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Problem B: How Many Languages?

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1. Introduction

1.1 Background

There are currently about 6,900 languages spoken on Earth. About half the world's population claim one of the following ten languages (in order of most speakers) as a native language: Mandarin (incl. Standard Chinese), Spanish, English, Hindi, Arabic, Bengali, Portuguese, Russian, Punjabi, and Japanese. However, much of the world's population also speaks a second language. The total number of speakers of a language may increase or decrease over time because of a variety of influences that include the language(s) used and/or promoted by the government in a country, the language(s) used in schools, social pressures, migration and assimilation of cultural groups, and immigration and emigration with countries that speak other languages. Moreover, in our globalized, interconnected world, additional factors allow languages that are geographically distant to interact. These factors include international business relations and increased global tourism. To determine how the number of speakers of particular languages changes over time, there are two factors that we need to consider:

- Changes in the number of native speakers of a language
- Changes in the number of secondary speakers of a language

Native speakers are characterized by people who speak a certain language fluently and from birth. Second-language speakers are people who speak a certain language without much difficulty but this language in question is not the first language they learned (not their native language).

1.2 Problem Overview

In the rapidly globalizing world that we live in, many multinational companies are looking to expand their operations into various countries worldwide. As a result, our aim of this project is to identify which combination of languages should the employees in these companies be able to speak in order to communicate with the greatest number of potential customers. Additionally, we will also aim to identify the countries/cities where these companies should open new offices in.

1.3 Assumptions

- Since native speakers are those who speak a language since birth, the number of native speakers of a language only changes according to birth/death rates.

- Children that are born into a country that immigrants have migrated to are considered to be native speakers.

- Since secondary speakers of a language learn the language in question after their native language, only immigrants are considered to increase the number of secondary speakers of a specific language. The death rates of these immigrants also affect the number of secondary speakers of a specific language. Death rates of immigrants will be assumed to be the same as the death rates of the country/region they are migrating to.

- Only native speakers and secondary speakers of a language are representative of the total number of speakers of a language.

- We take the children of immigrants as sources of native speakers of a language since immigrant children need to learn the language of the country that they have migrated to in order to fully function in their new society.

- We omit individuals who learn new languages through school (including international students) or through online sources because there is no clear basis that these individuals

will use the new languages they have learned beyond a purely educational setting. As a result, it is difficult to claim that these individuals will become proficient in their new language.

1.4 Methodology - Solution Overview

To determine how the number of speakers of languages changes over time, we will model how the number of both native speakers and secondary speakers of a language changes. The number of native speakers changes only according to the birth and death rates of the population that speaks a particular language as their national language. The number of secondary speakers changes according to the immigration rates of people who are migrating into a country that speaks a different national language from the country that they are migrating from. We will use our mathematical model to predict how the number of speakers of languages changes over the next 20 and 50 years. From here we will identify the languages that will be most prominent in the future and recommend that these are the languages that employees of multinational companies should pick up. Based on the most widely spoken languages of the future, we will identify the countries/cities that multinational companies should expand into.

2. Data Processing

2.1 Data Source

The data source we will be using is a dataset of the top 26 most spoken languages worldwide in 2017. The dataset is produced by *Ethnologue* as part of their 2017 20th edition. The dataset has 7 variables that include the name of the language, the family that the language belongs to, the number of native speakers and secondary speakers of each language, the rank of each language

relative to the number of native speakers of other languages, the rank of each language relative to the number of secondary speakers of other languages, as well as the total number of speakers of each language derived by combining the total number of native speakers and secondary speakers. After deriving our model, we will use data from *Ethnologue* 25th edition (2022) to observe the accuracy and validity of our model and make the appropriate refinements if necessary. In addition, we will also be using the birth, death, and immigration rates for the countries that speak a language as their national language to identify the rates at which the number of native and secondary speakers of a language change.

2.2 Preliminary Data Exploration

Upon exploring the dataset, Punjabi, Japanese, Wu Chinese, Korean, Yue Chinese, and Vietnamese have missing values. As a result, we will be omitting these languages. Furthermore, we will only focus on the top 10 languages in 2017 from the remaining 20 languages. We will only be using the number of native speakers and secondary speakers of each language, and the total number of speakers of each language from the dataset in our analysis.

2.3 Model and Data Source-specific assumptions

- Assume Urdu speakers also speak Hindi, so we consider the whole Urdu population as a part of Hindi second language speakers. Therefore, we dropped Urdu in the 2022 dataframe.
- Assume Malay speakers also speak Indonesian, so we consider the whole Malay population as a part of Indonesian second language speakers. Therefore, we dropped Malay in the 2022 dataframe.

- We will assume the birth, death, and immigration rates in 2017 will remain constant over time.

3. Modeling Process and Analysis

3.1 Determining model parameters

To determine the growth rates of the native speakers of a language, we identified the birth and death rates of the largest countries (by population) whose official language is the language in question. For the growth rates of secondary speakers of a language, we took a similar approach: we took the net migration rates of the largest countries (by population) whose official language is the language in question. The birth, death, and net migration rates were extracted from a website called Macrotrends.net and reported as a value representing the number of births, deaths, and net migration per 1000 people. The birth, death, and net migration rates of each country, whose official language is the language in question, were then weighted according to the populations of each country with respect to each other. The mean of the weighted rates were then taken to represent the rate of change of the number of speakers of each language.

For example, to calculate the rate of change for the number of native speakers of Arabic, we took the populations of Egypt, Algeria, and Sudan. Egypt has a population of approximately 100 million while Algeria and Sudan have a population of approximately 40 million each. Thus, the rate of change of the number of native speakers of Arabic is given by:

$$Arabic_{L1} = 2.25 \times (B_{Egypt} - D_{Egypt}) + 0.875 \times (B_{Algeria} - D_{Algeria}) + 0.875 \times (B_{Sudan} - D_{Sudan})$$

where B represents birth rate and D represents death rate

3.2 Producing the initial model

Since our assumptions state that the number of native speakers of language change according to births and deaths of the native population, and the birth rate of immigrant population, our equation for calculating the number of native speakers over time can be given by:

$$L1_n = L1_0(1 + (B - D))^n + L2_{n-1}B^n$$

where, L1 = number of native speakers

L2 = number of second-language speakers

n = number of years

B = birth rate

D = death rate

Since our assumptions state that the number of secondary speakers of a language change according to net migration rate of a population, and since the net migration rate is contingent on the population of the country that an individual is migrating to, our equation for calculating the number of native speakers over time can be given by:

$$L2_n = (L2_0 + L1_{n-1}I^n)(1 - D)^n$$

where, I is the net migration rate

Putting it all together, our model is given by:

$$L1_n = L1_0(1 + (B - D))^n + L2_{n-1}B^n$$

$$L2_n = (L2_0 + L1_{n-1}I^n)(1 - D)^n$$

$$T_n = L1_n + L2_n$$

where T is the total number of speakers of a language

3.3 Validation

To validate the results of our model, we simulated our model from 2017 to 2022 to predict the number of speakers of each language in 2022. We then compared our predictions to the actual data published and also calculated the percentage difference between our predicted values and the actual values.

	Language	First language (L1) speakers	Second language (L2) speakers	Total speakers (L1+L2)	Language	First language (L1) speakers	Second language (L2) speakers	Total speakers (L1+L2)
0	Mandarin Chinese	9.197693e+08	1.862826e+08	1.106052e+09	Mandarin Chinese(incl. Standard Chinese, but e...	929000000.0	1.987000e+08	1.118000e+09
1	English	3.777981e+08	5.859605e+08	9.637586e+08	English	372900000.0	1.080000e+09	1.452000e+09
2	Hindi	3.476453e+08	2.073268e+08	5.549721e+08	Hindi(excl. Urdu)	343900000.0	2.583000e+08	6.022000e+08
3	Spanish	4.538661e+08	8.790678e+07	5.417729e+08	Spanish	474700000.0	7.360000e+07	5.483000e+08
4	Arabic	3.232340e+08	1.281145e+08	4.513485e+08	Modern Standard Arabic(excl. dialects)	0.0	2.740000e+08	2.740000e+08
5	Indonesian	8.224505e+07	1.988032e+08	2.810483e+08	Indonesian(excl. Malay)	43600000.0	1.554000e+08	1.990000e+08
6	Bengali	2.583279e+08	1.847773e+07	2.768056e+08	Bengali	233700000.0	3.900000e+07	2.727000e+08
7	Russian	1.533154e+08	1.061656e+08	2.594810e+08	Russian	154000000.0	1.041000e+08	2.582000e+08
8	Portuguese	2.205131e+08	1.050524e+07	2.310183e+08	French	79900000.0	1.942000e+08	2.741000e+08
9	French	7.661301e+07	1.481961e+08	2.248091e+08	Portuguese	232400000.0	2.520000e+07	2.577000e+08

Fig 1: Predicted values from initial model (first 3 columns) vs actual values (last 3 columns) for the number of speakers of each language in 2022

	index	Language	First language (L1) speakers	Second language (L2) speakers	Total speakers (L1+L2)
0	1	Mandarin Chinese(incl. Standard Chinese, but e...	-0.993612	-6.249310	-1.068698
1	0	English	1.313528	-45.744400	-33.625439
2	2	Hindi(excl. Urdu)	1.089071	-19.734109	-7.842558
3	3	Spanish	-4.388855	19.438554	-1.190429
4	5	Modern Standard Arabic(excl. dialects)	0.000000	-53.242898	64.725712
5	10	Indonesian(excl. Malay)	88.635446	27.930004	41.230292
6	6	Bengali	10.538238	-52.621195	1.505536
7	7	Russian	-0.444520	1.984253	0.496145
8	8	Portuguese	-5.114863	-58.312542	-10.353784
9	4	French	-4.113882	-23.688931	-17.982815

Fig 2: Percentage difference between predicted values from the initial model and actual values for the number of speakers of each language in 2022

As can be seen from Fig 1 and Fig 2, there were huge discrepancies between the predicted and actual values for each language. Thus, we decided to have a closer look at the data in Fig 2 to identify the areas that contributed to such significant discrepancies. Upon further analysis, it appears that the greatest percentage differences between the predicted values and the actual values occurred in the Second-language speakers column of the dataframe. In fact, the percentage differences in Fig 2 show that our model consistently under-predicts the change in the number of second-language speakers for each language. Moreover, this under-prediction is of a significant magnitude. Thus, it appears that the greatest flaws in our model lie in the second-language speaker component of the model. More notably, our model is under estimating the growth rates of second-language speakers.

3.4 Modifying parameters and additional assumptions

Through our validation process, we identified a significant flaw in our methodology. In our initial thought process, we assumed that only the death rates of immigrants affect the number of second-language speakers since we assumed that births of immigrants only contribute to changes in the number of native speakers. This assumption was made on the basis that children of immigrants will learn only the official language of the country they are migrating to and so will contribute only to the number of native speakers. However, through validation of the initial model, this assumption does not seem to be entirely true. In fact, it is probably much more likely that the children of immigrants will pick up both the official language of their new country while also learning the official language of the country that their parents migrated from. This will ultimately mean that the children of immigrants and the birth rates of immigrants will affect both the number of native speakers as well as the number of secondary speakers. As a result, an important new assumption is that:

- The birth and death rates of immigrants also affect the number of secondary speakers of a specific language. Birth and death rates of immigrants will be assumed to be the same as the birth/death rates of the country/region they are migrating to. Children that are born into a country that immigrants have migrated to are considered both native speakers and second-language speakers.

In addition, since we are now including immigrant birth rates as a factor for changing the number of second-language speakers, this would mean that the number of second-language speakers in the next year depends on the number of second-language speakers in the current year. Thus, a recurrence relation must be introduced to our second-language speaker equation. With these new

considerations, our new equation for calculating the number of second-language speakers is given by:

$$L2_n = (L2_{n-1} + L1_{n-1}I^n)(1 + B - D)^n$$

4. Final Model

With the necessary changes made to the second-language speaker equation, our new model is given by:

$$L1_n = L1_0(1 + (B - D))^n + L2_{n-1}B^n$$

$$L2_n = (L2_{n-1} + L1_{n-1}I^n)(1 + B - D)^n$$

$$T_n = L1_n + L2_n$$

To check the validity of our new model, we compared our model's predicted values to the actual values in 2022. We also calculated the percentage difference between our predicted values and the actual values like we did when validating our initial model. The figures below compare our model's results to the actual results for the year 2022.

	Language	First language (L1) speakers	Second language (L2) speakers	Total speakers (L1+L2)	Language	First language (L1) speakers	Second language (L2) speakers	Total speakers (L1+L2)
0	Mandarin Chinese	9.197693e+08	2.078387e+08	1.127608e+09	Mandarin Chinese(incl. Standard Chinese, but e...	929000000.0	1.987000e+08	1.118000e+09
1	English	3.777981e+08	6.479357e+08	1.025734e+09	English	372900000.0	1.080000e+09	1.452000e+09
2	Hindi	3.476453e+08	2.535094e+08	6.011547e+08	Hindi(excl. Urdu)	343900000.0	2.583000e+08	6.022000e+08
3	Spanish	4.538661e+08	1.025169e+08	5.563830e+08	Spanish	474700000.0	7.360000e+07	5.483000e+08
4	Arabic	3.232340e+08	1.824926e+08	5.057266e+08	Modern Standard Arabic(excl. dialects)	0.0	2.740000e+08	2.740000e+08
5	Indonesian	8.224505e+07	2.485751e+08	3.308201e+08	Indonesian(excl. Malay)	43600000.0	1.554000e+08	1.990000e+08
6	Bengali	2.583279e+08	2.238119e+07	2.807091e+08	Bengali	233700000.0	3.900000e+07	2.727000e+08
7	Russian	1.533154e+08	1.139344e+08	2.672498e+08	Russian	154000000.0	1.041000e+08	2.582000e+08
8	French	7.661301e+07	1.567389e+08	2.333519e+08	French	79900000.0	1.942000e+08	2.741000e+08
9	Portuguese	2.205131e+08	1.154717e+07	2.320602e+08	Portuguese	232400000.0	2.520000e+07	2.577000e+08

Fig 3: Predicted values from the final model (first 3 columns) vs actual values (last 3 columns) for the number of speakers of each language in 2022

	index	Language	First language (L1) speakers	Second language (L2) speakers	Total speakers (L1+L2)
0	1	Mandarin Chinese(incl. Standard Chinese, but e...	-0.993612	4.599253	0.859397
1	0	English	1.313528	-40.005957	-29.357175
2	2	Hindi(excl. Urdu)	1.089072	-1.854659	-0.173575
3	3	Spanish	-4.388855	39.289239	1.474190
4	5	Modern Standard Arabic(excl. dialects)	0.000000	-33.396849	84.571761
5	10	Indonesian(excl. Malay)	88.635446	59.958221	66.241271
6	6	Bengali	10.538238	-42.612327	2.936947
7	7	Russian	-0.444520	9.447046	3.504963
8	4	French	-4.113882	-19.289946	-14.866132
9	8	Portuguese	-5.114863	-54.177879	-9.949463

Fig 4: Percentage difference between predicted values from the final model and actual values for the number of speakers of each language in 2022

As can be seen from Fig 3 and 4, our predicted values are now much closer to the actual values in the year 2022, most notably in the total speakers column. Two languages where there are still huge discrepancies in the values are Arabic and Indonesian. However, these discrepancies can be

easily explained by the fact that the actual data presented for Arabic and Indonesia in 2022 appear to be incomplete or altered in a way that makes it extremely difficult to make comparisons between the data in 2022 and the data in 2017. Apart from these two languages, every other language lies within a 30% error margin in the total speakers column. Moreover, if we omit English as well, every other language lies within a 15% error margin in the total speakers column. Lastly, when we omit Arabic and Indonesia, our new model's ranking of the languages in descending order of total number of speakers is almost identical to the actual ranking of the languages. The only discrepancy is that the actual values have English as the most spoken language in the world in 2022 while our model predicts that Mandarin Chinese will be the most spoken language in the world in 2022. As a result, the error margins and ranking similarity imply that our model is reasonably valid for making predictions in the short-term.

5. Final Model Results and Simulations

5.1 Language Trends over 5 years (2017-2022)

In line with today's language trends. Our model predicts that the top 3 languages in the world are still Mandarin Chinese, English and Hindi with the notable point that Mandarin Chinese is the most spoken language in the world followed by English and Hindi.
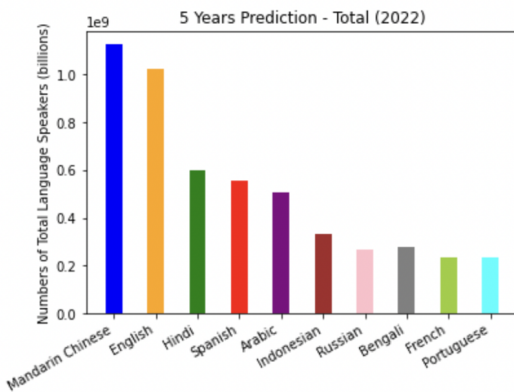

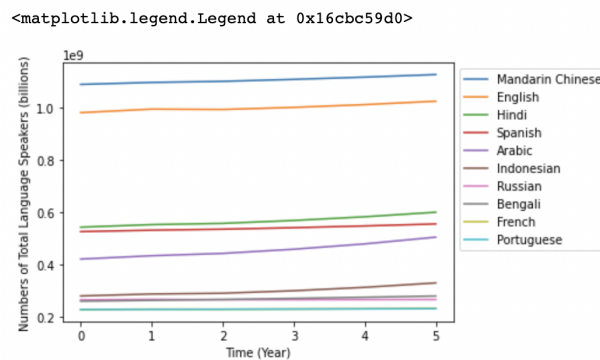Fig 5: Our final model's prediction for the total number of speakers of each language in 2022.

Fig 6: Line graph showing the change in the total number of speakers of each language over time from 2017 to 5 years after 2017 (2022).
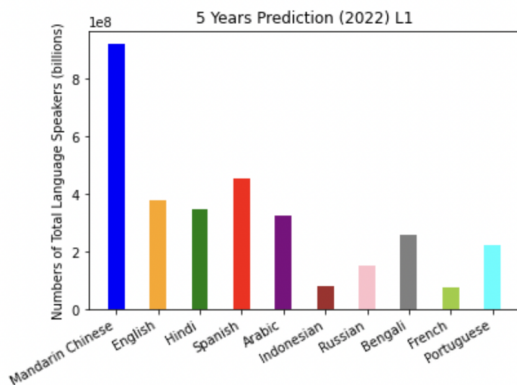

Fig 7: Our final model's prediction for the number of native speakers of each language in 2022.
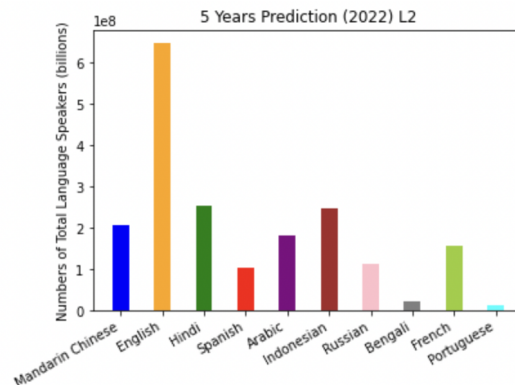

Fig 8: Our final model's prediction for the number of second-language speakers of each language in 2022

5.2 Language Trends over 20 years (2017-2037)

In 20 years, Arabic, Indonesian and Hindi will become the top 3 languages in terms of total number of speakers and number of second-language speakers. Mandarin Chinese, Spanish, and Arabic are the top three languages by total number of native speakers.
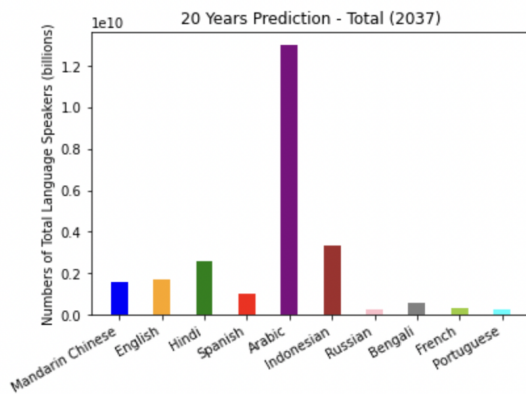

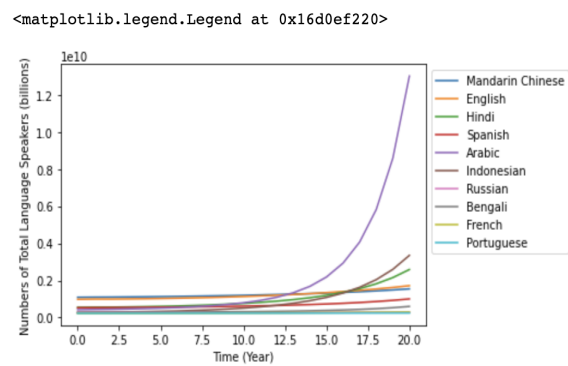Fig 9: Our final model's prediction for the total number of speakers of each language in 2037

Fig 10: Line graph showing the change in the total number of speakers of each language over time from 2017 to 20 years after 2017 (2037).
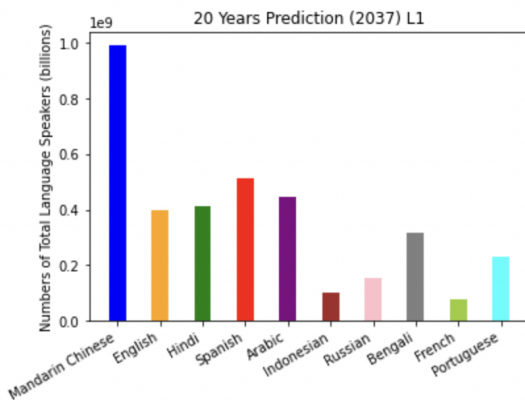

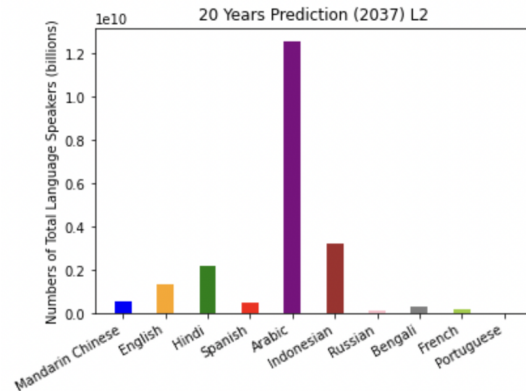Fig 11: Our final model's prediction for the number of native speakers of each language in 2037

Fig 12: Our final model's prediction for the number of second-language speakers of each language in 2037

5.3 Language Trends over 50 years (2017-2067)

In 50 years, Arabic, becomes the dominant language. Arabic's place as the only dominant language is spearheaded by Arabic becoming the only second-language that people learn. In 50 years time, the languages with the most native speakers are Mandarin Chinese, Arabic, and Spanish.
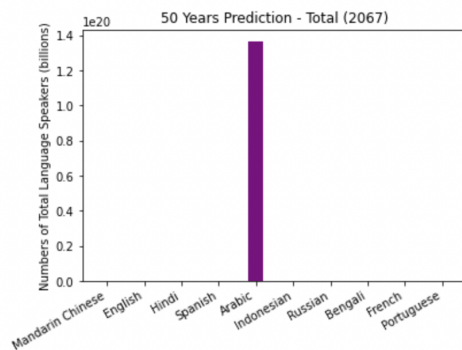

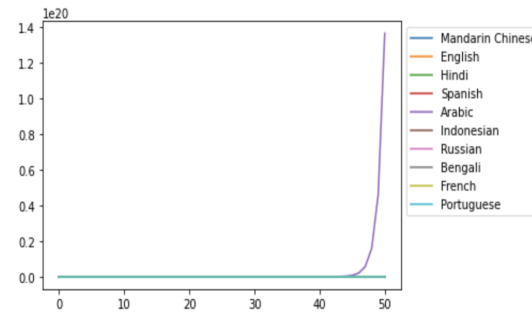Fig 13: Graph showing the total number of speakers of each language over time in 2067.

Fig 14: Line graph showing the change in the total number of speakers of each language over time from 2017 to 50 years after 2017 (2067).
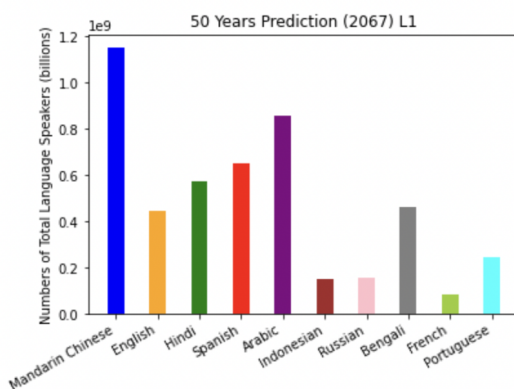

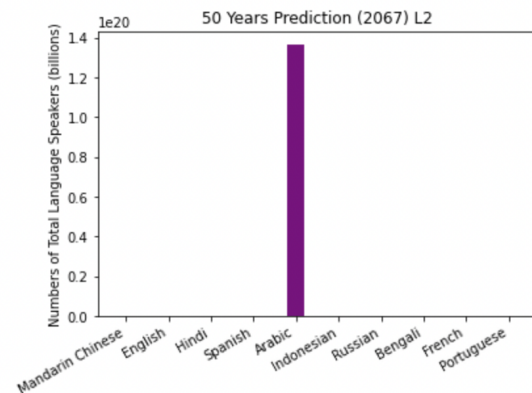Fig 15: Our final model's prediction for the number of native speakers of each language in 2067

Fig 16: Our final model's prediction for the number of second-language speakers of each language in 2067.

6. Conclusion

6.1 Summary and Analysis of Results

After simulating our model over the next 20 years, the top three languages in terms of both number of total speakers and second language speakers in 2037 are Arabic, Indonesian and Hindi in decreasing order of total speakers. This is an interesting phenomenon because it contradicts our current reality and shatters current stereotypes. A possible reason for this is that the birthrates of populations that speak English and Mandarin (the top two languages currently) predominantly are much lower than the populations that speak Arabic, Indonesian, and Hindi. On the other hand, immigration fell by more than half in almost all of the hot spots for foreign-born migrants.[1] Beyond data derived from the model, possible external reasons for this phenomenon is that compared to 2017, the number of Chinese and English learners and native speakers might have reached a saturation point or global trade demand has shifted considerably. As a result, it appears that Arabic, Indonesian and Hindi will become the hottest choice for language learners in the future. However, it is interesting to note that the top 3 languages in terms of native speakers in 20 years time are Mandarin Chinese, Spanish, and Arabic in descending order.

There are two main reasons for the increase in the number of speakers of Arabic, Indonesian and Hindi, one is the demand for economic and trade needs, and the other is the continuous growth of the birth rate. To be more specific, according to *DayTranslationsBlog*, it states the reason why Arabic is growing popular is because "Its population is growing and with a huge GDP, it is a prime market for export of services and goods.[2]" The reasons for the popularity of Indonesian and Arabic have something in common. In the website of *Critical Language*

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[1] The Atlantic https://www.theatlantic.com/newsletters/archive/2022/03/american-population-growth-rate-slow/629392/

[2] Top 14 Reasons Why It Is Important To Learn Arabic https://www.daytranslations.com/blog/why-learn-arabic/

Scholarship, it indicates that "Today, Indonesia features a rapidly growing economy and is gaining momentum on the international stage. By studying Bahasa Indonesian, you can add an in-demand language to your repertoire and prepare to contribute globally in your field, whether it's medicine, environmental policy, or music and the arts."[3] It can be seen that economics and trade has a great impact on people's language needs.

Among the three most spoken languages, Hindi is the most unsurprising because "Hindi is the 3rd most spoken language of the world in 2019 with 615 million speakers." India has the second largest population in the world, and as India's birth rate increases in the future, the number of native speakers of Hindi will also increase.

Since the number of people using Arabic, Indonesian and Hindi will increase dramatically in the next 20 years, the best country to build an office will be cities like Egypt. This is because Egypt holds the record for the largest Modern Standard Arabic-using population at around 65 million people. [4]Indonesia and India are close behind and are also good options.

Additionally, in 50 years, our model predicts that Arabic will remain as the most spoken language in the world as well as the most spoken second-language in the world. In fact, Arabic will become so widely spoken that the total number of speakers of every other language will not even be a fraction of the total number of Arabic speakers. However, for number of native speakers of languages, our model predicts that in 50 years, Mandarin Chinese will still have the largest number of native speakers followed by Arabic and Spanish. Thus, our model predicts that in the long term (50+ years), the only second-language that people will learn is Arabic.

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[3] Critical Language Scholarship https://clscholarship.org/languages/indonesian

[4] Babbel Magzine
https://www.babbel.com/en/magazine/how-many-people-speak-arabic#:~:text=Egypt%20holds%20the%20record%20for,Iraq%2C%20Saudi%20Arabia%20and%20Morocco.

6.2 Evaluation of the model/further investigation

For long-term predictions (50+ years), we observed that the number of Arabic speakers outweighed the numbers of speakers of other languages due to the fixed growth rate (1+B-D)^n we used where we selected the birth, death, and immigrate rate of 2017 only. Therefore, we believe our model breaks in the long-run due to the fixed growth rate power of the number of the years, and it does not arrive at a fixed state. This is because our model predicts that in 50 years time, the total number of Arabic speakers will be 1.4×10^{20} which is a totally unrealistic and absurdly huge number. Thus, this is indicative that our model breaks in the long-term since it is not possible for the Earth to hold that many people. In order to fix the problem, we believe that applying a logistic model will help us to adjust the fixed growth rate and define limitations of growing populations where each language should reach a fixed state at some point. However, we did try to use a logistic model but were unable to construct it properly which resulted in terrible simulations both in the short and long term simulations. Hence, we decided to use the model we presented.

Another weakness of our model is that we did not include catastrophe stochasticity which would include catastrophic events like wars, natural disasters, and pandemics. We were unable to include this aspect since it would cause us to cross the page limit by a significant amount. However, one could imagine that such catastrophes could have major affects on the language trends and populations of language speakers in both the short and long term.

Lastly, we believe our analysis and model creation was quite one-sided, especially for the calculation of second-language speakers since we only decided to use net migration rates. This is

highly evident in our prediction of the number of people who speak English as a second-language. One can imagine that since English is a hugely popular language in pop culture and social media, there are a great deal of factors that can represent changes in the number of second-language speakers of English such as educational and online resources, social media content, and international students. As a result, our model could be more accurate if we included more real world aspects. However, this was not possible since such real world statistics were extremely difficult to find.

6.3 Summary of Contributions

Yun Lin: Data Processing, Mathematical Model creation and analysis, Model Simulation, Visualizations and Validation.

Maximus Ong: Introduction, Data Processing, Mathematical Model creation and analysis, Model Validation.

Xi Wu: Data Processing, Visualizations, Conclusion, Memorandum.

Yuetong Li: Data Processing, Mathematical Model creation and analysis, Model Simulation, Memorandum.

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MEMORANDUM

TO: Chief Operating Officer of the service company

FROM: Yun Lin, Maximus Ong, Xi Wu, Yuetong Li

DATE: June 9, 2022

SUBJECT: Trends of global languages and location options for new offices

Dear Chief Operating Officer,

We are writing to inform you that we believe that the best locations for new offices in the future will be in Arabic-speaking countries like Egypt, Indonesia, and India according to the 20-year prediction of the trends of global languages made by our model .

As our company continues to set up international offices, the trend of global language is one of the most important factors when we decide where to open offices at. The more people are learning one specific language, the more powerful the corresponding countries are, theoretically. The dominant position in language learning means more opportunities, larger markets and stronger diplomacy. Therefore, we should open our international offices to countries whose language is widely being learned. We created a model to predict the trends of each language, which by assumption, are influenced by the immigration rate, birth rate and death rate of the corresponding country. Our group did both 20-year and 50-year simulations and the conclusions for both simulations are very similar. Arabic, Indonesian and Hindi will take the lead after 20 years and finally, Arabic will dominate the global language landscape in approximately 50 years. Those three places would be the most promising places in the world, so we suggest those are where our offices should be.

Please let us know if you have any questions.