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Multi-Criteria Analysis of Optimal Educational Teacher Allocation System

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Abstract: This paper presents a model for automatically selecting and allocating secondary education teachers to schools while considering various factors such as the diversity of sections and lessons, school distances, teacher specializations, teaching workloads, and other constraints. This poses a complex challenge that educational authorities in prefectures must address. Our proposed model is inherently multi-objective, as it encompasses a range of financial and pedagogical objectives. By employing this model, decision-makers can explore the competition between these objectives and the necessary trade-offs required to enhance performance in specific areas. To illustrate the model's practical applicability, we conducted a case study focusing on the Prefecture of Ilia in Western Greece.
Key words: education management; optimization; distribution; multicriteria analysis

Análisis multicriterio del sistema óptimo de asignación de profesores educativos
Resumen: Este artículo presenta un modelo para la selección y asignación automática de profesores de educación secundaria a las escuelas, considerando diversos factores como la diversidad de secciones y lecciones, las distancias entre las escuelas, las especializaciones de los profesores, las cargas de trabajo docentes y otras restricciones. Esto representa un

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desafío complejo que las autoridades educativas en las prefecturas deben abordar. Nuestro modelo propuesto es inherentemente multiobjetivo, ya que abarca una gama de objetivos financieros y pedagógicos. Al emplear este modelo, los tomadores de decisiones pueden explorar la competencia entre estos objetivos y los compromisos necesarios para mejorar el desempeño en áreas específicas. Para ilustrar la aplicabilidad práctica del modelo, realizamos un estudio de caso centrado en la Prefectura de Ilia, en el oeste de Grecia.
Palabras clave: gestión educativa; optimización; distribución; análisis multicriterio

Análise multicritério do sistema ótimo de alocação de professores na educação
Resumo: Este artigo apresenta um modelo para a seleção e alocação automática de professores de educação secundária às escolas, considerando diversos fatores como a diversidade de seções e aulas, as distâncias entre as escolas, as especializações dos professores, as cargas de trabalho docente e outras restrições. Isso representa um desafio complexo que as autoridades educacionais nas prefeituras precisam enfrentar. Nosso modelo proposto é inerentemente multiobjetivo, pois abrange uma gama de objetivos financeiros e pedagógicos. Ao empregar este modelo, os tomadores de decisão podem explorar a concorrência entre esses objetivos e os compromissos necessários para melhorar o desempenho em áreas específicas. Para ilustrar a aplicabilidade prática do modelo, realizamos um estudo de caso focado na Prefeitura de Ilia, no oeste da Grécia.
Palavras-chave: gestão educacional; otimização; distribuição; análise multicritério

Multi-criteria Analysis of Optimal Educational Teacher Allocation System

Literature Review

Operational Research (OR) methods have been employed to address a variety of problems in education. Typical examples include the allocation of pupils to schools (Singleton et al., 2011; Thelin & Niedomysl, 2015; Xavier et al., 2020) the calculation of land and real estate prices due to educational policy (Lee, 2015; Wen et al., 2018) or the allocation of school buildings (Murad et al., 2020). In many cases the research has been directed to higher education. Either to assign the courses to the lecturers in an optimal way (Cunha & Souza, 2018) or to achieve an improvement in the quality indicators of the education. This is achieved in a number of ways which have to do with selecting teachers for courses taking into account their preferences and workload (Domenech & Lusa, 2016). The workload is calculated by the authors considering various factors, which in this case is related to the functioning of the universities. Factors such as class capacity, course contact hours, course credits, and the number of courses per lecturer (Seboni et al., 2023). However, the applicability of OR methods in education has not been as widespread as one would expect due to several reasons that are mostly related to the realization that different approaches are adopted in different countries when it comes to educational policy and planning.

Especially in secondary education, the differences between countries are very large for many reasons. As a result, several studies have appeared in different countries that address different decision-making problems in the context of education. With respect to teacher shortages in the United States, researchers have identified low wages as a primary cause of this problem in many states. In addition to inadequate compensation, other factors contributing to the shortage include the distance between teachers' hometowns and their workplaces, as well as challenging working conditions (Darling-Hammond & Sykes, 2003; Ingersoll, 2001). The papers by Dur & Onur (2012), Gunawan & Ng (2011), Cechlárová et al. (2014), Koski & Horng (2007), Eir & June (2016) and Jaramillo (2012) discuss a variety of problems arising in the management of educational systems in different countries.

In Brazil, researchers developed an optimization model for the combined district-level planning problem of simultaneously allocating pupils to schools, sizing classes to fit available classroom infrastructure, matching teacher specializations to schools and to classes and classrooms, and minimizing student commuting times (Mayerle et al., 2022). However, the differences that prevail in each country, due to culture, economics, tradition, etc., have not facilitated the wide application of such decision models in other educational systems.

This paper discusses the problem of allocating secondary education teachers to schools and assigning them to classes considering different aspects of cost, the most important of which are monetary and pedagogical cost. In the Greek education system this task is undertaken by the Directorate of the Secondary Education Council of each Prefecture, mainly at the beginning of the academic year with placements of permanent teachers (Directorate of Secondary Education Ilia, 2022a) as well as temporary staff (Directorate of Secondary Education Ilia, 2022b).

The Greek Education System

In the Greek educational system, there are six (6) high school classes. According to the relevant legislation[1], each class can have general education sections where pupils attend general lessons and specialization sections where pupils study more specialized lessons such as Chemistry or Ancient Greek (Sections And Lessons In High School, 2013). The number of sections that will be made in each school has to do with the number of pupils and their preferences. Note that the legislation also determines the minimum number of pupils required to create a new section (Departmental Operating Requirements, 2019). A lesson is essentially a subject taught by a teacher to a specific class throughout the academic year. For example, "General Education Physics" for Class B of the Gymnasium is considered one lesson. Similarly, "General Education Physics" for Class C of the Gymnasium is treated as a separate lesson, as it may have different characteristics, such as the number of teaching hours per week or the assignment to specific teacher specialties.

Once all the sections are created across all schools, the demand for teachers is determined and the best allocation of the available resources is sought. Teachers are divided into 3 categories with respect to their labor status and into several specializations depending on their formal qualifications. The teachers of each specialization may be asked to teach certain lessons as their first, second or even third assignment depending on how closely these lessons are related to the specialization in question (General Lyceum Lesson Assignment Circular, 2018). Given a list of teachers of various specialties and working relationships on the one hand, and a list of sections in various schools on the other, the objective of the model is to allocate resources in the best possible way.

The educational policy of the Greek Ministry of Education aims to staff schools as quickly as possible. However, the needs of schools change each year due to several fluctuating factors, leading to both teacher shortages and surpluses. These factors include the number of pupils, their choice of lessons, teacher leaves and retirements, the presence of temporary staff, and changes in legislation. Frequent legislative changes, in particular, pose a significant challenge to Greek educational policy. As a result, at the beginning of each school year—and sometimes even during the school year—the Secondary Education Council of each Prefecture must decide where to place teachers based on current needs. These decisions are guided by national educational policy criteria.

When performing this exercise, the executives of each Education Directorate focus on balancing educational needs with cost reduction. As we will explore further, costs are influenced by the number of temporary staff hired each year, as well as by expenses related to overtime and travel for teachers who must cover positions at multiple schools.

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[1] The current legislation is particularly volatile as especially in education the laws succeed one another. Therefore, every reference to current legislation concerns the moment that the specific paper is written (2022). Despite the difficulties, an effort was made to make the model adaptable to these changes.

The allocation is assessed based on different aspects of cost. Starting with the obvious one, the monetary cost consists of extra teachers' salaries, travel costs (Travel expenses - domestic travel, 2015) and overtime costs (Information on overtime compensation for secondary school teachers, 2016). However, the monetary cost comes into conflict with the quality of the education provided. Specifically, efforts to reduce monetary costs may lead to the deterioration of other factors, such as the number of schools a teacher must visit or the lessons they must teach outside their main specialization.

Anxiety and depression are also factors that affect the educational work, as the need to travel long distances from their place of residence is a serious aggravating factor (Kalogianni, 2022) for each teacher. Fatigue is also created by the overtime that a teacher is asked to cover above his/her mandatory hours (Furihata et al., 2022). Apart from the fact that these factors contribute to the teacher's fatigue, the above conditions also burden his/her teaching and pedagogic work. In addition, the requirement to teach a lesson that is not the teacher's first assignment based on his/her specialization also reduces the quality of the education provided.

These factors, such as the need to travel to multiple schools and the requirement to teach outside of one's specialization, represent the pedagogical burden imposed on teachers. This burden, distinct from the direct monetary cost of their assignments, can be approximated by metrics like the total distance traveled, the number of schools visited, or the number of lessons taught outside of a teacher's area of expertise.

In prefectures with many schools and teachers, the process of allocating teachers to schools is painstaking and is completed in several phases, sometimes lasting more than 1 month, involving several meetings of the Secondary Education Council. This implies operational problems in schools, unnecessary expense of resources, errors, subjectivity and often difficulty in finding satisfactory solutions. In this paper, we develop a multi-objective mixed integer programming model to alleviate these problems, placing particular emphasis on the needs of pupils and teachers as human beings.

Our contribution can be summarized as follows:

- We have attempted to model various aspects of pedagogical cost, namely factors that adversely affect the quality of educational services offered.
- We introduce a new model for allocating teachers to schools considering monetary as well as pedagogical objectives.
- We employ this model to investigate the competitive nature of the different objectives and explore the tradeoffs that are implied when trying to improve some of them.
- We have applied the model in a real case study concerning a prefecture in Western Greece and have demonstrated how it can provide satisfactory solutions in realistic circumstances.
- In addition to the specific case study in Western Greece, the underlying principles of the model can be applied to other educational contexts with varying characteristics. This adaptability allows decision makers to tailor the model to fit the specific needs and challenges of different educational systems.

The proposed model may be used as a useful decision-making tool to assist planners to determine the allocation of teachers to schools that satisfy financial criteria and at the same time considers education needs and contributes to quality improvements. We have tried to model the problem as closely as possible to the current legislation. In fact, the variability and the unpredictable nature of the legislation significantly increases the complexity of the problem. It has been argued that only the changes in the legislation regarding the selection of Heads of School in the last decade constitutes a separate topic for research (Skrepetaris, 2019).

We introduce a mixed integer programming model that was implemented within the AIMMS environment for creating and solving optimization problems. We experiment with real data concerning the Prefecture of Ilia (Greece). It is a Prefecture where schools are scattered in small urban centers, in the mountains and in the plains. The biggest city (Pirgos) has 44.000 residents and the second largest has 29.000 residents (Amaliada; Aftodioikisi.gr, 2021). There are 57 schools of secondary education (Directorate Secondary Education Ilia, 2021) and the maximum distance between schools is 116 km with an average distance is 41,5 km (Ministry of Infrastructure Transport, 2023). Teachers' salaries are determined based on their years of service which is estimated taking into account an average value from active Greek teachers in Secondary Education (Kordis, 2016).

The rest of the paper is organized as follows: In the following section we formally present the nature of the problem. We then introduce the multi-objective mixed integer model for allocating teachers to schools and discuss its solution using the AIMMS modelling environment. In the next section we present the results of the model for the case study in Western Greece, and we finally draw some conclusions and indicate some possible directions for future research.

Conceptual Framework and Problem Specification

With respect to the conceptual framework of our study, our objective is to:

- firstly, determine the factors influencing the assignment of secondary education teachers to different schools in Greece;
- secondly, consider the implications of current teacher assignment practices on student achievement and teachers' satisfaction; and
- thirdly, develop a model that will support the decision makers to perform the assignment taking into account both monetary and pedagogical criteria.

Teachers are characterized by their specialization, years of experience and employment status whereas schools are characterized by their location and the set of lessons they must offer. Since teachers may need to visit multiple schools to cover their teaching schedule, there is a considerable monetary cost that is associated with such transfers that burdens the annual budget of the local Education Directorate. Apart from the financial aspects, the assignment of teachers to schools also influences the overall effectiveness of the teaching process. According to Darling-Hammond (2000), Ronfeldt et al. (2013), and Johnson et al. (2012), the appropriate assignment of teachers to schools impacts their effectiveness and is positively correlated with higher student achievement and better educational outcomes.

Consequently, our objective is to develop a modelling framework for assisting the relevant decision-makers, namely the Executives of the local Education Directorate, to perform teachers' assignment on a regular basis taking into account all the relevant criteria, monetary as well as pedagogical.

The challenge of allocating teachers to secondary schools across a wide geographical area is inherently multi-objective in nature as it involves at least two key criteria: the monetary cost and the pedagogical cost associated with teacher assignments. Monetary costs arise from the hiring of teachers to meet educational demands. Additionally, these expenses also rise as some teachers may be asked to work overtime or to commute between different schools. On the other hand, the pedagogical cost, as defined in this paper, refers to the impact on the quality of education provided. For instance, when teachers work overtime to address teaching needs, it can lead to increased fatigue, ultimately affecting the quality of instruction delivered in the classroom. These two cost factors, monetary and pedagogical, are in direct competition with one another.

Typically, improvements in one criterion tend to result in a deterioration of the other. This competitive relationship can be attributed to a variety of factors.

Assigning teachers to teach a subject other than their primary assignment may contribute to cost savings as it reduces the need to hire extra staff. However, it may significantly increase the educational burden for the teachers in question who may feel inadequate to teach these subjects compared to their first assignment subjects (Athanassoula, 2018). For instance, a Sociologist may be asked to teach, as a second assignment, Principles of Economic Theory which is examined on a nationwide basis as part of the university entrance exams. Although such an assignment may be financially beneficial since it will not be necessary to move a teacher of Economics from another school unit or to hire another teacher, it may also heavily increase the educational burden and the responsibility for the Sociologist in question who will be expected to teach at the highest level a subject he/she may not be familiar with.

Monetary savings are also possible when a teacher is working in different schools since he/she may serve the needs of various school units. At the same time this arrangement burdens the teacher's relationship with the school unit, the pupils, his/her colleagues, or the directors (Kokoviadou, 2021). It also burdens the school units themselves as they do not employ staff on a stable and permanent basis, making it difficult to resolve issues of educational everyday life.

Arguably, one of the most critical factors contributing to an increase in the pedagogical cost is the employment status of teachers. The job insecurity faced by temporary teachers, coupled with the financial challenges experienced by part-time temporary staff, places a substantial burden on educational work and medium- to long-term pedagogical planning, as argued by Kiriakaki & Loupi (2016) and Tsilafaki (2017).

Furthermore, due to their employment status, temporary teachers find themselves assigned to different school units each academic year, effectively changing their work environment approximately every 10 months across various locations in Greece. While these employment arrangements may benefit the state budget through reduced salary expenses, they also lead to increased levels of anxiety and insecurity among teachers, resulting in a notable increase in the associated pedagogical cost.

Since teacher commuting contributes to both monetary and pedagogical cost, its minimization is beneficial for both types of objectives. Every relocation incurs monetary expenses and contributes to teacher fatigue, as noted by Kalogianni (2022), both of which certainly impact teacher's performance. However, teacher commuting is sometimes unavoidable since some teachers cannot fulfill all their working hours within a single school unit.

It is worth noting that in a multi-objective system searching for an optimal solution, namely one that simultaneously optimizes all objectives, is a futile endeavor. What is optimal in terms of one objective may not be optimal for others. Methods developed for such systems aim to find a compromise or an intermediate solution that satisfies the decision-makers. In general, multi-objective analysis reflects the analyst's aspiration to make the model more realistic by accounting for multiple optimization objectives.

Mathematical Model

The essence of the proposed mathematical model is to determine the assignment of teachers to schools in a way that best fits the monetary and pedagogical criteria. Hence, the model can be thought of as a generalized multi-objective assignment problem. The main decision to be taken concerns whether or not a particular teacher will teach a lesson l at a school s. Based on this decision, the monetary cost of the aggregate assignment may be calculated as well as the various aspects of pedagogical cost. To formulate the problem, we consider the following sets, indices, and parameters.

Sets and Indices

S: set of schools, indexed by s, s_1
TL: set of lessons, indexed by l
E: set of teachers' specializations, indexed by e
I: set of teachers, indexed by i
A: set of teachers' employment status, indexed by a

Parameters

$TCWoH$: the cost of each overtime hour
$LH(l)$: the hours each lesson *l* is taught per week
$D(s,l)$: number of weekly hours for lesson l required at school s
$SE(a)$: the salary depending on the employment status α

$$TE(i,a) = \begin{cases} 1 & If\ teacher\ i\ belongs\ to\ employment\ status\ a \\ 0 & Otherwise \end{cases}$$

$$TLA(i,l) = \begin{cases} 1, & \text{if teacher } i \text{ can teach lesson } l \\ 0, & \text{otherwise} \end{cases}$$

$$TLAL(i,l) = \begin{cases} 1 & If\ teacher\ i\ has\ lesson\ l\ as\ 1st\ assignment \\ 2 & If\ teacher\ i\ has\ lesson\ l\ as\ 2st\ assignment \\ 3 & If\ teacher\ i\ has\ lesson\ l\ as\ 3st\ assignment \end{cases}$$

$$TMS(i,s) = \begin{cases} 1 & If\ teacher\ i\ has\ the\ main\ placement\ in\ school\ s \\ 0 & Otherwise \end{cases}$$

$$AoE(a) = \begin{cases} 1 & If\ employment\ status\ \alpha\ is\ for\ permanent\ teachers \\ 2 & If\ employment\ status\ \alpha\ is\ for\ substitute\ teachers \\ 3 & If\ employment\ status\ \alpha\ is\ for\ hourly\ teachers \end{cases}$$

$Dist(s, s_1)$: distance between schools s and s_1
$TCpKm$: The monetary compensation per kilometer

$$TC(s,s_1) = Dist(s,s_1) \times TCpKm \times 2\text{: Daily transfer cost from school } s \text{ to school } s_1$$

$TMWH(i)$: Maximum teaching load (hours) of teacher i depending on his/her employment status
$TMWoH(i)$: Maximum overtime hours of teacher i depending on his/her employment status

Decision Variables

$As(i,s,l)$: An integer specifying the number of lessons *l* that teacher *i* will take over in school *s*

$$Em(i) = \begin{cases} 1 & If\ teacher\ i\ is\ hired \\ 0 & Otherwise \end{cases}$$

$Dis(i,s)$: An integer indicating the days teacher *i* works at school *s*.

$$WSpT(i,s) = \begin{cases} 1 & If\ teacher\ i\ works\ at\ school\ s \\ 0 & Otherwise \end{cases}$$

$WoHpT(i)$: The number of overtime hours teacher *i* will take.
$TWH(i)$: The working hours of teacher *i*
$TWS(i)$: A variable that accounts for the pedagogical cost of serving multiple schools

The model is multi-objective as it includes six minimization functions, one of which refers to the monetary cost and the other five to the pedagogical cost, i.e., the cost that is related to the deterioration of the quality of education that is due to adverse teaching conditions. These minimization functions are formulated as follows:

(Model M1)

$$min\ z_1 = \sum_i \left(\sum_a (TE(i,a) \times SE(a)) \times Em\,(i) \right) + \sum_i TCWoH \times WoHpT(i) + \sum_i \sum_s \sum_{s_1} TC(s,s_1) \times TMS(i,s) \times DiS(i,s_1)$$

$$\min z_2 = \sum_i \sum_s \sum_{s_1} TMS(i,s) \times Dist\,(s,s_1) \times DiS(i,s_1)$$

$$min\ z_3 = \sum_i TWS\,(i)$$

$$\min z_4 = \sum_i WoHpT(i)$$

$$min\ z_5 = \sum_i \sum_s \sum_l As\,(i,s,l) \times TLAL\,(i,l)$$

$$min\ z_6 = \sum_i \sum_a TE\,(i,a) \times AoE\,(a) \times Em\,(i)$$

These functions are minimized subject to the following constraints:

Constraints

$$Em(i) \geq \frac{\sum_s \sum_l As(i,s,l)}{|TL|} \quad \forall\, i,s,l\ \in\ I,S,TL \qquad \text{(M1.1)}$$

$$Em(i) \leq \frac{\sum_s \sum_l As(i,s,l) \cdot LH_i}{0.9} \quad \forall\, i,s,l\ \in\ I,S,TL \qquad \text{(M1.2)}$$

$$\textstyle\sum_i \big(As\,(i,s,l) \times TLA\,(i,l)\big) = D\,(s,l) \quad \forall\, i,s,l\ \in\ I,\ S,\ TL \qquad \text{(M1.3)}$$

$$TWH\,(i) = \textstyle\sum_s \sum_l As\,(i,s,l) \times LH\,(i) \quad \forall\, i,s,l\ \in\ I,S,TL \qquad \text{(M1.4)}$$

$$TWH\,(i) \leq TMWH\,(i) + WoHpT\,(i) \quad \forall\, i \in I \qquad \text{(M1.5)}$$

$$DiS\,(i,s) \geq \frac{\sum_l As\,(i,s,l) \times LH\,(l)}{6} \quad \forall\, i,s,l\ \in\ I,S,TL \qquad \text{(M1.6)}$$

$$\textstyle\sum_s DiS\,(i,s)\ =\ Em\,(i) \times 5 \quad \forall\, i,\ s\ \in\ I,S \qquad \text{(M1.7)}$$

$$WSpT\,(i,s) \leq DiS\,(i,s) \quad \forall\, i,s\ \in\ I,S \qquad \text{(M1.8)}$$

$$WSpT\,(i,s) \geq \frac{DiS(i,s)}{5} \quad \forall\, i,s\ \in\ I,S \qquad \text{(M1.9)}$$

$$Em(i)\ \geq \frac{DiS(i,s)}{5} \quad \forall\, i,s\ \in\ I,S \qquad \text{(M1.10)}$$

$$WoHpT\,(i) \leq TMWoH\,(i) \times Em(i) \quad \forall\, i\ \in\ I \qquad \text{(M1.11)}$$

$$TWS\,(i)\ \leq 0.8 \times \textstyle\sum_s WSpT(i,s) \quad \forall\, i,s\ \in\ I,S \qquad \text{(M1.12)}$$

$$TWS\,(i)\ \geq \textstyle\sum_s WSpT(i,s) - 1.5 \quad \forall\, i,s\ \in\ I,S \qquad \text{(M1.13)}$$

$$\begin{gathered} As(i,s,l)\ \in \{0,1\} \quad \forall\, i,s,l\ \in\ I,S,TL \\ Em\,(i)\ \in \{0,1\} \quad \forall\, i\ \in\ I \\ TWS(i) \in \mathbb{Z}_+ \quad \forall\, i\ \in\ I \\ Dis(i,s)\ \in \mathbb{Z}_+ \quad \forall\, i,s\ \in\ I,S \\ WApT(i,s)\ \in \{0,1\} \quad \forall\, i,s\ \in\ I,S \\ WoHpT(i) \in \mathbb{R}_+ \quad \forall\, i\ \in\ I \\ TWH(i) \in \mathbb{R}_+ \quad \forall\, i\ \in\ I \end{gathered}$$

(M1.14)

The first objective function (z_1) minimizes the total cost associated with employing teachers. More specifically, the first term refers to the salary expenses, while the second term addresses the total cost incurred due to overtime employment and the third term expresses the total monetary cost of transfers for teachers required to relocate to schools other than their primary base. Travel costs arise if we multiply the distance between the two schools (the basic placement and the school where the teacher will travel to complete his/her hours) by the compensation per kilometer paid by the Ministry. Finally, this product is multiplied by two because the return is also taken into account.

The second objective function (z_2) minimizes the total pedagogical cost of transfers for teachers required to relocate. It needs to be minimized since the necessity to switch between various schools not only raises financial expenses but also places a substantial pedagogical burden on teachers. Objective function z_3 minimizes the pedagogical cost associated with the number of schools that a teacher may be assigned to. Clearly, the more schools that a teacher must visit, the harder it is for them to achieve the highest level of their teaching ability. Objective function z_4 refers to the pedagogical burden imposed on teachers who must work overtime. Objective z_5 minimizes the pedagogical cost associated with teachers having to teach lessons other than their first assignment according to their specialization. Note, that parameter $TLAL(i,l)$ is essentially a penalty that increases this aspect of pedagogical cost the further that lesson l is from the main specialization of teacher i. Finally, objective function z_6 minimizes the pedagogical cost associated with teachers' employment status. To elaborate, parameter $AoE(a)$ is assigned a value according to the insecurity of employment status a. The more insecure the employment status e.g., for hourly teachers, the higher the value of the parameter.

Moving on to the constraints of the model, constraints (M1.1) ensure that the binary variable $Em(i)$ takes value 1 whenever teacher i is assigned at least one lesson. If teacher i is assigned at least one lesson, then the right-hand side of the constraint is greater than zero which forces variable $Em(i)$ to take the value 1. Otherwise, the right-hand side of the constraint is equal to zero and as a result $Em(i)$ is also equal to zero due to the minimization of the objective functions. On the other hand, constraints (M1.2) force variable $Em(i)$ to take value 0 when teacher i is not assigned any teaching hours. Constraints (M1.3) stipulate that each lesson must be assigned to teachers that are eligible to teach it. Constraints (M1.4) define the total teaching load of each teacher i as the sum of all hours assigned to him/her whereas constraints (M1.5) restrict this teaching load to the maximum allowed teaching load according to the teacher's employment status. Furthermore, constraints (M1.6) imply that the days a teacher spends at a certain school should be at least those corresponding to 6 teaching hours per day while constraint (M1.7) ensures that each teacher is employed exactly 5 days a week. Constraints (M1.8) and (M1.9) guarantee that the binary variable $WSpT(i,s)$ is assigned the value 1 only when teacher i is employed at school s and 0 otherwise. More specifically, if variable $Dis(i,s)$ is equal to 0, then the binary variable $WSpT(i,s)$ that expresses whether teacher i is employed at school s, is forced to take value 0. Otherwise, if $Dis(i,s) > 0$, the variable $WSpT(i,s)$ is forced to take value one, due to constraint (M1.9). Similarly, constraints (M1.10) ensure that a teacher i cannot appear to be spending days at any school s unless he/she is employed. Constraints (M1.11) stipulate that the overtime hours assigned to each teacher cannot exceed the maximum overtime hours applicable to his/her employment status. These constraints also enforce that a teacher that is not employed cannot be assigned any overtime hours. Constraints (M1.12) and (M1.13) specify that the pedagogical cost implied by working at multiple schools is zero if the teacher is employed at only one school and then increases by one for each additional school where the teacher is employed. Finally, constraints (M1.14) concern the nature of the decision variables.

Solution Process

The model presented in the previous section considers multiple objectives to be optimized. It is evident that these objectives can sometimes conflict with one another. Various techniques have been developed to address these challenges. One of the most common ones is Goal Programming (GP) which has been used to address problems from a wide range of applications such as finance (Ballestero & Romero, 1998) or, more recently, problems related to macroeconomic issues and environmental policies (André & Cardenete, 2009; André et al., 2009). The popularity of GP can be attributed to the fact that it is easy to understand and to explain to decision makers. Additionally, GP relies on the active engagement of the decision makers in the whole process, which is always desirable in realistic problem situations.

The essence of GP is to define an equality constraint for each objective k in the multi-objective problem in question:

$$z_k + n_k - p_k = t_k \qquad k \in (1, \dots, 6) \qquad \text{(M2.1)}$$

Where:

z_k is the achievement function of the k-th objective,

t_k is a desired target value for objective k, as set by the decision makers,

n_k is the underachievement with respect to the target value t_k measuring possible outcomes below the target,

p_k is the overachievement variable, measuring possible outcomes above the target.

Hence constraints (M2.1) are added to the problem formulation presented in the previous section as well as non-negativity conditions for the deviation variables n_k and p_k, i.e.

$n_k \geq 0$ and $p_k \geq 0$ for all k

The target values t_k are typically set by decision-makers based on strategic priorities, historical data, prior knowledge related to the problem, and specific expectations. These values also take into account resource limitations and other constraints. Targets are often refined through a sensitivity analysis process, which examines how changes in these values may impact the overall solution.

The objective function concerns the minimization of some function of the unwanted deviation variables, depending on the nature of the objectives. In our proposed model all objectives concern some type of cost, financial or other, which implies that the unwanted deviation variables are the overachievements p_k for all k. These deviation variables express the amount by which we exceed the target value for each minimization objective. Hence, the GP formulation of our assignment problem, with the six objectives described in the previous section, may be stated as follows:

(Model M2)

$Min \quad z = g(p_1, p_2, \dots, p_6)$

Subject to the constraints:

(M1.1) to (M.14) from Model M1

(M2.1)

$n_k \geq 0$ and $p_k \geq 0$ for all k

In general, function $g(p_1, p_2, \dots, p_6)$ may be any increasing function with respect to the unwanted deviation variables. A commonly used form that helps to limit model complexity is the linear form. Furthermore, because the unwanted deviation variables are measured in different units, they cannot be directly compared. To address this, they are expressed as percentage deviations relative to their respective target values. Consequently, the objective function to be minimized becomes:

$$Min \;\; z = \sum_{k=1}^{6} \frac{p_k}{t_k}$$

As reported by Tamiz & Jones (1996) the minimization of this objective function above may lead to inefficient solutions, in the sense that it may be possible to improve one objective without deteriorating any other. One way to check the resulting solution for efficiency is to perform a test introduced by Hwang & Masud (1981) which relies on the maximization of the wanted deviation variables subject to constraints that ensure that the achievement of the goals from the GP model (M2) is not degraded. More simply, the following optimization problem is formulated:

(Model M3)

$$Max \quad z' = h(n_1, n_2, \ldots, n_6)$$

Subject to:

$z_k \leq z_k^*$ for all k (M3.1)

All the other constraints of model M2

where z_k^* is the value of the k-th objective obtained by the solution of model M2.

Similarly to the objective function of model M2, the objective function of model M3 is also expressed in linear form as follows:

$$Max \;\; z' = \sum_{k=1}^{6} \frac{n_k}{t_k}$$

The proposed model is linear as it includes only linear objective functions and linear constraints. It may be solved using any available software that is capable of solving Linear Programming (LP) problems e.g. CPLEX, Gurobi, etc. It is important to note that model M3 is solved after model M2. Specifically, the objective values obtained from solving model M2 are used as constraints in model M3. The model was applied to a case study concerning the assignment of teachers to schools in the Prefecture of Ilia, Western Greece.

Case Study: The Region of Ilia, Western Greece

The proposed model has been applied to a case study in the Prefecture of Ilia, Western Greece which is a typical region in the Greek territory in the sense that it includes both coastal and mountainous areas and has a total population of around 150,000 inhabitants living in 7 major municipalities. The model was implemented within the AIMMS modelling environment. The data is stored in two main spreadsheet (Excel) files, the one containing stable data such as distances and legislative issues and the second data that changes periodically such as the availability of teaching staff or the demand for lessons in different schools.

More specifically, the first "fixed data" file (Gavriil, 2021a) contains distinct fields, derived from the region's geography and the relevant legislation. These fields include School names, Specialty names, Lessons titles etc. (see details in the Appendix). In general, this file contains parameters of the problem that do not change often. The second data file (Gavriil, 2021b) contains the fields, which result from data available to the education directorates of each prefecture (see details in the Appendix). Naturally, these data vary from prefecture to prefecture and from year to year. Obviously, the data from the second excel file is also the one that changes every year. Whereas the data from the first excel file either hardly ever changes or changes every few years. In Greece, unfortunately, the legislation changes frequently.

The dataset is substantial, even for comparatively smaller prefectures like Ilia. To provide a sense of the scale of the challenge, the data for the prefecture of Ilia is as follows:

Number of schools: 57
Number of different lessons: 109
Number of specialties: 18
Number of employment statuses: 3 main, 32 secondary (from hours available to permanent and hourly teachers)
Number of lessons (demand) requiring staff coverage: 79
Number of available teachers (supply) of various specialties and employment statuses: 100

Based on this data, the initial model (model M1) consists of approximately 640,000 variables and 40,000 constraints.

The model was developed using the AIMMS platform, which incorporates an algebraic modeling language and is linked with various optimizers for solving optimization problems. It was implemented on a computer system equipped with an Intel i5 processor and 8 GB of RAM, utilizing CPLEX as the optimizer, with a maximum allowed solution time of 30 minutes.

Preliminary Analysis

In the analysis of multi-criteria problems (André et al., 2009), a typical initial step involves constructing a payoff table. This table essentially reports the performance of other objectives when a specific objective is optimized. It highlights the competitive dynamics among the objectives of the problem and the degree to which one objective deteriorates when one other objective is improved. Table 1 shows the payoff table for the application of the model to the prefecture of Ilia.

Table 1

Payoff Table for the Prefecture of Ilia

	Monetary cost	Pedag. transfers	Pedag. num. of schools	Pedag. overtime	Pedag. assignment	Pedag. empl. status
Monetary cost	**65289**	19689	<u>76</u>	18880	<u>195</u>	5
Pedag. transfers	512131	**10291**	59	92800	182	60
Pedag. num. of schools	<u>867316</u>	<u>109276</u>	**5**	<u>156800</u>	185	<u>81</u>
Pedag. overtime	473744	67824	74	**0**	191	52
Pedag. assignment	632576	89856	50	118400	**148**	62
Pedag. empl. status	136400	27120	63	70400	190	**3**

Each row of the table concerns the optimization of each separate objective. The optimal value of the objective is indicated in bold. The remaining entries in the row report the values of the other objectives when the row objective is optimized. For each objective, the worst (maximum) value is underlined.

From this table, the conflict between the criteria, particularly monetary and pedagogical aspects, becomes apparent. Specifically, in instances where the monetary cost is minimized, two pedagogical criteria reach their maximum values namely, the number of schools and the assignment of another subject.

Nevertheless, conflicts arise among pedagogical criteria as well. For instance, when aiming to minimize the pedagogical cost related to the number of schools, two other pedagogical criteria reach their least favorable values. Similarly, when minimizing the pedagogical cost associated with assignments, two additional pedagogical criteria—specifically, those related to work situation and overtime—attain their second least favorable values.

Solution of GP Model – Stage 1

From Table 1 it becomes clear that none of the optimal solutions for each objective can be accepted. Hence, the Goal Programming (GP) approach is employed to obtain a satisfactory solution. As a first step, the average value of each objective is used as a target value, namely $t_k = av_k$ for all objectives k, where av_k is the average value of objective k from the payoff table. These average values are shown in Table 2.

Table 2

Average Value for Each Objective

Objective	**Average Values** (after objective minimization)
Monetary Cost (in Euros)	447910
Transfer Cost (pkm)	54010
Pedagogical Cost of Number of Schools	55
Pedagogical Cost of Overtime	76213
Pedagogical Cost of Assignment	182
Pedagogical Cost of Employment Status	44

Note that the pure monetary cost is stated in monetary units (Euros) whereas the various aspects of the pedagogical cost are expressed by penalty functions that increase as the corresponding pedagogical conditions deteriorate. The objective function of the GP model to be minimized expresses the sum of the percentage unwanted deviations of all objectives with respect to their target values:

$$Min \ \ z = \sum_{k=1}^{6} \frac{p_k}{t_k}$$

Subject to all the constraints of the GP model M2.

The optimal solution to the GP model returns zero values for all unwanted deviations ($p_k = 0$) which implies that all target values are satisfied. Hence, it is necessary to perform the test introduced by Hwang & Masud (1981) to ensure that the final solution is efficient in the sense that it is not possible to improve the value of one objective without deteriorating another.

Solution of GP Model – Stage 2

To test whether the solution obtained at Stage 1 is efficient or not, we need to maximize a function of the wanted deviation variables, namely:

$$Max \ \ z' = \sum_{k=1}^{6} \frac{n_k}{t_k}$$

subject to the following constraints:

$$z_1 \leq \text{Total\_Cost\_Achievement}$$
$$z_2 \leq \text{Transp\_Cost\_Achievement}$$
$$z_3 \leq \text{Num\_of\_Schools\_Achievement}$$
$$z_4 \leq \text{Overtime\_Achievement}$$
$$z_5 \leq \text{Assignment\_Achievement}$$
$$z_6 \leq \text{Empl\_Status\_Achievement}$$

Constraints of model M2

These constraints ensure that the achievement of the six goals from Stage 1 of the GP model is not degraded. The results for each objective in comparison to the corresponding ideal value are shown in Table 3.

Table 3

Deviations (%) from Objectives' Ideal Values

Objective	Best Value	Results after 2nd stage of GP	% Deviation
Monetary Cost	65289	102979	58
Pedag. Cost of Transfers	10291	21379	108
Pedag. Cost Num of Schools	5	46	820
Pedag. Cost Overtime	0	3840	∞
Pedag. Cost Assignment	148	162	9
Pedag. Cost Employment Status	3	6	100

We observe deviations from the ideal values ranging from 9% to infinity. This variability is anticipated, considering the competitiveness of the criteria. The most extreme discrepancies arise in the pedagogical cost associated with overtime and the pedagogical cost related to the number of schools. Such variations are expected, as minimizing the sum of overtime hours results in an ideal value of zero. This occurs when educational needs are met by increasing the number of employed teachers. A similar situation occurs when examining the pedagogical cost associated with the number of schools whose ideal value is near zero. However, as soon as other objectives are considered, it is beneficial to relocate teachers to neighboring schools.

Although the comparison with the ideal values of each objective seems disappointing at first sight, the following table shows a more optimistic side. Table 4 shows the percentage deviations from the average value of each objective, calculated over its values when the other objectives are optimized.

Table 4

Deviations (%) from Objectives Average Values

Objectives	Average Value	Results after 2^{nd} stage of GP	% Deviation
Monetary Cost	447910	102979	-77
Pedag. Cost of Transfers	54010	21379	-60
Pedag. Cost Num of Schools	55	46	-16
Pedag. Cost Overtime	76213	3840	-95
Pedag. Cost Assignment	182	162	-11
Pedag. Cost Employment Status	44	6	-86

Table 4 presents a more optimistic outlook, as the values of all objectives constitute substantial improvements compared to the average values. These improvements range from 11% for the pedagogical criterion of the assignment to 95% for the pedagogical cost of overtime. This solution is satisfactory across all objectives and may be used as a viable starting point for relevant directors in determining the final assignment. As far as the computation times are concerned, Stage 1 was solved to optimality and Stage 2 was terminated after 30 minutes with an optimality gap of 0.82%, indicating that the final solution is very close to the optimal one.

We tried changing some parameters to see the changes in the results. In this way, we wanted to show that educational policy planners have a useful tool in their hands that, in a minimum of time and without errors, they can see the results of some changes that may arise either from their own decision or from external factors. The first we have tried is a large increase in fuel prices which will lead to corresponding compensation for teachers moving from one school to another to meet educational needs. The current compensation in Greece is €0.15 for each kilometer. The results we had with this compensation are mostly those reported in this paper, with additional data listed in Table 5. Data such as:

- Compensation per kilometer in euros
- Number of recruits
- Total overtime
- Recruitment and travel costs
- Pedagogical costs: serving several schools, level of lessons assignment, employment status

We assumed a new compensation of €0.30, which is more realistic even with today's fuel prices (in Greece the average price of a liter of unleaded is €1.75/lt - 09/2024). As we can see from the results shown in Table 5, the cost of travel increased dramatically. However, it did not double as the compensation per kilometer because the model chose to hire an hourly teacher. (Let's not forget that the cost of travel affects the pedagogical cost due to teacher fatigue). In other words, increasing recruitment costs was preferred as a solution. A reduction in overtime hours was also observed, probably because due to the increased cost of travel, teachers are not as easily moved while being burdened with teaching hours at another school. Correspondingly, the pedagogical cost of serving in other schools and assignments also decreased, precisely because of this limitation of movements.

Table 5

Results Before and After Changing Some Parameters

	Results from application of original data	Results after doubling compensation	Results after compensation subsidy	Results after removing overtime
Compensation per km (€)	0,15	0,3	0,05	0,15
Recruitment of substitute teachers	6	6	6	11
Recruitment of hourly teachers	0	1 for 15 hrs per week	0	0
Number of permanent teachers covering school vacancies	23 with 10 hrs available per week	23 with 10 hrs available per week	24 with 10 hrs available per week	20 with 10 hrs available per week
Total number of overtime hrs	12	7	12	0

	Results from application of original data	Results after doubling compensation	Results after compensation subsidy	Results after removing overtime
Recruitment cost (€)	77.760	100080	77.760	142.560
Travel cost (€)	21.379	38112	7.126	21.350
Pedagogical cost of number of schools	46	45	46	42
Pedagogical cost of assignment level	162	158	162	157
Pedagogical cost of employment level	6	9	6	11

Let us now assume that a subsidy for travel costs is provided by the Ministry of Finance, reducing the burden on the education directorates to just €0.05 per kilometer, compared to the initial €0.15 per kilometer. As we can see in Table 5, one more permanent teacher is chosen to move, while at the same time the cost of moving is greatly reduced.

The last change in the parameters is the abolition of overtime. This is very easily achieved in the model by either changing a constraint, or simply setting a very large cost for each hour of overtime. In this case, because the model cannot give many hours of overtime to permanent staff, it hires several additional substitute teachers, simultaneously increasing the cost of recruitment. However, the pedagogical cost of serving in many schools and the corresponding assignments are reduced since staff are hired in appropriate locations and with the appropriate specialty.

Discussion, Conclusions and Prospects

Teacher shortages in some states of America can be addressed through several strategies, according to studies (Darling-Hammond & Podolsky, 2019; Darling-Hammond & Sykes, 2003), which can also be applied to Greek education policy. These strategies include proper funding of schools, competitive remuneration for teachers in order to attract and retain talented teachers, careful recruitment by hiring teachers who demonstrate a strong commitment and willingness to teach and, finally, overall support for new teachers and improvement of their working conditions. These strategies are essential to create a robust educational workforce capable of delivering quality education to all pupils. Also supporting working conditions is a key factor for education systems in all countries (Podolsky et al., 2019).

A teacher allocation model would be highly beneficial, particularly for education policy in Greece. This model combines factors that improve the quality of education with decision-making management science, offering several advantages. For instance, it saves time for the executives of local Education Directorates who are responsible for allocating teachers, and it minimizes errors related to human judgment. Another significant advantage of this model is that it considers pedagogical factors in addition to financial ones. It is crucial for a country's educational policy to focus on enhancing the quality of education provided. As discussed earlier in this article, key factors contributing to this improvement include reducing teachers' fatigue from frequent relocations, allowing them to teach in fewer schools, and minimizing overtime.

This paper demonstrates how GP models may be utilized to develop educational policies that consider a variety of objectives, both monetary and pedagogical. The formulation of different objectives allows the analyst to take into account multiple factors such as the cyclicality of incomes, the future performance of educational work (McMahon, 2008), the cost in human lives due to commuting (Delgado-Fernández et al., 2022), the environmental footprint of commuting (Matz et al., 2019), insurance contributions, the invalidation of degrees through second and third assignments, etc.

While the impact of education, particularly in the primary and secondary sectors, extends into various unpredictable facets of life beyond the reach of computer models, we feel that the proposed model can serve as an invaluable tool for regional educational planners. It facilitates improved resource utilization and efficient allocation of teachers to schools. As a decision aid, this model can be employed either autonomously or in conjunction with human intervention.

Our model, following linear programming methodologies and allied with the versatile and powerful AIMMS software, manages to solve a problem with 640,000 variables and 40,000 constraints. It accepts two excel files as input and determines the placements of teachers in schools in a few minutes, satisfying all the constraints that have been set. Once the optimal solution has been calculated, each school and subject-class will have a designated teacher assigned to it. This ensures that the right teacher is allocated to each specific lesson. At the same time, the system provides detailed information about each teacher, including the schools they will serve, the number and types of lessons they will teach, and the associated costs for the prefecture's education directorate, such as recruitment, travel, and overtime expenses.

However, the results produced by the model after the processing process are not only the lesson assignments and the monetary cost of education. The pedagogical cost of these assignments is also calculated, i.e., a large part of the quality offered in the schools of the specific prefecture. As we can see in the results for the specific instance of the model (Table 4), after the second level of goal programming we have achieved the following compared to the average values from different model solutions:

- Reduce the monetary cost by 77%.
- Reduction of pedagogical cost caused by teacher transfers from school to school by 60%.
- Reduction of pedagogical cost by serving in many schools of teachers by 16%.
- Reduction of pedagogical cost due to teachers taking overtime hours by 95%.
- Reduction of pedagogical cost of assigning lessons to teachers of different levels compared to the first level of assignment by 11%.
- Reduction of pedagogical cost due to job insecurity from the various employment regimes by 86%.

In terms of saving time, it is estimated that the assignment of teachers to schools in a large educational directorate requires the engagement of five people for 3 hours per day each for an entire month. Across all 50 educational directorates of Greece, this translates to around 10,000 person-hours. Using the proposed model, a highly satisfactory solution to the problem can be obtained within only 30 minutes. In addition, the implementation of the model in question creates a sense of objectivity for teachers as it eliminates any suspicions of favoritism or bias in the assignment process.

Apart from the cost and time savings, the proposed model also helps to reduce accidents and the environmental footprint of travel as it reduces the kilometers implied by the final allocation. The quality of education is also promoted as the fatigue of teachers is directly incorporated into the analysis as well as the teaching of subjects that are closer to each teacher's specialization. Factors such as overtime, serving multiple schools, and employment status are evaluated in relation to their monetary benefits, leading to the selection of the most satisfactory solution.

It is also important to consider the fact that having a model for allocating teachers to schools introduces flexibility into the planning process. This flexibility enables rapid adjustments and improvements whenever conditions change. For instance, changes in the relevant legislation or fluctuations in the availability of teachers may be easily accommodated into the decision-making process. This model allows the easy formulation of educational policy, at least for the Greek educational system. At the Ministry of Education level, this model can be run on powerful computers to reduce costs while simultaneously improving the quality of education. By leveraging technology, decisions can be made efficiently, minimizing time and human effort and reducing the risk of errors in implementing educational policy. Furthermore, changes in specific parameters, such as cost coefficients, can be easily and effectively considered.

By adjusting key parameters like the permissible assignment of lessons for each specialization or by modifying fundamental sets like the set of employment statuses, the model can be adapted to accommodate teacher assignments in diverse educational systems. Consequently, the proposed framework is highly flexible and can be applied to a wide range of educational contexts, demonstrating its potential for addressing various teacher assignment challenges and for achieving the following policy objectives:

- Effective allocation of teachers to schools based on pupils' needs, school resources, and teacher qualifications.
- Teacher mobility and retention by reducing their educational burden and by addressing teacher burnout and improving job satisfaction.
- Equity and fairness by ensuring that all pupils have access to qualified teachers, regardless of their socioeconomic background or location.
- Cost-effectiveness by reducing the monetary costs of the assignment.
- Educational objectives by achieving a creative learning environment for teachers and pupils alike.

In closing, we should mention that the application of operational research models in education, as well as the introduction of objectives other than monetary ones highlights several promising research directions. Firstly, since the solution of large instances of integer programming models may be time consuming, it is important to investigate whether heuristic solution methods may be developed to provide good solutions to the problem in short computation times in comparison to exact methods. It may be also worth investigating whether the proposed model may be extended to include the uncertainty that is often inherent in realistic applications, especially the ones that are more human centered in nature.

References

Aftodioikisi.gr. (2021). *Apografi 2021 Greece*. https://www.aftodioikisi.gr/ota/dimoi/apografi-2021-o-plithysmos-ana-dimo-pinakes/

André, F. J., & Cardenete, M. A. (2009). Designing efficient subsidy policies in a regional economy: A multicriteria decision-making (MCDM)-computable general equilibrium (CGE) approach. *Regional Studies*, *43*(8), 1035–1046. https://doi.org/10.1080/00343400802049062

André, F. J., Cardenete, M. A., & Romero, C. (2009). A goal programming approach for a joint design of macroeconomic and environmental policies: A methodological proposal and an application to the spanish economy. *Environmental Management*, *43*(5), 888–898. https://doi.org/10.1007/s00267-009-9276-x

Athanassoula, A. (2018). *Recording non-biology teachers' views on teaching biology.* [Postgraduate Thesis]. Democritus University of Thrace.

Ballestero, E., & Romero, C. (1998). *Multiple criteria decision making and its applications to economic problems*. Springer Science. https://doi.org/10.1007/978-1-4757-2827-9

Cechlárová, K., Eirinakis, P., Fleiner, T., Magos, D., Mourtos, I., & Oce, E. (2015). Approximation algorithms for the teachers assignment problem. *3th International Symposium on Operational Research*, *5*, 479–484.

Da Cunha, J. J., & de Souza, M. C. (2018). A linearized model for academic staff assignment in a Brazilian university focusing on performance gain in quality indicators. *International Journal of Production Economics*, *197*(March 2017), 43–51. https://doi.org/10.1016/j.ijpe.2017.12.010

Darling-Hammond, L. (2000). Teacher quality and student achievement: A review of state policy evidence. *Education Policy Analysis Archives*, *8*. https://doi.org/https://doi.org/10.14507/epaa.v8n1.2000

Darling-Hammond, L., & Podolsky, A. (2019). Breaking the cycle of teacher shortages: What kind of policies can make a difference? *Education Policy Analysis Archives*, *27*. https://doi.org/10.14507/epaa.27.4633

Darling-Hammond, L., & Sykes, G. (2003). Wanted: A national teacher supply policy for education: The right way to meet the "highly qualified teacher" challenge. *Education Policy Analysis Archives*, *11*, 1–55. https://doi.org/10.14507/epaa.v11n33.2003

Delgado-Fernández, V. J., Rey-Merchán, M. D. C., López-Arquillos, A., & Choi, S. D. (2022). Occupational traffic accidents among teachers in Spain. *International Journal of Environmental Research and Public Health*, *19*. https://doi.org/10.3390/ijerph19095175

Directorate_Secondary_Education_Ilia. (2021). *Schools statistics in Ilia perfecture*. http://dide.ilei.sch.gr/index.php/sxol-monades/

Directorate_Secondary_Education_Ilia. (2022a). *Dispositions of teachers to complete the schedule*. http://dide.ilei.sch.gr/index.php/2022/10/07/6149/

Directorate_Secondary_Education_Ilia. (2022b). *Placements of Deputy Teachers 3-10-2022*. http://dide.ilei.sch.gr/index.php/2022/10/05/6140/

Domenech, B., & Lusa, A. (2016). A MILP model for the teacher assignment problem considering teachers' preferences. *European Journal of Operational Research, 249*(3), 1153–1160. https://doi.org/10.1016/j.ejor.2015.08.057

Dur, U., & Kesten, O. (2018). Sequential versus simultaneous assignment systems and two applications. *Economic Theory*, *68*, 251–283. https://doi.org/10.1007/s00199-018-1133-9

Eiriksdottir, I. L. (2016). *Optimization model for assigning teachers to classes*. Reykjavik University.

Furihata, R., Kuwabara, M., Oba, K., Watanabe, K., Takano, N., Nagamine, N., Maruyama, Y., Ito, N., Watanabe, I., Tsubono, K., Ikeda, C., & Sakamoto, J. (2022). Association between working overtime and psychological stress reactions in elementary and junior high school teachers in Japan: A large-scale cross-sectional study. *Industrial Health*, *60*(2), 133–145. https://doi.org/10.2486/indhealth.2021-0069

Gavriil, K. (2021a). *Data from law, Geography and Secondary Education of Pyrgos*. https://docs.google.com/spreadsheets/d/1ctTqomskXI_vjhnKaPSRuvLd-Y8bhCKH/edit?usp=share_link&ouid=116919517587003796435&rtpof=true&sd=true

Gavriil, K. (2021b). *Data from Secondary Schools of Pyrgos* (p. 7). https://docs.google.com/spreadsheets/d/1Xjg48nTKBwdASGDFz_rCwhjlaemIHC8z/edit?usp=share_link&ouid=116919517587003796435&rtpof=true&sd=true

General High School Lesson Assignment legislation, Pub. L.No. 76099/D2 (2018). http://www.minedu.gov.gr

Gunawan, A., & Ng, K. M. (2011). Solving the teacher assignment problem by two metaheuristics. *International Journal of Information and Management Sciences*, *22*(1), 73–86. https://doi.org/10.1177/004057368303900411

Hwang, C. L., & Masud, A. S. M. (1979). *Multiple objective decision making: Methods and applications; A state-of-the-art survey* Springer Science. https://doi.org/10.1007/978-3-642-45511-7

Information regarding overtime compensation for teachers Department of Education, Pub. L.No. 26020/E2 (2016). https://www.esos.gr/arthra/42441/ti-ishyei-gia-tin-yperoriaki-apozimiosi-ton-ekpaideytikon-dthmias-ekpsis

Ingersoll, R. M. (2001). Teacher turnover and teacher shortages: An organizational analysis. *American Educational Research Journal*, 499–534. https://journals.sagepub.com/doi/10.3102/00028312038003499

Jaramillo, M. (2012). The spatial geography of teacher labor markets: Evidence from a developing country. *Economics of Education Review*, *31*(6), 984–995. https://doi.org/10.1016/j.econedurev.2012.07.005

Johnson, S. M., Kraft, M. A., & Papay, J, R. (2012). How context matters in high-need schools: The effects of teachers' working conditions on their professional satisfaction and their students' achievement. *Teachers College Record*, 1–39. https://doi.org/10.1177/016146811211401004

Kalogianni, C. (2020). *Investigating anxiety and depression in substitute teachers with frequent commuting*. Postgraduate Thesis. University of Thessaly, Greece.

Kokoviadou, Th. (2021). *Work stress and the efficiency of secondary education teachers: The case of the Regional Unit of Kozani*. Thesis. Greek Open University.

Kordis, N. (2016). *Age of teachers*. https://www.alfavita.gr/ekpaideysi/202216_40hronon-kai-pano-oi-anaplirotes-ekpaideytikoi-statistika

Koski, W., & Horng, E. (2007). Getting down to facts: A research project to inform solutions to California's education problems. *Flora*, *124*(January).

Kyriakaki, G., & Loupi, A. (2016). *The professional burnout of permanent and substitute teachers of primary and secondary public education in Greece*. Postgraduate Thesis. University of Piraeus.

Lee, Y. S. (2015). School districting and the origins of residential land price inequality (land-prices). *Journal of Housing Economics*, *28*, 1–17. https://doi.org/10.1016/j.jhe.2014.12.002

Matz, C. J., Egyed, M., Hocking, R., Seenundun, S., Charman, N., & Edmonds, N. (2019). *Human health effects of traffic-related air pollution (TRAP): A scoping review protocol*. 1–5. https://doi.org/10.1186/s13643-019-1106-5

McMahon, W. (2008). *External benefits of education*. University of Illinois. http://dx.doi.org/10.1016/B978-0-08-044894-7.01226-4

Ministry of Infrastructure of Transportation. (2023). *Mileage calculator*. https://kmd.ggde.gr/

Mayerle, S. F., Rodrigues, H. F., Neiva de Figueiredo, J., & De Genaro Chiroli, D. M. (2022). Optimal student/school/class/teacher/classroom matching to support efficient public school system resource allocation. *Socio-Economic Planning Sciences*, *83*. https://doi.org/10.1016/j.seps.2022.101341

Murad, A. A., Dalhat, A. I., & Naji, A. A. (2020). Using geographical information system for mapping public schools distribution in Jeddah City. *International Journal of Advanced Computer Science and Applications*, *11*(5), 82–90. https://doi.org/10.14569/IJACSA.2020.0110513

Podolsky, A., Kini, T., Darling-Hammond, L., & Bishop, J. (2019). Strategies for attracting and retaining educators: What does the evidence say? *Education Policy Analysis Archives*, *27*, 1–47. https://doi.org/10.14507/epaa.27.3722

Ronfeldt, M., Loeb, S., & Wyckoff, J. (2013). How teacher turnover harms student achievement. *American Educational Research Journal*. https://journals.sagepub.com/doi/10.3102/0002831212463813

Seboni, L., Rakgomo, K., & Mhalapitsa, B. (2023). Development and validation of an integer linear programming model for the lecturer-to-course assignment problem. *Journal of Optimization in Industrial Engineering*, *16*(34), 155–165.

Sections and lessons in the day general high school, Pub. L.No. Official Gazette 193/17-9-2013 (2013). https://www.minedu.gov.gr/publications/docs2018/N_4186_2013_fek193.pdf

Sections Operating Conditions, Pub. L.No. 108575/D2/04-07–2019, Ministry of Education (2019). https://edu.klimaka.gr/sxoleia/lykeio/1012-leiturgia-katevthynsewn-lykeiu-mathhmata-epiloghs

Skrepetaris, H. (2019). *Comparative presentation of the legislative regulations of the last decade, regarding the selection of education officers*. Postgraduate Thesis. University of Patras. https://doi.org/10.1080/0142569920130209

Singleton, A. D., Longley, P. A., Allen, R., & O'Brien, O. (2011). Estimating secondary school catchment areas and the spatial equity of access (for parents). *Computers, Environment and Urban Systems*, *35*(3), 241–249. https://doi.org/10.1016/j.compenvurbsys.2010.09.006

Tamiz, M., & Jones, D. F. (1996). Goal programming and Pareto efficiency. *Journal of Information and Optimization Sciences*, 291–307. https://www.tandfonline.com. https://doi.org/10.1080/02522667.1996.10699283

Thelin, M., & Niedomysl, T. (2015). The (ir)relevance of geography for school choice: Evidence from a Swedish choice experiment (students choice). *Geoforum*, *67*, 110–120. https://doi.org/10.1016/j.geoforum.2015.11.003

Travel expenses - domestic travel, Pub. L.No. Law 2685/1999 (Official Gazette 35/A/1999) (2015). https://www.alfavita.gr/ekpaideysi/168592_ti-ishyei-gia-ta-odoiporika-exoda-kai-tis-metakiniseis-ton-ekpaideytikon

Tsilafaki, A. (2017). *Professional stress and burnout of secondary school teachers.* Postgraduate Thesis. University of Thessaly. https://doi.org/10.26253/heal.uth.4921

Wen, H., Xiao, Y., Hui, E. C. M., & Zhang, L. (2018). Education quality, accessibility, and housing price: Does spatial heterogeneity exist in education capitalization? (prices). *Habitat International*, *78*(October 2017), 68–82. https://doi.org/10.1016/j.habitatint.2018.05.012

Xavier, C. M., Fernandes Costa, M. G., & Filho, C. F. F. C. (2020). Combining facility-location approaches for public schools expansion (students). *IEEE Access*, *8*, 24229–24241. https://doi.org/10.1109/ACCESS.2020.2970385

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Appendix

Excel File #1

This file contains the following data:

- **Lesson assignments** within each specialty, and the **assignment level** of each lesson in each specialty. For example, the economist has as first level of assignment the lesson: "principles of economic theory" and as second level of assignment the lesson: "political education". This is necessary initially because by law the lesson can only be taught by an appropriate teacher. In addition, the level of the assignment (1st, 2nd, 3rd) also determines the pedagogical benefit (large, medium, small, corresponding to the levels)
- **Duration** of each lesson, in hours per week
- **Characteristics of each employment status** (There are three basic forms of employment in the Greek education system: permanent teachers, substitute teachers and hourly teachers) such as:
    - **Teaching hours.** Depending on the employment status and years of service, the law sets specific teaching hours per week.
    - **Maximum allowable overtime hours**. Depending on employment status, the law defines specific teaching hours per week that a teacher can work as overtime.
    - **Annual salary**, which depends on employment status and years of educational service.
    - **Pedagogical cost**, since each employment status has different job insecurity, and this is reflected in performance in the classroom. Thus, the biggest burden is on hourly teachers and the least on permanent teachers.
- **Distances in kilometers between schools**, which is necessary to calculate the costs of moving teachers between schools but also the fatigue of teachers from moving which has an impact on the pedagogical work.
- **Travel cost per kilometer** in euros, which compensates each teacher for moving from one school to another, by the Directorate of the Secondary Education Council.
- **Overtime cost per hour** in euros, which the teacher is compensated in case he will teach more hours than his teaching hours.

Excel File #2

This file contains the following data:

- **The number and type of lessons**, required to be covered in every school in prefecture of Ilia, in Western Greece.
- **A set of teachers** with characteristics such as:
    1. **Specialization**
    2. **Employment status**
    3. **Teaching hours**
    4. **Maximum allowable overtime hours**
    5. **Annual salary**
    6. **The primary placement school.** The education directorate of each prefecture places the teacher in one school and then completes his/her schedule in other schools as well. The teacher's travel (fatigue and cost) is measured with respect to the school where he/she is primarily based and not by his/her place of residence.

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