CSS 600 Fall 2024
Group 4 Technical Annex
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Technical Annex

This is the technical annex that provides supporting evidence of our model presented in:

Migration Movement Agent-Based Model

Based on the original model and documentation of the following:

1. Al-Khulaidy, A. and Swartz, M. 2020. ABM Migration SpringSim2020. https://github.com/msgeocss/ABM_Migration_SpringSim2020. 2020 Spring Simulation Conference, Fairfax, VA.
2. Al-Khulaidy, A. and Swartz, M. 2020. "Along the Border: An Agent-Based Model of Migration Along the United States-Mexico Border." 2020 Spring Simulation Conference, Fairfax, VA. https://doi.org/10.22360/SpringSim.2020.HSAA.012

The purpose of the original model (Al-Khulaidy Swartz 2020) is to implement an agent-based model (ABM) that simulates migration patterns to the U.S.-Mexico border from migrants south of the border.

Other credits and references to the original model is found below:

1. Bah, T. L., & Batista, C. 2019. “Understanding Willingness to Migrate Illegally: Evidence from a Lab in the Field Experiment.”
2. Huber, P., & Nowotny, K. 2018. “Risk Aversion and the Willingness to Migrate in 30 Countries”. [Working Paper].

Problem Formulation

Building on an existing ABM that simulates decision-making of Mexican citizens migrating to the U.S., this project adds migrants from Central America. This expanded ABM yields data on migration at the country level, given border restrictions, willingness to migrate and risk aversion.

According to the Migration Policy Institute’s (Bersin 2024) report, there are four key factors driving the decision to migrate to the approximately 2,000 miles long Southwest border of the U.S.:

1. The mix of push and pull factors: The relative importance of these factors varies by the individual and uniquely influenced by their country of origin.
2. Cost to migrate: This includes the financial cost as well as the risk and danger of the journey.
3. Likelihood to reach border checkpoint and being admitted: Migrants consider the chances of being admitted to the destination country.

4. The consequences of being turned away: The potential repercussions to being turned away or apprehended at the border checkpoint.

To examine the influence of key driving factors on migration, Al-Khulaidy and Swartz (2020) developed an ABM that examines the movement of Mexican migrants towards the southwest border, focusing specifically on how Mexican migrants decided which port of entry to cross into the U.S. Given the increase in U.S.-Mexico border encounters among non-Mexico migrants (Alba 2024), this project expands on prior work to focus on the composition of migrants arriving at the U.S.-Mexico border. We focus on whether migrants were more likely to be from Mexico or Guatemala, Belize, Honduras, and El Salvador. The specific question that this project is trying to answer is: Do migration patterns between Mexican and Central American migrants differ by enforced border restrictions, willingness to migrate, and risk aversion?
H0: There is no difference in the ratio of migrants by different countries of origin.
H1: There is a higher ratio of migrants who are from Central American countries than Mexico.

Original Model and Purpose
The link to the original model (ABM Migration SpringSim2020) and reference documentation is included on the first page of this technical annex. There are no TRACE or ODD documents available for this model.

Al-Khulaidy and Swartz (2020) created an ABM model whose purpose is to simulate migrant decision-making of selecting border port of entries to enter the US and to understand group behavior of migrants along the southwest border. The U.S.-Mexico border is 1,945 miles long with 48 border crossings and 330 active ports of entry (Homeland Infrastructure Foundation-Level Data 2019). Al-Khulaidy and Swartz take a bottom-up approach to model individual's decision to migrate, and the "route" taken to cross into the US. Figure 1 shows the entity of the migrant as an agent in the NetLogo model, their attributes, and behaviors.

Figure 1. Entity Model of Migrant Agent

Figure 2 shows the migrant's decision-making process in the model. Migrants are selected from population based upon individual and country-level factors. Then, they choose an initial port of entry (POE) to enter the U.S. On the way, they encounter other migrants and receive information and may choose to follow a caravan of migrants. If border-restriction is in place once they arrive at a POE, they choose the nearest border to them.

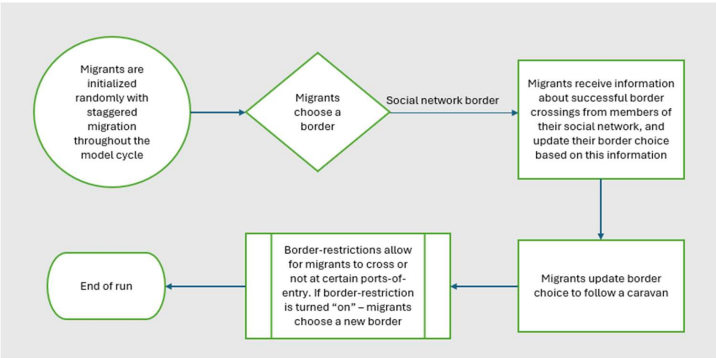


Figure 2. Flow Diagram of Migration Movement Decision-Making

The ABM Migration SpringSim2020 model displays migration patterns of migrants from south of the border and entering the U.S. through one of the official POE. The map below shows the movement through Mexico toward the destination border. There is only one direction that agents move: south to north with no return in the other direction. Once migrants cross into the U.S., they disappear with no information on their destination. Each patch is scaled to represent 25 sq km, which is the approximate distance that a migrant would travel in one day. With this, each tick in the model represents one day and the model is run for 365 days to represent one year.

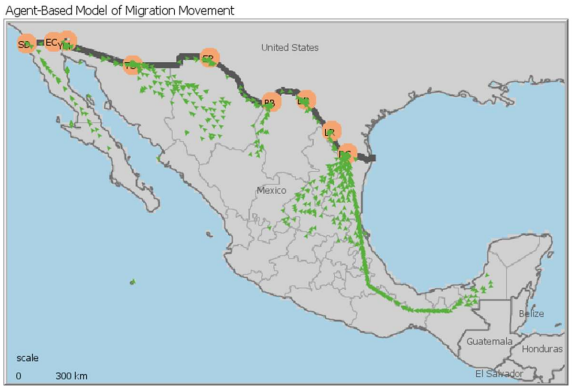


Figure 3. Map of U.S – Mexico Region and Active Migrants

The model has output metrics to include the number of migrants crossed and at which POE. Results are graphed as a percentage of all migrants. There are counters for each POE and an overall counter of total number of agents actively migrating, at a border, or who have crossed into the U.S.

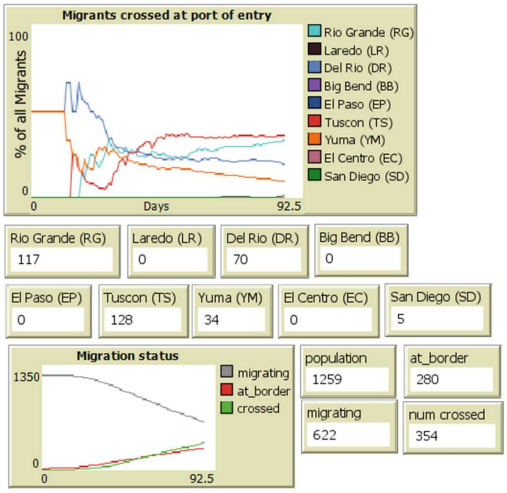


Figure 4. Graph of Migrants crossed at port of entry and Number of Migrants at Each U.S. Port of Entry

Modifications

The ABM Migration SpringSim2020 was used as a starting point because it already had agents that represented migrants from Mexico, geographical elements showing the U.S.-Mexico region, and the parameters influencing decision to migrate--willingness to migrate, risk aversion, means, and border restrictions. Our updated model—Migration Movement ABM—examines migration patterns at the country level so additional countries were added and color coded to display in the model: El Salvador, Honduras, Guatemala, and Belize.

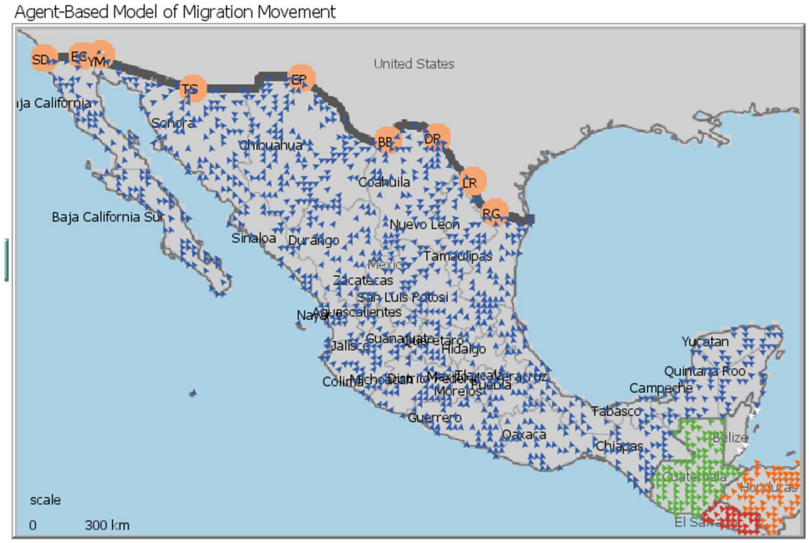
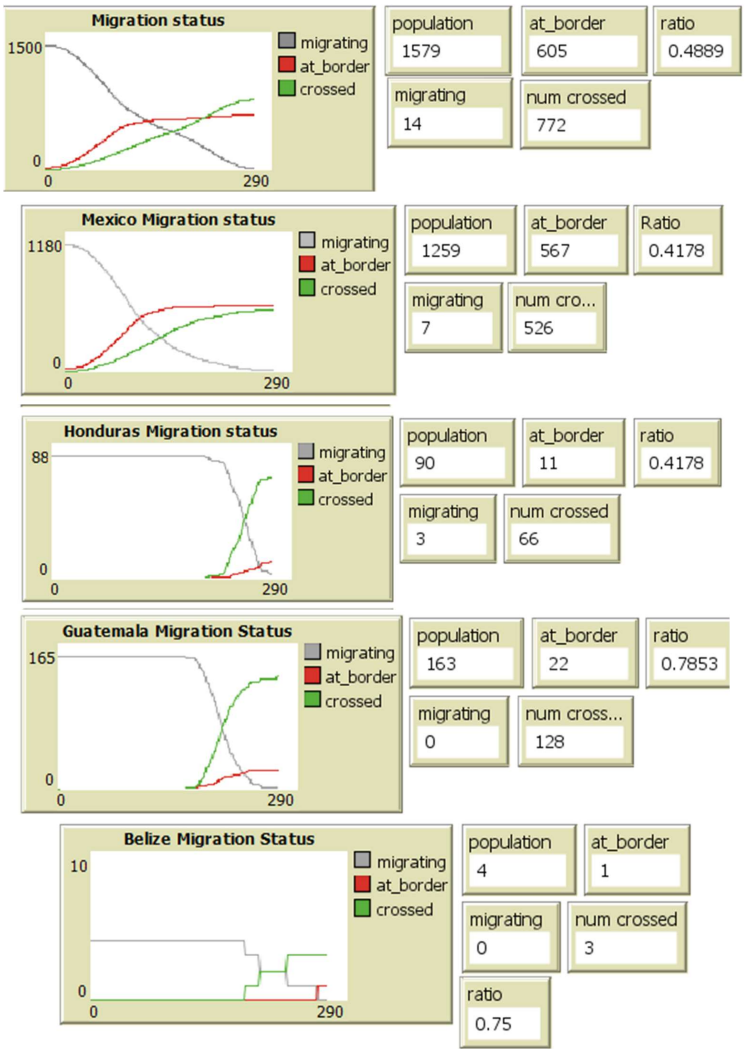


Figure 5. U.S.-Mexico Region with Migrants from Mexico, Belize, Honduras, El Salvador, Guatemala

The pop-display was updated on the interface to display the expanded list of countries as well as two categories: All and Non-Mexico. "All" includes Mexico, Belize, Honduras, Guatemala, and El Salvador. Non-Mexico includes all countries **except** for Mexico.

Figure 6. Updated NetLogo pop-display

Another major modification in the original model was made to the plots and metrics displayed. Our research question required the counts of migrants for each country which included those actively migrating, at the border, and cross into the U.S. We also need to calculate the ratio of migrants to the total number of agents for the country.



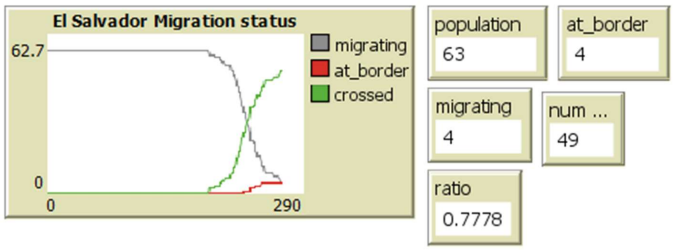


Figure 7. Updated NetLogo Monitor by Each Country with Ratio who Crossed the Border

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To incorporate unique risk at the country level that modifies a migrant's willingness to migrate, we incorporated the European Union's INFORM Risk Index for each country. The European Union created a measure called INFORM Risk Index based on three main dimensions: Hazard & Explores, Vulnerability, Lack of Coping Capacity (Marin-Ferrer and Poljansek 2017). An agent's home country's risk index scaled as a fraction is used to adjust willingness to migrate, where higher country risk increases an agent's willingness to migrate and lower risk decreases an agent's willingness to migrate.

Country Name	INFORM Risk Index
Belize	3.7
El Salvador	4.2
Guatemala	4.9
Honduras	4.2
Mexico	5.5

Table 1. Countries and their INFORM Risk Index

Table 2 below outlines global parameters and variables of the Migration Movement ABM with description and sample input values. New parameters and variables created for this project are highlighted in green.

Model Variable/Parameter	Description	Sample Value
countries	Country polygons	Map of whole country
Mex_districts	The districts within Mexico	(-103, 25)
Border_line	Black border line	(-115.2,33)
Border_pts	Actual ports of entry	(-115.2,33)
bbox	Bounding box for the model's spatial area	(-100, 25)
Patch-scale	Includes a certain square for determining patch size	25sq km
Scale-bar	Standard of the distance in the map	100 km

Global-willingness	Represents the global level willingness of agents to migrate in the model	0
Global-means	Represents the global level means to migrate of agents	0
Global-risk	Represents the global level risk of agents to migrate in the model	0
Current-display	Display the agents based on the setting	Migrants only
Num-crossed	Number of people who crossed the border	32
Country-risk	Country's own level of risk to migrate	["Mexico" 0.055] ["Guatemala" 0.049] ["El Salvador" 0.042] ["Honduras" 0.056] ["Belize" 0.037]
Num-migrating	Number of people who is migrating	132
Num-at-border	Number of people who stay at the border	24
Total-migration-count	Sum of num-crossed, num-migrating, and num-at-border	893
My-willingness-to-migrate	Agent's own level of willingness-to-migrate	62
My-risk-aversion	Agent's own level of risk-aversion	24

Table 2. Fall 2024 Migration Movement ABM Global Parameters and Variables

Initialization

The class project employs data from a simulated migration model designed to analyze movement patterns and decisions based on geographic and various push-and-pull factors. The data adopted in the model is representative for migrants from each country and has been synthesized to simulate realistic migration scenarios using actual country-level information related to migration. Key input parameters, such as willingness to migrate and risk aversion, were calibrated using theoretical frameworks and migration studies. These inputs were refined to ensure the scenarios maintain their basis in real-world data.

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For initialization, the model incorporates country-specific migration risk values derived from the INFORM Risk Index, which adjusts a migrant's willingness to migrate. This index, which is based on dimensions such as hazard exposure, vulnerability, and lack of coping capacity, was scaled as a fraction to reflect each country's risk level. Country risk indices were set as following Mexico (0.055), Guatemala (0.049), El

Salvador (0.042), Honduras (0.056), and Belize (0.037). These values were used as base conditions for agent decision-making.

To expand the analysis to the country level, the model was updated to indicate those countries, Guatemala, El Salvador, Honduras, and Belize. These countries adapted different colors for clarity, and the pop-display was updated to include two new categories, which are "All" (Mexico, Guatemala, El Salvador, Honduras, and Belize) and "Non-Mexico" (excluding Mexico).

Figure 8 indicates the migration ratio by each country, showing the volume of migrants moving across geographic boundaries (borders). The histogram synthesizes plausible migration behaviors, derived from initialized values of migration willingness and risk aversion. From this simulation, it was observed that migration ratios varied based on agents' willingness to migrate and risk aversion, with the ratio of agents crossing the border ranging from 0.2 to 0.6 over the simulated days.

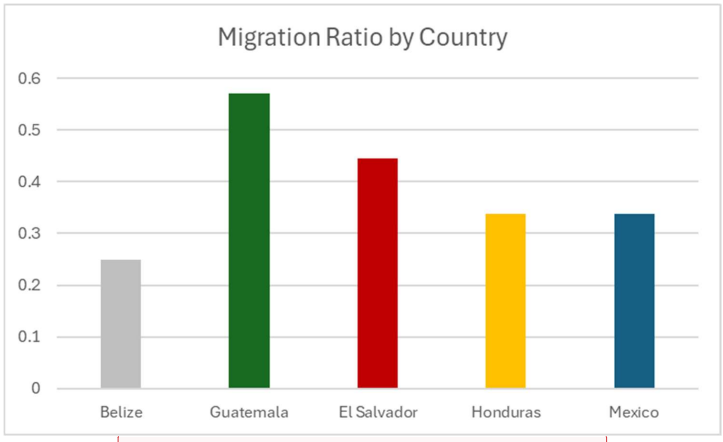

Figure 8. Histogram of Migration Ratio by Each Country

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Testing

In order to ensure that the modifications to the migration ABM were simulated as intended, systematic testing was conducted using NetLogo's Behavior Space to evaluate the impact of key parameters and validate the newly incorporated features. Testing scenarios explored combinations of border restrictions, willingness to migrate, and risk aversion to assess migration patterns and agent behaviors under varying conditions.

Figure 9 provides results from an exploratory analysis of the model. Results confirmed that agents did not migrate when WTM<50. When WTM increased from 50 to 60, the upper limit of migrants who crossed the U.S. border doubled from approximately 400 to 800. Conversely, agents were more likely to migrate with lower levels of RA. When RA increased from 20-30 to 40, the average number of migrants who crossed decreased by approximately 30%. Risk aversion greater than 40 overall did not result in migration movement.

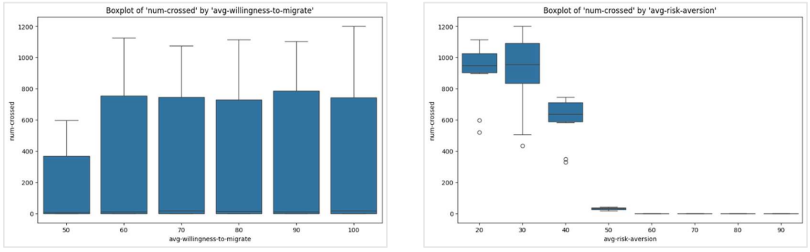

Figure 9. Preliminary Analysis of Willingness to Migrate and Risk Aversion

Results from the exploratory analysis revealed very clear values to use in the experiment. Willingness to migrate at values of 50 and 60 to analyze their effect on migration flows. Similarly, risk aversion at values of 20 and 40 to evaluate the sensitivity of migration patterns to agents' risk tolerance. These findings show that higher willingness to migrate increased migration flows, while higher risk aversion resulted in fewer agents attempting to migrate.

Additionally, the expanded pop-display categories ("All" and "Non-Mexico") were tested to ensure accurate representation of migration patterns. The migration ratios for both categories were calculated and validated to reflect the expanded list of countries. Figure 10 provides a screenshot of the updated interface, showing the integration of these features.

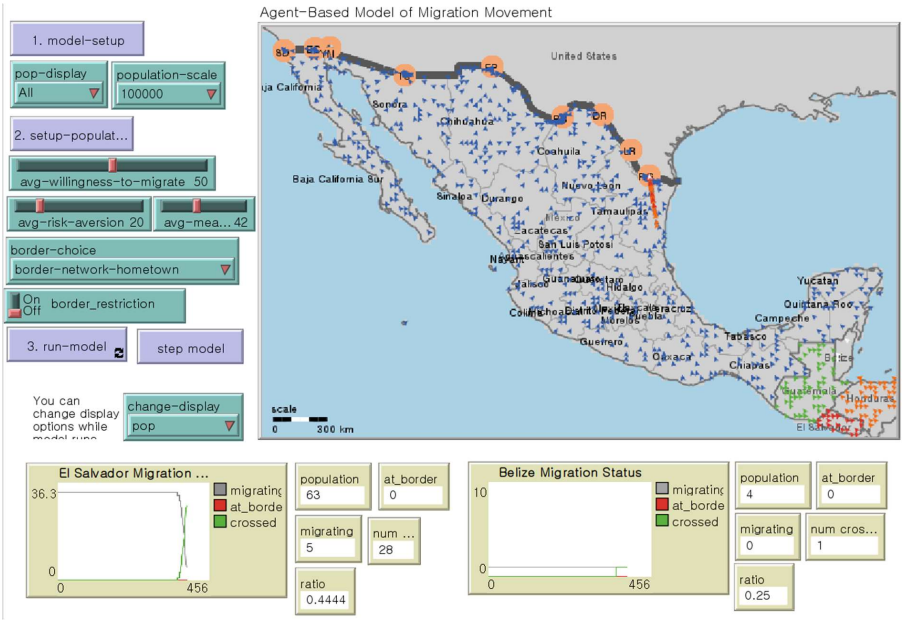

Figure 10. NetLogo Dashboard to analyze the migration patterns

Lastly, we inspected agents from different countries and examined their properties. By comparing the "my-willingness-to-migrate" property from a Mexican migrant versus Honduras migrant as an example, we could confirm the correct implementation of adjusted WTM using country-risk.

These tests demonstrated that the model modifications worked as intended, producing results consistent with migration studies and theoretical frameworks.

Experiments

After setting the input of the project model with the certain values, a number of experiments were conducted to determine the impact of input variables to include changes in migration ratio of agents by each country, and migration patterns. The main report focuses on the following scenarios:

- **Base Country Risk:** Mexico (0.055), Guatemala (0.049), El Salvador (0.042), Honduras (0.056), and Belize (0.037)
- **Case 1:** Border Restriction = OFF
- **Case 2:** Border Restriction = ON
- **Case 3:** Average Willingness-to-Migrate = 50
- **Case 4:** Average Willingness-to-Migrate = 60
- **Case 5:** Average Risk-Aversion = 20
- **Case 6:** Average Risk-Aversion = 40

Figure 11 and Table 3 show the percentage of migrants by given cases.

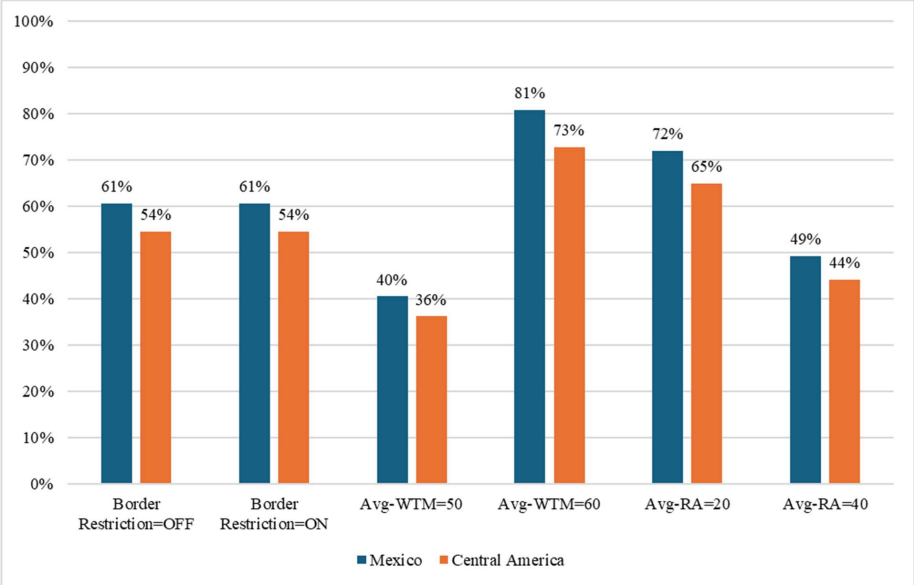

Figure 11. Histogram of Percentage of Migrants Crossed

	Border Restriction: Off	Border Restriction: On
Mexico	61%	61%
WTM=50, RA=20	48%	48%
WTM=50, RA=40	33%	33%
WTM=60, RA=20	96%	96%
WTM=60, RA=40	66%	65%
Non-Mexico	54%	54%
WTM=50, RA=20	43%	43%
WTM=50, RA=40	29%	29%
WTM=60, RA=20	86%	86%
WTM=60, RA=40	59%	59%

Table 3. Percentage of Migrants Crossed by Country for Cases 1 to 6