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Abstract

The prediction of needs in the eyecare workforce is critical for the development of professional education institutions. Vensim system dynamics software (Ventana Systems Inc.) was used to model the optometric and ophthalmologic workforce in the Dominican Republic after the recent opening of a new professional optometry program. The model showed that the optometry profession will saturate after 15 years if practitioners without university education (mostly empiricists) continue to practice. Even without empiricists, saturation will occur after 60 years. Legislation must be enacted to reduce empiricism. The optometry program must expand the scope of optometric education and legislation and monitor the number of students to best serve the needs of the Dominican population and avoid professional workforce saturation. System dynamics simulation can be used to model the eyecare workforce and model public health issues in optometric education.

Key Words: *system dynamics, optometric workforce, ophthalmologic workforce, public health, Dominican Republic, visual mapping*

Background

The determination of needs in the eyecare workforce of a nation is critical for the education, training and allocation of optometrists, ophthalmologists and other ophthalmic personnel. Given the multiple interacting variables, it is often challenging to predict these needs.[1-2] The Dominican Republic is a country in the Caribbean region with a population of approximately 11 million people.[3] The prevalence of blindness in the 50 and older age group in the Dominican Republic is 2.1%.[4] A recent study in a clinical population in Pedernales, a Dominican town at the border with Haiti, found an overall presenting prevalence of visual impairment of 48.2%, which was reduced to 15.8% after refractive correction. Among the patients 50 years and older, the presenting visual impairment was 60.2%, the highest reported in Latin America. The prevalence of impairment was reduced to 23.8% with eyeglasses, indicating the need for optometric care.[5-6]

In the Dominican Republic, as in the United States, ophthalmologists are medical doctors with additional residency training in ophthalmology. They may perform refractions, diagnose and manage ocular disease, and perform ocular surgeries. In 2019, the Dominican Republic had 350 practicing ophthalmologists.[7-8] Medical education is regulated and accredited by the Ministry of Higher Education, Science and Technology (MESCyT), and medical practice is regulated by the Colegio Medico Dominicano (Dominican Medical Association).[9-10]

The practice of optometry in the Dominican Republic is not regulated or supervised as a health profession by any government agency. Optometric practitioners pay taxes on the sale of eyeglasses and contact lenses as businesses. There are approximately 500 optometric practitioners in the nation.[11] In the absence of professional optometric regulation, those without any formal optometric training are the majority of practitioners (empiricists) who perform autorefraction and dispense eyeglasses. This group has only a high school education. A second group of optometric practitioners (approximately 20) received limited technical training after high school (one to two years), previously at the Armando Espaillat Cabral Institute and most recently at the Universidad de la Tercera Edad. They perform refractions (retinoscopy and subjective) and dispense eyeglasses and contact lenses. A third group — composed of only four university-trained practitioners — received professional optometric degrees (four to five years university education) outside the Dominican Republic and perform refractions and external and internal eye examinations.[a] Since 2019, optometric education is accredited by the MESCyT.[12]

The Dominican Optometric Association (ASODOP), founded in 1991, is an organization that represents about 300 optometric practitioners.[11] ASODOP holds annual meetings with educational programs for its members. In 2012, the association promoted an agreement between Inter American University of Puerto Rico School of Optometry (IAUPR) and the Autonomous University of Santo Domingo (UASD) to establish a professional optometry program. UASD canceled the agreement in 2016 before the opening of the program. In 2018, ASODOP supported a new agreement between IAUPR and the Technological University of Santiago (UTESA), which led to establishing and opening the first professional optometry program.[13]

UTESA, founded in 1976, is the largest private university in the Dominican Republic. Its mission is to offer non-denominational higher education to students of disadvantaged economic and social backgrounds. It has eight campuses across six cities in the Dominican Republic. It offers professional degrees in the health sciences (medicine, dentistry, pharmacy, optometry, psychology, veterinary medicine, nursing), engineering, law, education, economics and business administration. The professional Bachelor of Optometry program (Licenciatura) opened in September 2019 at two UTESA campuses in the capital city of Santo Domingo. This four-year optometric curriculum has 185 credit hours, including 2,135 lecture hours and 1,440 lab hours (including patient care).[13]

System dynamics modeling has been used to forecast workforce needs in medicine, dentistry, pharmacy and social care in England, nursing in Korea and dentistry in the United States.[14-16] System dynamics has also been used to develop scientific, social, business and political models.[17] More recently, it has been applied to public health planning.[18-19] In education, it is a useful tool to promote deeper learning and critical-thinking skills among students.[20]

Saraji and Sharifabadi reviewed 28 studies on the effectiveness of system dynamics models in forecasting specific outcomes. The studies included predictions on the demand for air travel, water, urban transportation, housing and petroleum. They also involved predictions of the housing supply, fuel and coal prices, and sales of cars. They found that system dynamics models can make accurate predictions compared to actual outcomes (less than 5% error) or more reliable forecasts than alternate methods such as multiple linear regression, exponential smoothing or artificial neural networks.[21-26]

General systems thinking postulates that a deeper understanding of systems can be obtained by examining patterns of behavior over time. These behaviors result from the interaction among many variables through feedback loops. Deep inside these patterns are structures and mental models of an organization. System dynamics involves simulation models using general systems theory to explore the inter-relationship among variables to produce outcomes of interest. Instead of a single snapshot, the models allow exploration of how outcomes change over time.

The present study explores the use of system dynamics to model the eyecare workforce needs in a developing country after opening its first professional optometry university program.

Methods

A system dynamics simulation model was developed using the software Vensim PLE 7.3.5 (Ventana Systems Inc.).[27,b] Vensim is available as a free version and an upgraded paid version. There are more than 50 free tutorials available on YouTube and the company's website. Vensim was developed in 1985 for large business simulation. Its functionality expanded through time with Windows and Macintosh versions and a free personal learning edition (PLE) for educational use.[28] Vensim models have been successfully applied in the pharmaceutical, financial, energy, environmental, aerospace and health scenarios.[29-32]

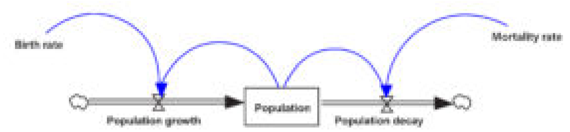

Figure 1. A simple system dynamics simulation model for population changes using stocks, flows and feedback loops. Rectangles represent stocks. Flows are represented by pipes, flow regulators and spigots.
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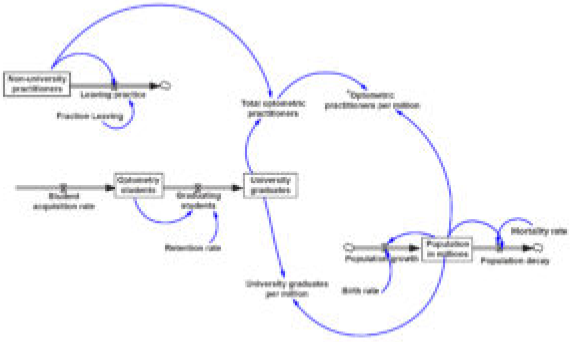

Figure 2. The optometric workforce of Dominican Republic model using Vensim modeling software. Rectangles represent stocks. Flows are represented by pipes, flow regulators and spigots. Click to enlarge

System dynamics models in Vensim are based on three elements: stocks, flows and feedback loops. Stocks are variables that accumulate over time, such as “population” in **Figure 1**. Flows can increase or decrease stocks, as in the case of “population growth” (which increases “population”) and “population decay” (which decreases “population”) in Figure 1. Feedback loops can be reinforcing (promoting growth or decay) or balancing (promoting the achievement of the desired state).

The model is based on the initial values, rate of change and factors that affect the stocks. For example, in our optometric workforce model **(Figure 2)**, the stock “total optometric practitioners” has an initial value of 500, and it is affected by the stock “university graduates” and “non-university practitioners.” The initial 500 practitioners include approximately 476 without formal optometric training, 20 with some technical training, and four with foreign university-level optometric degrees. The total number of optometric practitioners present in the Dominican Republic was acquired from the Board of the Dominican Optometric Association.[9] “University graduates” has an initial value of 0, and changes by the “student acquisition rate” (60 per year) and the university “retention rate” (80%). UTESA provided data about the admitted students per year and the new university optometry program’s expected retention rates.[13] The “non-university practitioners” has an initial value of 496 and changes by the rate “fraction leaving.” Finally, the “university graduates per million” variable is based on the “university graduates” and the Dominican “population in millions.” The Dominican “population in millions” is based on the “birth rate” and “mortality rate.” Demographic information (population, birth and mortality rates) for the Dominican Republic was obtained from the Dominican Republic Census.[3] The ratio of 100 optometrists per million of optometrists (1 per 10,000 population) in developed countries such as the United States was used as a standard for comparison.[33]

The total predicted number of ophthalmologists per million over time was based on the current number of practicing ophthalmologists, the number of new ophthalmologists, their annual attrition rate per year, and the population of the Dominican Republic. The current number of practicing ophthalmologists was obtained from the website of the Dominican Society of Ophthalmology.[7] The number of new ophthalmologists per year was supplied by the Institute Against Blindness due to Glaucoma.[8] The criteria for the recommended minimum number of ophthalmologists per million in Latin America was based on Hong et al.[34]

Model assumptions

Based on the sources listed, the following model assumptions were used:

- 500 optometric practitioners in 2019, including 476 without any formal training (empiricists), 20 with limited technical training, and four with university optometric degrees from outside the Dominican Republic
- A decrease in the number of practitioners without university training once the university program is initiated (This assumption is based on the availability of trained optometrists to substitute the empiricists and the approval of a law

ASSOCIATION of SCHOOLS and COLLEGES of OPTOMETRY

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prohibiting optometry practice without professional education.) The model explores annual attrition rates of 0%, 5%, 10% and 20%
- 60 optometry students per year in the bachelor's program of optometry
- 80% retention rate at the school of optometry
- 350 ophthalmologists in practice in 2019
- 18 new ophthalmologists per year

Two independent models were run. The first was a simulation of the optometric workforce **(Figure 2)**, and the second was a simulation of the ophthalmologic workforce **(Figure 3)**.

Results

Figure 4 shows the total predicted number of optometric practitioners per million population for 60 years after opening the UTESA professional optometry program. The curves show how the ratio changes as the non-university practitioners (mostly empiricists) decrease by 0%, 5%, 10% and 20% annually. A ratio of 100 practitioners per million (1 per 10,000 population) will occur in 15 years with no attrition (0%) of empiricists. This ratio will occur in 24 years if the empiricists' annual attrition rate is 5% and in approximately 27 years if it is 10% or more. A short-term decline in the ratio lasting no more than five years will occur if the attrition rate is greater than or equal to 10%. After 60 years, the number of optometric practitioners will stabilize to approximately 160 per million (1 per 6,250 population) if there is no attrition of empiricists. After 60 years, it will stabilize to about 140 optometrists per million (1 per 7,000 population) if the attrition rate is 5% or more.

Figure 5 shows the predicted number of ophthalmologists per million population for the 60 years after the UTESA optometry program's opening. The curves show how this ratio changes as the number of ophthalmologists decreases (attrition rates) by 0%, 1% and 2% annually. Under all conditions, the starting point is the current (2019) ratio in the Dominican Republic of 32.5 ophthalmologists per million. If there is no attrition of ophthalmologists (0%), the ratio will maximize at 46.2 ophthalmologists per million after 31 years. With a 1% attrition rate, the ratio will be a maximum of 38.7 ophthalmologists per million after 20 years. With a 2% attrition rate, the ratio will maximize at 34.5 ophthalmologists per million after 11 years.

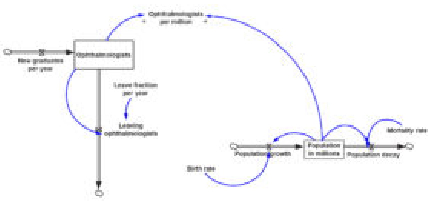

Figure 3. The ophthalmologic workforce model of the Dominican Republic using Vensim modeling software. Rectangles represent stocks. Flows are represented by pipes, flow regulators and spigots.
Click to enlarge

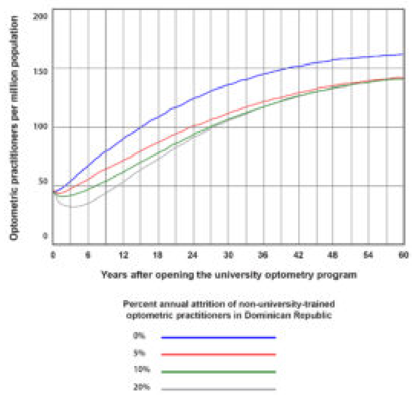

Figure 4. Ratio of optometric practitioners per million (university-educated and non-university-educated optometrists) in the Dominican Republic during a period of 60 years. Year 0 represents the year when the university optometry program was initiated (2019). The curves represent annual attrition rates of non-university-trained optometrists of 0%, 5%, 10% and 20%.
Click to enlarge

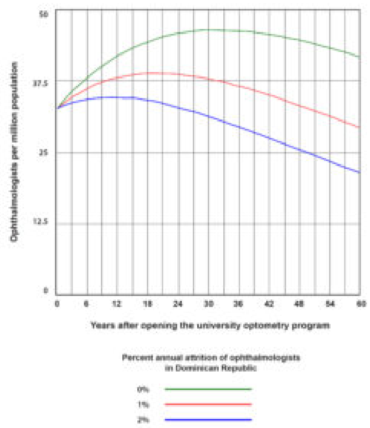

Figure 5. Ratio of ophthalmologists per million in the Dominican Republic during a period of 60 years. Year 0 represents the year when the university optometry program was initiated (2019). The curves represent annual attrition rates of ophthalmologists of 0%, 1% and 2%. Click to enlarge

Discussion

The system dynamics simulation shows that if non-university-trained practitioners (mostly empiricists) can practice without restriction (0% attrition) along with university-educated optometrists, the number of optometrists per million population will achieve the United States' ratio in only 15 years. This scenario will create an oversupply of practitioners that may decrease the demand for university-educated optometrists. The public may not be able to differentiate between empiricists and trained optometrists to the detriment of primary eyecare quality. This was the experience of countries like Mexico, where the practice of the profession was unregulated until 2014.[35]

One important recommendation for the Dominican Optometric Association derived from the simulation is the promotion of legislation to prohibit optometry practice without a professional degree. The model indicates that such a law should be implemented to ensure an attrition rate of 5% or more annually among non-university-trained practitioners. The model predicts a ratio of one optometrist per 7,000 population after approximately 60 years with an attrition rate of non-university-trained practitioners of 5% or more. This ratio will create an eventual saturation that may decrease the number of applicants to the professional program or promote optometrists' migration to neighboring countries. UTESA should monitor the workforce needs in the coming years and adjust its admission policies to avoid this possible scenario.

Based on the available clinical data, the leading cause of visual impairment in the Dominican Republic is uncorrected refractive error.[5] The UTESA program must prepare its students to provide excellent refractive and functional care. The leading causes of blindness are cataracts, glaucoma and diabetic retinopathy.[4] UTESA must also prepare students for the diagnosis, treatment and management of primary ocular disease to serve the Dominican population's needs. In Colombia, an optometric therapeutic law was approved in 1997 before the country's optometry schools adequately prepared their students.[36] Legal challenges to the law required all schools to implement significant curricular changes to prepare optometrists for the expanded new role. Today, optometry is recognized by the Colombian Ministry of Health in the national eyecare programs.[37] The Colombian experience indicates that UTESA should develop, as early as possible, a broad curriculum to justify therapeutic privileges for the profession. A follow-up study should address the UTESA professional program's effectiveness in addressing the Dominican Republic population's eyecare needs.

The current (2019) ratio of ophthalmologists per million population in the Dominican Republic is 32.5. This ratio is above the minimum recommended international standard of 27 ophthalmologists per million population.[34] Nevertheless, it is well below the current (2019) ratio of 59 ophthalmologists per million population in the United States.[38] All our simulation scenarios predict that the ratio in the Dominican Republic will never achieve the United States' ratio.

In the United States, based on a survey of male ophthalmologists between 50 and 85 years of age, the annual attrition rate of ophthalmologists was about 2.7% annually.[39-40]

Because approximately half of ophthalmologists in the United States are younger than 50 years, the actual annual attrition rate for all ophthalmologists is below 2.7%.[41] According to our model, assuming a 2% annual attrition rate of ophthalmologists in the Dominican Republic, the number of ophthalmologists per million will reach a maximum of 34.5 per million after 11 years and decrease thereafter. One recommendation from this scenario is the expansion of the ophthalmology resident positions within a decade to avoid a decline in the ratio of ophthalmologists to population.

The conclusions obtained from the models have several limitations. First, it is assumed that there is no interaction between the optometric and ophthalmologic workforce models. It is likely that as the number of university-educated optometrists increases, there will be pressure exerted by non-surgical ophthalmologists to decrease the growth of the university program. A future expansion of optometry scope to include the treatment and management of ocular disease is also likely to increase ophthalmologic opposition. This situation could be incorporated into the model by assuming a dampening factor on the number of optometric applicants. The value of the dampening factor would increase as the number of optometrists grows.

Second, the current models consider stable birth and mortality rates through time in the Dominican Republic. In a future paper, as reliable information about changing birth and death rates becomes available, the model may be refined through a table or graph function for the Vensim simulation.

Third, it is assumed there is no attrition of university-trained optometrists during the 60-year period. In the United States, where the profession is mature and well-established, approximately 2% of optometrists retire annually.[42] When assuming a cohort of young graduates in the Dominican Republic (less than 25 years old), one can expect low percentages of retirees during the first 40 years. On the other hand, when assuming a cohort of older students entering the program, one may expect a higher percentage of annual retirees. Future data on the student body composition may allow for better refinement of the optometric workforce model.

Fourth, the model is limited in scope and only addresses eyecare workforce needs based on international ophthalmologic standards and the United States' optometric standards. Further refinements of the model may consider workforce needs based on population-based data on the prevalence of refractive error, visual impairment and ocular pathologies in the Dominican Republic. The currently available information is limited in detail and quality but may improve in the near future to allow model refinements.

Lastly, as in all simulation models, the present model is based on assumptions that may change over time, such as the number of admitted optometry students and their retention rate, as well as the number of new ophthalmology residents. However, the model could be refined as the values of these variables are known and applied in the simulation.

Conclusion

This paper has shown an application of system dynamics to model the optometric and ophthalmologic workforce in the Dominican Republic. The model produces predictions of the changes in the supply of eyecare professionals under varying annual attrition rates. These predictions allow for useful recommendations to be made regarding optometric legislation to curb empiricism, future expansion of the scope of the profession, changes in the number of admitted optometry students, and changes in the number of ophthalmology residents. Optometric educators could apply system dynamics simulation in their public health courses in diverse areas. For example, it could be used to model demographic changes, the development of epidemics, the effects of air pollution, the provision of immunization services, or workforce needs as in the present case.[14-19]

Footnotes

[a] Mariano Belen, former President of the Dominican Optometric Association. Conversation with author, Santo Domingo, Dominican Republic. He has given permission to publish this information.

[b] The author has no financial arrangement with or interest in the Vensim software or Ventana Systems.

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