Developing tools to assist the planning of the Healthcare Workforce, with application to the Portuguese National Health Service

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Abstract – Strategic healthcare workforce planning is a complex task, which must consider multiple objectives, while at the same time deals with a range of rules and restrictions. The problem is to assess and establish the right number of professionals, with the right skills in the right place at the right time. In order to accomplish that it is necessary a continuous supply of specially trained human resources. This study aims at developing generic planning mathematical programming models that support decisions related to the training of physicians, and applies those methods to the Portuguese physicians' education. Two alternative deterministic, multi-period and mono-objective models are proposed that set the optimal number of students to admit in the medicine course, and the optimal number of vacancies to open in each of the 42 medical specialties. Both models aim at minimizing the gap between the supply and demand of physicians throughout the planning horizon. Although these models are mono-objective, the selected objective functions encapsulate multiple objectives of different stakeholders. A sensibility analysis is made to understand the impact of the uncertain parameters. Results show that a readjustment of the vacancies to be opened in each of the medical specialties is required in Portugal. Nevertheless, it is showed that it is necessary to resettle the *numerus clausus*. Moreover, the uncertain parameters have an impact on the results, so an extension to stochastic programming must be considered as further work.
Keywords – *Decision analysis, optimization, strategic planning, health-care workforce planning, training, Portugal.*

1. Introduction

Strategic healthcare workforce planning is a complex task, which must consider multiple objectives and needs from different stakeholders. At the same time, it must deal with a range of rules, restrictions and uncertain dynamic parameters (Price et al., 1980). The problem is to assess and establish the right number of professionals, with the right skills in the right place at the right time (HEE, 2016).

Across Europe, several studies are published and multiple joint and individual initiatives are found (EU, 2013). However, many challenges are recognized in the healthcare workforce planning across Europe (Perfilieva and Buchan, 2015), as well as in Portugal (WHO, 2010; Santana et al., 2014) (see Section 2.1).

In order to meet those challenges, a continuous flow of recently graduated and highly specialized healthcare professionals is required. This is the only way to guarantee a sufficient number of professionals to replace those that will retire in the future (Lavieri and Puterman, 2009). Many studies deal with the supply and the demand of physicians or nurses (Van Greuningen, 2012; Barber and López-Valcárcel, 2010), but very few try to optimize the training of the healthcare professionals in order to minimize the gap between supply and demand of physicians or nurses today and in the future (Senese et al., 2015).

Students' admission in medical schools and physicians' admission in different medical specializations has many rules and bad decisions have long term implications. Admitting too many students may cause an oversupply of professionals leading to inefficiencies in resource allocation, unemployment or increased healthcare costs because of the supplier-induced demand. However, admitting less students is also not desirable, since it may cause a shortage of professional, with consequences such as: lower quality and quantity of healthcare services; increased waiting lists; delays in necessary treatments; preventable patients' death and professional burnout.

Moreover, physicians training takes time and significant financial investment.

To contribute to literature in this area, this study proposes two deterministic, mono-objective and multi-period mixed integer linear programming (MILP) models to support decision-makers (DMs) in strategic planning of healthcare workforce, in particular physicians' training. These models inform DMs on how many vacancies to open in each medical specialization and how many vacancies to open in medical schools in each year of the planning horizon.

Although both models are mono-objective they are built to consider multiple objectives and necessities of different stakeholders. Particularly, Model A minimizes the gap found between supply and demand of physicians every year, considering also equity in distribution of vacancies between different fields of specialization. And Model B considers the same objectives (with gap minimization in the end of each sub-period of the planning horizon) and minimize the variability in the number of vacancies opened in each year of planning horizon. This last concern is a key issue for medical schools, since it is very difficult to adjust the number of vacancies yearly. Both models are generic and can be applied in countries with a National Health Service (NHS) and public medical education. The models are applied for the medical education context in Portugal for the 2016-2050 period. A sensibility analysis is made to explore the impact of uncertain parameters in planning decisions.

The remainder of this article is organized as follows. The workforce planning context and planning problem under study is outlined in Section 2. A literature review of relevant methods and studies is presented in Section 3. The proposed models are presented in Section 4. Section 5 presents the case study and discusses key results. Models' and dataset's limitations are presented in Section 6 conclusions as well as lines for further research are given in Section 7.

2. Workforce Planning Context and Problem Statement

In order to build support decision models for the strategic planning of healthcare workforce in countries with a NHS and public medical education it is necessary to consider multiple aspects. Firstly it is necessary to understand the historical background on the topic (2.1) and then proceed to the problem statement. A more detailed description of the problem under study follows (2.2), with topics such as: (i) medical training; (ii) planning decisions and stakeholders; (iii) objectives; (iv) constrains; and (v) uncertainty. The Portuguese context, being characterized by a NHS and public medical education system, is used as reference for this study.

2.1 Portuguese Workforce Planning background and Challenges

In 1977 it was implemented *numerus clausus* in Portuguese medical schools, with the objective of reducing the number of physicians in the market (Barros et al., 2011). The consequences of this policy remain today, with an elderly physicians' population and lack of some specialties. Almost one third of physicians will have 70 years old by 2025 (Santana et al., 2014). In 2014 almost 30% of physicians had between 50 and 59 years old (Santana et al., 2014). There is a major need in adjust the vacancies in different fields of specialization in order to replace elderly physicians by young physicians.

Portuguese physicians can work in both systems – private and NHS, since 1979 (Conceição et al., 2007). However, it is believed that this is one of the possible threats to the sustainability of the Portuguese NHS (Dussault, 2014). This happens because medical training in Portugal is public and is founded mostly by the state. However, after graduate or after completing the internship, physicians can start their career in a private hospital. So the investment made by the Government to educate physicians is not used by the NHS. Since 1999, Bologna Process allowed Portuguese students to study in other countries (DGES, 2007). This international experience contributes to the raise of Portuguese physicians' emigration rates.

Financial crisis had also consequences on the healthcare workforce. The wages were reduced as well as the number of extraordinary hours (Sakellarides et al., 2014). This had a significant impact on the emigration of specialists to other European countries (Ribeiro et al., 2014). There is no

formal monitoring of the numbers of emigration, however it is known that this numbers are alarming (Ribeiro et al., 2014).

In 2010, World Health Organization (WHO) published a report to evaluate Portuguese National Health Plan (WHO, 2010). One of the problems found was the lack of a strategy for the healthcare workforce. We present here the most recent data for the same problems that WHO found in 2010:

- *Equity in distribution of physicians between different fields of specialization* – 67,5% of physicians have hospital specialization, 30,5% have general and family specialization and only 2% are specialized in public health (Ministério da Saúde, 2014a);
- *Equity in distribution of health professionals across the country* – national average of nurses per 1000 population was 6,23 in 2013, while in Coimbra it was 11,33 and in Leiria it was 4,09 (OE, 2014);
- *Healthcare workforce indicators* – in 2013, the number of physicians per 1000 population was 4,3, higher than the average of OCDE 3,3 (OCDE, 2015).

Physicians' training is facing several challenges in Portugal. The amount of time necessary to train a specialized doctor is at least 9 years (DGES, 2016). This training is very expensive, although it is not possible to know exactly the cost of training one specialist (Ono et al., 2013). There is also a lack of communication between the two Ministers responsible for the medical formation and sometimes vacancies in the internship ate not enough for all the students admitted in the medical schools (DN, 2015). Within this context, one can say that there is clearly the need to develop research so as to support an adequate planning at this level.

2.2 Problem Statement

Medical Training

In Portugal medical training starts in the medical school where students complete their Master's degree in 5 years (first step) (DGES, 2016). There are 7 medical public schools financed mostly by the state. Portugal has no private medical schools (DGES, 2016).

After concluding a Master's degree, physicians must pass an exam which gives the access to the medical specialization that takes 4 to 6 years depending on the specialization field (second step).

There are different situations which can affect the expected duration of medical education. During the first step students may give up of the course (dropout rates) or fail exams (attrition rates). It is also possible to fail the access to the specialization exam or pause the training (e.g.gap year). During the second step (internship) students may study abroad, start a PhD or have maternity/paternity leaves. Finally, students may switch the field of specialization or even give up of the internship. Note that if a student fails one of the steps of the internship, he/she must repeat that step and the duration depends on the internship responsible decision.

Note that in Portugal, a physician without specialization cannot work in the NHS. If a student fails the internship admission exam, or if there are no vacancies, he/she must wait for the next year to repeat the exam. Otherwise, they can work only in the private sector as a physician without specialization.

Planning Decisions and Stakeholders

This study considers as main decisions:

(i) How many vacancies should be open every year in medical schools?
(ii) How many vacancies should be open in each medical specialization every year?

In Portugal different stakeholders are involved in every step of medical training. *Direção Geral do Ensino Superior* and *Ministério da Ciência, Tecnologia e Ensino Superior* are responsible for the first step – fix the *numerus clausus* in medical schools. Ministry of Health is responsible for the next step – medical internship (medical specialization). But there are other stakeholders involved such as *Administração Central de Sistemas de Saúde* (ACSS), *Conselho Nacional do Internato Médico*, Regional Health Administrations and Portuguese Medical Council. Teaching institutions and Medical Student Associations are important stakeholders in each step of medical education.

* Since 2017/2018 Medical Master's Program will be finished in 5 years instead of 6 (Observador, 2015).

Planning objectives

Different stakeholders are aware of the importance and necessity of strategic healthcare workforce planning, but their objectives may vary. A more detailed description of different stakeholders' objectives follows:

- *Medical Schools and Internship Institutions* – Medical education is highly specialized and needs teachers, material and teaching sites recognized as suitable for education. This is the reason why it is difficult to make quick adjustments to the number of vacancies in short term. Teaching sites are interested in maintain a stable number of students (Smits et al, 2010).
- *Medical Council and Medical Students Associations* – Usually, physicians are averse to situations of too much competition (Van Greuningen et al, 2012). In Portugal, Medical Council and Medical Students Associations argued in 2015 that the *numerus clausus* in medical schools should be reduced (DN, 2015). This idea was seen as a solution to the problem of lack of vacancies in internship for every student that finishes medical school and want to start medical specialization.
- *Portuguese NHS* – There are three main objectives that Portuguese NHS aims to achieve with the proper strategic planning of healthcare workforce:
  1. Gap minimization (WHO, 2010; Dussault, 2014; Senese et al, 2015). This is the most important objective for the NHS. It is absolutely necessary to minimize the gap between supply and demand of healthcare workforce today and in the future.
  2. Cost minimization. One must be aware about the crisis period lived in Portugal and the consequences on the health system (Sakellarides et al, 2014). In one hand it is necessary to admit as many medical students as it will be necessary in the future, but in the other hand we must minimize the cost of the medical education and salaries (Lavieri and Puterman, 2009).
  3. Equity maximization. Generally equity is one of the most important objectives in any NHS (WHO, 2012; Ministério da Saúde, 2015a). In the planning of healthcare workforce it is necessary to maximize the equity on the distribution of physicians between different specializations (Ministérios da Saúde, 2014a; Senese et al., 2015).

Note that gap minimization is indirectly responsible for promoting other goals such as: (i) maximizing the quality of healthcare workforce; (ii) maximizing health gains and improving population's health; and (iii) minimizing risks associated to bad planning.

Planning constraints

One of the most important constraints in the planning of healthcare workforce is the capacity of the training system. It is known that in Portugal there are 1600 vacancies for the medical internship (Governo de Portugal, 2012). Although it is not possible to quantify other limitations, we must identify them: (i) budget for medical education; (ii) number of professionals available to train students; (iii) number of qualified institutions for internship; (iv) maximum number of vacancies to be closed in each specialization; and (v) maximum number of vacancies to be open in each specialization.

Uncertainty

It is important to understand which key information may have impact on the planning of the healthcare workforce. There are several sources of uncertainty, such as: (i) the gap is uncertain and it is natural to present uncertainty on the side of supply or demand; (ii) number of students who give up of medical school or fail exams; (iii) number of students who give up of internship; (iv) maternity/paternity leaves; (v) death of students; (vi) number of recently graduated physicians who decide to work in private system or emigrate; (vii) technologic evolution; (viii) political stability; and (ix) number of Portuguese students who return to Portugal after graduate in other counties.

3. Literature review

3.1 Strategic planning

This work focuses on strategic planning of healthcare workforce. Strategic planning

is the long term planning used to support decisions focused on location, capacity, size and type of business (Anthony, 1965). Usually it supports decisions that needs a great amount of money and time. In healthcare there are some examples of this type of planning. Mestre et al. (2014) developed a system to support strategic planning of hospital networks. Senese et al. (2015) studied strategic planning of healthcare workforce, in particular physicians.

In our work we pretend to build a model to support the strategic planning of physicians' training through a systematic and organized process (Perera and Peiró, 2012). This model should allow the system to progress from the actual situation (gap between supply and demand of physicians) to the desired one (minimization of the gap).

3.2 Mathematical models to support workforce planning

Workforce planning have been treated extensively in the literature since 1950 (Price et al., 1980; Amorim Lopes et al., 2015). Strategic workforce planning problems are usually dynamic and involve uncertain parameters (Price et al., 1980). Two different types of mathematical models can be used – descriptive and normative (Price et al., 1980).

Descriptive models are useful to forecast workforce needs in the future and study the consequences of different policies on the system (Price at al., 1980). Markov models (Kinstler et al., 2008; Lagarde and Cairns, 2012), simulation models (Van Greuningen, 2012) and system dynamics (Barber and López-Valcárcel, 2010) are examples of descriptive models. However, this type of models do not provide a plan of actions to solve problems found in the system. This step is made by the normative models.

Normative models are thus built in order to achieve the goals established by the DMs through optimization of resources and considering restrictions of the system (Price et al., 1980). Different approaches have been used, but the most popular one is linear programming (LP) (Price et al., 1980; Stewart et al., 1994). However, the use of LP has been facing a critical limitation since most of existing studies propose mono-objective models. In fact, Healthcare workforce planning deals with multiple objectives, so it is necessary to extend existing LP models to a multi-objective formulation. There are examples of LP multi-objectives studies in the literature, such as:

- Goal programming (Topaloglu and Selim, 2010);
- Weighted programming (Cardoso et al., 2016);
- Pareto efficiency (Craft et al., 2007).

3.3 Normative models to support strategic workforce planning

Few normative studies developed to support strategic workforce planning in healthcare are published (see Table 1). Most of this type of studies are found in other fields of application (see Table 1).

Most mathematical programming models developed for healthcare workforce planning make use of a single objective and are mostly deterministic (see Table 1). This studies are mainly focused in only one profession – nurses or physicians –, and are decision support models applied to a regional level.

The method usually used to support strategic workforce planning is mixed integer linear programming (MILP) (see Table 1).

Only one normative study focuses exclusively on physicians' training. Senese et al. (2015) developed a decision support tool to optimal assignment of medical specialization grants for each year of projection with the objective of minimize de gap between supply and demand of physicians. However, this study focuses only on the specialization and do not provide information about how many vacancies should be open in medical schools. It is also a mono-objective, deterministic and regional study. Table 1 identifies key features considered as relevant for strategic healthcare workforce planning and key studies in the area. It is showed that there is scope for building more comprehensive and complete models to assist DMs in the strategic planning of healthcare workforce. In this context, this article proposes two models developed to support the strategic planning of healthcare workforce, in particular physicians' formation.

Table 1 – Key features and studies for strategic planning of healthcare workforce.

Study	Field of application	Healthcare workforce	Method	Multi-objective	Deterministic	Stochastic	Planning Level
Stewart et al. (1994)	Industry		LP	✔	✔		
Yu et al. (2004)	Aeronautics		MILP		✔		
Srour et al. (2006)	Construction		LP		✔		
Santos et al. (2008)	Information Technology		MILP	✔		✔	
Horn et al. (2015)	Armed Forces		MILP		✔		
Wishon et al. (2015)	Agriculture		MILP		✔		
De la Torre et al. (2016)	Public University		MILP	✔	✔		
Werker (2012)	Radiotherapy center		MILP	✔		✔	
Lavieri et Puterman (2009)	Healthcare	Nurses	LP		✔		Regional
Schell et al. (2015)	Healthcare	Nurses	LP		✔		Regional
Hu et al. (2015)	Healthcare	Nurses	LP		✔		Regional/ National
Senese et al. (2015)	Healthcare	Physicians	MILP		✔		Regional

4. Models Developed

In this section we present two mathematical models developed to support the strategic planning of healthcare workforce, in particular physicians' training. These models were developed in a generic way, to be applied in any public health system. As we said before both models are MILP deterministic, mono-objective and multi-period. Although the proposed models are deterministic, we consider stakeholders' multiple perspectives and needs. The following models were developed:

1. **Model A** – minimize the gap between supply and demand of physicians each year of the planning period; and maximize the equity in the distribution of vacancies among different specializations.
2. **Model B** – maximize the equity in the distribution of vacancies among different field of specialization, as well as Model A does. It also minimizes the gap over a longer period of time, so that the vacancies opening variability could be minimized.

Note that the gap definition in this study is the difference between the demand and supply of physicians. When the gap is negative, supply is higher than demand so vacancies in medical schools and specialization should be closed. When the gap is positive, supply is lower than demand, so vacancies in medical schools and specialization should be opened.

The opening or closing of vacancies should take into account the time period necessary to train physicians. For instance, if in 2030 there is a lack of 20 surgeons, and it took 5 years to complete Master's degree plus 6 years of specialization, we should open 20 extra vacancies in 2024 for that specialization and 20 extra vacancies in *numerus clausus* of 2019.

The mathematical formulation of this model has required the definition of 30 equations. The complete mathematical formulation of both models is presented in thesis.

5. Case Study

In this work, we applied the models developed to the Portuguese context, in particular to the physicians' public training and specialization over the 2016-2050 period.

5.1 Application to the Portuguese NHS

Dataset used

The dataset used is presented in Table 2.

Assumptions

To apply these models to the Portuguese context, we have had to use several assumptions presented in Table 3.

Table 3 – Assumptions used.

Rate	Value (%)	Rate	Value (%)
Emigration rate	1	Dropout rate	1
Migration to private sector rate	5	Students who finished the Master's in 5 years rate	91

Table 2 – Dataset used.

Data set	Source	Comment
Doctors' supply	FEUP	The supply was projected by FEUP, for 43 specialties, for 2016-2050 period.
Physicians' demand	ACSS (ACSS, 2009)	The demand is from *Estudo das Necessidades Previsionais em RHS Médicos*, for 42 specialties, for 2008-2020 period.
Master's duration	DGES (DGES, 2016)	We consider 5 years duration.
Specialty duration	ACSS	Specialty duration defined by ACSS, provided by FEUP.
Base nº of vacancies opened in Master's	DGES (DGES, 2016)	Base vacancies nº opened in Master's is from 2015/2016.
Base nº of vacancies opened in each specialty	*Colégios da especialidade*	Base vacancies nº opened in each specialty is from 2013, provided by FEUP.
Maximum internship capacity	ACSS (Governo de Portugal, 2012)	Maximum capacity for the internship is from May, 2012 (1600 interns).

Furthermore, since data available for the demand is only until 2020, we used linear regression technique to project the demand until 2050.

In order to apply Model B, the planning period was divided in 3 sub-periods – from 2016 to 2030; 2031 to 2040 and 2041 to 2050.

5.2 Results

In this section we present the results for the application of the proposed models to the Portuguese context. First, we compare the results obtained by applying both models, and then we present the sensitivity analysis results.

Model A vs Model B

Figure 1 shows the vacancies number that should be open until 2050 for the General and Family Medicine specialty, for Model A and B, comparing the results with the base vacancies number opened in 2013 for that specialty. As it is possible to observe, Model A application results in a high vacancies opening variability. The same happens for Internal Medicine specialty (Figure 2). In addition to the high variability, Model A shows zero vacancies to be opened in Internal Medicine in the first three years of planning period. In both cases, Model B results in a lower vacancies opening variability throughout the planning period. However, one must notice that Model B minimizes the gap not yearly (as the Model A does), but at the end of each sub-period. It is necessary to discuss with DMs the viability of opening 914 vacancies in General and Family Medicine in 2018 (see Figure 1), since the base number of 2013 for that specialty is 446 vacancies.

In addition to that, we must alert DMs to the total closure of Internal Medicine specialty in the first three years (see Figure 2) and discuss the possible consequences for the medical training system. Probably in this case it would be beneficial to follow a smoother adjustment of vacancies, as suggested by Model B.

The total vacancies opening for each medical specialty each year of the planning period planning map can be consult in Thesis.

Regarding the *numerus clausus* in medical schools, it is shown in Table 4, for both models. Recently, Medical Council and Medical Students Association defended the reduction of *numerus clausus* in medical schools (DN, 2015). It is curious to see that results from both models show the contrary. If we compare the results with 1441

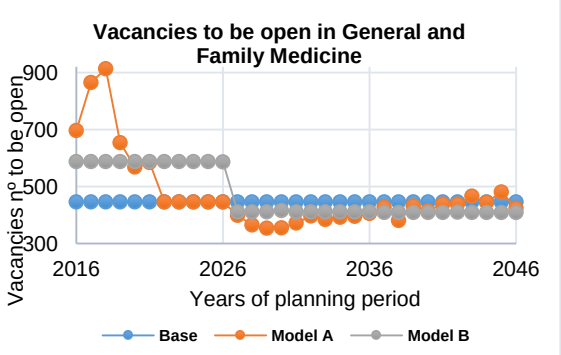

Figure 1. Vacancies nº to be open in General and Family Medicine for the planning period, considering Model A, Model B and base vacancies opened in 2013.

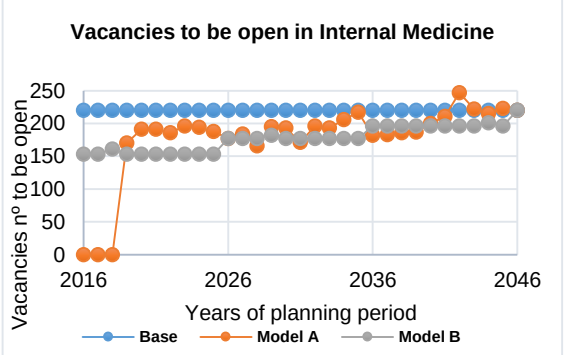

Figure 2. Vacancies nº to be open in Internal Medicine for the planning period, considering Model A, Model B and base vacancies opened in 2013.

Table 4 – *Numerus Clausus* for all national medical schools for each year of the planning period, for Model A and Model B.

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
A	1747	1755	1714	1604	1605	1549	1494	1443	1407	1431	1352	1479	1496	1475	1540	1503	1507	1538	1542	1605	1579	1644	1714
B	1649	1640	1649	1644	1647	1754	1558	1562	1568	1567	1562	1550	1558	1543	1533	1542	1529	1525	1517	1522	1528	1533	1523

vacancies opened in 2015/2016 in all medical schools we see that, in the first years of planning period, we need to open more vacancies instead of closing them.

This result from the necessity of adjusting specialization vacancies over the planning period. However, one needs to critically analyze this result once we assumed dropout and attrition rates, and further analysis must be done.

Finally, based on a simple cost analysis, it is possible to verify that Model B results in a more expensive planning for Master's degree, while Model A results in a more expensive planning for the internship (see Table 5). The total training cost is 0,42% more expensive for Model A, so we can assume that there is almost no cost advantage in implementing one or another model's planning results.

Table 5 – Cost Analysis for both models.

Cost	Model A	Model B
Master's degree (€)	3 251 920 000	3 258 880 000
Internship (€)	6 299 256 172	6 251 981 161
Total Cost (€)	9 551 176 172	9 510 861 161

Sensitivity analysis

In order to understand the impact of uncertain parameters in planning decisions, we choose two different scenarios to perform a sensitivity analysis, Table 6.

Table 6 – Dataset used in both scenarios.

	Uncertainty source	Alteration (relative to base scenario)	
Scenario 1	*Gap*	Supply	- 5%
		Demand	+5%
Scenario 2	Friction factors	Emigration rate	+9%
		Migration to private sector rate	+5%

The results have shown to be sensitive to changes on both uncertainty sources. Scenario 1 results for both models in an increase on the number of specialties that have shortage of physicians after planning, when compared with the base-line scenario. The number of years necessary to annul de gap is also greater for scenario 1 for both mod els. These results were expected, since the new gap has a higher demand and lower supply of physicians.

Regarding the second scenario, the new fricction rates have no effect on the results of Model B. In Model A it results in more years to annul de gap and a higher number os specialties with shortage of professionals.

6. Discussion

Weaknesses of the models

Both models do not follow students that give up or fail at some point of training. In practice, students who fail exams can repeat them and finish the course later. Students who give up from medical school may return, since their vacancy is frozen for some years.

The internship model was simplified. We did not consider changes of specialty neither attritions. We know from ACSS experts that these are important uncertainties.

There are several sources of uncertainty that we did not explore in this study, such as: (i) students death; (ii) maternity/paternity leave; (iii) nº of students who return to Portugal after conclude medical school abroad; and (iv) nº of students from nursery schools and other courses who can apply for special vacancies in medical schools.

Limitations related to the dataset and assumptions used

In order to calculate the gap we used the demand estimated until 2020, using linear regression for data between 2020 and 2050.

Table 7 – Results of sensivity analysis for both scenarios and both models.

	Model A		Model B	
	Base-line	Scenario 1	Base-line	Scenario 1
Nº of specialties with professional shortage	24	33	0	29
Nº of years necessary to annul gap	15	24	15	35
	Base-line	Scenario 2	Base-line	Scenario 2
Nº of specialties with professional shortage	24	26	0	0
Nº of years necessary to annul gap	15	18	15	15

The emigration rate was estimated for all physicians instead of recently graduated physicians, and it is news-based. Dropout rates and migration to the private sector were assumed, requiring further analysis.

Note that all the rates used are the same for all specialties. In order to obtain more accurate results these rates should be specific for each field of specialization.

Discussion of the results obtained

Given the fragilities of dataset and assumptions used, the results obtained should be analyzed carefully. However, the results are sufficient to understand what kind of analysis can be made.

When it is not possible to annul the gap, at least two actions may be considered by the DMs: (i) when there is an oversupply, retraining strategies may be considered, for instance, physicians specialized in a field with an oversupply can be retrained and work in other specialties; and (ii) when there is a shortage of physicians, the model shows the period in which that shortage exists, and it is possible to contract foreign physicians only for the necessary period of time.

Since the emigration and migration to the private sector rates are important uncertainty sources, DMs may consider obligate recently specialized physicians to stay in the NHS for a given amount of years.

It is also very important for the DMs to remain alert to the political changes in Europe, in particular in countries where a tradition for Portuguese students studying medicine exists. Changes in their education system may have consequences on the Portuguese medical education system.

Since this is a strategic planning, the results obtained today may not be valid in 10 years, so it is necessary a continuous analysis and adaptation of the models to the different socio-economical scenarios.

DMs, stakeholders and experts in the healthcare workforce planning are extremely important in order to construct meaningful models. Their participation is fundamental to obtain the weights to prioritize vacancies opening between different fields of specializations. We also consider that there are other ways to minimize the gap, such as to: (i) minimize the maximum of the gap found; (ii) minimize the gap in the end of the planning period; or (iii) other ways that may be considered as proper by the DMs.

7. Conclusions and Further Work

Conclusions

Strategic planning of healthcare workforce is recognized as a health policy priority not only in Portugal, but also in the rest of Europe.

We have developed two models to support strategic planning of the healthcare workforce, that support DMs in planning the admissions of students in medical schools and the vacancies for different fields of medical specialization. The models developed are generic and can be applied in countries with a NHS and public medical training. Both MILP models are deterministic and mono-objective. Nevertheless, both models encapsulate several objectives and different concerns of stakeholders involved.

The development of these models contributes to the existing literature in the field and is an innovation in the Portuguese context. The contribution of this study to the literature is as follows: (i) it proposes a methodology to support the planning of medical training that not only considers the academic education but also internship training; (ii) it considers friction rates; (iii) it allows national planning; (iv) although these are mono-objective models, the proposed models are built in order to contain several needs and concerns of different stakeholders; (v) it allows DMs to choose the constraints to use and adapt the models, depending on the dataset and information available in each case; and (vi) it proposes a sensitivity analysis to explore the impact of uncertain parameters on planning decisions.

Finally, it is important to mention that the results discussed previously are preliminary and need further investigation.

Further Work

This work represents a first approach to a very complex problem and many aspects need further investigation.

Since the usefulness of the models and the accuracy of results is highly dependent on the dataset used, we suggest the implementation of an information system in order to collect the required data, especially dropout and attrition rates.

Taking into account the weaknesses of the developed models, we suggest some improvements, such as: (i) developing a multi-objective model, taking into account

the cost minimization and/or maximization of the equity (regional); (ii) developing a multi-criteria decision analysis (like MACBETH) in order to obtain weights to prioritize the opening of vacancies among different specialties (Oliveira et al, 2012; Cardoso et al, 2016); (iii) studying the nº of professionals who teach medicine; (iv) investigating the nº of Portuguese students studying abroad and the impact of their return on the internship vacancies; and (v) given the amount of uncertain parameters, it is important to extend models to stochastic formulation.

In addition to the models we have developed in this work, we suggest the extension of the models to nurses' training.

Since the costs were estimated, it is necessary to investigate further the real cost of a student (medical school and internship).

Finally, in addition to the mathematical tools developed, it is important to understand if the medical student's population represents Portuguese population regarding gender and ethnicity (Fritzen et al., 2007; Barbazza et al., 2015). If it is not, strategies for the improvement of this problem should be discussed and included in the models.

8. References

Anthony R.N. (1965). Planning and control systems: a framework for analysis. *Harvard Business School, Boston*.

Barbazza E, Langins M, Kluge H, Tello J. (2015). Health workforce governance: Processes, tools and actors towards a competent workforce for integrated health services delivery. *Health Policy*, 119, 1645-1654.

Barros P, Machado S, Simões J. (2011). Portugal: Health system review. *Health Systems in Transition*, 13(4), 1–156.

Cardoso T, Oliveira M. D, Barbosa-Póvoa A, Nickel S. (2016). Moving towards and equitable long-term care network: A multi-objective and multi-period planning approach. *Omega*. 58, 69-85.

Conceição C, Lima C, Ferrinho P. (2007). Reforming the Portuguese health services system: key human resources for health issues. *Cahiers de Sociologie et de Démographie Médicales*, 47(3), 241-257.

de la Torre R., Lusa A., Mateo O. (2016). A MILP model for the long term academic staff size and composition planning in public universities. *Omega*, 63, 1-11.

DGES. (2016). Site da Direção Geral de Ensino Superior, http://www.dges.mctes.pt/DGES/pt/, visited between March and June, 2016.

DN (2015). Ordem dos Médicos quer redução de vagas nas faculdades, in *Diário de Notícias*.

Dussault G, (2014) Roteiro de Intervenção Recursos Humanos em Saúde (RHS). Documento de Trabalho. Plano Nacional de Saúde 2012-2016.

EU. (2013). Site do Joint Action on health workforce planning and forecasting, http://healthworkforce.eu/, visited in February, 2016.

Fritzen S. (2007). Strategic management of the health workforce in developing countries: what have we learned? *Human Resources for Health,* 5:4.

Governo de Portugal. (2012). Revisão do Regime do Internato Médico. Relatório Final. Maio de 2012.

HEE. (2016). Site do Health Education England, https://hee.nhs.uk/about-us/, visisted in March, 2016.

Hu W, Lavieri M, Toriello A, Liu X. (2015). Strategic Health Workforce Planning. Available in http://www2.isye.gatech.edu/~atoriello3/hc_wf_plan_r3.pdf.

Lavieri M.S, Puterman M.L. (2009). Optimizing nursing human resource planning in British Columbia. *Health Care Management Science,* 12(2), 119-128.

Mestre A.M, Oliveira M.D, Barbosa-Póvoa A. (2015). Location-allocation approaches for hospital network panning under uncertainty. *European Journal of Operational Research,* 240 (3), 791-806.

Ministério da Saúde. (2014a). Balanço Social Global do Ministério da Saúde e SNS.

Ministério da Saúde. (2015a). Plano Nacional de Saúde. Revisão e extensão a 2020. Maio 2015.

Observador (2015). Ano de internato em Medicina "deixará de existir a partir de 2017/2018", in *Observador*.

OE. (2014). Dados estatísticos a 31-12-2013. Ordem dos Enfermeiros.

OECD. (2015). Health at a Glance 2015: OECD Indicators, *OECD Publishing*, Paris.

Oliveira M.D, Rodrigues T, Bana e Costa, C.A, Sá A.B. (2012). Prioritizing Health Care Interventions: A Multicriteria Resource Allocation Model to Inform the Choice of Community Care Programmes. In E. Tanfani and A. Testi (Editors) Advanced Decision Making Methods applied to Health Care. *Springer*, 141-154.

Ono T, Lafortune G, Schoenstein M. (2013). Health Workforce Planning in OECD Countries: A Review of 26 Projection Models from 18 Countries, *OECD Health Working Papers, 62, OECD Publishing*.

Perera F, Peiró M. (2012). Strategic Planning in Healthcare Organizations. *Revista Española de Cardiologia*. 65(8), 749-754.

Perfilieva G, Buchan J. (2015). Making progress towards health workforce sustainability in the WHO European region. *World Health Organization*.

Ribeiro J. et al. (2014) Health professionals moving to…and from Portugal. *Health Policy*, 114(2-3), 97-108.

Sakellarides C, Castelo-Branco L, Barbosa P, Azevedo H. (2014). The impact of the financial crisis on the health system and health in Portugal. *European Observatory on Health Systems and Policies*.

Santana P, Peixoto H, Duarte N. (2014). Demografia Médica em Portugal: Análise Prospetiva. *Acta Médica Portuguesa,* 27(2), 246-251.

Santos C, Beyer D, Brau E, Jain S. (2008). Methods for planning workforce resources. *United States Patent Application Publication*. Pub. No.: US 2008/0103868 A1.

Schell G.J, Lavieri M.S, Li X, Toriello A, Martyn K.K, Freed G.L. (2015). Strategic Modeling of the Pediatric Nurse Practitioner Workforce. *Pediatrics*, 135(2), 298-306.

Senese F, Tubertini P, Mazzocchetti A, Lodi A, Ruozi C, Grilli R. (2015). Forecasting future needs and optimal allocation of medical residency positions: the Emilia-Romagna Region case study. *Human Resources for Health,* 13:7.

Smits M, Slenter V, Geurts J. (2010). Improving Manpower Planning in Health Care. *23rd Bled eConference eTrust: Implications for the individual, enterprises and society.*

Srour I, Haas C, Morton D. (2006). Linear Programming Approach to Optimize Strategic Investment in the Construction Workforce. *Journal of Construction Engineering and Management*, 132(11), 1158-1166.

Stewart B.D, Webster D.B, Ahmad S, Matson J.O. (1994). Mathematical models for developing a flexible workforce. *Int. J. Production Economics,* 36(3), 243-254.

Van Greuningen M, Batenburg R.S, Van der Velden L. (2012). Ten years of health workforce planning in the Netherlands: a tentative evaluation of GP planning as an example. *Human Resources for Health,* 2012, 10:21.

Werker G. (2012). Strategic Resource Planning in Healthcare Under Uncertainty. *Master Thesis*. *The University of British Columbia*.

WHO. (2010). World Health Organization Evaluation of the National Health Plan of Portugal (2004–2010).

Wishon C, Villalobos J.R, Mason N, Flores H, Lujan G. (2015). Use of MIP for planning temporary immigrant farm labor force. Int. J. Production Economics, 170 (2015), 25-33.

Yu G, Pachon J, Thengvall B, Chandler D, Wilson A. (2004). Optimizing Pilot Planning and Training for Continental Airlines. *Interfaces*, 34 (4), 253-264.