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A System Dynamic Model for The Supply and Demand Planning of Mathematical Sciences Graduates in Malaysia

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Abstract

The study investigates the interaction between the supply and demand of mathematics graduates through system dynamics (SD) modelling. Mathematics education plays a crucial role in preparing individuals for careers in science, technology, engineering, and mathematics (STEM), The study employs a holistic system dynamics framework and historical data on enrollment, graduation rates, dropout rates. Feedback loops and causal relationships between various factors such as enrollment rates, graduation rates, employment opportunities are incorporated into the model to simulate the system's behavior over time. Additionally, the study predicts future demand and supply of mathematics students based on the developed model. Furthermore, the research incorporates behavioral analysis to explore individual and collective behaviors influencing the supply and demand dynamics. This study contributes to the field of mathematics education by providing valuable insights into the dynamics of supply and demand and ease decision making by policymakers and institutions to enhance mathematics education availability and quality. It also fosters a robust pipeline of qualified mathematics professionals for the STEM workforce. Overall, the study demonstrates the significance of SD modeling in predicting future demand and supply, offering insights to address challenges and optimize resource allocation for skilled mathematics workforce.

Keywords: System dynamic modelling; supply and demand; behavioral analysis

1. Introduction

Based on the Malaysian Education Blueprint (MEB) 2013-2025, one of the agenda is to strengthen quality of Science, Technology, Engineering and Mathematics (STEM) education. The government viewed seriously the number of students enrolled in STEM education, which helps produce a skilled workforce important for the nation to navigate the Fourth Industrial Revolution (4IR). For Malaysia to remain competitive at the global state, the country should not be left behind in STEM education (Povera, 2022). However, there is a lack of awareness about the diverse career opportunities available to mathematics graduates, and organizations struggle to find suitable candidates for specialized positions. Based on Critical Occupations List (COL), organizations in the mathematical sciences industry face difficulties in finding suitable candidates, leading to extended hiring periods and hindering business growth. The extended hiring periods and talent gap hinder the growth and development of businesses relying on mathematical sciences.

While mathematics is widely recognized as a subject applicable in various fields, the specific job opportunities related to mathematics students may still be less known. Many individuals are unaware of the diverse range of career paths available to mathematics graduates. The demand for mathematics graduates is growing as industries rely more on data analysis, quantitative decision-making, and technological advancements. To maintain a balance in the labor market, the supply of talent should align with the demand. Workforce planning is essential to ensure that organizations have a steady supply of qualified professionals with the necessary expertise.

To address this issue, the development of a SD model for the supply and demand of mathematical science graduates is crucial. SD modeling provides a holistic approach to analyze the behavior of the system, identify key drivers, and visualize the system's behavior under different conditions (Sterman 2000). It is well-suited for framing, understanding and discussing complex problems (Azar 2012). By analyzing the behavior of the system over time and exploring the impacts of different policies or interventions, SD modeling can assist in workforce planning and bridge the experience gap in the industry.

The objective of this study is to identify the key factors influencing the supply and demand of mathematical sciences graduates and to build a system that could give the prediction of the supply and demand of mathematical sciences graduates for the following years through simulating a different scenario.

The study will encompass a comprehensive range of data to analyze the supply and demand dynamics of mathematical sciences graduates in Malaysia by using SD modeling. The data needed are the historical data of the number of mathematics students of two mathematics courses in the Department of Mathematical Sciences, Faculty of Science, UTM Johor Bahru, which are Bachelor of Science in Mathematics (SSCE) and Bachelor of Science in Industrial Mathematics (SSCM) from 2018 to 2022 and also the birth and death rate of Malaysian in 2018. VENSIM is used to develop the dynamic simulation.

As the data are only available for one year, it is important to address the availability of the data as the limitation. Additionally, the model used in the study may not accurately consider all the factors that affect supply and demand of the mathematical students as it focuses specifically on graduates from the Department of Mathematical Sciences at UTM Johor Bahru and does not consider data from other universities. Furthermore, the study assumes constant birth and death rates, which do not account for potential variations over time, such as changes in government planning policies. Another limitation is the lack of consideration for time-lags in the variables, such as the transition period from being a math graduate to entering the workforce, which can influence the dynamics of supply and demand. These limitations should be acknowledged when interpreting the study's findings

2. Literature Review

System Dynamic Model

The behavior of a system emerges from its underlying structure, which consists of causal loop diagrams (CLD), stocks and flows, and nonlinearities (Sterman 2000). These models capture the interaction between the physical and institutional structures of a system and the decision-making processes of the agents within (Sterman 2000). It involves constructing causal maps and influence diagrams to explore system structure and interrelationships, as well as developing computer models to simulate material or information flows (Srijariya, Riewpaiboon et al. 2008).

A key characteristic of SD models is their ability to combine qualitative and quantitative aspects to represent and simulate the behavior of dynamic systems. On the qualitative side, causal maps or influence diagrams are constructed to explore system structure and interrelationships. On the quantitative side, computer models are developed to simulate material or information flows. This combination allows for the analysis of different scenarios and the assessment of strategies and decisions (Srijariya, Riewpaiboon et al. 2008).

With the unique key characteristic, SD has the advantages compare to other modeling paradigms that focus on steady-state solutions. SD models aim to capture the dynamic relationships between variables and how they evolve over time. This makes SD particularly suitable for studying systems with nonlinear behavior and feedback loops. By tracking the changes in stocks and flows, SD models depict dynamic behavior and explicitly map information flows, enabling the representation of feedback interactions. This allows for the exploration of how changes in one variable can propagate throughout the system (Sterman 2000).

Over the past few decades, SD has been applied in various fields, demonstrating its usefulness as a decision aid system in different contexts. In the area of sustainable water resources management, Xi and Poh (2013) highlighted the importance of using SD models to structure water infrastructure and meet long-term water requirements in Singapore. Currie, Smith et al. (2018) explored the application of SD in managing environmental health issues, specifically focusing on understanding the interactions between human health and the environment. Zapata, Castaneda et al. (2019) utilized SD to simulate the impact of investment incentives in renewable and conventional energies on the supply and demand of the Colombian electricity market, showcasing the benefits of renewable complementarities in ensuring a cleaner and more balanced system. Relić and Božikov (2020) applied SD to predict the future supply and age distribution of physicians in Croatia, concluding that there is no need to increase enrollment in medical schools to maintain a sufficient number of physicians per capita.

Model Building Process

Figure 1 System dynamic modelling process (Sterman, 2000)

Using SD quantitatively implies the development of a 5-step process (Sterman 2000)

1. Articulate Problem. This step involves selecting the theme or focus, identifying the key variables involved, determining the time horizon (past, present, and future), and understanding the reference modes or behaviors of the key variables.
2. Form Dynamic Hypothesis. A dynamic hypothesis is formulated to explain the behavior of the system. CLD and Stock and Flows Diagram (SFD) are employed to understand the relationships between the stocks (accumulations), flows (rates of change), and feedback structures that best describe the observed reference modes of the key variables.
3. Build Simulation Model. A simulation model is developed based on the identified stocks, flows, and feedback loops. This involves assigning mathematical equations, defining parameters and specifying initial conditions.
4. Test Simulation Model. This step comprises extensive model testing in terms of dimensions, fit with historical data or observed behavior of key variables, robustness under extreme conditions and sensitivity.
5. Design and Evaluate Policy. Design of policies and experimentation with the model through changes in parameters, feedback processes, what if and decision rules.

3. Methodology

Model Formulations

In order to describe the model, the state/block variables and parameters are defined as follow:

State/Block Variables:

$x_1(t)$: Number of populations
$x_2(t)$: Number of Year 1 students from SSCE
$x_3(t)$: Number of Year 2 students from SSCE

$x_4(t)$: Number of Year 3 students from SSCE
$x_5(t)$: Number of Year 4 students from SSCE
$x_6(t)$: Number of Year 1 students from SSCM
$x_7(t)$: Number of Year 2 students from SSCM
$x_8(t)$: Number of Year 3 students from SSCM
$x_9(t)$: Number of Year 4 students from SSCM
$x_{10}(t)$: Number of math related jobs
$x_{11}(t)$: Number of math graduates

Parameters:
$r_1(t)$: Birth rate of the populations
$r_2(t)$: Death rate of the populations
$r_3(t)$: Dropout rate for SSCE Year 1 students
$r_4(t)$: Rate of SSCE Year 1 to Year 2
$r_5(t)$: Dropout rate for SSCE Year 2 students
$r_6(t)$: Rate of SSCE Year 2 to Year 3
$r_7(t)$: Dropout rate for SSCE Year 3 students
$r_8(t)$: Rate of SSCE Year 3 to Year 4
$r_9(t)$: Dropout rate for SSCE Year 4 students
$r_{10}(t)$: SSCE graduation rate
$r_{11}(t)$: Dropout rate for SSCM Year 1 students
$r_{12}(t)$: Rate of SSCM Year 1 to Year 2
$r_{13}(t)$: Dropout rate for SSCM Year 2 students
$r_{14}(t)$: Rate of SSCM Year 2 to Year 3
$r_{15}(t)$: Dropout rate for SSCM Year 3 students
$r_{16}(t)$: Rate of SSCM Year 3 to Year 4
$r_{17}(t)$: Dropout rate for SSCM Year 4 students
$r_{18}(t)$: SSCM graduation rate
$r_{19}(t)$: Loss rate of the number of individuals working in math-related field
$r_{20}(t)$: A fraction of math graduates who actually work in math-related field
$r_{21}(t)$: Adjustment factor of student enrollments

The initial value of the number of students in their respective year of study is obtained from year 2018.The dropout rate for both SSCE and SSCM course for all the years of study used in the model are only based on assumptions. The initial value of the number of students in their respective year of study is obtained from year 2018.The dropout rate for both SSCE and SSCM course for all the years of study used in the model are only based on assumptions.

System Equations

$$\frac{dx_1}{dt} = x_1 r_1 - x_1 r_2 \tag{1}$$

$$\frac{dx_2}{dt} = intake * r_{21} - x_2 r_3 - x_2 r_4 \tag{2}$$

$$\frac{dx_6}{dt} = intake * r_{21} - x_6 r_{11} - x_6 r_{12} \tag{3}$$

$$\frac{dx_3}{dt} = x_2 r_4 - x_3 r_5 - x_3 r_6 \tag{4}$$

$$\frac{dx_7}{dt} = x_6 r_{12} - x_7 r_{13} - x_7 r_{14} \tag{5}$$

$$\frac{dx_4}{dt} = x_3 r_6 - x_4 r_7 - x_4 r_8 \tag{6}$$

$$\frac{dx_8}{dt} = x_7r_{14} - x_8r_{15} - x_8r_{16} \tag{7}$$

$$\frac{dx_5}{dt} = x_4r_8 - x_5r_9 - x_5r_{10} \tag{8}$$

$$\frac{dx_9}{dt} = x_8r_{16} - x_9r_{17} - x_9r_{18} \tag{9}$$

$$\frac{dx_{10}}{dt} = x_5r_9 + x_{10}r_{18} - x_{10}r_2 - x_{10}r_{19} \tag{10}$$

$$\frac{dx_{11}}{dt} = x_5r_{10} + x_9r_{18} - x_{11} \tag{11}$$

4. Results and Discussion

Causal Loop Diagram

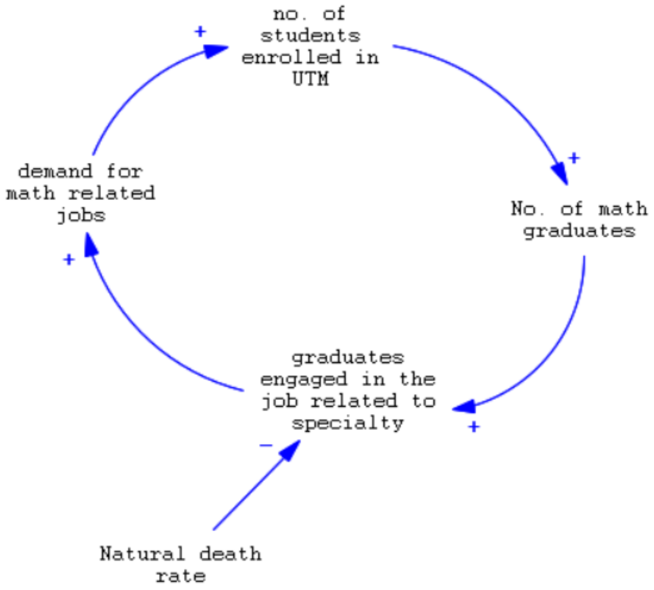

Figure 2 Causal loop diagram for the model

The CLD presents a comprehensive view of the factors influencing the supply and demand of mathematical sciences graduates in Malaysia. It emphasizes the interconnectedness of variables such as the number of students enrolled, the number of math graduates, engagement in specialty jobs, and the death rate. An increase in the number of students enrolled in math programs leads to a higher number of math graduates. The number of math graduates reflects the effectiveness of the educational institution and is influenced by dropout rates and graduation rates. A higher number of math graduates can contribute to the availability of skilled professionals in the field. The proportion of graduates finding employment in math-related fields indicates the demand for such jobs. A stronger demand for math-related jobs may encourage more students to enroll in math programs, leading to an increased supply of math graduates. The death rate can have adverse effects on the graduates engaged in the job related to specialty. When individuals with specialized skills and expertise pass away, it creates a void in the workforce and causes skills shortage, potentially impacting the quality of services or products provided.

Stock and Flow Diagram

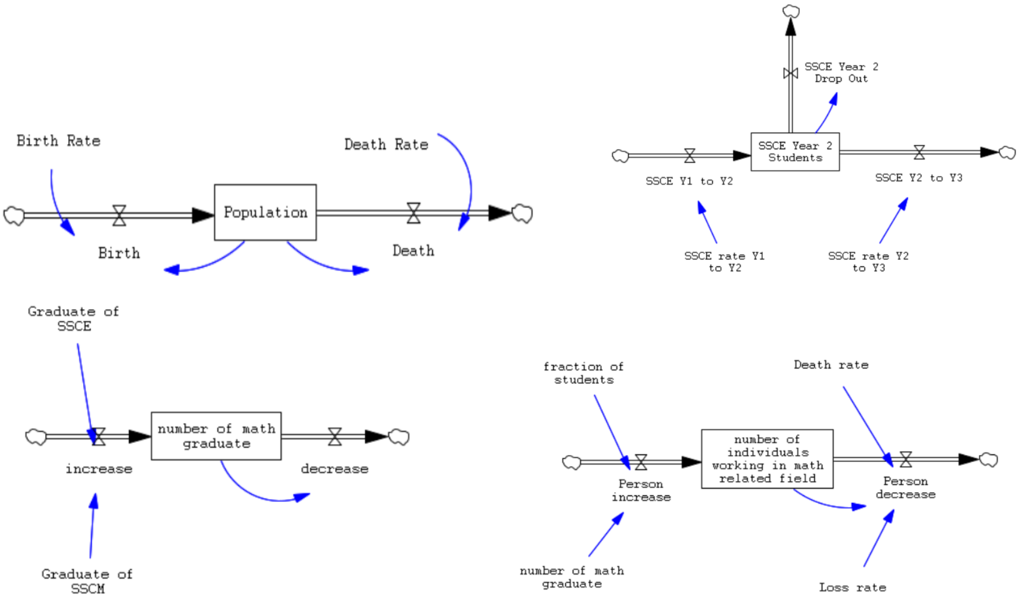

Figure 3 Stock and flow diagram for every stocks

Figure 3 shows 4 different stock model. The variables that are in the rectangular shape are the stock variable. There are two main flows that affected the population stock: the birth rate and the death rate. The number of math students' stock and is divided into Year 1, Year 2, Year 3 and Year 4. The inflow into Year 2 represents the students who have completed Year 1 and continue their studies into Year 2. Conversely, the outflow from each year signifies two distinct outcomes: students who successfully continue their studies to the next year and students who choose to discontinue their studies. For number of math graduate stock, the inflow is consisting of the number of graduates from the SSCE and SSCM while the outflow is the math graduate itself. The number of people working in math-related jobs is influenced by two main flows: the inflow and the outflow. The inflow of the number of individuals working in math-related fields primarily consists of individuals who have recently graduated with a mathematics degree and able to contribute to the increase in the workforce employed in math-related professions. Conversely, the outflow represents the decrease in the number of people working in math-related jobs.

Behavioral Analysis

Scenario 1 – Birth Rate

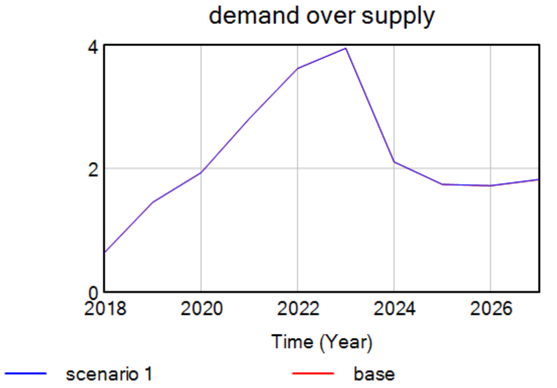

Figure 4 Comparison of demand over supply between two different birth rates

Scenario 1 is the scenario where the birth rate is adjusted to 0.013961 and is compared to the base case with birth rate of 0.016836. Figure 4 showed that the demand over supply ratio exhibiting little variation. Thus, it can be concluded that the birth rate of the population does not affect the ratio of demand over supply significantly

Scenario 2 – Death Rate

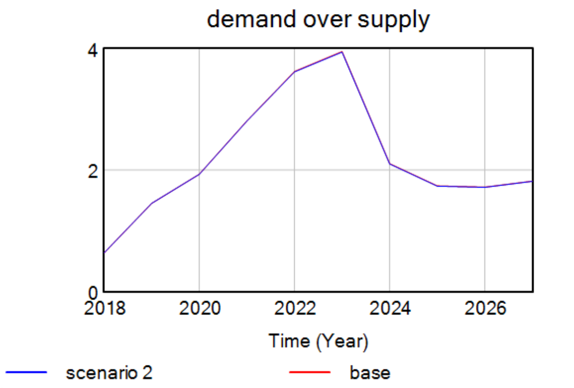

Figure 5 Comparison of demand over supply between two different death rates

Scenario 2 is the scenario where the death rate is adjusted to 0.006142 and is compared to the base case with death rate of 0.005054. From Figure 5, the ratio of demand over supply for the scenario 2 exhibit little variation. It can be concluded that the death rate of the population does not affect the ratio of demand over supply significantly.

Scenario 3 – Fraction of students that actually worked in math-related fields

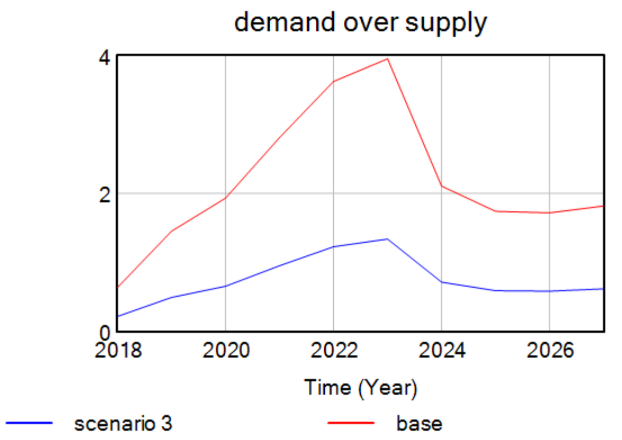

Figure 6 Comparison of demand over supply between two different proportions

Scenario 3 is the scenario where the fraction of students who actually worked in math-related field is adjusted to 0.27 and is compared to the base case with initial value of 0.797752. The changes in the fraction of math graduates who actually work in math-related fields have no effect on the total number of math graduates. However, these changes have a significant impact on the number of individuals working in math-related jobs. An decrease in the proportion of math graduates working in math-related fields leads to a corresponding decrease in the number of people employed in such jobs. This effect is reflected in the ratio of demand over supply, which also decreases while the number of math graduates remains unchanged.

Scenario 4 – Loss Rate

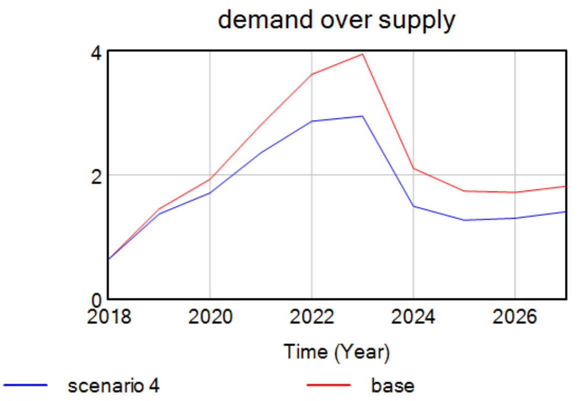

Figure 7 Comparison of demand over supply between two different loss rates

Scenario 4 is the scenario where the loss rate is adjusted to 0.25 and is compared to the base case with loss rate of 0.13. The changes in the loss rate have no effect on the total number of math graduates. However, these changes have a significant impact on the number of people working in math-related jobs. An increase in the loss rate leads to a corresponding decrease in the number of people employed in such jobs. This effect is reflected in the ratio of demand over supply, which also increases while the number of math graduates remains unchanged in both scenarios.

Scenario 5 – Adjustment factor of student enrollments

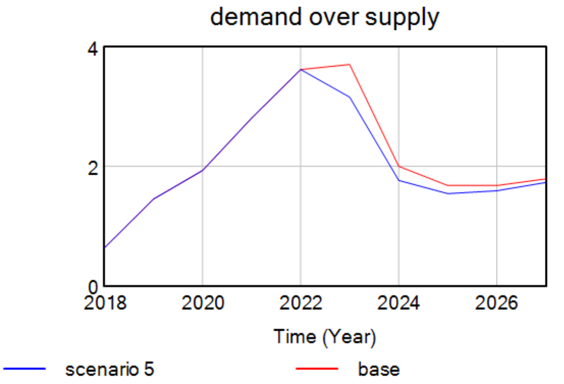

Figure 8 Comparison of number of math graduates between two different adjustment factors

Scenario 5 is the scenario where the adjustment factor of student enrollments is adjusted to 1.25 and is compared to the base case with initial value of 1. The increase of the adjustment factor lowers the ratio of demand over supply. This is mainly because the adjustment factor effect more on the supply more than the demand, causing the ratio of demand over supply to decrease.

Conclusion

The study can provide a comprehensive understanding of the current and future supply and demand dynamics for mathematical sciences graduates in Malaysia. This includes insights into factors affecting supply (enrollment rates, graduation rates, attrition) and demand. The study can also predict the future trends of supply and demand for mathematical sciences graduates in Malaysia. The system dynamics model is also used to conduct scenario analyses, exploring the potential effects of different scenarios.

The behavioral analysis explored different scenarios to understand their impact on the supply and demand of mathematics graduates. Both scenario 1 (birth rate) and scenario 2 (death rate) showed that the factors only had limited influence on the ratio of supply and demand of math graduates. In scenario 3, changing the fraction of math graduates in math-related fields brought a great impact on the number of individuals working in math-related jobs and the ratio of supply over demand of math graduates. Scenario 4, by adjusting the loss rate, the number of individuals employed in math-related fields also affected and led to changes in the demand-to-supply ratio. Lastly, Scenario 5, reflecting government encouragement programs, it significantly influenced both the number of math graduates and individuals working in math-related fields. The findings emphasize the importance of government initiatives in promoting mathematics education and the potential impact on the workforce supply and demand dynamics.

To address the limitations identified in this study, future research should focus on collecting longitudinal data to capture long-term trends in the supply and demand of mathematics graduates. Instead of assuming constant birth and death rates, future research could incorporate dynamic demographic factors that vary over time. More data can be used to capture the pattern of the parameters so that the parameters are adjusted as a function of time. Furthermore, expanding data collection efforts beyond a single institution would enhance the findings by including data from multiple universities and educational institutions. Refining the model's assumptions and parameters, such as accurately estimating the loss rate by considering factors like retirement or job migration, would provide a more precise representation of the workforce dynamics. Additionally, incorporating time lags in the model to account for the transition period from mathematics graduates to the workforce is recommended. By considering these recommendations, future research can overcome limitations and provide a comprehensive understanding of the supply and demand dynamics of mathematics graduates, contributing to effective policy-making and planning in the field of mathematics education and employment.

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