A COMPUTER SIMULATION MODEL TO DETERMINE THE EFFECTS OF BRIDGE-DELAYS ON POLLUTION

PROBAL DUTTAROY

Mechanical & Industrial Engineering

APPROVED:

Dr. Larry M. Roderick, Chair

Dr. René Villalobos

Dr. J.C. McClure, Jr.

Associate Vice President
for Research and Graduate
Studies

A COMPUTER SIMULATION MODEL TO DETERMINE THE EFFECTS OF BRIDGE-DELAYS ON POLLUTION

by

PROBAL DUTTAROY, B.S.M.E.

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fullfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Mechanical & Industrial Engineering

THE UNIVERSITY OF TEXAS AT EL PASO

December, 1992

ACKNOWLEDGEMENTS

I want to thank my Committee Chairman, Dr. Larry M. Roderick, without whose advice, help and encouragement this thesis would not have been possible.

I would also like to express my gratitude to Dr. René Villalobos and Dr. J.C. McClure for serving on my thesis committee.

I want to express my appreciation of Dr. C. K. Wu's help in providing the computer and helping in the installation of the SLAM II system.

I would also like to express my thanks to Mr. John Behnam, Air Programs Branch, United States Environmental Protection Agency and Mr. Joe Saenz, Texas Air Control Board for their help.

Special thanks are due to all my friends for helping me with the collection of data and putting the document together.

July 31, 1992

ABSTRACT

The El Paso/Ciudad Juarez urban area, for all practical purposes, could be considered a single metropolis. Communication links between the two areas of this metropolitan area are a major determinant of its growth and well-being. Delays in transportation, both commercial and passenger retards industrial growth on both sides of the border by inhibiting potential investors from expanding their existing facilities or opening new ones. A study of the traffic flow across the border is essential to determine its effects on pollution. This thesis is primarily a study of the functioning of the trans-border vehicular traffic so as to determine a valid and reasonably accurate method of studying its effects on vehicular emission. A computer simulation of one of the bridges provided a valid method of studying the operation of border traffic. The bridge selected for this study was the Cordova Bridge. The results obtained give a reasonable idea of the effects of the operating parameters of the bridge on vehicular emissions.

TABLE OF CONTENTS

PAGE NO.

ACKNOWLEDGEMENTS iii

ABSTRACT iv

TABLE OF CONTENTS v

LIST OF TABLES viii

CHAPTER

1. INTRODUCTION 1

1.1 Background 1

1.1.1 Pollution 6

1.1.2 Simulation Model for Pollution . . . 9

1.2 Computer Simulation Language 10

1.3 Organization Of This Document 12

2. PROBLEM STATEMENT AND LITERATURE SURVEY 14

2.1 Scope Of Study 14

2.2 Problem Statement 16

2.2.1 Passenger Traffic - U.S. Side . . . 18

2.2.2 Commercial Traffic - U.S. Side . . . 19

2.2.3 Passenger Traffic - Mexican Side . . 20

2.2.4 Commercial Traffic - Mexican Side . 22

2.3 Literature Review 23

2.3.1 Air Pollution 23

2.3.2 Costs 30

CHAPTER PAGE NO.

3. MODEL LOGIC 33
3.1 Slam II Model 33
3.1.1 Creation Of Entities 35
3.1.2 Determination Of Pollution Indices . 40
3.1.3 Northbound Passenger Traffic 41
3.1.4 Northbound Commercial Traffic . . . 42
3.1.5 Southbound Passenger Traffic 43
3.1.6 Southbound Commercial Traffic . . . 44
4. RESULTS AND VALIDATION 45
4.1 Validation Of Distribution for Arrival Times45
4.1.1 Validation Using Chi-Square Test . . 46
4.2 Results Of the Simulation 53
4.2.1 Validation Of Queue Lengths 56
4.2.2 Validation Of Results - Pollution . 56
5. CONCLUSIONS AND RECOMMENDATIONS 58
5.1 Conclusions 58
5.2 Recommendations 59
5.2.1 Pollution 59
5.2.2 Costs 60
REFERENCES 62
Appendix A
SLAM II MODEL 63
Appendix B
FORTRAN SUBROUTINES 78

CHAPTER PAGE NO.

Appendix C
SAMPLE OUTPUT 84

Appendix D
REQUIRED VALIDATIONS 88

CURRICULUM VITAE 90

LIST OF TABLES

TABLE PAGE NO.

1.1 Maquiladora Industry In Juarez 2

1.2 Northbound Traffic For All Bridges 4

1.3 Composite Ranking of MSAs with Data for All Criteria Pollutants 7

1.4 1990 Texas Pollution Statistics (24-hr) 8

2.1 Commercial Traffic At U.S. Customs, Cordova Bridge, El Paso - 1991 21

2.2 Commercial Traffic At Mexican Customs, Cordova Bridge, Ciudad Juarez - 1991 24

2.3 CO Concentrations At Paso Del Norte and Cordova Ports Of Entry 28

2.4 Vehicle Emissions Resulting From a 90-minute Delay . 29

3.1 Inter-Arrival Rates of Traffic at Cordova Bridge (in minutes) 36

4.1 Inter-Arrival Time Samples 48

4.2 Chi-Square Test Results for First Sample 50

4.3 Chi-Square Test Results for Second Sample 51

4.4 Chi-Square Test Results for Third Sample 52

4.5 Pollution Generated Per Year (tons) 54

4.6 Number of Passenger Vehicles Processed 55

CHAPTER 1

INTRODUCTION

1.1 Background

The population of the El Paso/Ciudad Juarez metropolitan area is among the ten largest on the North American continent. More important, this urban area is also one of the fastest growing regions on the continent. This area could be considered a single entity for the purpose of any study. However, until very recently, this critical and self-evident truth has been ignored. Today there is a greater awareness that the problems on one side of the border have a direct impact on the problems on the other side. Any problem affecting one city cannot be viewed in isolation.

The rapid increase of industrialization in the region is, in the long run, going to strain the available resources. Therefore, it is necessary to plan ahead to avoid problems directly affecting the normal functioning of both cities. Table 1.1 shows the growth in the number of maquiladoras in Ciudad Juarez over the last two decades. Under these conditions of unprecedented growth, it is critical to be able to predict future trends.

Table 1.1

Maquiladora Industry in Ciudad Juarez

(Large Plants Only)

Year	**Number of Plants**	**Number of Employees**
1969	11	255
1977	82	28,000
1978	100	31,237
1979	112	37,500
1980	119	41,525
1981	n/a	43,601
1982	125	42,810
1983	150	66,000
1984	170	75,000
1985	184	80,000
1986	210	89,600
1987	240	98,850
1988	265	118,112
1989	320	134,838

Communication links between the two parts of the metropolitan area are a key to future development. There are four bridges connecting Ciudad Juarez with El Paso.

1. Santa Fe Bridge (for northbound vehicular traffic)
2. Stanton Bridge (for Southbound vehicular traffic)
3. The Bridge of the Americas (Cordova Bridge)
4. Zaragosa Bridge

Table 1.2 shows the volume of vehicular traffic into El Paso across all bridges. Though there are no records available on traffic flow into Ciudad Juarez, it would be reasonable to assume that the volume would be approximately equal. While the volume of passenger traffic has been increasing at a steady rate of less than 2% per year, commercial traffic has been increasing at a rate of up to 97% per year.

Even in the absence of a formal free-trade agreement there has been a gradual reduction in tariffs on the Mexican side of the border; in effect a form of free trade. Since March 1991, tariffs have been reduced from 200% to 23% for plants within the 30 Kilometer border zone and 32.8% for goods with an interior destination.[1] In addition, the active

[1] Source: Mexican Customs - Verbal

Table 1.2
Northbound Crossings

Year	Frieght Carriers	Passenger Carriers	Total Carriers
1968	65,074	11,109,160	11,174,234
1969	65,194	11,192,347	11,257,541
1970	58,734	11,427,443	11,486,177
1971	65,526	11,677,649	11,743,175
1972	76,804	12,002,678	12,079,428
1973	91,249	12,456,923	12,548,172
1974	74,857	11,329,230	11,404,087
1975	73,188	11,166,995	11,240,183
1976	85,501	11,125,504	11,211,005
1977	93,621	12,328,611	12,422,232
1978	95,285	13,580,151	13,675,436
1979	93,697	13,524,187	13,617,884
1980	135,912	14,369,378	14,505,290
1981	258,270	13,834,807	14,093,077
1982	106,740	13,459,721	13,566,461
1983	127,008	13,691,502	13,818,510
1984	135,381	12,731,142	12,866,523
1985	149,029	12,329,673	12,478,702
1986	168,067	11,958,398	12,126,465
1987	172,278	12,459,010	12,631,288
1988	183,667	15,259,590	15,443,257
1989	258,750	15,576,009	15,834,759
1990	511,083	15,278,014	15,789,097
1991	522,087	12,513,264	13,035,351

participation of the two governments in the encouragement of the twin-plant program has resulted in a tremendous boost for cross-border commercial traffic. There is also an awareness throughout the world that in an increasingly competitive industrial environment, where costs and quality are critical, the significance of low inventory levels cannot be overemphasized. Whether these inventory levels are reduced by a formal program, such as Just-in-Time, or simply by cutting stock levels by conventional methods, is not relevant. What is important, is to understand the effects such manufacturing philosophies have on the operation of any industry and on other infrastructural facilities.

In the case of manufacturing plants on the US-Mexican border, where most of the industries are maquiladoras, the direct result of this reduction in inventory levels has resulted in a rapid increase in the volume of vehicular traffic. The effect of inventory control methods on the transportation facilities of commercial organizations has not been quantified, but is self-evident. A manufacturing plant operating with smaller batch sizes and a Just-in-Time philosophy requires deliveries with increasing frequency, especially when the organization has plants on both sides of the border. Thus, changing manufacturing philosophies require corresponding improvements in transportational infrastructure.

1.1.1 Pollution

The entire border region has an existing pollution problem of massive proportions. A combined $1 billion is proposed to be spent over a period of three years by the Mexican and United States governments under an environmental plan unveiled in February 1992 [1]. Specific commitments were $460 million over three years from the Government of Mexico and $380 million from the U.S. government in the current and the next fiscal year. The proposal sets aside $3 million from the Environmental Protection Agency for air-pollution studies in the El Paso-Ciudad Juarez, San Diego-Tijuana and the Calexico-Mexicali areas. That is small compared to the $552 million the Environmental Protection Agency wants to spend in the new fiscal year to fight air pollution in the entire United States [2]. These paltry figures indicate that the gravity of the situation is yet to attract the attention of the fund-allocating authorities.

Table 1.3 shows that the El Paso metropolitan statistical area was ranked seventh highest out of sixty-four cities nation-wide for all pollutants. Table 1.4 shows the pollution levels of all pollutants in Texas. The El Paso metropolitan statistical area (MSA) has the highest levels of Particulate

2

Table 1.3
Composite Ranking of MSAs with Data for All Criteria Pollutants

Rank	Metropolitan Statistical Area	State	Pop 1000s	Pollutants exceeding the NAAQs. Ranked left to right - Highest to Lowest
1	Riverside	CA	2119	OZONE PM10
2	St. Louis	MO	2458	PM10 LEAD OZONE
3	Steubenville	OH	149	CO SO2
4	Los Angeles	CA	8505	OZONE CO PM10 NO2
5	Philadelphia	PA	4866	LEAD OZONE
6	Pittsburgh	PA	2105	PM10 SO2
7	El Paso	TX	573	CO PM10 OZONE
8	Nashville	TN	573	LEAD OZONE
9	Minneapolis	MN	2336	LEAD
10	Memphis	TN	972	LEAD
11	New York	NY	8529	OZONE CO
12	Cincinnati	OH	1438	OZONE
13	Anaheim	CA	2219	OZONE CO
14	Salt Lake City	UT	1055	CO
15	New Haven	CT	519	OZONE PM10
16	Sacramento	CA	1336	CO OZONE
17	Cleveland	OH	1851	
18	Gary	IN	604	PM10
19	Newark	NJ	1891	OZONE
20	Indianapolis	IN	1229	LEAD

[2]Source for Tables 1.3 and 1.4: U.S. Environmental Protection Agency, 1990

Table 1.4
1990 Texas Pollution Statistics (24-hr)

Metropolitan Statistical Area	Pop 1000s	PM10	SO2	CO	NO2	O3	PB QMAX
Amarillo	197	26			.017		
Austin	738	44	.003	6	.013	.11	
Beaumont	371	48	.055	2		.15	0.02
Brazoria	187					.15	
Brownsville	264	51					
Corpus Christi	360	78	.016		.018	.10	
Dallas	2456	88	.022	5	.017	.14	1.62
El Paso	573	179	.060	14	.012	.14	0.42
Fort Worth	1269	51	.008	5		.14	0.03
Galveston	211	56	.063		.029	.15	0.02
Houston	3228	82	.039	8		.22	0.04
Killen-Temple	234	21					
Laredo	124	61					
Longview	167					.13	
Lubbock	228	61					
Odessa	127	36					
San Antonio	1307	55		5		.10	.07
Texarkana	120	48					
Tyler	153	48					
Victoria	75					.07	
Wichita Falls	126	56					
Total	**12515**	**18**	**8**	**7**	**6**	**12**	**7**
Average	596	61	.006	6	.018	0.13	0.32
Maximum	3228	179	.012	14	.029	0.22	1.62
Minimum		21	.001	2	.012	0.07	0.02

Matter (10 microns or less), sulfur-dioxide and carbon monoxide. It also has the second highest levels of nitrous oxide and lead.

The growing trend in politico-economic terms is to express qualified support for the Free Trade Agreement and its impact on the border environment. Thus, in the U.S. election year of 1992, implementation of the Free Trade Agreement has been opposed by a wide political spectrum ranging from isolationists to environmental activists. El Paso mirrors the debate over the free trade proposal that seeks to take advantage of the close proximity of a large mass of Mexican labor and the development of new consumer markets both in Mexico and around the globe [3].

The El Paso economy faces the same debate Texas and the rest of the country will have to confront over free trade; how can it be made to work without wrecking the environment while making the transition as painless as possible for the American worker.

1.1.2 Simulation Model for Pollution

It was determined that a computer simulation model would be a reasonably accurate method of studying the existing

problem of pollution on the bridge generated by idling vehicles. A study of the flow of vehicular traffic was done to determine its effects on vehicular pollution. The vehicles passing through the system was represented by entities in a computer simulation model.

1.2 Computer Simulation Language

The essential feature of modeling a real system by computer simulation is the possibility of experimentation without affecting the real system. Once computer simulation is chosen as the approach to study a problem, the process can be divided into three steps; modeling, programming and experimentation and validation.

The resulting model includes events such as entities arriving to the system. This arrival process is probabalistic. That is, the use of probability distributions is required to represent the arrival of entities to the system and processing times that are not fixed but vary according to a particular distribution. A simulation model can be validated through statistical procedures. By comparing portions of the results, it is possible to verify that the model is representative of reality. Portions of the output differing significantly from known results would indicate the need to either remodel the problem or examine the data used.

Once the model of the real system is available, it can be used as a forecasting tool. There are many methods of using the simulation model to study the functioning of the bridge under different circumstances. One method would examine the effects of changing the processing times or the number of servers. Another would aid in the analysis of the functioning of the bridge under a greater flow of traffic.

For this research, SLAM II (Simulation Language for Alternative Modeling) is used. SLAM II is a FORTRAN based simulation language designed and programmed by C. Dennis Pedgen and further developed and supported Pritsker and Associates [6]. In SLAM II the modeler defines EVENTS as FORTRAN subroutines. A FORTRAN subroutine library provides simulation housekeeping routines. The choice of a simulation language is important and it is necessary to clearly appreciate the advantages of using a simulation language over a general-purpose language like FORTRAN, C or BASIC [4].

Models of systems can be classified as either discrete changes or continuous change [6]. In fact, it may be possible to model the same system with either a discrete change or a continuous change model. In most simulations, time is the major independent variable. Other variables included in the simulation are functions of time and are the dependant

variables.

Discrete simulation occurs when the dependent variables change discretely at specified points in simulated time, referred to as event times. The time variable may be either continuous or discrete in such a model, depending on whether the discrete changes in the dependent variable can occur at any point in time or only at specified points. The values of the dependent variables for discrete models do not change between event times.

In continuous simulation the dependent variables of the model may change over simulated time. A continuous model may be either continuous or discrete in time, depending on whether the values of the dependent variables are available at any point in simulated time or only at specified points in simulated time. The continuous representation permits the user to supply difference or differential equations.

In combined simulation the dependent variables of a model may change discretely, continuously, or continuously with discrete jumps superimposed. The time variable may be continuous or discrete. The most important aspect of combined simulation arises from the interaction between discretely and continuously changing variables.

The study has been modeled as a discrete simulation. A discrete model is adequate is because it is necessary to model only traffic flow. Even though this model could accurately represents the traffic flow, it would be possible to incorporate continuous variables if necessary.

1.3 Organization of this Document

The presentation of this document is as follows. Chapter two presents the problem and reviews pertinent literature. Chapter three describes the model logic and the method used. Chapter four presents the results obtained from the simulation model. The recommendations and conclusions are discussed in chapter five.

CHAPTER 2

PROBLEM STATEMENT AND LITERATURE REVIEW

2.1 Scope of Study

International traffic across the border flows through four bridges. Bridge delays have the following effects:-

a) Increased operating costs of industrial plants due to delays in transportation of goods from one side to the other.

b) Pollution caused by idling traffic on the bridges and its approaches.

c) Increased costs of energy.

The scope of a study covering all the effects of a bridge's operation would be wide and would require a long period of study to analyze the problem in its full extent. Data relevant to a study of this nature has been provided by two agencies, 1) The El Paso Department of Planning, Research and Development and 2) The Treasury Department, Bureau of Customs. These agencies, however, have not studied the impact of waiting time on commercial operations in the metropolitan area or the effect on pollution levels. This thesis studies