A Report to the Arizona Department of Transportation

Forecast and Capacity Planning for Nogales' Ports of Entry

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1 Executive Summary

This document provides the final report of the activities performed under the project Nogales POEs Traffic Study: Forecast and Capacity Planning for Nogales' Ports of Entry sponsored by the Arizona Department of Transportation (ADOT) under Grant JPA 08-024T. Some of the main activities of this study include:

- A baseline analysis of the Nogales Ports of Entry (POEs), Mariposa POE and DeConcini POE. Including analysis of historical data for these POEs, a visit to the Mariposa POE and conclusions gathered from any relevant previous studies.
    - Different types of traffic were investigated, including commercial traffic (mainly truck), POV (Privately Owned Vehicle), pedestrian, bus and train.
    - Through our analysis, we discovered that the truck traffic contained a very strong seasonality pattern while other modes of traffic did not.
    - Previous to our study, there were not many studies dedicated to forecasting border crossing traffic.
    - None of the studies we reviewed had dealt with the seasonality pattern we observed here.
    - Economic indices were usually incorporated in the models; however, one should take caution when choosing the proper indices to incorporate into the model.
    - The Mariposa POE was the only one of the Nogales POEs that processed truck crossings, thus a traffic spilt between POEs only occurred with POV, buses and pedestrian traffic.
    - The traffic split between the two POEs was stable throughout the years. For pedestrians, the DeConcini POE consistently accounted for nearly 95% of the pedestrian traffic. POV traffic had a ratio of roughly 60:40 (DeConcini: Mariposa) before 2007, and then 70:30 (DeConcini: Mariposa) from late 2007 onwards. Bus traffic had a ratio of roughly 25:75 (Deconcini: Mariposa) over the years analyzed.
- Testing of various model alternatives on the historical data for the different modes of traffic to find the best methods for creating our forecasts.
    - We built different types of models on the historical data, including different types of regression models and time series models. The performance of the models was compared, and the best performing models were chosen to produce the forecasts.
    - For the POV traffic, we built the model based on the number of vehicles, since the POVs were processed by vehicle.
    - Models for bus traffic were built on the number of bus passengers, since bus vehicle capacity might not be fully utilized.
    - Generally, the time series models were better for short term forecasts.

    - We found that the exchange rate between the Mexican Peso and US dollar was the most influential economic variable for truck traffic.
    - We tested the external variables on other traffic types, but none of them was statistically significant. However, we found that including Arizona employment data improved the quality of the models for pedestrian traffic.
    - No model was built for rail traffic because only the Union Pacific operates through Nogales, and company-specific decisions seemed to drive the history.
- Using the chosen models to provide forecasts of border crossings for the next 5, 10 and 15 years into the future
    - Time series models were used to produce all the short term (5 year) forecasts for all the traffic modes.
    - Regression models were used to produce the long term (10-year and 15-year) forecasts for POV, pedestrian and bus.
    - Time series models were used to produce the long term (10-year and 15-year) forecasts for trucks.
    - Long term forecasts for the economics indices were not available, so we defined plausible scenarios and used these scenarios in our models for crossing traffic.
    - According to our forecasts we found that the number of Commercial Vehicle (mainly truck) crossings might increase up to 50% in 15 years when compared to the number of crossings recorded in 2008.
    - The POV traffic and pedestrians were more sensitive to the changes in the economic climate and therefore their forecasts are less reliable than those obtained for commercial vehicles.
    - Our forecasts suggest that, in the near future, POV, pedestrian and bus traffic will decrease slightly. We do not believe they will continually decrease; however, we could not be sure when the declines will reverse.
    - These near term trends are probably driven by the economic downturn that began in late 2007.
- Creating a simulation model to test the capacity of the Nogales POE given our forecasted future traffic demands. Some of the results produced through this simulation include the following:
    - If our forecasts are correct, the maximum queue length based on our capacity estimates will be approximately 2300 trucks (over one day's backlog). The bottleneck location is the super-booth area for most of our scenarios.
    - Given existing infrastructure and time constraints (i.e. 11 hour workday), the current Mariposa POE does not have capacity to service our predicted maximum levels of traffic.

2 Introduction

This report documents the findings and the activities performed under ADOT grant JPA 08-024T. The overall purpose of this study was to forecast the number of border crossings by mode of traffic at the Nogales-Mariposa and DeConcini Ports of Entry (POEs), and to assess the interaction between the Mariposa and DeConcini Ports of Entry. Significant population growth and economic development in the Ambos Nogales area requires new comprehensive planning to address growing demands placed on the two land POEs. In addition, this growth and development calls for an examination of port of entry needs and opportunities.

In order to meet the expected increase in traffic at the international POEs in Nogales, the federal government and the State of Arizona plan to expand the capacity of the Nogales POEs in the near future. Sizing this new capacity requires forecasting the demand for each of the POEs as a foundation for developing appropriate expansion plans.

This report covers the activities completed from the start date of the project: 06/01/2008 to the end date of the project: 12/31/2009. The major product of this study will be a final report which contains projections of the number of border crossings by mode of transportation over five, ten and fifteen year periods and a description of the interaction between the Mariposa and DeConcini Ports of Entry, which is primarily in the area of passenger vehicles and, to a lesser extent, pedestrians and buses.

The general steps to be completed as part of this project include the following:

1. Identify, assess and classify previous studies dealing with traffic forecasts of the targeted Ports of entry
2. Analyze and document current conditions of the POEs
3. Develop preliminary assessment of forecast models and refine scope of work
4. Present preliminary findings and proposed model to ADOT
5. Develop the accepted forecast models
6. Collect data and validate forecast models
7. Determine infrastructure capacity
8. Interim report preparation
9. Final report preparation

In the rest of this report we provide a brief summary of the activities performed to accomplish these tasks.

3 Refinement of Tasks

The proposed initial tasks to conduct *Nogales POEs Traffic Study: Forecast and Capacity Planning for Nogales' Ports of Entry* were presented to the Technical Advisory Committee (TAC) in the inter-plenary kickoff meeting in August 2008.

After the objectives were approved by the TAC we developed a set of detailed activities required to complete the scope of work for the project. These activities are as listed above.

These tasks were then updated during a meeting with ADOT on June 20, 2009 when it was also decided that in addition to the three modes of traffic that had already been analyzed as a part of this study (Commercial Vehicle, Pedestrian and POV), bus and train traffic should be added to the scope of this study.

The remainder of this report is organized according to the following activities:

- Documentation of previous studies related to the scope of this project
- Analysis of the historical data of border crossings for various modes of traffic
- Analysis of the current state and traffic split of both Nogales POEs
- Summary of data collected during a visit to the Mariposa POE
- Testing of different model types on the historical data for each mode of traffic, with a focus on regression based and time series based models
- Application of the models to truck, POV, pedestrian and bus traffic
- Forecasts of five, ten and fifteen year time spans for commercial vehicles, POV, pedestrians, and bus passengers
- Description of Mariposa POE simulation model and results
- Conclusions drawn from this study
- Suggestions for future research topics

4 Documentation of Previous Studies

The main purpose of this activity was to identify the previous studies having a direct or indirect relation with either of the Nogales Ports of Entry so that redundant work would be avoided. In order to document and analyze the previous studies dealing with the Nogales ports we did the following:

- Identify relevant previous projects
- Complete a literature review on similar studies related to border crossing traffic.
- Read through each study and develop a matrix which includes the documents researched and any relevant contributions they may have to the current project
- Develop a brief summary of the findings from the past projects
- Identify those areas that have not been covered by previous projects
- Incorporate, if feasible, the identified knowledge gaps into the current project

As an initial activity of the *Nogales POEs Traffic Study: Forecast and Capacity Planning for Nogales' Ports of Entry*, previous studies were identified, gathered, and summarized. The studies were identified through a literature search using citation indices, internet tools and from citations from the studies themselves. The following is a list of the studies reviewed:

1. Currency Movements and International Border Crossings (2000)
2. Unified Nogales/Santa Cruz County Transportation 2000 plan (2000)
3. Estimating Texas-Mexico North American Free Trade Agreement Truck Volumes (2001)
4. Specification of a Borderplex Econometric Forecasting Model (2001)
5. Cross Border Cargo Vehicle Flows (2002)
6. Assessment of Automated Data Collection Technologies for Calculation of Commercial Motor Vehicle Border Crossing Travel Time Delay (2002)
7. El Paso Customs District Cross-Border Trade Flows (2003)
8. Borderplex Bridge and Air Econometric Forecast Accuracy (2004)
9. Canada-United States-Ontario-Michigan Border Transportation Partnership Planning/Need and Feasibility Study: Strategic & Geographic Area Overview (2004)
10. Canada-United States-Ontario-Michigan Border Transportation Partnership Planning/Need and Feasibility Study: Existing and Future Travel Demand (2004)
11. Canada-United States-Ontario-Michigan Border Transportation Partnership Planning/Need and Feasibility Study : Travel Demand Analysis Process (2004)

12. Canada-United States-Ontario-Michigan Border Transportation Partnership Planning/Need and Feasibility : Study Partnership of Transportation Problems and Opportunities Report (2004)
13. Traffic Forecast Based on Real Data (2004)
14. An Error Correction Analysis of US-Mexico Trade Flows (2005)
15. Analyzing highway flow patterns using cluster analysis (2005)
16. Tradeoffs between security and Inspection Capacity: Policy Options for Land Border Ports of Entry (2006)
17. Socioeconomic determinants of Mexican Circular and Permanent Migration (2006)
18. AZ Multimodal Freight TM1:Analysis of Freight Dependent Industries (2007)
19. AZ Multimodal Freight TM2:Assessment of Arizona's Existing Freight Infrastructure (2007)
20. AZ Multimodal Freight TM3:Strategic Directions for Freight Planning (2007)
21. Use of Box and Jenkins Time Series Technique in Traffic Volume Forecasting (2007)
22. Nogales Railroad Small Area Transportation Study (2007)
23. Bottleneck Study of Mariposa POE (2008)
24. Mariposa/I-19 Connector Route Study (2008)

One of the tasks included in this project was to compile a summary of previous studies. The project team elected to summarize previous findings using two instruments:

- An Excel Matrix
- A written summary of the previous studies

The two instruments are described next:

An Excel matrix was prepared with the various studies in the leftmost column and the other relevant information such as the year of the study, a brief summary, main methods used and author(s) of the study described in the columns to the right. The Excel Matrix consists of five separate sheets – Factors Considered, Procedure, Scope, Detail and Data Source.

A summary of each study was prepared that describes the main elements of the document and indicates the findings that seem to be relevant to this project. It is suggested that the reader first look at the matrix to see which studies may contain relevant data, and then go to either the study summaries or the studies themselves to find the information they are seeking. The written summary is included as a literature summary appendix to this report, and the Excel matrix is also included in that appendix. Complete bibliographical data can be found in the literature appendix. Conclusions drawn from Previous Studies:

After reviewing previous studies related to border crossing traffic we discovered that for the majority of the studies concerning the southern US border, Texas or California are the areas of focus. To the best of our knowledge, there is no study dedicated to forecasting the border crossing traffic for the POEs in Arizona.

We also reviewed a number of studies regarding AZ highways and POEs. From this review we found one thing to note, as pointed out by a previous, the Mariposa POE Bottleneck Study; Border Wizard, the tool used by GSA for planning, actually does not forecast the volume of traffic, but rather takes the forecasted volume as an input (Study 23 in Documentation of Previous Studies).

From the review of methodology, we found there was no widely accepted systematic way of building models for border crossing traffic, because the infrastructure, types of traffic and other conditions varies widely between ports. The mainstream methods used in the literature are regression based models and time series analysis based models. However, previous studies did not have to account for the significant seasonal variation associated with Arizona POEs. Our methodology is thus somewhat different from that used in other studies of border flows.

5 Baseline Analysis of Current Conditions

A preliminary phase of this study was to assess the existing conditions of each of the ports of entry in the Nogales area. This baseline analysis consisted of several processes which are listed below:

- Finding and analyzing the historical data of the border crossings for each mode of traffic. Then identifying the characteristics of this data to propose potentially suitable methods for further analysis.
- Determining the current traffic split among each of the ports of entries (Mariposa and DeConcini).
- Visiting the Mariposa port of entry to measure the time it currently takes a commercial vehicle to cross the border. These data were later used to create a simulation model to test the capacity of the Mariposa POE.
- Reviewing and gathering conclusions from previous studies related to either border crossing traffic or to Arizona highways and ports of entry.

5.1 Introduction

The two international points of entry (POEs) connecting the cities of Nogales, Arizona with Nogales, Sonora in Mexico are vital for the economy of these two cities as well as the surrounding region. These two POEs, the Mariposa POE and the DeConcini POE, (see M and D in Figure 5-1) are also extremely important for trade between the United States and Mexico. For instance, one of the main economic drivers of Santa Cruz County and Nogales is the fresh produce industry which relies heavily on these POEs as they are the principal import points for winter fresh vegetables from Mexico to the United States.

Additionally, Nogales, Sonora is one of the Mexican border cities with a high level of industrial (maquiladoras) development. Consequently, the increased presence of American (and foreign in general) companies on the Mexican side of the border generates the need for daily transportation of materials across international boundaries. The shipping of goods proves to be a challenging task for the Logistics and Traffic departments of these businesses because the greater the congestion at the POEs in Nogales, the less competitive these companies become and alternatives such as moving to locations with more efficient POEs may then be considered.

Figure 5-1 Mariposa and DeConcini POEs at Nogales

In our analysis of current conditions, we assessed the existing conditions of the Commercial Traffic, POVs (Privately Owned Vehicles) and pedestrian traffic crossing the POEs in Nogales. First, we provide an overview of the historical data and then proceed to a more specific assessment of the commercial traffic which showed a cyclic pattern that, to the best of our knowledge, had not been addressed by any previous study. Next, we analyzed the traffic split between the Mariposa and DeConcini POEs. Last, we provided a brief description of the conclusions we drew from our research of relevant previous studies.

5.2 Historical Data

There are three principal modes of traffic which we explored: commercial traffic (trucks), POV, and pedestrians. In the original scope of the project, we had not planned on taking into account rail freight or bus traffic since they account for a very small percentage of traffic crossings. However it was later determined that they should also be considered. The data for these two modes of traffic is also presented in this section.

The historical monthly data (from January, 1994 - current) used was gathered from the Bureau of Transportation Statistics website (BTS). The daily truck crossing data of 2008 and the data regarding the traffic split between different POEs was obtained from US Customers and Border Protection Tucson Field Office (Donahue 2009).

The historical monthly crossing data for the commercial traffic, POVs and pedestrians are depicted in Figure 5-2. Note the vertical line marks the date of the event "9/11". We believe that the event "9/11" brought significant changes to border crossing traffic. Note that we plotted the number of Privately Owned Vehicles (POVs) crossing the border but not the number of persons crossing the border by POV because the POV crossings are processed vehicle by vehicle. However, the change in the number of POVs should be highly correlated with the number of persons crossing the border by POV.

As Figure 5-2 indicates, the truck data has very strong cyclic properties and subsequent statistical analysis quantified this behavior. As noted above, both POV and pedestrian traffic showed significant changes right after "9/11", while truck and bus crossings appear to be relatively unchanged. The correlation between these different modes of traffic is displayed in Table 5-1. Three approaches were used to calculate correlations: 1) using the entire range of data, 2) including only the data before "9/11" (until 2009/08); 3) including only the data after "9/11". From both the graph and our correlation data we can see that after "9/11" the changes in POV traffic and pedestrian traffic are negatively correlated with each other.

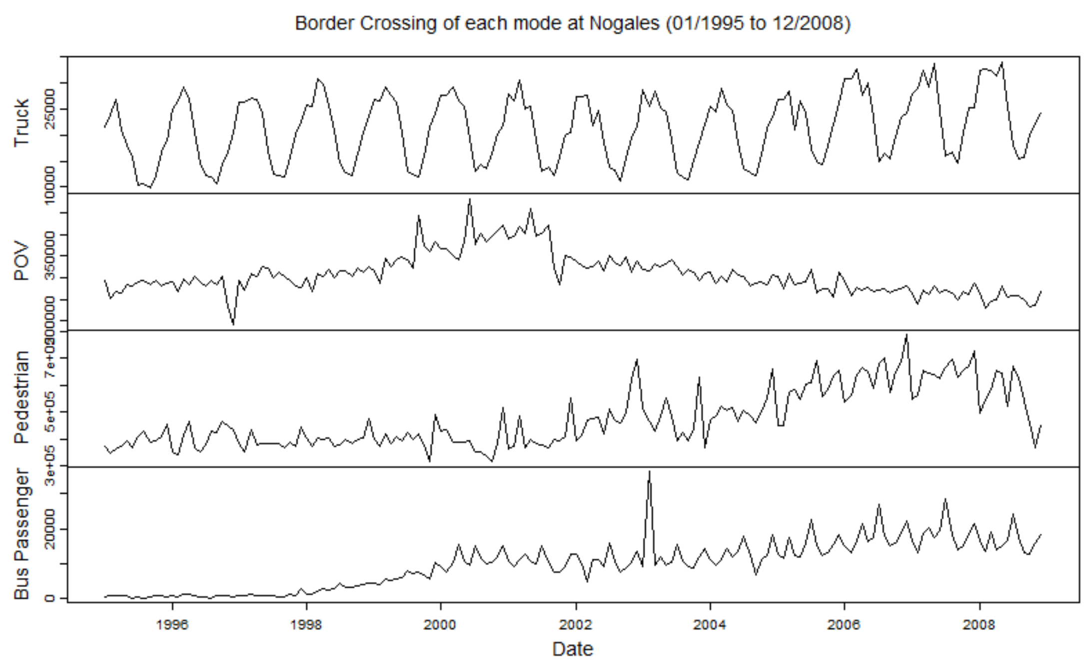

Figure 5-2 Crossings by Mode

Table 5-1 Correlation between different traffic modes

		Truck	POV	Pedestrian	Bus Passenger
All data	**Truck**	1.000	-0.102	0.216	0.202
	POV	-0.102	1.000	-0.395	-0.057
	Pedestrian	0.216	-0.395	1.000	0.707
	Bus Passenger	0.202	-0.057	0.707	1.000
Before 9/11	**Truck**	1.000	0.045	0.113	0.116
	POV	0.045	1.000	0.023	0.845
	Pedestrian	0.113	0.023	1.000	0.022
	Bus Passenger	0.116	0.845	0.022	1.000
After 9/11	**Truck**	1.000	-0.208	0.193	0.156
	POV	-0.208	1.000	-0.422	-0.367
	Pedestrian	0.193	-0.422	1.000	0.548
	Bus Passenger	0.156	-0.367	0.548	1.000

From the first four rows of Table 5-1 we can also tell that out of any two modes of traffic the strongest correlation was between Pedestrian and Bus traffic followed by the correlation between POV and Pedestrian traffic. By separating the data into "before and after 9/11", we observed that the POV and pedestrian traffic had little correlation "before 9/11"; however, they showed a strong negative correlation "after 9/11". Also, we observed that the POV and bus traffic had strong positive correlation beforehand, but they showed a strong negative correlation after "9/11". The pedestrian and bus traffic are positively correlated. However, by separating the data, we can tell that this correlation mainly happened after "9/11". Thus, It appears that the preference for personal border crossing shifted from vehicle to foot and bus after 9/11.

Among the four modes of traffic, the pedestrian traffic contained the most variation, and the commercial vehicle traffic was the most stable. Note that for 2008, the pedestrian data exhibited a significant drop while the other two modes remained relatively stable. This could be interpreted as the pedestrian traffic being more sensitive to changes in the economic climate, considering the current recession.

Table 5-2 below lists the yearly number of crossings for each type of traffic. One interesting fact is that the number of POV crossings has been decreasing since 2001, and that 2007 and 2008 were both lower than POV crossings in 1995. In contrast, truck and pedestrian crossings have trended upward since 2001, with the exception of a decrease in pedestrian crossings in 2008.

Table 5-2 Yearly number of crossing of each mode

	Truck	POV	Pedestrian	Bus Passenger
1995	206,032	3,368,337	4,698,049	7,608
1996	229,337	3,316,799	4,864,717	8,637
1997	242,830	3,587,985	4,643,538	11,477
1998	258,828	3,698,273	4,796,884	34,470
1999	256,426	4,186,962	4,806,076	75,976
2000	254,694	4,681,567	4,677,819	136,471
2001	249,237	4,590,933	4,874,738	126,530
2002	242,237	3,978,640	5,911,866	125,264
2003	243,365	3,836,372	5,583,533	156,406
2004	247,553	3,571,230	6,131,407	150,073
2005	266,233	3,445,984	6,930,198	178,306
2006	289,590	3,282,781	7,726,045	217,093
2007	295,267	3,180,548	7,722,877	221,410
2008	303,757	3,026,767	6,568,207	195,741

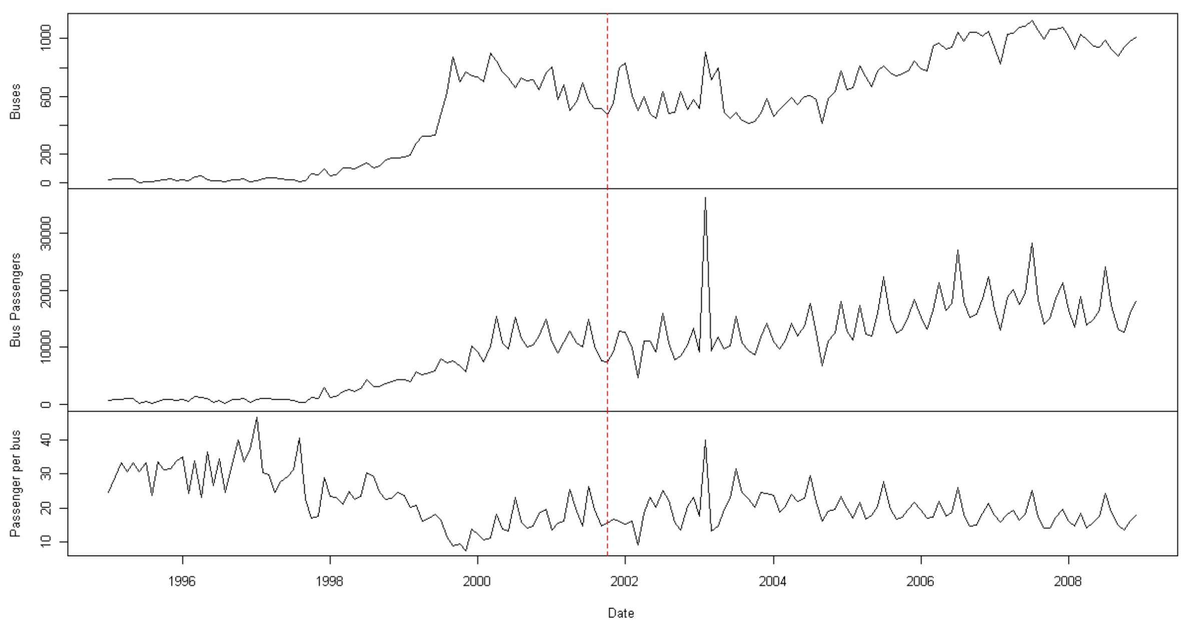

Figure 5-3 Historical data of bus crossings and bus passengers

Figure 5-3 shows the historical data of the bus crossings and the number of passengers crossing by bus. The number of crossings by bus started to increase in the middle of

1997, and had a sharp jump in 1999. After that it was relatively stable with a slight decreasing trend until 2005. In 2005, there was another significant increase which lasted until 2007, when the number of bus crossings once again stabilized. Similarly, the number of passengers crossing by bus started to increase at the end of 1997 and stabilized during the year 2000. After that, the number of bus passengers remained relatively stable with a slight increasing trend. The only exception occurred during 2003, when an abnormally steep spike occurred. The bottom panel of Figure 5-3 is the average number of passengers per bus, which shows that the average number of passengers per bus started to decrease in 2005, although the downward trend is slight.

The number of bus passengers is much smaller than the number of passengers crossing by other modes. We found that although the number of bus passengers has increased very quickly during the last few years, it still only comprises a small fraction of the total number of passenger crossings. In 2008 for example, the average number of monthly pedestrian crossings was 547,351, the average monthly POV vehicles was 706,023, but the monthly bus passengers was 16,312, which was roughly 2.9% of the pedestrian crossings and 2.3% of the POV vehicles.

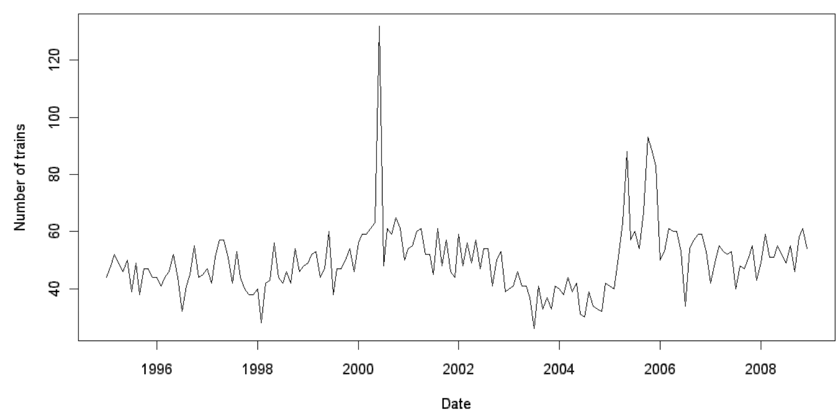

Figure 5-4 The number of trains crossing the border

Figure 5-4 shows the number of trains crossing the border from January 1995 to December 2008. We did not have reported train crossings for February 1995 and April 1995. We used the average of the preceding and the following month to represent these missing values. Before 2000, the number of trains was relatively stable with a slight increasing trend. In the middle of 2000, there was a large spike and after this occurrence the number of trains followed a decreasing trend which continued until early 2005. 2005 saw another sudden increase, and since then train crossings have been relatively stable. Note that train crossings are partly dependent on the number of schedules Union Pacific chooses to run, and that the actual amount of freight crossing the border depends on the length and consists of the trains Union Pacific chooses to run.

5.3 Traffic split between the Nogales POEs

Commercial vehicles cross only at the Mariposa POV; therefore we did not have any data for the traffic split of the trucks. However, POV, pedestrians and bus crossings occurred at both of the POEs. We had a limited amount of data, starting from October 2004, for the traffic recorded by mode and by POE. Figure 5-5, Figure 5-6 and Figure 5-7 depict the split of the POV traffic, pedestrian traffic and bus traffic (number of buses) respectively. From Figure 5-5 we observe that the POV traffic has a ratio of roughly 60:40 (DeConcini: Mariposa) from 2004 to 2007, and then 70:30 (DeConcini: Mariposa) from late 2007 onward. Figure 5-6 shows that the majority of pedestrian traffic passes through the DeConcini POE, and this split has been relatively stable throughout the years. Figure 5-7 shows that the bus traffic has a ratio of roughly 25:75 (DEconcini: Mariposa) all over the years, except from April 2007 to September 2007. For the recent months (including the whole year of 2008), the ratio tended to be quite stable. We believe there are several causes for this stable trend in pedestrian traffic:

- The Mariposa POE is not adapted for handling pedestrian traffic.
- The DeConcini POE is closer to most of the Nogales population and business compared to Mariposa
- The DeConcini POE has more booths for pedestrian traffic than the Mariposa POE.
- The route via Mariposa POE is the preferred route to the bus traffics, which is opposite to that of the POV and pedestrian traffics.

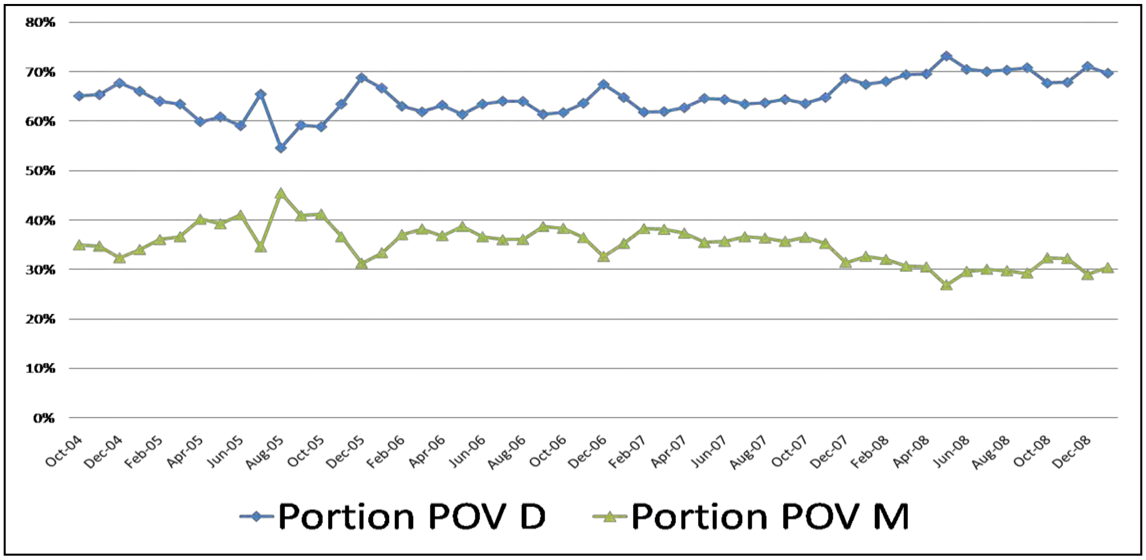

Figure 5-5 POV traffic split

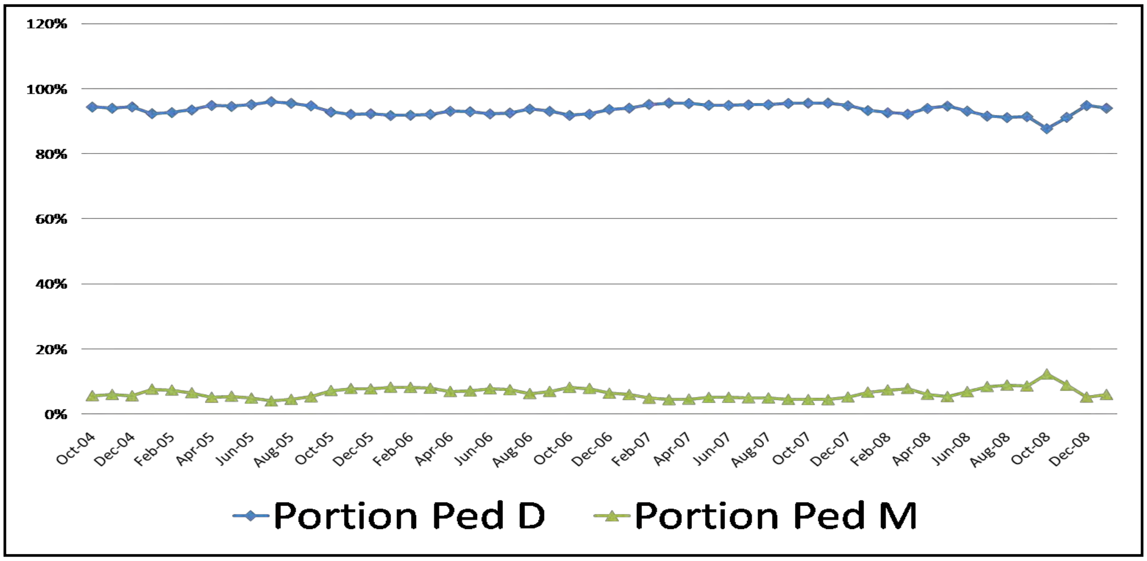

Figure 5-6 Pedestrian traffic split

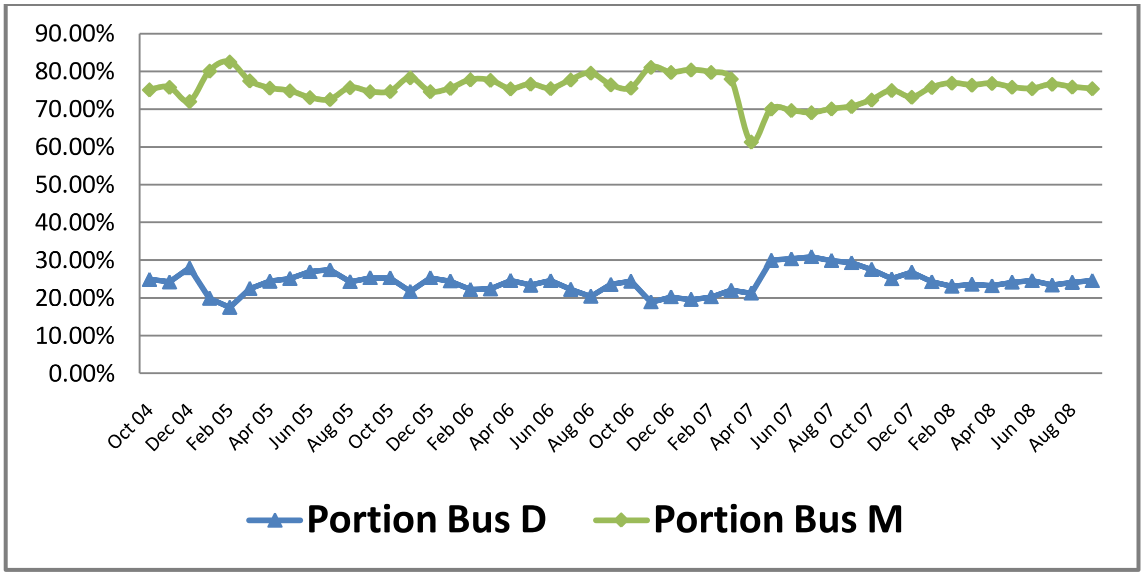

Figure 5-7 Bus traffic split

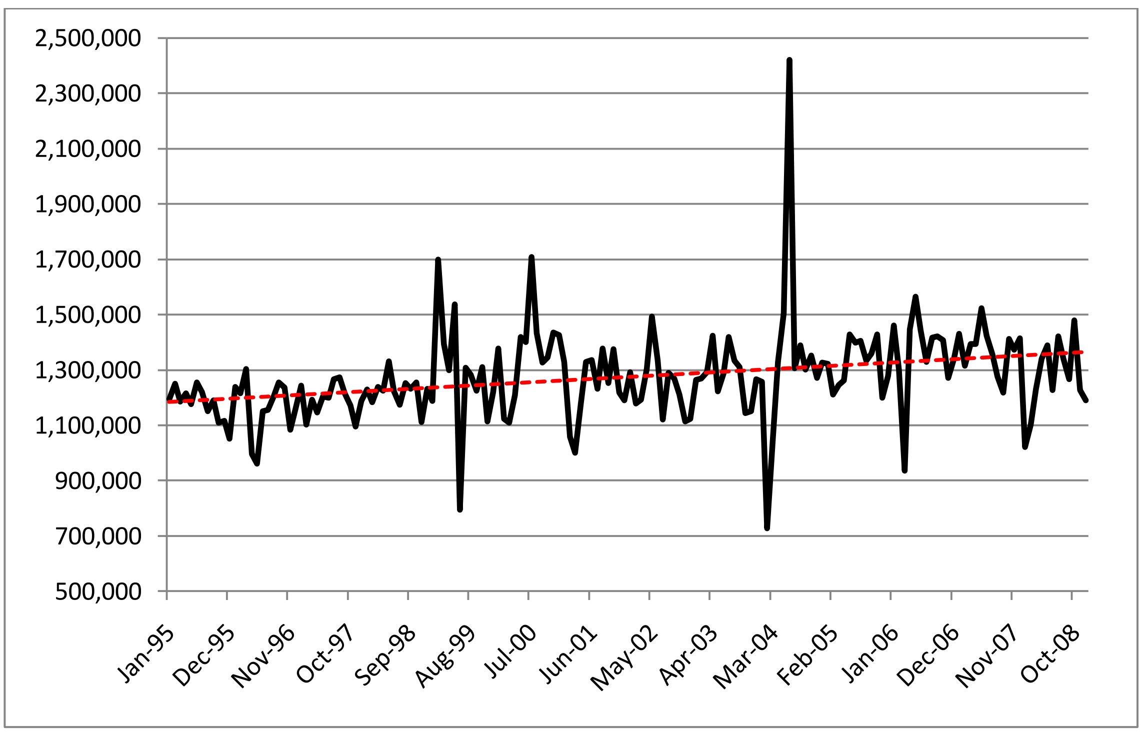

Figure 5-8 Total number of persons crossing (POV+Pedestrian+Bus Passengers) at the POEs in Nogales

Figure 5-8 depicts the total number of persons crossing (POV passenger, bus passengers and pedestrian) crossing at both POEs in Nogales by month, where the red straight line is a fitted trend line The change in total number of persons crossings the border from 1995 to 2008 was relatively small however the fluctuations from month to month were at times very significant. The greatest change occurred between the months of July and September 2004 with a decrease of about 1.7 million crossings, which was preceded by a very large increase. We do not have any concrete explanation for these fluctuations however we hypothesize that it may have to do with changes in the measurement process.

5.4 Mariposa POE Site visit

Our visit to the Mariposa POE was conducted on Tuesday May 25, 2009. The main purpose of this visit was to measure the time for a commercial vehicle (mainly referring to trucks) to cross the border. To gather our measurements we had 4 observation points, which were Weigh-in-Motion (WIM), SBs (Super Booths=primary inspection), ADOT inspection and the exit to the highway. The four observation points are marked in Figure 5-9.

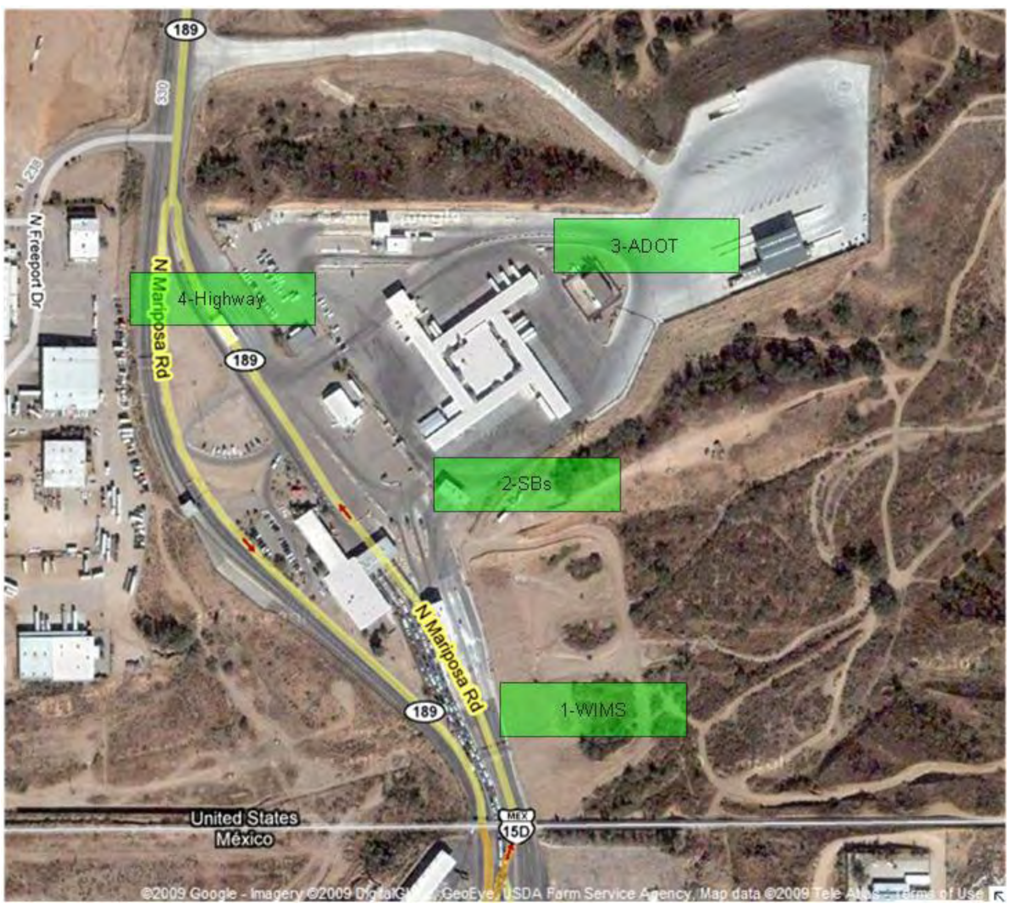

Figure 5-9 Measurement Points for Mariposa Crossing Times

We recorded the plate number of the vehicles passing every observation point and the time of passing. We also wrote a brief description of the vehicles in case we misread the plate or recorded different license plate numbers since it was very common for the border crossing vehicles to have multiple license plate numbers. We started our observations at 10:30 am and finished at 4:30 pm. These observations were only taken for commercial vehicles, since we were not granted access to observe other types of crossings. Also due to clearance issues, we were only able to gain a general idea of the amount of time spent at each location: WIM, SB, and ADOT (i.e. the time we recorded is a combination of the waiting time and processing time at these locations).

We observed approximately 600 trucks during the six hour time period. We summarize the time of passing of each observation point in Table 5-3. The histogram of number of trucks by hourly interval is provided in Figure 5-10. The bar marked as "14:17:27" is shorter, since the border was closed for half an hour during that time slot.

Table 5-3 Current result summary

	WIM	ADOT	CBP
Average	0:04:10	0:57:21	0:27:07
Standard Deviation	0:04:12	0:37:37	0:48:16

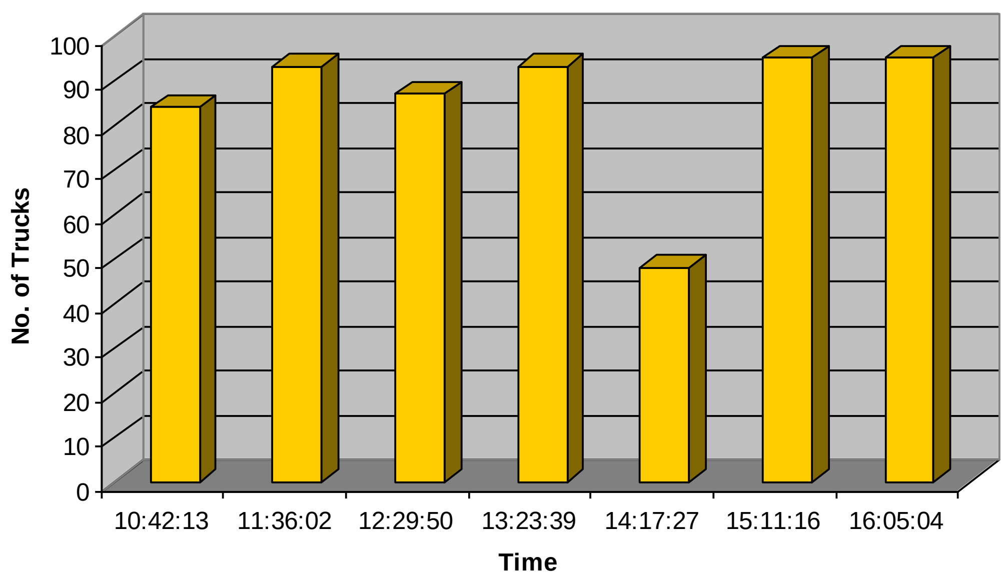

Figure 5-10 Number of Trucks Crossing by Time Period

After suitable processing we used this data to build a simulation model to assess the current capacity of the Mariposa POE.

5.5 Summary of Baseline Analysis

Our literature review also provided some useful insights for our model building. Economic indices like the Index of Industrial Production and the exchange rate were used in many previous studies. This motivated us to incorporate some of these indices in our model. Some preliminary analysis was also conducted to gain a more thorough understanding of the traffic characteristics. Through this process we identified the different modes of traffic to study and examined the historical data for each mode of traffic as well as the traffic split among the ports of entry. We noticed that the cyclic pattern shown in the truck crossing data was not addressed in other related work, although it has long been “taken for granted” in the Nogales import community. Valuable information was also obtained for our later capacity assessment simulation work through our visit to the Mariposa POE.

6 Model Alternatives

In this section, we test different types of models on the historical data to find the best alternative for forecasting. Generally, the models can be categorized into two types, regression based and time series based models. We begin with a brief introduction of each type of model, and then we use the commercial vehicle model as an example to describe the way we selected the models. Following this section, we present the models we built and the resulting forecasts. As with the baseline analysis section, an appendix to this section provides a more detailed review of the related technical issues.

6.1 Regression models

Univariate regression model

The univariate linear regression model, which is the simplest type of regression model, only takes time as a regressor (regression variable). Its basic equation is shown in equation (6.1.1) (Montgomery, Peck, and Vining 2006a). In this equation y is the target traffic, t is the time and ϵ is the irregular fluctuation around the trend, which is usually assumed to follow a normal distribution.

$$y = \beta_0 + \beta_1 t + \epsilon \tag{6.1.1}$$

The βs are the coefficients we need to estimate. This is the first type of model we applied, however, we will explain later in this report why this was not the best choice for our forecasts.

Multivariate regression model

The second model we tested was the multivariate model because from the available literature, we found that border crossing traffic may be influenced by several exogenous variables, such as the GDP of the countries that share a common border. Unlike the univariate regression model, this type of model takes exogenous variables into consideration. The model has the form shown in equation (6.1.2) (Montgomery, Peck, and Vining 2006b), where y represents the target traffic and $x_i, i = 1, 2, \cdots, k$ are the exogenous variables. In our study, each economic index will be an exogenous variable.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \epsilon \tag{6.1.2}$$

Based on previous research results and the conditions of the Nogales POEs, we identified a list of candidate exogenous variables as shown in Table 6-1. However, since there were only 14 years of available data, a limited number of variables could be used in the regression model. Thus, a variable selection procedure was used to identify the "best" variables to include in the model.

Table 6-1 List of candidate external variables

Data Name	Time range	Frequency
US national GDP	from 1949 to 2008 Q4	quarterly
Mexican national GDP	from 1993 to 2008 Q4	quarterly
Exchange rate (1USD in MNX)	Since Jan 1994	daily, monthly
Arizona GDP	1997 -2007	yearly
US fuel price (Gasoline and Diesel)	1994 Jan to 2008 Dec	monthly
Arizona Population	1990 to 2008	yearly
Sonora Population	1995 to 2008	yearly
US Index of Industrial Production(IIP)	Since 1919	monthly
MX Index of Industrial Production(IIP)	Since 1990	monthly
US Consumer Price index (CPI)	Since 1990	monthly
MX Consumer Price index (CPI)	Since 1990	monthly
Real exchange rate	Calculated from exchange rate and CPIs Since Jan 1995	monthly

Two tier regression model for the truck traffic

We noticed from our baseline analysis that the truck traffic has a stable cyclic pattern. The existence of this cyclic pattern prevents us from using the multiple regression models directly, however, since this pattern is stable, we can build a two tier regression model. In the two tier model, we first built a regression model on the yearly data, and then split it into months according to monthly percentages. In contrast, for POV and pedestrian traffic, we built the model directly on the original monthly data as they had no obvious seasonality. Furthermore, it should be noted that the regression models used are all linear models.

Figure 6-1 is the box plot of the truck crossings of each month. This plot reveals some useful information about the truck data:

1. The box plot is a confirmation of cyclic pattern as we observed from Figure 5-2.
2. For all our data the percentage of total crossings for the year for each month stays relatively stable. For example if the number of crossings in January 1995 was 10% of the total number of crossings for that year, the percentage of total crossings for 2008 occurring in January 2008 will also be roughly 10%.

The month of May is the month with the most outliers in the number of crossings, while April is the month with most variation.

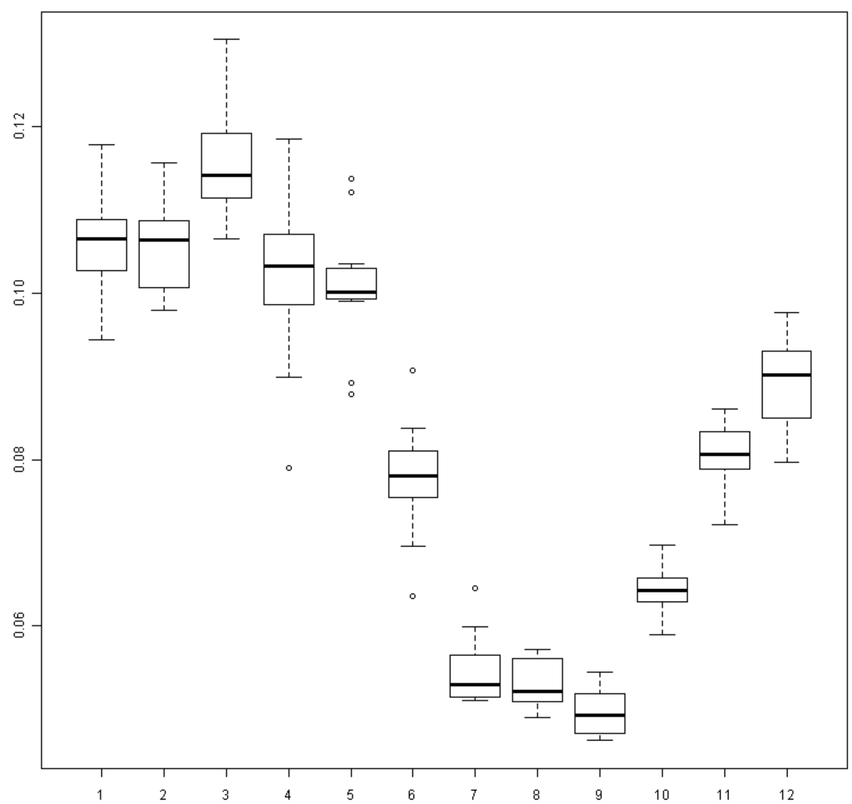

Figure 6-1 Box plot of truck crossings by month of the year

Mathematically, we explain the two tier model as described subsequently. Suppose we have N years of monthly data points available. Let y_{ij} be the data for month i in year j. Let $T = \sum_{j=1}^{N}\sum_{i=1}^{12} y_{ij}$ be the total number of crossings in the data set. Then the portion corresponding to month i can be calculated as $p_i = \left(\sum_{j=1}^{N} y_{ij} \right) / T$. Therefore, when the number of crossings for year j is calculated, namely y^j, the estimated number of crossings of month i in year j can be calculated as $\hat{y}_{ij} = y^j \times p_i$. Note that all the p_i's are calculated from the data in the training data set, the data set we used to build the model When applying the method to new data, we still use the p_i's calculated from the training data set values on which we built the model.

Variable selection

Given the small size of the variable pool and the limited number of data points we used an exhaustive method for variable selection. Using this method we enumerated all the possible combinations of up to 5 variables, and then built the corresponding regression models. The resulting models were then evaluated using several criteria:

- R-square[1] : The R square value can be interpreted as the proportion of variation explained by the model. When using linear models, the R-square value will be between 0 and 1, however, when using other types of models, this cannot be guaranteed.
- VIF (Variance Inflation Factor)[2] : measures the multicollinearity between models' variables. Multicollinearity exists when at least one variable can be represented by the linear combination of other variables. In other words, this measures whether several of our independent variables are highly correlated and thus can be replaced by only one or two variables.
- Expert knowledge about the relationship among the variables selected and the target variable to be estimated.

For our variable selection, we applied the above criteria to both the training data set and the validation data set. When there was a tie, we chose the model with fewer variables.

6.2 Time series model

Another type of model commonly used in previous studies was the time series model. Particularly, we considered the ARIMA (Autoregressive-integrated-moving average)

[1] Refer to R square section of appendix of statistical details for further explanation
[2] Refer to VIF section of appendix of statistical details for further explanation

model[3] (Farnum and Staton 1989; Shumway and Stoffer 2006a). In order to build a credible time series model, we needed to further explore the characteristics of the data. For example, the first question we needed to address was whether to use a regular model or a seasonal model.

The ACF (Auto Correlation Function) and PACF (Partial Auto Correlation Function)[4] act as tools for determining the appropriate type of time series model as well as the structure of the model. Figure 6-2 depicts the ACF and PACF of the truck data. These functions allow us to determine seasonal and other patterns of the data. Note the unit of the lag is year, so 0.5 means 6 months. The ACF at lag 0.5 has a negative value near -1 while the value at lag 1.0 is near 1, which confirms the need to use a seasonal ARIMA model to forecast border crossings.

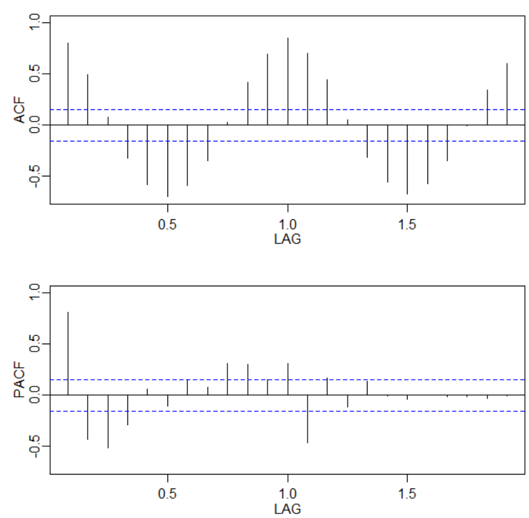

Figure 6-2 ACF and PACF plot of the Truck data

Univariate time series model

We mainly considered the ARIMA model and Holt-Winter's model for the univariate time series models. We have mentioned the ARIMA model in the previous paragraph, which is a type of time series model. The Holt-Winter's model is a more specific time series model, which is capable of handling both trend and seasonality in the data simultaneously. Due to the strong presence of seasonality in the truck traffic, we first tried the additive Holt-Winter's model on the truck traffic data. For the POV and the pedestrian flows, we used the non seasonal ARIMA model. Note that the Holt-Winter's

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[3] Refer to the ARIMA model section of appendix of statistical detail for further explanation
[4] Refer to ACF and PACF section of appendix of statistical detail for further explanation

model can be converted to a corresponding ARIMA model. The details of these two models are explained in the appendix of statistical details.

The Holt-Winter's model decomposes the target data into three parts: *level*, which is the non seasonal mean of the data; *Trend*, which is the slope of the likely line through data points; and an index of *seasonality*. Mathematically, it can be written as:

$$y_t = a_t + b_t t + S(t) + \epsilon_t \qquad (6.2.3)$$

where a_t is the unseasoned level of time series at time t, b_t is the slope of the trend at time t, s_t is index of season $i, i = 1, 2, \cdots, L$. i corresponds to the season of current time t. The parameter estimating methods and the updating forecast methods are explained in the Appendix of Statistical Details.

An ARIMA model is usually written as $ARIMA(p,d,q)$, where p is the AR (Autocorrelation) order, d is the degree of differencing, and q is the MA (Moving Average) order. When applying the ARIMA model, it is important to first decide the structure of the model. PACF and ACF act as tools for determining the structure of an ARIMA model. Since it is possible to have potential models that work equally well, it is preferable to come up with a list of reasonable ARIMA models and then select from this candidate list. Therefore, instead of deciding the (p,d,q) directly from ACF and PACF, we defined ranges for (p,d,q), and tested all the possible combinations of the parameters within the established ranges. We used Theil's U statistic[5], which is a measure of the similarity between two time series, as a criterion for model selection. R square was not used because when a data set contains nonlinearities, a large R square does not necessarily imply a good model. We use the same method to find the structural parameters in our multivariate time series models.

Multivariate time series models were another type of model chosen to forecast border crossings. To build this kind of model, we introduced exogenous variables into the model rather than only taking the data itself into consideration. We referred to the previous studies we reviewed to decide what exogenous variables should be incorporated in the model. We also referred to the variables selected in the multivariate regression model, and field knowledge.

A seasonal ARIMA model has seven structural parameters to determine (Shumway and Stoffer 2006b), which are shown in Table 6-2. A model with those parameters is usually reported as $ARIMA(p,d,q)(P,D,Q)_L$.

[5] The definition of Theil's U statistic is stated in the Appendix of Statistical Details

We used the same method as we used in the univariate ARIMA model building to get a list of good model candidates, and then selected models from this candidate list.

Table 6-2 list of ARIMA structural parameters

p	AR (Autocorrelation) order
d	The degree of differencing
q	MA (Moving Average) order
P	Seasonal AR order
D	The degree of seasonal differencing
Q	Seasonal MA order
L	Seasonal period

6.3 Comparison of the models

Before applying the models to generate forecasts, we first tested the performance of the models on our data. We split the historical data into two subsets, a training set and a validation set. As described in the Historical Data section, we have data available from January 1995 to December 2008. We designated the last three years' data as the validation set, and used the rest as the training set.

We use the truck data to illustrate the procedure we used to compare the models:

1. Prepare the variables to use in the multivariate regression model and the multivariate time series model
2. Build model of each type of model on the training data set
3. Use the models to forecast the traffic of the last three years (validation data set)
4. Compare the forecasted values to the validation set values

We defined some criteria for model selection; however, we may not strictly select the model with the best criteria. There are many reasons for doing this:

- The criteria may not be able to fully reflect the performance of the model
- A "too good" performance on the training set may lead to over fitting and thus the model would perform badly on the forecast task
- Other issues that are not incorporated in the model, but need to be considered, for example the stability of the model.

Variable selection

We use the variable selection procedure described in 6.1. Table 6-3 shows the best R square values we obtained using different numbers of regressors (independent regression variables). These values were obtained by applying the resulting forecast models to the validation data. As we observed from the table, there was a significant increase in the R square value when using two regressors as opposed to just one. However, when the number of regressors was greater than 2 there was not much benefit in terms of the gain in R square value. In addition, some of the variables were highly correlated, which could cause multicollinearity issues, resulting in a forecast model that was unstable. In order to minimize multicollinearity issues we used the Variance Inflation Factor (VIF) metric to choose variables that were not highly correlated.

Table 6-3 Best R square VS number of regressors

Number of Regressors	Best R Square on Validation data
1	0.6388321
2	0.8365505
3	0.8611884
4	0.8616332
5	0.8649311

Table 6-4 Some of the variable selection results

Model	Training R Square	Validation R Square	VIF	VIF	VIF
Truck~USIIP+Xrate	0.9675	0.6710	2.8646	2.8646	
Truck~MXIIP+Xrate	0.9671	0.6558	2.2812	2.2812	
Truck~AZemp+sonpop	0.9711	0.6524	8.2115	8.2115	
Truck~USIIP	0.9667	0.6388			
Truck~RXrate+USIIP	0.9668	0.6342	1.3426	1.3426	
Truck~MXIIP	0.9667	0.6331			
Truck~MXIIP+RXrate	0.9668	0.6279	1.2049	1.2049	
Truck~RXrate	0.9668	0.6201			
Truck~Xrate	0.9668	0.6043			
Truck~AZpop+MXIIP	0.9711	0.5786	3.0764	3.0764	
Truck~MXIIP+sonpop	0.9709	0.5681	2.2072	2.2072	
Truck~AZemp+sonpop+USDiesel	0.9714	0.5636	8.6778	9.0878	3.5406

Note: AZpop: Arizona Population; AZemp: Arizona Employment; Xrate: Exchange rate; RXrate: real Exchange Rate; sonpop: Sonora Population; IIP: Index of Industrial Production;MX: Mexico

Table 6-4 shows part of the variable selection process for the trucks. Column 1 is the model we used, the variable to the left side of "~" is the target mode of traffic, and the variables to the right side of"~" are the variables in the model. Column 2 is the R square value on the training data, and Column 3 is the R square value on the validation data. All the columns after Column 3 are VIF values. The items were sorted according to the Validation R Square values in descending order. Those models having VIF values greater than 10 were excluded from this table, as this indicates multicollinearity issues (Montgomery, Peck, and Vining 2006c). If there was only one regressor no VIF value was provided, for two regressors the VIF for these two regressors will be identical and for greater than three regressors each regressor has its own VIF. This table shows that of the models analyzed, a regression model using the Index of Industrial Production for the US (US IIP) and the exchange rate between US Dollar and to Mexican Peso would render the best results for forecasting the truck traffic border crossings.

We first decided the structural parameters of the multivariate ARIMA model. Table 6-5 lists the results of some of the ARIMA models tested, sorted by the Theil's U statistic (obtained by using the time series model on the training data set. A lower U indicates a better fit). In Table 6-5, we filtered out the models whose residual violates normality assumptions as these would potentially create misleading forecasts. One needs to be careful when choosing the parameters. All of the parameters listed in Table 6-5 were generally good candidates. When selecting among the list of parameters, the experience of the modeler, the plot of the fitted values as well as the residuals and reasonableness of the model all play important roles in the selection process. Here we chose the model with $(p,d,q)(P,D,Q)_L = (1,1,4)(2,1,2,)_{12}$ to compare with other type of models, which is NO. 4 in Table 6-5. The subscript 12 means that we use a seasonal ARIMA model with seasonal period of 12 months.

Table 6-5 List of ARIMA models for truck

ID	p	d	q	P	D	Q	Validation R square	Theil's U (Training)	Theil's U (Validation)
1	5	0	4	2	1	0	0.900769	0.028775	0.039771
2	5	0	4	2	1	1	0.891993	0.028457	0.040779
3	3	1	4	2	1	2	0.890986	0.029925	0.041243
4	1	1	4	2	1	2	0.887973	0.030065	0.04177
5	1	1	5	2	1	2	0.885679	0.029985	0.042002
6	1	1	5	2	1	1	0.884808	0.03024	0.0422
7	1	1	4	2	1	1	0.885581	0.030341	0.042243
8	1	1	4	1	1	1	0.88376	0.030368	0.042512
9	0	1	4	1	1	2	0.881525	0.030079	0.042681
10	6	0	3	2	0	2	0.884909	0.035388	0.042749

The comparison result

We were mostly concerned about the ability of the models to forecast future traffic crossings. Therefore, we used the models built on the training data set to forecast three years ahead and compared the forecasted values with the real data in the validation data set. Table 6-6 shows the comparison among the multivariate regression model, the Holt-Winter's method and the multivariate time series model. We could see that the multivariate time series model (ARIMA) outperforms the other two methods in terms of R square and Theil's U statistic.

Table 6-6 Compare of different models

Method	**R square** (The higher the better)	**Theil's U statistic** (The lower the better)
Multivariate Regression	0.765	0.06315865
Holt-Winter's	0.760	0.05936151
Multivariate time series	**0.889**	**0.04156882**

Figure 6-3 is a graph of the three model forecasts. From the graph, we can tell that all the models fit well to the real data at the beginning. However, the Regression model tended to underestimate and the Holt Winter's method tended to overestimate later. From this example, we preferred to use the multivariate ARIMA model in our forecast.

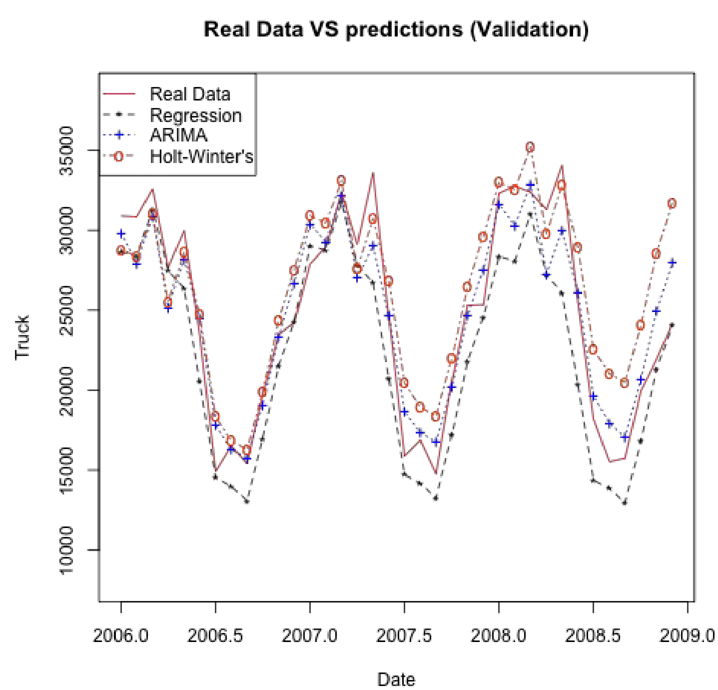

Figure 6-3 Forecasts vs. Actual

6.4 Model alternatives for other modes

In section 6.3 above, we used the truck data as an example to show the model alternatives, and the results show that the ARIMA model outperforms other models. Therefore, our first choice was to use the ARIMA model on the other modes of traffic. Since the Holt Winter's method could be converted into an ARIMA model, we only considered ARIMA models on the other data sets. Before we made this choice we applied the same variable selection procedure on the other modes of traffic. The results of this testing did not show any variables which improved the quality of the models, such as the US IIP and the exchange rate which we found for the truck data. Thus, we mainly relied on the ARIMA model with no exogenous variables to forecast the other traffic modes.

In particular we note that the bus and train modes of traffic run on a relatively stable schedule, which did not typically change in response to economic variations as do the other modes of traffic.

POV

We first generated the ACF and PACF of the POV data as in Figure 6-4. The ACF tails off and the PACF cuts off after 3. Although we did not see any spike after 1, we chose to use a seasonal ARIMA model. We believed the POV traffic also had some patterns that repeated from year to year. Table 6-7 lists some ARIMA models we tested on the POV historical data. We left out the last three years' data for validation as we did for the truck data. The last three columns are the R square value on the validation set, the Theil's U statistic on the Training set and the Theil's U statistic on the Validation set respectively. The table was ordered according to the Theil's U statistic on the Validation set in ascending order. As with the truck data, choice of model was not solely based on the order of the parameters listed in this table. Some other factors were also considered, such as the validation plots of the models.

We picked the model with structural parameters $(p,d,q)(P,D,Q)_L = (6,2,6)(2,0,1)_{12}$, and plotted the forecasted result against the real data in Figure 6-5. The fitted data seemed to overestimate the traffic. However, we also noticed that the real data had several fluctuations and the model was only able to capture the main trend excluding these fluctuations. If we tune the parameters to follow this fluctuating pattern, we may end up over fitting the model, thus generating an extremely implausible forecast. Instead, it may be appropriate to estimate a fixed correction, depending on discussions with subject experts.

Table 6-7 List of ARIMA models for POV

p	d	q	P	D	Q	Validation R Square	Theil's U(T)	Theil's U(V)
5	0	3	2	0	3	0.2712246	0.03882831	0.02571694
2	1	6	2	0	3	0.2568555	0.03870172	0.02588999
6	2	6	2	0	1	0.2476303	0.03940341	0.02618603
6	2	6	2	0	0	0.2508674	0.03869041	0.02628177
5	2	3	2	0	3	0.2257206	0.03882943	0.0263639
6	0	3	2	0	1	0.2199377	0.03977416	0.02655877
5	2	3	1	0	3	0.09908995	0.03884228	0.02833369
6	2	6	0	0	1	0.1044766	0.0393614	0.02846729
4	2	5	0	0	3	0.08501245	0.0391253	0.02860754
3	2	6	0	0	3	0.05758358	0.03913235	0.02901835
6	2	5	1	0	0	0.05689941	0.0395814	0.02913005

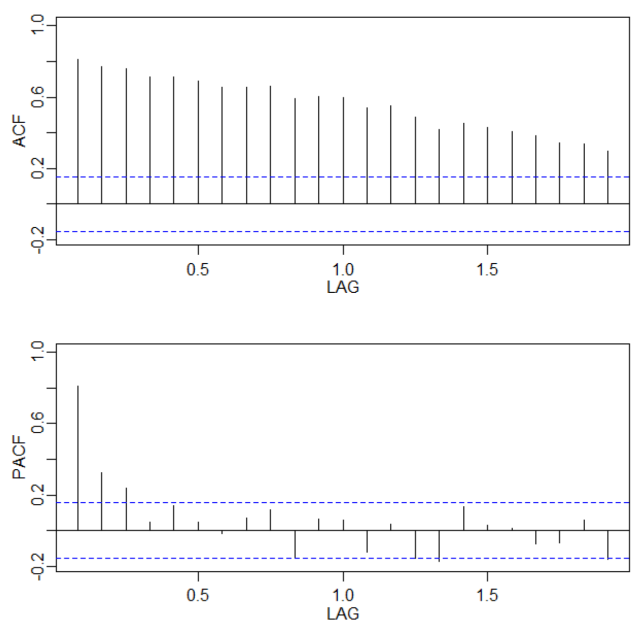

Figure 6-4 ACF and PACF of the POV data

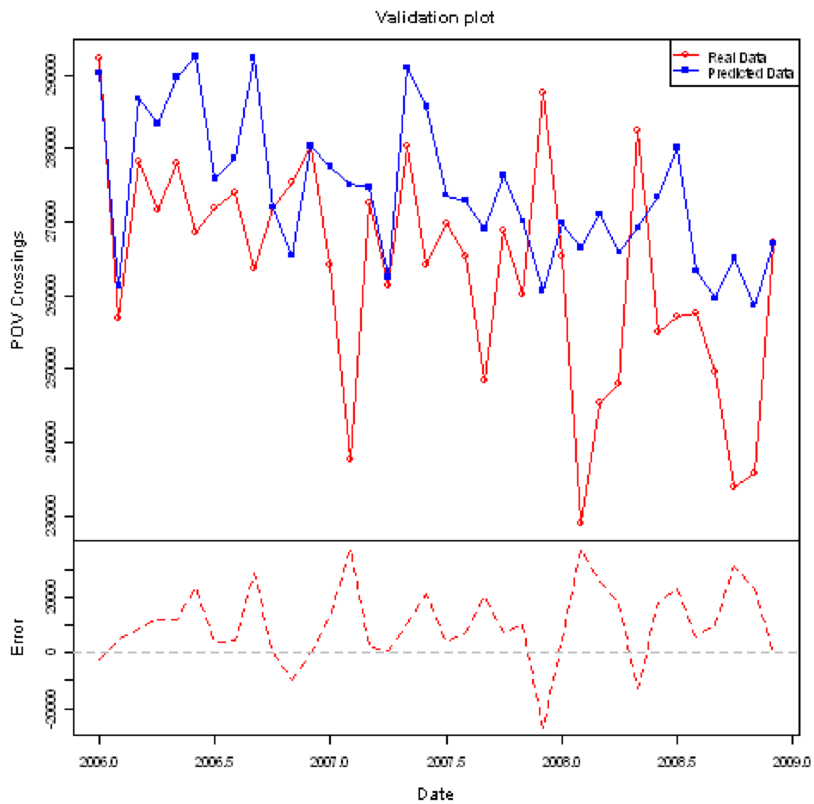

Figure 6-5 Plot of the fitted data to the real data on validation set (POV)

Pedestrian

As we stated at the beginning of the section, we could not find an exogenous variable that would allow us to build a reasonable regression model for the pedestrian data. However, since we believe the majority of the people crossing the border by foot are locals, we thought that employment in Arizona might influence this crossing. Therefore, we incorporated Arizona employment into our time series model. We show the ACF and PACF of the data as in Figure 6-6. The ACF tails off, while the PACF dies off after 4 steps.

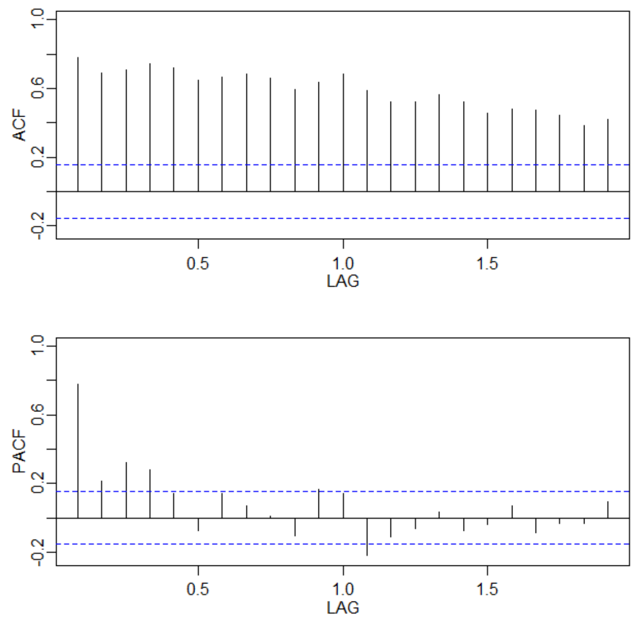

Figure 6-6 ACF and PACF of the Pedestrian data

Similarly, we have a list of relatively good models, which are listed in Table 6-8. We chose the model with structural parameters $(p,d,q)(P,D,Q)_L = (3,2,1)(2,0,2)_{12}$ to see how it performed on the forecast. Figure 6-7 plots the fitted data against the real data in the validation set. We can see before the middle of 2008, the fitted values follow the real data relatively well. However, a big drop occurred in late 2008, which was not captured by the model.

Table 6-8 List of ARIMA models for Pedestrian

p	d	q	P	D	Q	Validation R Square	Theil's U(T)	Theil's U(V)
3	2	1	1	0	1	0.34989	0.057766	0.054331
3	2	1	2	0	2	0.348045	0.057426	0.054253
3	2	1	1	0	0	0.347597	0.0586	0.054569
3	2	1	0	0	1	0.337429	0.058797	0.055034
3	2	1	1	0	2	0.32706	0.057466	0.054939
3	2	1	2	0	1	0.312486	0.057518	0.055427
6	2	6	1	0	0	0.311573	0.053171	0.055578
2	2	5	1	0	0	0.297323	0.056882	0.056197
6	2	5	1	0	0	0.293468	0.055045	0.056611
3	2	4	2	0	2	0.291586	0.055999	0.056388

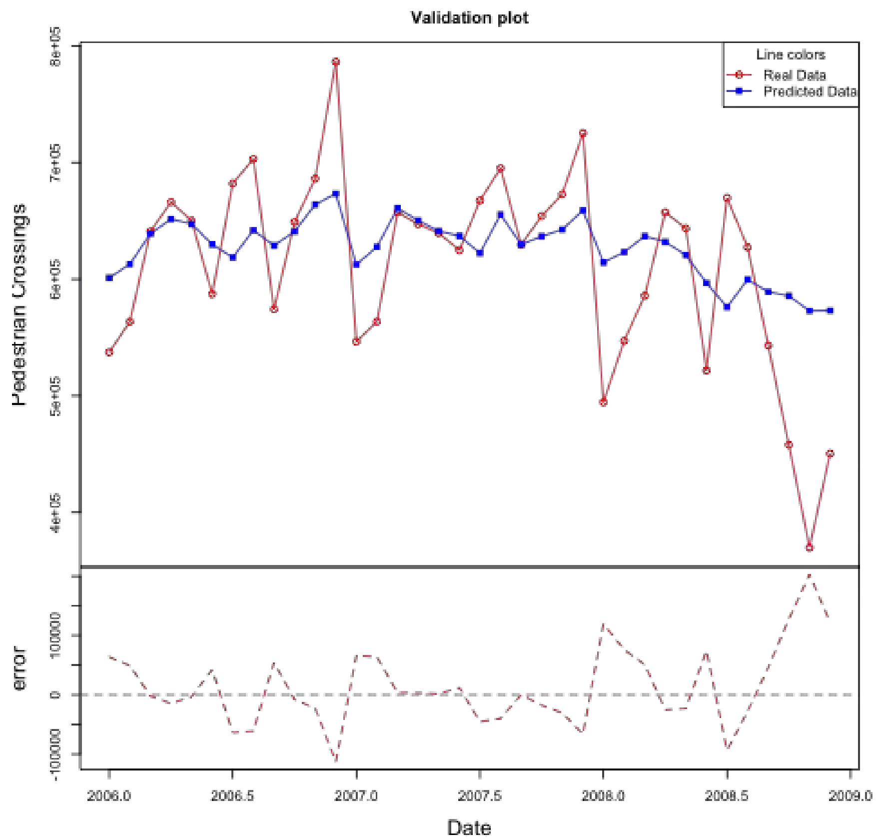

Figure 6-7 Plot of the fitted data to the real data on validation set (Pedestrian)

Bus

We depicted the historical data of the bus crossings in section 5.2 Historical Data. We show the graph of historical bus traffic and bus passengers crossing the border as Figure 6-8 here for review. Note that the bus traffic started to increase by the end of 1997 and then began increasing faster in 1998. The amount of bus traffic jumped up significantly in the middle of 1999. According to a fact sheet from USDOT (U.S. DOT 2002), "the NAFTA timetable also called for the United States and Mexico to lift all restrictions on regular route, scheduled cross-border bus service by January 1, 1997." We believe this jump was associated with the implementation of the NAFTA. Therefore, we decided to use the data after NAFTA had been implemented, and the impact of this implementation had stabilized. For convenience, we used crossings since January 2000.

Comparing the bus traffic and the bus passenger data, we found that there was a slight difference between the patterns of these two data sets. For example, the bus passenger data did not show any decrease in its general trend between 2000 and 2008, while the bus traffic started to decrease after 2000, and then began increasing in 2005. We decided to build the model based on bus passenger data rather than the number of buses crossing the border. First, there are many companies involved in the bus operations. There are always new companies joining in and other companies leaving this business. This makes the number of bus crossings more difficult to predict. Secondly, bus capacities may not be fully utilized. If this is the case, predicting the number of buses will not reflect the number of passengers crossing the border.

Figure 6-9 depicts the ACF and PACF function of the bus passenger data. Note that there was a stem at lag 1, which is 1 year. This spike indicated that there was some autocorrelation with an interval of 12 months. However, when examining the bus passenger data, we could not find a stable seasonality effect such as we found in the truck data. Thus the two tier regression model we used for the truck data was not viable here. Instead we decided to use the time series model. However, similar to the POV and pedestrian data, we did not think the time series model was capable of giving a good extended forecast; therefore, a regression model based on the yearly bus passengers was also built to produce the extended forecast.

We tested different models to find a relatively good time series model for the bus data. We used the ARIMA model with $(p,d,q)(P,D,Q)_L = (9,0,7)(1,0,0)_{12}$. In this case, the training data was from January 2000 to December 2005, and the validation data set was from January 2006 to December 2008. We found that the data for February 2003 was abnormally high, which prevented us from finding a good model, thus we used the average of January 2003 and March 2003 data to replace the original data point. Figure 6-10 shows the fitted value against the real value on the validation data. Due to the variety in the data, the model was unable to follow each fluctuation in the real data, but the general trend does not deviate. The Theil's U statistic is 0.091 on the validation set, which was high compared to those from other modes. However, this was a relatively good result among the models we tested.

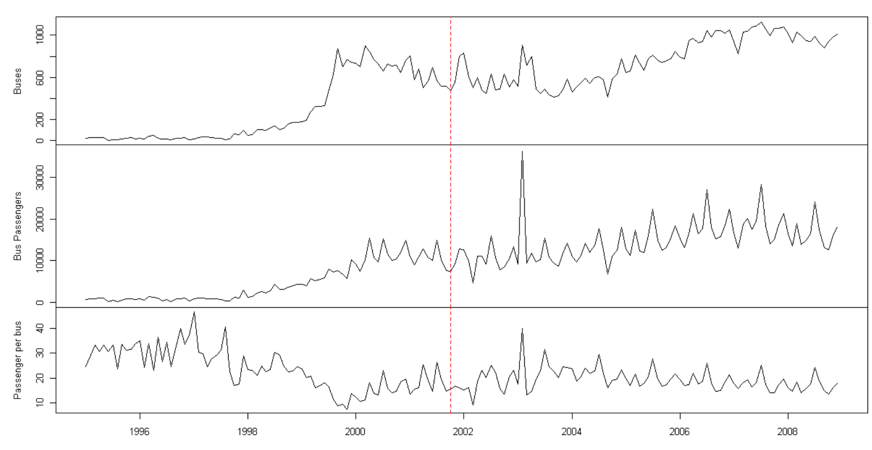

Figure 6-8 Historical data of bus crossings and bus passengers

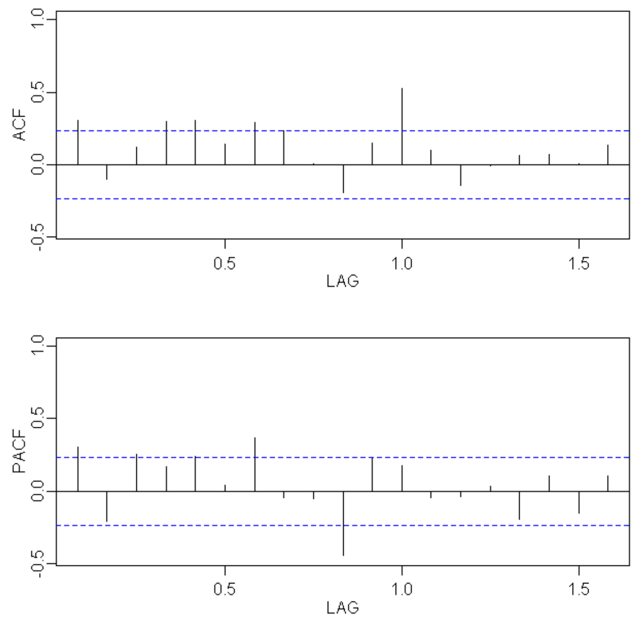

Figure 6-9 ACF and PACF of the bus passengers

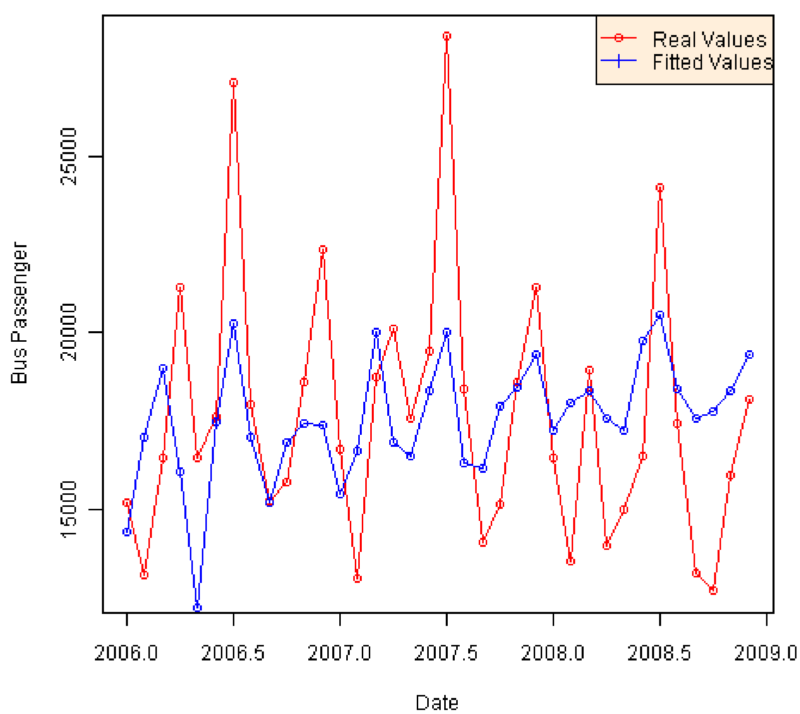

Figure 6-10 Plot of the fitted data to the real data on validation set (Bus Passenger)

Rail

Besides the relatively stable schedule of the trains, train traffic was also highly dependent on the availability of equipment and underlying customer demand. Recall the historical data of the train crossing we listed in section 5.2 Historical Data. We plot the graph here again in Figure 6-11. There were three huge spikes during the last 14 years. During the years 2003 and 2004, traffic was significantly lower than other years. Aside from these two instances, the railway traffic was relatively stable, though some fluctuations existed. Realistic projections of rail traffic will depend critically on Union Pacific's assessment of customer demand and other external factors such as the success of Punta Colonet, rerouting away from the center of Nogales, and expansion of the port of Guaymas.

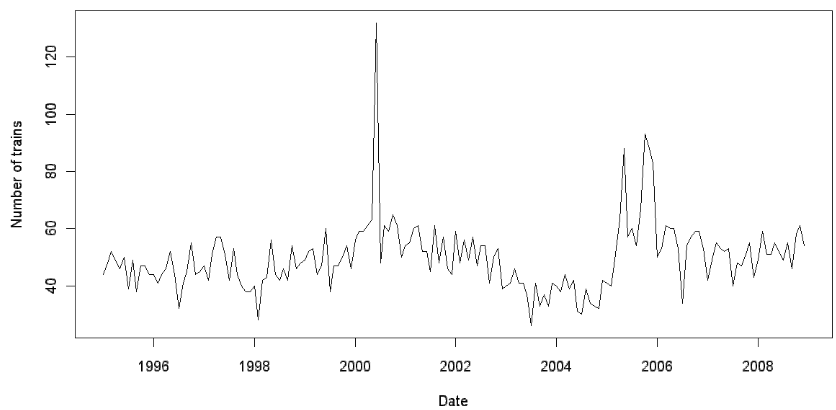

Figure 6-11 Historical data of the number of trains crossing the border

7 Models

After a preliminary evaluation of each of the possible model types the following framework was adopted to generate forecasts:

- Time series models were used to conduct all the short term (5 year) forecasts for all the traffic modes
- Regression models were used to conduct the long term (10-year and 15-year) forecasts for POV, pedestrian and bus.
- Time series models were used to conduct the long term (10-year and 15-year) forecasts for truck.

After our initial analysis of the train data, we decided not to build any forecast model for the train traffic for the following reasons: 1) The trains were running on a relatively stable schedule. 2) Only one company was involved in the railway transportation business in this area. Any changes in schedule were highly dependent on this particular company.

In this section, we show the models we actually used for the forecasts. Note the modes we mentioned in the previous section, Model Alternatives, were built on training data, which left out the last three years' data for validation purpose. The models shown in this section were built upon the full data set, and aimed to forecast the future traffic. For each model we built, we show the model and the diagnostic methods for the corresponding model. We believed the best way to explain the methods is with an example, so the methods will be explained when first used in the following part of this section. An overall summary of the techniques used are summarized in the appendix called "*Statistical Detail*".

7.1 Models for Truck Traffic

We used the ARIMA model with $(p,d,q)(P,D,Q)_L = (1,1,4)(2,1,2)_{12}$, and then we estimated the coefficient for each parameter based on the full dataset. The computer package used to do this estimation was R(R Development Core Team 2009), a freely available statistical software package. The computer outputs are shown as in Table 7-1[6]. Table 7-1 lists the coefficients of the parameters and their standard deviation

[6] Refer to the ARIMA model part in the statistical detail appendix for the detailed meaning of this result report

estimates below the corresponding coefficient (The lines start with “s.e.”). Figure 7-1 shows the fitted values and the real values, which shows the fitted values are very close to the real values for historical data.

One important criterion used to check the adequacy of the model was to analyze the residuals, which were the differences between the fitted values and the real values in the training set. In our models, we assumed the residuals are normally distributed with mean 0. So we needed to check the validity of this assumption. In the time series model, we also wanted to make sure there was no trend existing in the residuals. A good way to check this was with the ACF and PACF function as we used before. However, instead of applying these functions on the original data, we applied them on the residuals. If there was no significant autocorrelation between the residuals, we believed there was no trend in the residuals.

Figure 7-2 shows a series of diagnostic plots for the model. The upper panel shows the standardized residuals. The middle left panel is the ACF of the residuals. From the plot we conclude that there was no significant autocorrelation among the residuals, and thus we claim that there is no trend contained in the residuals. The middle right panel is the Normal plot of the residuals. All the points are tightly clustered around the straight line in this plot, which is a good indication that the residuals are normally distributed. The lower panel is the plot of Ljung-Box test statistics. The X axis in the plot is the lag, while the y axis is the p-value, and the blue dash line is the limit. If the p-value is within limits at lag i, then the residuals have no autocorrelation at lags of i or less. From this graph, we can say residuals have no autocorrelation at lags up to 30. Thus we believe that the model and parameters satisfy the requirements for good model fit.

Table 7-1 Computer output: The coefficients for the parameters, Truck model

```
          ar1      ma1      ma2      ma3     ma4     sar1     sar2
sma1
      -0.9318  0.4383  -0.9395  -0.3056  0.1567  -0.6268  -0.0325
0.0643
s.e.   0.2324  0.2388   0.1265   0.1256  0.0837   0.2505   0.1700
0.2434
         sma2  constant    USIIP      Xrate
      -0.4692    3.7757  164.8073  -273.2759
s.e.   0.1989       NaN   75.8264   266.4386
```

Xrate stands for exchange rate

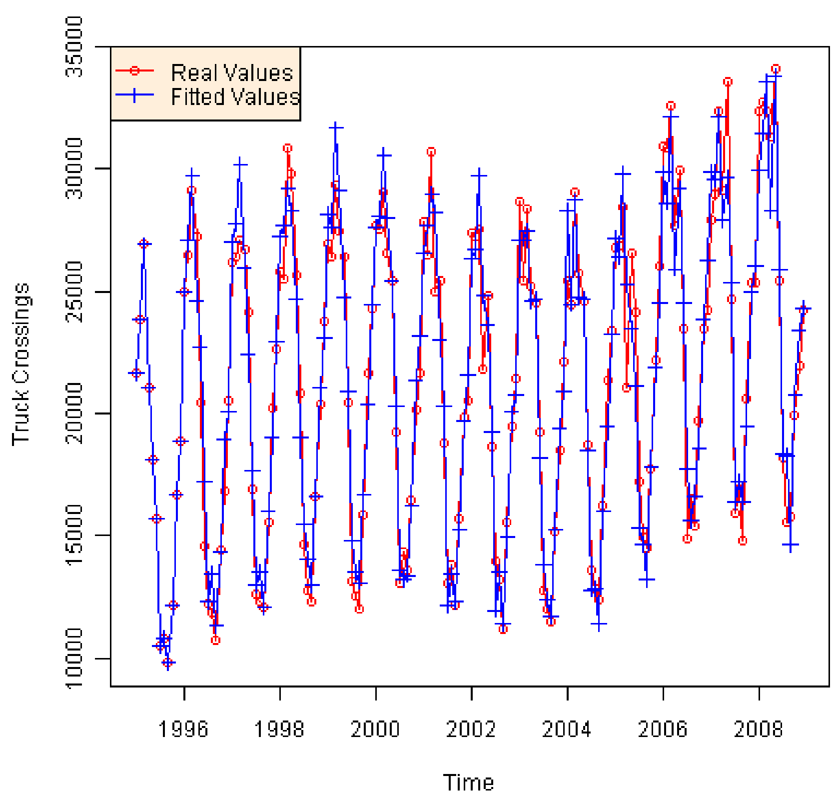

Figure 7-1 Fitted values vs Real values, Truck

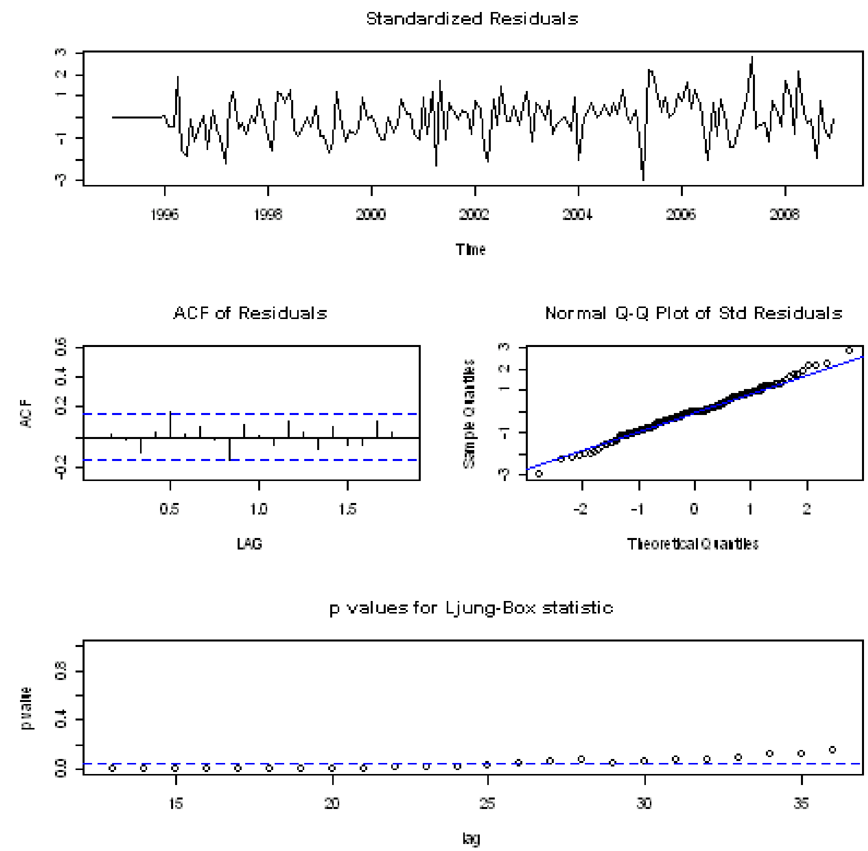

Figure 7-2 Diagnosis plots of the Truck model

7.2 Models for POV Traffic

We used both a time series model and a regression model for the POV traffic. The time series model was used to produce the short term forecast (5 year), and the regression models were used to produce the extended forecasts.

The time series model used was a seasonal ARIMA model with structural parameters $(p,d,q)(P,D,Q)_L = (2,1,6)(2,0,3)_{12}$. Table 7-2 shows the computer output of the ARIMA model, which contains the coefficients of the parameters. Figure 7-3 plots the real values and fitted values together. We can see the fitted values follow the trend of the real values generally well except for those points whose value increase or decrease suddenly. Figure 7-4 shows the diagnostic plots of the POV time series model. The upper panel shows the standardized residuals. We can see that there are some places the residuals are abnormally high or low. Comparing the position of their corresponding time stamp to the time stamps of the sudden increase and decrease in historical POV data as shown Figure 7-3, we can see that the time stamps match each other. We intend not to incorporate these sudden increases or decreases in our model. Otherwise, the model might be over fitted. From the ACF plot of the residual and Ljung-Box test statistics, we believe that the residuals are normally distributed with mean 0, except for a few exceptional points.

Table 7-2 Computer output: The coefficients for the parameters, POV model

```
        ar1      ar2      ma1      ma2      ma3      ma4     ma5     ma6
      -1.1039  -0.9917  0.5475  0.2996  -0.6448  -0.0728  0.0675  0.0576
s.e.   0.0161   0.0144  0.0843  0.0993   0.0990   0.0895  0.0893  0.0821
        sar1     sar2     sma1     sma2     sma3       XmatT
      0.8037   0.0094  -0.7022  -0.0747  0.1956    153.8429
s.e.  0.3838   0.3860   0.3801   0.3554  0.1005  11102.8878
```

XmatT contains the time index

As we can tell from the Figure 7-5, the real values cannot be fitted by a single linear model. Thus, we decided to use piecewise linear regression, and used different pieces as different scenarios in our later forecasts. One thing we needed to decide was how many break points to have and where to place these break points. We used the method introduced in (Achim Zeileis et al. 2002) and (Achim Zeileis et al. 2003) to finish these two tasks simultaneously. The breakpoints we located were 56 and 80, which were corresponding to August, 1999 and August 2001. Figure 7-5 shows the breakdown of the historical data. An interesting finding here is that the POV traffic actually started to drop in August 2001, which just one month prior to “9/11”. After “9/11”, the decrease was magnified, and it continued to late 2008.

For each segment, we labeled the data from 1 to *n* according to the sequence of their original time stamp, where *n* was the length of data in that segment. We fitted a simple linear regression model for each segment. The fitted line and the real values are plotted in Figure 7-5. The computer outputs of these models are shown in Table 7-3, which contains the coefficients of each segment's model and corresponding tests. Segment 1, 2 and 3 are corresponding to the segments labeled 1, 2 and 3 in Figure 7-5. The slopes of the three segments are 1004.6, 1777.5 and -1057.45 respectively. The model for segment 2 is not as good in terms of the p-value (the smaller the better) as in segments 1 and 3. Segment 2 contained some big spikes, and our model was a linear model, which was not capable of capturing all these spikes. However, according to the Figure 7-5, this fit was still acceptable since the general increasing trend was captured. The whole set of historical data may have different trends in different time frames, thus we use the piecewise regression to find the possible segments and the slope of each segment. Each segment provides a possible trend within a time span. When we have difficulty in conducting a forecast, we may refer to these segments to estimate the future trend. In our study, we used each segment as a scenario.

Table 7-3 Computer output: models of different segments, POV data

```
Segment 1:
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 267733.4     5874.3  45.577  < 2e-16 ***
ind           1004.6      179.3   5.603 7.32e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 21690 on 54 degrees of freedom
Multiple R-squared: 0.3677,   Adjusted R-squared: 0.3559
F-statistic:  31.4 on 1 and 54 DF,  p-value: 7.316e-07

Segment 2:
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 374845.5    13180.1  28.440   <2e-16 ***
ind           1777.5      922.4   1.927    0.067 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 31280 on 22 degrees of freedom
Multiple R-squared: 0.1444,   Adjusted R-squared: 0.1055
F-statistic: 3.713 on 1 and 22 DF,  p-value: 0.06699

Segment 3:
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 338274.70    3211.91  105.32   <2e-16 ***
ind          -1057.45      62.68  -16.87   <2e-16 ***
---
```

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 14940 on 86 degrees of freedom
Multiple R-squared: 0.7679,   Adjusted R-squared: 0.7652
F-statistic: 284.6 on 1 and 86 DF,  p-value: < 2.2e-16
```

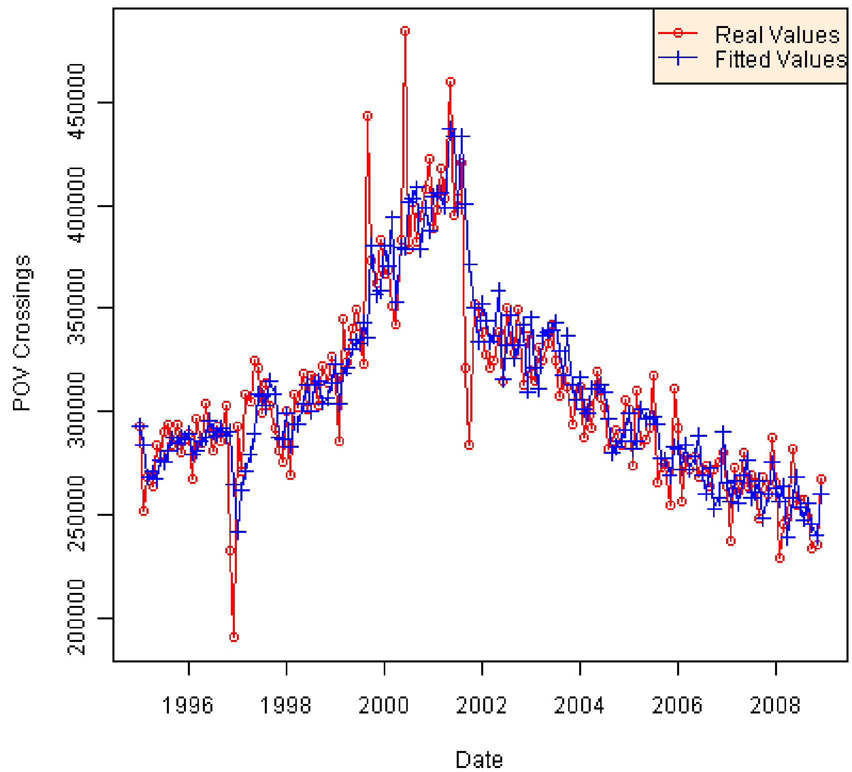

Figure 7-3 Fitted values vs Real values, POV

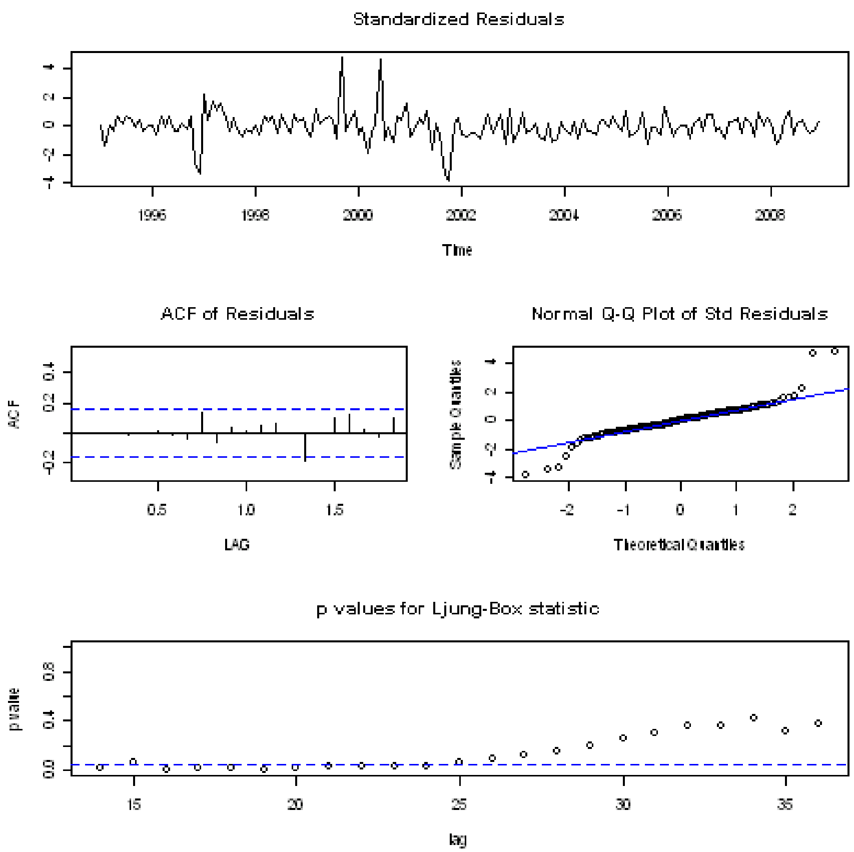

Figure 7-4 Diagnosis plots of the POV

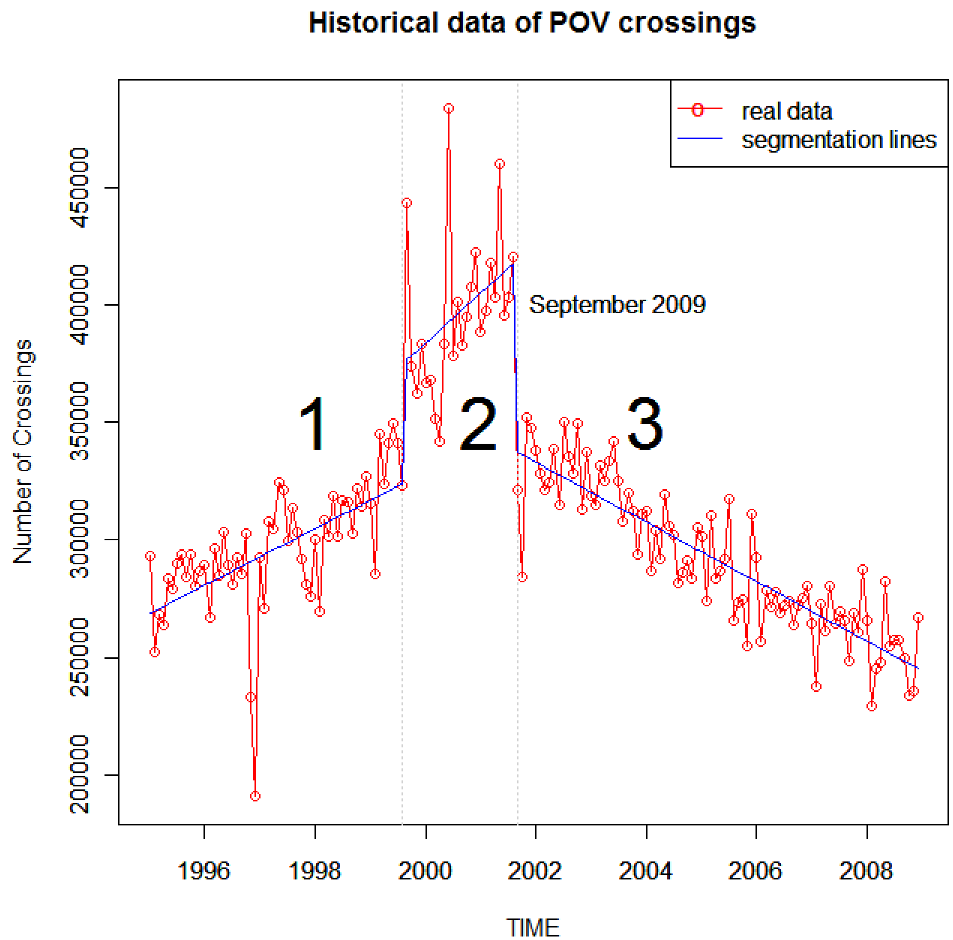

Figure 7-5 Piecewise regression on POV data

7.3 Models for Pedestrian Traffic

According to our data as well as interviews with people who had work experience in the Nogales area, we found that the pedestrian traffic was the most sensitive of the three modes of traffic under study, i.e. the pedestrian traffic contained the most variability. Similar to the POV traffic, we built a time series model for the pedestrian traffic for short term forecasting and simple regression models for extended forecasting. As we stated in the Model Alternative section, we incorporated "Arizona Employment" as an exogenous variable into the time series model. However, given the high level of variability in the pedestrian crossing history, the long term forecast should be used with caution, and multiple scenarios might be considered.

The ARIMA model we used had structural parameters $(p,d,q)(P,D,Q)_S = (3,2,1)(2,0,2)_{12}$. Table 7-4 shows the computer output of the coefficients of the ARIMA models, which contains the coefficients of the parameters.

Table 7-4 Computer Output: The coefficients for the parameters, Pedestrian model

```
           ar1      ar2      ar3      ma1     sar1    sar2    sma1
sma2
      -0.5697  -0.4191  -0.2584  -1.0000  0.2254  0.2998  0.0090  -
0.0237
s.e.   0.0756   0.0851   0.0783   0.0155  0.4671  0.4512  0.4775
0.3786
      constant     AZemp
      -557.051  700.5331
s.e.       NaN  211.8245
```

AZemp: "Arizona Employment"

Since the pedestrian traffic data contained so much variability, it was not appropriate to produce the long term forecast using a time series model. Thus we used piecewise linear regression to build regression models on historical data of the pedestrian traffic, and used them for different scenarios in the forecast. We used the same method as for the POV traffic to locate the number and locations of the break points, and then fitted simple regression models for each segment. Note that the "Arizona Employment" factor was not involved in these simple regression models. The break points were 66, 97 and 142, which were corresponding to June 2000, January 2003 and August 2006 respectively. Figure 7-8 depicts the breakdown of the historical data and the corresponding fitted model of each segment. We labeled the segments as 1, 2, 3 and 4 according to time stamp of each segment as shown in Figure 7-8. The slopes of the lines corresponding to segment 1, 2, 3 and 4 are 236.4, 6745, 5053.0 and -7149. We can see the slopes differ not only in the absolute values, but also the sign. The slopes of the first three segments are positive, while the slope for segment 4 is negative, which indicates the trend changed from increasing to decreasing.

Table 7-5 Computer Output: Models of different segments, Pedestrian data

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 389459.6     8206.6   47.46   <2e-16 ***
ind            236.4      212.9    1.11    0.271
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 32960 on 64 degrees of freedom
Multiple R-squared: 0.0189,   Adjusted R-squared: 0.003569
F-statistic: 1.233 on 1 and 64 DF,  p-value: 0.271


Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   329561      22393  14.717 5.49e-15 ***
ind             6745       1222   5.521 5.97e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 60840 on 29 degrees of freedom
Multiple R-squared: 0.5125,   Adjusted R-squared: 0.4957
F-statistic: 30.48 on 1 and 29 DF,  p-value: 5.966e-06


Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 425631.8    17990.6  23.659  < 2e-16 ***
ind           5053.0      681.1   7.419  3.2e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 59340 on 43 degrees of freedom
Multiple R-squared: 0.5614,   Adjusted R-squared: 0.5512
F-statistic: 55.04 on 1 and 43 DF,  p-value: 3.201e-09


Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   702805      31521  22.296  < 2e-16 ***
ind            -7149       2041  -3.503  0.00183 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 78060 on 24 degrees of freedom
Multiple R-squared: 0.3383,   Adjusted R-squared: 0.3107
F-statistic: 12.27 on 1 and 24 DF,  p-value: 0.001830
```

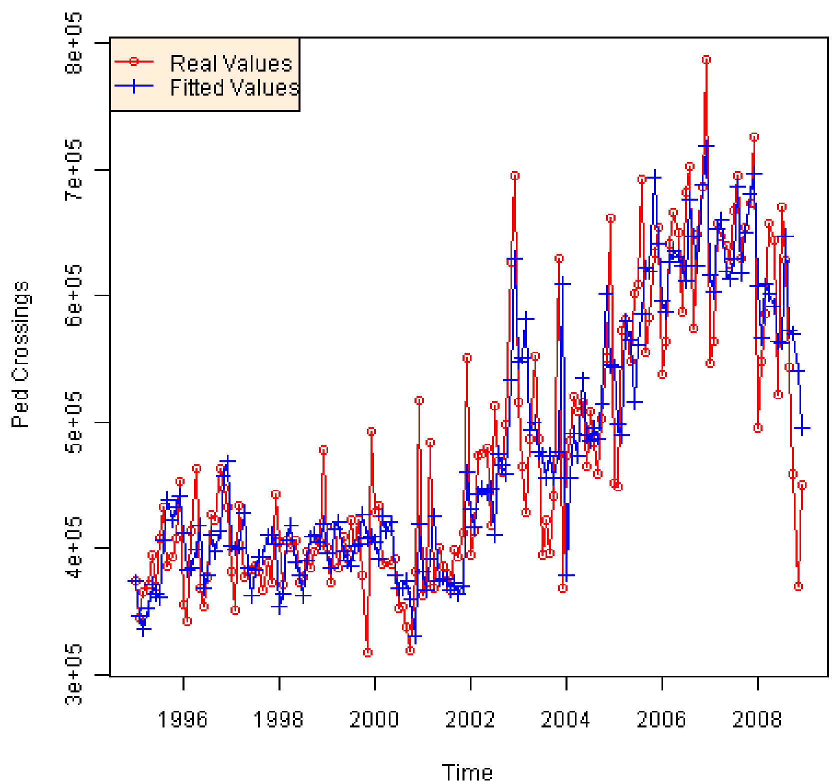

Figure 7-6 Fitted values vs real values

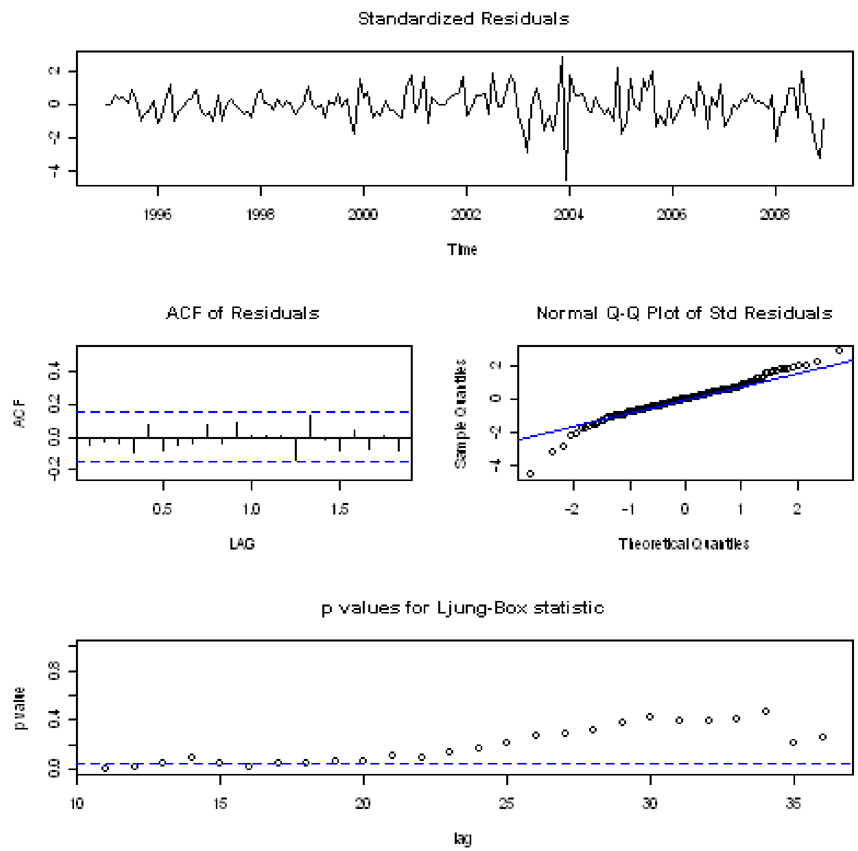

Figure 7-7 Diagnosis plots of the Pedestrian

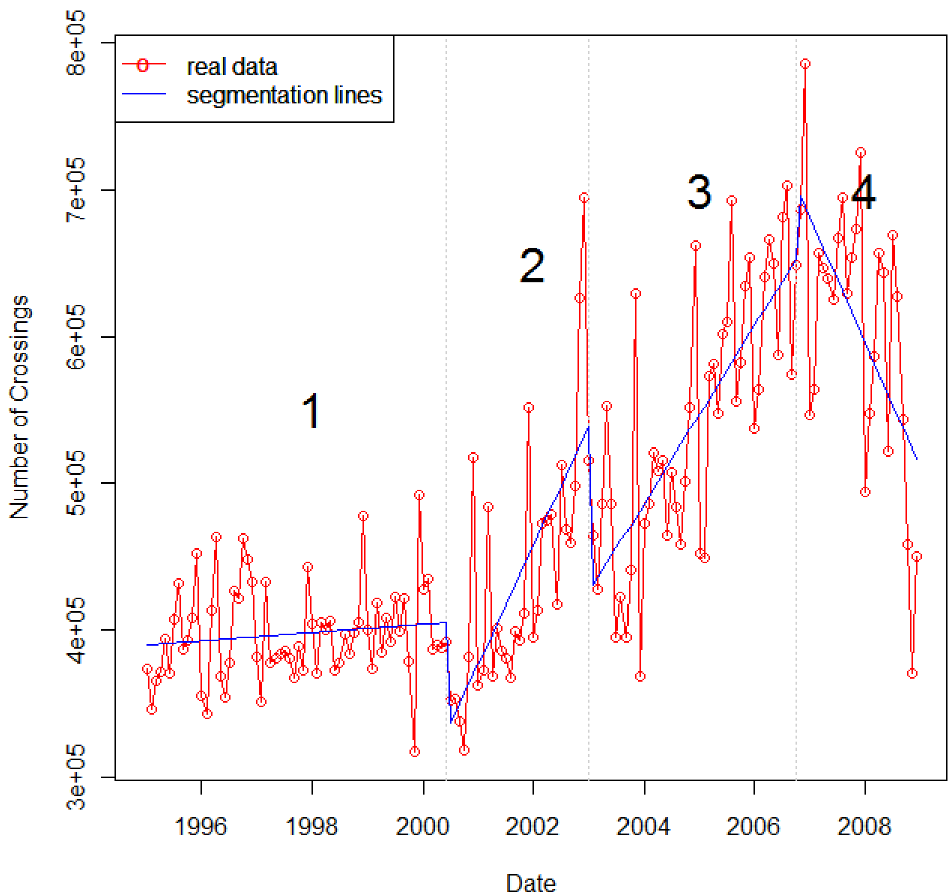

Figure 7-8 Piecewise regression on Pedestrian data

7.4 Models for Bus Traffic

We decided to build the model of bus traffic based on the number of bus passengers instead of the number of buses in section 6.4. When building the models for bus traffic, we had some issues that we did not face in other data. When we tested the model alternatives, we left out the last three years' data for validation purpose. We used the full set of data (note here the full data set indicates the data from January 2000 to December 2008) to build the forecast model. However, when we put all the data into the model, we found the ACF and PACF completely changed. Figure 7-9 compares the ACF and PACF of the data in training data set and the whole data set, where the left panels are ACF and PACF of the training data set, and the right panels are the ACF and PACF of the whole data set. To explain the cause of this difference, let's revisit the historical data since 2000, which are plotted in Figure 7-10 with red dots. We can see that the traffic before 2006 was increasing and the 2006 traffic increased compared to that of 2005, while 2007 was almost the same as 2006. The traffic started to decrease in 2008. The ARIMA model we used in the model alternative section actually did not work here, since singular numbers are produced and thus the model will not converge. We built new models according to the new ACF and PACF functions of the full data. The model we were using had the structural parameters $(p,d,q)(P,D,Q)_L = (9,1,7)(0,0,1)_{12}$. The coefficients of the model are shown in Table 7-6. The diagnostic plots are shown in Figure 7-11. From the plots, we can tell that the residuals conform to the normal assumption.

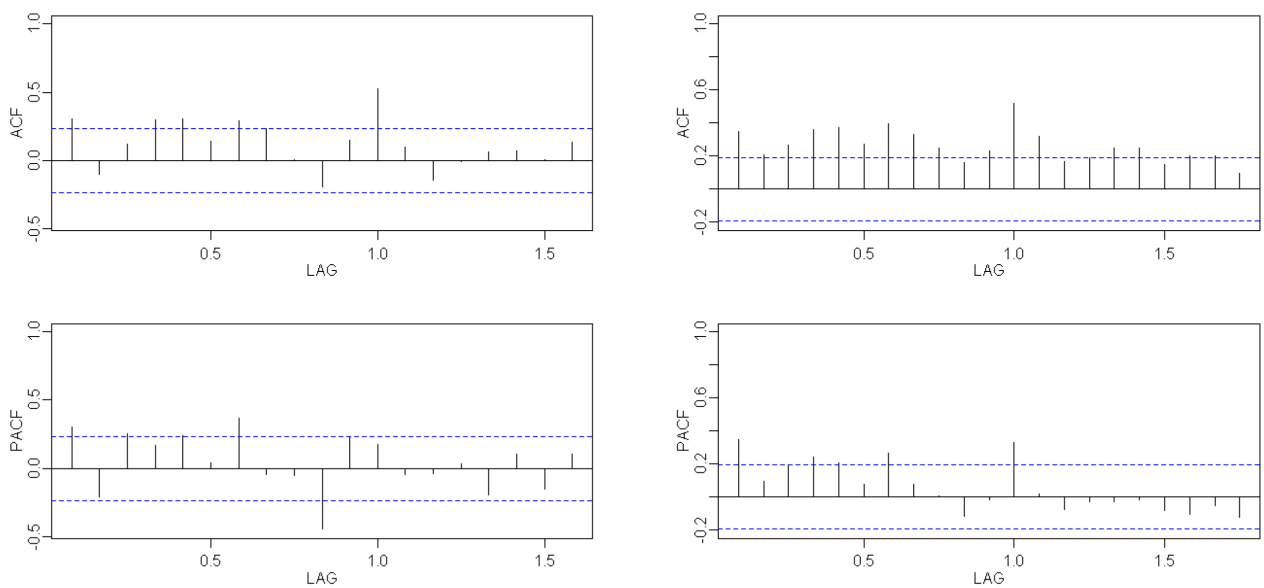

Figure 7-9 Comparison of ACF and PACF.

Left side are from the training data, right side are from the whole data set

Table 7-6 Computer Output: ARIMA model coefficients, Bus Passenger

	ar1	ar2	ar3	ar4	ar5	ar6	ar7	
	-1.0606	-1.5195	-1.4992	-1.0064	-0.7799	-0.5072	-0.1904	
s.e.	0.6870	1.1418	1.7192	2.0331	1.9004	1.6589	1.2629	
	ar8	ar9	ma1	ma2	ma3	ma4	sma1	XmatT1
	0.0074	0.1390	0.4316	0.4197	0.3989	-0.5887	0.3502	6.3708
s.e.	0.7695	0.3901	0.6211	0.6400	0.6447	0.6289	0.1009	1118.6583

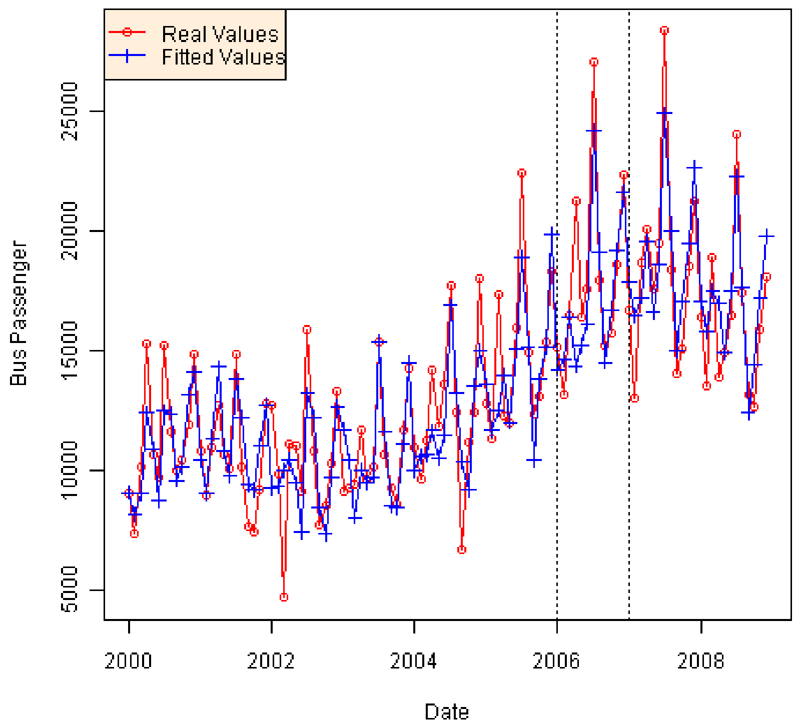

Figure 7-10 Historical data for bus passengers since 2000 vs. fitted data
(the February, 2003 data is replaced by average of January 2003 and March, 2003)

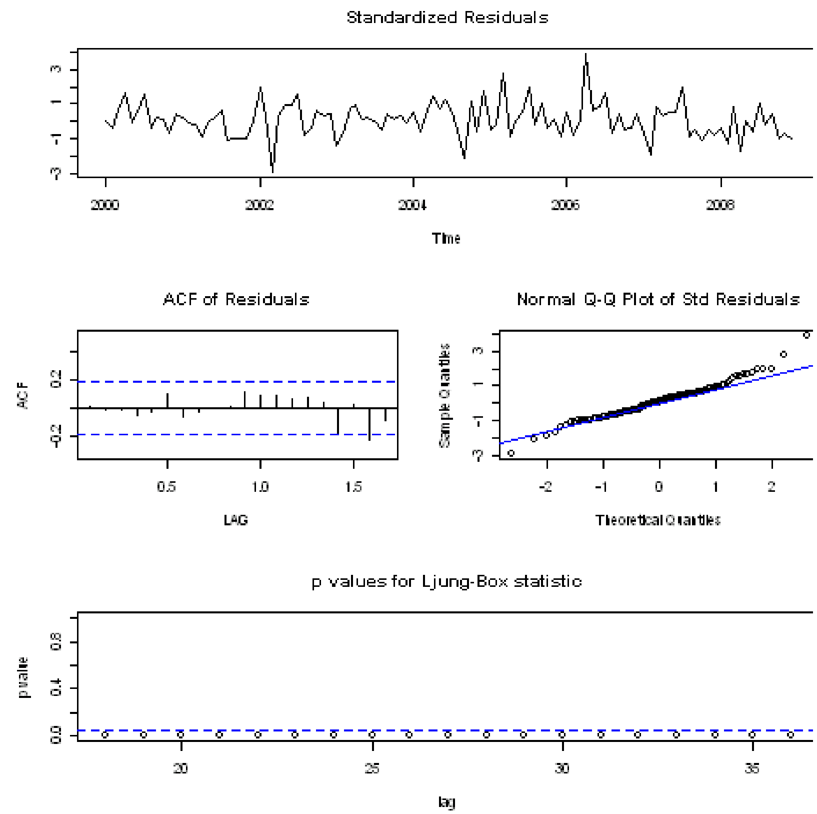

Figure 7-11 Diagnostic plots of the Bus Model

8 Forecasts

Once the forecasting models were built and validated using the available data, the next step was to use these models to provide forecasts of border crossings for the next 5, 10 and 15 years. However, given the unstable economic conditions at the time the models were built and the data was collected, instead of giving a single estimate for each of these time periods into the future it was decided to prepare multiple forecasts based on different scenarios.

For instance, during the model building stage, it was found that the Mexican Peso to US Dollar Exchange rate and the US Index of Industrial Production (IIP) significantly influenced border crossing traffic, especially commercial vehicle crossings. Thus, we first analyzed the trend scenarios of these two indices. Based on these scenarios we developed forecasts for border crossings for the different modes of traffic. In the following sections we provide forecasts for four modes of traffic: commercial vehicles, Privately Owned Vehicle (POV) pedestrians and Bus. For each mode, we provide a 5-year, 10-year and 15-year traffic forecast.

8.1 Forecasts for Commercial Vehicles

Overview of Exchange Rate and Index of Industrial Production(IIP)

The historical data for the exchange rate (If we don't indicate specifically, the exchange rate means the exchange rate between US Dollar and Mexican Peso, represented by the value of 1 US Dollar in Pesos) and US IIP(Index of Industrial Production) are available from the Federal Reserve Board. Various companies provide forecasts of these two indices, but most of these forecasts are only for a horizon of 36 months. We obtained the 36-month forecasts from the organization forecasts.org, and we call these forecasts the external forecasts. Since our intention was to give 5-year, 10-year and 15-year forecasts, we used forecast models in combination with these external forecasts. In cases where there was no external forecast available, we used only our own forecast. Due to the complexity of the forecast, we did not have a perfect forecast of these indices. What our forecasts did was to capture the general trend of the indices. We used simple regression for the 5 and 10 year forecast and used piecewise linear regression for the 15-year forecast. In the development of our forecasts, we considered different scenarios by assuming different trends of the underlying forecasting regressors (USIIP and Exchange rate). To begin we first reviewed the historical trends of the exchange rate and US IIP data. Figure 8-1 and Figure 8-2 plot the historical data (beginning March 2003) and the 36 month forecast (beginning May 2009) of the Exchange Rate and US IIP respectively, both of which were obtained from the organization forecasts.org. Figure 8-3 and Figure 8-4 show the data for a longer time span, where all available historical data was included and the forecasted data was excluded.

Considering that there was a devaluation of the Mexican Peso in late 1994 (Joseph A. Whitt 1996), we used the data starting from January 1995 to estimate the long term trend for the Exchange Rate. Also, because another significant devaluation of the Mexican Peso occurred during late 2008/early 2009, the trend of the Exchange Rate beginning in 1995 provided insightful information for the trend of the Exchange Rate after 2008/2009. The US IIP data, with its history dating back to 1919, provided relatively better historical records for estimating the future trends, especially for those trends occurring after recessions.

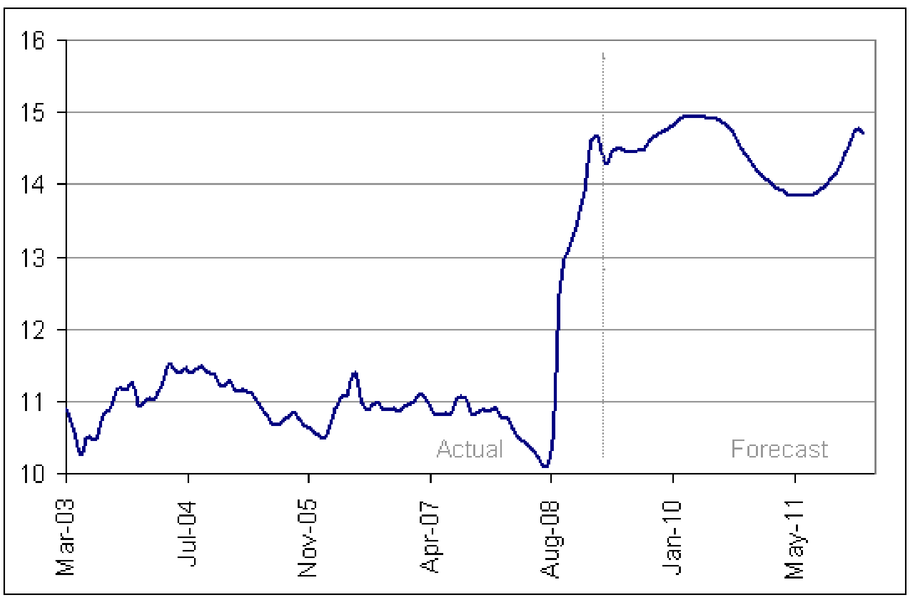

Figure 8-1 Mexican Peso to US Dollar Exchange Rate Forecast:
Past Trend & Future Projection (forecasts.org)

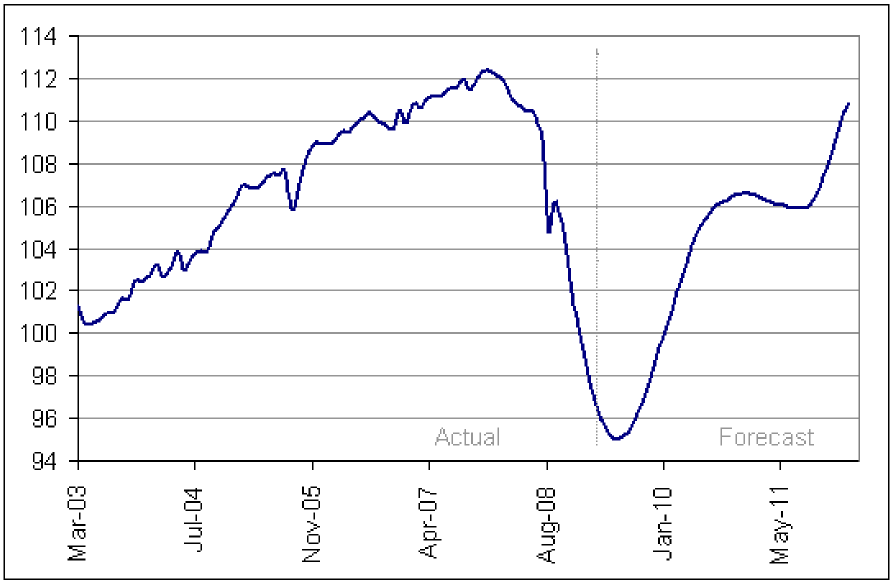

Figure 8-2 U.S. Industrial Production Index Forecast: Past Trend & Future Projection (forecasts.org)

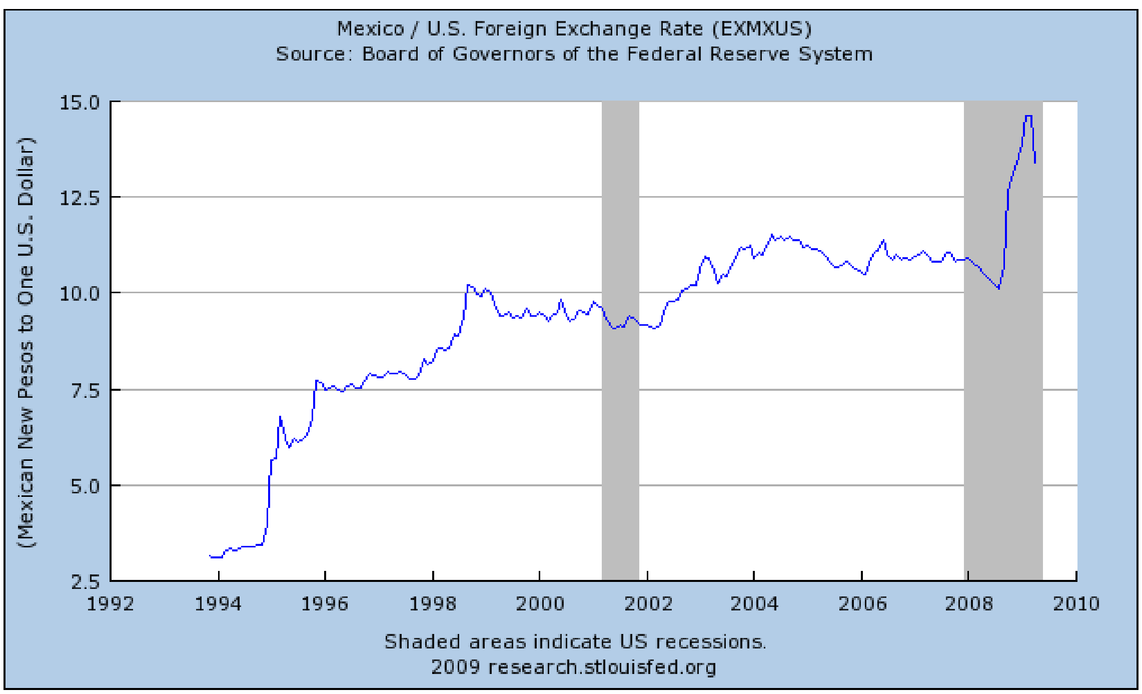

Figure 8-3 Mexican Peso to US Dollar Exchange Rate Historical Trend (Federal Reserve)

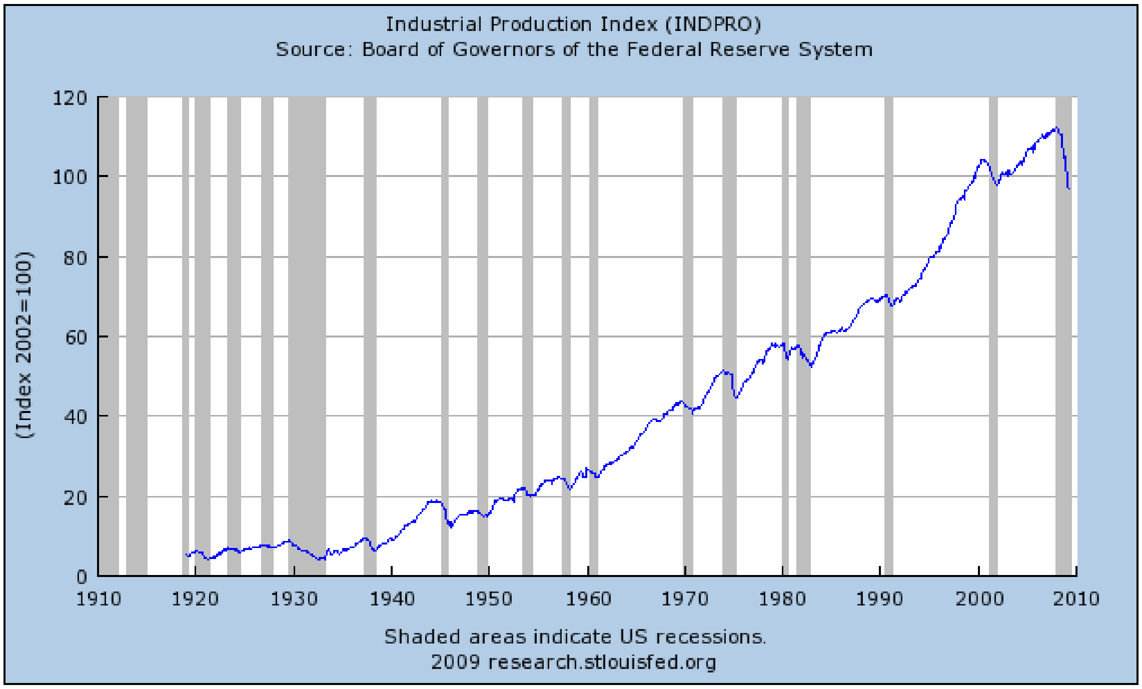

Figure 8-4 Historical data of U.S. Industrial Production Index (Federal Reserve)

Five-Year forecast

In order to estimate the 5 year trend of the exchange rate, we divided the historical data into groups of five-year length segments, and fitted those segments separately. We plotted the segmented data as shown in Figure 8-5. From this figure, we can tell that there are different possible trends for a 5 year time span, as shown by line segments 1, 2 and 3 which have very different slopes. For instance, segment 3 is almost a horizontal line, suggesting a very stable exchange rate. A similar situation occurred with the IIP data, which is shown in Figure 8-6, i.e., different 5-year segments resulted in significantly different trends.

In order to develop different forecast scenarios we chose different combinations of the exchange rate and the IIP trends as input to the models to obtain different forecasts of traffic. We defined different trends for the two indices (or variables) as shown in Table 8-1. There were 9 different combinations in total. For notation simplicity, we assigned each possible trend combination a two digit code, where the first digit represented the trend of the exchange rate and the second one represented the trend of US IIP. For example, the code 31 meant forecasts using “Staying relatively stable” for exchange rate and “Growing fast” for the US IIP. Figure 8-7 shows all the 9 different combinations of the future Exchange Rate and US IIP graphically. Figure 8-8 shows the forecasts of all the different scenarios graphically. Here the X axis represents the time and the Y axis represents the number of trucks crossing the border. Figure 8-9 aggregates the results to yearly level. The solid blue lines in Figure 8-8 are the forecasted values while the red dash lines represent one-standard deviation intervals. Note that all the scenarios have the same result for the first three years because they all used the same 36 months forecasts of the two indices from forecasts.org.

Table 8-1 Possible trend types for exchange rate and IIP within 5-year span

Exchange rate	US IIP
Growing fast (1)	Growing fast (1)
Growing mildly (2)	Growing slowly (2)
Staying relatively stable (3)	Staying relatively stable (3)

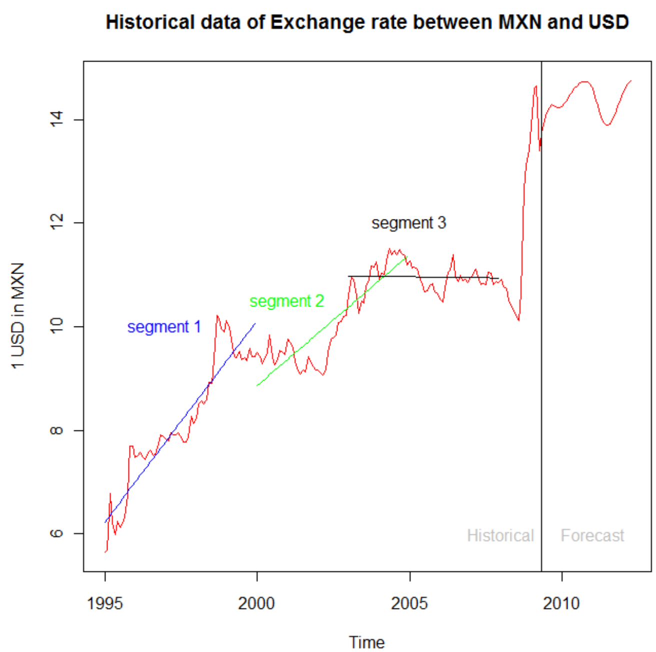

Figure 8-5 Historical Exchange Rate data with external forecast (5 year segments)

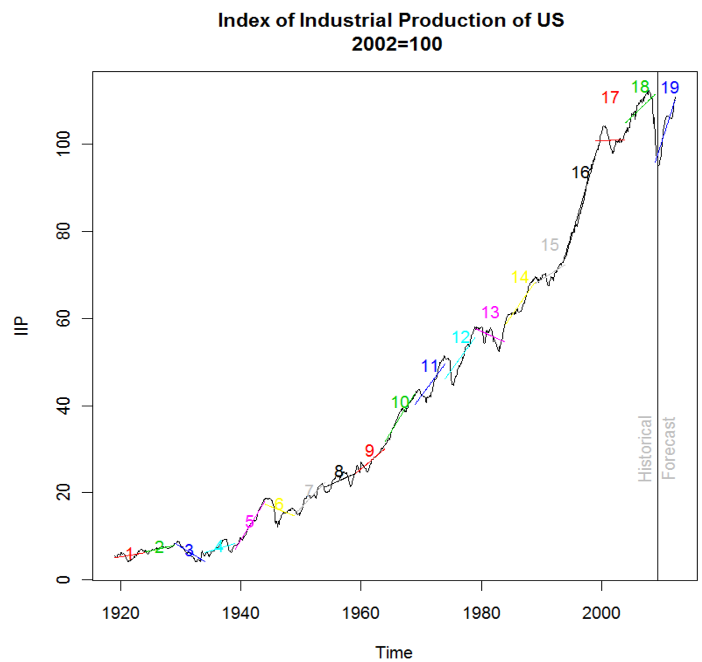

Figure 8-6 Historical data of US IIP with forecast from forecasts.org (5-year segments)

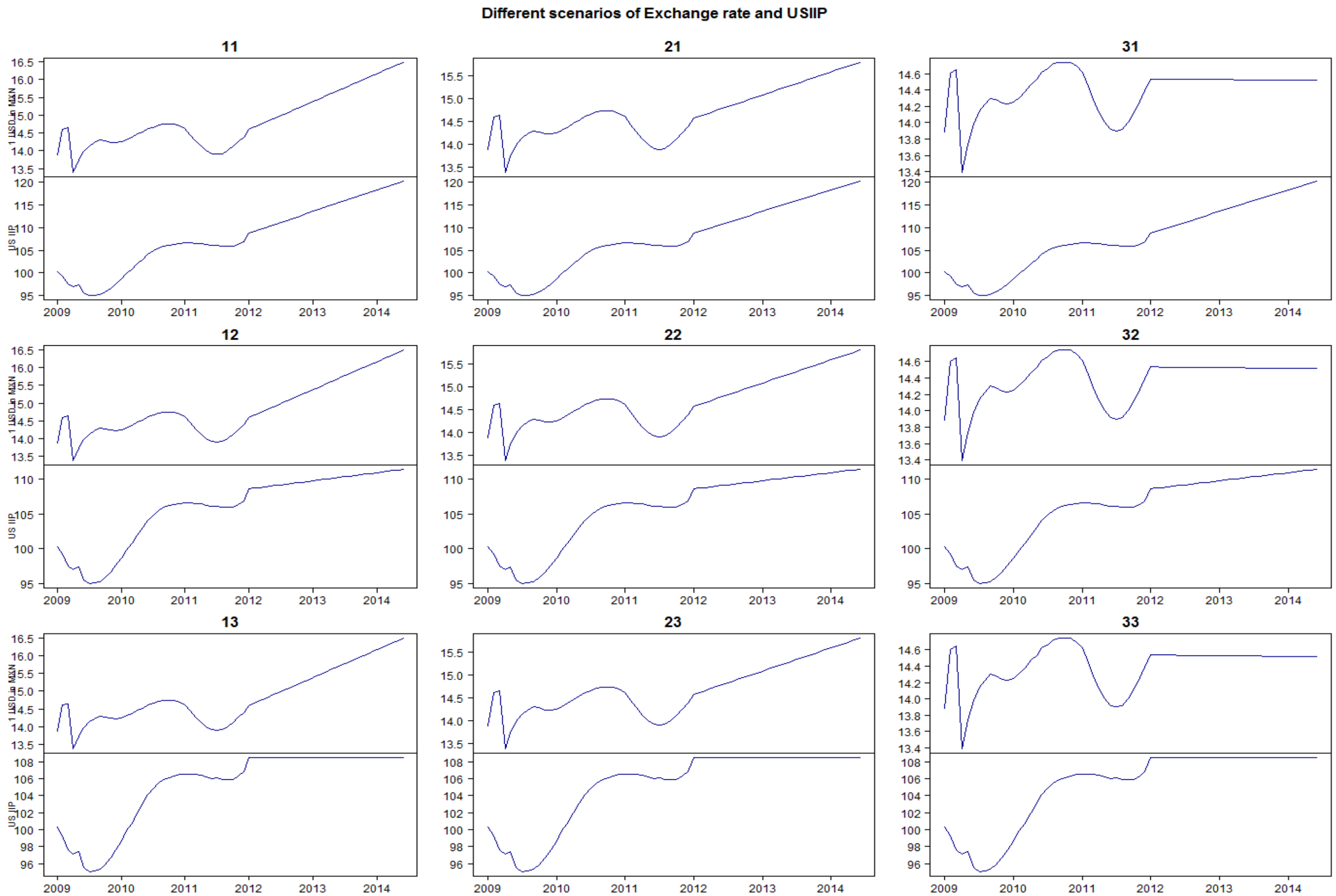

Figure 8-7 Different scenarios of Exchange Rate and US IIP

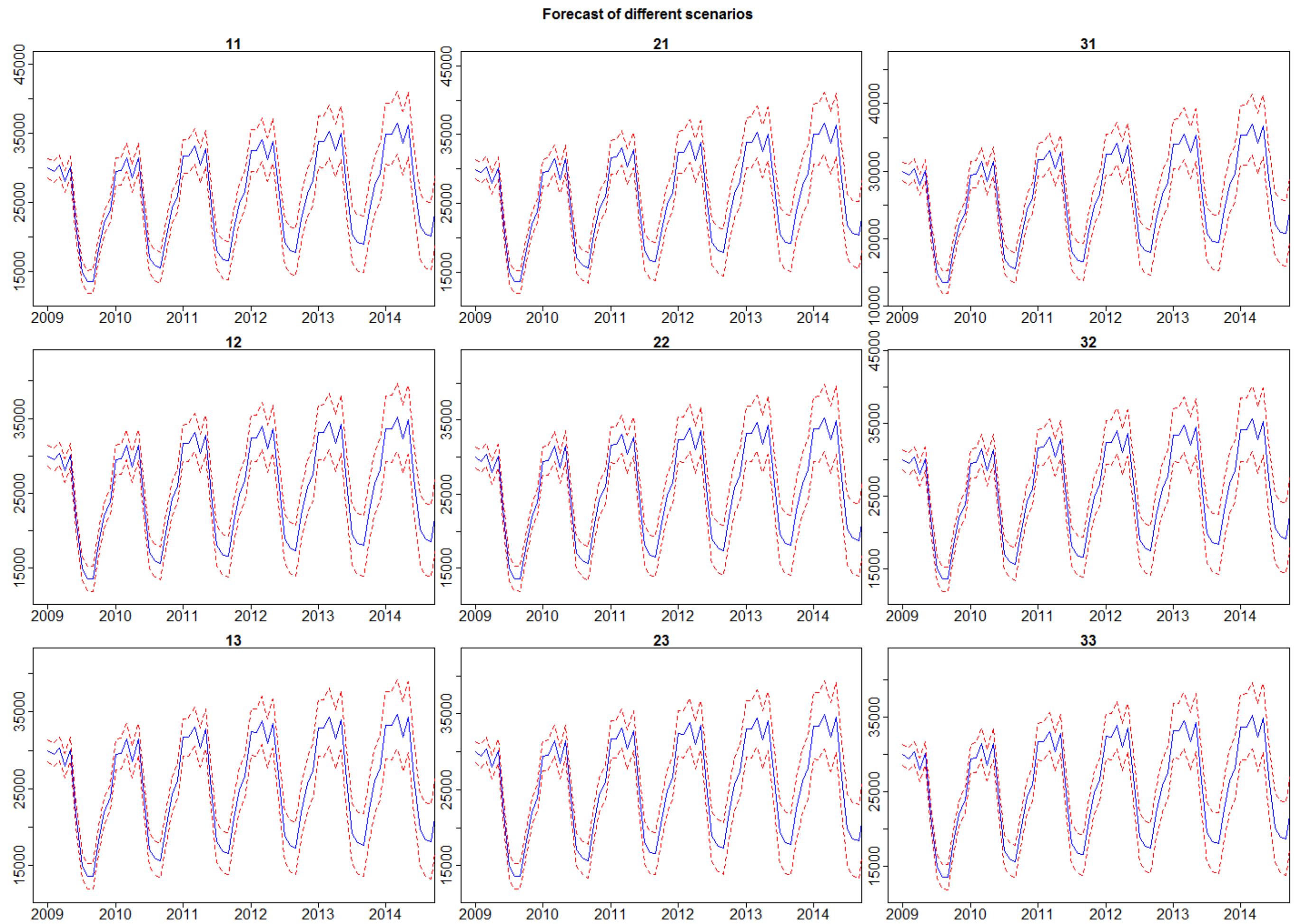

Figure 8-8 Forecasts under different scenarios;

solid blue line: the forecast, dashed red lines: one time standard deviation interval

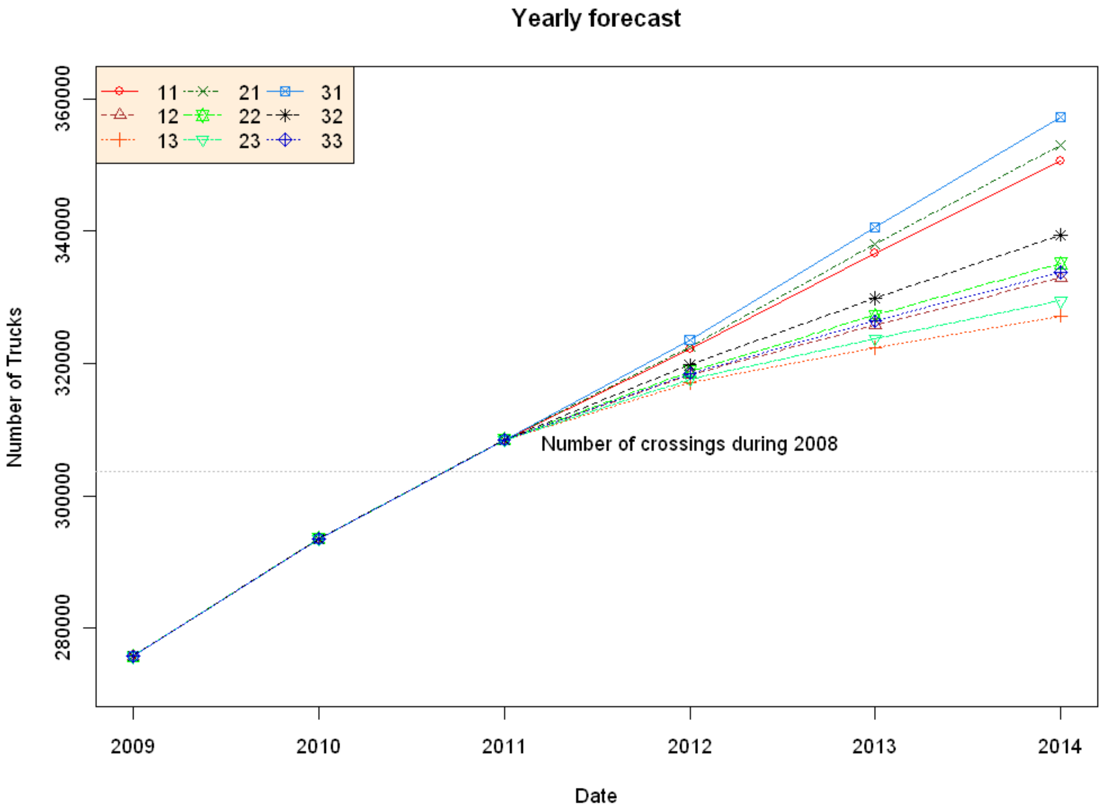

Figure 8-9 Yearly aggregation of the 5-year truck crossings forecast

Table 8-2 Five year forecast of different scenarios, compared to 2008

Increment of 2014 (%) 2008=100			
	+ Exchange Rate Growth speed -		
+ US IIP Growth Speed -	**11**	**21**	**31**
	15.4	16.2	17.6
	12	**22**	**32**
	9.6	10.3	11.7
	13	**23**	**33**
	7.7	8.5	9.9

Table 8-2 shows the percentage of increase of commercial vehicle crossings compared to the number of crossings in 2008. We can see the increment will be between 7.7% and 17.6%, based on the different trends of the exchange rate and the change of US IIP. The biggest increase will happen if the Exchange rate stays relatively stable and the US IIP grows fast. Comparing Table 8-2 by columns, we can tell that for the same trend of Exchange Rate, a "growing fast" trend of US IIP renders the largest increase of truck crossings. We can also conclude that for the same US IIP trend, a stable trend of Exchange Rate results in the biggest increase of truck crossings.   Ten-Year forecast

For the ten-year forecast, we applied a similar procedure. When examining the trend of the Exchange Rate over a ten-year time span, we found that it was unlikely to be stable, as can be seen in Figure 8-10. Therefore, we only prepared two scenarios for the Exchange Rate, “growing fast” and “growing mildly”. Figure 8-11 shows all the 10-year segments of the historical US IIP data. For the US IIP, historical data leads us to believe that all three possible trends could still occur during a 10-year time span, so we kept the same three US IIP scenarios as we did for the 5-year forecast. We used a similar coding method to that used in the five-year forecast to indicate the different scenario combinations. Table 8-3 lists all the scenarios we considered for the Exchange Rate and US IIP. Due to the long term uncertainty, we only give yearly forecasts as opposed to the monthly forecasts that were given in the 5-year forecast.

Table 8-3 Possible trend types for exchange rate and IIP within 10-year span

Exchange rate	US IIP
Growing fast (1)	Growing fast (1)
Growing mildly (2)	Growing slowly (2)
	Keeping relatively stable (3)

Figure 8-13 below shows the forecast of yearly commercial vehicle crossings under different scenarios and Table 8-4 shows the increase in number of crossings forecasted in 2019 when compared to those in 2008. From this table we can see that the ten year increase will be in the range of **18.8%** and **32.9%**. When comparing across columns, we can see that a “Growing mildly” trend of Exchange Rate renders a larger increase in the crossing of commercial vehicles. When comparing across rows, we can see that a “Growing fast” trend of US IIP renders a faster increase of the commercial vehicle crossings. Figure 8-13 depicts these differences graphically; here we can see the difference of increase is more significant among the scenarios with different US IIP trends. For the maximum growth of truck traffic, the US IIP should increase fast and the exchange rate kept relatively stable. For the minimum growth of truck traffic, the US IIP should stay relatively stable and the exchange rate grows fast.

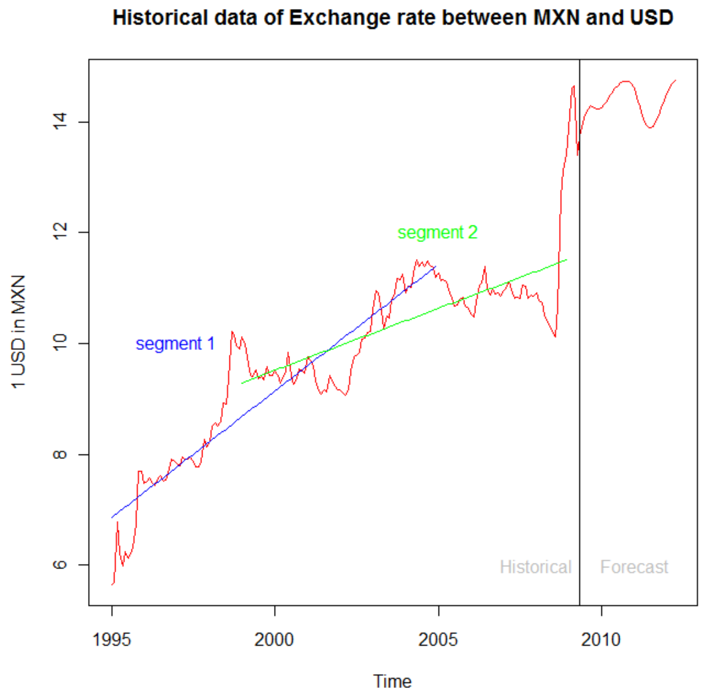

Figure 8-10 Historical Exchange Rate data with external forecast (10-year segments)

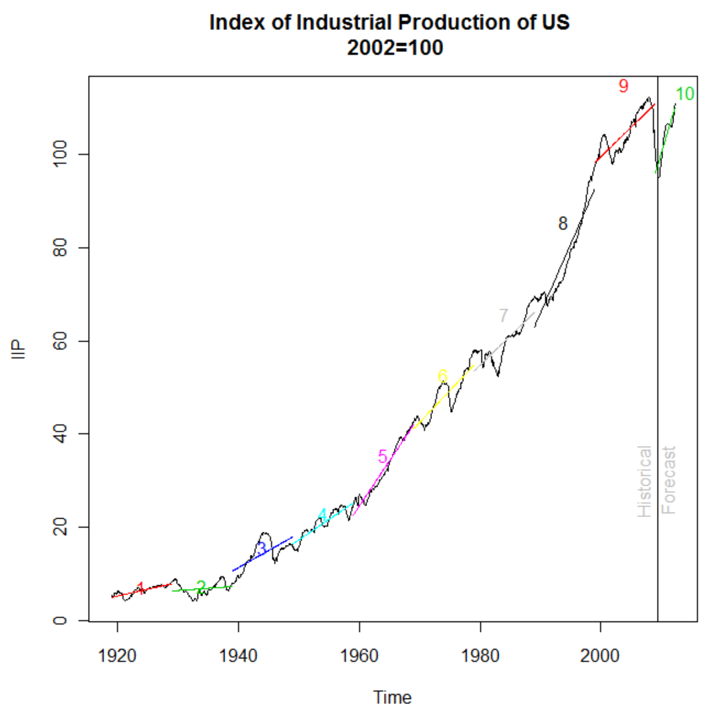

Figure 8-11 Historical data of US IIP with forecast from forecasts.org (10-year segments)

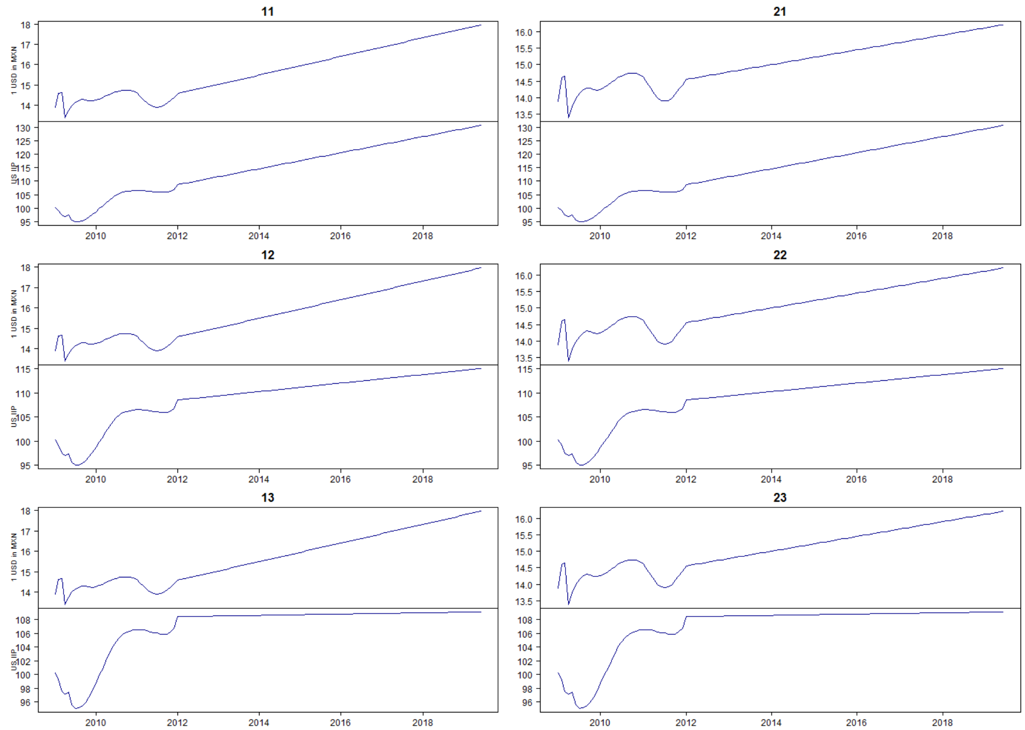

Figure 8-12 Different scenarios of exchange rate and US IIP (10-year segments)

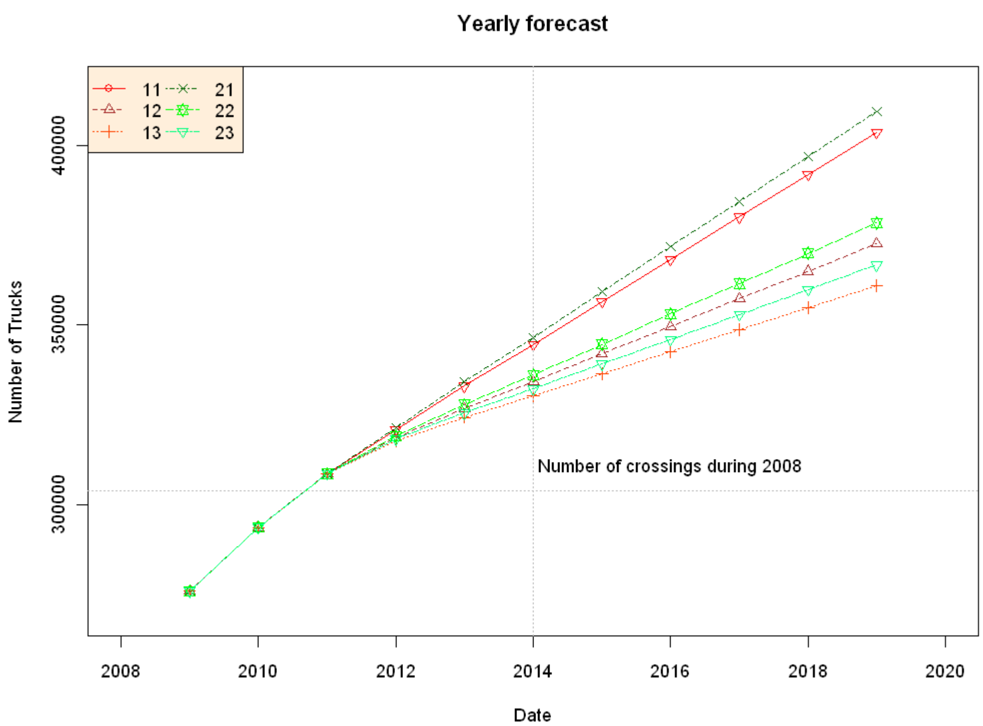

Figure 8-13 Yearly aggregation of the 10-year truck crossings forecast

Table 8-4 Ten-year forecast of different scenarios, compared to 2008

Increment of 2019 (%) 2008=100		
	+ Exchange Rate Growth speed	-
US IIP -Growth Speed+	**11**	**21**
	32.9	34.8
	12	**22**
	22.7	24.6
	13	**23**
	18.8	20.8

Fifteen-Year forecast

For the fifteen year forecast we had to use a different approach to handle each of the scenarios for exchange rate changes because we only had 14 years of historical data available. Instead of separating the data into different segments and determining the speed of growth (stable, mild or fast), we used different forms of piecewise linear regression methods to build the scenarios. We used a package named “segmented” (Muggeo 2008) in the R system (R Development Core Team 2009) to locate the breakpoints. The two scenarios for Exchange rate are shown in Figure 8-14, where the blue lines indicates scenario 1 and the green lines indicates scenario 2. For the US IIP, we used a similar approach as the one used in 5-year and 10-year forecasts. Figure 8-15 shows the 15-year segments of the historical US IIP data. We categorized the trends into three different types as listed in Table 8-5.

Figure 8-16 shows all the possible combined scenarios of exchange rate and US IIP. Figure 8-17 shows the forecasted yearly truck crossings within a 15-year time span. The two vertical dash lines in Figure 8-17 mark the years 2014 and 2019. For this forecast, we focused on the data points after 2019. Table 8-6 shows the increase the yearly truck crossings for the year of 2024 compared to that of 2008. From this table we can see the increase will be between **29.1%** and **47.2%** in accordance with our various scenarios. When examining Figure 8-17, one can see that for forecasts with the same US IIP trend, the predicted forecasts over the 15-year time span will be very close. In long term, the US IIP may play a more important role than the exchange rate in influencing border crossing traffic. A fast growing US IIP trend Is the scenario associated with the fastest growth in truck traffic.

Table 8-5 Possible trend types for exchange rate and IIP within 15-year span

Exchange rate	US IIP
Blue Scenario (1)	Growing fast (1)
Green Scenario (2)	Growing slowly (2)
	Keeping relatively stable (3)

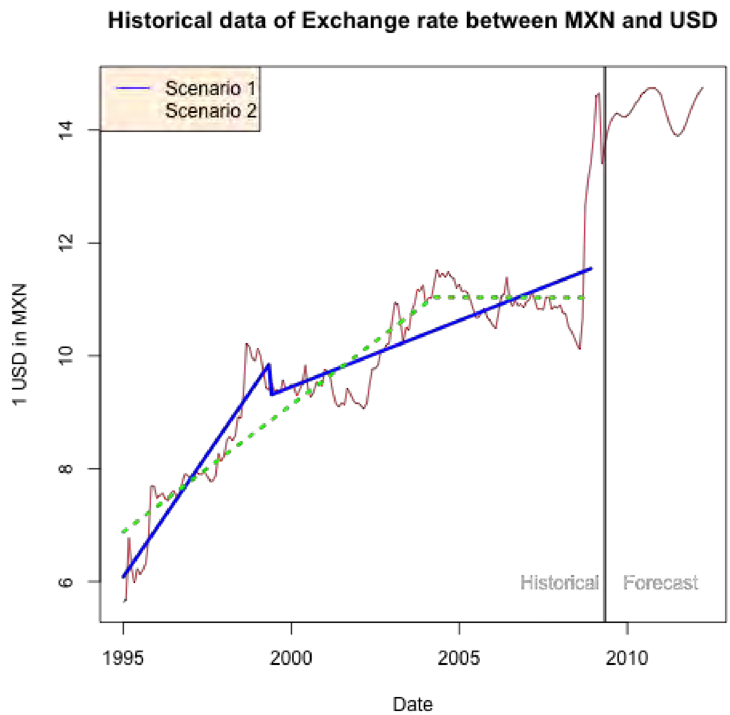

Figure 8-14 Different segment methods for Exchange Rate

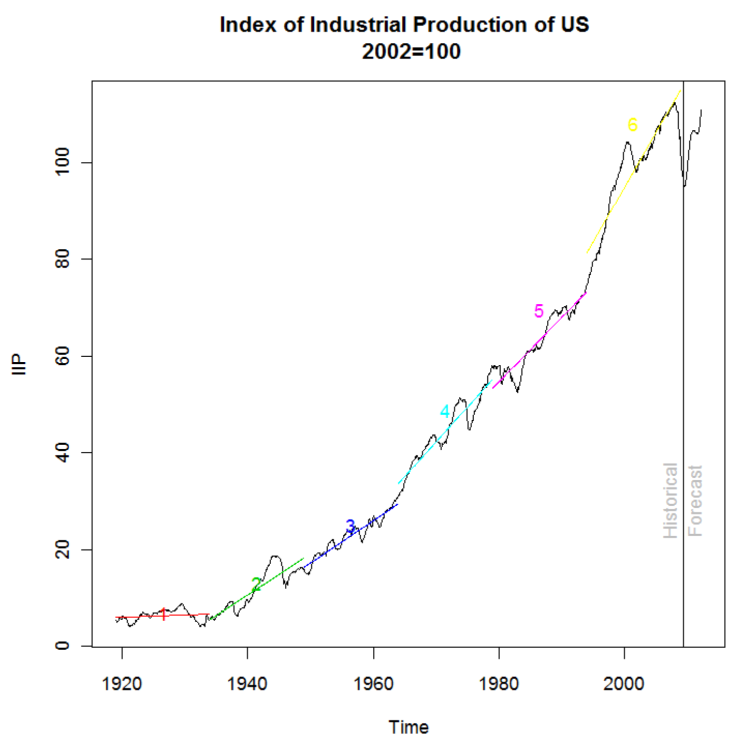

Figure 8-15 Historical data of US IIP with forecast from forecasts.org (15-year segments)

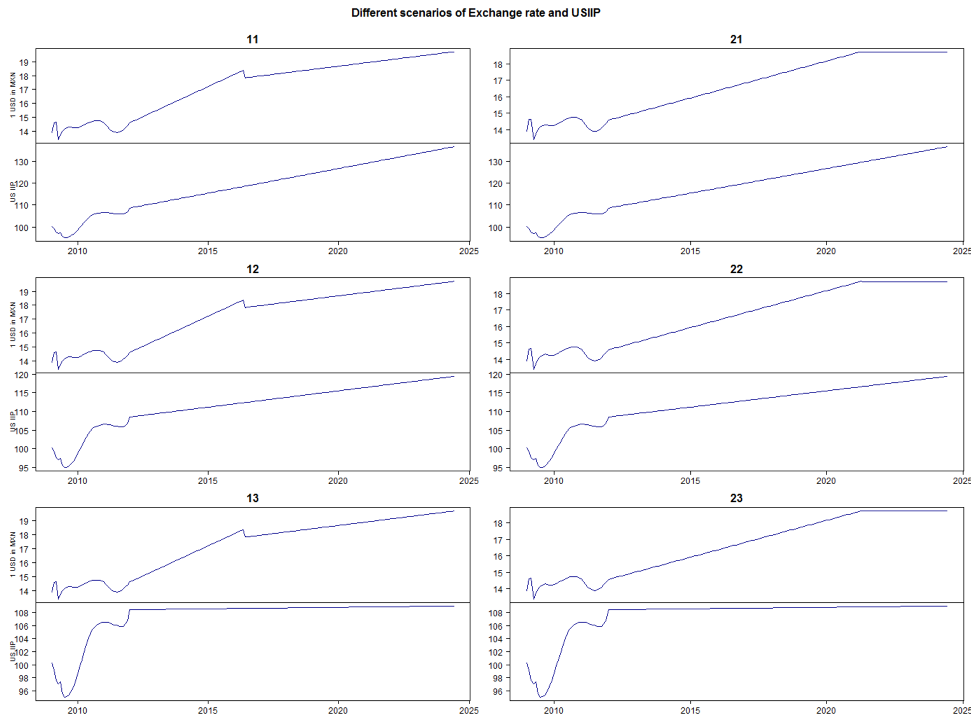

Figure 8-16 Different scenarios of exchange rate and US IIP

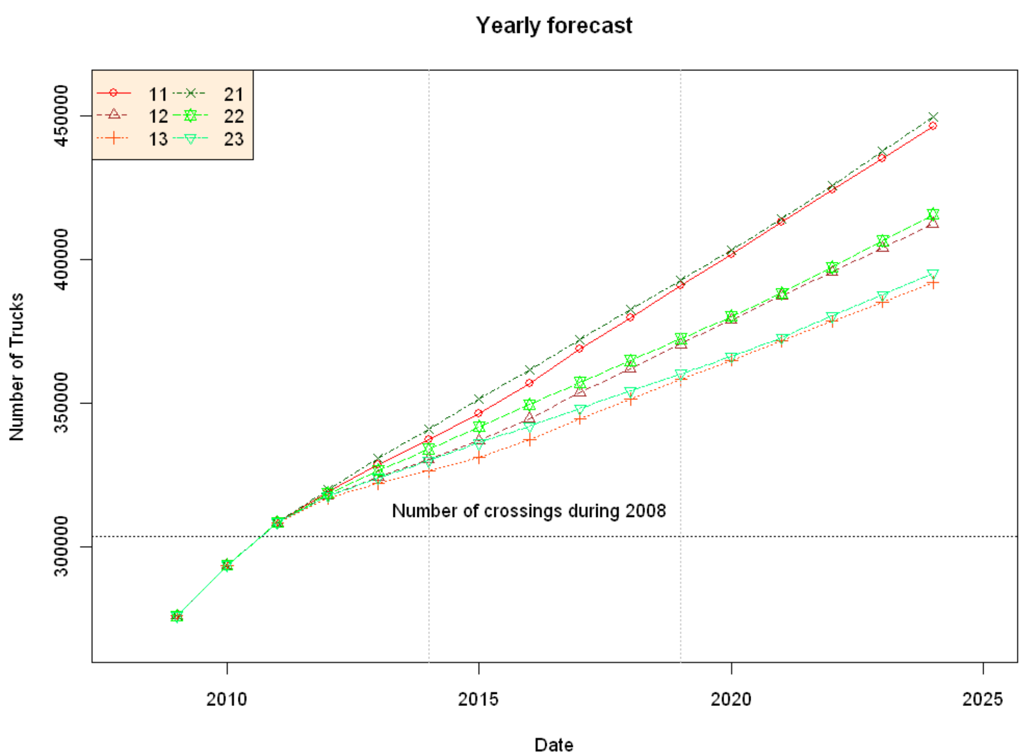

Figure 8-17 Yearly crossing forecasts of different scenarios

Table 8-6 Fifteen-year forecast of different scenarios, compared to 2008

	Increment of 2024 (%) 2008=100	
US IIP -Growth Speed+	**11**	**21**
	47.2	42.3
	12	**22**
	35.9	37.0
	13	**23**
	29.1	30.2

8.2 Forecast for the POV

As we stated previously, we used the time series model to produce the five-year forecast and used the regression model to produce the extended forecasts.

Figure 8-18 depicts the five-year forecast of POV crossing, which mainly is an extension of the decreasing trend of segment 3 in Figure 7-5. Considering the recession started in late 2007, this forecast seemed reasonable. However, we were not sure what the trend would be after the economy recovers from the recession. Segment 1 in Figure 7-5 shows the trend of POV crossings after the 1994 Mexican Peso crisis, which was increasing until "9/11" happened.

Figure 8-19 depicts the forecast for 10 years and 15 years, where we assumed the POV traffic would start to recover after the current recession is over. Extra attention should be paid to the turning point marked by the red dashed circle around 2014. Although it was drawn around 2014, it was meant to suggest that the turning point will occur when the economy recovers from the recession, which will happen at an unknown point of time into the future. The two scenarios in Figure 8-19 were based on the trends of segment 1 and segment 2 in Figure 7-5 respectively. They showed a significant difference in long run. Table 8-7 shows the forecasted POV crossing under these two scenarios. When comparing the highest previous crossing level, which was 2000, scenario 1 was equal to the previous high, while scenario 2 slightly exceeded it.

Table 8-7 Forecasted POV crossing

	Historical Highest(2000)	Bench mark 2008	2019	2024
Scenario 1	4682 K	3027 K	3264 K	3988 K
Scenario 2	4682 K	3027 K	3770 K	5050 K
Difference between scenarios			506 K	1062 K

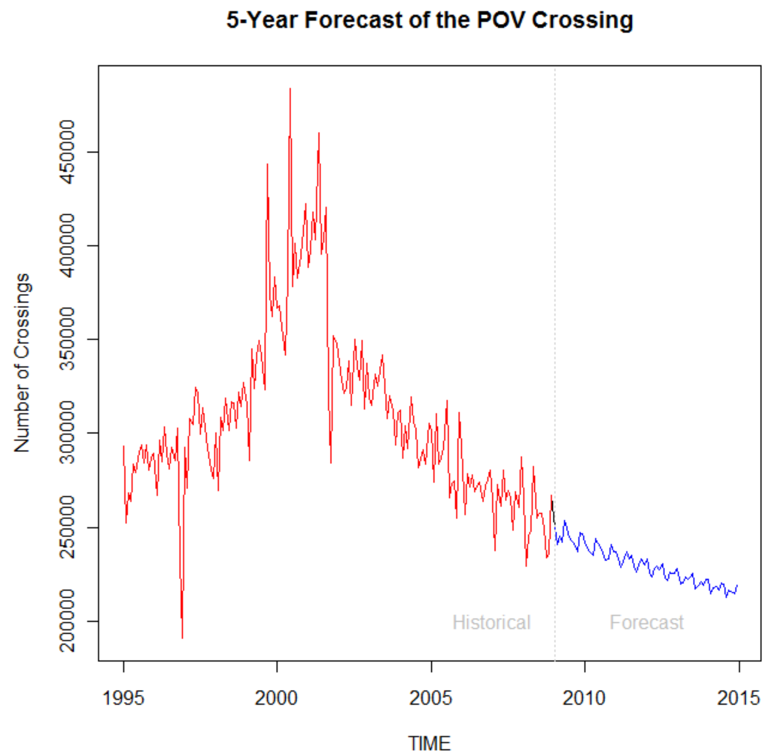

Figure 8-18 Five Year forecast of the POV crossing

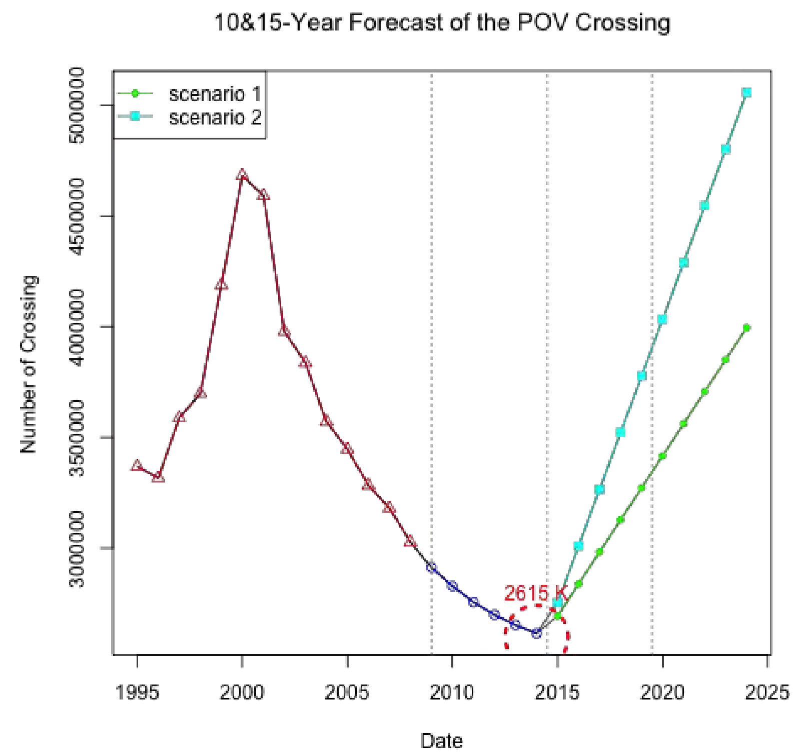

Figure 8-19 10 & 15-Year forecast of the POV crossing

8.3 Forecast for pedestrian crossings

As we did for the POV data, we produced the 5-year forecast of the pedestrian traffic by ARIMA model and the extended forecast by the regression method. We used "Arizona Employment" as an external variable in the ARIMA model, thus we first produced a forecast of "Arizona Employment". We used a 2nd order polynomial function to fit the "Arizona Employment", which is shown in Figure 8-20. Again, the forecast for "Arizona Employment" was not meant as an accurate forecast, but as an attempt to capture the main trend.

Figure 8-21 depicts our 5-year forecast of the pedestrian traffic, which was a monthly forecast. The overall trend was going down, which continued the trend of segment 4 in Figure 7-8. As we mentioned in previous section, we were unsure when the current recession would be over, thus we were not sure when the descending trend of the pedestrian crossings would end, since pedestrian crossings are very sensitive to economic climate changes.

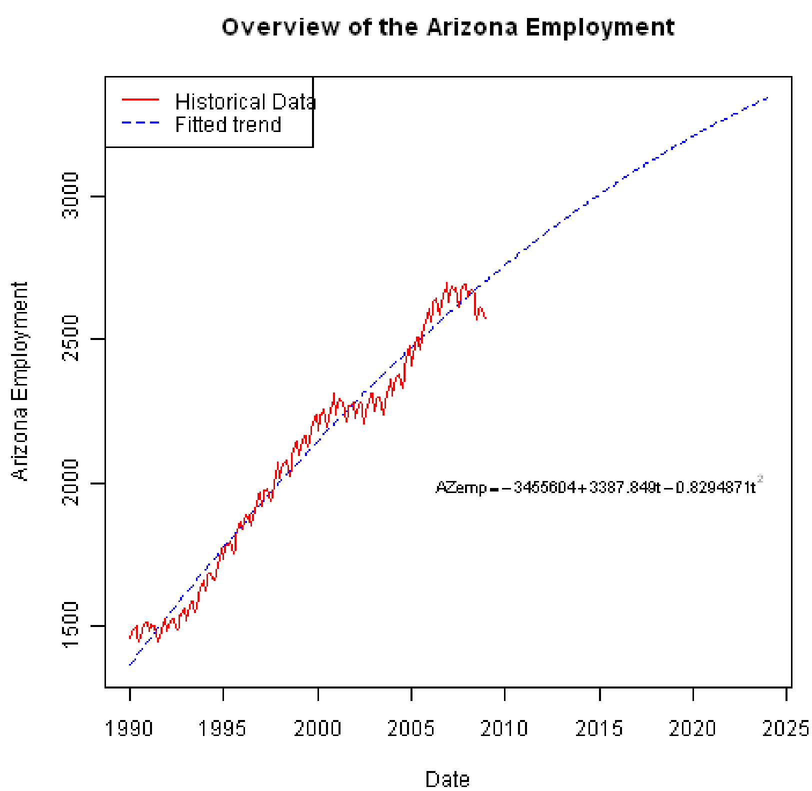

Figure 8-20 Historical data and a 2-order polynomial fit

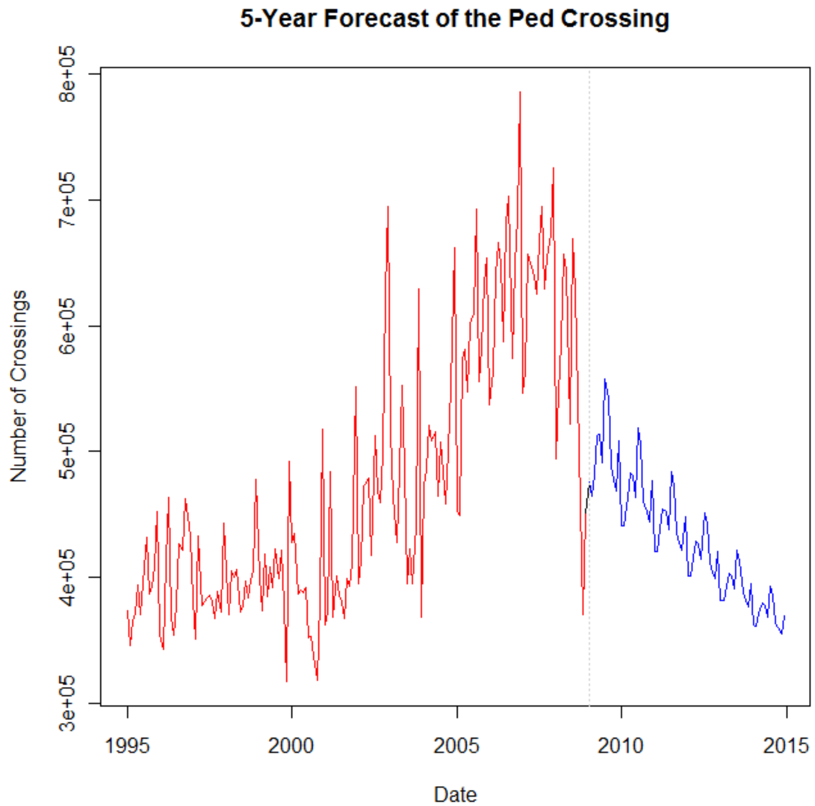

Figure 8-21 5-Year forecast of the pedestrian crossings

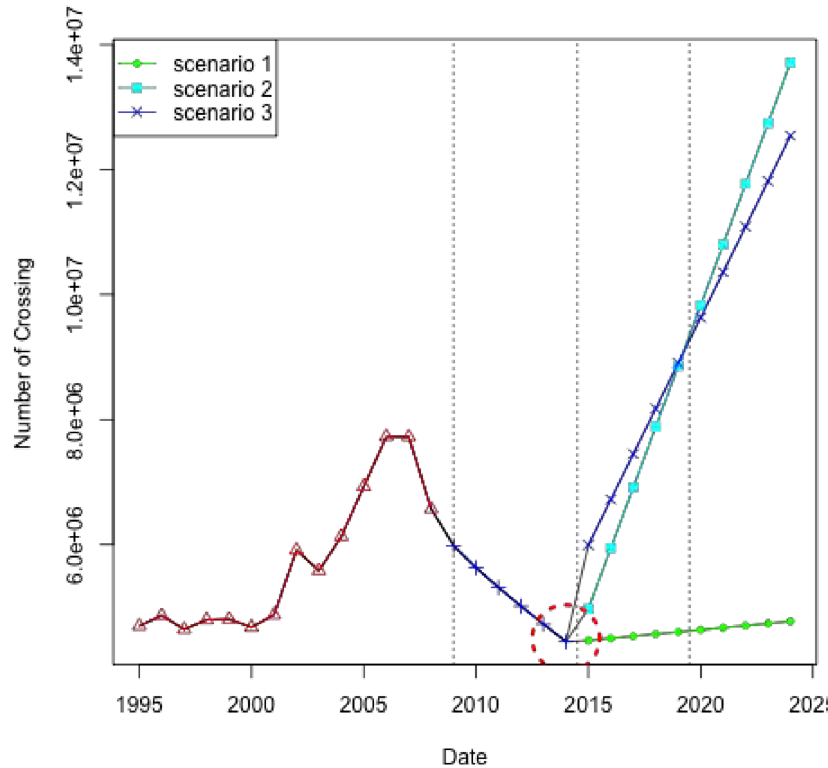

Figure 8-22 10 & 15-year forecast of pedestrian crossings

Table 8-8 Forecasted pedestrian crossing

	Historical Highest(2006)	Bench mark 2008	2019	2019/2008 (%)	2024	2024/2008 (%)
Scenario 1	7726 K 7726 K	6568 K 6568 K	4602 K	70.07%	4772 K	72.66%
Scenario 2			8858 K	134.87%	13715 K	208.82%
Scenario 3			8905 K	135.58%	12543 K	190.97%

Figure 8-22 shows the 10 & 15-year forecasts of pedestrian crossings. Scenarios 1 to 3 correspond to the trend of segments 1 to 3 in Figure 7-8. The dashed red circle in Figure 8-22 indicated the end of the economic recession, which would occur at an undetermined point in time in the future. Table 8-8 shows the predicted yearly crossings of pedestrians in 10 & 15 years and how these compared to the number in 2008. In scenario 1, the 2019 crossing of pedestrian will be around 70% of 2008, while the other two scenarios will be about 135%. For 15 years, scenario 1 will be about 73% of 2008, scenario 2 will be 209% of 2008 and scenario 3 will be 191% of 2008. Scenarios 2 and 3 are very similar in long run, while both of them had a significant difference when compared to scenario 1. Both scenarios 2 and three predicted the increasing rate to be much faster than that of scenario 1.

8. 4 Forecast for Bus Passengers

We used the time series model we built in the model section to produce the five-year forecast, and used simple regression models to produce the extended forecast. The number of passengers between 2002 and 2007 increased much faster than other years, so we used the data from 2000 to 2007 to build one regression model, and used all the data to build another one. Thus, we have two scenarios for forecasts.

1. Scenario 1: Used all the data and the regression model had a slope of 88.54.
2. Scenario 2: Used data between 2002 and 2007, and the regression model had a slope of 155.6.

Note that when building the models, we numbered the time periods consecutively. For example, for the data between 2002 and 2007, we marked January 2002 as 1, February 2002 as 2, and so on.

All the forecasts were given at a yearly level. As we observed from the data there is a great deal of variability in the data so we think a monthly forecast is not likely to be useful.

Figure 8-23 shows the five year forecast of the bus passengers. According to the ARIMA model, bus traffic will stay relatively stable over the next few years if the current condition does not change. Figure 8-24 shows the yearly forecasts of the bus passengers. Similarly, the turning point circled by the dashed red circle was an imaginary point, which indicated the ending of the current recession. Table 8-9 shows the forecasted bus passengers of 2014, 2019 and 2024 respectively. Also, we compared the predicted number of crossings to the crossings of 2008. In both of the scenarios, the number of crossings will increase. However, the scenarios differ in terms of the increasing rate. For the 2019 and 2024 forecasts, we had two scenarios, which were based on the different regression models we described previously. The future increases will be higher if the factors influencing bus passenger traffic are similar to those between 2002 and 2007. However, the factors driving bus passenger traffic still should be subject to further study.

Table 8-9 Forecasted bus passengers

	Benchmark 2008	2014	2019	2019/2008(%)	2024	2024/2008(%)
Scenario 1	195741 (196 K)	179706 (180 K)	243 K	135.00%	307 K	170.56%
Scenario 2			292 K	162.22%	404 K	224.44%

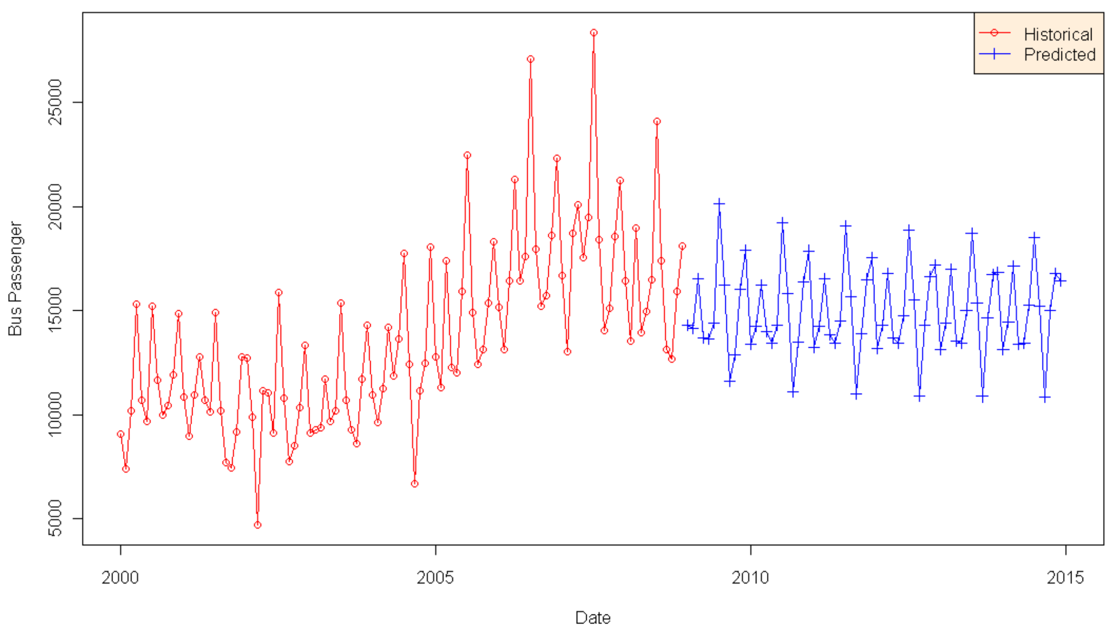

Figure 8-23 5-Year Forecast for the Bus passengers

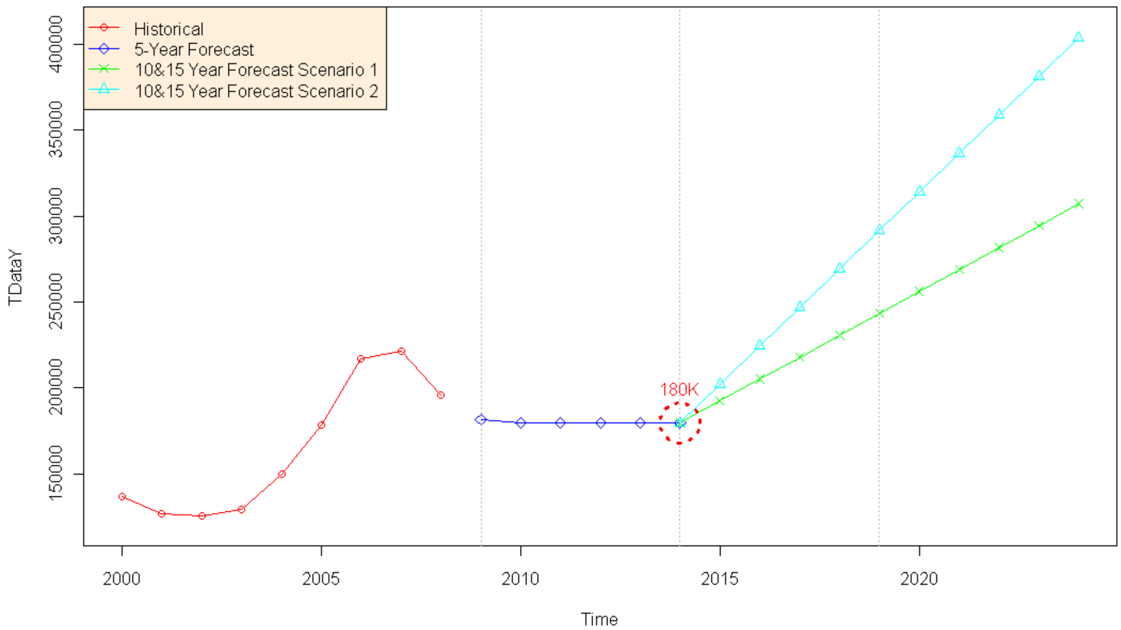

Figure 8-24 10 & 15 Year forecasts for Bus passengers

9 The Simulation Model

The simulation model we used for this study was an updated version of the model used in the ADOT project entitled *Logistics Capacity Study of the Guaymas-Tucson Corridor* (Villalobos et al.). This model was updated using data our team observed on a visit to the Mariposa POE conducted on Tuesday May 29, 2009. To begin our updates we made the following modifications to the physical infrastructure of the original simulation:

- Increased the number of highways/lanes all the way through the primary inspection area from two to four
    - The routing process assigned before a truck visibly enters the system was then changed accordingly
- Increased the number of inspection stations at each stop in the primary inspection area from two to four
- One highway/lane is designated as Free and Secure Trade (FAST) and assigned a different inspection time than that of the other three normal lanes
    - Added FAST as an attribute to trucks to determine which vehicles will be allowed to enter the FAST lane

In the previous version of the simulation trucks could cross over between FAST and normal lanes prior to entering the super-booths but in our updated version trucks may not make this crossover. Furthermore, the trucks in the topmost lane (FAST lane) are routed directly to the highway exit after completing primary inspections. Based on the data we collected in our visit we found that there was an insignificant amount of variation between the primary inspection times of a truck using the normal lanes as opposed to the FAST lanes therefore primary inspection times are the same for all vehicles. However, the simulation is set up so that the FAST versus normal lane inspection times can be easily changed later if variation between the inspection times is observed. The final determined inspection times of each area of the POE are displayed in the Table 9-1:

Table 9-1: Inspection times in Simulation Model

Inspection	Time Distribution (min)
Pre-Screening	ERLANG (0.72, 3)
Primary Inspection	ERLANG (1.33, 3)
*** 20% including ADOT in Super-Booth**	ERLANG (2, 3)
Document Revision	ERLANG (30.745, 3)
Full Inspection	ERLANG (82.2, 3)
Hazardous and weapons Enforcement	ERLANG (82.2, 3)
X-Ray	ERLANG (8.27, 3)
ADOT	TRIANGULAR (25, 30, 35)

Another change we made based on the observations from our visit was the percentage of trucks that are required to pass through additional inspections after completing primary inspections. This includes all CBP area inspections (Document, X-ray, Full, and Weapons Enforcement Inspections) and ADOT inspections. We determined that trucks that have a total time in the system of less than 4 min and 45 seconds left the system directly after primary inspections. We used this cutoff time and the data times we measured to determine the final percentage of trucks routed through only primary inspections. All other percentages of trucks requiring each type of inspection were kept consistent with those used in the Guaymas study (Villalobos et al.). These percentages are all shown in Table 9-2.

Table 9-2: Percentage of trucks requiring each type of inspection

Percentage	Description
100 %	Pre-Screening
100 %	Primary Inspection
30.74 %	Released to enter the US from Primary inspection (FAST lane)
69.26 %	Required further inspections and enter the compound (normal lanes)
***Out of the 69.26 % that require more inspection:**	
33 %	Required X-Ray
17 %	Required Full Inspection or Hazardous and Weapons Inspection
83 %	Required Documentation Review
20 %	Required to enter the ADOT yard for Inspection

After we updated and validated our simulation model we then tested the ability of the current infrastructure of the Mariposa POE to handle the daily demands of truck traffic we had predicted with our forecasts. In order to do this we ran the simulation model 5 times with a total runtime for 24 hours for each scenario. The scenarios are differentiated by the total amount of trucks tested for each scenario. Their respective arrival times (distributed according to an Erlang distribution) are summarized in Table 9-3.

Table 9-3 Daily Traffic Demand and Arrival times for each Scenario

Scenario	Daily Traffic Demand	Time between arrivals (Erlang distribution)
1-1	1928	0.00571
1-2	1800	0.00611
1-3	1759	0.00625
1-4	1945	0.00566
1-5	1816	0.00606
1-6	1775	0.00620
1-7	1976	0.00557
1-8	1847	0.00596
1-9	1806	0.00609
2-1	2131	0.00516
2-2	1969	0.00559
2-3	1909	0.00576
2-4	2161	0.00509
2-5	2000	0.00550
2-6	1939	0.00567
3-1	2302	0.00478
3-2	2139	0.00514
3-3	2042	0.00539
3-4	2325	0.00473
3-5	2159	0.00509
3-6	2062	0.00533

The logical flow of entities (trucks) in the simulation is explained in further detail in the diagram Figure 1 in Appendix H of the Guaymas study (Villalobos et al.). In summation, the logical process flow is as follows: when a truck enters the system it must pass through all primary inspections then depending on what attributes it has already been assigned it will either be routed straight to the highway exit or it will go through additional inspections and then be routed to the highway and exit the system.

The whole system can be divided into four different sections:

1. Pre-Screening and Primary Inspections: These are the first two steps in the process and all trucks are required to go through them.
2. Secondary Inspection: Different tasks can be done in this section such as: normal secondary inspection, Full (100%) inspection, weapons and enforcement inspection and others.
3. X-ray: three stations for x-ray inspection.
4. ADOT compound: ADOT's Motor Vehicle Division safety inspection and Federal Motor Carrier Safety Administration (FMCSA) inspections are conducted here.

The physical movement of the trucks can be observed in the animation of the simulation shown in Figure 9-1. Currently the trucks cross the border in four lanes, one of them being a FAST lane assigned to trucks with pre-cleared operators and CTPAT certified ownership, and the other three being regular lanes. All trucks will then enter a pre-screening station, follow to one of the four primary inspection super-booths, and then proceed to either Nogales, Arizona (if they were in the FAST lane) or else go on for further inspection in a counter clockwise (CCW) motion around the compound.

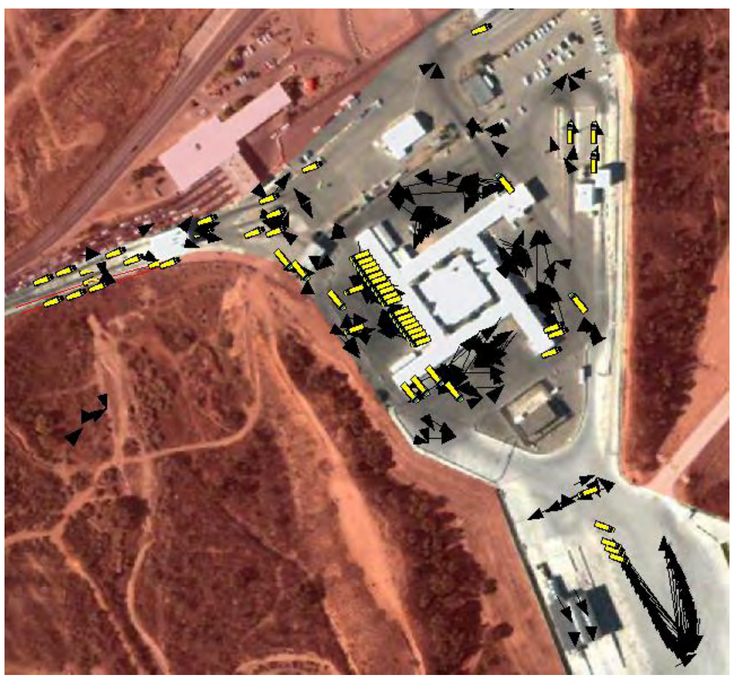

Figure 9-1 Image of Simulation

The results after running our simulation under the previously described scenarios are displayed in

Table 9-4 below. In this table, the first two columns show the scenario number and the number of trucks used as a daily demand input for each scenario. The third and fourth columns represent the total number of hours required to process all trucks and how many of those are additional hours over the current 11 hour workday that the port is open. The fifth column shows the average amount of time (in minutes) that a truck will spend in the system. The sixth and seventh columns show the 95% low and high confidence intervals for the maximum number of trucks that will wait in queue on the highway. The last two columns on the right show the bottleneck locations and their approximate utilizations for each scenario.

Table 9-4 Results of running the simulation

Scenario	# Trucks	Required Process time	Extra hours required	Avg. time in system (min)	Max in Queue (low 95%)	Max in Queue (high 95%)	Bottleneck	Approx. Utilization
1-1	1928	15.50	4.50	389.710	1888.26	1893.74	Super-booths	87.70%
1-2	1800	14.66	3.66	368.655	1759.58	1767.42	Super-booths	80.75%
1-3	1759	14.66	3.66	361.327	1719.37	1727.03	X-ray	81.50%
1-4	1945	16.22	5.22	395.704	1904.04	1908.96	Super-booths	81.30%
1-5	1816	15.14	4.14	367.047	1773.80	1781.40	Super-booths	78.84%
1-6	1775	14.64	3.64	362.902	1735.65	1740.15	Super-booths	79.42%
1-7	1976	17.04	6.04	401.391	1934.06	1940.34	Super-booths	84.87%
1-8	1847	15.62	4.62	370.460	1807.50	1813.50	Super-booths	82.69%
1-9	1806	15.15	4.15	363.639	1764.67	1772.33	Super-booths	81.27%
2-1	2131	17.51	6.51	424.579	2091.24	2096.76	Super-booths	84.12%
2-2	1969	16.92	5.92	399.541	1928.55	1936.45	Super-booths	78.84%
2-3	1909	15.60	4.60	387.990	1868.91	1875.69	Super-booths	89.04%
2-4	2161	17.91	6.91	432.178	2121.45	2128.35	Super-booths	84.56%
2-5	2000	16.51	5.51	407.981	1960.05	1964.35	Super-booths	81.25%
2-6	1939	15.89	4.89	388.628	1896.77	1904.83	Super-booths	86.60%
3-1	2302	18.39	7.39	458.475	2262.94	2270.06	Super-booths	87.69%
3-2	2139	17.21	6.21	426.991	2098.73	2107.67	Super-booths	81.43%
3-3	2042	16.65	5.65	412.149	2000.89	2008.31	Super-booths	81.44%
3-4	2325	18.82	7.82	471.270	2285.52	2291.08	Super-booths	87.71%
3-5	2159	17.28	6.28	433.375	2119.19	2127.61	Super-booths	83.49%
3-6	2062	16.70	5.70	416.790	2020.59	2030.21	Super-booths	87.21%

From this table we can observe the following:

- The maximum number of trucks that will wait in a queue on the highway according to our 95% confidence intervals is within the range of 2119 and 2127 trucks.
- For almost all scenarios the bottleneck location is the super-booths (Insp_PrePri_Norm1, Insp_PrePri_Norm2, Insp_PrePri_Norm3), with the exception of Scenario 1-3 where the bottleneck location is X-ray inspection.
- Based on our forecasts for daily truck traffic we can see that the current system is already at capacity due to the fact that in every scenario additional hours over the typical 11 hour workday are required for all trucks to be processed.

In order to validate our simulation we used the data times collected on our Mariposa POE visit and updated the simulation created in the Guaymas study (Villalobos et al.) so that the simulations output times match those we observed on our visit. We found that the most accurate manner in which to compare the times recorded in our visit with those in the simulation was by syncing the times a truck spent in the CBP area. In other words the average time a truck spends in the CBP area that we observed in our visit matches the times spent in the CBP area of trucks in our simulation model. Furthermore we changed the percentage of trucks that did not pass through any secondary inspections to match those observed in our visit. For further details regarding these changes refer to simulation appendix.

In conclusion, the results of running the simulation model compared to the actual inspection times measured in our visit to the Mariposa POE give us confidence in the validity of the results produced by our simulation model. Put another way, we found that if we tuned the simulation to our observed results for CBP times and percentage of trucks diverted, the overall average time spent in the system was relatively consistent with our observations. From our results we can see that given the forecasted future demands of traffic the system is already at capacity and would be unable to handle these traffic demands with the current infrastructure of the POE and length of workday (11 hours). We also found that for all but one of our forecasted scenarios the bottleneck of the system occurred at the same location, which we found to be the super-booths.

10 Conclusions and Recommendations

10.1 Findings

After completing the designated activities we agreed upon with ADOT we have drawn the following conclusions from our study:

1. The traffic characteristics at the POEs at Nogales are very different from that of other POEs, specifically in the seasonality pattern shown in the truck traffic. This is because of the high volume of fresh produce crossing this POE, which varies drastically in different seasons.
2. Economic indices are likely to be correlated with the level of border crossing traffic, especially for commercial traffic.
3. We provided various scenarios for each forecast due to the uncertainty of the future. The truck crossing traffic may increase up to 50% compared to the crossings in 2008, while the most conservative forecast showed the increase will be 30%. The POE should be prepared to handle the increase of the traffic with infrastructure and human resources.
4. The POV flows and pedestrian traffic flows are more sensitive to the economy than the truck traffic, thus the forecasts for these two types of traffic are likely to be less accurate than the forecasts for truck traffic.
5. As an example, we show our predicted truck crossing of 2009 against the recorded values in Table 10-1 below. The two columns of data are very close to each other.

Table 10-1 Pedicted truck traffic vs actual record of the year 2009

	Predicted Value	Actual Record
Jan	29,968	29,667
Feb	29,458	27,926
Mar	30,329	28,952
Apr	27,974	29,773
May	30,104	26,213
Jun	21,819	22,779
Jul	14,935	14,712

6. As with any long term prediction, one should be cautious when using the extended forecasts.

7. The simulation model suggests that the current setup of the Mariposa POE would be unable to handle future traffic demands. This lends credibility to the approved project to expand and reconfigure the port.

10.2 Future Research Opportunities

In our models, we used some exogenous variables such as the exchange rate. However, it was very difficult to forecast the future exchange rate and we were unable to find any single person or institute willing to give this kind of long term forecast. As a remedy to this problem we propose to use Delphi techniques to collect opinions from experts about the future trends of exogenous factors, and build our scenarios based on these opinions.

Another problem we encountered was that collecting all the necessary data for this project was difficult to accomplish during the model building process. For example, some data we found was incomplete. Therefore we suggest having a professional, technical and independent “data clearing house” to serve as the repository of border data and research results. We believe that such a “data clearing house” would not only be beneficial for this study, but also other similar studies involving data collection in border areas.

After all our analysis, we found many questions we could not answer based solely on the historical data. For instance, why after at least a 6-year upward trend has the POV traffic kept shrinking since 9/11? Furthermore, if the POV traffic does not start to increase even when the current recession is over, at what level will it become stabilized (i.e. it can’t keep shrinking down to zero)? Is there any relationship between the trends of POV and pedestrian crossings after “9/11” since they appear to be opposite to each other? What is the economic impact of not having the proper infrastructure or procedures for border crossings which either prevents people from crossing the border or make walk rather than drive across? Also, how is it that the traffic split between the Mariposa and DeConcini ports relates directly to the capacity of each one? How do people make the decision of what port to use that makes the overall system “efficient”?

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Appendix A – Literature Summary

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4 Specification of a borderplex econometric forecasting model (2001)
5 Cross Border Cargo Vehicle Flows (2002)
6 Assessment of Automated Data Collection Technologies for calculation of commercial motor vehicle border crossing travel time delay (2002)
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24 Socioeconomic determinants of Mexican Circular and permanent Migration

1. Currency movements and international border crossings (2000)

This report analyzed the responses of international commuter flows to exchange rate valuation shifts. This study was conducted around one of the main border crossing points between the US and Mexico which was the El Paso, Texas and Ciudad Juarez, Mexico border. Rather than focusing on the movements of physical goods, this report focused on the movement of commuters as a result of the US dollar/Mexican Peso exchange rate. This was particularly significant to our study as we found that the exchange rate was one of the external factors that considerably impacted the movement of truck crossings through the Nogales POE.

2. Unified Nogales/ Santa Cruz County Transportation 2000 Plan (2000)

This plan was provided to the city of Nogales by Kimley-Horn and Associates, Inc. Due to the growth of the Nogales/Santa Cruz County region there arose a need for changes within the current transportation infrastructure so that it could efficiently handle the growing amounts of traffic in the area. The primary purpose of this report was to provide a five-year (short term), ten-year (mid-term), and twenty-year (long term) transportation plan that addresses the needs of the area. This report includes a summary of the existing conditions of Nogales/Santa Cruz County as well as its transportation needs.

3. Estimating Texas-Mexico North American Free Trade Agreement Truck Volumes (2001)

This study addressed the issue of accommodating NAFTA truck traffic along international highway trade corridors and border points of entry linking the US and Mexico. There were two data sources available for estimating the number trucks crossing the border, one being the counts of trucks crossing the bridges and the second being the US international trade data. Based on each of these two data sets the study developed two methods of estimation.

The first method which used cross-border volumes was theoretically weakest because it required a number of assumptions to be made. The second method used densities and volumes in explaining why results show that the average value per truckload per port varies significantly. In conclusion, the methods developed can be used successfully to estimate commodity truck volumes; however, a large effort was still required to analyze, match and use current trade statistics and calibrate results. Further analysis of trailer loads in relation to commodity densities and volumes that were crossing border ports would enable more accurate standardized ETT(Equivalent Trade Truck) volumes to be determined. This data was important because it could possibly be incorporated into federal and state planning actions that address maintenance, rehabilitation, and reconstruction of international trade corridors in the United States.

4. Specification of a borderplex econometric forecasting model (2001)

This article used the El Paso-Ciudad Juarez borderplex as the framework for assessing the whether or not the traditional approach used for econometric modeling could also be applicable to border metropolitan areas. This question was addressed by first estimating an econometric model and testing it under various currency conditions as well as comparing the results of the model simulation to extrapolations from a Bayesian vector autoregressive model. The results showed that the traditional approach was in fact applicable for analysis of business trends in international border regions.

Although the traditional method was sufficient to analyze international border regions there were still several areas in which it could be improved. More specifically, inclusion of data regarding maquiladoras and their impact on the El Paso-Ciudad Juarez borderplex would be helpful due to their prominence in the Ciudad Juarez region. This study also included a discussion of a slight alteration in the traditional model to account for the fact that economic conditions in Ciudad Juarez frequently diverge from the conditions in the rest of the Mexican macro economy.

5. Cross Border Cargo Vehicle Flows (2002)

This article was written by Thomas M. Fullerton Jr. and Roberto Tinajero and was funded by the NAFTA Intermodal Institute at the Public Policy Research Center at the University of Texas at El Paso. With the growth of the maquiladora sector in Northern Mexico there had been in increase in merchandise trade and thus the volume of cargo across international borders had also increased. The study conducted by Fullerton and Tinajero attempted to determine if the trends caused by these changes could be modeled through analysis of the short-term time series characteristics of the cargo vehicle flows through El Paso, Texas. In this report the econometric methodologies involved both univariate and transfer function ARIMA analysis.

After analyzing the data the factors which were found to impact the monthly fluctuations in border region cargo vehicle flow traffic were as follows: the maquiladora employment in Ciudad Juarez, the non agricultural employment in El Paso, inflation adjusted exchange rate and both Mexican and U. S. industrial activity.

6. Assessment of Automated Data Collection Technologies for calculation of commercial motor vehicle border crossing travel time delay (2002)

The data in this report was prepared by Batelle for the Office of Freight Management and Operations of the Federal Highway Administration of the U.S. Department of Transportation. The purpose of this study was to test various technologies that could potentially be used as a means to collect truck travel time data instead of the onsite data collectors that were at the border crossings of U.S. to its neighbors. Specifically the report highlighted which characteristics did and did not make them suited to collect this data as well as their maturity for deployment. Furthermore this study also investigated technologies that were still in their development stages. The results of this analysis, however, did not provide detailed specifications of each of the technologies and were meant to be used simply as guidelines.

The findings of this study did not return any clear winner as the best type of technology to be used due to the fact that there were so many variables that needed to be considered. When choosing which to use the authors of the report suggested taking into account the following: the technology's functionality, cost, purpose of operations, maturity and availability as well several secondary issues such as susceptibility to vandalism.

The study defined what criteria that would make a selected technology a viable candidate to use to collect truck travel times. In the appendix of this study, each of the tested technologies was listed and summarized with its advantages and disadvantages of using each.

7. El Paso Customs District Cross-Border Trade Flows (2003)

With an emphasis on the linkage between El Paso and Ciudad Juarez this paper analyzed the monthly trade flows through the El Paso Customs District. The study differentiated itself from previous studies in that earlier studies focused on US demand for aggregate imports and exports while this study focused on bilateral trade flows with Mexico. It also provided an analysis of the empirical regularities associated with monthly exports and imports of merchandise trade in the El Paso Customs District area. Also within this report a time series methodology was used to potentially quantify cross-border trade flows through El Paso.

The results of the analysis showed that borderplex international trade did respond fairly rapidly to economic activity changes as well as changes in cross-border relative prices. It was concluded that a better understanding of border trade and regional economic performance could be gained through additional empirical analysis.

8. Borderplex Bridge and Air Econometric Forecast Accuracy (2004)

This study focused on the borderplex area surrounding El Paso, Texas. At the time of the study there were two sets of transportation equations in the borderplex model (Fullerton 2001). One equation was used for the northbound traffic at the El Paso/Ciudad Juarez international bridge and the other was used for the passenger, cargo and mail flows at the El Paso international airport. This study was focused on the borderplex transportation variable forecasts that were published during the years 1998 to 2003. Each of these studies was measured based on its predictive accuracy relative to a random walk benchmark. At the time this study was conducted there had not previously been any formal accuracy assessments on the transportation variables included in the border region system of simultaneous equations. Also included in the report was information on regional econometric forecasting research, borderplex model attributes, as well as suggestions for future research topics.

The results showed that air freight, airmail, bridge auto, and bridge pedestrian series forecasts were somewhat more accurate than random walk benchmarks over the course of the sample period in question. For air passenger and bridge cargo random walk benchmarks tended to work better.

9. Canada-United States-Ontario-Michigan Border Transportation Partnership Planning/Need and Feasibility Study: Strategic & Geographic Area Overview (2004)

This report was prepared by the IBI group for URS Canada and was part of a series of several technical working papers which served to devise a long term strategy to provide safe and efficient travel of people and goods to and from Southeast Michigan and Southwest Ontario. This report was the first in the series seeks to evaluate the current conditions of the transportation routes used to connect Southeast Michigan and Southwest Ontario and thus determine any areas of need. More specifically this is done through a study of the geographic and demographic characteristics of each of these regions, the infrastructure of the border crossings and traffic flows at the border crossings.

10. Canada-United States-Ontario-Michigan Border Transportation Partnership Planning/Need and Feasibility Study: Existing and Future Travel Demand (2004)

This report was prepared by the IBI group for URS Canada and was part of a series of several technical working papers which served to devise a long term strategy to provide safe and efficient travel of people and goods to and from Southeast Michigan and Southwest Ontario. This particular report described, analyzed and evaluated the current and future rail and road conditions with the ultimate goal of providing both qualitative and quantitative perception of the travel demands in this region. The modes of transportation covered in this report including passenger cars, commercial vehicles, rail and marine. Although all types of transportation were covered there was a particular emphasis on the vehicle traffic on the three bridges and tunnel crossings connecting Southwest Ontario and Southeast Michigan due to the extensive delays that occur in these areas.

11. Canada-United States-Ontario-Michigan Border Transportation Partnership Planning/Need and Feasibility Study : Travel Demand Analysis Process (2004)

This report was prepared by the IBI group for URS Canada and was part of a series of several technical working papers which served to devise a long term strategy to provide safe and efficient travel of people and goods to and from Southeast Michigan and Southwest Ontario. This report provided an analysis of estimated future demand at both the existing border crossings between these two regions as well as potential new crossings. These potential new crossings were also analyzed based on their impact on the existing transportation systems (i.e. any diversions they might cause).

In particular this paper included:

- A review of available data and modeling and forecasting techniques
- A description of how to develop a travel demand analysis process covering the various means of travel (highways, roads, railroads) as well as a model to forecast regional travel demand
- A description of the Validation of the aforementioned model to conditions in the base year (2000)

12. Canada-United States-Ontario-Michigan Border Transportation Partnership Planning/Need and Feasibility : Study Partnership of Transportation Problems and Opportunities Report (2004)

This report was prepared by the IBI group for URS Canada and was part of a series of several technical working papers which served to devise a long term strategy to provide safe and efficient travel of people and goods to and from Southeast Michigan and Southwest Ontario. This particular report served to give a general overview of the type of transportation issues that would be addressed in this planning study, the extent of these issues and lastly the characteristics of the area with regards to transportation and socioeconomic conditions.

Upon completion of this analysis three major transportation problems were defined that needed to be addressed in this study. The first problem was lack of alternative routes for border crossings in the case of operational failure, heavy congestion, major incidents or any other type of disruption that could block or slow down one of the crossing routes. The second problem defined was that Windsor-Detroit roadway crossings do not have sufficient roadway capacity to efficiently handle the forecasted future travel demand. The third problem found was also at the Windsor-Detroit border crossing and is caused by lack of border crossing capacity at this crossing to handle both existing and future travel demands.

There were also several opportunities for improvement found at in this region that were addressed in this study, they are listed as follows:

- Development of a multi-modal strategy for a balanced transportation system that provides more transportation choices
- Protection of future required right-of-way
- Optimization of existing infrastructure
- Facility rehabilitation to avoid or delay replacement

- Partnerships with other proponents to co-operatively address common problems and/or shared objectives
- Revenue generation and/or cost reduction
- Support for provincial, state and national economic and planning objectives

13. Traffic Forecast Based on Real Data (2004)

Within this report different methods to forecast traffic were analyzed and discussed. The analysis was based on the traffic at a highway in Duisburg, Germany. Data was collected over a 2 year period and then separated into four basic classes. Two models for short term forecasting were examined, the constant and the linear model. It was concluded that for short term horizons and constant model provided a good prediction and for more long term forecasts it was better to use a heuristic.

14. An error correction analysis of U.S.-Mexico trade flows (2005)

This report was written by Thomas M. Fullerton Jr. and Richard L. Sprinkle to estimate the bilateral trade elasticities between the U.S. and Mexico. Most previous studies had focused on analyzing aggregate trade flows. One of the key goals of this particular study was to gain an understanding of the response of bilateral trade to changes in relative prices and changes in income. More specifically there was an emphasis on determining if the bilateral trade flows react to domestic prices, foreign prices or the exchange rate between Mexican Pesos and U.S. dollars. Also, an error connection approach was used, taking into account both short-run dynamic adjustments and long-term determinants of trade flows, to estimate import and export demand functions. The findings of this study validated the fact that error correction model could be used to analyze trade flows and that in the case of U.S. and Mexico these flows responded heterogeneously to prices, income and their exchange rate.

15. Analyzing highway flow patterns using cluster analysis (2005)

This paper investigated the determination of historical traffic by patterns by means of Ward's hierarchical clustering pattern. Using this procedure days were classified into working and non-working days and more specifically the working days were classified by the day of the week and whether they were in a vacation period. After analyzing the traffic flow it was concluded that a pre-classification into working days and non-working days significantly improved the clustering result. Four types of working days were classified: Mondays, core week days, Friday's and days within vacation periods. The working day patterns discovered could be used as input for macroscopic traffic models and as a basis for traffic management scenarios.

It is important to note that the cluster analysis was only executed for one location and due to the fact that different highways serve different traffic types precautions should be taken when translating the results of this study to other locations.

16. Tradeoffs between security and Inspection Capacity: Policy Options for Land Border Ports of Entry (2006)

This study was conducted in response to the terrorist attacks that occurred on September 11, 2001. Its purpose was to propose solutions that help increase national security (i.e. more rigorous inspections at international borders) and also avoid causing issues with existing regional traffic networks. This report explored three potential options in order to have more thorough primary inspections at the border crossing between El Paso, Texas and Ciudad Juarez, Mexico. After analyzing each of the three proposed options it was concluded that none of them were suitable solutions because they would not allow for a more detailed inspection at the border crossing without also causing extra delays in local traffic flows. The study did, however, suggest that these options have the potential to be implemented successfully if they were to be implemented in increments thus alleviating their interference with local traffic.

17. AZ Multimodal Freight TM1: Analysis of Freight Dependent Industries (2007)

This report is the first in a series of three reports prepared by Wilbur Smith Associates for the Arizona Department of Transportation that analyzed Arizona’s multimodal freight system. This first report summarized trends within the industry as well as Freight flows specific to the Arizona Freight market. It also presented the findings of surveys and interviews conducted among various businesses and transportation providers in Arizona. This study built on the work of previous studies in order to make Arizona’s freight system a more integral part of the long range transportation planning process. It was split into three sections which served to identify both key industries that deal with freight systems as well as trends and key issues in those industries.

18. AZ Multimodal Freight TM2: Assessment of Arizona's Existing Freight Infrastructure (2007)

This report was the second in a series of three reports prepared by Wilbur Smith Associates for Arizona Department of Transportation that analyzes Arizona’s multimodal freight system. This study analyzed Arizona’s freight infrastructure which affects Arizona’s freight movement. Key areas focused on in this study including the number of lanes, traffic congestion areas, and locations of steep grades.

19. AZ Multimodal Freight TM3: Strategic Directions for Freight Planning (2007)

This report was the third in a series of three reports prepared by Wilbur Smith Associates for Arizona Department of Transportation that analyzes Arizona's multimodal freight system. One of the main objectives of this three part study was to come up with a way to make freight analysis an integrated part of Arizona's long range planning process. This report suggested 6 different strategic directions for freight planning in Arizona as well as specific tactics for how to implement them and test their performance. The six strategic directions determined by this study are as listed as follows:

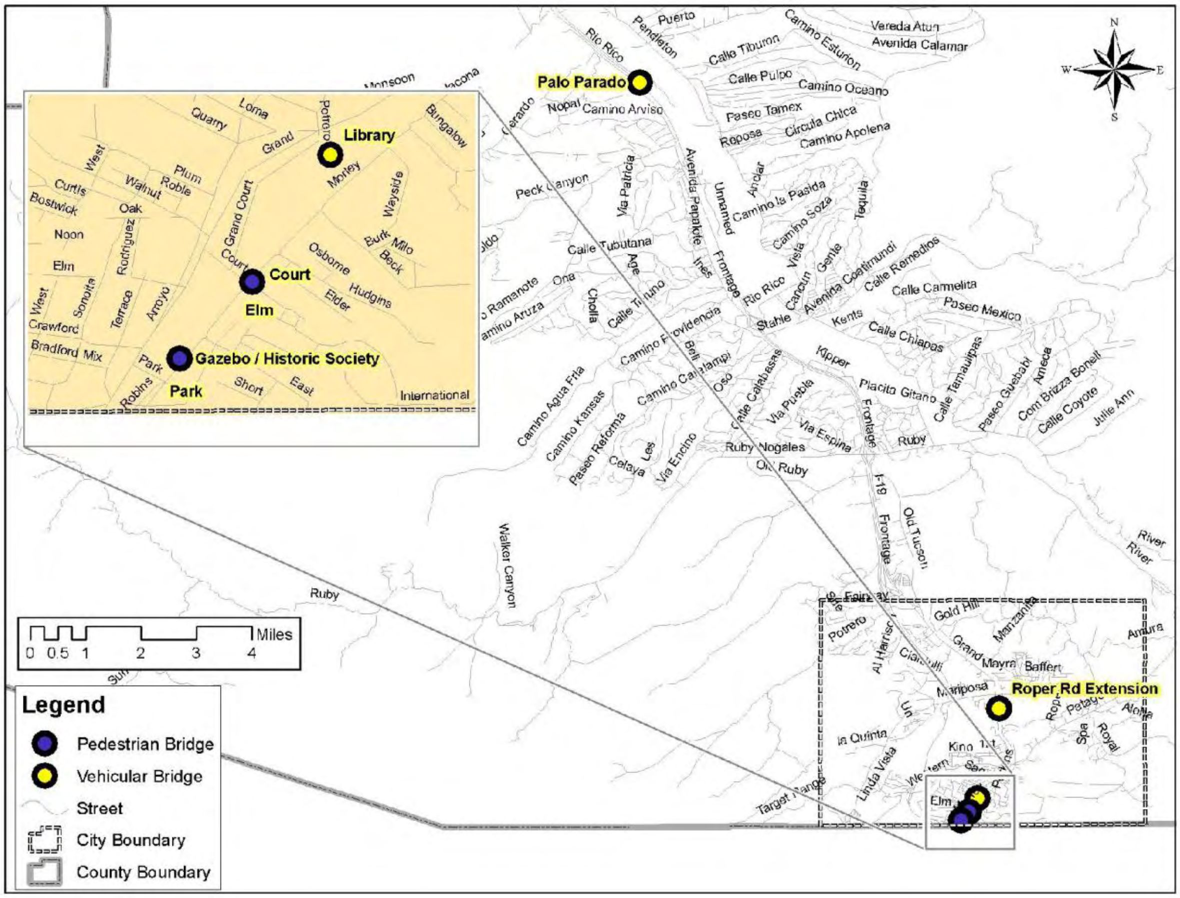
1. Strengthen the planning relationship between freight transportation and economic development
2. Coordinate freight planning with local land use planning
3. Preserve and prioritize key freight infrastructure
4. Seek Opportunities to Improve Freight Operations
5. Enhance Freight System Safety and Security
6. Promote Environmental Preservation and Energy Efficiency in Freight Operations

20. Use of Box and Jenkins Time Series Technique in Traffic Volume Forecasting (2007)

This paper investigates the application of analysis techniques developed by Box and Jenkins to predict a daily traffic volume for a certain Egyptian intercity road. Data was collected for 14 years starting in 1990 and was used to forecast for the year 2003 and this forecast was compared with actual traffic volume in 2003.

21. Nogales Railroad Small Area Transportation Study (2007)

This report was prepared by Kimbley-Horn and Associates for the City of Nogales. The purpose of this report was to analyze the existing situation of the Freight Rail Operations that run through both Nogales, Arizona and Nogales, Sonora. This study provided recommendations as to possible locations for both pedestrian and vehicular bridges over the existing railroads in Nogales. For each suggestion there was also an analysis of its affect on the minority populations surrounding the area and proposed solutions to keep the public informed and thus avoid discriminating against any minority populations. The findings for possible bridge locations can be seen on the map below.



22. Bottleneck Study of Mariposa POE (2008)

This study was conducted at the Mariposa Port of Entry at Nogales in order to determine bottleneck areas which would cause significant delays in the movement of people or goods across the border and to suggest solutions to eliminate these delays. This was done through traffic data collection and analysis to identify the location and nature of bottlenecks both going into and leaving the Mariposa POE. Lastly, the study proposed improvements to alleviate congestion and provides estimates of associated costs.

23. Mariposa/I-19 Connector Route Study (2008)

This study was conducted by Wilbur Smith Associates for the Arizona Department of Transportation Planning Committee. The purpose of this study was to plan for adequate roadway capacity and safe traffic movements to and from the Mariposa Port of Entry to I-19 while keeping in mind the mix of commercial versus privately owned vehicles and the mix of Port versus local traffic.

The traffic moving through the Mariposa Port of Entry primarily used Arizona State Route 189 (SR189), Mariposa Road, to access Interstate Highway 19 (I-19) or Grand Avenue located on the east side of I-19. There was no convenient alternative route to access I-19 and the only possibility would be to use Target Range Road. This route was unsuitable for most travelers due to its circular path as well as the fact that it passed through residential neighborhoods and by the local hospital to access I-19 at the Western Avenue Interchange.

At the time of the study it was believed that SR189 would be unable to adequately handle the anticipated traffic volume in both a safe and effective matter therefore this study explored various options to address this problem. It was determined that if no improvements were made to handle the increasing traffic volumes at the Mariposa POE, extreme congestion could be expected in the area of Frank Reed Road to the Mariposa Road/I-19 TI and beyond to Grand Avenue.

24. Socioeconomic determinants of Mexican Circular and permanent Migration

This study determined which factors had impacted the duration of the Mexican temporary and permanent migrants to the United States. Through surveys the following determinants were found to have a significant impact on Mexican circular and permanent migration: socioeconomic, human capital, migration experience, social capital and labor. We reviewed this study in particular because we had originally hypothesized that the factors that impact the origin and destination of migration across the U.S./Mexico border would be significant in forecasting the amount of POV and Pedestrian crossings.

Factors Considered

Title	Currency movements and international border crossings	Unified Nogales/ Santa Cruz County Transportation 2000 Plan	Estimating Texas-Mexico North American Free Trade Agreement Truck Volumes	Specification of a Borderplex Econometric Forecasting Model	Cross Border Cargo Vehicle Flows	Assesment of auto. data collect. techno. for calc. of commer. MV border cross. travel t delay	El Paso Customs District Cross-Border Trade Flows	Borderplex Bridge and Air Econometric Forecast Accuracy	Need and Feasibility Study: Strategic & Geographic Area Overview	Need and Feasibility Study: Existing and Future Travel Demand	Need and Feasibility Study : Travel Demand Analysis Process	Need and Feasibility : Study Partnership of Transportation Problems and Opportunities Report	Traffic Forecast Based on Real Data	An Error Correction Analysis Of U.S.-Mexico Trade Flows	Analyzing highway flow patterns using cluster analysis	Tradeoffs between security and Inspection Capacity: Policy Options for Land Border Ports of Entry	Socioeconomic determinants of Mexican Circular and permanent Migration	AZ Multimodal Freight TM1:Analysis of Freight Dependent Industries	AZ Multimodal Freight TM2:Assessment of Arizona's Existing Freight Infrastructure	AZ Multimodal Freight TM3:Strategic Directions for Freight Planning	Use of Box and Jenkins Time Series Technique in Traffic Volume Forecasting	Nogales Railroad Small Area Transportation Study	Bottleneck Study of Mariposa POE	Mariposa/I-19 Connector Route Study
Year	**2000**	**2000**	**2001**	**2001**	**2002**	**2002**	**2003**	**2004**	**2004**	**2004**	**2004**	**2004**	**2004**	**2005**	**2005**	**2006**	**2006**	**2007**	**2007**	**2007**	**2007**	**2007**	**2008**	**2008**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
National																								
Truck						x									x	x								
Passenger Car						x				x			x		x	x								
Pedestrian																								
Rail																								
Population									x															
Employment									x															
Currency X-Rate	x			x	x		x			x	x			x										
GDP										x	x													
Category of Prods									x	x														
Trade									x	x				x										
Daily Pattern															x									
Monthly Pattern	x				x						x				x									
Quarterly Pattern														x	x									
Yearly Pattern											x				x									
Other				x	x		x							x										
Regional																								
Truck		x	x			x				x	x				x	x		x			x		x	x
Passenger Car		x				x		x		x	x		x		x	x	x				x		x	x
Pedestrian		x						x		x	x						x					x	x	x
Rail		x									x							x				x		
Other Modes		x																x						
Population	x	x		x					x	x	x	x						x				x		x
Origin-Destiny										x	x						x							
Trip Purpose									x	x	x	x					x							
Place-of-Work										x														

Factors Considered

Employment		x								x														
GDP										x								x						
Trade			x				x		x											x				
Fuel Price Dif.										x									x					
Facility/Infrast.									x		x	x								x				x
Daily Pattern									x	x	x	x			x						x			
Monthly Pattern							x		x	x	x	x			x									
Quarterly Pattern															x									
Yearly Pattern									x	x	x	x			x		x							
Other				x																				
Procedure																								
Verbal Description	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Flow Chart			x	x							x	x								x				
Other Graphic						x						x	x		x		x			x	x	x	x	x
Data Tables		x	x			x			x	x	x	x	x		x		x	x	x	x	x	x	x	x
Maps		x							x	x	x	x						x	x	x		x	x	x
Equations	x			x	x		x						x	x							x			
Sugg. Improv.?																	x			x			x	x
Scope																								
Trucks									base 2000	base 2000	base 2000	base 2000												
Pedestrian									base 2000	base 2000	base 2000	base 2000												
Passenger Veh.									base 2000	base 2000	base 2000	base 2000												
Last Avail. Data		2000			1980-1999	2000-2002	1995-2002	1998-2003	2000	2000	2000	2000		2003	1980-2002	2003	2007	2005			1990-2002	2007	2008	2008
Forecast Horizons		2005, 10, 15						2007	2030	2030	2030	2030									2003			
AZ Port		x											x		x				x	x		x	x	x
Non AZ Port			ELP, TX			CA, TX, etc		ELP, TX	MI	MI	MI	MI						ELP, TX						

Procedures Used in the studyies

	Currency movements and international border crossings	Unified Nogales/ Santa Cruz County Transportation 2000 Plan	Estimating Texas-Mexico North American Free Trade Agreement Truck Volumes	Specification of a Borderplex Econometric Forecasting Model	Cross Border Cargo Vehicle Flows	Assesment of Automated Data Collection Technologies for calculation of commercial motor vehicle border crossing travel time delay	El Paso Customs District Cross-Border Trade Flows	Borderplex Bridge and Air Econometric Forecast Accuracy	Need and Feasibility Study: Strategic & Geographic Area Overview	Need and Feasibility Study: Existing and Future Travel Demand	Need and Feasibility Study : Travel Demand Analysis Process	Need and Feasibility : Study Partnership of Transportation Problems and Opportunities Report	Traffic Forecast Based on Real Data	An Error Correction Analysis Of U.S.-Mexico Trade Flows	Analyzing highway flow patterns using cluster analysis	Tradeoffs between security and Inspection Capacity: Policy Options for Land Border Ports of Entry	AZ Multimodal Freight TM1:Analysis of Freight Dependent Industries	AZ Multimodal Freight TM2:Assessment of Arizona's Existing Freight Infrastructure	AZ Multimodal Freight TM3:Strategic Directions for Freight Planning	Use of Box and Jenkins Time Series Technique in Traffic Volume Forecasting	Nogales Railroad Small Area Transportation Study	Bottleneck Study of Mariposa POE	Mariposa/I-19 Connector Route Study	Socioeconomic determinants of Mexican Circular and permanent Migration
Year	**2000**	**2000**	**2001**	**2001**	**2002**	**2002**	**2003**	**2004**	**2004**	**2004**	**2004**	**2004**	**2004**	**2005**	**2005**	**2006**	**2007**	**2007**	**2007**	**2007**	**2007**	**2008**	**2008**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Verbal Description	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Flow Chart			*	*							*	*							*					
Other Graphic						*						*	*		*				*	*	*	*	*	*
Data Tables		*	*			*			*	*	*	*	*		*		*	*	*	*	*	*	*	*
maps		*							*	*	*	*					*	*	*		*	*	*	
Equations	*			*	*		*						*	*						*				
Suggested Improvements?																			*			*	*	*

Scope of the Studies

	Currency movements and international border crossings	Unified Nogales/ Santa Cruz County Transportation 2000 Plan	Estimating Texas-Mexico North American Free Trade Agreement Truck Volumes	Specification of a Borderplex Econometric Forecasting Model	Cross Border Cargo Vehicle Flows	Assesment of Automated Data Collection Technologies for calculation of commercial motor vehicle border crossing travel time delay	El Paso Customs District Cross-Border Trade Flows	Borderplex Bridge and Air Econometric Forecast Accuracy	Need and Feasibility Study: Strategic & Geographic Area Overview	Need and Feasibility Study: Existing and Future Travel Demand	Need and Feasibility Study : Travel Demand Analysis Process	Need and Feasibility : Study Partnership of Transportation Problems and Opportunities Report	AZ Multimodal Freight TM1:Analysis of Freight Dependent Industries	Traffic Forecast Based on Real Data	AZ Multimodal Freight TM2:Assessment of Arizona's Existing Freight Infrastructure	Analyzing highway flow patterns using cluster analysis	Tradeoffs between security and Inspection Capacity: Policy Options for Land Border Ports of Entry	AZ Multimodal Freight TM2:Assessment of Arizona's Existing Freight Infrastructure	AZ Multimodal Freight TM3:Strategic Directions for Freight Planning	Use of Box and Jenkins Time Series Technique in Traffic Volume Forecasting	Nogales Railroad Small Area Tranportation Study	Bottleneck Study of Mariposa POE	Mariposa/I-19 Connector Route Study	Socioeconomic determinants of Mexican Circular and permanent Migration
Year	**2000**	**2000**	**2001**	**2001**	**2002**	**2002**	**2003**	**2004**	**2004**	**2004**	**2004**	**2004**	**2004**	**2004**	**2005**	**2005**	**2006**	**2007**	**2007**	**2007**	**2007**	**2008**	**2008**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Trucks									base 2000	base 2000	base 2000	base 2000												
Pedestrian									base 2000	base 2000	base 2000	base 2000												
Passenger Vehicles									base 2000	base 2000	base 2000	base 2000												
Last Available data		2000			Jan 1980 - Dec 1999	2000-2002	Jan 1995 - Dec 2002	1998-2003	2000	2000	2000	2000		2003	1980:Q1~ 2002:Q4	2003	2005			1990-2002	2007	2008	2008	2007
Forecast Horizons		2005, 2010, 2020						next 3 years	2030	2030	2030	2030								2003				
AZ Port		*											*		*			*	*		*	*	*	
Non AZ Port			El paso			CA, TX, ME, MI, NY, WA		El Paso	Michigan	Michigan	Michigan	Michigan					El Paso							

Appendix: Statistical details

Time Series

The set of data points observed at successive times we call time series data. Let Y be the time series data, then $y_t, t = 1, 2, \cdots$ represent the data points of the time series Y.

If the time series contains no trend, it can be represented as:

$$y_t = \beta_0 + \epsilon_t \tag{1}$$

where β_0 is the unchanging average level of the series, ϵ_t is a random variable representing irregular fluctuations around the average level at time t.

If the time series contains a trend, it can be written as:

$$y_t = T_t + \epsilon_t \tag{2}$$

where $T_t = f(\beta_0, \beta_1, \cdots; t), t = 1, 2, \cdots$, is the expected value (trend) of the series at time t, $f(\beta_0, \beta_1, \cdots; t)$ is an increasing or decreasing function describing the trend pattern. ϵ_t is a random variable representing irregular fluctuations around the trend at time t.

Seasonal Series

Time series observed at shorter than yearly intervals often display a regular pattern of fluctuations that repeat from year to year. The commercial truck data in our study is a good example of this kind of pattern. This periodic pattern is usually described as **seasonal movement**, **seasonality** or **seasonal**. In this section, we will briefly introduce what seasonality is and how it is represented. There are two types of seasonality, *Additive* and *Multiplicative.* In our example we use “year” to describe the interval of seasonality, however, the interval of seasonality is not limited to being described in years.

A time series Y, observed L times per year at time $t = 1, 2, \cdots, L$ is said to have constant seasonality if the average value of Y changes over time such that

Additive: $$E(y_t) = f(\beta_0, \beta_1, \cdots; t) + S_t \tag{3}$$

Multiplicative: $$E(y_t) = f(\beta_0, \beta_1, \cdots; t) \bullet S_t \tag{4}$$

where

$$S_t = S(t + L) = S_{t+2L} = \cdots$$

and

Additive: $$\sum_{t=1}^{L} S_t = 0$$

Multiplicative $$\sum_{t=1}^{L} S_t = L$$

and $f(\beta_0, \beta_1, \cdots; t)$ is a function describing the trend. Each observation period is called a season, and L, the length of the seasonality, is the number of seasons in a year. The S_t values are called seasonal indexes.

Let ϵ_t be the irregular fluctuation away from the trend and seasonal effects at time t, and $T_t = f(\beta_0, \beta_1, \cdots; t)$. Then the general seasonal models can be written as

Additive $$y_t = T_t + S_t + \epsilon_t$$

Multiplicative $$y_t = T_t \, S_t \, \epsilon_t$$

Additive Holt-Winter's Model

Holt-Winter's model is one type of exponential smoothing model, which is capable of handling the trends and seasonality of our data. There are two kinds of Holt-Winter's models, one is additive and the other is multiplicative. We only consider the additive Holt-Winter's model here.

In additive Holt-Winter's model, we decompose y_t in the following way:

$$y_t = a_t + b_t t + s_t + \epsilon_t \quad (5)$$

where a_t is the unseasoned level of time series at time t, b_t is the slope of the trend at time t, s_t is index of season $i, i = 1, 2, \cdots, L$. i is corresponding to the season of current t.

The additive Holt-Winters prediction function (for time series with period length L) is

$$\hat{y}_{t+h} = a_t + b_t h + s_{t+1+(h-1) \bmod L}$$

where a_t, b_t and S_t are given by

Level: $$a_t = \alpha(y_t - s_{t-L}) + (1-\alpha)(a_{t-1} + b_{t-1}) \quad (6)$$

Trend: $$b_t = \beta(a_t - a_{t-1}) + (1-\beta) b_{t-1} \quad (7)$$

Seasonality $$s_t = \gamma(y_t - a_t) + (1-\gamma) s_{t-L} \quad (8)$$

All the three equations are updated dynamically. The equations are intended to give more weight to recent observations and less weight to observations occurring further in the past.

In the result of Holt-Winter's model, we will report the value of α , β and γ used in the model as well as the estimated values for the level, trend and seasonal components, which are shown a , b and $s_i, i = 1, \cdots, L$. Due to the fact that the level and trend are constantly changing throughout the model building process, time is represented using the subscript t . However, the level and trend in the result is the estimated overall level and trend.

ARIMA models

ARIMA stands for autoregressive-integrated-moving average model. ARIMA models are one of the most commonly used time series model. Different ARIMA models are identified by the number of autoregressive parameters (p), the degree of differencing (d), and the number of moving average parameters (q). For short, we write is as $ARIMA(p,d,q)$. If there is not differencing term, i.e. d=0, we call it $ARMA(p,q)$. We define the ARIMA model as below:

y_t	=	The actual value of the series at time t
y_{t-i}	=	The value of the series at time $t-i$
ϵ_t	=	The error term at time t
ϵ_{t-i}	=	The error term at time $t-i$
ϕ_i	=	The autoregressive parameter for y_{t-i}
θ_i	=	The moving average parameter for ϵ_{t-i}
w_t	=	$\Delta^d y_t$, the y_t series differenced d times

$$w_t = \phi_1 w_{t-1} + \phi_2 w_{t-2} + \cdots + \phi_p w_{t-p} + \epsilon_t + \theta_0 - \theta_1 \epsilon_{t-1} - \theta_2 \epsilon_{t-2} - \cdots - \theta_q \epsilon_{t-p} \quad (9)$$

Note that $\epsilon_t, \epsilon_{t-1}, \epsilon_{t-2}, \cdots$ are uncorrelated to each other, also the meaning of $\Delta^d y_t$ is shown as below:

$$\Delta^d y_t = y_t - y_{t-d}$$

To build an ARIMA model, we need to choose the value of (p,d,q) first, which determine the structure of the model. After that, we need to estimate all the parameters ϕ_i and θ_i . In the result of ARIMA model, we will report all the ϕ_i's and θ_i's. Sometimes, we may use ARi to represent ϕ_i and MAi to represent θ_i . The (p,d,q) values are specified by the model builder, and the computer program takes them as input.

For those who have more interest on this topic, we recommend the building ARIMA model section in Shumway and Stoffer's book.

Forecasting of the ARIMA model

When we have identified the model, we need to use the model to forecast the future values. One can refer to the Updating Equations for ARIMA Forecasting section in Farnum and Stanton's book for mathematical details for parameter estimating and updating.

We give the general procedure for forecasting the ARIMA model here and take the $ARIMA(1,1,1)$ model as an example to illustrate it. According to equation (9), $ARIMA(1,1,1)$ can be written as:

$$w_t = \phi_1 w_{t-1} + \theta_0 + \epsilon_t - \theta_1 \epsilon_1 \tag{10}$$

where $w_t = \Delta y_t = y_t - y_{t-1}$.

step 1: Rewrite the estimated model and solve for y_t as a function of all other terms in the model.
Equation (10) can be rewritten as

$$y_t = \theta_0 + (1-\phi_1) y_{t-1} - \phi_1 y_{t-2} + \epsilon_t - \theta_1 \epsilon_{t-1} \tag{11}$$

step 2: Replace t with $t+j$ in the equation resulting from step 1.
By doing this in equation (11), we get

$$y_{t+j} = \theta_0 + (1-\phi_1) y_{t+j-1} - \phi_1 y_{t+j-2} + \epsilon_{t+j} - \theta_1 \epsilon_{t+j-1} \tag{12}$$

step 3: Use actual values of the series when possible; otherwise use forecasts. Use estimates (residuals) for past error terms, and 0 (their expected values) for future error terms.
Suppose we are at time t, and going to forecast for $j = 1,2,3$ periods ahead of the $ARIMA(1,1,1)$ model.

a. t+1: $\hat{y}_{t+1}(t) = \hat{\theta}_0 + (1+\hat{\phi}_1) y_t - \hat{\phi}_1 y_{t-1} - \hat{\theta}_1 e_t$,
ϵ_{t+1} is replaced by 0, ϵ_t is replaced by the estimate, e_t.

b. t+2: $\hat{y}_{t+2}(t) = \hat{\theta}_0 + (1+\hat{\phi}_1) \hat{y}_{t+1} - \hat{\phi}_1 y_t$
both the error terms are in the future and are replaced by 0. y_{t+1} is also a future value, thus replaced by $\hat{y}_{t+1}$

c. t+3: $\hat{y}_{t+3}(t) = \hat{\theta}_0 + (1+\hat{\phi}_1) \hat{y}_{t+2} - \hat{\phi}_1 \hat{y}_{t+1}$
Every forecast from this point on depends on only the previous two forecasts.

All the above mentioned procedures are usually done by a computer package. In our study, we use the R system (R Development Core Team 2009) computer package to do the parameter estimation in model building. Shumway and Stonffer point out some issues of using R for time series models, which are very useful when using R to build ARIMA models.

Seasonal ARIMA mode

The ARIMA model can be easily extended to handle seasonality. The same methods as the in the nonseasaonal ARIMA models are used. However, we have two sets of parameters, one set to deal with the season-to-season movement and the other to deal with the movement within the seasons. We use (P, D, Q) corresponding to (p, d, q) in the nonseasonal ARIMA model. P is number of seasonal autoregressive parameters, D is the degree of seasonal differencing, Q is the number of moving average parameters. All the parameters for the seasonal part are changed to upper case. For example, the seasonal autoregressive parameter is Φ_i and the seasonal moving average parameter is Θ_i. We use $ARIMA(p,d,q)(P,D,Q)_L$ to represent a multiplicative seasonal ARIMA model with nonseasonal orders (p,d,q), seasonal orders (P,D,Q) and length of seasonal L. In the nonseasonal ARIMA model, the one order differencing is performed as $\Delta y_t = y_t - y_{t-1}$, while the one order seasonal differencing should take over a span of L periods rather than one period. Thus $\Delta_L y_t = y_t - y_{t-L}$. The following paragraphs will give some examples of the equations of seasonal ARIMA model.

There are two methods to combine the seasonal part and nonseasonal part together, one is Additive, and the other is Multiplicative. In the additive method, we just add all the seasonal terms and nonseasonal terms together, while in the multiplicative method, the combined model is formed by applying the nonseasonal model to the terms we get from a purely seasonal model.

We use the ARIMA model with one seasonal MA term (P=1) and one nonseasonal MA term (p=1) as an example. A purely seasonal model (without nonseasonal terms) first-order moving average model would be written:

$$y_t = \Theta_0 + \epsilon_t - \Theta_1 \epsilon_{t-L} \tag{13}$$

A purely nonseasonal first-order moving average model would be written:

$$y_t = \theta_0 + \epsilon_t - \theta_1 \epsilon_{t-1} \tag{14}$$

By combining additively, we write

$$y_t = \Theta_0 + \epsilon_t - \theta_1 \epsilon_{t-1} - \Theta_1 \epsilon_{t-L} \tag{15}$$

Note that the Θ_0 in equation (15) is different from that in equation (13).

Using the multiplicative way, we write the seasonal MA part as:

$$y_t = \Theta_0 + u_t - \Theta_1 u_{t-L} \tag{16}$$

then applying the nonseasonal MA term to the errors u, we have

$$u_t = \theta_0 + \epsilon_t - \theta_1 \epsilon_{t-1} \tag{17}$$

Substituting equation (17) back into (16) gives

$$\begin{aligned} y_t &= \Theta_0 + (\theta_0 + \epsilon_t - \theta_1 \epsilon_{t-1}) - \Theta_1(\theta_0 + \epsilon_t - \theta_1 \epsilon_{t-1}) \\ &= \Theta_0 + \epsilon_t - \theta_1 \epsilon_{t-1} - \Theta_1 \epsilon_{t-L} + \theta_1 \Theta_1 \epsilon_{t-L-1} \end{aligned} \tag{18}$$

Here we have the equation for y_t with both seasonal and nonseasonal parameters incorporated.

The parameter identification for the seasonal ARIMA model is really a two step process, one to determine the nonseasonal parameters, and the other to determine the seasonal parameters. In the result of seasonal ARIMA model, in addition to ϕ_i's and θ_i's, we also report Φ_i's and Θ_i's. In some cases, we may report Φ_i as SARi and Θ_i as SMAi.

ARIMA Model with exogenous variables

When taking exogenous variables into consideration. For example, if we take another series X in to consideration. We build the ARIMA model on the data set $Y-X$. Take the $ARIMA(1,1,0)$ model for example, the original model is

$$\nabla y_t = \phi \nabla y_{t-1} + \epsilon_t$$

After incorporating the X series, the new model becomes

$$\nabla (y_t - \beta x_t) = \phi \nabla (y_{t-1} - \beta(x_{t-1})) + \epsilon_t$$

Where β is another parameter we need to estimate during the model building stage, which will be reported in the result if we use any exogenous variable.

Explain of some statistics

In this part, we will explain some statistics we used in our report. We will cover the ACF (sample autocorrelation function), PACF (sample partial autocorrelation function), Theil's U statistic , R^2 (coefficient of determination), and VIF (Variance Inflation Factor).

ACF and PACF

When evaluating the autocorrelation coefficients evaluated at lag 1, lag 2, lag3, …lag *k*,… and graphed versus k, we get the sample autocorrelation function (ACF). Suppose we have the data series $Y = \{y_1, y_2, \cdots, y_i, \cdots y_n\}$, the sample autocorrelation coefficient of lag k, r_k can be calculated by the following way. Take $(y_1, y_{k+1}), (y_2, y_{k+2}), \cdots, (y_{n-k}, y_n)$ pairs of the data, and denote the subset $\{y_1, y_2, \cdots, y_{n-k}\}$ as Y_1, the subset $\{y_{k+1}, y_{k+2}, \cdots, y_n\}$ as Y_2. The correlation between Y_1 and Y_2 is r_k.

$$r_k = \frac{\sum_{i=k+1}^{n} (y_{i-k} - \bar{y}_1)(y_i - \bar{y}_2)}{\sigma_1 \sigma_2}$$

Where $\bar{y}_1$ and $\bar{y}_2$ are the means of Y_1 and Y_2 respectively, σ_1^2 and σ_2^2 are the variances of Y_1 and Y_2 respectively.

As long as the number of data points in the data series is large compared to k, substitution of the total means($\bar{y}$), and sums of square ($\sum (y_i - \bar{y})^2$) for partial ones does not greatly change the value of r. Thus, the r_k can be approximately calculated as :

$$r_k = \frac{\sum_{i=k+1}^{n} (y_{i-k} - \bar{y})(y_i - \bar{y})}{\sum_{i=1}^{n} (y_i - \bar{y})^2}$$

However, one needs to use the partial ones when then number of data points in the data series is not large enough.

PACF is another important tool for ARIMA model building. The partial autocorrelation coefficient of lag k, denoted as ϕ_{kk}, is a measure of the correlation between y_t and y_{t-k} after adjusting for the presence of all the y_t's of shorter lag, i.e. $y_{t-1}, y_{t-2}, \cdots, y_{t-k+1}$. The purpose for this adjustment is to see if there is any additional correlation between y_t and y_{t-k} above and beyond that introduced by the correlation y_t has with $y_{t-1}, y_{t-2}, \cdots, y_{t-k+1}$. Graphing the ϕ_{kk} with $k = 1, 2, \cdots$, we get the sample partial autocorrelation function (PACF). A common way for most computer packages to compute the partial autocorrelation function is to recursively use the knowledge of the autocorrelation coefficients r_k. For more details on the procedure, one can refer to the PACF section in Farnum and Stanton's book.

We use ACF as one of the main tools to build the ARIMA model. A slow decay in ACF is an indication that differencing may be needed. If ACF Cuts off after lag q, we may put a MA(q)

term in the ARIMA model. If the PACF cuts off after lag p , probably we need to put a $AR(p)$ term in the ARIMA model.

Table 1 summarizes the behavior of ACF and PACF for the ARMA/ARIMA models. Additionally, we use the ACF to decide whether to use differencing or not in ARIMA model.

Table 1 Behavior of the ACF and PACF for ARMA models

	$AR(p)$	$MA(q)$	$ARMA(p,q)$
ACF	Tail off	Cuts off after lag q	Tail off
PACF	Cuts off after lag p	Tails off	Tail off

Theil's U statistic

Theil's U statistic compares the forecast of a model to the "no-change" model. The "no-change" model refers to the model that assumes that the values are relatively stable, $\hat{y}_{t+1} = y_t$. Mathematically, the Theil's U statistic can be written as:

$$U = \frac{\sqrt{\sum e_t^2}}{\sqrt{\sum (y_t - y_{t-1})^2}} \quad (19)$$

$$= \frac{\sqrt{MSE(model)}}{\sqrt{MSE(''no-change''\ \text{model})}} \bullet \sqrt{\frac{n}{n-1}} \quad (20)$$

$$= \frac{\sqrt{\sum (A_t - P_t)^2}}{\sqrt{\sum A_t^2}} \quad (21)$$

where

$\hat{y}_t$ = Estimated value using the model being compared

e_t = $y_t - \hat{y}_t$ = the forecast error of the model being compared

P_t = $\hat{y}_t - y_{t-1}$ =the predicted change in period t

A_t = $y_t - y_{t-1}$ =the actual change in period t

A zero valued U statistic means the model being compared forecasts exactly to the real value, while a one valued U statistic means the model being compared is as good as the "no-change" model. A U statistic greater than one means the model being compared is worse than the "no-change" model, while a U statistic less than one means the model being compared is better than the "no-change" model. Note that the value of the U statistic is always greater than zero; therefore, we prefer the models that can render U statistics as small as possible.

Coefficient of Determination (R square)

The quantity

$$R^2 = \frac{SS_{model}}{SS_{total}} \quad (22)$$

$$= 1 - \frac{SS_{err}}{SS_{total}} \quad (23)$$

is called the coefficient of determination, and is usually called R square for short. The quantities involved in the above equations are defined as below:

$$SS_{total} = \sum_i \left(y_i - \bar{y}\right)^2$$

$$SS_{model} = \sum_i \left(\hat{y}_i - \bar{\hat{y}}\right)^2$$

$$SS_{err} = \sum_i \left(y_i - \hat{y}\right)^2$$

The R^2 value can be interpreted as the proportion of variation explained by the model. But the R^2 value should be used with caution, since it is always possible to make the R^2 value of a regression model as large as possible. For the regression model, the R^2 value is between 0 and 1, however, for other models, this cannot be guaranteed.

The two definition equations for the R^2 are not always equal. When the model used is a linear regression model, we have

$$SS_{total} = SS_{model} + SS_{err} \quad (24)$$

thus the two definition equations are equal to each other. However, when using some other models, where equation (24) does not hold, the values defined by the two definition equations are different. Depending on which definition is used, the R^2 can be below 0, if we use equation (23), or exceeding 1, if we use equation (22).

For the data with strong nonlinear relationship exists, the R^2 may be not a good measure of how well the model fit the data. When this happens, we would like to use the correlation between the predicted value and the real value to evaluate how well the model fitted value is.

VIF (Variance Inflation Factors)

The Variance Inflation Factors are used for a multicollinearity diagnostic. Multicollinearity among the regression variables implies near-linear dependence among the regressors (regression variables). The presence of near-linear dependencies can dramatically impact the ability to estimate the regression coefficients. Suppose now we have p regressors, then the VIF for the j^{th} regression coefficients can be written as

$$VIF_j = \frac{1}{1-R_j^2}$$

where R_j^2 is the coefficient of multiple determination obtained from regressing x_j on the other regressors. Clearly, if x_j is nearly linearly dependent on some of the other regressors, then R_j^2 will be near unity and VIF_j will be large. VIFs larger than 10 imply serious problems with multicollinearity. Note the VIF values are greater than 1 and less than infinity.

Apparently, if there is only one regressor, we do not have the problem of multicollinearity. If we have two regressors x_1 and x_2, VIF_1 will be equal to VIF_2. For more than two regressors, according to the calculation method of VIF_j, their VIF s are usually not equal to each other.

This section is only a brief introduction to multicollinearity and VIF values. For more details about this topic, we recommend the reader refer to the textbook by Montgomery, Peck, and Vining.

Statistical Tests

Ljung-Box test (Farnum and Stanton)

The Ljung-Box test is used to test autocorrelations for several different lags of a time series data. The Hypothesis of the test is as below:

$H_0: \quad \rho_k = 0 \quad \text{for all } k \le m$

$H_a: \quad \rho_k \ne 0 \quad \text{for some value of } k \le m$

The test statistic:

$$Q_m = n(n+2)\sum_{k=1}^{m} \frac{r_k^2}{n-k},$$

where m is the number of coefficients being tested and \$n\$ is the number of observations in the series.

The decision rule:

Reject H_0 if $Q_m > \chi_\alpha^2(m)$, otherwise, do not reject H_0. $\chi_\alpha^2(m)$ is the upper $\alpha \times 100\%$ points of the chi-square distribution with m degree of freedom.

Conclusion:

If H_0 is rejected, we conclude that with approximately $(1-\alpha)\times 100\%$ confidence that the series is nonrandom.

If H_0 is not rejected, we have some support for a random no-trend model.

In the process of building an ARIMA model, we usually apply the Ljung-Box test on the residual to check if the residual is random and contains no trend. For an ARIMA $(p,d,q)(P,D,Q)_L$ model, the n in the Q_m statistic is the number of terms in the series **after** differencing and m is the number of autocorrelation coefficients being tested. The number of degrees of freedom used in the chi-square test is: $m-(p+1)-(P+Q)$

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Appendix: Simulation Model Detail

1 Introduction

The simulation created for this model was based on a model created for a previous study also conducted by Arizona State University for ADOT entitled *Logistics Study of the Guaymas-Tucson Corridor* (Villalobos et al.). For specific details regarding the baseline structure of the simulation we will refer back to this study. The simulation for this study simulation was a follow up step for the Mariposa POE visit conducted in May of 2009. The data gathered during this visit was used to modify the previously created simulation model to make it an accurate representation of the current state of the Mariposa POE. Once the simulation was validated the forecasted values for commercial vehicles were used as inputs to the system to test the current capacity of the POE against predicted future traffic demands.

As previously mentioned, the underlying purpose of the simulation analysis of the Mariposa Port of Entry is to test the ability of the current setup of this POE to handle the increased traffic demands predicted for trucks in five, ten and fifteen year time periods into the future. Some of the measures of the ability of the POE to handle the varying traffic inputs (measured per commercial vehicle) are the following:

- Average time a truck spends in the system
- Time required to process all trucks and how many of those hours exceed the typical 11 hours workday
- Maximum number of trucks in queue
- Bottleneck locations
- Approximate Utilization of bottleneck locations

The ability of the current layout of the Mariposa POE in allowing commercial vehicles to cross the border in a timely matter is determined through the present simulation. The model is based on the ProModel® V6.0 Montecarlo simulation package and it is aimed to obtain the most accurate representation of the current systems flexibility in coping with forecasted future demands for commercial vehicles. By using a simulation model we are able to generate and test several scenarios of our forecasted daily demands of commercial vehicle traffic, in order to analyze and compare all potential outcomes.

For details about the structural elements already built into the simulation model please refer to Guaymas Study (Villalobos et al.).

2 Process Flow

In our simulation model each commercial vehicle is represented as an entity that enters the system according to a predetermined arrival time, which varies for each scenario. Based on historical data of the commercial vehicles each entity is assigned certain attributes which are used to determine the route the vehicle will take as it goes through the system. To begin, trucks are separated into two categories, those going through the fast lane or normal lanes (3 lane choices for normal). For those vehicles which are routed through the fast lane, they proceed directly from the primary inspections to the highway exit. If they are not routed directly to the fast lane it means they must pass through one or any combination of CBP inspections (including Document check, enforce, full inspection and X-ray) or ADOT inspections. Once all the necessary inspections are completed for each truck it is routed to the highway exit and leaves the system. Note before each truck visibly enters the system on the highway in the upper left corner (starting point of the POE) it is assigned specific characteristics to determine which inspections it will require. The percentages of trucks requiring each type of inspection are based on historical data of the Mariposa POE.

The logical flow of entities in the simulation is explained in further detail in the diagram Figure 1 in Appendix H of the Guaymas Study (Villalobos et al.). In summation, the logical process flow is as follows: when a truck enters the system it must past through all primary inspections then depending on what attributes it has been assigned it will either be routed straight to the highway exit or it will go through additional inspections and then be routed to the highway and exit the system.

The whole system can be divided into four different sections:

1. Pre-Screening and Primary Inspections: These are the first steps in the process and all trucks are required to go through them.
2. Secondary Inspection: Different tasks can be done in this section: normal secondary inspection, Full (100%) inspection, weapons and enforce inspection and others.
3. X-ray: three stations for x-ray inspection.
4. ADOT compound: ADOT's Motor Vehicle Division safety inspection and other Federal inspections are conducted here.

While the trucks move through all the different individually required steps of the inspection process, several institutions work together. A partial list includes:

- Customs and Border Protection (CBP)
- United States Department of Agriculture (USDA)
- Food and Drug Administration (FDA)
- Arizona Department of Transportation (ADOT)
- Federal Motor Carrier and Safety Administration (FMSCA)

The physical movement of the trucks can be observed in the animation of the simulation displayed in Figure 2-1 Graphical interface of the simulation program. Currently the trucks cross the border in four lanes, one of them being a fast lane and the other three being regular lanes. All trucks will then enter a pre-screening station, follow to one of the four primary inspection super-booths, and then proceed to either Nogales, Arizona (if they were in the fast lane) or else go on for further inspection in a counter clockwise (CCW) motion around the compound.

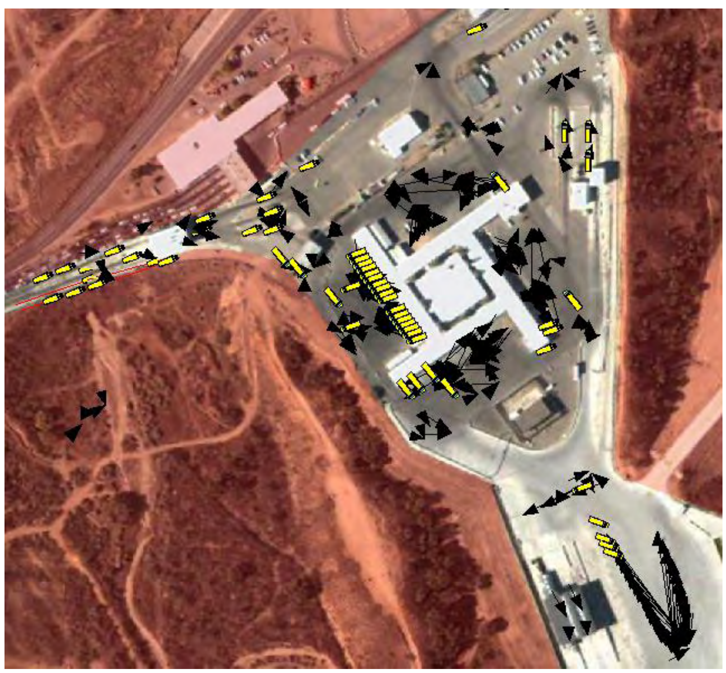

Figure 2-1 Graphical interface of the simulation program

3 Assumptions of the System

Given the security requirements at the site of the POE, we were not able to observe and record all the activities that we would have liked. We were unable to obtain clearance from CBP to enter into their inspection area and measure inspection times thus these inspection times were based on those used in simulation model of the previous study of the Guaymas-Tucson Corridor (Villalobos et al.).

3.1 Infrastructure

The physical infrastructure of the POE is presented in Figure 2-1 Graphical interface of the simulation program(in previous section). Each part of the facility is described next, these areas are displayed in Figure 2-1:

1. There are four pre-screening lanes and inspection stations (topmost lane is designated as fast and the other three are normal lanes)
2. There are four primary inspection stations (super-booths).
3. There are different quantities of docks in each side of the main compound, where the grading and detailed inspection takes place.
4. There are three X-ray stations.
5. There are two inspection lanes in the ADOT yard.
6. There are 25 parking spaces in the ADOT yard.

The detailed description of the infrastructure in the main compound is presented in Table 3-1. The information shown is this table was last updated in Dec 2005 as was used in a previous study, *Logistics Capacity Study of the Guaymas-Tucson Corridor* (Villalobos et al.). Changes may have occurred since that time but due to security issues this is the information we have to the best of our knowledge:

Table 3-1 Equipment Available at the main compound

Side	Docks Available
North	18
South	20
West	15
East	21

3.2 Movement Logic

Trucks move inside the compound in a counter clock wise (CCW) motion and follow the next priorities when several inspections are required:

1. X-ray
2. Enforcement (full inspection, hazardous and weapons inspection, etc.)
3. Document Review
4. ADOT (all inspections done at ADOT yard)

Due to physical limitations the trucks that are released in the fourth (last to the east) super-booth must go into the compound and drive around the compound again before they are able reach the highway exit. Trucks that require an X-ray inspection will go into the ADOT yard and form a line from there towards the X-ray booths.

3.3 Processing Detail

The daily volume of traffic for trucks was determined based on the results of our forecasts. The exact number of trucks for each scenario can be seen in

Table 3-4. The percentage of trucks that are assigned to go through each type of inspection can be seen in Table 3-2.

Table 3-2 Distributions of Inspection Procedures

Percentage	Description
100 %	Pre-Screening
100 %	Primary Inspection
30.74 %	Released to enter the US from Primary inspection (fast lane)
69.26 %	Required further inspections and enter the compound (normal lanes)
*Out of the 69.26% that requires more inspection:	
33 %	Required X-Ray
17 %	Required Full Inspection or Hazardous and Weapons Inspection
83 %	Required Documentation Review
20 %	Required to enter the ADOT yard for Inspection

The inspection times for each station were based on those previously determined in the Guaymas-Tucson Corridor Study (Villalobos et al.). The summary of these inspection times is shown in

Table 3-3 below. For further details refer to processing details in appendix H of Guaymas Study (Villalobos et al.).

Table 3-3 - Distribution of processing time of each activity at the POE

Inspection	Time Distribution (min)
Pre-Screening	ERLANG (0.72, 3)
Primary Inspection	ERLANG (1.33, 3)
* 20% including ADOT in Super-Booth	ERLANG (2, 3)
Document Revision	ERLANG (30.745, 3)
Full Inspection	ERLANG (82.2, 3)
Hazardous and weapons Enforcement	ERLANG (82.2, 3)
X-Ray	ERLANG (8.27, 3)
ADOT	TRIANGULAR (25, 30, 35)

The inspection times within the CBP area of the simulation (Document Revision, X-ray, Full, Hazardous and Weapons Enforce) were updated from those used in the Guaymas study (Villalobos et al.) in order to match the overall CBP inspection times collected on our visit to the Mariposa POE. Again due to clearance issues we were not given permission to enter and record data times in this area so their values were changed according to weighted percentages which will be explained more in detail in the validation section of the simulation appendix.

3.4 Simulation Scenarios

Ultimately, the goal of creating our simulation model was to test the capacity of the current setup of the Mariposa POE by changing the number of vehicles that enter the system. To do this we first analyzed the daily traffic data for the year 2008 and found that the percentage of trucks crossing each weekday (Monday-Friday) was a uniform 20% for each day. Then we took our monthly forecasted data and divided it by the average number of workdays in the month of May (20 days) when our visit was conducted to get a daily traffic demand.

To test the various forecasted traffic demands we used the last year in each scenario as our input data for the simulation since this was the largest demand and would greatest test the capacity of our system. All scenarios beginning with the number 1 refer to five year forecasts, those starting with 2 are ten year forecasts and those with 3 are the fifteen year forecasts. The second number after the hyphen refers to which scenario of the five, ten or fifteen year forecast is being used; refer to the section "forecast of commercial vehicles" for further details of what each scenario represents.

Table 3-4 Daily Demand for each Scenario

Scenario	Daily Traffic Demand
1-1	1928
1-2	1800
1-3	1759
1-4	1945
1-5	1816
1-6	1775
1-7	1976
1-8	1847
1-9	1806
2-1	2131
2-2	1969
2-3	1909
2-4	2161
2-5	2000
2-6	1939
3-1	2302
3-2	2139
3-3	2042
3-4	2325
3-5	2159
3-6	2062

4 Results and Statistical Evaluation

The results of running our simulation under the previously described scenarios are displayed in Table 4-1. In this table, the first two columns show the scenario number and the number of trucks used as a daily demand input for each scenario. The third and fourth columns represent the total number of hours required to process all trucks and how many of those are additional hours over the current 11 hour workday that the port is open. The fifth column shows the average amount of time (in minutes) that a truck will spend in the system. The sixth and seventh columns show the 95% low and high confidence intervals for the maximum number of trucks that will wait in queue on the highway. The last two columns on the right show the bottleneck locations and their approximate utilizations for each scenario.

Table 4-1 Results of running the simulation

Scenario	# Trucks	Required Process time	Extra hours required	Avg. time in system (min)	Max in Queue (low 95%)	Max in Queue (high 95%)	Bottleneck	Approx. Utilization
1-1	1928	15.50	4.50	389.710	1888.26	1893.74	Super-booths	87.70%
1-2	1800	14.66	3.66	368.655	1759.58	1767.42	Super-booths	80.75%
1-3	1759	14.66	3.66	361.327	1719.37	1727.03	X-ray	81.50%
1-4	1945	16.22	5.22	395.704	1904.04	1908.96	Super-booths	81.30%
1-5	1816	15.14	4.14	367.047	1773.80	1781.40	Super-booths	78.84%
1-6	1775	14.64	3.64	362.902	1735.65	1740.15	Super-booths	79.42%
1-7	1976	17.04	6.04	401.391	1934.06	1940.34	Super-booths	84.87%
1-8	1847	15.62	4.62	370.460	1807.50	1813.50	Super-booths	82.69%
1-9	1806	15.15	4.15	363.639	1764.67	1772.33	Super-booths	81.27%
2-1	2131	17.51	6.51	424.579	2091.24	2096.76	Super-booths	84.12%
2-2	1969	16.92	5.92	399.541	1928.55	1936.45	Super-booths	78.84%
2-3	1909	15.60	4.60	387.990	1868.91	1875.69	Super-booths	89.04%
2-4	2161	17.91	6.91	432.178	2121.45	2128.35	Super-booths	84.56%
2-5	2000	16.51	5.51	407.981	1960.05	1964.35	Super-booths	81.25%
2-6	1939	15.89	4.89	388.628	1896.77	1904.83	Super-booths	86.60%
3-1	2302	18.39	7.39	458.475	2262.94	2270.06	Super-booths	87.69%
3-2	2139	17.21	6.21	426.991	2098.73	2107.67	Super-booths	81.43%
3-3	2042	16.65	5.65	412.149	2000.89	2008.31	Super-booths	81.44%
3-4	2325	18.82	7.82	471.270	2285.52	2291.08	Super-booths	87.71%
3-5	2159	17.28	6.28	433.375	2119.19	2127.61	Super-booths	83.49%
3-6	2062	16.70	5.70	416.790	2020.59	2030.21	Super-booths	87.21%

Some of the results that can be obtained from the simulation include the following:

- The maximum number of trucks that will wait in a queue on the highway according to our 95% confidence intervals is within the range of 2119 and 2127 trucks.
- For almost all scenarios the bottleneck location is the super-booths (Insp_PrePri_Norm1, Insp_PrePri_Norm2, Insp_PrePri_Norm3), with the exception of Scenario 1-3 where the bottleneck location is X-ray inspection.
- Based on our forecasts for daily truck traffic we can see that the current system is already at capacity due to the fact that in every scenario additional hours over the typical 11 hour workday are required for all trucks to be processed.

5 Validation

In order to validate our simulation we used the data times collected on our Mariposa POE visit and updated the simulation created in the Guaymas study in order for its output times to match those we observed. We found that the most accurate manner in which to compare the times recorded in our visit with those in the simulation was by matching the times a truck spent in the CBP area.

Initially we found that time spent in CBP that we measured on our visit of 27.117 minutes was greater than the CBP time of 20.23 minutes in the original version of the simulation. To make up for the 6.887 minute difference we multiplied the inspection times of each area in CBP by a ratio as calculated in Table 5-1 below:

Table 5-1 Changing CBP inspection times

Inspection	% of trucks that receive each inspection	calculation	ratios
DOC	83	(83/133) x 6.887	= 4.298
XRAY	33	(33/133) x 6.887	= 1.708
ENFORCE/FULL	17	(17/133) x 6.887	=0.880
TOTAL	**133**		**6.886**

The final inspection times determined for Document, X-ray, Full, and Weapons Enforce Inspections can be found in

Table 3-3.

Aside from comparing CBP times we also used some subjective measurements to validate our simulation model. From our visit to the Mariposa POE we determined that if a truck was to enter the system and only pass through primary inspections then exit the system directly afterwards, it would have a total time spent in the system of 4 min 45 seconds or less. Therefore we used the this information to change the percentage of trucks in the simulation that are routed through the fast lane and directly leave the system after primary inspections to 30.74% in accordance with our observations (see Table 3-2).

6 Conclusion

The results of running the simulation model compared the actual inspection times measured in our visit to the Mariposa POE give us confidence in the validity of the results produced by our simulation model.

From our results we can see the given the forecasted future demands of traffic the system is already at capacity and would be unable to handle these traffic demands given the current infrastructure and length of workday (11 hours). We also found that for all but one of our forecasted scenarios the bottleneck of the system occurred at the same location, which we found to be the primary inspection or super-booths.