addressing workers experience, capacity, and so on.

In regards of personnel policies, the present paper proposes two different analyses for discussion. The first one is related to contract policies addressing the impact of permitting or not firing workers in permanent categories within subset KC. In some universities, workers within these categories can be fired and this is the main difference with workers under permanent tenure contracts. The second is referred to favor the inside promotions against hiring new workers from the labor market. Doing this, the university expresses the idea of giving incentives to keep workers rather than leave the organization. This implies that the money spent in training workers can be recovered. Note that in practice, prioritizing promotions over foreign contracting means to activate model constraints (6.17) to (6.19) in the model (see Chapter 6).

The second type of analysis addresses the impact of considering different admissible promotional ratios and personnel budget. The achievement of preferable workforce composition and economic optimization may be challenged by constraining personnel promotions and economic resources, and this is going to be addressed in this analysis. In practice, this leads to vary over the time the model input data: the personnel budget B_t and the promotional ratios r_{uskt}. In particular, r_{uskt} and B_t have been considered constant, monotonically increasing or decreasing at different ratios throughout the considered time horizon (8 years). This yields different scenarios for analysis.

7.4.2.2 Academic policies

Academic policies refer, amongst other factors, to the determination of the number, location and type of studies that students can apply to, as well as to the design of the academic programs (number of years, subjects, etc.). All these factors affect greatly the demand (the number of students willing to be enrolled in the university). The requirements are also influenced by the educational model; for example, with a smaller number of students per group more lecturers are needed. The analyses aim to evaluate the impact of different trends in demand for the strategic planning. In practice, demand C_{ut} has been considered constant, monotonically decreased or increased by 1.5% per year.

7.4.2.3 University model

Bearing in mind different strategic visions can come up with different preferable workforce structures for universities. These strategic visions are referred to several factors, such as the generational replacement, personnel training, experience and capacity of workers, as well as others related to the vocation of the university to develop different kind of activities such as transfer of technology. In order to establish the preferable compositions, a poll on university management was addressed to a selected group of relevant academics. The results of the poll yielded three preferable compositions:

- **Model A**. The university is devoted to create knowledge that should be exported to other sectors. In this regard, one can define an academic structure based on the training of a huge volume of assistant professors and PhD students that cannot only provide enough people to build up future generations of permanent categories, but they also feed other universities and industry. This yields a workforce composition with an important share in personnel within KT. This subset presents high rotation rates and a reduced capacity; so, this envisages a workforce with higher number of workers and personnel hired from labor market than in other models.

- **Model B**. Attending to the generational replacement, it is necessary to develop mentoring programs for PhD students and assistant professor. These programs will favor the sustainability of the organization, ensuring a proper volume of workers to build up future permanent categories. Therefore, the university can retain the generated knowledge. As a difference with Model A, the aim of adopting this model is not to export knowledge to other sectors of society. So, the desired percentage of total workers in KT is sensibly lower than in Model A.

- **Model C**. By decreasing the share of workers in KT, this Model C proposes to configure a university workforce with high knowledge expertise. This vision could be adopted bearing in mind that experienced academic personnel can develop more tasks and with better performance than those carried out by less experienced workers. One potential drawback of this model is the advisable scarcity of young researchers in KT. Therefore, the generational replacement could be compromised and/or satisfied by just hiring workers from labor market.

The numerical results of the above-mentioned poll yielding all three university models are summarized in Table 7.9. The last column corresponds to the real situation in the UPC at the end of 2014. As it can be noted, for all university models, the desired share in categories within KC is almost the same. This is because workers usually aim to access to these categories are adding academic merits to finally gain a position in KP (permanent tenure pathway).

Given the contract policies for the UPC in the last years, the current workforce structure is closer to Model C than to the rest. It is remarkable the little amount of workers in KT (just 18% of total workers); thus, permanent contracts for experienced workers with high capacity are preferred.

Table 7.9: Proposed university models and current UPC structure

	Model A	Model B	Model C	UPC structure
Proportion of workers in KT	42%	34%	27%	18%
Proportion of workers in KC	17%	18%	16%	20%
Proportion of workers in KP	41%	48%	57%	62%

7.4.2.4 Summary of the proposed scenarios for study

All the proposed issues discussed in previous sections are translated into 27 different scenarios for optimization, which are summarized in Table 7.10 for the sake of clarity. The model has been executed 10 times for each scenario varying the parameters UP_{kt} and LP_{kt} (the preferable bounds for the proportion of workers that belong to the category k in the period t). Their respective results are discussed in Sections 7.4.3.1 to 7.4.3.3.

Table 7.10: Scenarios for analysis

Issues	Demand	Promotional ratio and personnel budget	Dismissals in KC	Priority to internal promotions	Scenario per university model
Layoffs and	Constant	Constant	Yes	No	1A, 1B, 1C
internal	Constant	Constant	No	No	2A, 2B, 2C
promotions	Constant	Constant	No	Yes	3A, 3B, 3C
Promotion	Constant	Increasing	Yes	No	4A, 4B, 4C
and	Constant	Decreasing	Yes	No	5A, 5B, 5C
personnel	Constant	Increasing	No	Yes	6A, 6B, 6C
budget	Constant	Decreasing	No	Yes	7A, 7B, 7C
Demand	Increasing	Constant	No	Yes	8A, 8B, 8C
	Decreasing	Constant	No	Yes	9A, 9B, 9C

7.4.3 Analysis of the results

The following sections discuss on the computational results obtained from solving the scenarios summarized in Table 7.10. With the aim of evaluating the performance, different metrics were defined and presented in Section 7.2.

7.4.3.1 Discussion on the impact of personnel policies concerning contracts

The aim of this section is to discuss the impact that personnel policies concerning contracts have in the definition of the strategic capacity planning of the university. In particular, the discussion presented here tries to answer in which ways the economic optimization and towards an ideal workforce composition of the university is influenced by the fact that personnel within KC –i.e. workers under a contractual pathway– can be fired or not. Moreover, discussion goes around the impact of prioritizing inside promotions against hiring new workers from the labor market. To this aim, the data used correspond to the first three computational scenarios and for each of the three university models under consideration A, B and C (see Table 7.10).

As noted in Table 7.10, the three computational Scenarios consider constant the demand, the workforce promotional ratio and the personnel budget over the considered horizon. They differ in the applied contractual personnel policies. In the first one, dismissals for workers within KC are permitted, but there is no policy favoring the promotion of the workers of the university over those from the labor market. On the second and third scenarios, firing workers belonging to KC is permitted. In the third one, workers already working at the university are prioritized over the rest. These three scenarios permit to evaluate the impact of these personnel policies, without the influence of other aspects.

Discussion on dismissals for personnel in KC The results for the first and second scenarios show that the possibility of firing workers within KC has very little influence in the achievement of a preferable workforce composition under the considered time horizon and for all the university models. This can be graphically observed in Figure 7.8, which plots the Average Global Discrepancy, $\overline{GD}_t$.

As noted in Figure 7.8, major changes in workforce composition are applied in the very first years. These changes mainly correspond to the decision of promoting and/or firing workers within KC to other categories within KC or KP. The adjustment of the workforce composition to the preferable one is quite slow in the subsequent years. This is due to the resiliencies against changes in permanent categories within KP. Workers in these categories cannot be fired and are already at the top of the workforce pyramid. So, their promotional ratio to other categories is low and the size of these categories mainly is reduced based on retirements.

Further, it is interesting to note the difference in the trend for the model A in comparison to those for models B and C. This is because, as indicated in Table 7.9, the initial composition of the university is very different from model A and, especially for categories in KP. The need of reducing the weight of KP in workforce takes more time than modulating the composition of KT and KC, since workers in KP normally leave the organization just in case of retirement.

The effect of having the possibility of firing or not workers in KC can be further analyzed in Table 7.11.

This table presents the decision variables Q_{hkut} (number of workers belonging to the unit u who access to the category h from the category k at time t), for all the categories and only in KC, w^{-}_{ukt} (number of workers fired at time t, in the unit u, category k) and w_{ukt} at the end of the horizon for scenarios 1 and 2. As can be noted, there is a great number of movements of workers (see variable Q_{hkut}) in the university along the horizon. At the end, though, the total number of workers for both scenarios is almost the same (1599 compared to 1597 for model A, 1533 compared to 1512 for model B and 1443 compared to 1430 for model C). This denotes that, despite the workers' firing within KC is not possible, it successes in determining almost the same workforce. However, such workforce is achieved differently for scenarios 1

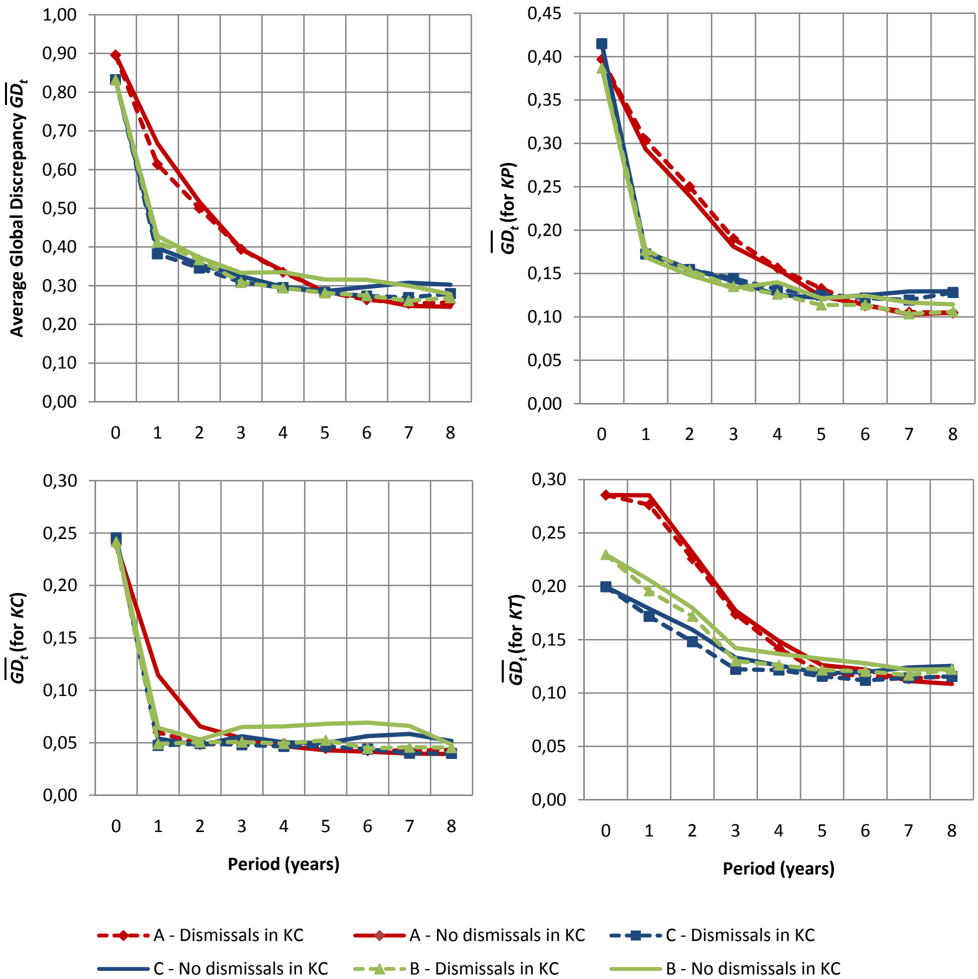


Figure 7.8: Average Global Discrepancy for models A, B and C, in scenarios 1 and 2 for the evaluation of personnel contractual policies.

Table 7.11: Assessment of promotions and fired personnel (during the time horizon) and final workforce size for models A, B and C in scenarios 1 and 2

Variable	Scenario 1 (Dismissals in KC permitted)			Scenario 2 (Dismissals in KC not permitted)		
	Model A	Model B	Model C	Model A	Model B	Model C
Movements $\sum_{\forall u,k,h,t} Q_{hkut}$	921	849	672	1039	961	841
Promotions in KC $\sum_{\forall u,k \in KC,h,t} Q_{hkut}$	164	189	132	311	309	314
Firings $\sum_{\forall u,k,t} w^{-}_{ukt}$	129	132	160	0	0	0
Workforce size at the end $\sum_{\forall u,k,t=8} w_{ukt}$	1599	1533	1443	1597	1512	1430

and 2. For scenario 1, between 17% to 22% of total movements correspond to workers in categories within KC (164 out 921 total movements for model A, 189 out 849 total movements for model B and 132 out 672 total movements for model C). The percentage of movements for workers in KC is higher in scenario 2, i.e. in the case firing workers in KC is forbidden, along with an increment in total movements for all university models. It can be seen that approximately all workers fired in scenario 1 (129 workers for model A, 132 for model B and 160 for model C) are promoted in scenario 2 (the sum of the 129 workers fired in scenario 1 plus the 164 promoted workers in KC approximately corresponds to the total number of workers promoted in scenario 2, 293 out 311).

At this point of the analysis, it must be underlined that the total number of workers determined by the model at the end of the horizon, 1599, is much lower than 1999 (the initial workforce). Computing the ratio between the initial workforce capacity (at time 0) and the demand, it results an excess of capacity around 32%. We should keep in mind that the presented analysis just considers teaching tasks for workers, leaving out other tasks such as those managerial and research-related. In order to consider these additional tasks in the present analysis a workforce oversized by around 15% is accepted. Taking this into account, the "effective excess of workforce capacity for the UPC at the beginning of the horizon is around 17%. On the other hand, the same ratio computed at the end of the horizon, it results around 16% for any university model (close to the aforementioned 15%). It is important to note that the results presented in all sections of this paper refer to the particular example of a university that needs a reduction in the workforce.

Going back to the impact assessment of firing or not workers in KC, Figure 7.9 illustrates the adjustment in workforce composition throughout the horizon, for one of the 42 units in the university, in which the optimization algorithm determines firing workers in categories within KC (when permitted). The department under consideration, one of the biggest units in the university, is initially composed by 105 workers. Its structure can be viewed as a representative example of the average composition of a unit. At the end of the horizon, the number of workers is 73 regardless dismissals for workers within KC are permitted or not. For both cases, the number of workers within KT is increased from 13 to 23, and under KP is decreased from 61 to 41 (or 40 if dismissals are allowed). With these adjustments in workforce composition, the workforce pyramid becomes nearer to the preferable one for the university model A than for models B and C in this case. The promotions of workers in categories within KC are indicated by right arrows ($\rightarrow$) in Figure 7.9. As it can be observed, most of these promotions are firstly motivated by the need of moving workers from the category $KC1$ to others. Indeed, the preferable weight of category $KC1$ is 0% according to the preferable workforce composition (e.g. this category could be representative of a closed category defined by new laws). In the case dismissals are not permitted, the solution includes promoting 18 out of the 22 workers initially in the category $KC1$. This number of workers promoted from $KC1$ decreases down to 9 in case dismissals are allowed. For optimization purposes, the category with the best capacity/salary is $KC3$; that is why many workers are promoted to this category instead of remaining in others within KC.

Discussion around the priority on internal promotions To evaluate the impact of prioritizing internal promotions over hiring workers from the labor market, scenarios 2 and 3 are compared (see Table 7.10). The obtained computational results are summarized in Table 7.12.

As can be seen, the number of internal promotions is much larger in scenario 3 than in scenario 2. It results in a reduction in the number of new workers hired from the labor market (e.g. 1958 external hiring for model A in scenario 3 out of 2306 hiring for model A in scenario 2). The final composition of the university workforce (indicated by the final number

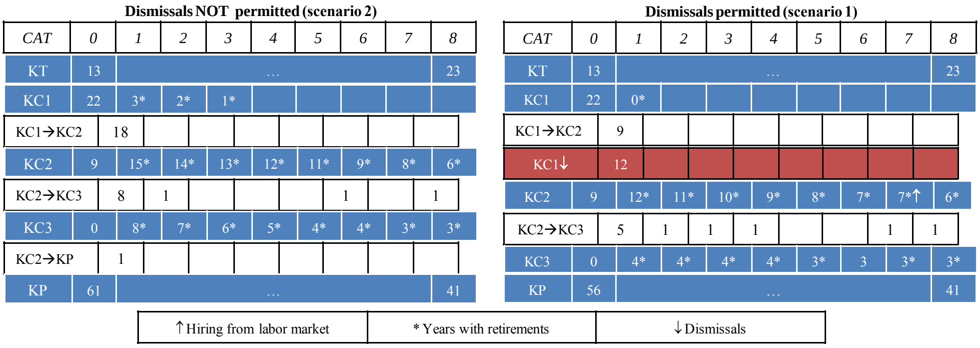


Figure 7.9: Workforce modulation throughout the considered time horizon for one of the 42 units of the university and for scenarios 2 and 1.

Table 7.12: Impact assessment of internal promotions prioritized for models A, B and C, in Scenarios 2 and 3

Variable	Scenario 2 (internal promotions NOT prioritized)			Scenario3 (internal promotions prioritized)		
	Model A	Model B	Model C	Model A	Model B	Model C
Movements $\sum_{\forall u,k,h,t} Q_{hkut}$	1039	961	841	1521	1447	1412
Hirings: $\sum_{\forall u,k,t} w^{+}_{ukt}$	2306	2034	1806	1958	1670	1380
Workforce size at the end $\sum_{\forall u,k,t=8} w_{ukt}$	1597	1512	1430	1594	1531	1436
$\overline{GD}_{t=0} - \overline{GD}_{t=8}$	0.650	0.553	0.530	0.644	0.578	0.531
$\sum_{t=1}^{T} Z_t$ (M€)	1,010.5	1,001.7	986.5	1,011.1	1,003.1	990.4

of workers) and the reduction achieved in Average Global Discrepancy are almost the same for both scenarios. The last row in Table 7.12 presents the total personnel management cost, according to the definition of metric Z_t (see equation (7.4)). It is interesting to note that by prioritizing internal promotions, i.e. investing in personnel training, the university does not incur in larger costs related to personnel management (note the marginal cost difference between scenarios 2 and 3 in Table 7.12).

7.4.3.2 Discussion around the impact of personnel policies in regard of promotional ratios and personnel budget

This section aims to evaluate the impact that different promotion ratios and personnel budgets have in the determination of the strategic capacity planning. To do that, personnel budget B_t and promotion ratio r_{uskt} have been considered monotonically increased or decreased at determined ratios throughout the considered time horizon, yielding scenarios 4 to 7. For analysis purposes, results are compared to scenarios 1 and 3, which are characterized by concerning invariable the above mentioned factors. These analyses are discussed in the following subsections.

Discussion around workers promotional ratios Workers promotional ratio can have great impact in the economic optimization and in the workforce management towards a preferable composition of the university. A lower promotional ratio over the time can affect internal mobility of workers, thus forcing the university to adopt other mechanisms to be able to achieve the preferable workforce composition. In this regard, Table 7.13 provides a first insight on the impact of different trends in promotional ratios. This table compares the results obtained from solving the proposed optimization model for scenario 1, in which inputs B_t and r_{uskt} are invariable over the time, with those obtained for scenarios 4 and 5. scenario number 4 is characterized by the fact that the budget B_t is monotonically increased by 1% yearly and the threshold promotion ratio r_{uskt} is, as well, monotonically increased by 5% respect to the previous year. On the other way round, scenario 5 proposes a steady decrement for the budget of 1% per year, and a decrement for r_{uskt} of 5% respect to the previous year. The results for these two scenarios are presented in Table 7.13 as relative to results for scenario 1.

Table 7.13: Impact assessment of considering different promotional ratios and personnel budget. Dismissals for workers in KC are permitted. Budget is reduced and increased by 1% per year, and promotion ratio r_{uskt} monotonically varies by +5% per year (scenario 4) and -5% per year (scenario 5)

Variable	Scenario1 (constant B_t and r_{uskt})			Scenario 4 (increasing B_t and r_{uskt})			Scenario 5 (decreasing B_t and r_{uskt})		
	Model A	Model B	Model C	Model A	Model B	Model C	Model A	Model B	Model C
Movements $\sum_{\forall u,k,h,t} Q_{hkut}$	921	849	672	+0.3%	+3.7%	+1.2%	-9.5%	-11.4%	-12.8%
Hirings $\sum_{\forall u,k,t} w^{+}_{ukt}$	2445	2149	1945	-0.1%	+0.3%	+0.9%	-0.1%	+0.3%	-0.3%
Firings $\sum_{\forall u,k,t} w^{-}_{ukt}$	129	132	160	-0.7%	-0.6%	+1.5%	+11.6%	+8.7%	+11.3%
Workforce size at the end $\sum_{\forall u,k,t=8} w_{ukt}$	1599	1533	1443	-0.4%	+0.2%	-0.7%	-0.8%	-0.9%	-2.1%
$\overline{GD}_0 - \overline{GD}_8$	0.639	0.563	0.553	+0.6%	+1.1%	+1.2%	+0.9%	-2.3%	+1.9%
$\sum_{t=1}^{T} Z_t$ (M€)	1,005.5	1,001.3	1,003.8	+0.1%	-1.9%	+0.1%	-0.3%	-2.4%	-0.4%

As can be seen in Table 7.13, the proposed decreasing trend for promotional ratio r_{uskt} in scenario 5 has great impact in the strategic planning, since it greatly constrains workers promotion; the magnitude for the total decision variables Q_{hkut} become reduced between 9.5% and 12.8%, depending on the university model. This reduction in the number of workers promoted during the horizon is accompanied by an increment in the number of people fired. Thus, the possibility of firing workers becomes a source of flexibility towards achieving the preferable workforce composition in this case. On the other hand, the impact in dismissals when an increasing r_{uskt} is considered has low influence (see results for scenario 4 in Table 7.13).

Figure 7.10 complements the numeric evaluation presented in Table 7.13. It presents the deviation in the total number of promotions, Q_{hkut}, the number of hiring decisions w^+_{ukt}, and for dismissals for workers in KC, w^-_{ukt}, compared to scenario 1 and for different increasing and decreasing yearly variations in r_{uskt} of up to 5%. Note that positive temporal trends for r_{uskt} correspond to scenario 4, while negative ones correspond to scenario 5. Here, it can be clearly identified a correlation between the considered trend (either positive or negative) for r_{uskt} and the number of promotions. However, such correlation is, again, not so clear for dismissals in case of considering different trends for positive r_{uskt}. We conclude that dismissals are not influenced by the considered positive promotional ratios under the conditions of the experiment.

The above analysis concerns dismissals for workers in KC, as it refers to scenarios 1, 4 and 5. The same discussion can be proposed now considering scenarios 3, 6 and 7, so forbidding workers dismissals (see Table 7.10). The budget is reduced or augmented by 1% per year, and the promotion ratio r_{uskt} monotonically varies by +5% per year (scenario 6) or -5% per year (scenario 7). The obtained results for scenarios 6 and 7 are summarized in Table 7.14, which, similar to Table 7.13, are now referred as relative to those obtained for scenario 3.

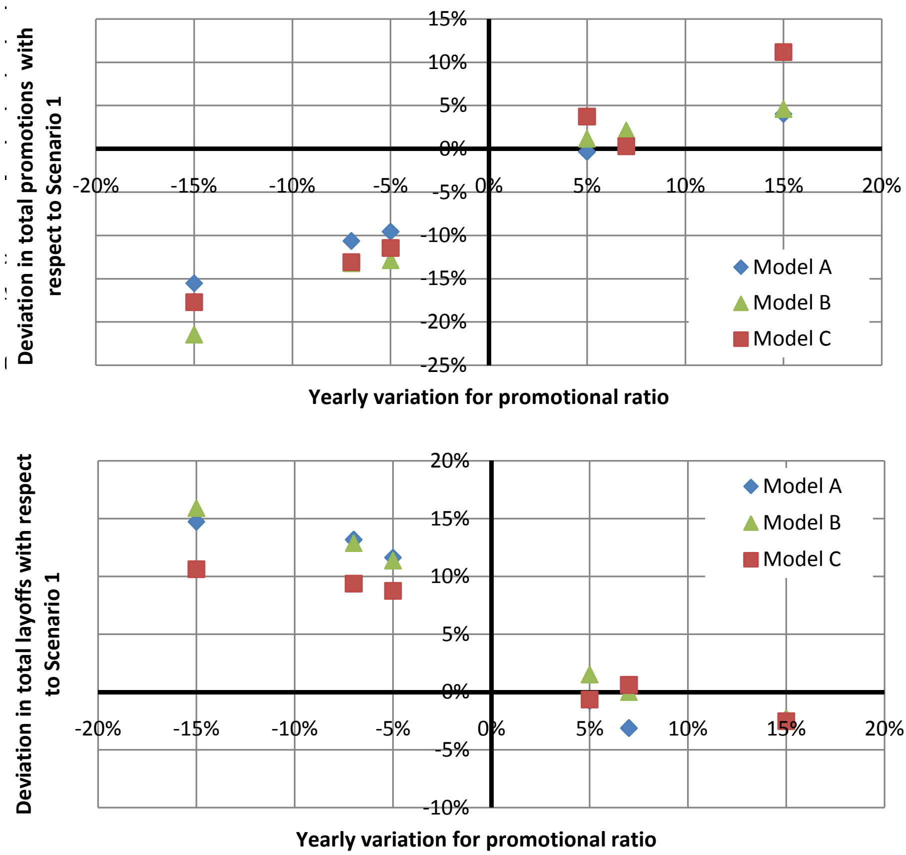


Figure 7.10: Relationship between internal promotions and dismissals for workers in KC with admissible promotional ratio.

Table 7.14: Impact assessment of considering different promotional ratios and personnel budget. Dismissals for workers in KC are not permitted. Budget is reduced and augmented by 1% per year, and promotion ratio r_{uskt} monotonically varies by +5% per year (scenario 6) and -5% per year (scenario 7).

Variable	Scenario 3 (constant B_t and r_{uskt})			Scenario 6 (increasing B_t and r_{uskt})			Scenario 7 (decreasing B_t and r_{uskt})		
	Model A	Model B	Model C	Model A	Model B	Model C	Model A	Model B	Model C
Movements $\sum_{\forall u,k,h,t} Q_{hkut}$	1521	1447	1412	+5.8%	+3.7%	+3.9%	-11.6%	-12.3%	-15.2%
Hirings $\sum_{\forall u,k,t} w^+_{ukt}$	1958	1670	1380	+0.1%	+2.5%	-0.6%	+0.8%	+0.8%	+2.9%
Firings $\sum_{\forall u,k,t} w^-_{ukt}$	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Workforce size at the end $\sum_{\forall u,k,t=8} w_{ukt}$	1594	1531	1436	+0.5%	+0.6%	+0.4%	-0.5%	-0.3%	-0.3%
$\overline{GD}_{t=0} - \overline{GD}_{t=8}$	0.644	0.578	0.531	+1.1%	-0.7%	+3.4%	-0.9%	0.0%	+2.4%
$\sum_{t=1}^{T} Z_t$ (M€)	1,011.1	1,003.1	990.4	+0.1%	+0.1%	-0.2%	-0.4%	-0.4%	-0.6%

Considering together the data in Tables 7.13 and 7.14, it can be concluded that the application of a sustained decrement in the promotional ratio is translated in a reduction in the number of internal promotions, regardless dismissals for workers in KC are permitted or not. This reduction in the number of promotions is sensibly higher in the case of dismissals for workers in KC are forbidden (compare results for scenarios 5 and 7 in Tables 7.13 and 7.14, respectively).

Discussion around personnel budget In the experiments carried out in Section 7.4.3.2, personnel budget has been considered constant, monotonically increasing or decreasing. However, this variability did not affect the obtained results because the resultant personnel costs were sensibly lower than the available budget. This can be observed in Figure 7.11, in the subplot below, comparing the available budget for scenario 7 (university model A) with the resultant personnel costs (red line). Regardless the decreasing trend for budget, economic resources, needed to optimize the strategic capacity planning, were much lower than available budget. In addition, if only the economic criteria are just considered to optimize the strategic planning for the university (blue line), the incurred personnel costs are much lower than those obtained taking also into account the achievement of the preferable workforce composition (red line). At the end, the area comprised between the blue and the green line bounds the set of feasible solutions for the problem.

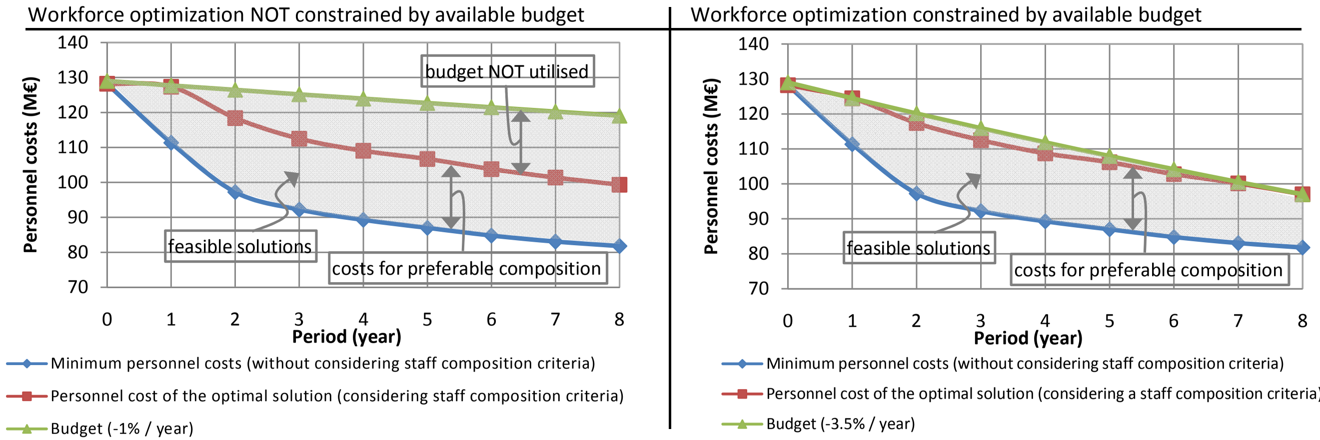


Figure 7.11: Personnel costs and budget for scenario 7 under different budget decreasing temporal trends.

In Figure 7.11, in the subplot below, budget is decreased by 1% yearly, but if it is decreased in 3.5% yearly, then personnel costs for strategic planning optimization can become actually constrained by the available budget, as Figure 7.11, in the subplot above, shows. Under such scenario, the achievement of the preferable workforce composition can be compromised. This can be observed in Table 7.15, which presents results for university models A, B and C in scenario 7, for two different budget temporal trends. Results for the higher reduction in personnel budget are referred as relative to those obtained for small budget reductions.

Table 7.15: Impact assessment of considering different trends for personnel budget. Promotional ratio decreases by 5% yearly

Variable	Scenario 7. Small reduction for B_t (-1% yearly). Optimization not constrained by available budget			Scenario 7'. High reduction for B_t (-3.5% yearly). Optimization constrained by available budget		
	Model A	Model B	Model C	Model A	Model B	Model C
Workforce size at the end $\sum_{\forall u,k,t=8} w_{ukt}$	1585	1527	1431	-4.0%	-3.7%	-3.5%
KT Workforce size at the end $\sum_{\forall u,k \in KT,t=8} w_{ukt}$	538	442	323	-13.5%	-18.2%	-13.3%
KC Workforce size at the end $\sum_{\forall u,k \in KC,t=8} w_{ukt}$	249	264	216	-9.0%	-6.0%	-6.0%
KP Workforce size at the end $\sum_{\forall u,k \in KP,t=8} w_{ukt}$	798	821	892	+4.7%	+2.1%	+2.6%
$\overline{GD}_{t=0} - \overline{GD}_{t=8}$	0.637	0.578	0.544	-21.0%	-19.8%	-10.5%
$\sum_{t=1}^{T} Z_t$ (M€)	1,006.5	998.8	984.6	-1.0%	+0.07%	-0.5%

From Table 7.15, it is clear that the number of workers in the university is reduced when personnel budget constrains strategic planning optimization and the achievement of a preferable workforce composition results clearly sacrificed (the obtained reductions in Average Global Discrepancy become lower). The ratio capacity/salary for workers within KP is the highest ratio amongst all categories in this university system. Thus, in case of higher reductions in personnel budget, the plan tries to supply the demand with workers in KP whilst the size of the rest of the categories is reduced.

7.4.3.3 Discussion around the impact of academic policies: demand

The impact assessment in strategic capacity planning of considering different trends in demand is based on comparing computational results for scenarios 3, 8 and 9, according to Table 7.10. These results are offered in Table 7.16. In these scenarios only demand varies in time, leaving the budget and admissible promotional ratios unalterable over time. Doing this, the variability in the obtained results can be directly associated to the variability in demand. Results for scenarios 8 and 9 are relative to those obtained for scenario 3.

Compared to the initial number of workers for the university (1999 workers), at the end of the time horizon the sum of the variables $w_{uk,8}$ becomes reduced for all university models and scenarios. This reduction in workforce size for all cases shows the current oversizing of the university workforce according to the preferable structure models.

A first insight to the computational results in Table 7.16 also clearly depicts that all the shown variables for model A present higher values than those for the rest of the models. This fact yields a higher number of promotions, workers hiring from the labor market, workers at the end of the time horizon and the Average Global Discrepancy variation (see results for scenario 3). This happens because the composition considering model A is the most different from the current composition of the university.

Addressing now the differences between scenarios, it is interesting to observe that the obtained number of workers at the end of the horizon for any model is also coherent with the considered temporal trends in demand. For instance, given the model A the number of workers at the end of the horizon is increased by 7.6% in scenario 8, and decreased down by around 6.9% for scenario 9. These results are those envisaged applying the idea that the size of university workforce should be adapted to the volume of activity carried out.

Table 7.16: Impact assessment of required capacity in scenarios 3, 8 and 9. Dismissals for workers in KC are not permitted. Demand is increased monotonically by 1% per year (scenario 8) and reduced monotonically by -1% per year (scenario 9).

Variable	Scenario 3 (constant demand)			Scenario 8 (increasing demand)			Scenario 9 (decreasing demand)		
	Model A	Model B	Model C	Model A	Model B	Model C	Model A	Model B	Model C
Movements $\sum_{\forall u,k,h,t} Q_{hkut}$	1521	1447	1412	+7.4%	+7.6%	+7.7%	-9.0%	-6.2%	-8.5%
Hirings $\sum_{\forall u,k,t} w^+_{ukt}$	1958	1670	1380	+3.0%	+8.8%	+1.8%	-6.2%	-2.1%	-5.1%
Workforce size at the end $\sum_{\forall u,k,t=8} w_{ukt}$	1594	1531	1436	+7.6%	+9.4%	+8.2%	-6.9%	-7.1%	-8.3%
$\overline{GD}_{t=0} - \overline{GD}_{t=8}$	0.644	0.578	0.531	-1.1%	+4.0%	-0.6%	-0.1%	-3.0%	-4.9%
$\sum_{t=1}^{T} Z_t$ (M€)	1,011.1	1,003.1	990.4	+4.7%	+2.1%	+3.5%	-2.3%	-2.6%	-3.9%

7.5 Study III. Specific evaluation on the impact of strategic decisions around personnel promotions

This section presents the required data and the obtained results for the study case III. According to the objectives of the study case, this third study case specifically addresses the relationship between economic resources to help workers' promotion and the preferable staff composition pursued in strategic staff planning for universities. The scope and model's formulation for the following analyses were presented in Chapters 5 and 6 in the corresponding sections.

7.5.1 Data

In this third study case, in spite of considering all 42 units or departments of the UPC, analysis will be performed around just three departments. These departments hold the average capacity for all departments of the UPC. Further, their initial workforce composition matches with ideal or preferable different university models A, B and C, as previously introduced for the study case II, in Table 7.9. The reduced size of the problem facilitates the model evaluation in this study case. Also, it is important to note that since no strategic decisions related to interdepartmental personnel transfer are considered, departments are viewed by the optimization problem as independent units for optimization. This enables us to reduce the analysis around just the three equivalent departments, instead of modeling all 42 departments of the UPC. Besides, the initial compositions of the three equivalent departments have been resembled to three preferable compositions derived from a survey –which is addressed to experienced academics–. This permits to evaluate the obtained results of the optimization problem under different initial workforce compositions.

These assumptions do not prevent us from adopting most of the data presented for study cases I and II in this third study case. Indeed, just note that the required annual capacity for each of the three departments is not any of the presented in Table B.3, in the Appendix B, but around 4000 points/year. The demand is around 3660 points/year. The annual considered budget for each of the three departments is 3.1 M.

The number of workers at the beginning of the time horizon, composing each of the 3 departments for preferable compositions A, B and C are presented in Table 7.17.

The value θ_k, which includes additional expenditures for personnel promotions, is assumed to be around 10% of the salary of a worker in a category

Table 7.17: Initial composition for each of the three departments resembling to university models A, B and C

Cat.	Model A	Model B	Model C
$KT1$	2	2	1
$KT2$	2	2	2
$KT3$	2	2	1
$KT4$	3	2	2
$KT5$	3	2	2
$KT6$	2	2	1
$KT7$	3	2	1
$KT8$	2	2	1
$KC1$	0	0	0
$KC2$	5	6	4
$KP1$	0	0	0
$KP2$	0	0	0
$KC3$	3	2	3
$KP3$	16	16	19
$KP4$	3	6	7

k, $\forall t$. For the particular case of the UPC, the relationship between $c_{kt} \cdot \theta_k$, $\forall t$ and category is represented in Figure 7.12. As can be noted, additional resources for training, research, dissemination activities and others, all helping workers to achieve required merits for promoting, are proportional to worker's salary (so function of the category). This relationship is valid for all time periods in the time horizon, since the salary c_{kt} is considered constant. The relationship between promotion expenditures and category results totally inversed in Figure 7.13, referring the expenditures to workers' capacity. Addressing the high capacity of skilled workers, and despite their high salary, relative expenditures for promotion are lower than for temporary workers.

Finally, just underline that the admissible promotional ratios in Table B.5, in the Appendix B, are not applied in this study case, since promotional ratios are precisely a decision variable for this model. However, the promotional ratios to be determined by the model are bounded by r_{ukt_min} and r_{ukt_max}. This way, admissible promotional ratios for temporary categories are bounded by $r_{ukt\_min} = 0.4$ and $r_{ukt\_max} = 1$. For permanent contractual categories, the adopted limits are $r_{ukt\_min} = 0.4$ and $r_{ukt\_max} = 0.8$. Finally, for permanent public / tenure categories, promotional ratios results are bounded by $r_{ukt\_min} = 0.2$ and $r_{ukt\_max} = 0.8$. These values have been derived from historic data for the particular case of the UPC [UPC 2014]. Finally, r_{ukt} can increase or decrease up to 10% yearly, so $|\Delta r| = |r_{ukt} - r_{uk,t-1}| \leq 0.1$.

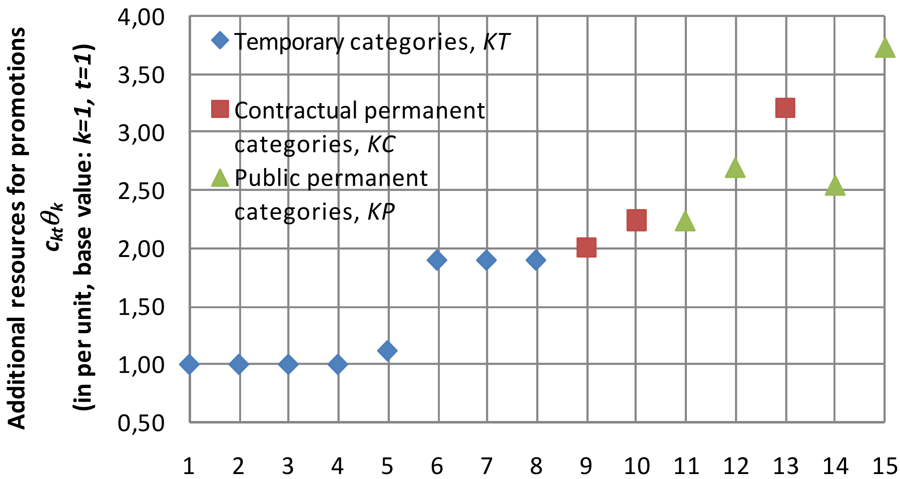


Figure 7.12: Relationship between assumed additional resources for encouraging worker's promotions and category. Values are expressed as relative to assumed $c_{1,1} \cdot \theta_1$, so for category 1.

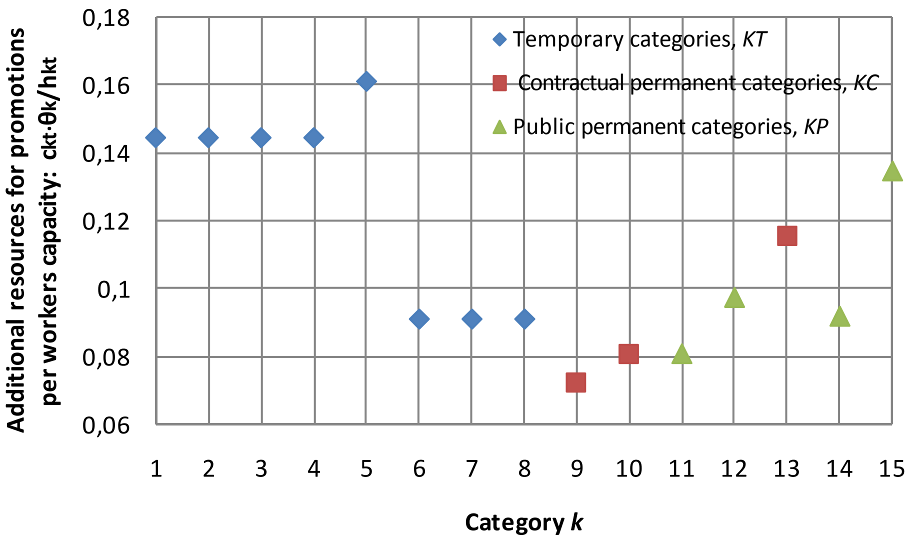


Figure 7.13: Relationship between assumed additional resources for encouraging worker's promotions and category, expressed as relative to workers' capacity. This relationship is valid for all time periods, since the salaries c_{kt} and h_{kt} do not vary over time.

7.5.2 University models and scenarios for analysis

The university models and computational scenarios considered for study are presented in the following.

7.5.2.1 University models

The university models correspond to the same three preferable compositions previously presented for the study case II. As can be noted in Table 7.9, the share of personnel within KT progressively decreases from model A to model C, in charge of progressively increasing the share in KP. According to the results of the survey, the share of personnel within KC remains almost unalterable for all university models. This reflects the preference of experienced workers to follow the public / tenure pathway rather than the contractual pathway.

7.5.2.2 Scenarios for evaluation

This section presents several scenarios for analysis, which are mainly characterized by considering different initial and preferable compositions as well as different temporal trends in demand and available budget. This yields a list of scenarios depicting different academic and personnel policies. The list of scenarios for preferable composition is succinctly presented in Table 7.18. The list of scenarios will be complemented with those for models B and C in Tables 7.19 and 7.20.

Table 7.18 presents all computational scenarios considering the university model A as the preferable workforce composition. Some scenarios propose a sort of steady state situations, in which neither demand nor available budget vary over time, and even preferable composition matches with the initial one. Their results in such circumstances can be intended as references or base cases. On the other hand, scenarios such as number 5, 12 and 19 add difficult to the determination of staff planning since demand is progressively increased over time, while available budget remains constant. For such scenarios it will be very interesting to evaluate in what extent the objective of adopting preferable compositions (and personnel promotions) are sacrificed to prioritize economic resources. In this regard, scenarios 7, 14, 21 show totally opposed temporal trends in demand (increasing) and budget (decreasing). Finally, some additional scenarios could be those characterized by considering decreasing or constant demand with an increasing trend for budget. These are left out of discussion, since an excessive budget will not have a great influence in the strategic capacity planning for the university.

Table 7.18: List of scenarios for analysis. The preferable composition is according to that specified in model A

Scenario	Initial composition	Preferable composition	Demand	Budget
1	A	A	Constant	Constant
2	A	A	Constant	Decreasing
3	A	A	Decreasing	Constant
4	A	A	Decreasing	Decreasing
5	A	A	Increasing	Constant
6	A	A	Increasing	Increasing
7	A	A	Increasing	Decreasing
8	B	A	Constant	Constant
9	B	A	Constant	Decreasing
10	B	A	Decreasing	Constant
11	B	A	Decreasing	Decreasing
12	B	A	Increasing	Constant
13	B	A	Increasing	Increasing
14	B	A	Increasing	Decreasing
15	C	A	Constant	Constant
16	C	A	Constant	Decreasing
17	C	A	Decreasing	Constant
18	C	A	Decreasing	Decreasing
19	C	A	Increasing	Constant
20	C	A	Increasing	Increasing
21	C	A	Increasing	Decreasing

Table 7.19: List of scenarios for analysis. The preferable composition is according to that specified in model B

Scenario	Initial composition	Preferable composition	Demand	Budget
22	A	B	Constant	Constant
23	A	B	Constant	Decreasing
24	A	B	Decreasing	Constant
25	A	B	Decreasing	Decreasing
26	A	B	Increasing	Constant
27	A	B	Increasing	Increasing
28	A	B	Increasing	Decreasing
29	B	B	Constant	Constant
30	B	B	Constant	Decreasing
31	B	B	Decreasing	Constant
32	B	B	Decreasing	Decreasing
33	B	B	Increasing	Constant
34	B	B	Increasing	Increasing
35	B	B	Increasing	Decreasing
36	C	B	Constant	Constant
37	C	B	Constant	Decreasing
38	C	B	Decreasing	Constant
39	C	B	Decreasing	Decreasing
40	C	B	Increasing	Constant
41	C	B	Increasing	Increasing
42	C	B	Increasing	Decreasing

Table 7.20: List of scenarios for analysis. The preferable composition is according to that specified in model C

Scenario	Initial composition	Preferable composition	Demand	Budget
43	A	C	Constant	Constant
44	A	C	Constant	Decreasing
45	A	C	Decreasing	Constant
46	A	C	Decreasing	Decreasing
47	A	C	Increasing	Constant
48	A	C	Increasing	Increasing
49	A	C	Increasing	Decreasing
50	B	C	Constant	Constant
51	B	C	Constant	Decreasing
52	B	C	Decreasing	Constant
53	B	C	Decreasing	Decreasing
54	B	C	Increasing	Constant
55	B	C	Increasing	Increasing
56	B	C	Increasing	Decreasing
57	C	C	Constant	Constant
58	C	C	Constant	Decreasing
59	C	C	Decreasing	Constant
60	C	C	Decreasing	Decreasing
61	C	C	Increasing	Constant
62	C	C	Increasing	Increasing
63	C	C	Increasing	Decreasing

7.5.3 Analysis on strategic decisions around personnel promotions

This section discusses around the computational results obtained in each of the considered scenarios. The results are evaluated through metrics to test the adjustment of the achieved workforce composition to the preferable one, as well as the promotional ratio and the associated additional expenditures for workers' promotion. The following sections discusses around these number in a succinct and organized manner.

7.5.3.1 Evaluation of workforce composition

Once presented the numerical metrics for evaluation, this section evaluates the results for all 63 computational scenarios (see Tables 7.18 to 7.20) in terms of the adjustment of workforce composition to the preferable one, i.e. using Global Discrepancy GD_{ut}.

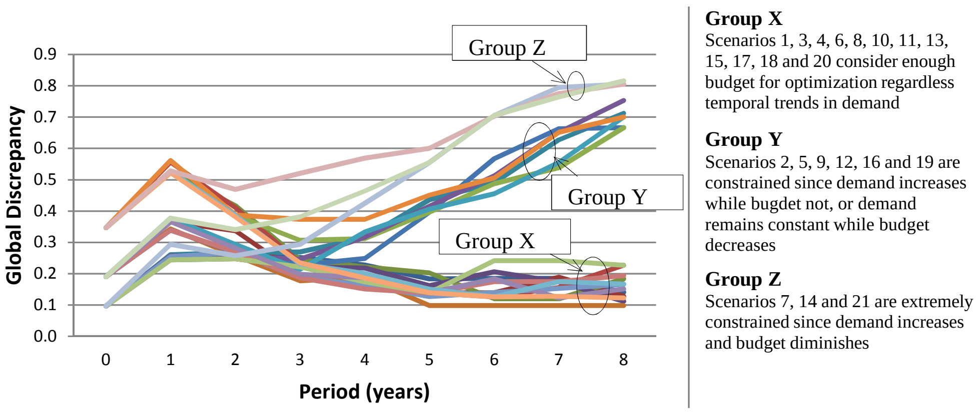


Figure 7.14: Global discrepancy for scenarios 1 to 21, university model A for the preferable composition, considering different initial compositions as well as different temporal trends in budget and demand.

Scenarios 1 to 21 can be organized in three main groups, addressing the evolution of global discrepancy. Those scenarios steading global discrepancy at the end of the considered time horizon are included in the Group X. In such scenarios there is enough budget for optimization regardless temporal trends in demand. For instance, in the scenario 1, neither available budget nor demand vary over time, yielding enough economic resources for workforce optimization, in regard of the achievement of a preferable structure. Another example for Group X is the scenario 13, considering increasing temporal trends (around 1.5% per year) for both demand and available budget. Under these circumstances, the university also has enough economic resources, thus adjusting workforce composition to a preferable one.

Scenarios not included in Group X have been classified in Groups Y and Z. Those included in Group Y are characterized by a progressive decrement in economic resources with respect to demand, which constrains the achievement of a preferable composition. This yields a progressive increment in global discrepancy, which is directly related to the aforementioned progressive decrement in economic resources. For instance, scenario 2 concerns a linear and yearly decrement of about 1.5% in budget, while demand remains constant. Thus, the achievement of a preferable composition is progressively sacrificed to prioritize economic resources to maintain the necessary personnel for teaching. Further exacerbating this progressive mismatch between available budget and demand, the results for scenarios in Group Z depict even higher global discrepancies.

Finally, just note that the considered initial composition for all scenarios in Figure 7.14 can be identified by noting the initial global discrepancies (year 0). As can be observed, for those scenarios considering an initial workforce composition which can be resembled to that for university model A, the initial global discrepancy is minimum (around 0.1). Similarly, for those concerning an initial composition most resembling to model B, the initial global discrepancy is sensibly higher (around 0.2). Finally, major initial global discrepancies are intended for those scenarios concerning initial composition similar to university model C.

Similar trends in global discrepancy are observed for scenarios pursuing preferable workforce composition for university models B and C, as depicted in Figure 7.15 and Figure 7.16, respectively. Note that analogously to the classification in the Groups X, Y and Z of scenarios with university model A, scenarios pursuing university model B are classified in Groups R, S and T, and scenarios pursuing university model C are divided into Groups U, V and W.

Deeping further in the evaluation of the obtained results, Figure 7.17 contributes to the understanding of the obtained global discrepancies. Again, and for the sake of clarity, results are aggregated in terms of the above identified groups of scenarios. In particular, now analysis goes around the comparison between the obtained workforce pyramids at the end of the considered time horizon and the preferable compositions pursuing university models A, B and C.

As can be observed in Figure 7.17, the achieved workforce pyramids for Groups X, R and U are quite similar to their corresponding reference models, A, B and C. As a reminder, scenarios in Groups X, R and U are those

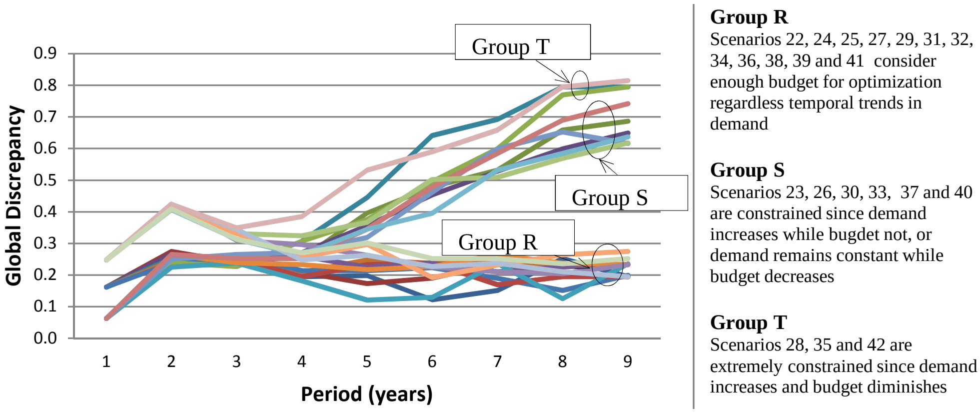


Figure 7.15: Global discrepancy for scenarios 22 to 42, in which the preferable composition is university model B, considering different initial compositions as well as different temporal trends in budget and demand.

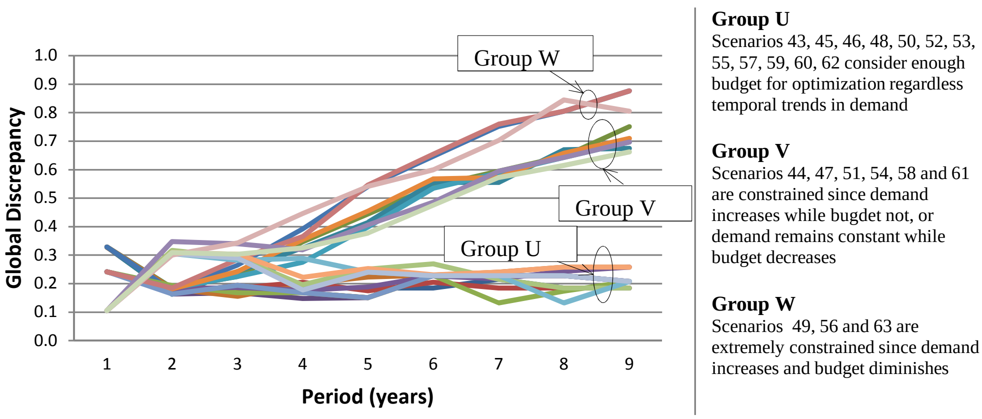


Figure 7.16: Global discrepancy for scenarios 43 to 63, in which the preferable composition is university model C, considering different initial compositions as well as different temporal trends in budget and demand.

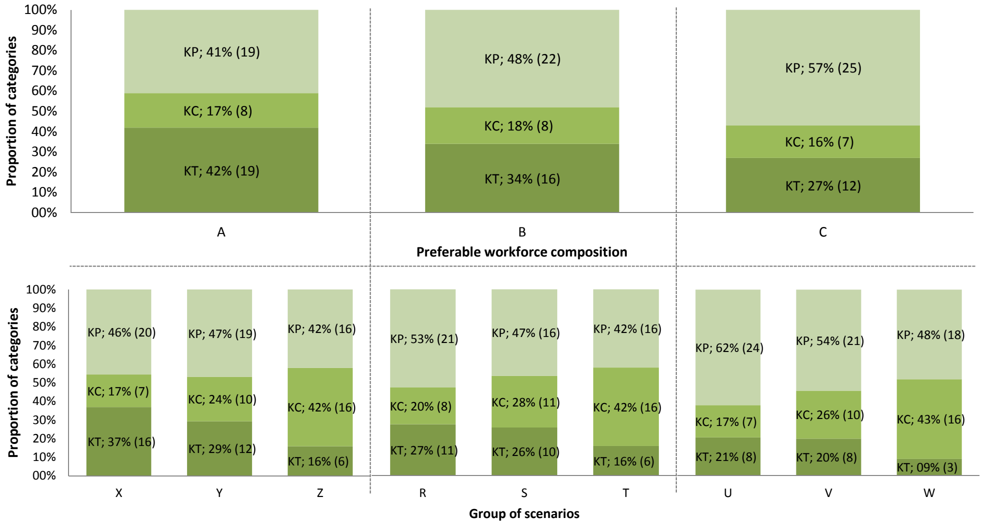


Figure 7.17: Comparison between the achieved workforce composition per group of scenarios and preferable workforce structures, while pursuing university models A, B and C. The initial number of workers adopting university models A, B and C are included in parenthesis.

characterized by concerning enough economic resources regardless temporal trends in demand. For these groups of scenarios, it is interesting to note that the achieved workforce pyramids at the end of the time horizon do not match exactly with preferred compositions. For instance, despite the fact that the initial workforce compositions in scenarios within Group X most resemble to that concerning university model A, the optimization problem tends to slightly modify staff composition increasing the weight of categories within KP, at the sacrifice of the capacity hold by categories within KT. The same behavior can be observed for the pairs Group R - university model B and Group U - university model C. These deviations are result of the proposed optimization model for staff planning, which permits deviating categories' size up to $\pm 25\%$ from their preferable weight without penalization. Thus, the solution uses this flexibility to slightly increase the proportion of high skilled workers within KP, as their cost per capacity unit is lower than for personnel within KT.

Another interesting conclusion, comparing the achieved workforce structures in Groups X to Z, R to T and U to W, is that the more constrained the budget with respect to demand is, the more the weight for categories within KC is. For instance, scenarios within Group Z are quite constrained in budget with respect to demand profiles, and the proportion of expensive personnel –in terms of cost per working capacity unit– is greatly reduced overweighting categories within KC, which hold low cost personnel in relation to their working capacity. The deviations between the weight of categories within KC and KT from preferable weights are the main contributors to global discrepancy, as depicted in Figures 7.14 to 7.16.

7.5.3.2 Discussion around promotional ratios

Section 7.5.3.1 evaluated the obtained results for each of the considered 63 computational scenarios in terms of the adjustment of workforce composition to a preferable one. Such adjustment or modulation of workforce composition is enabled and governed by policies on personnel promotions. Accordingly, this last section discusses how policies on personnel promotions should be adapted to the particularities of each scenario, so as to achieve an optimized staff planning.

In this regard, Figure 7.18 depicts the average promotional ratio for personnel in KT and KC, under the conditions of all computational scenarios and for the considered time horizon. As can be observed, the average promotional ratio for categories within KT progressively decreases from those obtained in scenarios within Groups X, R and U, to those achieved in scenarios in Groups Z, T and W, respectively. Conversely, promotional ratios for personnel within KC slightly increase. These trends are aligned to the conclusions achieved in Section 7.5.3.1: the number of workers building up personnel within KC increases combined with a reduction in personnel within temporary categories KT, under scenarios constrained in economic resources with respect to demand.

In addition, it is important to note that for all considered scenarios –economically constrained or not with respect to demand–, the optimal staff planning determines promotional ratios for both KT and KC higher than the defined minimum levels r_{ukt_min}. This points that additional expenditures (training, dissemination activities and others) for personnel promotion are economically justified.

The above decrement in promotional ratio for KT greatly affects the total number of promotions for the time horizon, as depicted in Figure 7.19. Indeed, the number of promotions decreases from nearly 120 (in average, for scenarios in Group X) to 80 (in average, for scenarios in Group Z), so around 40% less. Lower decrements, around 30%, can be observed comparing the number of promotions for scenarios in Group R with Group T; and around 28%, comparing scenarios in Group U with Group W.

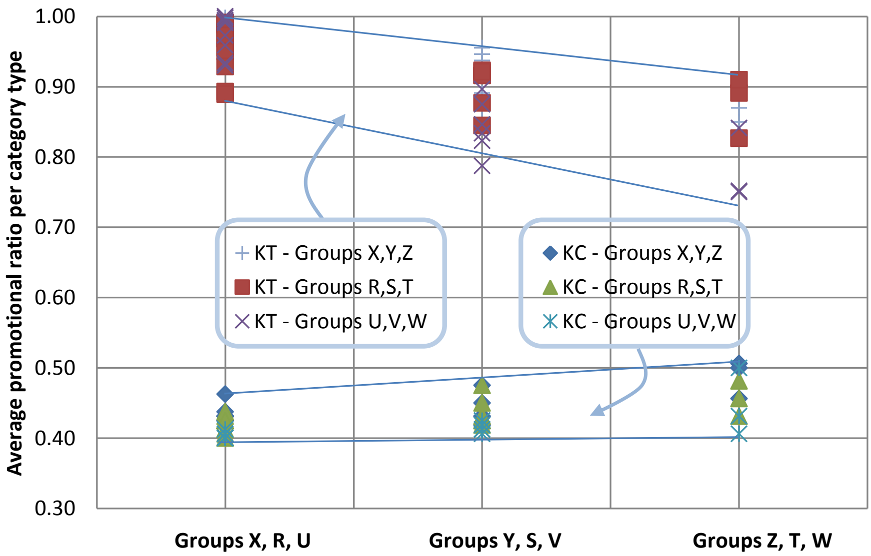


Figure 7.18: Average promotional ratio for personnel within KT and KC, under the conditions of all the scenarios.

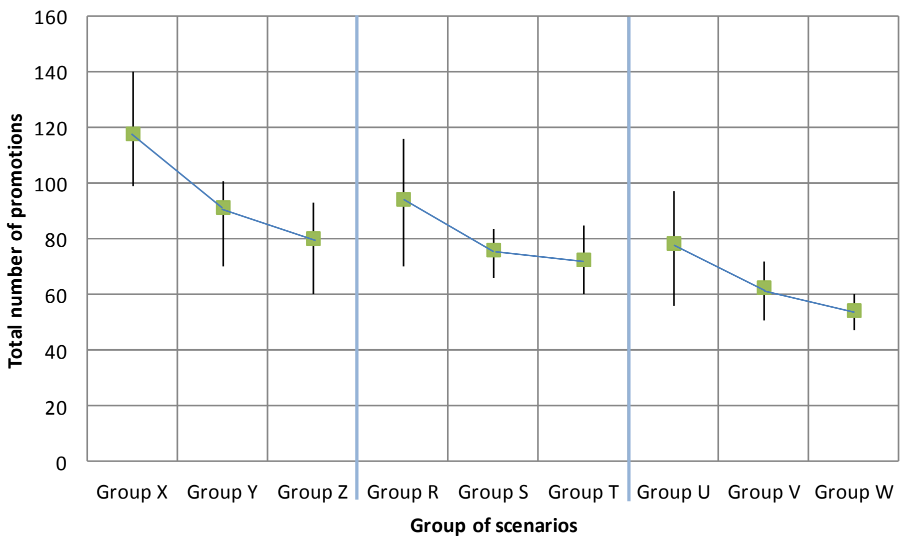


Figure 7.19: Total number of promotions for all groups of scenarios and for the considered time horizon.

So, the decrement in the total number of promotions depicted in Figure 7.19 envisages also a decrement in additional expenditures incurred for such purpose. This can be clearly observed in Figure 7.20, which presents the total cost for personnel promotions for the considered time horizon and all the scenarios. For the sake of clarity, results for Groups Y and Z, S and T, and V and W, are expressed as relative to the average cost in Groups X, R and U respectively.

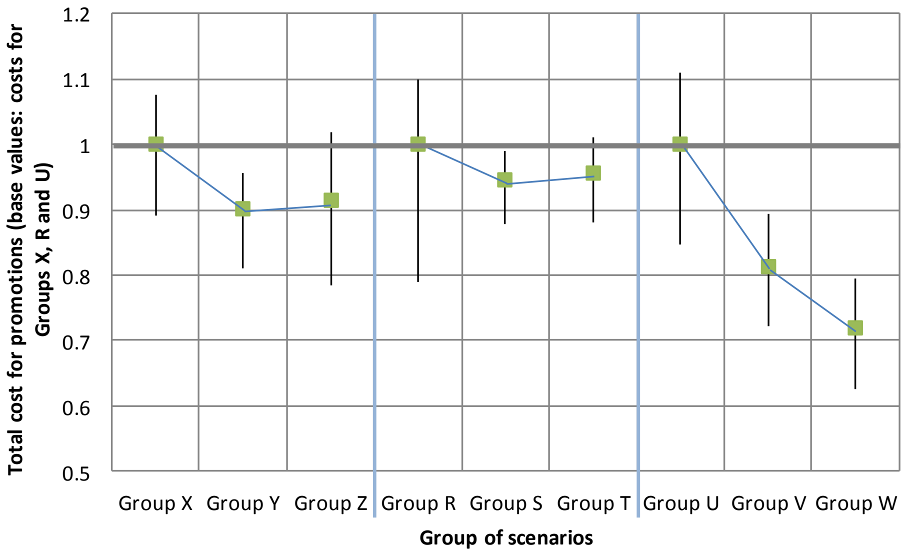


Figure 7.20: Total cost incurred for personnel promotions (during the time horizon and for all the scenarios), expressed as relative to the average cost in scenarios within Groups X, R and U.

As can be observed, the additional expenditures for personnel promotion decay in scenarios constrained by economic resources with respect to demand. For scenarios pursuing the university model A, i.e. those in Groups X, Y and Z, additional expenditures for personnel promotion in Groups Y and Z decay down to 10% in average, with respect to additional expenditures envisaged for scenarios in Group X. Similarly, for scenarios pursuing a staff composition according to university model B (Groups R, S and T), the above mentioned reduction results around 5%.

In addition, the reduction in additional economic resources for promotion is clearly exacerbated in Groups V and W, with respect to those contemplated for scenarios in Group U. (i.e. a staff composition according to that specified for university model C). As indicated in Figure 7.17, the preferable weight for personnel within KT in university model C is the lowest amongst all three considered university models. Thus, in the case of economic restrictions in relation to demand (scenarios in Groups V and W), the results for staff planning exacerbate the replacement of personnel within KT by high skilled personnel in KC. Altogether is translated in a decrement of nearly 30% in average for additional expenditures for promotions in scenarios in Group W with respect to those in Group U.

7.6 Chapter remarks

This Chapter discussed on the results determined by the optimization model for the strategic staff planning object of study in this thesis. As presented, three study cases are proposed for model's exploitation. The first study case prove the performance of the model under various scenarios characterized by concerning different university size. Also, this first study case discussed on basic managerial insights according to the variation of input data. The obtained results depict that the model successes in determining a close staff structure to a preferable one.

After these first analyses, the second study case tackled the impact that various strategic decisions on personnel policies, academic policies and preferable university models have in the strategic staff planning. Such analyses are carried out through several computational scenarios, characterized by varying various affecting factors such as demand, available personnel budget and the preferable staff composition the university aims to achieve. The work developed in this second study case is devoted to help decision makers on staff planning.

Finally, the third study case specifically addressed the economics on workers' promotion, related to the adopted preferable staff composition in strategic planning. As for the second study case, related analyses are carried out by proposing several computational scenarios which, in this case, are characterized by considering different initial and preferable workforce compositions, university models as well as temporal trends in demand and budget. Results yield that policies on personnel promotions should be adapted to the particularities of each scenario for the university (i.e. temporal trends in budget and demand), to achieve the optimization of staff planning.

8 Conclusions

This thesis presents an optimization model in the core of a methodology for the strategic staff planning in public universities. The model was exploited to evaluate different managerial aspects, which are the object of three study cases. Among the considered aspects, the impact of decisions on personnel hiring, firing and promotions in staff planning optimization have been studied. Altogether considering the influence of various factors such as demand, available personnel budget and the adoption of a preferable staff composition as an optimization criteria.

The first study case, whose results are in Section 7.3, tests the performance of the model under different scenarios and university sizes. Also, this study case offers first managerial insights according to the variation of some input data. It is important to note that for this study case, as well as for the rest of the proposed study cases, analyses are based on real data from a Spanish public university (the Universitat Politècnica de Catalunya). The final remarks for this first study case are:

- The designed model successes in obtaining a close composition to a preferable one taking into account constraints associated to budget and required service level. In particular, the Global Discrepancy, which refers to the preferable workforce composition, has been reduced up to its maximum reachable value.

- The main benefits of the proposed model are that it can be used to effectively and efficiently adjust the workforce to the requirements, for each unit (e.g., department), avoiding an excessive oversizing and that helps obtaining the decisions on hiring, dismissals and promotions that make the staff composition (pyramid) become similar to the desired one, without increasing the staff costs and taking into account the regulations (career pathway) and budget constraints.

- The model can be applied to most real universities since all of them have a similar category structure. Of course, for some circumstances the results of the model can be better than for others. For example, if the initial staff was composed mainly on permanent staff, the flexibility to achieve different compositions would be very limited and, even though the model could be still used for staff decisions, the results would not be very good in terms of discrepancy between desired and obtained staff composition. Anyway, note that this is not a limitation of the model but a limitation due to a particular situation.

- The proposed planning procedure, based on a MILP model, fills an existing research and practical gap since, to the best of our knowledge, there are no formalised procedures for planning the staff considering the career pathway (promotions between categories) and other criteria than the purely economic ones. The computational experiment also demonstrates that using MILP for strategic decisions (which usually involve a high number of binary variables) is possible with the software and hardware technology available nowadays.

- On the other hand, the main limitations of the model are the following: first, as usually with strategic planning procedures, some data and decisions are considered in an aggregate way (in this case, workers are not treated individually); even though this does not invalidate the results, it could happen that the results were not fully accurate (a detailed analysis should be done); and second, a proportion of people from one category that can pass to an upper category has been taken as a data, considering its average value. In reality the considered average proportion is a probability; so, it could happen that some decisions on promotions given by the model could not be applied in reality because less people than the expected had acquired the merits to be promoted. For very small departments, this could mean a significant loss of accuracy.

- As it can be seen from the results of the experiments, achieving a composition similar to the preferable one is not an easy and fast thing. To guarantee a bit of stability in the university staff decisions, it is advisable that the preferable composition be somehow agreed by the university community, and not only by its government (the rector and his/her team).

- The main features of the model could be applied to other organizations that may have different evaluation criteria and structure (e.g., consultancies in which workers may be classified by other criteria rather than unit and category or the objective in a private firm is different than in a public university). With the aim of widening the applicability of the proposed model, the problem specification adopted is applicable to any KIO. The proposed general specification can be adapted taking into account the particularities of each type of organization, for instance, possible differences in the structure (in universities, research centres).

The second study case, whose results are in Section 7.4, discusses on the impact that different strategic decisions regarding personnel policies, academic policies and preferable university models have in the determination of the strategic staff planning. The main conclusions of these analyses are:

- On personnel policies concerning contracts, the obtained results reveal that the possibility of firing workers in categories within KC has a very little influence in the achievement of a preferable workforce composition, for the particular university case adopted for discussion. In case that dismissals are not permitted, the university takes advantage of other sources of flexibility, like internal promotions to optimize the strategic staff planning. Further, given the priority to internal promotions, the university does not incur in significantly larger costs in personnel management.

- In regard of personnel policies around promotional ratio and budget, the obtained results yield that by decreasing values in admissible promotional ratios, the number of internal promotions for workers becomes diminished, while optimizing the strategic staff planning. However, the model adjusts efficiently the workforce composition to the same extent than in the case of considering non-decreasing promotional ratios. Under decreasing promotional ratios, workforce is adjusted emphasizing in hiring from labor market and when permitted dismissals. Moreover, if personnel budgets are reduced in the strategic planning, the achievement of a preferable workforce composition results clearly compromised. The strategic planning, in this case, determines to increase the weight of workforce within KP, since their workers are the most efficient ones in terms of the ratio capacity (teaching hours) per salary received. As a consequence, the weight of workforce in temporal categories diminishes.

- The results around academic policies (demand) clearly yield that a sustained increment in demand is directly translated in a higher workforce size. This positive correlation is repeated, as well, in the number of promotions and personnel hired from the labor market throughout the time horizon. Conversely, the university size becomes reduced when sustained reductions in demand happen. These results are those envisaged applying the idea that the university size should be adapted to the volume of activity carried out.

- Finally, in regard of the impact of considering different university models: it is interesting to see that, as depicted in Figure 7.8, the adjustment in the workforce composition is slower for university model A than for models B and C. This happens because the initial composition of university workforce differs much from model A in the desirable size for categories within KP. These categories are almost immovable as their workers are already at the top of the structure and normally leave the organization just in case of retirement.

The third study case, whose results are in Section 7.5, specifically concentrates in finding the relationship between the economic resources for workers' promotion and the preferable staff composition pursued in strategic staff planning. To this aim, several computational scenarios were evaluated, concerning different initial and preferable workforce structures, i.e. different university models, and different temporal trends in budget and demand. It was depicted in terms of the discrepancy between the achieved workforce composition and the preferable one at the end of the time horizon for analysis. All 63 scenarios were classified into three main categories:

- The first one, composed by Groups X, R and U, were characterized by enough budget, regardless temporal trends in demand. This permitted to steady the global discrepancy over time. For these scenarios, the optimization model succeeded in determining a workforce structure adjusted to the preferable one.

- Conversely, the second and third ones, including Groups Y and Z, S and T and V and W, were characterized by a constrained budget with respect to temporal trends in demand. For such scenarios, the global discrepancy increased over time, weighting the extent the workforce composition was deviated from the preferable one. For these scenarios, although the university model pursued did not matter, the objective of achieving a preferable workforce structure was sacrificed, in more or less extent, to prioritize economic resources to maintain the strictly necessary personnel to front teaching demand. In practice, this was translated into an increase in high skilled workers at the sacrifice of young researchers in temporary categories. This happened because skilled workers, according to the adopted cost data, offered better working capacity with respect to their cost than young researchers.

- The obtained results in terms of global discrepancy were aligned with those specifically addressing workers' promotion in Section 7.5.3.2. Altogether indicates that policies on personnel promotions should be adapted to the particularities of each scenario, i.e. temporal trends in budget and demand, so as to achieve the optimization of staff planning. In particular, results depicted that promotional ratios for young researchers within temporary categories became decreased under scenarios constrained in budget with respect to temporal trends in demand. Conversely, and under such circumstances, promotional ratios for high skilled personnel within permanent categories were slightly increased. In any case though, for all scenarios, promotional ratios for young researchers resulted between 75% and 100%. For permanent workers in categories within KC, promotional ratios hardly exceeded 50% at the maximum.

- In terms of total promotions, and comparing scenarios constrained and not constrained in budget with respect to demand, the number decreased between 28% and 40%, depending on the pursued university model and initial workforce composition. This reduction in the number of promoted workers was directly translated into a reduction in additional expenditures to be envisaged for such purpose. In particular, expenditures for personnel promotions resulted reduced down to 10% and 5% in average for those scenarios pursuing the university models A and B respectively, and reached the 30% for those scenarios pursuing university model C.

The final remarks above presented around the three study cases for model exploitation, along with other aspects, suggest the *general conclusions of the thesis*, and these are listed in the following:

- There is a great number of aspects influencing staff planning in universities (and KIOs in general), ranging from the organizational structure, personnel categories and demand, to finance aspects and those related to uncertainty in various externalities and the evaluation criteria. All of them suggest to adopt a formalized procedure for the strategic staff planning, so as to avoid managerial inefficiencies and short-sight decision making on strategic aspects for the university.

- To guide the design of a strategic staff planning, a formalized procedure as that proposed in the present thesis results appropriate. Such formalized procedure, since formulated as general enough, could serve to guide the development of the strategic staff planning not only in the particular case of public universities, but also in other KIOs.

- The formulated optimization model, answering one of the phases of methodology, results appropriate for solving the strategic staff planning in public universities. This way, it can contribute to strategic decision making processes of the organization, thus facilitating the sustainable development of public universities.

- The optimization model is a useful deterministic procedure that permits –from data habitually handled by the administration department of universities and prospectives on future data–, to determine the optimum size and composition of the workforce in a long term horizon. The optimization model permits to easily define various computational scenarios, from which evaluate the impact of academic and personnel policies, as well as the preferable organizational structure in the strategic planning. The model provides with numerical results for the objective evaluation of such policies and related alternatives, all adopting a long term, strategic vision.

Answering the objectives of the present thesis, the *main contributions* are:

- A literature review on strategic capacity planning in Knowledge Intensive Organizations. This work yielded the formalization of the principal characteristics and affecting factors around the strategic staff planning of KIOs in general, and universities in particular.

- The design of a general methodology for the strategic staff planning in KIOs. In the core of the methodology, an optimization model for the staff planning in public universities has been formulated.

- The exploitation of the optimization model for staff planning, under the conditions of different study cases and adopting data from an actual public university. Derived analyses addressed various managerial insights on personnel and academic policies, as well as around the adoption of different preferable university models.

Further research. Various research lines can be derived from the present thesis and some of them are suggested in the following last contents. In regard of the capabilities and performance of the optimization model, two research lines are listed.

First, and with the aim of overcoming one of the main limitations of the model, this could be modified to consider the uncertainty of some data (as the demand, the promoting ratios, etc.). And second, the model could be adapted to other organizations, particularly to other KIOs as, for example, business consultancies.

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A

Appendix. List of publications

This Chapter lists the publications in peer-reviewed journals, book chapters, conference papers and other relevant outcomes, as main results derived from the development of the thesis.

A.1 Peer-reviewed journal articles

- de la Torre, R., Lusa, A., Mateo, M. (2015). A MILP model for the long term academic staff size and composition planning in public universities. Omega, The International Journal of Management Science. Accepted for publication.

- de la Torre, R., Lusa, A., Mateo, M. (2015). Evaluation of the impact of strategic decisions in a university using a MILP model. Submitted to European Journal of Industrial Engineering.

- de la Torre, R., Lusa, A., Mateo, M. (2015). The impact of strategic decisions on promotions in Public Universities. Article in preparation.

A.2 Book chapters

- de la Torre, R., Lusa, A., Mateo, M. (2014) Methodology for the Strategic Capacity Planning in Universities. Chapter in: Iglesias, C., López-Paredes, A., Pérez-Ríos, J.M. (Eds.) Managing Complexity: Challenges for Industrial and Operations Management, Springer (ISBN: 978-3-319-04705-8).

- Martinez, M., Lusa, A., Mas, M., de la Torre, R., Mateo, M. (2012) Strategic capacity planning in KIOs: A classification scheme. Chapter in: Prado-Prado, J.C, Garcia-Arca, J. (Eds.) Annals of Industrial Engineering 2012. Industrial Engineering: Overcoming the Crisis, Springer (ISBN: 978-1-4471-5348-1).

A.3 Contributions in conferences

- de la Torre, R., Lusa, A., Mateo, M. (2013). Procedimiento para la planificación estratégica de la capacidad en las universidades. Oral presentation in ELAVIO Congress - Escuela Latino-Iberoamericana de Verano en Investigación Operativa, Valencia, Spain.
- de la Torre, R., Lusa, A., Mateo, M. (2013). Methodology for the strategic capacity planning in universities. Oral presentation in 7th International Conference on Industrial Engineering and Industrial Management, Valladolid, Spain.
- de la Torre, R., Lusa, A., Mateo, M. (2013). A MILP model for the strategic capacity planning in universities. Oral presentation in 26th European Conference on Operational Research, Rome, Italy.
- Martinez, M., Lusa, A., Mas, M., de la Torre, R., Mateo, M (2012). Strategic capacity planning in KIOs: a classification scheme. Oral presentation 6th International Conference on Industrial Engineering and Industrial Management. XVI Congreso de Ingeniería de Organización, Vigo, Spain.
- Mateo, M., Benedito, E., de la Torre, R., Lusa, A., Martinez, M., Mas, M. (2012). Strategic capacity planning in knowledge intensive organizations. Oral presentation in 25th European Conference on Operational Research, Vilnius, Lithuania.

A.4 Others

The author has participated in a competitive project related to the topic of the thesis. Project DPI2010-15614 - Planificación de la capacidad a largo plazo y diseño de la red de suministro (2010-2014). Funded by Ministerio de Ciencia e Innovación. Principal investigator: Amaia Lusa.

B Appendix. Data

This Appendix includes those data which, for the sake of clarity, have not been previously included and are needed for developing the models presented in previous chapters of the thesis.

B.1 Data for model solving

The required data for solving the optimization model, under the scope of the study cases I and II, are introduced in the following. Data refer to economic costs, demand, promotions and retirements.

- The costs associated to the staff for category (c_{kt}, v_t), have been estimated from the university public information [UPC 2014] and are listed in Table B.1.
- The teaching capacity of workers h_{kt} for each category and period is also derived from [UPC 2014] and presented in Table B.2.
- The required capacity (demand) for each unit or department is deduced from the number of students for the subjects offered by each department of the university [UPC 2014] (Table B.3).
- The expected personnel retirements L_{kt} (Table B.4) and internal promotions r_{uskt} (Table B.5) are deduced from historical data [AQU 2014], [ANECA 2014] and [Ministry 2014].

Otherwise indicated, the above presented data also serves to evaluate the study case III in Chapter 7, Section 7.5.

Table B.1: Personnel costs c_{kt} per category

Category	Cost (k€/year)
$KT1, KT2, KT3, KT4$	26.00
$KT5$	29.00
$KT6, KT7, KT8$	49.00
$KC1$	52.00
$KC2, KP1$	58.00
$KP2$	70.00
$KC3$	83.00
$KP3$	66.00
$KP4$	97.00

Table B.2: Workers' teaching capacity h_{kt} per each category of workforce

Category	Capacity (points/year)
$KT1, KT2, KT3, KT4, KT5$	18.00
$KT6, KT7, KT8$	54.00
$KC1, KC2, KP1, KP2, KC3, KP3, KP4$	72.00

Table B.3: Required annual capacity for each department of the university, C_{ut}

Unit	Demand (points/year)	Unit	Demand (points/year)
1	7829	22	2175
2	1937	23	5515
3	1887	24	1239
4	3650	25	1384
5	3488	26	2990
6	2574	27	4466
7	2948	28	936
8	3006	29	3011
9	2782	30	6909
10	5788	31	7155
11	1499	32	1333
12	2225	33	2351
13	2736	34	4432
14	666	35	2326
15	1768	36	1508
16	1576	37	1812
17	2500	38	2194
18	2211	39	2052
19	1363	40	3660
20	2770	41	1033
21	3085	42	1946

Table B.4: Proportion on the expected personnel retirements per category and time period, L_{kt}

Category	$L_{k,0}$	$L_{k,1}$	$L_{k,2}$	$L_{k,3}$	$L_{k,4}$	$L_{k,5}$	$L_{k,6}$	$L_{k,7}$	$L_{k,8}$
$KT1$	-	-	-	-	-	-	-	-	-
$KT2$	-	-	-	-	-	-	-	-	-
$KT3$	-	-	-	-	-	-	-	-	-
$KT4$	-	-	-	-	-	-	-	-	-
$KT5$	-	-	-	-	-	-	-	-	-
$KT6$	-	-	-	-	-	-	-	-	-
$KT7$	-	-	-	-	-	-	-	-	-
$KT8$	-	-	-	-	-	-	-	-	-
$KC1$	-	-	-	-	-	-	-	-	0.070
$KC2$	-	-	-	-	-	-	-	-	-
$KP1$	-	0.010	0.010	0.010	0.015	0.015	0.036	0.036	0.036
$KP2$	-	0.008	0.008	0.008	0.008	0.008	0.0413	0.0413	0.0413
$KC3$	-	-	-	-	0.060	0.070	0.06	0.07	0.07
$KP3$	-	0.009	0.009	0.009	0.013	0.013	0.03	0.03	0.03
$KP4$	-	0.026	0.026	0.026	0.030	0.030	0.064	0.064	0.064

Table B.5: Proportion on the admissible promotional ratio per category and time r_{uskt}

Cat.	$r_{usk,0}$	$L_{usk,1}$	$L_{usk,2}$	$L_{usk,3}$	$L_{usk,4}$	$L_{usk,5}$	$L_{usk,6}$	$L_{usk,7}$	$L_{usk,8}$
$KT1$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
$KT2$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
$KT3$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
$KT4$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
$KT5$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
$KT6$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
$KT7$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
$KT8$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
$KC1$	-	-	-	-	-	-	-	-	-
$KC2$	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
$KP1$	-	-	-	-	-	-	-	-	-
$KP2$	-	-	-	-	-	-	-	-	-
$KC3$	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400
$KP3$	-	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
$KP4$	-	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100

Table B.6: Initial workforce composition ($w_{uk,0}$) for the departments 1 to 10 of the UPC

Cat./Unit	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
$KT1$	1	0	1	3	3	2	1	0	2	0
$KT2$	0	0	0	1	1	0	0	0	0	0
$KT3$	0	0	0	0	0	0	0	0	0	0
$KT4$	1	0	0	2	1	1	0	0	1	0
$KT5$	1	0	0	1	1	1	0	0	1	0
$KT6$	2	2	0	1	0	2	1	0	2	1
$KT7$	3	3	0	1	1	3	1	0	5	1
$KT8$	0	0	0	0	0	0	0	0	0	0
$KC1$	18	2	1	3	5	0	15	3	9	13
$KC2$	13	4	0	1	0	5	8	6	3	13
$KP1$	1	1	2	5	15	1	3	8	18	16
$KP2$	0	3	0	0	0	0	1	2	2	3
$KC3$	0	1	0	1	0	0	0	0	0	0
$KP3$	35	9	14	8	2	6	22	8	12	63
$KP4$	13	9	2	10	0	7	8	9	1	10

Table B.7: Initial workforce composition ($w_{uk,0}$) for the departments number 11 to 20 of the UPC

Cat./Unit	#11	#12	#13	#14	#15	#16	#17	#18	#19	#20
$KT1$	0	1	0	1	0	1	1	1	1	1
$KT2$	0	0	0	0	0	0	0	0	0	0
$KT3$	0	0	0	0	0	0	0	0	0	0
$KT4$	0	1	0	1	0	0	0	1	1	1
$KT5$	0	1	0	1	0	0	0	1	1	1
$KT6$	0	1	1	0	2	0	0	0	0	2
$KT7$	1	2	3	1	3	0	0	0	0	3
$KT8$	0	0	0	0	0	0	0	0	0	0
$KC1$	3	17	3	0	4	0	9	5	2	4
$KC2$	3	4	16	0	0	0	0	1	0	8
$KP1$	1	3	9	3	1	7	25	9	11	4
$KP2$	1	2	10	2	0	0	0	0	0	1
$KC3$	2	0	2	0	0	0	0	0	0	1
$KP3$	3	9	21	2	18	10	3	12	1	18
$KP4$	5	5	12	4	7	6	1	1	0	5

Table B.8: Initial workforce composition ($w_{uk,0}$) for the departments number 21 to 31 of the UPC

Cat./Unit	#21	#22	#23	#24	#25	#26	#27	#28	#29	#30	#31
$KT1$	2	2	0	0	1	0	0	2	0	7	2
$KT2$	0	1	0	0	0	0	0	0	0	2	1
$KT3$	0	0	0	0	0	0	0	0	0	0	0
$KT4$	1	1	0	0	0	0	0	1	0	4	1
$KT5$	1	1	0	0	0	0	0	1	0	3	1
$KT6$	2	1	3	0	1	0	3	1	1	2	2
$KT7$	3	2	5	1	3	1	6	2	1	4	5
$KT8$	0	0	0	0	0	0	0	0	0	0	0
$KC1$	2	4	22	3	1	2	8	1	0	14	0
$KC2$	13	0	9	4	10	3	8	2	0	1	3
$KP1$	7	3	5	2	2	5	11	1	25	7	10
$KP2$	4	1	0	0	0	0	5	1	3	3	0
$KC3$	0	0	0	0	0	0	2	0	0	0	0
$KP3$	43	2	43	14	26	30	19	9	9	21	16
$KP4$	7	5	13	4	6	8	6	3	3	6	4

Table B.9: Initial workforce composition ($w_{uk,0}$) for the departments number 32 to 42 of the UPC

Cat./Unit	#32	#33	#34	#35	#36	#37	#38	#39	#40	#41	#42
$KT1$	1	4	0	0	1	0	0	0	1	0	0
$KT2$	0	1	0	0	0	0	0	0	0	0	0
$KT3$	0	0	0	0	0	0	0	0	0	0	0
$KT4$	0	2	0	0	0	0	0	0	1	0	0
$KT5$	0	2	0	0	0	0	0	0	1	0	0
$KT6$	1	0	0	1	1	0	2	1	1	0	1
$KT7$	2	1	0	2	2	0	3	2	2	0	1
$KT8$	0	0	0	0	0	0	0	0	0	0	0
$KC1$	2	7	15	2	1	7	1	11	20	3	4
$KC2$	0	3	7	1	0	2	5	7	2	0	4
$KP1$	5	3	4	0	7	2	3	5	3	4	2
$KP2$	0	1	2	0	4	0	1	0	10	1	1
$KC3$	0	0	0	0	1	0	0	0	1	0	0
$KP3$	9	6	60	13	4	7	30	23	7	6	5
$KP4$	1	11	34	8	1	0	7	4	3	0	3

C

Appendix. Cplex code

This Appendix includes the Cplex code adapted according to the specificities of the study cases I to III. The same code is required for the first two study cases, while some modifications are implemented (due to linearization) for the study case III.

C.1 Cplex code for study cases I and II

This section illustrates the Cplex code of the optimization model configured according to the purposes of the study cases I and II.

```
/*********************************************
* OPL 12.2 Model
* Author: Rocio de la Torre
*********************************************/

//Parameters
int K=15; //set of categories
int H=15; //set of categories
int U=42; //cost worker/category k
int T=9; //time horitzon
int c[1..K][1..T]=...; //cost full time worker
float v[1..T]=...; //cost part time worker
int D[1..U][1..T]=...; //demand
int h[1..K][1..T]=...; //capacity worker
int ww[1..K][1..U]=...;
float Lpj[1..K][1..T]=...; //retirements
{int} gammapositive[1..K] =
```

```
   [{2},{3},{4},{5},{6},{7},{8},{10,14},
{10},{13,14},{14},{14},{0},{15},{0}];
{int} gammanegative[1..K] =
   [{0},{1},{2},{3},{4},{5},{6},{7},{0},
{8,9},{0},{0},{10},{8,10,11,12},{14}];
{int} laborals={10,13}; //permanent categories
{int} extlaborals={9}; //permanent categories
{int} ministry={14,15}; //permanent tenure categories
{int} extministry={11,12}; //permanent tenure categories
float rkt[1..K][1..T]=...; //max. prop. for promotions
float UP[1..K][1..T]=...; //upper bound for composition
float LP[1..K][1..T]=...; //lower bound for composition
float cf=1.2; //cost associated to firing staff
float alpha=0.15; //excess of capacity
int lambda[1..K][1..T]=...; //penalty in obj. function
int mu=100; //penalty in obj. function
int omega=1000; //penalty in obj. function
int B[1..T]=...;          //budget
float G=0.4; //bound for capacity of part-time lecturers
float eco=1; //weight of economic part
float ide=1; //weight of ideal composition

//Variables
dvar int+ w[1..U][1..K][1..T]; //workers
dvar float+ A[1..U][1..T]; //part term workers
dvar int+ Q[1..K][1..H][1..U][1..T]; //promotions
dvar int+ L[1..U][1..K][1..T]; //retirements
dvar float+ wpositive[1..U][1..K][1..T]; //hirings
dvar float+ wnegative[1..U][1..K][1..T]; //firings
dvar float+ sigmapositive[1..U][1..K][1..T]; //pos.
   discrep.
dvar float+ sigmanegative[1..U][1..K][1..T]; //neg.
   discrep.
dvar float+ sigma[1..U][1..T]; //max. discrep.
dvar float+ delta[1..T]; //max. discrep.
dvar boolean y[1..K][1..H][1..U][1..T];

//Objective function
minimize
eco*(sum(u in 1..U)(sum(t in 2..T)(A[u][t]*v[t]*54+(sum(k
    in 1..K)(w[u][k][t]*c[k][t]))+(sum(k in laborals)
   wnegative[u][k][t]*c[k][t]*cf)+(sum(k in extlaborals)
   wnegative[u][k][t]*cf*c[k][t]))))+
ide*(sum(t in 2..T)(sum(k in 1..K)(sum(u in 1..U)(lambda[
   k][t]*(sigmapositive[u][k][t]+sigmanegative[u][k][t]))
```

```
    )+sum(u in 1..U)(mu*sigma[u][t]))+sum(t in 2..T)(omega
    *delta[t]));

//Constraints
subject to{

forall (t in 1..T, u in 1..U)
        (sum(k in 1..K)(w[u][k][t]*h[k][t])+A[u][t])>=(1+
            alpha)*D[u][t];

forall (u in 1..U, k in 1..K)
        w[u][k][1]==ww[k][u];

forall(u in 1..U, k in 1..K)
        L[u][k][1]==0;

forall(t in 2..T, u in 1..U, k in 1..K)
        {
       L[u][k][t]<=Lpj[k][t]*w[u][k][t-1]+ 1;
       L[u][k][t]>=Lpj[k][t]*w[u][k][t-1];
        }

forall (t in 2..T, u in 1..U)
        w[u][1][t]==wpositive[u][1][t];

forall (t in 2..T, u in 1..U)
        w[u][6][t]==sum(s in gammanegative[6]:s!=0)(Q[s
            ][6][u][t])+wpositive[u][6][t];

forall (t in 2..T, u in 1..U, k in 1..K:((k<=8)&&((k!=1)
    &&(k!=6))))
        w[u][k][t]<=rkt[k][t]*w[u][k-1][t-1];

forall (t in 2..T, u in 1..U, k in laborals)
        w[u][k][t]==w[u][k][t-1]+sum(s in gammanegative[k
            ]:s!=0)(Q[s][k][u][t])-sum(h in gammapositive[
            k]:h!=0)(Q[k][h][u][t])+wpositive[u][k][t]-L[u
            ][k][t]-wnegative[u][k][t];

forall (t in 2..T, u in 1..U, k in extlaborals)
        w[u][k][t]==w[u][k][t-1]-sum(h in gammapositive[k
            ]:h!=0)Q[k][h][u][t]-L[u][k][t]-wnegative[u][k
            ][t];

forall (t in 2..T, u in 1..U, k in ministry)
```

```
        w[u][k][t]==w[u][k][t-1]+sum(s in gammanegative[k
           ]:s!=0)Q[s][k][u][t]-sum(h in gammapositive[k
           ]:h!=0)Q[k][h][u][t]+wpositive[u][k][t]-L[u][k
           ][t];

forall (t in 2..T, u in 1..U, k in extministry)
        w[u][k][t]==w[u][k][t-1]-sum(h in gammapositive[k
           ]:h!=0)Q[k][h][u][t]-L[u][k][t];

forall (t in 2..T, u in 1..U, k in laborals)
        wnegative[u][k][t]<=0.5*w[u][k][t]+1;

forall (t in 2..T, u in 1..U, k in 1..K: (k==6) || (k>=9)
   , j in gammapositive[k]:j!=0)
        Q[k][j][u][t]<=rkt[j][t]*w[u][k][t-1];

forall (t in 2..T, u in 1..U, k in 1..K:(k==6)||(k in
   ministry) || (k in laborals), j in gammapositive[k]:j
   !=0)
        {
         Q[k][j][u][t]>=(rkt[j][t]*w[u][k][t-1]-1)-rkt[j
            ][t]*(((1+alpha)*D[u][t])/h[k][t])*y[k][j][u
            ][t]-1;
      wpositive[u][j][t]<=(((1+alpha)*D[u][t])/h[k][t])
         *(1-y[k][j][u][t]);
        }

forall (t in 2..T,k in 1..K,u in 1..U)
        {
      w[u][k][t]>=((LP[k][t]*(sum(k in 1..K)(w[u][k][t]))
         )-sigmanegative[u][k][t]);
      w[u][k][t]<=((UP[k][t]*(sum(k in 1..K)(w[u][k][t]))
         )+sigmapositive[u][k][t]);
      sigma[u][t]>=sigmapositive[u][k][t]+sigmanegative[u
         ][k][t];
        }

forall (t in 2..T, u in 1..U)
        delta[t]>=sigma[u][t];

forall (t in 2..T, u in 1..U)
        A[u][t]<=G*D[u][t]*(1+alpha);

forall (t in 2..T)
        sum(u in 1..U)(A[u][t]*v[t]*54+(sum(k in 1..K)(w[
```

```
            u][k][t]*c[k][t])))<=B[t];

}
```

C.2 Cplex code for study case III

This section illustrates the Cplex code of the optimization model configured according to the purposes of the study case III.

```
/*******************************************
 * OPL 12.2 Model
 * Author: Rocio de la Torre
 *******************************************/

//Parameters
int K=15; //set of categories
int H=15; //set of categories
int U=1; //set of units
int T=9; //time horitzon
int c[1..K][1..T]=...; //cost full time worker
float v[1..T]=...; //cost part time worker
int D[1..U][1..T]=...; //demand
int h[1..K][1..T]=...; //capacity worker
int ww[1..K][1..U]=...;
float Lpj[1..K][1..T]=...; //retirements
{int} gammapositive[1..K] = [{2},{3},{4},{5},{6},{7},{8},
{10,14},{10},{13,14},{14},{14},{0},{15},{0}];
{int} gammanegative[1..K] =
   [{0},{1},{2},{3},{4},{5},{6},{7},
{0},{8,9},{0},{0},{10},{8,10,11,12},{14}];
{int} laborals={10,13}; //permanent categories
{int} extlaborals={9}; //permanent categories
{int} ministry={14,15}; //permanent tenure categories
{int} extministry={11,12}; //permanent tenure categories
{int} temporary={2,3,4,5,7,8}; //temporary
float rkt[1..K][1..T]=...; //max. prop. for promotions
float UP[1..K][1..T]=...; //upper bound for composition
float LP[1..K][1..T]=...; //lower bound for composition
float alpha=0.15; //excess of capacity
int lambda[1..K][1..T]=...; //penalty in obj. function
int mu=100; //penalty in obj. function
int omega=0; //penalty in obj. function
int B[1..T]=...; //budget
```

```
float G=0.4; //bound for capacity of part-time lecturers
float eco=1; //weight of economic part
float ide=1; //weight of ideal composition

//Variables
dvar int+ w[1..U][1..K][1..T]; //workers
dvar float+ A[1..U][1..T]; //part term workers
dvar int+ Q[1..K][1..H][1..U][1..T]; //promotions
dvar int+ L[1..U][1..K][1..T]; //retirements
dvar float+ wpositive[1..U][1..K][1..T]; //hirings
dvar float+ wnegative[1..U][1..K][1..T]; //firings
dvar float+ sigmapositive[1..U][1..K][1..T]; //pos.
    discrep.
dvar float+ sigmanegative[1..U][1..K][1..T]; //neg.
    discrep.
dvar float+ sigma[1..U][1..T]; //max. discrep.
dvar float+ delta[1..T]; //max. discrep.
dvar boolean y[1..K][1..H][1..U][1..T];

//Parameters and variables for linearization
int NR=11;
int NW=26;
float vr[1..NR]=...;
int vw[1..NW]=...;
float rkmin=...;
float rcmin=...;
float rpmin=...;
dvar boolean yr[1..NR][1..U][1..K][1..T];
dvar boolean yw[1..NW][1..U][1..K][1..T];
dvar boolean yrw[1..NR][1..NW][1..U][1..K][1..K][1..T];
dvar float+ rukt[1..U][1..K][1..T];

//Objective function
minimize

eco*(sum(u in 1..U)(sum(t in 2..T)(A[u][t]*v[t]*54+(sum(k
     in 1..K)(w[u][k][t]*c[k][t]))+(sum(k in laborals)
    wnegative[u][k][t]*c[k][t]*cf)+(sum(k in extlaborals)
    wnegative[u][k][t]*c[k][t]*cf))))+
ide*(sum(t in 2..T)(sum(k in 1..K)(sum(u in 1..U)(lambda[
    k][t]*(sigmapositive[u][k][t]+sigmanegative[u][k][t]))
    )+sum(u in 1..U)(mu*sigma[u][t]))+sum(t in 2..T)(omega
    *delta[t])+0.5*sum(u in 1..U)(sum(t in 2..T)(sum(k in
    temporary)(c[k][t]*(rukt[u][k][t]-rkmin))))+0.5*sum(u
    in 1..U)(sum(t in 2..T)((c[6][t]*(rukt[u][6][t]-rkmin)
```

```
    )))+0.5*sum(u in 1..U)(sum(t in 2..T)(sum(k in
    laborals)(c[k][t]*(rukt[u][k][t]-rcmin))))+0.5*sum(u
    in 1..U)(sum(t in 2..T)(sum(k in ministry)(c[k][t]*(
    rukt[u][k][t]-rpmin)))));

//Constraints
subject to{

forall (t in 1..T, u in 1..U)
        (sum(k in 1..K)(w[u][k][t]*h[k][t])+A[u][t])>=(1+
           alpha)*D[u][t];

forall (u in 1..U, k in 1..K)
        w[u][k][1]==ww[k][u];

forall (k in 1..K, uw in (1..UW):uw==ww[k][1])
        yw[uw][1][k][1]==1;

forall (k in 1..K, uw in (1..UW):uw!=ww[k][1])
        yw[uw][1][k][1]==0;

forall(u in 1..U, k in 1..K)
        L[u][k][1]==0;

forall(t in 2..T, u in 1..U, k in 1..K)
        {
       L[u][k][t]<=Lpj[k][t]*w[u][k][t-1]+ 1;
       L[u][k][t]>=Lpj[k][t]*w[u][k][t-1];
        }

forall (t in 2..T, u in 1..U)
        w[u][1][t]==wpositive[u][1][t];

forall (t in 2..T, u in 1..U)
        w[u][6][t]==sum(s in gammanegative[6]:s!=0)(Q[s
           ][6][u][t])+wpositive[u][6][t];

forall (t in 2..T, u in 1..U, k in temporary)
        w[u][k][t]==sum(s in gammanegative[k]:s!=0)(Q[s][
           k][u][t]);

forall (t in 2..T, u in 1..U, k in laborals)
        w[u][k][t]==w[u][k][t-1]+sum(s in gammanegative[k
           ]:s!=0)(Q[s][k][u][t])-sum(h in gammapositive[
           k]:h!=0)(Q[k][h][u][t])+wpositive[u][k][t]-L[u
```

```
        ][k][t]-wnegative[u][k][t];

forall (t in 2..T, u in 1..U, k in extlaborals)
     w[u][k][t]==w[u][k][t-1]-sum(h in gammapositive[k
        ]:h!=0)Q[k][h][u][t]-L[u][k][t]-wnegative[u][k
        ][t];

forall (t in 2..T, u in 1..U, k in ministry)
     w[u][k][t]==w[u][k][t-1]+sum(s in gammanegative[k
        ]:s!=0)Q[s][k][u][t]-sum(h in gammapositive[k
        ]:h!=0)Q[k][h][u][t]+wpositive[u][k][t]-L[u][k
        ][t];

forall (t in 2..T, u in 1..U, k in extministry)
     w[u][k][t]==w[u][k][t-1]-sum(h in gammapositive[k
        ]:h!=0)Q[k][h][u][t]-L[u][k][t];

forall (t in 2..T, u in 1..U, k in laborals)
     wnegative[u][k][t]<=0.5*w[u][k][t]+1;

forall (t in 2..T, u in 1..U, k in 1..K)
     {
      sum(nr in 1..NR)yr[nr][u][k][t]==1;
      rukt[u][k][t]==sum(nr in 1..NR)vr[nr]*yr[nr][u][
         k][t];
     }

forall (t in 2..T, u in 1..U, k in 1..K)
     {
      sum(uw in 1..NW)yw[uw][u][k][t]==1;
      w[u][k][t]==sum(uw in 1..NW)vw[uw]*yw[uw][u][k][
         t];
     }

forall (t in 2..T, u in 1..U, k in 1..K, j in
    gammapositive[k]:j!=0, nr in 1..NR, uw in 1..NW)
     {
    2*yrw[nr][uw][u][k][j][t] <= yr[nr][u][j][t]+yw[uw
       ][u][k][t-1];
      yr[nr][u][j][t]+yw[uw][u][k][t-1] <= 1+yrw[nr][
         uw][u][k][j][t];
     }

forall (t in 2..T, u in 1..U, k in 1..K, j in
    gammapositive[k]:j!=0)
```

```
        {
         Q[k][j][u][t]<=sum(nr in 1..NR)(sum(uw in 1..NW)
            (vr[nr]*vw[uw]*yrw[nr][uw][u][k][j][t]));
        }

forall (t in 3..T, k in 1..K)
        {
         rukt[1][k][t]-rukt[1][k][t-1]<=0.1;
         rukt[1][k][t-1]-rukt[1][k][t]<=0.1;
        }

forall (t in 2..T, k in temporary)
        {
         rukt[1][k][t]>=rkmin;
         rukt[1][k][t]<=1.0;
        }

forall (t in 2..T)
        {
         rukt[1][6][t]>=rkmin;
         rukt[1][6][t]<=1.0;
         rukt[1][9][t]==0;
         rukt[1][11][t]==0;
         rukt[1][12][t]==0;
        }

forall (t in 2..T, k in ministry)
        {
         rukt[1][k][t]>=rpmin;
         rukt[1][k][t]<=0.6;
        }

forall (t in 2..T, k in laborals)
  {
        rukt[1][k][t]>=rcmin;
        rukt[1][k][t]<=0.7;
  }

forall (t in 2..T,k in 1..K,u in 1..U)
        {
      w[u][k][t]>=((LP[k][t]*(sum(k in 1..K)(w[u][k][t]))
         )-sigmanegative[u][k][t]);
      w[u][k][t]<=((UP[k][t]*(sum(k in 1..K)(w[u][k][t]))
         )+sigmapositive[u][k][t]);
         sigma[u][t]>=sigmapositive[u][k][t]+
```

```
            sigmanegative[u][k][t];
        }

forall(t in 2..T, u in 1..U)
        delta[t]>=sigma[u][t];

forall (t in 2..T, u in 1..U)
        A[u][t]<=G*D[u][t]*(1+alpha);

forall(t in 2..T)
        sum(u in 1..U)(A[u][t]*v[t]*54+(sum(k in 1..K)(w[
           u][k][t]*c[k][t])))<=B[t];

}
```