TIME PHASED MANPOWER MODEL FOR EDUCATION PLANNING IN AFGHANISTAN

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ABSTRACT

This work provides the education planner with an introduction into the use of a time phased linear programming manpower model as it pertains to teacher demands at the provincial and national level. We first explain model fundamentals and then propose the use of such a model to provide keen insights into potential futures regarding a state's education system. Then, we provide a case study that delves into the Afghanistan education system providing insights into teacher training capacity issues as well as potential disparities across genders and provinces. A modification of the model to provide sensitivity analysis regarding policy, assumptions, and uncertainty is also presented, which demonstrates the power of linear programming as a decision tool within the realm of complex policy analysis.

INTRODUCTION

The demand for qualified teachers is a first principal in the determination and following prescription of education policy through planning. Teacher management is a critical governance issue in fragile state contexts, and especially those in which the education system has been destroyed by years of conflict and instability (Kirk, 2008). The importance of teacher planning to a society is only reemphasized by the United Nations Millennium Goal #2 – "ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling" (United Nations, 2010, p.1). Teacher supply and demand manpower planning has been brought to the forefront given the continued and ever growing role of the international community in education development throughout the world. However, given natural challenges to teacher development such as an unqualified supply pool for teachers in many countries, competing national interests, security concerns such as in Afghanistan, societal implications, and disease concerns such as in Africa, it is of particular importance that education planners make the most of the planning and policy comparison tools available to them. Here we present a linear programming manpower model which was developed in accordance with many of the premises of education planning. We use this model to provide insight into potential future teacher demand and educational frictions in Afghanistan, but we assert this model structure is useful in numerous cases. Additionally, we explain the assumptions and potential weaknesses in the model as these matters are likely common. Included in this study is a brief overview of the mathematical modeling technique of linear programming to expose how such a model cannot only be insightful, but transparent, allowing the education planner and decision maker to understand the assumptions and limitations within the model.

TEACHER SUPPLY AND DEMAND WITHIN THE CONTEXT OF EDUCATION PLANNING

Across the literature, one of the more referenced definitions for education planning is given by Phillip Coombs [1], "[Education Planning is] the application of rational, systematic analysis to the process of educational development with the aim of making education more effective and efficient in response to the needs and goals of its students and societies" (Coombs, 1970, p.14). The purpose of manpower forecasting is to provide decision makers insight to ensure training and inventory focus on the areas needed (Cashbaugh et al., 2007). Bringing these two designations together as Reichardt does, we see

> The main purpose of a teacher supply and demand study should be to improve the education of all learners, by helping policymakers create targeted policies that ensure all learners are taught by high quality qualified teachers, all of the time. Understanding the actual extent of the need for qualified teachers is the first step in ensuring that there is a qualified teacher in every classroom" (Reichardt, 2003, p.2).

The supply of people does not immediately meet the demand for teachers. Qualified teachers and the processes which train these teachers are resource intensive. The allocation of resources to meet current needs given future requirements requires the "rational, systematic analysis" referred to by Coombs. Inarguably, this is a rather important part of any government's duty to its populace and should therefore be conducted deliberately and without bias. That being said, it would be interesting to know how many planners intentionally use proven mathematical models for educational manpower planning, and of those who do, how many education planners understand the implications and assumptions. A search of the current literature shows, although improvements have been made in the quantitative models of education focused on planners, much of the focus is on statistical and data analysis techniques and gains can still be made in forecast modeling.

This is by no means a new problem in the realm of education planning. In his 1970 article, Mathematical Programming Models in Education Planning (McNamara, 1971), James McNamara conducts a rather broad sweep of what is the beginning of a deliberate marriage between the management science of Operations Research and Education Planning. He focuses on the use of mathematical programming to support the design of education policy in the realms of curriculum selection, design of physical facilities, resource allocation, cost accounting, salary schedule analysis, and student population projections. He further classifies most educational planning models into the subsets of social demands approach which attempts to project individuals' demands for places in the educational system as opposed to society's demands for trained manpower and the manpower-requirement approach which ascertains future needs for manpower from projections of the growth of the economy and inputs of labor of various skills (McNamara, 1971). McNamara provides examples of such models such as Galloday who constructed a Macro dynamic linear programming model for education in Morocco (Golladay, 1968).

These models, which were computationally expensive at the time, can now be solved relatively easily on a typical personal computer. Additionally, the growth of the field of management science has brought many of these techniques to the forefront of analysis, proving they can provide a tremendous benefit to educational planners.

[1]Phillip Coombs was the first US Assistant Secretary of State for Education and the organizer of IIEP.

Johnstone (1974) conducted a comprehensive review of model development in educational planning which surpassed looking only at mathematical programming – one of his greater conclusions was:

> [regarding model development] the interest shown in models, however, is one sided. Most research has been carried on in research centers or in institutions of higher education; there is little evidence in the published literature to indicate that much is done in ministries or departments of Education where plans and policies are formulated (p.194)

We believe that there has not been enough done over the past 50 years to remedy this. Here we provide a tractable model and use of Operations Research to assist in the improvement of this breach. This study further provides an introduction to linear programming for an educational planner and follows it with a case study of Afghanistan using open source data.

LINEAR PROGRAMMING

Linear programming is a mathematical technique that maximizes (or minimizes) a linear function subject to a system of linear constraints. This linear function, together with the system of linear constraints, forms what is called the linear programming model (LP). The canonical form of an LP is shown below (Hillier & Lieberman, 2010):

$$\begin{array}{ll} \text{Maximize} & c_1x_1 + c_2x_2 + \dots + c_nx_n \\ \text{Subject to} & a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n \le b_1 \\ & a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n \le b_2 \\ & \dots \\ & a_{m1}x_1 + a_{m2}x_2 + \dots + a_{mn}x_n \le b_m \\ & x_1 \ge 0,\ x_2 \ge 0,\ \dots,\ x_n \ge 0 \end{array} \tag{1}$$

Notice that the LP consists of (a) a linear function called the objective function that measures the relationship between a solution set of parameters and decision variables, (b) a set of linear inequalities or equations called functional constraints which define restrictions or limitations of available resources or required demand, and (c) nonnegativity restrictions for decision variables called nonnegativity constraints (Cook and Russel 1977). The linear programming model (1) can be written compactly as below:

$$\begin{array}{ll} \text{Maximize} & \displaystyle\sum_{i=1}^{n} c_i x_i \\ \text{Subject to} & \displaystyle\sum_{i=1}^{n} a_{ji} x_i \le b_j, \ \text{ for } j = 1, ..., m \\ & x_i \ge 0, \text{ for } i = 1, ..., n \end{array} \tag{2}$$

Here, the objective function has the goal of maximizing some combination of c_i and x_i, where c_i is a set of constants and x_i is a decision variable whose value is determined when the model is solved. Their values provide the answer which the model seeks to solve. For example, the optimal number of first grade teachers could be represented by x_1. The a_{ij}, c_j, and b_i are model parameters which are representative of data or model input – following the linear programming models (1) and (2), c_1 could represent the known salary of a first grade teacher.

A form of linear programming is that of network models. A lead principle in network models is that of balance of flow (or conservation of flow), which states that total flow into a location minus total flow out of a location equals the net demand at every predefine point. This often takes the canonical form:

$$\sum_i \sum_j x_{ij} - \sum_i \sum_j x_{ji} = b_k \qquad (3)$$

where x_{ij} is the variable input flow from location i to location j and x_{ji} is the output flow from location j to location i, and b_k is the net demand. This is also referred to as a balance constraint as it assures that in-flows equal out flows for materials and products by one stage of production and consumed by others (Rardin, 1998). This model can then be expanded to create a time phased balanced constraint. Rardin provides a salient way to understand this time phased concept as shown below.

$$L_{t+1} = L_t + I_t \qquad (4)$$

where L_t and L_{t+1} represents respectively starting level at time periods t and $t+1$, whereas I_t represents impacts of period t decisions. We can now see a common premise found in many manpower models – in that the number of personnel employed by an agency in the current year is dependent on those who were employed the previous year and impacted by policy decisions such as hires and releases as well as exogenous factors such as unplanned losses.

Balance of Flow Manpower modeling is a transparent and efficient way to provide key insights into the manpower requirements for teachers in a developing for educationally struggling country. Such modeling can easily account for training requirements, spatial implications, temporal needs, uncertainty, and cultural implications. These models run in relatively short times allowing iterative exploration and sensitivity analysis. In this work, we explain a mathematical model in terms meant for the education planner who might not have a background in linear programming, but as with any good planner or policy maker, feels he or she must understand a model if it is to be used to inform policy.

THE CONTEMPORARY PLANNING ENVIRONMENT

The recent international community's emphasis on education is made apparent in the United Nations Millennium Goals. Goal #2 is to ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling" (UNDP Afghanistan, 2011). In a recent article Thomas Friedman expounds upon two financial commitments by the United States, one to Egypt for $1.3 Billion worth of tanks and fighter jets, and one for $13.5 million in scholarships for Lebanese youth to attend tertiary education. He states "The $13.5 million in full scholarships has already bought America so much more friendship and stability than the $1.3 billion in tanks and fighter jets ever will" (Friedman, 2012, p. A27). This drives the question, how can an investment order of magnitude less than another be more impacting? The answer lies in the utility of education.

Education has proven an important driver for economic growth, development, fertility management, lessening mortality, and improving health (Mackenbach et al., 2008)2008. Education provides stability, a basis for conflict sensitivity instruction, and a place for learning and remembrance; however, if education in conflict is not planned adequately it can provide space for the exacerbation of the frictions which are inherent to conflict (Smith, 2005).

It is apparent that in this globalized world, countries which have the capability to provide support in education should do so; not only because of education's moral importance, but also for righteous self interests. As is often the case in public utilities, human capital is the driving force behind the ability of a nation to provide education to its people – nowhere is this more evident than in fragile or developing states. It is these states with the limited capacity where acute planning is arguably more important than in developed countries where the societal capacity (i.e. trained people pool) can compensate for poor planning. But in many fragile and developing countries, human capacity is a precious resource – whether due to a lack of current capacity, security considerations, disease outbreaks, poverty, cultural frictions, or ethnic strife, there are circumstances which influence the teacher production pool, and these should be planned for and analyzed.

This dynamic environment provides complexities and challenges which require creative modeling to simulate. For example in a very recent publication, Marchant and Lautenbach show the importance of disaggregation in looking at teacher demand in South Africa as well as the importance of accounting for student teacher ratio goals and the implications regarding the quality of education. They also show that due to an aggregated look at the teacher supply in South Africa – many teacher training colleges (TTCs) which were later proved critical were closed (Marchant & Lautenbach, 2011). Often the integrated impacts in a system are lost when a myopic view is taken, while the converse is also true as intricacies are lost when studying the system in the aggregate. Here we show how a relatively simple linear program can be used to conduct analysis at a disaggregated provincial level to inform decisions regarding teacher training colleges in Afghanistan. We also demonstrate how sensitivity analysis can be used to provide prescriptive policy insights while accounting for uncertainty and potential interactions within the system.

A CASE STUDY: MODELING THE AFGHANISTAN EDUCATION SYSTEM

In this next section, we provide an example of a use of linear programming to explore the potential futures of the Afghan Education System. Over the previous three decades, torn from multiple wars and an intolerant governing regime, the education system in Afghanistan has been decimated. Only in the recent decade has there been a unified effort towards the improvement of education. This emphasis, regarding education, has provided benefit, but has also brought unexpected problems. There has been a seven fold increase in the demand for primary and secondary education with nearly seven million children enrolled in school today (Ministry of Education, 2011). Unfortunately, in a country with 27%

adult literacy, an ongoing war upon its soil, an opium trade as a primary gross domestic product, and an inefficient use of international aid, meeting the increasing demand for education is difficult at best (Sigsgaard, 2009). The Afghanistan Ministry of Education (MOE) has stated that the future of Afghanistan depends on the capacity of its people to improve their own lives, the well being of their communities, and the development of the nation.

As of 2012, there are 56 primary donors who have donated approximately $57 billion U.S. to Afghanistan (Margesson, 2009). The UN Coalition is dedicated to the security and infrastructure improvement of Afghanistan in order to ensure Afghan Government success. In 2014, with the anticipated withdrawal of coalition forces and a newly autonomous Afghan state, the future is uncertain. The purpose of the following case study was to use mathematical modeling to demonstrate potential outcomes and points of friction regarding the demand for teachers in Afghanistan, given the substantial forthcoming changes in the country.

This case study focuses on the capacity for teacher training in Afghanistan as it pertains to the growing demand for education. Although the current pool of teachers has a mixed training background (73% of teachers have not met the grade 14 graduate requirement (Ayobi, 2012), the Afghanistan Ministry of Education requires a two year teacher training college (TTC) after a potential teacher has passed the equivalent of 12th grade (Ministry of Education, 2011). Therefore, it is rather important to determine the number of future teachers required to enter the training base each year to support the increasing education demand. Of equal importance is discovering potential weaknesses in training capacity, and where these potential friction points exist. The issues cannot be remedied in the short run. Therefore, it is beneficial to use insights gained through modeling to inform policy decision.

The following modeling technique is based on a network flow mixed integer linear program which has been successfully applied to a wide range of problems such as school facility decision (Greenleaf & Harrison, 1987), transportation network (Current & Marsh 1993), generation expansion planning (Kim et al., 2011), energy management (Manfren, 2012), and so on. Our network flow integer program provides insight into potential weaknesses in the development of the future of teacher training.

We use Bombach's individual demand approach to education forecasting where the potential supply of educated manpower is derived from the present and the expected future individual demand for education. The projection is based on the rate of growth and the age composition of population, the present structure of the educational system, the number of students already enrolled, the prevailing graduation rates and trends, and the possible changes in the social structure of inflow into education (Bombach, 1965). Supporting this principle, the recent work of Marchant and Latenback explains "The growth in demand for teachers is determined by the growth in learner numbers and the post provisioning norm (PPN) or learner educator ratio (LER) that is applied institutionally. The demand for teacher replacement is determined by the in-service attrition rate, which can manifest as, for example, teachers retiring or seeking employment in other sectors" (Marchant & Lautenbach, 2011).

The proposed model determines the number of teachers that should be in training across Afghanistan by province, grade, gender, and time. The change in requirements by year is based on an increasing demand for education due to population increase, desire, near spontaneous development, a dynamic LER, and parity across gender and social class.

The model's primary premise is that of a balance of flow (Bombach, 1965). The number of teachers you can have in any given year is dependent on the number you had the previous year, the number that stopped teaching (quitters, deaths, retirees), the number that completed training, and the number that were reassigned within elementary, middle, and high school. Unfortunately, due to a fledgling current teacher base and limited teacher production capability, meeting the desired student teacher ratio in every province is infeasible. Therefore, we develop an integer program with elastic constraints to allow for a feasible solution set.

DATA AND ASSUMPTIONS

The MOE uses the Educational Management Information System (EMIS) system to collect a substantial amount of data regarding its teachers in order to provide transparency to the people of Afghanistan, as well as the international donor community. We feel this data, although not 100% accurate, provide enough truth to allow modeling. Due to the difficult situation in Afghanistan, we extended the current United Nations charter for 100% enrollment in primary education by 2015 to 2025. The intent of the model is to provide insight at 2020. We therefore use truncation to mitigate end effects regarding this relatively short horizon (Grinold, 1983). The UNESCO Institute for Statistics (UIS) projections provided an estimate of the number of additional teachers, or inflow, required to compensate for attrition rates in order to assess potential training needs. Therefore, based on the UIS data, three scenarios are based on different attrition rates: low (5%), medium (6.5%) and high (8%) (UNESCO, 2006). Due to disparity across Afghanistan, we assume the current annual salary for a teacher is $2000 US which we acknowledge as a gross approximation. Another assumption used in this analysis, which is easily permuted is that a 35 person classroom provides the optimal size, and is therefore the goal by 2025[2]. Although relaxed in some urban areas, gender separation is a requirement in much of the country and the MOE is vying for gender parity. We therefore assume no cross gender education (except in TTC). Teachers that attend the two year Teacher Training College in a province will teach in that same province (we relax this later during the sensitivity analysis). UN population estimates for 2025 were used (United Nations, 2011)[3]. A suitable mathematical technique is a linear extrapolation of the population based on the futures of the ages and the current population proportion across provinces (Mehta, 2004). This method provides values relatively close to the MOE's provided in the 2011 Ministry of Education Interim Plan.

For this model, the population growth rate is determined using the UN population forecast for Afghanistan each year and is assuming that 100% of primary aged school children and 80% of secondary aged school children will be enrolled by 2025. This assumption was proportionally decomposed across province, sub-age group, and gender. This provides a linear expectation for enrollment at each future year, accounting for the current education demand while anticipating the future demand.

[2]The current plan by the MOE is 35.6 person classrooms by 2015.

[3]This is an aggregate of all 34 provinces, so we used the ratio of the population by province in 2009 from the LandScan 2009 Global Population Database (The NATO standard for assessment in Afghanistan) and used linear forecasting to determine future enrollment based on the Enrollment Ratio Method, 'which is calculated on the basis of past data, and is extrapolated into the future by applying a suitable mathematical technique or a specific logic' (Mehta, 2004).

Model Explanation

The premise of the model is that of an employee hiring-training problem (Wagner, 1975). The Afghan Ministry of Education must hire, train, and graduate enough teachers from TTC each year to meet the growing demand of education in Afghanistan. Due to a severe shortage of female teachers and academically qualified individuals in some of the more rural areas, these challenges of parity must be accounted for. Below we go into detail regarding the objective function and some of the important constraints.

The objective function of the model is to minimize the total cost in dollars based on the annual salary of an Afghan teacher and the annual cost of training an Afghan teacher. Also, due to the infeasibility of meeting some of the constraints under variable conditions, elastic variables are used and the penalty is incorporated in the objective function. Although the objective function "drives" the model, we will soon show it is not the key premise to such a model.

$$\text{Minimize} \sum_t \sum_d \sum_e \sum_g c(X_{deg}^t) + \sum_t \sum_d \sum_e \sum_g f(Y_{deg}^t) + \sum_t \sum_d \mathit{penalty}(\mathit{slack}_d^t) \qquad (5)$$

Here, X^t_{deg} is the decision variable representing the number of employed teachers in year *t*, province *d*, of gender *e*, and grade *g*. Y^t_{deg} is the decision variable for the number of teachers in training across year t, province *d*, of gender *e*, and grade *g*. Also, in the objective function, we introduce a *penalty* value which is multiplied by $slack^t_d$. The *slack* variable is the repercussion of the elastic constraint. In the case of Afghanistan, as often the case, the current capacity (of the TTCs) cannot meet the demand in the out years. One issue with linear programming is its required feasibility. By introducing the *slack* we can provide some elasticity in our constraints; thus allowing the model to solve under penalty as opposed to solving infeasible.

To explain in more detail – we want to minimize the total of salary cost (*c*) and the training cost (*f*) each year while all provinces (*d*), genders (*e*), *and* grade levels (*g*); plus the penalty for not meeting the required capacity (*slack*) in each district. These values are all indexed over annual time steps (*t*). Table 1 shows an example of a notional solution set pertaining to the year 2012 in Province A, male teachers, across grades 1 through 5. The table includes the shortages in capacity – because in this model we only concern ourselves with shortages in districts annually (and not grade nor gender) the shortage is 2 for the entire province in the year 2012.

Table 1. Notional data example.

Year	Province	Gender	Grade	Shortage in Training Capacity (Slack)	Teachers	Teachers in Training
2012	A	Male	1	2	10	12
			2	2	12	14
			3	2	9	13
			4	2	13	14
			5	2	11	15

Table 1 also shows the number of teachers required in the province in that year as well as the number that need to be in training. Given the cost of salary of *c* and the cost of training *f*, for example the first row of the table would cost 10*c* + 12(*f*)+ *penalty*(2). The entire cost for the table equals *c*(10+12+9+13+11) + *f*(12+14+13+14+15) + *penalty*(2) – please note this would be done across gender for all years. The goal of the model is to minimize this cost. However, the objective function alone is of no value. Using only the objective function, the easiest way to minimize this cost would be to have zero teachers. However, this is not a feasible solution. We therefore use constraints to mold the problem. If the objective function drives the problem, the constraints steer the solution into the realm of feasibility. We propose a basic balance of flow model for both its simplicity and pragmatic solution. For this particular model, the balance we must maintain is that the number of teachers working in a current year must be equal to the number of teachers from the previous year plus any additional teacher training college graduates, adjusting for teacher attrition. Using mathematical notation this becomes:

$$\sum_g X^{t}_{deg} = \sum_g X^{t-1}_{deg} - \sum_g P^{t-1}_{deg} + \sum_g Y^{t-2}_{deg} \quad \forall\, t, d, e \tag{6}$$

Fundamentally, equation (6) states that the number of teachers employed in the current year for each province, gender, and grade must equal the number of teachers employed last year in each province, gender, and grade accounting for *P* – those that were lost due to attrition of various sorts, and adding in the second year cohort graduates from TTC. As the model solves for all years from 2012 to 2025, X^{t}_{deg} can be determined for the entire set of years. A snap shot of equation (6) for the year 2015 would be:

$$\sum_g X^{2015}_{deg} = \sum_g X^{2014}_{deg} - \sum_g P^{2014}_{deg} + \sum_g Y^{2013}_{deg} \quad \forall\, d, e \tag{6a}$$

That is, the number of teachers employed in 2015 is equal to the teachers employed in 2014 subtracting out the 2014 losses while adding in the graduating class of TTC students who began school in 2013. Using our previous chart as a starting point what we have is:

Table 2. Notional data including losses.

Year	Province	Gender	Grade	Teachers	Teachers in Training 2nd Year	Teachers in Training 1st Year	Losses
2012	A	Male	1	10	12	12	3
			2	12	14	14	4
			3	9	11	13	3
			4	13	10	14	2
			5	11	9	15	1

In order to meet the constraint of equation (6) we see that in 2013 the number of 1st grade male teachers in province A would be 19 (i.e., 10+12-3). Note that these values are all variables which the model itself solves for in order to minimize the overall cost. For this particular model, the requirement to keep working teachers in line with their previously assigned grade seemed over restrictive. We therefore reduce this constraint allowing teachers to move across grades within their subset of primary, secondary, or post secondary education. The resultant requirement for primary school (grades 1-4) teachers in the year 2013 would then be 79 (i.e., 10+12+9+13+12 +14+11+10-3-4-3-2). Relaxation of a constraint creates a larger solution space. For this particular model, the balance constraint (6), based on research, proved overly restrictive. The balance equation as presented states that first grade teacher in year *t* will remain as first grade teacher in year *t+1*. By relaxing this constraint from grade to education level, the model is permitted to shift teachers within primary, secondary, and post secondary education levels to meet requirements.

The last constraint we explain in detail in this paper is the capacity constraint of the TTCs, which represents how many teacher candidate students can accommodate a teacher training college each year. It turns out that this is a dominant limiting factor in this model. In constraint (7) we introduce k_d which represents the TTC capacity for the respective province. Another concept introduced in constraint (7) is that of ordinality. The function to the right of the inequality notation is similar to the equation used to determine the impacts of compound interest. Since the main difference is because we are interested in knowing each year's required TTC capacity, we raise the growth formula by the index of each year. For example, as the model begins in 2011, the set {2011, 2012, 2013} has ordinal values {1, 2, 3}. This allows the TTC capacity to grow by 10% compounded annually. This is a bit lower than the MOE goal for the next three years, but is an adequate fit for the out years. Additionally, we use a slack variable to account for a lack of capacity, providing elasticity and allowing the model to handle infeasibility. That is, this slack variable accounts for the additional required capacity in the province's training base. This capacity corresponds to the required number of training positions in TTC for the respective province beyond that of current or forecasted capacity. This constraint can as easily model supply of qualified personnel for teachers as it does capacity of the training ground.

$$\sum_e \sum_g Y_{deg}^t + \sum_e \sum_g Y_{deg}^{t-1} \le k_d (1+0.1)^{ordinality(t)} + slack_d^t \quad \forall\, t, d \tag{7}$$

Additionally, we account for the learner educator ratio (LER) as emphasized by Marchant and Lautenbach (2011). This constraint established a goal of 35 students to one teacher by 2025. As many provinces are far from meeting this goal, we established a linear glide path beginning in 2012 with the current provincial LER, thus establishing annual goals (which the model must meet) along the path to 2025. Once again, we can use the concept of ordinality to help establish the slope of the linear path. We will later discuss the trouble in making the gross assumption of linearity. Another important constraint is that of non negativity. Because it is infeasible to have negative teachers in training or in classrooms, it is important to define such constraints to prevent the model from "cheating" and exploiting potential solutions sets with negative variables.

RESULTS AND DISCUSSION

Based on current production estimates, reaching the goal of having at least 35 students in each classroom in the next thirteen years at the prescribed growth rate is infeasible in eleven of the provinces. However, the model provides enlightening insights into the requirements and information on why the infeasibility exists. With a goal of converging from current classroom sizes to 35-student classrooms by 2025, and a growth rate of teacher training capacity of 10% compounded annually with a loss of at least 6.5% for each gender respectively, there is a requirement to hire and train approximately 212,000 male teachers and 223,000 female teachers for a total of about 435,000 teachers over the next 12 years. On the average, this would cost approximately 500 million U.S. dollars a year in teachers' salaries alone (approximately 9% of Afghanistan's 2009 total international aid (Poole, 2011) and 30% of its 2010 annual revenues (CIA, 2012). In order to grow the teaching force to the required size while accounting for planned losses, the current production based on the 10% growth will fall short by approximately 125,000 teachers in 11 of 34 provinces and Kabul City. Table 3 shows the breakdown of the Afghan provinces which will be short of teachers in at least one year from 2013 to 2023.

Table 3. Two groups of Afghan provinces lacking required capacity.

No Additional Capacity Required	Additional Capacity Required
Badakhshan, Baghlan, Balkh, Bamyan, Farah, Faryab, Ghazni, Ghor, Hirat, Jawzjan, Kaprisa, Khost, Kunar, Kunduz, Laghman, Nangahar, Nimroz, Nuristan, Panjshir, Parwan, Samangan, Takhar, Wardak	Daikundi, Hilmand, Herat, Badghis, Kabul City, Kabul, Kandahar, Paktia, Paktika, SariPul, Uruzgan, Zabul

Figure 1 shows the required employment of teachers across the education levels to meet the 2025 education requirements in a stacked bar chart, while overlying the breakdown of this expectation by gender. We see that the initial focus will be amongst primary school teachers as the younger student population continues to grow at newly found rates; however, by 2020, we begin to see an increased growth of demands for secondary education, and by 2023 the upper secondary education growth rate becomes exceptional, overcoming that of the primary grades.

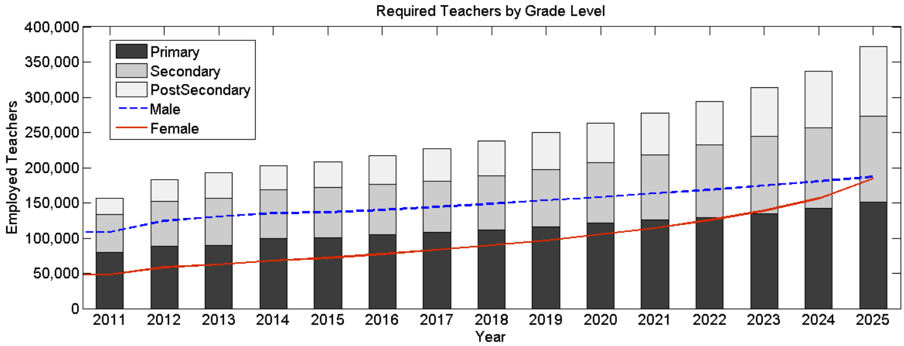

Figure 1. Required Teachers by Grade Level & Gender in Afghanistan to meet 35:1 LER in 2025

As of 2010, 245 out of 412 urban and rural districts did not have a single qualified female teacher – illustrating the gender disparity regarding teachers (Ayobi, 2012). However, the population of students is growing to parity amongst genders (Ministry of Education, 2011). We found that in the year 2020, the rate at which the model graduates and employs female teachers increases substantially above that of the men. The lines in Figure 2 show the required convergence assuming that females must be taught by females. This is both based on the requirement for female teachers to teach females and the growing population of female students. Although this growth is infeasible due to capacity restrictions, it is a basis to determine the required growth in female teachers. It is likely infeasible for all provinces to provide this many 12th grade graduate females by 2025. Based on this graph, Afghanistan can expect to need a tremendous number of female teachers with an emphasis of growth on secondary and post secondary education in the future. Although beyond the scope of this research, this lends itself to implications regarding tertiary education demands as well.

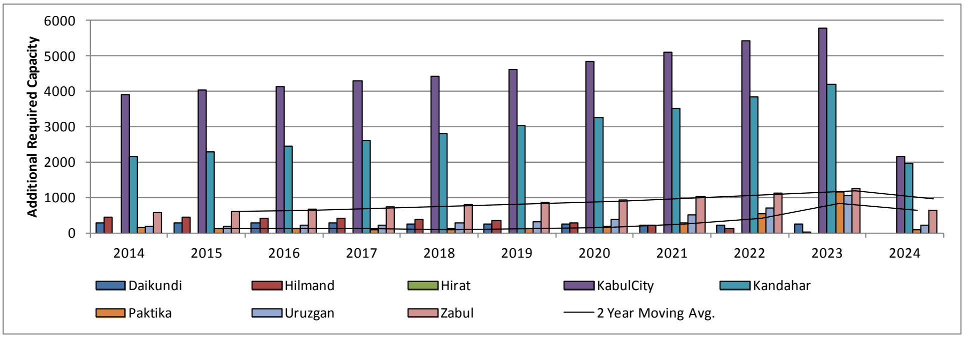

Figure 2. Overage required to meet the Model Demand for Teachers by 2025.

Referring back to Table 3, it became of interest to use the model to conduct further analysis into the provinces which lack the required capacity to meet the demand. Figure 2 shows the eight provinces with the greatest shortage in TTC capacity. Immediately, we notice that Kandahar, Zabul, and Kabul are consistently suffering from lack of capacity. Of note, most of the distressed provinces display a rather stable growth in the required training capacity past 2014 with the exception of Paktika. This is brought to attention in Figure 2 by displaying a two year moving average filter across Zabul and Paktika. Zabul, which is similar to the other provinces, display the smooth trend which is almost linear in nature. However, we see a sharp growth in Paktika during the year 2022. Further investigation reveals that Paktika's overage and required growth in the 2022 to 2023 time frame is dependent on the current and excessively high female learner to educator ratio. Because of this, as the model moves to close this gap over the 12 year time span, it is at a 70:1 ratio in 2024 and moves to a 35:1 in 2025. Therefore, it must double the number of female teachers in the province. This highlights an important point – the provinces are different, and it is going to take individual policies to grow the teacher population accordingly. In the case of Paktika, a linear growth rate is not preferred, and a greater rate of growth up front would be beneficial. Clearly, when modeling at a rather low resolution, assumptions can be very impactful and must be explained to the decision maker.

Because the model accounts for region and gender, we are able to glean insights into the gender disparity in those provinces that display some of the greatest difficulty in meeting the requirements. For example, nine provinces display substantial disparity in the hiring of females in the early years to compensate for their current disproportion. However, in the mid years, the model reaches equilibrium in hiring only to surge growth regarding female teachers in 2022. This correlates to what was seen in Figure 1, regarding a significant growth of upper secondary demand. For example, in 2023, the model hires approximately 2,700 female teachers for upper secondary in Nangahar. This accounts for 58% of all hires for Nangahar in 2023. Although this can be gleaned by conducting data analysis, we feel this is a successful instance where optimization can provide insights parsimoniously. The bottom line seems glaringly obvious, there is a lack of capacity to which there is likely no simple answer, and this can cause disparity in education throughout the country unless other techniques for training and hiring teachers are used.

SENSITIVITY ANALYSIS

One benefit of using a somewhat simple model which solves quickly is its flexibility allowing further exploration of the problem. In conducting sensitivity analysis, we delve into both the model's susceptibility to the assumptions as well as its ability to explore policy implications. For example, the infeasibility of meeting demand requirements for teachers in almost half of the provinces in Afghanistan resulted in a requirement for further investigation into the modeling assumptions as well as potential changes in the teacher training system which might provide significant impacts to the production of teachers. This sensitivity analysis includes investigating the effects of changing TTC from two years to one year, relaxing the geographic restrictions on teacher training to hiring, and stochastically varying the assumptions regarding teacher losses.

As previously mentioned, an important aspect of the Afghan educational policy is the actual teacher training program. An alternative policy option, if human capacity and infrastructure cannot support additional TTC capacity, is the trade of time for training seats. We, therefore, felt it worthwhile to investigate the impacts if the two year TTC mandate is changed to a one year program. Not surprisingly, the results show a dramatic impact in teacher training growth. A one year program allows 30 of the 34 provinces to provide enough teachers to meet the demand. Kabul City, Kandahar, Uruzgan, and Zabul still fall well short of the required demand when using the one year program. Not only does the number of provinces which do not meet the capacity substantially decrease, but we also see a substantial decrease (about 50%) in the overage required to grow the required teacher force across the nation. Time can be traded for capacity, and this trade can be of great assistance. What is surprising with this excursion is that the one year program will allow Helmand, one of the more notorious provinces, to maintain the required field of teachers. Although there are a limited number of people qualified to attend TTC, it is possible that this course of action is viable to support the immediate growth needed throughout Afghanistan or at least be of a greater assistance in the selected provinces.

The current model is limited in that if a teacher candidate attends TTC in a province, he or she must teach in that same province. Although there are national incentive programs to encourage the dispersion of teachers, it appears that this is the current state in Afghanistan. However, as security in the country improves, freedom of movement should follow (Dressler, 2011), and we should expect teachers to move across provinces. The resulting set of excursions relaxes the geographic constraint from provincial to regional using the NATO regional command areas. This was used under the assumption that NATO had conducted research into the geographic regions of the country and the resultant spatially based regional commands are accurate depictions of potential state relations (US Department of Defense, 2011). This relaxation is visually depicted in Figure 3 which shows all 34 Afghan provinces which was the original constraint. The color coding on the map aggregates the provinces into five grouping.

Figure 3. NATO Afghanistan Regional Commands (Source: ISAF, 2012).

By allowing the transfer of teachers from TTC to any provinces within the respective region, we found the provincial constraint rather binding, and its relaxation is effective. The relaxed model results in only seven of the provinces failing to meet the constraint versus the 11 from earlier. We also found that the number of teachers required decreases by 33% across the entire country. Of importance are the continued troubles in Kandahar and Helmand provinces. Not surprisingly, we found that the South, Southwest, and West Regional Commands cannot meet the required demand. This is a common trend and is a dangerous disparity within Afghanistan. The rural areas do not have the capability to produce the required number of teachers. Notably, these are the least educated regions with much of the instability. Incentives to travel and the freedom of teachers being trained and working in different provinces do provide significant improvement. However, it still will not completely solve the disparity in the rural parts of Afghanistan – some of which are of the greatest concern for the country's stability and security. Because this is initial research for a large scale simulation, it is beyond the scope to determine the exact provinces that should be supportive of interprovincial blending amongst teachers, but clearly, it pays tremendous benefits.

Clearly, the futures regarding education in Afghanistan exhibit intrinsically non-deterministic behavior. Therefore, we created a probabilistic version of the model to attempt to account for uncertainty and simulate heightened disruption or retention success across provinces, genders, and time. This was done using a random normal distribution to determine teacher losses. The purpose of the analysis was to determine potential interesting points of friction and the likeliness of friction within a province. Using a normal distribution with a mean of 6.5% losses annually, and the 2.5 and 97.5 percentiles being approximately 5% and 8%, respectively, we ran 100 repetitions – each with a different annual rate of teacher loss. The results showed that the system is not overly sensitive to teacher retention, yet the changes in teacher retention are not without influence. No new provinces are added to the initial set of provinces lacking required capacity. However, when losses are at the lower end of the spectrum, Paktia and SariPul fall off the list of provinces with inadequate training capacities (28% and 38% of the respective runs). We also found Badghis and Daikundi to be the provinces most sensitive to teacher retention with differences of 28% and 20% in the maximum and minimum capacity requirement. It appears that there is something to be gained by a successful teacher retention program. Table 4 summarizes the results of the stochastic runs for the four most influenced provinces for the years 2012, 2013 and 2023 as the other years display nominal requirements.

Table 4. Results of 100 excursions accounting for uncertainty.

Province	2013			2014			2023		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Badghis	67	110	157	0	14	42	345	385	430
Dakundi	298	393	459	117	167	197	213	297	377
Paktia	0	0	0	0	0	0	0	81	200
SariPul	0	30	92	0	0	0	0	0	0

These four provinces are close to meeting the required capacity due to changing retention rates. According to the results, SariPul is under capacity by nearly 100 teachers in 2013 when retention is poor, but when retention is high, it is capable of meeting the demand. Badghis displays similar results in 2013 and is rather sensitive to retention potentials. Further stochastic exploration can provide significant insights regarding exogenous circumstances such as security and funding.

CONCLUSIONS

This paper presents a time phased manpower linear programming model as a decision tool which should be exploited by educational planners. The intent was to not only provide insights into a large, messy problem which has the international community's attention, but to clarify and emphasize linear programming as it pertains to manpower planning within the educational planning community. The Afghanistan case study was done with minimum manpower and using open source data which can be found on the Afghanistan Ministry of Education Website. The model employed a mixed integer linear programming premised on the balance of flow to show provincial difficulties in meeting the demand for the quickly growing Afghan education system. Simultaneously, using elastic constraints, stochastic optimization, and a researched understanding of the problem provides insightful futures in analysis regarding a rather unknown environment. We have been able to isolate those provinces in Afghanistan which are critically short either teachers or training capacity and clearly demonstrate the severity. Additionally, the techniques provide insights into potential solutions and their impacts, shortening the requirement for TTC, relaxing geographic constraints regarding the relationship between TTC and actual employment, or ensuring the adequate retention of teachers. Although we provide a rather limited model in this study, the growth of such a model is only limited by the creativity of the educational planner and his or her understanding of management science. The appropriate marriage of the Operations Research techniques and the education planning can irrefutably result in improved courses of actions and inferences which our policy makers require in complex and resource-constrained environments.

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