

**Dynamic Modelling of Demand Risk in PPP Infrastructure  
Projects  
“The Case of Toll Roads”**

**By**

**Rajaa Alasad**

**Submitted for the degree of Doctor of Philosophy**

**Heriot-Watt University  
School of Energy, Geoscience, Infrastructure & Society**

**August, 2015**

The copy right in this thesis is owned by the author. Any quotation from the thesis or use of any of the information contained in it must acknowledge this thesis as the source of the quotation or information.

## ABSTRACT

Infrastructure is the main driver of prosperity and economic development. To fill the gap between increasing demand for infrastructure and supply, the role of the private financing has become increasingly critical. Concession contracts in which the investment cost is recovered via payments from the end users are the most dominant among all PPP types. Although this mechanism has been seen as an efficient way to achieve infrastructure projects in terms of realising the project on time and to budget, the demand risk faced in the operation stage has heavily limited this efficiency. Evidence has shown that shortfall in demand can seriously jeopardize the scheme's viability. Demand is dependent on a range of interrelated, dynamic factors such as economic conditions, willingness to pay and tariff for using the facility. In addition, uncertainty is an inherent aspect of most demand-underlying factors which makes demand estimation subject to high level of uncertainty. However, this uncertainty is largely ignored by modellers and planners and single demand estimate is often used when evaluating the facility. Given the threat to the project success resulting from potential variation between predicted and actual demand, it is believed that a demand risk assessment model is essential. This research is therefore devoted to developing a system dynamics model to assess demand risk by capturing the factors affecting demand and their relationships and simulating their change over time.

A system dynamics based conceptual model was developed for mapping factors affecting demand for service provided by a typical PPP concession project. The model has five Causal Loop Diagrams (CLDs) which include: socio-economic, public satisfaction, willingness to pay, competition and level of fee. Based on the developed conceptual model, a quantitative simulation model for assessing traffic demand in toll road projects was developed. This model has six sub-models which are: socio-economic, public satisfaction, willingness to pay, competition, toll and expansion factors sub-models. With the use of case study of M6 toll roads (UK), it was demonstrated the potential application of SD as a tool for the assessment of demand risk in toll roads.

Univariate and multivariate sensitivity analysis, as well as risk analysis using Monte Carlo approach, were conducted using the developed SD model. Univariate sensitivity analysis helps identify the significance of the demand underlying factors when they change individually. Toll was identified as the most critical factor affecting toll traffic demand followed by congestion on the alternative un-tolled facility. Multivariate sensitivity analysis showed how demand changes when several factors change. Four scenarios were developed to show the impact of change in conditions and policies on the level of traffic. Monte Carlo simulation, on the other hand, provided level of demand with a range of confidence intervals. Providing such estimates of the expected value and the confidence level offers useful information throughout their ranges and creates overall risk profiles by providing the probability of achieving a specific result. The main contribution of the research is in the development of a system dynamics model as a tool for assessing demand in PPP projects and informing decision making, which is new to the area of demand risk modelling.

## **Acknowledgment**

*ALL THANKS AND PRAISE IS DUE TO ALLAH THE ALMIGHTY, MOST  
MERCIFUL, MOST GRACIOUS*

I would like to express my sincere gratitude to my first supervisor Dr. Ibrahim Motawa for his support and encouragement throughout the course of this research. His insightful advice for completion this work is highly appreciated. Special thanks are extended to my second supervisor, Professor Stephen Ogunlana for his guidance and support.

I would like to acknowledge all the experts and practitioners who participated in the interviews during the model conceptualisation, formulation and validation stages. I would also like to thank all the respondents of the questionnaire survey for sharing their insights.

I am particularly grateful and deeply indebted to my family, friends and colleagues for their continuous support.



## Table of Contents

<b>1. Chapter One: Introduction .....</b>	<b>1</b>
1.1. Research Background.....	1
1.2. Research Problem.....	4
1.3. Research Aim and Objectives .....	8
1.4. Research Scope.....	9
1.5. Summary of the Research Methodology .....	10
1.6. Structure of the Thesis.....	10
1.7. Summary .....	14
<b>2. Chapter Two: Demand Risk in PPP Projects .....</b>	<b>16</b>
2.1. Introduction .....	16
2.2. The PPP Journey .....	16
2.3. Main PPP Principles.....	19
2.4. Risk Classification in PPPs .....	24
2.5. Demand Risk Allocation in PPPs.....	27
2.6. Concession Contracts .....	29
2.7. Demand Risk in PPP Concessions .....	32
2.8. Factors Affecting Demand in PPP Infrastructure Projects .....	37
2.8.1. Socio-Economic Factors .....	38
2.8.2. Public Satisfaction.....	39
2.8.3. Willingness To Pay (WTP).....	41
2.8.4. Historical Experience of Paying.....	43
2.8.5. Public Involvement in ongoing Facility Management.....	44
2.8.6. Competition from Alternative Facilities .....	45
2.8.7. Level of Fee.....	46
2.8.8. Behaviour of Demand Risk Factors .....	49
2.9. Demand Modelling.....	50
2.9.1. Time Series Models.....	51
2.9.2. Causal Models.....	51
2.9.3. Artificial Neural Networks (ANNs).....	52
2.9.4. System Dynamics.....	53
2.10. Summary.....	54
<b>3. Chapter Three: Traffic Demand Risk in Toll Roads .....</b>	<b>55</b>

3.1.	Introduction .....	55
3.2.	PPP in Road Infrastructure .....	55
3.3.	Road Concessions.....	57
3.3.1.	Toll Concessions .....	57
3.3.2.	Shadow toll Concessions .....	57
3.4.	Current Practice of Toll Roads .....	58
3.5.	Significance of Demand Risk in Toll Roads .....	62
3.6.	Sources of Variations in Traffic Demand.....	64
3.6.1.	Model Adequacy .....	64
3.6.2.	Model Inputs and Assumptions.....	73
3.6.3.	Optimism Bias and Strategic Misrepresentation.....	85
3.7.	Traffic Estimation Uncertainty .....	86
3.8.	Modelling Uncertainty of Traffic in Toll Roads .....	90
3.8.1.	Reference Class Forecasting .....	90
3.8.2.	Judgments and Reality Checks .....	91
3.8.3.	Sensitivity Analysis.....	91
3.9.	Summary .....	93
<b>4.</b>	<b>Chapter Four: Research Methodology .....</b>	<b>95</b>
4.1.	Introduction .....	95
4.2.	Research Design .....	95
4.3.	Research Philosophy/ Knowledge Claim .....	97
4.4.	Research Approaches/Strategies of Inquiry .....	98
4.4.1.	Quantitative Research Strategies.....	98
4.4.2.	Qualitative Research Strategies.....	99
4.4.3.	Mixed Method Research Strategies .....	102
4.5.	Research Techniques/Data Collection Methods.....	102
4.6.	Research design as Philosophy, Strategies, and Methods: Approaches to Research .....	103
4.6.1.	Quantitative vs. Qualitative Methodologies.....	103
4.6.2.	Mixed Method.....	106
4.7.	Research Methodology Adopted .....	107
4.7.1.	Statement of the Research Aim.....	107
4.7.2.	Selection of the Research Method.....	107
4.8.	Summary .....	113
<b>5.</b>	<b>Chapter Five: System Dynamics .....</b>	<b>115</b>

5.1.	Introduction .....	115
5.2.	System Dynamics .....	115
5.3.	Background of SD .....	116
5.3.1.	Application of SD in PPP Field .....	116
5.3.2.	Application of SD in Transportation Modelling .....	117
5.4.	Application of SD in the Current Research .....	119
5.5.	SD Modelling Principles .....	120
5.5.1.	Causal Loop Diagrams (CLDs).....	120
5.5.2.	Stock and Flow Diagrams (SFDs) .....	121
5.5.3.	Patterns of Dynamic Behaviour .....	122
5.5.4.	Non-linearity .....	126
5.5.5.	SD Modelling Process.....	126
5.6.	Demand Risk Model Development .....	127
5.6.1.	Problem Identification.....	129
5.6.2.	Model Conceptualization .....	129
5.6.3.	Model Formulation .....	129
5.6.4.	Model Simulation.....	133
5.6.5.	Model Validation .....	134
5.6.6.	Model Application .....	134
5.7.	Data Collection.....	134
5.7.1.	Literature Review.....	135
5.7.2.	Questionnaire .....	135
5.7.3.	Interview .....	137
5.7.4.	Case Study.....	139
5.7.5.	Secondary Data .....	139
5.8.	Summary .....	140
<b>6.</b>	<b>Chapter Six: Model Conceptualisation.....</b>	<b>141</b>
6.1.	Introduction .....	141
6.2.	Factors Validation and Prioritization .....	141
6.2.1.	Factor Prioritization Using ANP .....	145
6.3.	Causal Loop Diagrams (CLDs) Development .....	153
6.3.1.	Socio-economic CLD.....	155
6.3.2.	Public Satisfaction CLD.....	158
6.3.3.	Willingness to pay CLD.....	161

6.3.4.	Competition CLD .....	164
6.3.5.	Level of fee CLD .....	167
6.3.6.	High Level Conceptual Model .....	170
6.4.	Summary .....	171
<b>7.</b>	<b>Chapter Seven: Model Formulation .....</b>	<b>173</b>
7.1.	Introduction .....	173
7.2.	Model Overview .....	173
7.2.1.	Model Boundary Chart.....	174
7.2.2.	Sub-models Diagram.....	177
7.3.	Model Formulation.....	179
7.3.1.	Socio-economic Sub-model .....	181
7.3.2.	Public satisfaction sub-model .....	186
7.3.3.	WTP sub-model .....	189
7.3.4.	Toll sub-model .....	197
7.3.5.	Expansion Factors Sub-model .....	199
7.3.6.	Competition Sub-model .....	201
7.4.	Summary .....	203
<b>8.</b>	<b>Chapter Eight: Model Simulation (The Case of M6 Toll Road) .....</b>	<b>204</b>
8.1.	Introduction .....	204
8.2.	Project Profile.....	204
8.2.1.	Planning and Construction.....	204
8.2.2.	Operation.....	209
8.3.	Parameter Estimation .....	216
8.4.	Model Input .....	217
8.4.1.	Population, Employment and GDP Growth Rate .....	218
8.4.2.	Corridor Traffic.....	218
8.4.3.	Corridor Adjustment Factor (CAF).....	219
8.4.4.	Induced Traffic Rate .....	219
8.4.5.	Public Consultation .....	220
8.4.6.	Project Location and Environmental Considerations.....	220
8.4.7.	Toll and Toll Change .....	221
8.4.8.	Toll Adjustment Factor (TAF).....	222
8.4.9.	Value of Travel Time Saving (VTTS) .....	222
8.4.10.	Rival V/C .....	222



8.4.11.	Electronic Tag Usage .....	223
8.4.12.	Normal Travel Time and Rival Normal Travel Time .....	224
8.4.13.	Historical Experience of Paying.....	224
8.1.1	Expansion Factors .....	224
8.4.14.	Change in Fuel Price .....	225
8.4.15.	Ramp-up.....	225
8.4.16.	Non-compete Clause .....	225
8.4.17.	Guarantee .....	226
8.4.18.	Rival Toll .....	226
8.5.	Base Case Run.....	226
8.6.	Summary .....	241
<b>9.</b>	<b>Chapter Nine: Validation and Model Testing.....</b>	<b>243</b>
9.1.	Introduction .....	243
9.2.	Model Validation.....	243
9.3.	Participations in the Model Validation.....	244
9.4.	Structure-oriented Tests .....	247
9.4.1.	Boundary Adequacy Tests .....	247
9.4.2.	Structure Assessment Tests.....	248
9.4.3.	Dimensional Consistency Tests .....	249
9.4.4.	Parameter Assessment Tests .....	249
9.4.5.	Extreme Conditions Analysis.....	251
9.5.	Behaviour-oriented Tests .....	254
9.5.1.	Behaviour Reproduction Tests.....	254
9.5.2.	Sensitivity Analysis.....	257
9.6.	Summary .....	258
<b>10.</b>	<b>Chapter Ten: Model Application - Sensitivity and Risk Analysis.....</b>	<b>260</b>
10.1.	Introduction.....	260
10.2.	Univariate Sensitivity Analysis .....	261
10.2.1.	Population Growth Rate.....	262
10.2.2.	Employment Growth Rate.....	264
10.2.3.	GDP Growth Rate .....	265
10.2.4.	Corridor Traffic Growth.....	267
10.2.5.	Value of Travel Time Saving (VTTS) Growth Rate.....	269
10.2.6.	Change in Toll Rate .....	271

10.2.7.	Rival V/C Change .....	274
10.2.8.	Change of Fuel Price .....	276
10.2.9.	Proportion of Heavy Good Vehicle (HGVs).....	277
10.2.10.	Summary of Univariate Sensitivity Analysis.....	278
10.3.	Scenario Analysis/Multivariate Sensitivity analysis.....	281
10.3.1.	Scenario 1: Better Economic Conditions .....	282
10.3.2.	Scenario 2: Better Economic Conditions and Higher Change in Toll ....	283
10.3.3.	Scenario 3: Higher Toll and Higher Congestion on the Untolled Alternative Facility .....	284
10.3.4.	Scenario 4: Freezing Toll and Higher Change in Corridor Traffic .....	286
10.4.	Risk Analysis .....	288
10.5.	Summary .....	297
<b>11.</b>	<b>Chapter Eleven: Conclusions and Recommendations.....</b>	<b>298</b>
11.1.	Introduction.....	298
11.2.	Achievement of the Research Objectives and General Conclusions .....	298
11.3.	Originality of the Research and Contribution to Knowledge .....	304
11.4.	Recommendations for Practice .....	305
11.5.	Limitation of the Research.....	306
11.6.	Recommendations for Further Research.....	308
	<b>References .....</b>	<b>1</b>



## Table of Figures

Figure 1.1: Thesis Outline.....	11
Figure 2.1: Typical PPP Concession Scheme .....	31
Figure 3.1: Ratio of Actual/Forecast Traffic for S&P's Sample.....	60
Figure 3.2: A Typical Four Step Model and the Integration of Tolling.....	67
Figure 3.3: Sample Toll Diversion Curves .....	69
Figure 3.4: GDP versus. Traffic Growth, UK 1967-1997 (Indexed to 1967=100).....	75
Figure 4.1: Nested Research Model (Kagioglou et al., 2000).....	96
Figure 4.2: The Research Onion (Saunders et al., 2003) .....	96
Figure 5.1: Cause-Effect Relationship .....	121
Figure 5.2: Stock and Flow Structure .....	122
Figure 5.3: The Structure (Reinforcing Feedback Loop) and Behaviour of the Exponential Growth , Source (Sterman, 2000) .....	123
Figure 5.4: An Example of Exponential Growth Structure .....	123
Figure 5.5: The Structure (Self-Balancing Feedback Loop) and Behaviour of the Goal Seeking, Source (Sterman, 2000).....	124
Figure 5.6: An Example of the Goal Seeking Structure .....	124
Figure 5.7: The Structure (Self-Balancing Feedback Loop) and Behaviour of the Oscillation, Source (Sterman, 2000) .....	125
Figure 5.8: An Example of the Oscillation Structure.....	126
Figure 5.9: The Main Stages, Activities and Data Collection Methods involved in developing the SD Model .....	130
Figure 6.1: ANP Network Structure for Factors Affecting Demand for Service Provided by PPP Projects. ....	147
Figure 6.2: Socio-economic Causal Loop Diagram.....	158
Figure 6.3: Public satisfaction Causal Loop Diagram .....	161
Figure 6.4: Willingness to Pay Causal Loop Diagram.....	164
Figure 6.5: Competition Causal Loop Diagram.....	167
Figure 6.6: Level of Fee Causal Loop Diagram.....	170
Figure 6.7: High Level Conceptual Model of Demand in PPP infrastructure Projects	171
Figure 7.1: Sub-Models Diagram.....	178
Figure 7.2: Socio-economic Sub-model.....	185
Figure 7.3: Public satisfaction sub-model.....	187
Figure 7.4: Effect of project Location and Environmental Consideration Lookup .....	188

Figure 7.5: Division of toll facility user based on Toll collection method .....	192
Figure 7.6: WTP Sub-Model for ETC Users .....	193
Figure 7.7: WTP Sub-Model for Non-ETC users .....	194
Figure 7.8: Effect of V/C on Travel Time Lookup .....	196
Figure 7.9: Toll rate sub-model.....	198
Figure 7.10: Expansion Factors sub-model.....	200
Figure 7.11: Competition Sub- Model .....	202
Figure 8.1: M6 toll concession structure.....	206
Figure 8.2: Location of the M6 Toll Motorway within England .....	207
Figure 8.3: Tube Style Map of M6 Toll road.....	208
Figure 8.4: M6 toll TAG device.....	212
Figure 8.5: The dedicated Tag lane on M6 toll.....	212
Figure 8.6: HGVs Usage against HGVs Toll.....	215
Figure 8.7: TAG users Vs M6 toll users .....	223
Figure 8.8: Population growth in the Base Case scenario.....	227
Figure 8.9: Employment Growth in the Base Case scenario .....	228
Figure 8.10: GDP growth in the Base Case scenario .....	229
Figure 8.11: Regional Traffic behaviour in the Base Case Scenario .....	230
Figure 8.12: VTTS in the Base Case scenario .....	231
Figure 8.13: WTP in the Base Case Scenario .....	232
Figure 8.14: Toll rate in the base Case scenario .....	233
Figure 8.15: Travel Time Saving of Non-ETC Users .....	234
Figure 8.16: Non-ETC Users Toll Share .....	235
Figure 8.17: ETC Users Toll Share.....	236
Figure 8.18: Non-ETC traffic demand .....	237
Figure 8.19: ETC Traffic demand.....	237
Figure 8.20: Demand for different Traffic segmentations in the Base Case Scenario..	238
Figure 8.21: Total Demand Traffic in the Base Case Scenario.....	239
Figure 8.22: Toll or Traffic Revenue .....	241
Figure 9.1: ETC users Toll share under Toll change of £0 per year .....	252
Figure 9.2: ETC users Toll share under Toll change of £2 per year .....	252
Figure 9.3: ETC users Toll share under VTTS change rate of +5% .....	253
Figure 9.4: ETC users Toll share under VTTS change rate of -5% .....	253
Figure 9.5: Regional Traffic in the Base Case Scenario against the Actual Data.....	256
Figure 9.6: Total Traffic Demand in the Base Case Scenario against the Actual Data	257

Figure 10.1: Impact of Change in Population Growth Rate on AADT .....	263
Figure 10.2: Impact of Change in Employment Growth Rate on AADT .....	265
Figure 10.3: Impact of Change in GDP Growth Rate on AADT.....	267
Figure 10.4: Impact of Change in Corridor Traffic Growth on AADT .....	268
Figure 10.5: Impact of Value of Travel Time Savings Growth on AADT .....	270
Figure 10.6: Impact of Change in Toll rate on AADT.....	273
Figure 10.7: Impact of Change in Toll rate on Traffic Revenue.....	273
Figure 10.8: Impact of Change in Rival V/C on AADT .....	275
Figure 10.9: Impact of Change of Fuel Price on AADT.....	277
Figure 10.10: Impact of Change in Heavy Good Vehicles on AADT.....	278
Figure 10.11: Tornado Diagram of Different Variables Influencing AADT.....	281
Figure 10.12: Traffic Demand under Better Economic Conditions Scenario .....	283
Figure 10.13: Toll road Traffic Demand under Better Economic Conditions and Higher Toll Scenario .....	284
Figure 10.14: Toll road Traffic Demand under Higher Toll with Higher Congestion on untolled Alternative Facility Scenario .....	286
Figure 10.15: Toll road Traffic Demand under Frozen Toll and Higher Corridor Traffic Growth Scenario.....	287
Figure 10.16: Histogram and normality Curve of Employment Growth Rate.....	291
Figure 10.17: Q-Q Plot of Employment Growth Rate .....	292
Figure 10.18: Monte Carlo Simulation of AADT.....	294

## Table of Tables

Table 2.1: Comparison between Traditional and PPP Projects.....	21
Table 2.2: Risk classification in PPP Projects .....	26
Table 2.3: Forecast vs Actual Passenger kilometres .....	33
Table 3.1: Four-zone trip Matrix.....	65
Table 3.2: An example of a Stated Preference Choice question .....	72
Table 3.3: Variations between forecasted and actual population growth rate .....	75
Table 4.1: Components of the four Research Design Models .....	97
Table 4.2: A comparison between quantitative and qualitative approaches .....	105
Table 4.3: Relevant Situations for Different Research Strategies.....	108
Table 5.1: System Dynamics Modelling Process across the Classic Literature .....	128
Table 5.2: Thesis objectives and the corresponding data collection and analysis methods .....	131
Table 6.1: A list of the Factors affecting Demand Identified based on the Literature..	142
Table 6.2: Respondents' Experience and Associated Organisation .....	144
Table 6.3: Demand risk factors means based on the questionnaire survey.....	145
Table 6.4: A list of demand risk clusters and factors.....	147
Table 6.5: Pairwise Judgement Scale.....	149
Table 6.6: Pairwise Comparison with respect to user characteristics (UC).....	152
Table 6.7: Pairwise Comparison with respect to facility characteristics (FC).....	152
Table 6.8: Pairwise Comparison with respect to area characteristic (AC) .....	152
Table 6.9: CLDs Validation Respondents Profile.....	155
Table 7.1: Model Boundary Chart of the Demand Risk Assessment Model.....	175
Table 7.2: Symbols used in stock and flow diagram .....	179
Table 7.3: Model Formulation Respondents Profile .....	180
Table 7.4: Sample data for UK GDP, West midlands population and Employment ....	182
Table 8.1: Summary of M6 Toll Pricing.....	209
Table 8.2: Estimation of the Coefficients of Traffic Equations .....	217
Table 8.3: Toll change rates used in the model.....	221
Table 9.1: SD Validation Tests .....	245
Table 9.2: Validation Respondent Profile.....	247
Table 9.3: Some SD Model Parameters, Values and Sources .....	250
Table 9.4: Model Fit Statistics .....	255

Table 9.5: Results of behavioural sensitivity analysis .....	258
Table 10.1: Sensitivity Analysis Results for the impact of Population Growth Rate on AADT.....	263
Table 10.2: Sensitivity Analysis Results of the impact of Employment Growth Rate on AADT.....	264
Table 10.3: Sensitivity Analysis Results of the impact of GDP Growth Rate on AADT .....	266
Table 10.4: Sensitivity Analysis results of the Impact of Corridor Traffic Growth on AADT.....	268
Table 10.5: Sensitivity Analysis results of the Impact of VTTS Growth Rate on AADT .....	270
Table 10.6: Sensitivity Analysis results of the Impact of Toll Change on AADT .....	272
Table 10.7: Sensitivity Analysis results of the impact of Rival V/C on AADT .....	275
Table 10.8: Sensitivity Analysis results of the impact of Change of Fuel Price on AADT .....	276
Table 10.10: Normality Tests for Population growth Rate Variable .....	292
Table 10.11: The Probability Distributions of the Exogenous Variables .....	293



## List of Publications

- Alasad, R., Motawa, I. and Ogunlana, S. (2014). Dynamic Traffic Demand Risk Assessment in Toll Road Projects. *Construction Management and Economic, in press.*
- Alasad, R., Motawa, I., Ogunlana, S. and Boateng, P. (2014). Prioritization of Demand Risk Factors in PPP Infrastructure Projects. *Construction Research Congress (CRC) 2014 (USA):* pp. 1359-1368.
- Alasad, R., Motawa, I. and Ogunlana, S. (2013). A System Dynamics Based Model for Demand Forecasting in PPP Infrastructure Projects – A Case of Toll Roads. *OTMC Journal.*
- Alasad, R., Motawa, I. and Ogunlana, S. (2013). Demand Risk in PPP infrastructure Projects- A Case of Toll Roads. [Poster]. UK Chapter of System Dynamics Conference: London, 7th-8th February, 2013.
- Alasad, R., Motawa, I. and Ogunlana, S. (2011). A System Dynamics Based Method for Demand Forecasting in Infrastructure Projects - A Case of PPP Projects, paper presented at Annual *ARCOM Conference*, Edinburgh, 4-6 September 2012.
- Alasad, R., Motawa, I. and Ogunlana, S. (2011). Identifying Demand Risk in Public Private Partnerships (PPP) infrastructure Projects, paper presented at *CIB TG72/ARCOM Doctoral Research Workshop, Public Private Partnerships*, ed. Akintoye, A, Liyanage, C, Renukappa,S. pp. 31-43. Preston. 12th October 2011

## **GLOSSARY**

AADT	Annual Average Daily Traffic
AC	Area Characteristics
AECOM	Architecture, Engineering, Consulting, Operations and Maintenance
ANP	Analytic Network Process
ASCE	American Society of Civil Engineers
AT	Annual Traffic
AWT	Average weekday traffic
BBNR	Birmingham North Relief Road
BLT	Built, Lease, Transfer
BOT	Built, Operate, and Transfer
CAF	Corridor traffic Adjustment Factor
CAMBBA	Carillion, Alfred McAlpine, Balfour Beatty and AMEC
CBR	Case Base Reasoning
CLDs	Causal Loop Diagrams
CPA	Causal Path Analysis
DBFO	Design, Build, Finance, and Operate
DfT	Department for Transport
EIB	European Investment Bank
EPEC	European PPP Expertise Centre
ETC	Electronic Toll Technology
FC	Facility Characteristics
GDP	Gross Domestic Production
HA	Highway Agency
HGV	Heavy Goods Vehicle
HM Treasury	Her Majesty Treasury
IWK	Indah Water Konsortium
LRMT	Light Rail Metro Train
MAPE	Mean Absolute Percent Error
MEL	Midland Expressway Ltd
MGI	McKinsy Global Institute
MOP	Multiobjective Programming

MPPT	Morning Peak Period Traffic
MSA	Motorway Service Area
MTS	Metro Transportes do Sul
NAO	National Audit Office
NFMAs	National Federation of Municipal Analysts
NOS	National Office of Statistics
NPV	Net Present Value
O&M	Operation and Maintenance
OECD	Organisation for Economic Co-Operation and Development
OLS	Ordinary Least Square
ONS	Office of National Statistics
ORT	Open Road Tolling
OYA	One Year After Study
PFI	Private Finance Initiative
PPIAF	Public-Private Infrastructure Advisory Facility
PPP	Public-Private Partnerships
PUTRA	Projek Usahasama Transit Ringan Automatik
QS	Quality of Service
$R^2$	Coefficient of Determination
RGSP	Real Gross State Product
S&P's	Standard & Poor's
SACTRA	Standing Advisory Committee on Trunk Road Assessment
SD	System Dynamics
SFDs	Stock and Flow Diagrams
SIMPLE	Simulation of Industrial Management Problem with Lots of Equations
SPVs	Special Purpose Vehicles
STRA	Sistem Transit Aliran Ringan
UC	User Characteristics
UCL	University College London
V/C	Volume to Capacity Ratio
VFM	Value for Money
VTTS	Value of Travel Time Savings
WTP	Willingness To Pay

# Chapter One: Introduction

## 1.1. Research Background

Infrastructure projects are essential in enhancing social welfare and supporting economic development. The substantial financial provision required to create and sustain these facilities is however a challenge. Estimates suggest that global infrastructure needs about US\$3 trillion per annum (ULI and Ernst & Young, 2013). Currently, McKinsey Global Institute (MGI)<sup>1</sup> reported that worldwide infrastructure demand between 2013 and 2030 requires \$57 trillion. The investment targets roads, rails, ports, airports, power, water and telecom with the majority of which (\$16.6 trillion) goes to roads infrastructure (MGI, 2013). To fill the gap between demand and supply under the government fiscal constraints, several alternative methods have been considered. Public Private Partnership (PPP) arrangements have been regarded as an efficient source to raise funds for providing necessary infrastructures and to decrease governments borrowing and spending. The PPP procurement route has been therefore increasingly employed to deliver many large scale and capital-intensive public infrastructure projects such as roads, ports, stadia, power stations, water utilities, etc. Between 1990 and 2009, more than 1300 PPPs with total value of more than € 250 billion have been signed in the European countries. In 2010, the total investments in all PPP projects in Europe reaching financial close was € 18.3 billion (Kappeler and Nemoz, 2010). Infrastructure Australia identified \$206 billion in public assets roads, ports, airports, rails, and power and water utilities where the private sector can fund infrastructure shortfalls and improve operational productivity. The UK government recognized 550 projects of \$471 billion (£310 billion), with a particular emphasis on transport and power where the private sector can be involved (ULI and Ernst & Young, 2013).

Unlike most PPP social projects (e.g. hospitals, schools, prisons) in which the private sector is to recover its initial investment by getting performance-based payments from

---

<sup>1</sup> McKinsey Global Institute (MGI) is business and economics research organisation established in 1990. The institute provides facts, insights and reports covering more than 20 countries and 30 industries.

the authorities, most PPP economic projects (roads, ports, airports, etc.) allow the private sector operator to recover its capital investment from the revenue produced by charging the end users. This kind of projects is broadly known as Concessions, User-based, or Financially free-standing. A research by Siemens (2007) indicates that there is a global trend toward pay-per-use charging for public service provision. Chiu and Boshier (2005) argue that this method of financing is particularly favoured by the public sector for contracting water and wastewater services, as it allows a radical change to the sector without relinquishing facility ownership. In addition, concessions have increasingly received an international attention as an alternative method for financing transportation projects in general and roads in particular (Evenhuis and Vickerman, 2010; Bain, 2009). Because the significance of investment in PPP transportation in general and road in particular, the following discussion will be more focused on this kind of projects. However, the research problem of this study is also related to all other PPP concession projects.

Transportation was the traditional base from which PPP have been developed to other areas of public service and building (Kappeler and Nemoz, 2010). It represents the sector where PPP model has mostly implemented (Roumboutsos and Macario, 2013). Vanelslander et al. (2014) argue that the transport sector has benefited the most from the private financing of infrastructure projects, particularly in European countries. European Investment Bank (EIB) (2007) reported that PPP type of contracts represent over 90% of total monetary investment in transportation sector. While the economic crisis resulted in reduction in the size of investment, the share of the PPP contracts in total investment in transportation sector is still significant at approximately 75%. Between 2004 and 2009, the transport sector represented 41% of the number and 76% of the value of PPPs in Europe. Within these figures, road projects have taken the highest proportion (71% of the number and 83% of the value). Esatche et al. (2007) argue that this is at the international level too. About 2500 privately financed infrastructure projects were implemented by the World Bank in developing countries between 1990 and 2001, of which 662 were transport projects with an investment of \$135 billion (Guasch, 2004). A World Bank database for 33 developing countries identified 811 roads projects in partnership with the private sector between 1990 and 2012 (Nicolas, 2012). According to the World Bank, the investments in roads in developing countries constituted about 53% of the total investments in transport infrastructure between 1990 and 2011 (Nicholas, 2012). Between 2004 and 2008, private investment in USA roads market

increased by tenfold from \$2.4 billion to of \$25 billion (Baxandall, 2009). Globally, of 34 new PPP transport projects reaching financial or contractual closure in the first semester of 2011, there were 23 road projects with investment of US\$8.7 billion (Nicholas, 2012). Road concessions, known as toll roads, are the dominant project type in the PPP transport sector (Roumboutsos and Macario, 2013). Toll road is a non-recourse project where the tolls charged to the end users are the only source of revenue. The significance of toll roads emerges from the economic importance of road projects and the substantial investments required to undertake the project.

The feasibility of concession projects is based upon a balance between costs and benefits (revenues). The actual values of both costs and revenues are not actually known and change over the project lifecycle. For instance, construction cost and schedule can significantly exceed that predicted due to risks associated with the construction stage such as unforeseen complications. Project revenue, on the other hand, is not easy to estimate due to the significant uncertainty associated with the future events such as improvements of competing facilities or economic conditions which can significantly affect the project demand and revenue. While several studies have discussed issues pertinent to the overall risks of PPP projects (Beidleman et al., 1990; Tiong, 1990, Woodward, 1992; Megens, 1997; Vega, 1997; Arndt, 1998; Zhang et al., 1998; Akintoye et al., 2001; Shen et al., 2001; Askar and Gab-Allah, 2002; Grimsey and Lewis, 2002; Rodeny and Gallimore, 2002; Ball et al., 2003; Thomas et al., 2003; Dey and Ogunlana, 2004; Hodge, 2004; Quiggin, 2004; Li et al., 2005; Akintoye and Chinyio, 2005; Shen et al., 2006; Jin and Doloi, 2007; Medda, 2007; Ng and Loosemore, 2007; Toan and Ozawa 2008; Zou et al., 2008; , Cheung et al., 2009; Chung et al., 2010; Ke et al., 2010; Yuan et al., 2010; Abd Karim, 2011; Jin, and Zhang, 2011; Heravi and Hajihosseini, 2012) less attention has been given to the project most significant risks such as demand risk associated with the operation stage (Cabral and Junior, 2010, Li and Ren, 2009), which will therefore be the focus of research.

Demand is the principal determinant of the financial feasibility and the ultimate project viability. It can be argued that transferring the responsibility of financing such large facilities to the private sector in addition to the uncertainty about demand level are the primary reasons behind the engagement of the public sector in these long-lasting concession contracts. Governments believe that the extra cost brought by private financing is outweighed by the advantage of transferring demand risk to the private

sector. For instance, in case of Eastern Distributor toll road project (USA), the government compared a privately-funded toll road to the publicly-financed option. While the comparison results showed that a publicly-funded toll road is financially preferred, the government pursued the privately-funded option to avoid debt rising in the case of publicly funded road, and to transfer demand risk to the private sector (Lam, 2006).

## **1.2. Research Problem**

Employment of PPP concessions as a way to deliver infrastructure projects makes the financial feasibility of the scheme the most significant driver underpinning the implementation decision. To assess the financial feasibility, the predicted revenue from operating the facility is the major variable in the equation. While there are many factors affecting revenue, demand for service provided by the facility is the most significant. The demand for the service determines the project's future cash flow and, consequently, the features of the debt service repayment. Employing concession contracts has therefore placed demand risk at the top of the project risks list. For instance, the results of a questionnaire survey (Norton Rose, 2004) and Interview survey (Chung et al., 2010) revealed that PPP projects stakeholders agree that demand traffic risk is the greatest risk.

For the kind of PPP projects in which the fares paid by the end users are the main source of revenue, the demand risk is entirely allocated to the private sector operator. However, in some cases, as a way to attract the private sector, the government chooses to share this risk with the concessionaire by providing minimum revenue guarantees, paying availability fees or issuing capital grants (Menzies and Perrott, 2010). These kinds of guarantees result in transferring the risk back to the public sector in case the project falls into distress which distorts the main aim of applying the PPP method.

Demand risk is identified as the unforeseen variations between the actual and forecasted demand for service provided by the facility. Variations in demand have widely been observed in PPP infrastructure projects in general and toll roads in particular, and documented by several researchers (Morgan, 1997; Bain et al., 2003, 2004, 2005; Flybjerg, 2005; Vassallo and Baeza, 2007; Prozzie et al., 2009; Li and Hensher, 2010;

Welde and Odeck, 2011 and Roumboutsos et al., 2013). Projects in the railway sector, such as the Sydney Airport Link Line (Australia), Skytrain project (Bangkok, Thailand), STAR and PUTRA project (Kuala Lumpur, Malaysia) are examples where out-turn demand was largely under projections. For example, the Skytrain in Bangkok recorded only one-quarter of the predicted demand in its first year of operations (150,000 user per day compared with an estimated 600,000–700,000) (Halcrow Group, 2004). International toll roads such as Lane Cove Tunnel, Sydney Cross Tunnel (Australia), Dulles Greenway (USA) and M6 toll road (UK) showed also similar behaviour. For instance, in Lane Cove Tunnel in Sydney (Australia), it was predicted that about 100,000 motorists will ride the scheme by the first year of operation (2007) increasing to 120,000 in 2010. However, only 40,000 and a round 50,000 users utilised the facility in 2007 and 2010 respectively (Department of Infrastructure and Transport, 2011). Evidence shows intolerant gap between actual and forecasted demand figure. This difference between actual and forecasted numbers has been attributed to many reasons such as forecast model structure, model inputs and assumptions and optimism bias (Flybjerg, 2005; Kriger et al., 2006, Prozzi et al., 2009, Bain, 2009). However, the uncertainty associated with the model inputs, which represent some of the demand influencing factors, was identified as the most significant (Zhao and Kockelman, 2002; De Jong et al., 2007; Matas et al., 2010).

The actual demand can slow down or increase during the concession period in a way that can seriously affect the project's revenues. In concession projects, when the demand is under predicted the private sector will not be able to gain the expected benefits and may even not be able to recover its investment. In this case, it is either the end users or the government that will bear the final responsibility for this risk and be required to compensate the private sector for the low demand for the project. This is typically based on contract arrangements such as: a guaranteed minimum usage for the facility or a minimum return on investment as discussed above. The end users will bear the responsibility in form of higher charge for using the facility or longer concession period. Conversely, in the case of inordinate demand performance (even though it is less common), the project would generate strong profitability which could far outperform that predicted. Thus, the project company would then be able to recover all of its investments before the end of the concession period. However in this case, the public would continue to be charged for using the facility during the full concession period, which could represent a compromise of public interests.



The sluggish usage performance leading the facility to function at lower level of demand has resulted in most of concession contracts to be renegotiated or become high-profile failures. Weld and Odeck (2011) argue that demand variation in the first year of operation is likely to have significant financial implications for the viability of a project. The demand variations lead the project to experience financial difficulties that requires loan refinancing, a prolonged payment period, increased fee or a combination of these alternatives. Viegas (2010) suggested that the considerable level of difficulty associated with monitoring the demand in transport projects has caused serious problems in respect of many contracts, forming a key reason for costly and prolonged renegotiations at the operation stage. Choi et al. (2010) reported that the bulk water supply contract of Shenyang Public utility in China was terminated because the actual demand was under that predicted.

In addition, variations in demand has several undesirable impacts on the investment environment of infrastructure projects, these impacts include but not limited to the following:

- Failure to opt the best investment. Thus, huge financial resources back unviable investments
- High demand risk which cause difficulties in connecting the private sector funding for future investments.
- Financial difficulties reducing the confidence in the investment regime (Department of Infrastructure and Transport, 2011).

These intensive impacts impose the necessity of identifying the major sources of demand risk and their impact with an ultimate aim of conducting robust demand risk assessment.

With the remarkable increase in using this kind of arrangement to deliver infrastructure projects, it is apparent that there is a lack of appreciation of the significance of demand risk when preparing and controlling this kind of contracts which tends to be *counterintuitive*. Current practice suggests investment decision makings are based on evaluations which do not adequately consider risk and uncertainty. The uncertainty associated with level of demand receives scant attention at best (Rasouli and

Timmermans, 2012). Most of demand studies tend to present demand estimation as a deterministic figure which ignores any possibility for potential variations (Clay and Johnston 2006; Litman 2009; Welde and Odeck, 2011 and Matas et al., 2010). Factors affecting demand include nontrivial level of uncertainty and they interact in different ways constituting main risk drivers and making uncertainty an inherent aspect of demand level. Lemp et al. (2009) argue that while such uncertainty is not unexpected, it is usually ignored by designers and planners. While minor changes in the underlying factors and assumptions may yield completely different results (Grimsey and Lewis, 2002, 2005; Ye and Tiong, 2000), demand risk assessment is seldom conducted. At best, risk is assessed via univariate sensitivity analysis to evaluate the impact on revenue, rather than demand, for a given change to one input variable, when all other variables are held constant. Financial communities and other institutions consider this kind of univariate sensitivity analysis inadequate to uncover the range of potential outcomes (Kriger et al., 2006). Single value estimates should necessarily be replaced by range values estimates for PPP infrastructure projects (Reilly and Brown, 2004; Grimsey and Lewis, 2005; Reilly, 2005).

In addition, this method ignores interdependency between inputs oversimplifying the estimate and reducing its accuracy. Balcombe and Smith (1999) noted that “Ignoring or underestimating correlations between variables will tend to understate outcome variance”. Sinha and Labi (2007) therefore consider univariate sensitivity analysis method impractical to use when the aim is to assess the impact of change of several correlated inputs which is the case of most demand factors. Most of the factors affecting demand are interconnected. In practice, users’ choice depends not only on fee levels but also on interactions of a host of factors such as quality of service and Willingness To Pay (WTP). In addition, these interactions among the demand factors often show nonlinear pattern. For example, congestion, one of the most significant determinants of quality of service provided by transportation projects, has a non-linear function with demand. A small reduction in traffic volume can provide a considerable increase in speed and consequently a reduction in travel time on highly congested roads. However, the same reduction has smaller impact on the speed when the road is less congested.

Moreover, factors affecting demand are both soft (e.g. public satisfaction) and hard (e.g. GDP). Soft or qualitative factors are often ignored in the studies related to PPP project evaluation and demand model. For instance, Deng (2004) did not assess the impact of

non-financial risk factors in the decision support system developed for PPP project funding and cash flow management. Mackie et al. (2003) criticized the current practices of evaluating PPP projects using cost-benefit analysis method because it is not able to quantify non-monetary factors. There is also reliability which is often ignored when modelling traffic demand on road facilities (Kriger et al., 2006).

Furthermore, factors influencing demand are not constant and they change over time. Socio-economic factors such as GDP is subject to annual changes. In addition, in most of the projects, private operators alter the fee for using the facility on an annual basis. Therefore, the incorporation of these potential changes is necessary to reflect the subsequent change in demand level.

On this basis, this research will focus on demand assessment taking into consideration the uncertain, complex and dynamic features of demand influencing factors. This is by proposing a new method capable of assessing the impact of change in one or more of the influencing factors on level of demand over time. This is likely to help making more informed decision which lowers the risk, reduces the concerns regarding contract renegotiation and lessens risk impacts on the government fiscal position.

### **1.3. Research Aim and Objectives**

The aim of the research is to develop a dynamic model to assess demand risk in PPP projects over the operation period. The model will provide a tool to quantify the effect of different underlying factors on demand level and help evaluate changes in demand over the operation stage. The comprehensive assessment of demand risk will help lessen its impact and reduce the possibility of renegotiations and the need to restructure the contract.

The proposed model will be a useful tool to aid decision-making in PPP projects. The model will enhance the level of confidence that the decision-makers have in the conclusions of an economic evaluation. The model can be used to investigate the feasibility of implementing the proposed facility. It provides a basis to determine whether the proposed facility deserves further investigation. It can also be a pre-feasibility demand estimation tool which provides a kind of benchmark against which

estimations from other tools can be compared as recommended by Boyce and Bright (2003); the procedure which can increase the reliability of the preliminary estimates.

The model is also intended to serve as an assessment and evaluation tool which can be used by several parties over the project lifecycle, as follows:

- Public sector, which is responsible for considering and planning the facility and other complementary and/or competing facilities.
- Private sector, who is in charge of construction, financing and long term operation of the facility
- Financial community which sales the capital debt.
- Credit rating agencies which evaluate the underlying credit quality and which are the most interested in risk assessment.

To achieve the research aim, the following objectives have been set:

- 1- To identify the key factors affecting demand for services provided by PPP projects.
- 2- To identify the relationships between these factors and how they ultimately affect demand.
- 3- To quantify the established relationships between the influencing factors and demand and develop a dynamic simulation model.
- 4- To validate the developed model in terms of structure and behaviour.
- 5- Using the developed model to assess the influences of variations of different factors on demand in PPP projects over the operation period. The M6 Toll road is used as a case study to achieve this objective.

#### **1.4. Research Scope**

The research is focused on PPP concession projects in which the fees paid by users is the main source of revenue.

In addition, the factors influencing demand for service provided by this kind of projects can be social, economic or technical and qualitative and/or quantitative in nature. Most

of the factors are not related to a specific sector, environment or geographical area. Therefore, a conceptual model is developed and validated by collecting data from various sectors of the PPP market. However, the value of these factors and the formula describing the relationships between them vary across sectors. Therefore, the proposed simulation model is developed for one particular type of concession project. Due to their dominance in terms of number of projects and size of investment as discussed in Section 1.1, toll road projects have been selected and further evaluated.

### **1.5. Summary of the Research Methodology**

The early parts of the research includes a comprehensive review of the literature which helped to identify the research problem and the research aim and objectives. Based on the research problem, aim and objectives, the research uses a mixed method of qualitative and quantitative approaches. System Dynamics (SD) is used as a modelling method. SD method considers both qualitative and quantitative approaches in developing the model. SD is mainly used to capture and model the different factors underlying demand and simulating their impacts on the level of demand.

To conduct the research and develop the model, several methods are used for data collection including questionnaire survey, interview and case study. Qualitative data is gathered based on reviewing related literature and interviews of experts. Interviews are conducted to validate the conceptual model, elicit equations, and validate the simulation model. Quantitative data are captured from official statistics organisations such as Office of National Statistics (ONS) and Department for Transport (DfT) and by investigating the case study related documents to develop some of the model equations and validate the model outcomes. The detailed research methodology will be discussed in chapters four and five.

### **1.6. Structure of the Thesis**

The development of the study is depicted in eleven chapters which follow a logical way to address the research objectives. Figure 1.1 shows the outline of the study and the chapters' overview as follows:

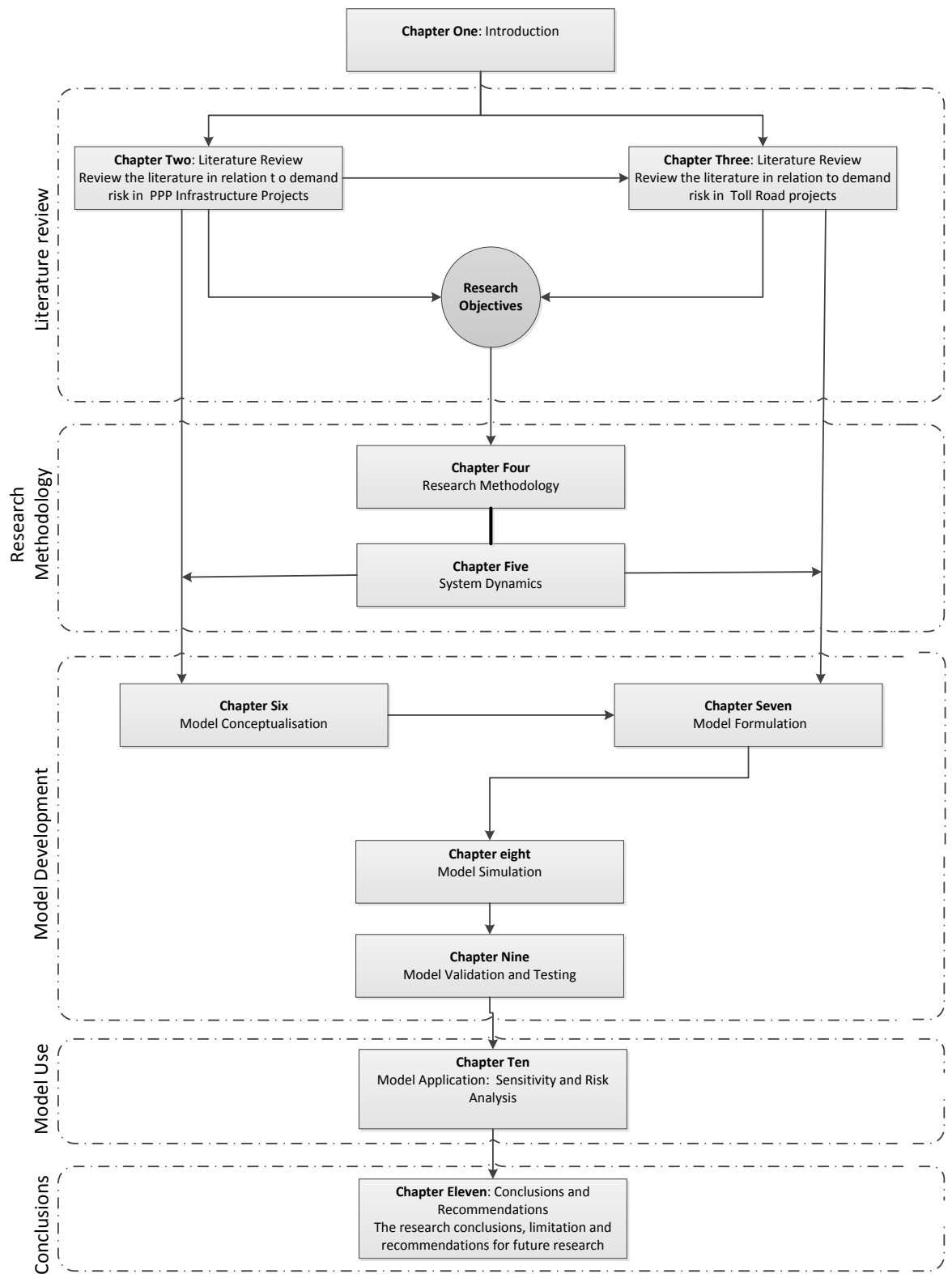


Figure 1.1: Thesis Outline

## **Chapter One: Introduction**

This chapter provides an introduction to the study by introducing the research background, the research problem, the research aim and objectives, the methodology used to conduct the research and the research outline.

## **Chapter Two: Demand Risk in PPP Projects**

This chapter describes the outputs from in-depth literature review of PPP infrastructure projects. It locates concession contracts within the PPP arrangements and document one of its major challenge: demand risk. It continues by describing the problem at hand by documenting the usage performance of PPP infrastructure projects and concludes with the main factors controlling the demand level.

## **Chapter Three: Demand Risk in Toll Roads Projects**

This chapter aims to explore and investigate the demand variation dilemma in toll road projects by reviewing and analysing the relative studies. It starts by providing an overview of toll road concept followed by presenting the significance of demand risk in this kind of projects. It then goes on to discuss the demand traffic variations and the major reasons behind it. It demonstrates the significance of the uncertainty of model inputs and assumptions leading the demand traffic estimation process. It finally concludes with the key methods used to deal with uncertainty of demand estimation.

## **Chapter Four: Research Methodology**

In this chapter, a review of the research methodology-related literature is conducted. The research design frameworks and its key components including research philosophy, research strategies and research methods are outlined. A particular emphasis is placed on comparing qualitative and quantitative research strategies to lay the foundation to select the most appropriate research methodology for the study in question. It then moves to justify the selection of the research methodology adopted and introduces it.

## **Chapter Five: System Dynamics**

This chapter describes the research methodology adopted to conduct the research. It begins by introducing the concept of System Dynamics (SD) and its main principles. The SD model development process for the study is also outlined in this chapter. The chapter concludes with the key methods used for data collection.

## **Chapter Six: Model Conceptualisation**

This chapter focuses on the conceptualisation process of the SD demand model. The chapter begins by describing the approaches and tools used for identifying, validating and prioritizing the key factors to be included in the SD model. The chapter then continues to discuss the methods used to develop and validate the Causal Loop Diagrams (CLDs) to achieve objective 2 of the research.

## **Chapter Seven: Model Formulation**

The objective of this chapter is to provide a quantitative description of the proposed model by formulating the relationships among different factors underlying demand. The methods used to quantify the relationships and develop the algebraic equations were explained. This chapter uses SD tools to develop a quantitative model for demand risk in toll roads projects to achieve objective 3.

## **Chapter Eight: Model Simulation (The Case of M6 Toll Road)**

This chapter makes use of M6 toll road (UK) as a case study to demonstrate the applicability of the model as an appropriate tool to address demand risk in toll roads projects. It begins by providing an overview of the case study and the value of the relative SD model constant variables. The SD model simulation results including demand behaviour are presented and discussed.



## **Chapter Nine: Validation and Model Testing**

Validation process is an important step of the SD model development process. In this chapter, the developed SD model is validated against both its structure and behaviour. SD specified-tests, experts' judgements, and historical data are employed to test and validate the model at hands and achieve objective 4.

## **Chapter Ten: Model Application: Sensitivity and Risk Analysis**

This chapter focuses on proofing the usefulness of the developed model and addressing objectives 5. The System Dynamics model is applied to assess demand risk effects over the operation period. Univariate sensitivity analysis, multivariate sensitivity analysis and Monte Carlo simulation are used. The sensitivity of demand to variations in the underlying factors individually and in combination is thus investigated in this chapter.

## **Chapter Eleven: Conclusions and Recommendations**

This last chapter provides conclusions drawn from the findings obtained and discuss the limitations of the research. It also makes suggestions and recommendations for future research.

### **1.7. Summary**

Concessions are long-term contracts in nature and in which the private sector recovers its investment from user fees. Whereas many countries have extensive experience in this kind of projects, lack of demand for service provided by the facility is still a particular concern. Variations in demand are an inherent aspect of PPP concession projects. While the problem is serious, decision makers are still depending on deterministic figures ignoring the potential dispersion of demand outcomes. Demand is a function of several dynamic and interrelated factors. Minor changes in underlying factors yield subsequent change in demand. This chapter introduced the demand variation problem as the subject matter of this research. The aim and objectives of the research were also set out and

presented. The research scope and the methodology used to deal with the research problem are depicted. The chapter concluded with outlining the structure of the thesis.

## **Chapter Two: Demand Risk in PPP Projects**

### **2.1. Introduction**

This chapter discusses the implementation of Public Private Partnership (PPP) and presents an overview of the use of PPP in the delivery of infrastructure projects. First, the chapter provides a historical background of the origin of Public Private Partnerships. Second, the PPP concept and its main principles are outlined and clarified. The risk profile of PPP projects across all phases is then investigated. One of these key risks, namely demand risk, and its influences is then detected and widely discussed. The chapter concludes with a section on the key factors affecting level of demand for service provided by PPP infrastructure projects.

### **2.2. The PPP Journey**

Infrastructure is essential to the economy development and society prosperity. Well-operating infrastructures offer the basis for the growth and evolution of all other sectors. Under financing fiscal deficits and capital spending cuts conditions, combining with high level of demand for infrastructure, public funding has become insufficient source to meet the rapid increase in demand. In 2007, the Organisation for Economic Co-Operation and Development (OECD) reported that the world will need to spend 2.5% of annual GDP up to 2030 on telecommunications, road, rail, power, and water (OECD, 2007). In the USA, American Society of Civil Engineers (ASCE) Infrastructure Report Card estimated a spending of \$1.6 trillion over the next 5 year for the USA's infrastructure (ASCE, 2005). Siemens (2007) estimated that the public infrastructure requires a spending of €15 trillion worldwide and some €4 trillion in Europe over the next 20 years. For Latin America region, it was reported that an annual spending of approximately US\$50 billion is required in infrastructure investment to maintain current rates of growth (Chrisney, 1996).

To bridge the gap between infrastructure demand and resources, governments worldwide started investigating prospects for introduction of private investments. Various forms of public private partnership, whereby capital projects were procured by the private sector have been established. Nations across the world have witnessed a major growth in the use of PPP over the last two decades and the method has become a main means of funding in many countries. The ninth annual survey conducted by Public Works Financing (2000) reported that between 1985 and 2000 more than 1370 infrastructure projects with estimated investment of over US\$575 billion have been proposed, in the process of being built, or completed under PPP arrangements in around 100 countries. A study by McKinsey (2008) suggested that the private sector raised \$105 billion to fund infrastructure facilities between 2006 and mid-2007. Governments are adopting public private partnerships as a method to deliver additional assets to its education, health, energy, water and wastewater, transport, defence and welfare sectors in order to undertake a larger investment in their infrastructure projects (Akintoye and Chinyio, 2005). The private sector bodies, in turn, have an obligation to make sure that their investment in public facilities is efficient and that they can undertake improvements in the social and economic aspects of community performance (Shen et al, 2006).

However, the notion of involving the private sector in providing public infrastructure is not new. The Suez Canal in the first half of the nineteenth century could be the best evidence. If regarded as a concessionary agreement, Public Private Partnership (PPP) can though be considered to have earlier origins. Mond (1982) stated that the first concession arrangement was in France (1782) and concerned a water distribution project. More recently, starting from 2000, the French government launched many projects under PPP arrangements, such as the Lyon–Turin and the Perpignon–Figueras high speed links. In Hong Kong, the PPP model dates back to the 1950s, when it was used to establish a vehicle tunnel project (Grimsey and Lewis, 2002). Hong Kong may be considered as a leader with many PPP projects in the 1970s, such as the Cross Harbour Tunnel in 1972. Since then, the PPP method has been used for procuring projects in different sectors, including water treatment, container terminals and transfer and disposal schemes. In Australia, the PPP arrangement can be traced back to 1988 and, according to Duffield (2000) PPPs in Australia can be divided into two generations separated by issuing the *Partnerships Victoria* policy by the Victorian Government. Duffield (2000) argues that the first generation was incentivised mainly by the desire of

the public sector to access private sector capital and to shift project risk, while the government's main objective was achieving value for money in the second generation.

In the UK, PPP was first embraced by the Conservative Government in 1992 (Akintoye et al., 2003). At the start, most of the projects were in the transportation sector, in particular the construction of the Channel Tunnel. Private Finance Initiative (PFI) of PPP, in which the private sector recovers its capital investment through regular payment from the government, has been promoted to be the most preferred method to procure public sector infrastructure and UK can be considered the world leader of this method. This situation did not change with the election of the Labour government in 1997. The main aim was to incorporate the private sector into providing public infrastructure and services. The reasoning behind this was first to bring the private sector experience and management skills to help accomplish the public facilities, and second because PFI was considered as a tool for decreasing the government's debt and spending. By the end of 2006, UK has signed a total value of PPP contracts of €63,668 million (Siemens Financial Services, 2007).

The European Commission, in turn, had realised the significance of PPP approach. It sought, therefore, to encourage the use of PPP programmes with its grant mechanism. It funded many large projects in Portugal, Greece, Netherland, Italy and Ireland (Horner, 1999). Private investments has totalled €6,471 million in Italy, €2,51 million in Spain, €2,043 million in France and €1,475 million in Germany by the end of 2006 (Siemens Financial Services, 2007).

In addition, developing countries sought to pursue the developed nations' line by involving the private sector, either domestic or international companies, to provide public sector assets. Kikeri and Kolo (2005) state that 7,860 biddings between 1990 and 2003 were undertaken in 120 developing countries, generating about £295 billion or 0.5% of a total GDP of developing country at that time. In Indonesia, for example, after 1990, the international aid was reduced and the government spending for public facilities became extremely difficult. Therefore, since the mid-1990s, public infrastructure funding has included private contribution in facilities delivery (Chang and Imura, 2002). In Malaysia, the privatization policy was embraced in 1983 in order to decrease governmental financial burdens, improve efficiency and productivity, and promote economic growth. Many types of PPP such as Build, Operate, Transfer (BOT)

and Build, Lease, Transfer (BLT) have been used (Abdul Rashid, 2007). However, it was formally applied in 2006 when the Malaysian Government established the PPP Central Unit in order to smooth the progress of the implementation of PPP on the public sector projects (Jayaselan and Tan, 2006).

Many other developed and developing countries are now in a race to adopt the PPP concept as a cure to their socio-economic weakness. The PPP approach has become the first option on the agenda of many governments for procuring public sector infrastructure. Several frameworks for a wide range of infrastructure facilities such as roads, rails, airports, schools, hospitals and prisons have therefore been initiated.

### **2.3. Main PPP Principles**

PPPs can be defined as the integration of public sector clients and private sector providers, allowing the private party to undertake the functions of design, finance, building, operation and maintenance of capital assets under contractual terms and conditions based on service provision rather than facility provision (Grimsey and Lewis, 2002). Under PPP contracts, the private sector is required to design and build the asset according to specifications agreed to by the public sector, operate the asset for the duration specified in the contract and when the contract expires, transfer the asset (if that is agreed when forming the scheme which is the case for most projects) to the latter party (Akintoye and Chinyio, 2005). The PPP concept is therefore based on purchasing services, rather than assets, for a long term and taking advantage of the private sector in terms of its experience and management skills. It also has a principal motivation of transferring financial risk from the public sector procurer to private sector provider. The attractiveness of PPP for public sector clients comes from its ability to offer the possibility of “off balance sheet” accounting (Akintoye et al, 2001). The PPP form of procurement allows the transfer of expenditure from the public budget to the private sector, relieving governments from a considerable amount of public debt caused by the reduction of the public money proportion tied up in assets investment.

PPPs are typically commissioned by an awarding party, and undertaken by a consortium (Pitt and Collins, 2006). The public sector client (the awarding party) is responsible for procuring the project. The public sector’s main objective is to achieve value for money

by transferring the risk related to both the asset accomplishment and service provision to the private sector (Fox and Tott, 1999). On the other hand, a PPP consortium is established especially for one PPP project or more with the aim of achieving a profitable return on their investment to invest in future infrastructure and pay capital debit and shareholder dividends. This kind of consortium as defined by Jefferies and McGeorge (2009) is a temporary establishment with a complicated synthesis of stakeholders each with own objectives, is responsible for delivering a capital asset and some services. It typically includes multiple organisations such as contractors, financiers (senior debt and equity) and facility management organisations. These joint ventures are usually called Special Purpose Vehicles (SPVs).

The PPP approach places stress on innovation by encouraging participants to provide the best solutions in order to meet the public sector requirements faster and at lower costs; thus, simultaneously with risks and rewards sharing, ‘win-win’ solutions will often be obtained (Parker and Hartley, 2003). Edler and Georghiou (2007) argue that PPP can be regarded as a procurement method for bringing creativity to meet the needs of the public sector in terms of assets and services. In addition, Barlow and Giaser (2008) stated that PPP is a method for modernising the public sector infrastructure, and a government’s demand for infrastructure can be regarded as an incentive for innovation. The whole-of-life-cycle method provided by PPP procurement is designed to create a single point of responsibility for the total project from inception to operation. This long-term responsibility can be considered as a strong motivation for the private sector to consider the impact of design and construction decisions on the efficiency of operation process and on the costs of managing and maintaining the asset. Consequently, the private sector will strive to provide the most innovative and efficient solution. Architecture, Engineering, Consulting, Operations and Maintenance (AECOM) Company (2007) supports this view and suggests that PPP provides *“increased incentives for the delivery of a higher quality plan and project because the contractor is responsible for the operation of the facility for a specified time period after construction”*.

In addition, the private sector is normally able to deliver services and perform the operational process in a more effective way by employing its experience, expertise, modern technology and continuous improvements (HM Treasury, 2003). This capacity contributes not only to decrease the cost of design and construction but also the

operation cost-distributed over 25 years or more- which is often estimated to be 10 times higher than the capital cost (Barlow and Gaiser, 2008). The Ministry of Defence (MoD) in the UK has reported that using the PPP approach to procure its project resulted in a cost saving of between 5% and 40% when compared with traditional procurement methods (Parker and Hartley, 2003). In addition, a survey by Ive et al. (2000) showed that the total cost savings for 67 PPP projects is between 5% and 10%, compared with traditional public procurement. Moreover, the National Audit Office (NAO) in 2001 estimated 20 percent cost savings of 15 investigated PPP-projects (NAO, 2003). However, the public sector client does not gain the benefits of employing the PPP alone. Pitt and Collins (2006) stated that the private sector can achieve from three to ten times more profit from PPP compared with the profit made from traditional methods. This increase in profits can largely be attributed to the amount of equity grasped in the consortium carrying out the PPP project.

Another benefit of PPP highlighted through many investigations is delivering the project on time and within budget. The practice proved that, under the public private partnership, the project's performance in regard to achievement of the work within time and to the agreed price is considered to be a significant improvement if compared with projects procured in a traditional method. The National Audit Office in the UK reported in 2003 that around three quarters of PPP projects had been delivered on time and according to budgeted cost as shown in Table 2.1 (NAO, 2003).

Table 2.1: Comparison between Traditional and PPP Projects

	<b>Traditional (%)</b>	<b>PPP (%)</b>
Projects over budget	73	22
Projects late	70	24

Source: (NAO, 2003)

These findings highlight the significant discrepancy between PPP and conventional procurement with regard to time and cost performance. This can be attributed to the fact that the payment stream in the PPP method does not normally start until the project has been transferred for use and met the requirements. This paying system encourages the private sector to complete the construction of the project as quickly as possible in order to collect the revenue from the authorities as unitary charge (stream of payments) or directly from the end users as fairs or tolls. Many other countries, such as Australia,



have led many successful examples proving the efficiency of PPP method. Among these projects are: Sydney Airport which was accomplished 4 months early and \$30 million under budget, providing an entire saving of \$200 million, and Australia Prison which was accomplished 12 weeks early and under budget, saving a total of \$3 million (Jefferies and McGeorge, 2009). Bangkok's skytrain (Thailand) is an urban rail line with 30 years concession period. The project was completed one month ahead of schedule and with no cost overrun.

However, the PPP method is widely criticized because of the complexity of project requirements and the long-time consumed in the negotiation and bidding process; the negotiation between the scheme advisers and public sector client about the contract conditions and preparing the contractual documents can take extensive time. In addition, the contract transaction process can cause lengthy delays and high participation cost (Li et al, 2005). Birnie (1999) highlighted the fact that the tendering cost for UK PPP projects is significantly higher than that of any other procurement method. The high bidding cost can be considered as one of the negative aspects of the PPP approach. These extensive costs can be largely attributed to the high legal and advisory costs associated with PPP projects, as well as to the considerable costs required to pay the fees of the lawyers involved at all project stages. Jefferies and McGeorge (2009) stated that the legal cost associated with PPP projects is extremely high, and can be considered as a hurdle to private sector bidders. The National Audit Office reported that the cost of PPP contract negotiation to deliver healthcare facilities was estimated to be seven times higher than for traditional tendering and advisory costs, representing about 3 percent of the capital cost (cited in Akintoye and Chinyio, 2005).

Furthermore, Ruane (2000) maintained that the critics of PPP consider this method to be controversial and complicated to the construction of the infrastructure for the public sector client. In addition, Li et al. (2003) argue that the development of public sector projects by using PPP is still new; there is, therefore, a lack of appropriate skills, poor understanding of the concept and limited PPP experience in both private and public parties. A survey by Li et al. (2005) for fifty three PPP projects in the UK proved that PPP is mainly dominated the large scale projects. The result of this survey showed that only 15% of the construction costs and 13.2% of the operation costs are under £10 million. These mega projects require high managerial and financial capacities, which increase the complexity of the PPP arrangements method as well as forming an

impediment for engaging the small and medium private companies in this type of contract. In addition, as a result of its complexity and the high cost for small projects and the tight output specification required for other projects, Grimsey and Lewis (2005) argue that PPPs are not, and unlikely to be, the most dominant way for procuring public sector projects. These conflicting perceptions for PPPs create complications in the task of participants involved in preparing the business case and, consequently, in the decision-making process for using this method for delivering public sector projects in general (Bing et al, 2005).

Moreover, as governments can usually borrow more cheaply than the private sector, it is of the utmost importance that PPP offer high level of cost savings that can compensate additional funding costs by the private parties (Parker and Hartley, 2002; Froud, 2003; Grimsey and Lewis, 2005). Only in this case can the project offer value for money.

Value for money (VFM) is the key reason for governments seeking to procure their infrastructure projects by using the PPP method. The public sector client argues that PPP can provide better value for money than traditional procurement routes (Khadaroo, 2008). Cheung et al. (2009) claim that in PPP projects, VFM is achieved by reducing the lifecycle costs of the whole project. However, Ball et al. (2003) argue that many PPP projects offer better value for money only because of the risk allocation. VFM is primarily achieved by optimal risk allocation between the public and the private sectors and through involving the experience, expertise and innovation offered by the private sector (HM Treasury, 1997, 2006). Moreover, a survey by Li et al. (2005) which included PPP participants from both the public and private sectors stressed that efficient risk allocation is considered to be the top value for money measure in PPPs. The UK government guideline on PPP recommended that the allocation of risks in PPP projects has to be based on the principle that the risk should be borne by the party best able to manage and control it, and this party should take responsibility for the risk in order to undertake the most optimal cost (HM treasury, 1997, 2003). It is crucial, hence, for the public sector client and the private sector provider to identify and assess all potential risks throughout the entire life of the project.

## **2.4. Risk Classification in PPPs**

Construction projects are complex, chaotic and dynamic (Baccarini, 1996). Construction projects are therefore associated with risk over all the stages, starting from conception and briefing through the design and construction phase. The HM Treasury defines risk as “uncertainty of outcome whether positive opportunity or negative impact” (HM Treasury, 2003). The longer term of PPP contracts requires the consortium to offer a long-term plan for the operation and control process and to introduce mechanisms to manage risk more efficiently. Akintoye and Chinyio, (2005) state that in PPP projects, risk management is fundamental and should be performed in order to ensure and maintain the best efficient operation of the facility. The financier, in turn, will examine the consortium’s plans before finalising the funding arrangements. This pre-contract scrutiny of PPP projects by the external funder is to increase the potential of PPP projects to be delivered on time, within budget (Shen et al., 2006) and the overall viability.

Shen et al. (2006) argue that the failure to identify and monitor risks efficiently may yield grave results, including poor quality, cost over-runs, schedule delays and protracted disputes. Li et al. (2005) suggest that realising value for money objectives in PPP projects requires the public and private sector parties to identify and assess all relative risks which may arise during project lifecycle in order to reach a satisfactory risks allocation framework.

Major risks in PPP come from the complexity associated with this kind of contract in terms of technical requirements, legal issues, finance and the large number of parties involved (Loosmore et al., 2006). Several studies have been performed and detected to identify and sort the different risks related to PPP projects.

The typical risks associated with PPP project have been identified in the PPP guidelines (HM Treasury, 1995) and classified by the UK Treasury Taskforce (1999) as illustrated in Table 2.2. The identified risks can be related to political, legal, economic, social conditions and the relationships among them.

Ng and Loosemore (2007) divided the risks associated with PPP projects into two main categories: project risks and general risks. Project risks are related to the way in which

the project is managed. These risks can include natural risks, design technical problems, plant/equipment/materials supply problems, etc. On the other hand, general risks do not have a direct relation to the project strategy, but they can significantly affect its outcomes. These risks usually arise from legal, economic, regulatory and political events in the broad environment surrounding the project. Ng and Loosemore went further and divided the risks relating to PPP projects into more specific groups, including credit risk of the public sector entity, construction risks, revenue structure, operating risk and financial and legal structure.

Moreover, Grimsey and Lewis (2002, 2004) defined nine collections of risk relating to PPPs: site risks (site conditions, site preparation, land use), technical risks, construction risks (cost overrun, delay in completion, failure to meet performance criteria), operating risks (operating cost overrun, delays or interruption in operation, shortfall in service), quality revenue risks (increase in input prices, changes in taxes, demand for output), financial risks (interest rates, inflation), *force majeure* risk (flood, earthquake, war), regulatory/political risks (change in law, political interference) and project default risk.

Li et al. (2005) divided risks associated with PPP projects according to their relationship with the project into three tiers: macro risks which could arise outside project's boundaries (economic, political, social, ecological, etc.), meso risks which have a direct relation with the project nature (project-engineering) and micro or soft risks which concern about the relations between the project parties.

Despite the wide scope of the studies into risk in general (Heravi and Hajihosseini, 2012; Abd Karim, 2011; Jin and Zhang, 2011; Ke et al., 2010; Cheung, 2009; Zou, 2008; JIN and Doloi, 2007; Medda, 2007; Ng and Loosemore, 2007; Shen et al., 2006; Akintoye and Chinyio, 2005, Grimsey and Lewis, 2004, 2002; Li et al., 2005, Froud, 2003; Arndt, 1998; Zhang et al., 1998; Vega, 1997), only a few attempts have focused on studying the impact that risks may have on the PPP project viability. Fewer studies were even devoted to assess the sources and impact of most important risks such as demand and revenue risks. An example of this is the study by Li and Ren (2009), who adopted Bayesian techniques to provide a method for allocating demand risk in PPP projects to better assign risk management responsibility between the public client and the private partners.

Table 2.2: Risk Classification in PPP Projects

<b>Risk Type</b>	<b>Description</b>
Availability risk	The risk that the services being provided are under the required level agreed in the contract.
Design risk	The risk that the design will deliver services at poor performance, otherwise it does not meet the required quality
Construction risk	The risk that the construction of the facility will not be accomplished on time, within budget or according to required specifications.
Legislative risk	The risk of cost increasing as a result of changes in legislation.
Demand risk	When the service demand does not match the expected level.
Inflation risk	When the real inflation rate is different from the predicted inflation rate.
Occupancy risk	It is a type of demand risk when the facility remains untenanted.
Planning risk	When the project implementation does not achieve the planning permission terms.
Technology risk	The risk that the technology development makes the services being delivered by non- most advantageous technology.
Operational risk	When the operating cost is higher than budget, the performance is under standard or the service cannot be delivered.
Policy risk	The risk of policy change.
Residual value risk	The uncertainty associated with the facility's value at the end of the concession's duration.
Maintenance cost	When the real cost of maintenance is higher than the budgeted one.

Source: (UK Treasury Taskforce, 1999)

## 2.5. Demand Risk Allocation in PPPs

Whatever the nature and categories of the risks, the significant concern in PPP is that those risks are assessed and assigned to the party best able to manage them. Froud (2003) argues that the public sector struggles to divest itself from the risk related to public facilities and services delivery and operation. However, the level of risk transferred from the public sector to the private sector as a result of using PPP procurement should be optimal. Official guidance states that not all risks related to PPP projects must automatically be transferred, but that the goal is to make sure an “optimal allocation” which can increase VFM (Treasury Task force, 1997). The need for achieving VFM by the public sector come, in most cases, into conflict with private sector’s requirement for a strong revenue stream to recover its investment. Therefore the public sector should decide, on a VFM basis, which risks it has to bear in order to provide best risk allocation. In any PPP project, all the potential risk are assigned or shared efficiently between the public and private partners. There is such an agreement between researchers that a majority of PPP projects risks will be allocated to the private party. The survey by Li et al. (2005) highlights the fact that (70%) of the risks should be allocated to the private partner. The public and private sectors would share those risks that one sector may be not able to manage alone. Therefore, the two parties together should commit and develop an efficient shared mechanism to deal with these kinds of risks. These risks could include lack of commitment from a partner, responsibilities and risk distribution and authority distribution between partnerships, changes in legislation (Li et al., 2005) development risks, market risks, financial risks and *force majeure* risk (Shen et al., 2006).

However, there are so many risks that it is difficult to allocate them to one of the parties. In addition, the allocation process of these risks will involve many exceptions and will depend greatly on the nature of the project (Medda, 2007). One of these risks is demand risk where the facility functions at low level of demand.

Vassallo (2007) suggests that demand risk is the most significant risk and the most difficult to manage in PPP infrastructure projects. Demand risk is identified as “the possibility of unforeseen variations in the demand for services generated by a project” (Quiggin, 2004). Norton Rose international legal practice conducted a survey in 2006.

The major aim of this survey was to identify the significance of different risk category associated with PPP contracts in economic projects including toll roads, sea ports, airports, heavy rail and mass rapid transit projects. The questionnaire target was PPP projects' stakeholders across Asia infrastructure markets. The survey results showed that, out of 10 types of risk listed, demand risk was identified as the most critical risk facing the project partners, regardless of the country or the sector (Norton Rose, 2006). In addition, similarly, Chung et al. (2010) investigated the risk perceptions of different stakeholders of toll roads in Australia via unstructured interviews. Chung et al. (2010) reported that all the participants agreed the traffic demand risk is the greatest risk in toll road projects. Mouraviev (2012) argues that due to long period of time over which demand and revenue need to be estimated revenue risk (or demand risk) is one of the most common and most difficult to assess. Viegas (2010) suggests that in PPP motorway contracts, the main risk is related to demand. Siemens Financial Service (2007) considered demand stability as one of the key success factor of PPP projects which raises the significance of this risk and its allocation.

As mentioned above, the allocation process of some risks in PPP projects depends on the nature of the project. Demand risk allocation in PPPs differs according to the financing model employed to deliver the facility. The allocation depends mainly on the payment mechanism in the PPP contract; this may requires transfer all, some or none of the demand risk to the private operator (EPEC, 2012). Alfen (2009) suggests that, based on the financing mode, PPP can be divided into two main categories; budget-financed and user-financed models. Under the former model, the private sector is recovering its initial investment by getting performance-based payments from the authorities. Users utilise the facility like any other public one; inattentive that it is financed and operated by a private company. Since the private sector receives availability-based payments from the public sector, demand risk is shared between the two parties. While under the second approach, the private sector operator has its capital investment recovered through receiving payment directly from the end users. The payments could take form of tolls, vignette, licensing fee, water tariffs and ticketing. Since the concessionaire has overall responsibility for the system, including operation and payment collection from the users, it accepts the risk that demand is not met and consequent revenue is less than its capital investment. Demand risk is, thus, totally allocated to the private company. However, in some cases, the public sector may share demand risk with the private sector. This is typically done based on the contract arrangements such as: a guaranteed

minimum usage for the facility, a minimum return on investment or flexible term concession. This kind of guarantee is safeguards which provide the concessionaire assurances to finance its obligations and maintain a reasonable rate of profit in the case that the facility suffered from poor performance in terms of usage. However, this kind of demand risk mitigation mechanism can cause transferring the demand risk back to the public. For instance, between 1994 and 1997, the Colombian government granted 11 concession contracts for constructing and operating 1,595 km of roads. On average, the actual traffic was 40% lower than expected. Because of minimum income guarantees, the Colombian government was obliged to spend high sums (Carpintero and Barcham, 2012). In 2000, the amount paid by the government equalled to 0.017% of GDP (Benavides 2008 cited in Carpintero and Barcham, 2012). Beato (1997) argues that this kind of guarantees is not likely to lessen the overall project risk because they transfer demand risk into credit and political risks. In addition, it is argued that this kind of guarantees is likely to weaken the private sector initiative as risk is significantly restricted (Roumboutsos and Macario, 2013). In this latter model in which the user fares are the main source of revenue, the private sector finances the project using the project's anticipated revenues rather than relying upon a direct sovereign guarantee for the project. This kind of PPP arrangements is broadly known as concession contracts and is the focus of this research.

## **2.6. Concession Contracts**

The notion of charging the public for using infrastructure facilities (e.g. toll roads) is not new (Hensher and Puckett, 2005). Concession contracts have been increasingly employed to deliver many large scale and capital-intensive public infrastructure projects such as toll roads, ports, stadia, power stations and water utilities (Evenhuis and Vickerman, 2010; Zhang and Kumarswamy 2001). The World Bank (1997) reported that concession contracts accounted for about 50% of overall PPP contracts and 80% of the PPP investment, making them the most popular type of PPP arrangements. Chiu and Boshier (2005) argue that this model of financing infrastructure projects is particularly favoured by the public sector for contracting water and wastewater services, as it allows a radical change to the sector without relinquishing facility ownership. Choi et al. (2010) stated that the excessive demand for new water facilities was the reason behind the dramatic increase in instances such procurement method for the purpose of



delivering water facilities throughout China. Evenhuis and Vickerman (2010) and Bain (2009b) suggests that concession is the most dominant model for financing highway projects worldwide. A research by Siemens (2007) indicates that there is a global trend toward pay-per-use charging for public service provision. Seimens Financial Service regards this kind of financing models as becoming essential to implement governance and accountability. Perrott and Menzies (2013) suggest that new light rail schemes are often covered by this kind of long-terms contracts. In 1988, the Chilean government introduced a new regulatory regime for water and sanitation aimed at allowing the private sector to finance the most needed facilities by charging prices that cover both operational and capital cost (Bitrán and Valenzuela, 2003).

A concession is a long-term (often 30 years or more) contractual agreement between public and private sector partners by which the private sector is responsible for all investment and operation. To recover its capital investment, the private company obtains its revenues through a fee charged to the end users over a predetermined period. In the end of the concession period, the asset reverts to the awarding authority. Figure 2.1 shows the structure of a typical concession scheme. A concession project typically encompasses three key parties: the awarding authority; the Special Purpose Vehicle (SPV)/concessionaire and third party funders (equity and loan). Concession schemes include the task of designing, constructing, financing and operating the facility for a predetermined period of time undertaken by the private sector. To achieve this, the private sector borrows the capital investment necessary to build and operate the assets. A PPP contract is usually funded with a senior debt to equity ratio of 90:10. This ratio is, however, affected by the degree of risk associated with a specific project, and it could be 80:20 or more for higher risk contracts (Parker and Hartley, 2002). The senior debit constitutes the majority of the project fund and it is usually provided by banks or other financial institutions. On the other hand, the equity capital is usually provided by shareholders in PPP projects, such as construction contractors and facility operators. This integration of funders in finance provision can provide motivation for them to create a whole-of-life cost effective asset and seek the best performance. This investment is intended to be reimbursed by the revenue collected from the fee charged to the end users, who are the main source of revenue for the concessionaire, over the concession period.

Despite the successful implementation of most concession contracts, in delivering the project on time and within budget, there are still some financial difficulties faced during the operation stage that may affect the success and overall viability of projects. The sluggish usage performance of many of these projects results in demand risk being a serious concern. Even though concession projects can be considered as attractive investments for the private sector, the financiers and other project parties' exposure to demand risk can significantly reduce their attractiveness. Chiu and Boshier (2005) argue that the demand risk in the water provision service, where users are charged on the basis of water usage, is a main concern for the service provider (private sector). Ward and Sussman (2006) consider traffic demand in toll road PPP projects as the main risk factor which is not easy to assess. Cruz and Marques (2013) suggest that construction cost and demand are the main uncertainties facing PPP contracts.

The dominance of concession model put particular emphasis on the need to efficient demand risk management. In addition, since the revenue for concession projects is basically based on service demand volume, any risk associated with demand in the operation stage will be translated into revenue risk which increases the significance of this risk.

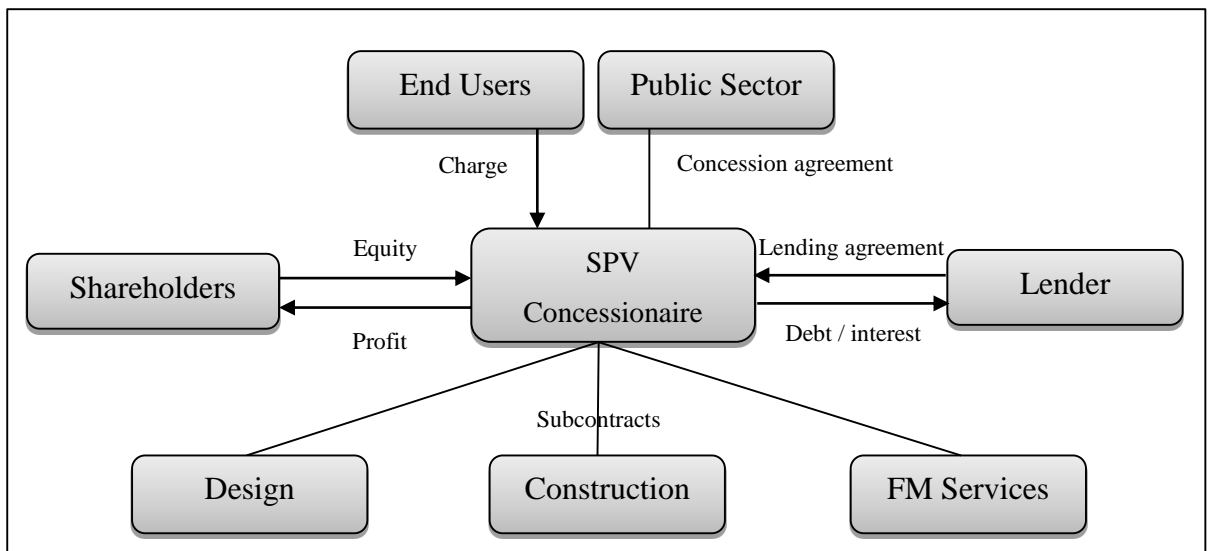


Figure 2.1: Typical PPP Concession Scheme

## 2.7. Demand Risk in PPP Concessions

Owing to the long term nature of concession contracts, ensuring stable demand for the service provided by the PPP facility has been identified as one of the key success factors of PPPs (Siemens Financial Service, 2007). The European PPP Expertise Centre (EPEC) (2012) reported that in case of PPP infrastructure projects “*demand risk relates to insufficient user volumes compared to base case assumptions*”. Variations in demand volume have been observed over a wide range of PPP infrastructure projects. The following section introduces examples for major facilities in key sectors which suffered from less than predicted demand and faced demand risk.

Channel tunnel between the United Kingdom and France is well documented example. The actual number of passengers that used the facility in its first year of operation did not exceeded 25 percent of that forecasted by the concessionaire. In 2003, after 10 years of operation, the facility actual revenues were only about third of the predicted level (Booz&Co, 2012).

Sydney Airport railway Link is another PPP project which has faced financial troubles due to less than forecasted demand. For this project, it was expected that the railway would be utilised by 48,000 passengers per day; however, the usage level averaged 12,500 passengers per day (Zou et al., 2008).

Bangkok’s skytrain, an urban rail line and is the Bangkok’s first private mass-transit concession, was designed with a capacity of up to 25,000 passengers per hour per direction. The system was thus expected to carry between 600,000 and 700,000 passengers per day for the first year of operation in 2000. However, the actual utilisation turned out to be less than quarter of the forecasted figure. Only 150,000 passengers used the train per day. The daily ridership improved overtime but it is still less than half the expected figure. In 2006, the ridership averaged about 350,000 passengers per day (Verougstraete and Enders, 2014; Spicer, 2006).

Orly val light rail system is a 30-year concession contract. The system links Paris’s Orly airport to the Réseau Express Régional train network in Paris (France). The concession contract needed financial restructure shortly after project opening for operation and was finally terminated and transferred to publicly owned company due to the actual ridership

being so low. While the system was designed to serve four million passengers per year, it eventually carried around 1.5 million passengers per year (Perrott and Menzies, 2010).

STRA (Sistem Transit Aliran Ringan) and PUTRA (Projek Usahasama Transit Ringan Automatik) are two Light Rail Metro Train (LRMT) concession contracts in Kuala Lumpur (Malaysia). For the two schemes, the actual ridership well lagged in relative to the initial expectations. STAR system averaged 49,468 passengers per day in comparison to 170,000 passengers predicted per day. As for PUTRA's route, usage performance was a bit better than that of the STAR system, yet initial patronage was still well less than expectations. Roughly 40,188 users per day used the system in the first year of operation (1998) which was less than half the expected figure. The two projects ultimately failed due to inadequate revenues and inability to repay debt. A public owned company finally purchased the systems (Perrott and Menzies, 2010).

Metro Sul do Tejo is 22 Km Light Rail Tram service in municipalities of Almada and Seixal (Portugal). The 30 years concession contract between the Ministry of Finance and Public Procurement and Public Works (IMTT) along with the local municipalities of Almada, Seixal and Barreiro and Metro Transportes do Sul S.A. (MTS) started in 2002. The concession contract was subject to renegotiation in 2011 due to lower than expected ridership. Actual patronage has been well below projections as shown in Table 2.3. The actual ridership in 2009 and 2010 accounted for 28.1% and 33.2% respectively of the projected traffic (Roumboutsos et al., 2013).

Table 2.3: Forecast vs Actual Passenger kilometres

<b>Passenger-km (M)</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>
Expected	16,14	88,06	88,23	88,68
Actual	1,89	24,73	29,33	32,26

Source: (Roumboutsos et al., 2013)

The Lane Cove Tunnel is a 3.6 kilometre tunnel in Sydney (Australia). It is a 30 year concession. The tunnel was completed and opened to traffic in 2007. For the first year of operation, it was predicted that about 100000 motorists will ride the scheme with an increase to 120000 in 2010. However, this figure did not materialise. The traffic was very much less than originally estimated. Only 40000 and a round 50000 users utilised

the facility in 2007 and 2010 respectively (Department of Infrastructure and Transport, 2011).

The expected traffic volume of Sydney Cross Tunnel, another example from Australia, was estimated at 35,000 vehicles per day at the initial uptake and to be 90,000 by the start of the second year of operation. While the tunnel reduces the travel time from 20 minutes to about 2 minutes, this expectation was not materialised and only 20,000 vehicle motorists have used the tunnel per day (Zou et al., 2008).

The Dulles Greenway is one of the first private toll road in the USA connecting Washington Dulles International Airport with Leesburg in Loudon County, Virginia. It is a critical transportation link in the region's infrastructure. The project was opened in 1995 after it was completed 6 month ahead of schedule. It was predicted that 34,000 vehicles will use the facility in the first year of operation. However, the actual patronage figure lagged behind by over one third (Sader, 2000). When the projected traffic did not materialise, the toll rate was decreased from \$1.75 to \$1 to attract more traffic. The traffic increased by 80%. Even with the resulting increase in traffic volume, the project was however losing money owing to less than predicted revenue (Spock, 1998).

Larnaca and Paphos Airport is the largest commercial international airport in Cyprus. The concession agreement was awarded the "Best Transport Project in Europe" in the competition for "PPP Awards 2013" by World Finance. Nevertheless, this project has suffered from less than predicted demand. The project demand was predicted as 8,5M, 9,0M and 9,5M passengers will use the facility in the 2012 under low, base and high case scenarios respectively. Yet, none of these scenarios have been materialised. The actual usage of the Larnaca & Paphos Airport averaged 7,5M passengers in 2012 (Roumboutsos et al., 2013)

In 1993, Aguas Argentinas started operating a 30-year concession contract as a private sector consortium for water and sanitation provision in the Buenos Aires area (Argentina). The concessionaire installed networks without determining potential consumers' willingness to pay for services. The majority of the costumers were living in poor areas and the tariff was simply not affordable and people refused to pay them. By the end of 1996, shortfall in revenue reached US\$ 30 million which forced the

concessionaire to suspend service leading to the renegotiation of the contract (Zerah, and Harrison, 2001).

In 1993, a U.S. \$1.6 billion concession agreement for the development of a national sewerage system was signed between the Malaysian government and Indah Water Konsortium (IWK) for 28 year concession period. IWK set the tariff for providing the service. Public resentment arose over imposed tariff and public refused to make payments for sewerage charges. Over 33 months, the private sector claimed to have lost about U.S. \$46.5 million. After 7 years of difficulties, the government purchased the facility in 2000.

Moreover, Flyvbjerg et al. (2005) investigated 210 transport projects including 27 of rail facilities and 183 tolled and non-tolled road projects (170 highways, 10 bridges and 3 tunnels) in 14 countries. The collected data covered the forecast and actual usage for the first year of operation. The results showed that passenger forecasts for nine out of ten rail projects are overestimated with an average of 106%. The actual number of travellers on 22 urban rail projects averaged 50.8% lower than predicted. The number of travellers for 75% of those projects was at least 40% lower than forecast, and only two schemes achieved the predicted demand. The work concluded that urban rail project actual demand is frequently far from projections. The study findings went along with a study conducted by US DOT in 1989. The US DOT study included ten heavy and light rail transit facilities in 9 USA cities. By comparing the actual and forecast ridership for each of this facility, the study concluded that the actual ridership is well below that forecasted (reported by Kriger et al. 2006).

For road projects, on average, an underestimation of about 9% has been recorded. The findings revealed that over 50% of transportation projects average a  $\pm 20\%$  discrepancy between actual and forecasted demand. The variations were larger than  $\pm 40\%$  for 25% of road facilities.

While the analysis by Flyvberje did not make any clear comparison between data related to different forms of procurement for the project delivery, or in other words, it did not differentiate between traditional and PPP projects outcomes, it provided a useful basis to identify potential demand variations in infrastructure service.

Naess et al. (2006), however, analysed the toll road data in Flyvbjerg et al. (2005) sample. For 7 toll roads investigated in Europe, the results show an average of 6.1% overestimation. However, an overestimation of 42% was reported for a sample of 14 toll roads in the USA. This analysis shows an obvious trend toward overestimation when compared to the whole sample where most of the roads are free facilities. Several other studies were conducted to assess such variations in toll roads as it will be further discussed in next chapter. Flyvbjerg (2005) argued that projects in other sectors-rather than transportation- are as liable to demand variation as are transportation projects.

Demand is the key player in deciding whether the project is viable or not. This kind of demand variations has resulted in most of concession contracts had to be renegotiated or become high-profile failures. Estache et al. (2008) and Roumboutsos and Macario (2013) reported that demand variations were the main source of PPP contract renegotiations.

Concession contracts always suffer from renegotiation (Guasch, 2004; Ho, 2004; Guasch et al. 2007, 2008; Engel et al. 2003, 2009; Marques and Berg 2010; Cruz and Marques, 2013). Guasch (2004) analysed a data set of more than 1,000 infrastructure concessions (telecommunications, energy, water and transport) in Latin America and Caribbean. On average, it was found that 40% of all studied project were renegotiated. The highest rate of renegotiation was relative to the water sector contracts (76%) and of the transportation contracts (53%). Furthermore, Cruze and Marques (2013) examined 87 infrastructure projects in Portugal, data were collected with respect to roads, rails, ports, water and waste water and energy. The study found a high rate of concession renegotiation where 67% of the concession contracts investigated were subject to renegotiation. This rate was particularly high with respect to transport and water contract where 100% of these contracts were renegotiated. Cruze and Marques (2013) identified two main reasons for renegotiation. These include the government inability to force the contractual agreement and variations in demand.

This kind of renegotiation which most often leads to restructuring the concession contract has become an inherent aspect of PPP infrastructure when the facility fails to generate the anticipated revenue and consequently it is unable to meet the requirements of the lenders and equity owners. In most cases, the renegotiation will lead to the capital costs needed to be written off either by the public sector in the form of governmental

payments or facility purchase or by the end users in the form of higher tariff or longer concession period. This implies the transferring of the demand risk back to the end users or the public party. In addition, the government or the end user will often carry the expensive cost of concession contract renegotiation process itself (Cruze and Marques, 2013). Mexican toll roads are a well-documented example. Out of 52 toll road concession (The 5,000 Km) awarded between 1987 and 1995, 23 projects witnessed a high profile failure due to traffic variation and cost overrun mainly. However, the government had the obligation to rescue the projects where about US\$5 billion was paid to the banks and 2.6 billion to the private company (Li and Hensher, 2010).

The aforementioned examples and discussion suggests that the problem of demand variations and consequent contract renegotiation is relatively serious in transportation sector. Emphasis therefore needs to be put on the sources and impact of demand risk in such projects.

Demand variability is the consequence of variety of factors and their interactions. Demand can be dramatically influenced by economic conditions, policy, and competition. These interrelated issues, which carry a significant level of uncertainty, represent a major risk threatening demand. Vassallo (2007) argues that demand change with the changes in the surrounding environment such as population, employment, user's fee and incomes of potential users. Next sections discuss in details the major underlying factors affecting demand for service provided by PPP infrastructure projects.

## **2.8. Factors Affecting Demand in PPP Infrastructure Projects**

To understand why demand variations occur in the first place, the factors which stimulate their occurrence have to be identified. Demand for service provided by PPP could be affected by number of factors and their interactions during the period of operation stage. These factors can consequently impact project revenue and viability.

Based on intensive case-study literature on PPP in wide range of sectors such as toll road, water and wastewater utility, railway and stadium, the author has identified a number of factors which affect the demand for financially free-standing projects. These factors will be discussed in the following sub-sections.



### **2.8.1. Socio-Economic Factors**

The economic conditions of the facility area are important drivers of demand for the service. Economic growth in the facility area should be properly investigated to avoid any adverse consequences during the operational stage. Due to the inherent uncertainty of the economic aspects, this is not always an easy task. Historical trends are the main way to predict future. An optimistic economic growth may lead to demand overestimation, which may lead to excessive costs and subsequent failure. On the other hand, pessimistic economic growth can cause very low projections for the project demand. A reliable evaluation of the economy performance in the future is a serious requirement for obtaining more accurate demand estimation. Niles and Nelson (2001) argued that changes to the economic mix, in the structure of some industries and in the levels of economic and social wealth nationally and regionally are the major drivers for demand variations.

Demand risk in PPP projects can be substantial if the project is not back up by reasonable economic growth in the facility area. The Mexican experience of toll road between 1989 and 1994 is an example. The 5,000 Km (53 concessions) toll road programme were not able to meet their original projections which led the project revenue to be under the expected level. Ruster (1997) attributes the programme breakdown to the failure of identifying the socio-economic parameters that would influence the road usage such as employment and population.

The downturn in the economy and the local recession due to troubles in economic vitality can cause serious reduction in demand levels. Bain (2009) suggested, based on the technical report of many international toll road projects, that the downturn in the economy is one of the main factors causing variance between actual and forecast demand. Evidence shows a strong relationship between economic growth and demand behaviour.

In addition, demographic aspects are another main factor affecting the future demand for the projects. Chiu and Boshier (2005) stated that the current and predicted population of a region represents the principle driver for demand in the water market. In 2002, Veolia's water company was obliged to close some of its facilities near Chengdu

(China) when it faced hard financial problems due to severe decrease in water demand (Hall et al., 2004, 2005). This downsized demand performance was attributed partly to the overestimation of population growth in the project area. Reduction in Bangkok population was considered one of the major factors that affected the ridership expectations of Bangkok Skytrain (Thailand). PUTRA LRMT (Malaysia) has performed better than STAR in terms of ridership, mainly because its route serves densely populated neighbourhoods and offers an alternative of private car use while STAR's route followed an existing abandoned industrial rail line. However, Kuala Lumpur population growth rate somehow helped to improve the STAR scheme usage performance. In 1996, when the STAR LRMT opened, Kuala Lumpur population was roughly 1.2 million. Since then the city's population has increased by more than one quarter, and the STAR utilisation has approximately doubled. Yet, the system still underperforms at about 60 percent of its designed capacity (Perrott and Menzies, 2010).

### **2.8.2. Public Satisfaction**

The public satisfaction of PPP facilities may have a serious impact on the project viability. Goran et al. (2013) suggest that potential users can impact the PPP facility viability by the degree of project acceptance. In Sydney Cross Tunnel PPP project (Australia), public satisfaction has been noted as a major reason behind the poor usage performance of the facility. The project was not well received by the motorists. The situation became worse when the government has tried to force the public to use the tunnel by making alterations and closing alternative existing road, the changes which have angered the public and affected their attitude towards using the tunnel (Zou et al., 2008). In Hungary, a section of the privately financed M1 motorway was opened for traffic in 1996. However, protests were the Hungarian motorists' response over level of tolls soon after the opening of the motorway. This serious outcry led to the project to be nationalised due to financial problems in 1999 (ASECAP website). In Malaysia, public outcry has arisen due to the charge from the private promoter for wastewater project. The government was obliged to review the charge level twice to appease public. The review led to lower user fee by injecting public fund in the privatised project (Abdul-Aziz, 2001).

Mouraviev (2012) suggests that the likelihood of public acceptance needs to be carefully assessed before the launch of any project with the help of surveys, interviews and public discussions. People should be given the chance to take part in shaping the project through participation in evaluating the scheme's proposal. Ouyahia (2006) suggests that participation of potential water facility customers helps build and sustain local support for the established performance standards and guarantee that such standards conform to local needs and willingness to pay. Flyvbjerg et al. (2003) argue that community consultation and engagement in decision-making is crucial to raise public support for a project and making the planning process accountable. The major aim of this kind of consultations is to inform the public about the project and seek their sights and comments on the project proposal and any other options available. In addition, public opinion regarding an appropriate tariff should be gauged by consulting the community representatives. Ignorance of public views regarding the project design and tariff level is likely to anger the community causing it to exercise pressure on the government leading to cancellation of the project (Bain 2002). Ward and Susman (2006) stated that, in many cases, protesters from public have forced the government to renegotiate the contract with the private sector causing the project to be deferred or even cancelled. Therefore, it is argued that while the public involvement in the planning process may incur additional cost due to the need for design changes and tariff amendments, the gain of having less community disruption in the subsequent stages can most often outweigh this cost. Miranda (2007) argues that concession contracts need to be reformed to include more transparency and public participation (Cited in Viegas, 2010). The governments need to avoid being reticent in forming the project proposal and imposing the user fee in concession contracts. Many governments, therefore, have recognised the importance of public involvement in project formation. In France, for example, duration of two years was spent on surveying, data collection and preliminary design of a section of 10 km to 20 km, followed by meetings with representatives of local residents, and public hearings. In Chile, the process of imposing or adjusting the water price starts one year before enforcing the tariff. This process included the disclosing to the public all the criteria taken into consideration in defining the tariff formulas to the public (Calvo and Cariola, 2004).

For the consultation to be effective, Illsley (2003) defines several criteria including predictable decision making process; access to documents and data; fair opportunities for stakeholders to offer input into plans; and transparent and accountable system

integrating stakeholder contribution into the final decision that are made. Consultation with public and other organisations would include assessing different aspects of the concerned project such as design, engineering, environmental, contractual and financial issues.

There is numerous numbers of methods to achieve this process and raise the awareness about the prospected project. These methods would include;

- Exhibitions: where information on the project proposal is provided and public views and comments are sought.
- Public meetings: members or representatives of the public and other organisations can attend and participate in discussing the project proposal.
- Websites: setting up a designated website for the proposed project is an excellent way for the public consultation. The website will include background information, documents, and hyperlinks relating to the project.
- Leaflet Questionnaire

Based on aforementioned, the public consultation is essentially held to disseminate information on the project proposal and offering kind of transparency regarding this proposal. Unfortunately, evidence shows that PPP contracts procured to date have offered limited levels of transparency or public participation reducing the meaningful public involvement in forming the project (Hodge, 2004; Siemiatycki, 2009). PPP arrangements have been widely criticized due to the confidentiality of the financially data and contract clauses. Given this, even though PPP model could be an effective approach to raise fund for new infrastructure facilities, lack or shortness of transparency is likely to be a reason for decreasing public involvement in project planning process, which could injure the public interest. It was therefore argued that concession contracts need to be reformed to include more transparency and public participation (Miranda, 2007 cited in Viegas, 2010).

### **2.8.3. Willingness To Pay (WTP)**

Edward (1996) argues that in addition to the capacity to pay, the public must also exhibit the willingness to pay for the treated water. Public is not used to pay for government for providing infrastructure service (especially in developing countries).

Thus, it might be so difficult to convince public to pay for services which were previously provided free of charge. The sense of entitlement to free government service heavily affects their willingness to pay (Mugabi and Kayaga, 2010). Thus, the impact of willingness to pay on facility demand level should not be underestimated. Hensher and Puckett (2005) reported that in Edinburgh (UK) 74% of the residents voted against introducing a congestion charge scheme similar to that applied in London. The public reaction led Edinburgh City Council to cancel its plans regarding the scheme. This reflects how important it is to consider the factor of public willingness to pay early in the feasibility study stage of the project. Ignorance of this factor can later lead to termination of the whole contract, or much lower than expected revenues being generated. In case of Dulles Greenway project (USA), for instance, no market survey was conducted to determine whether the Loudoun county residents are prepared to pay the imposed toll for using the facility and saving 10-15 minutes time. The result was aggressive where the scheme lagged in traffic demand relative to the initial projections (Spock, 1998).

Bain (2009) has stated that uncertainty over the user willingness to pay toll, especially when those tolls are higher than average, is one of the major drivers of demand risk. Buenos Aires water and waste water is an example. The concession was granted and the fee was set out without the need to determine the potential WTP. The charges were not affordable and most of people refused to pay them. The high monthly charge of up to US \$48 was a source of resentment. The public opposition because of unwillingness to pay the high charge led to contract renegotiation (Zerah, and Harrison, 2001).

User-based financing projects are self-financing facilities. For investment to be recouped, facility needs to attract, at least, the predicted number of users. The main determinants of service quality are key factors for enhancing public WTP. There is a wide argument that one of the prime reasons behind adopting PPP as a way to deliver infrastructure projects is the private sector efficiencies. Private companies are more efficient in providing services and have better facility management. Given this, private sector operation is expected to produce substantial change regarding quality of service which, in turn, should lead to enhance WTP and demand. Delivering the projects and services at public acceptable standard and quality is one of the measures for public private win-win principle in PPP projects (Zhang, 2005). Yuan et al. (2009) conducted a questionnaire survey study targeting individuals and organizations with experience or

interest in PPPs. The questionnaire aims at determining the relative significance and difference of performance objectives for different project stakeholders. The survey results showed that quality of service is one of the most important identified objectives.

Low quality of service constitutes major grounds for defusing public discontentment regarding the project in question and reducing their WTP. Community is not going to pay for bad service. For example in Indah water Konsortium (Malaysia) only 20% of the sewage treatment reached the standard required and determined by government (Abdul-Aziz, 2001), which was considered a reason for putting off the customers. Users will only be willing to pay to utilize the facility if it offers adequate level of service for the fee they pay. In the case of Sydney Airport railway Link, for instance, the limited space for luggage in the train and bad equipped stations were cited as factors for putting off the public (Zou et al., 2008).

Schwartzs (1995) suggests that consumers are willing to pay for service provided by PPP schemes if they can expect tangible benefits. Public perceptions towards using facilities and paying user fees depend to a large extent on the benefits gained from utilising the facilities and quality of service when compared to other available alternative. This comparison raised the significance of the quality of service and fee for using other competing facilities. In a toll road project, for example, it is important to understand that the public willingness to pay tolls depends first on a time saving benefit as well as qualitative measure such as reliability and safety provided by the toll facility when compared to other available roads.

#### **2.8.4. Historical Experience of Paying**

The public willingness to use a particular PPP facility is significantly affected by paying culture. In countries with previous experiences of such facility, it can be noticed that it is less difficult to accept a new PPP scheme if compared with others which only recently have embraced this method and where the public is not used to be charged for using such facilities (Bain, 2002). Thus, it can be argued that the social impacts on a new facility demand should not be underestimated. In countries with no previous experiences of PPP scheme, it will be of benefits to investigate the public views

regarding the expected values they put on the benefits offered by the prospective facility which can help to make the demand estimation process more reliable.

#### **2.8.5. Public Involvement in ongoing Facility Management**

The long term PPP contract poses serious question regarding the long term public involvement in the facility management. Infrastructure projects are inherent to the daily lives of users and they can have enormous implication on quality of life (Baxandall et al., 2009). Public engagement in long term facility management is therefore necessary to ensure coherent planning over long period of time. Community engagement in setting up maintenance and safety standard and adjusting tariff is to ensure high degree of prolonged public satisfaction and use. In addition, disclosing annual reports and accounting arrangements is a way to involve public and increase community willingness to use. For instance, Estache et al. (2000) argue that road concessions should have a mechanism for public participation and feedback. This can be achieved through surveying or forming group of users that can supply information on the qualitative aspects of the concession. This kind of mechanisms of public input is important for evaluating performance, to extend public knowledge of the project, and to build public support. Public will be more willing to use the facility when they know where their money is going. Particularly, if part of the facility revenue is assigned for improving the nearby freeway and maximizing the free flow of traffic.

Some governments have realised the importance of such kind of long terms public involvement. For instance, in France, the 1995 Barnier and Mazeaud Laws set out that the accounts of the private operator may be examined by regional audit commissions and the private operator is required to prepare formal reports on their technical and financial performance for the concerned municipality (Ballance and Taylor, 2005). In addition, the 91 Express Lanes and the Dulles Greenway are two toll roads in the USA which have a public consultation process before any toll adjustment is made (Lam, 2006).

### **2.8.6. Competition from Alternative Facilities**

Since the benefits from financially free-standing facilities basically rely on the service demand, building a new facility or rehabilitating an existing one can seriously diminish the viability of a project. It is hence important to recognise and understand how existing facilities can influence a suggested project during its entire operations stage. The existence of alternative facilities is likely to increase the complexity of the demand estimation. In toll road projects, for example, this competition could be based on the same mode, e.g. a toll road asset with a parallel toll-free road. In this case, it is vital for the project partners to consider the adjacent roads expansion early in the feasibility study. On the other hand, the toll road alternative could be from different modes. For instance, toll road with railway project or ferries in case of bridges for example. In real world, the latter could pose additional risk as the diversion process becomes more complex (Lemose, 2004). A precise study of all alternatives is therefore of particular importance in the business case stage to determine a reasonable demand for the project in consideration.

The Orly VAL system in France offers a proof for the significance of accounting for competition when planning PPP infrastructure facilities. The project went into insolvency as the contract parties failed to adequately account for competition from other public transport services in the planning stage (Perrott and Menzies, 2010). Dulles green toll road in Virginia (USA) is also a common example of projects in which the private sector went bankrupt due to tough shortfalls in usage and revenues as a result of construction adjacent competitive facility (Price, 2001). The absence of a non-competent clause, which could prevent building competing facility, from the concession agreement was the major reason behind the project failure. The non-compete clause is common terms in most PPP road projects which protects the private sector from competition (Baxandall et al., 2009).

Conversely, complementary facilities can affect demand in the other way. When assessing the demand for a specific project it is of particular importance to look beyond the facility itself to evaluate its appropriateness and convenience. It is, hence, crucial to evaluate the kind of supporting facilities which may affect the demand for the main project. The facility integration with other facilities can in many cases have a straight effect on the project demand. Menzies (2010) argues that when designing the urban



railways, the links available from other modes of transportation should be considered. Absence or shortage of supportive facilities, with which to ease access to the system like buses, taxis and park and ride, can contribute to a decline in demand. Decision makers should take into consideration how users can get to the stations and then to their final destination. Ruster (1997) attributes the lack of demand for many of Mexican toll roads to the absence of contiguous sections that would integrate the toll roads into the main network which highly deteriorated the attractiveness of these toll roads. On the other hand, in the Bangkok Sky train project, demand noticeably increased following the introduction of feeder bus services to address the poor demand performance when the project was first in operation (Halcrow Group, 2004; Menzies, 2010). Moreover, in the case of stadia projects, existence of commercial and other welfare facilities surrounding the stadium area enhances the attendance numbers and, at the same time, the project's viability. Cabral and Junior (2010) argued that developing a shopping centre as a part of the stadium investment would likely improve demand and encourage the private sector to invest.

#### **2.8.7. Level of Fee**

The public typically choose the cheapest alternative where one is available. Therefore, to guarantee a constant demand for a project the tariff should be set at a reasonable level. Pricing a service involves highly conflicting interests of project parties. While the main interest of the private sector is to maximize profit, users, on the other hand, seek to minimize their cost. In addition, price setting has also conflicting objectives such as cost recovery and affordability. The expensive construction cost and the private sector's desire to speed up repayment of the debt and gain high profits are the main reasons behind imposing high tariffs. Lemos (2004) argued that in some cases, the private sector's excessive expectations of return on their investment (for example 21%-25%) leads to the imposition of a high user fee, which as a consequence causes low project demand. Bain (2002) considered setting the toll price to be a real challenge for decision makers. Bain's study suggested that this price should not be excessively high because of its strong relationship to the public willingness to pay. It is thus essential to estimate the tariff based on the cost and users' WTP.

In the UK, the public outcry against the high tariff for the Manchester Metrolink project has led to termination of the concession (Menzies and Perrott, 2010). The poor usage performance of Sydney Cross Tunnel (Australia) was mainly attributed to the high cost for using the tunnel. The tunnel was considered to be one of the most expensive toll ways on a per km basis (Zou et al, 2008). A survey study targeted the tourists visiting Highlands, showed the 15% of the respondents cited the high toll level as the main reason for not considering Skye a choice for tourism destination. 11% of the respondents, who already had been to Skye, mentioned that they would not go there if they have heard about the toll charge in anticipation (System Three, 1996). On the other hand, it is not only the base price that can affect the demand level, but also the price adjustment regime has a significant influence. An excessive escalation in toll price can easily discourage the users from using the facility. In 25 de Abril PPP road project in Portugal, the government has been forced to rescind its decision concerning raising the tolls as a result of the public opposition. In this project the toll was frozen at €0.75 for 8 years when the government finally raised the toll to €1 (i.e. an increasing of 1.5 times instead of the planned 2.6 times of the base toll) (Lemose, 2004).

Tariff level should not be on the other hand, set too low as the revenue from the toll must be adequate to cover construction and operation costs. Choi et al. (2010) argued that the high water price in China is one of the key risk factors for private investor in the Chinese water sector. However, they argue that those prices should not set relatively low, disregarding the initial investment and desired profit by the private sector. While cheap fees can increase demand, they may also form a barrier to the private sector involvement, due to the decreased likelihood of an acceptable profit being returned in view of the limited capacity of the facility. A balance needs to be struck between level of imposed tariff and the level of concessionaire profit taking into consideration the financial viability of PPP scheme. Ye and Tiong (2003) suggest that both tariff and price adjustment mechanism should be set to safeguard users' interests without jeopardizing the project's viability and maintain private sector incentive to develop and operate projects efficiently.

Moreover, it is important for the success of any user-based financing infrastructure project to take into consideration whether the public can afford the user fee or not. While the fee charged for getting the service provided by most of these projects may not be that expensive for some wealthy groups, it can form a significant part of the income

of those on low incomes. Edward (1996) related the demand risk in Chinese water market to the purchasing power of users to pay water fair over the period of the PPP contract. The work showed that the risk can become more serious if the assumption regarding the consumer's income is too optimistic (Edward, 1996). Bansoll and Kelly (2005) suggest that introducing the user fee on the road will form a real barrier for low incomes people to drive, which can, consequently, have effects on the service demand. Raje et al. (2004a, b) mention that imposing the user fee can have its impact on the low-income vehicle owner making them either stop travelling or be obliged to pay tariff which can form additional financial burden on their limited resources. In addition, because the poorer people usually have less value of time, they prefer using the cheapest alternative which either untolled roads or other different transport modes. Moreover, Kocak et al. (2002) has the opinion that low incomes users may have limited access to bank cards which is indispensable for some toll collection systems. Furthermore, the toll collection systems may require the users' cars to be equipped with some necessary prohibitive tools which they could be unable to pay for. Zhang and Kumaraswamy (2001) therefore argue that in PPP revenue-reliant projects, users' affordability should be a determinant for the level of tariffs imposed for using the service. When assessing potential demand for service, the relationships among tariff level, user affordability and willingness to pay are an important issue.

Moreover, the way in which the concessionaire intends to collect the tariff can also have an impact on the project demand. Attention should be paid to selecting the most suitable method for tariff collection early in the project's lifecycle. In the case of toll road facilities, manual tollbooths have been used for decades. However, due to the fast technological development and limited processing capability of human beings, the tendency of most toll collection points nowadays is towards automated systems. Electronic Toll Collection (ETC) technology has been introduced in many countries. For instance, a distance-based charging system has been used in the German lorry road scheme. This system depends on using satellite-based electronic tariff collection technology. An on-board tool is to define the (pre-registered) car location and calculate the fee for each car class, this information is then transferred to the central tariff collection unite (Hensher and pucket, 2005). Bonsall and Kelly (2005) argue that automatic toll collection was one of the factors fostering and supporting the increasing use of toll road. In addition, introducing a new method (transit smart cards) to pay for multiple forms of transport, as in the case of rail line projects such as: London's Oyster

Card and Singapore Ez-link system, adds value to the project, increases public convenience and helps to meet project expected demand (Menzies and Perrott 2010).

However, employing the developed technology for collecting the user fee is not without problems. For example embracing the advanced technology to collect fee in toll road case requires the users to install some prohibitive tools in their vehicle, as discussed above, causing the motorists trying to avoid using the toll road. Koack et al. (2005) insist that not only the tariff could be costly for the community, but also some times the tools necessary for utilising the facility and paying the charged fee such as GPS and smart card. Moreover, adopting ETC technology requires the government to unify a standard tool for collecting tariffs across the nation. In Malaysia, a serious problem raised when different ETC systems have been embraced by different road operators around Kuala Lumpur. Thus, the vehicle drivers found themselves forced to use different transponders to be able to drive different roads in the capital (ward and Sussman, 2006). However, many countries have recognised this point and they transfer to a new stage of work relying on standardization the different toll collection methods. Portugal, for example, became the first country to apply a single, universal system to all tolls in the country. The tariff collection system should therefore be acceptable to the community to ensure a reasonable level of demand which guarantees the required stream of income.

In addition to these factors which are in common between many economic infrastructure projects, there are several other project-specific factors which depend on the nature of the project. Examples of these factors may include the sports-team's performance in case of stadium projects.

#### **2.8.8. Behaviour of Demand Risk Factors**

Obviously, most of the above-identified major factors include level of dependencies. In addition, each of the factors affecting demand involves several sub-factors which interact with each other. For instance, WTP is a function of level of fee, quality of service, user wealth and other factors. Level of fee itself is a function of several sub-factors such as project cost, intended profit and operation and maintenance cost. All

these sub-factors and factors interact in a complex way, affect each other and ultimately affect demand.

Furthermore, factors such as public satisfaction and historical experience of paying are qualitative (soft) factors. Conventional demand modelling methods such as time series analysis (ARIMA, moving average, exponential smoothing and neural networks) is able to consider quantitative factors only. The models work with a particular set of historical time series data of the quantitative factors as inputs to produce an output, often in a deterministic form with no possibility to accommodate such qualitative factors.

Moreover, the factors affecting demand tend to change with time. For example, level of population and employment as well as GDP, the major determinants of socio-economic conditions, are not constant over time. In addition, the private sector operator may increase (or decrease) the fee for using the facility often on annual basis implying change in the level of fee over time. These changes are likely to have a consequent impact on the level of demand. In most cases, the level of change is often unknown and uncontrollable which imposes a high level of uncertainty on the potential value of these factors and on the demand level too.

The high level of uncertainty associated with the underlying factors of PPPs service demand imposes a considerable difficulty in determining the values of those drivers and in estimating a reliable demand level for the service offered by the PPP facility. In addition, interdependencies and dynamicity pertinent to these factors increase the complexity of the estimation process. Any available scope for dealing with this uncertainty, dynamicity and complexity, which may reduce its impacts on demand level, would be in the sake of getting best value for users, public sector promoter and private operator alike. A demand risk assessment model that can consider features of complexity and dynamicity underpinning the identified factors and explain how these factors can influence demand behaviour is therefore needed, as will be considered by this research.

## **2.9. Demand Modelling**

Over course of decades, many methods have been employed to model demand for service provided by the infrastructure projects (energy, transportation, water and

wastewater, etc.). Liu et al. (1991) divided the forecasting models used for electricity demand into two groups: causal and time-series models. Lai et al. (1999) consider Box-Jenkins models, regression models, econometric models, neural networks are the most commonly used tools in energy forecasting studies (cited in Wang and Meng (2008)). Liu et al (2009) divided the methods used to water demand forecasting into three categories: white- box model (time series forecasting), gray-box model (grey forecasting model) and black-box model (Artificial neural networks). Moreover, Li et al. (2008) divided the traditional methods used to traffic forecasting into qualitative and quantitative. Qualitative methods consist of empirical judgement and market survey. On the other hand, quantitative methods include moving average method (time series) and regression analysis.

Next section discusses in more details the most common methods used for demand modelling.

### **2.9.1. Time Series Models**

A time series is a set of sequential observations of random variables. It offers tools for selecting a model that can be used to forecast of future events. Time series models assume that the demand is only related to its own past demand patterns. Auto-regressive (AR) models, moving average (MA) models and Autoregressive Integrated Moving Average ARMA are typical time series methods which have been used for demand forecasting. All these models assume that the time series is linear and follows a particular statistical distribution, such as the normal distribution. One of the major limitations of time series models is therefore the assumed linear of the associated time series which becomes inadequate in many situations (Zhang, 2003). In addition, these methods of demand models need a huge amount of historical data to predict its future behaviour (Wang and Meng, 2008; Zhai et al., 2009). Therefore, time series method is only suitable when past data is available as a base for future values (Celebi et al., 2009).

### **2.9.2. Causal Models**

While time series models assume that demand is a function of its own past patterns, causal models assume that there are some other factors affect level of demand. They are

thus measure the relationship between demand and the other factor(s). The most popular form of causal model is the regression analysis models. Regression analysis models try to predict dependent variables as a function of other correlated observable independent variables. For instance, Lee et al. (2004) employed multiple regression method to predict demand for sewer using sewer flow data over 10 years from Indianapolis city (USA) and Population and water consumption as an independent variables. Liu et al. (1991) suggest that the main drawback of regression models is that it relies on the availability and accuracy of these independent variables over all the forecasting duration which requires considerable efforts for data collection. Celebi et al. (2009) argue that the scarcity of causal variables data make the causal prediction techniques are not really practical in the real world situations. Moreover, Niu et al (2007) argue that conventional forecasting model for electric power such as time series and regression analysis are too simple to simulate the complexity and high changeability of the power loads.

Due to aforementioned drawbacks of statistical methods, many other approaches have been proposed to model demand in the recent years. The following sections present some of the modelling tools used more recently to forecast demand in infrastructure facilities.

### **2.9.3. Artificial Neural Networks (ANNs)**

ANNs are mathematical models of theorized mind and brain activity which try to exploit the parallel local processing and distributed storage properties believed to exist in the brain (Jain et al., 2000). ANNs is able to consider many input variables without the concern for correlation. In addition, it has the capacity to deal with non-linear relationships. Khotanzad et al. (1997) suggest that ANN models have the ability to combine the time series effect of demand with other inputs to generate more reliable outputs. ANNs has been widely used to estimate water demand (Msiza et al., 2007; Jain et al., 2000 Liu et al., 2009), sewer system demand (Lee et al., 2004); traffic demand (Li et al., 2008).

While ANNs have been widely used to forecast infrastructure demand, the method is not without drawbacks. A major deficiency of the method is its “black box” nature which fundamentally mean it is not obvious how the network is solving the problem (Wang and Meng, 2008; Liu et al., 2009). In addition, Wang and Meng (2008) argue that the

performance of ANNs, relies on the amount of training data and the way in which these data are represented which makes the method inappropriate when historical data are not available. Besides, the long learning time taken in the large-scale network is one drawback of the ANN (Liu et al., 2009).

#### **2.9.4. System Dynamics**

System Dynamics introduced by Jay W. Forrester aims at solving the simulating problems of large-scale systems. System Dynamics has the ability to constitute a feedback structure of the complex system taking into consideration the relationship between the system and interior factors constructing a complex dynamic model which is able to describe the complicated system and integrates knowledge and experience of decision makers complemented by computer simulation. The method is suitable for long term and non-linear complex problems (Zhai et al., 2009). In the recent years, System Dynamics has attracted attention as an effective forecasting tool which can include variety of factors from different nature in one package. Zhang et al. (2008a) adopted Systems Dynamic to forecast the total water demand of Tianjin city (China) per year. System Dynamics modelling tools has also been employed by Zhang et al. (2008b) to forecast annual water demand of Linkong city (China). Zhai et al., (2009) employed again the System Dynamic method to forecast the annual water demand of Tianjin Polytechnic University.

Obviously, each of the aforementioned methods has their own advantages and disadvantages. Therefore, it is of particular importance to implement the most appropriate mechanisms and techniques that can be properly used to model infrastructure demand. Infrastructure demand is a dynamic process influenced by many qualitative and quantitative factors. Infrastructure demand is a time-varying complex system which is affected by employment level, population, tariff price and many other factors. Different factors have different significance and can influence demand in different way. In addition, factors driving infrastructure demand often have some inter-relationships and these correlations are not necessarily linear. Not to add, as for PPP infrastructure projects, very little historical data are available. The nature of demand factors determines the complexity and dynamicity of demand system. To offset the discrepancy and dynamicity of this system and its elements, a model which can include



various factors affecting demand and be able to properly represent the relationships among them is a need.

## **2.10. Summary**

The willingness of the governments to decrease their borrowing and spending, as well as their awareness that private companies can supply assets and services at lower cost, have resulted in the introduction of various forms of public private partnership. PPP approach enables faster provision of most needed infrastructures than traditionally funded infrastructures. It ensures provision of committed funding for continuous maintenance and improvement and better management of public activities. The PPP type or the mode of financing choice is subject to the nature of infrastructure service. For most economic infrastructure, concession contracts are the dominant form. While this method has been successful in terms of delivering the facilities on time and to budget, the presence of demand risk mostly diminishes this viability. Notable failures of many of these privately financed schemes as a result of experiencing demand levels substantially below the levels required to service debt have been tracked. This made investors and governments aware of the significance and seriousness of demand risk since it became an inherent aspect of privately financed projects. This chapter presented several cases of major international PPP schemes and from a diverse range of infrastructure market for which the yielded outcomes were considerably different from what was originally foreseen leading to contract renegotiation or termination. Based on studying these cases, it was obvious that demand is a function of several major factors which include socio-economic factors, public satisfaction, WTP, historical experience of paying, public involvement in ongoing facility management, competition, and level of fee. Most of these factors are dynamic and interact in a complex way to affect demand. This imposes the need for a modelling approach that take into consideration the complexity and dynamicity involved in the demand system. In addition, the literature implies that the problem of demand risk and consequent contract renegotiation is significant in transportation sector. Being one of the major investments in PPP and in transportation as discussed in chapter one, toll roads will receive a particular focus in this research. Therefore, next chapter discusses the problem of demand risk in PPP roads or so-called toll roads.

## **Chapter Three: Traffic Demand Risk in Toll Roads**

### **3.1. Introduction**

The growing interest in private sector involvement in infrastructure provision in general, has coincided with similar particular growth of interest in privately-financed roads. Road sector benefited the most from private financing of infrastructure projects. PPP road projects were recognised as the most dominant in PPP transport sector as discussed in chapter one. On the other hand, the problem of demand variations and its impacts are more obvious and serious in road concessions. This chapter is therefore dictated to detail the problem of demand risk in concession road projects, known as toll roads. As discussed in the previous chapter, in concession contracts, the private sector (concessionaire) fund is used to finance, construct and operate the facility. For roads infrastructure, the private sector has then the right to toll the road for the concession period in return. This chapter presents in details the concept of concession in the field of road infrastructure. It starts by introducing the concept and its background. It then turns to describe one of the main risks faced in implementing this kind of contracts, traffic demand risk. It discusses the traffic variations dilemma and its sources. It then outlines some of the literature on trends and methods to deal with uncertainty and demand risk.

### **3.2. PPP in Road Infrastructure**

Road infrastructure is one of the key economic drivers for society. Economic growth and social development are the ultimate benefit of the road network. Road transport is the dominant form for movement. In Latin America, for instance, it constitutes 80% of domestic passenger and over 60% of freight of movement (Estache et al., 2007). The French road network carries 90% of passenger traffic and around 78% of freight traffic (Frayad et al., 2004a). In the UK, the proportion of road traffic rose from about 25% to 90% between the fifties and the nineties of the last century and has remained almost at those levels since then (DfT, 2011). In terms of goods movement, road transport account for more than 60 per cent (DfT, 2012a).

Economic growth and demographic change are leading to increasingly growing traffic in the urban and rural area. Motorization is also growing at annual rate of 3% approximately (Estache et al., 2007). For instance, the number of licensed vehicles in Great Britain (GB) has increased from about 4 million in 1950 to over 34 million in 2011. This continuous increase in roads traffic, not only in the UK but over world, leads to that existing roads are seeing increasing level of congestion. Congestion can seize economic growth as more time is spent on the road rather than doing other productive activities. Environmentally, the presence of congestion may result in higher level of pollution and carbon emissions as vehicles spend more time on roads. In the USA, it was reported that congestion cost annually about \$200 billion, or 1.6% of the U.S. GDP. Congestion on M6 road in the west midlands was predicted to cost the UK government around £2 billion a year (Calder, 2013).

The presence of the aforementioned conditions increases the demand for higher road capacity. In Asia, from 1984-1994, the road networks of Indonesia, Korea, Malaysia and Pakistan grew in length by more than 5% per year (Estache et al., 2007). Since 1990, France has built 2,700 miles of new motorway which is more than the entire UK motorway network. Yet, road development requires a huge magnitude of monetary fund to build and maintain. Traditionally, governmental budget and devoted taxes are the major funding source. Given the government fiscal constraints, especially that resulting from the downturn in economy and the consequent fall in tax revenues from incomes, the public fund has become inadequate to meet the increasing demand for road infrastructure. To fill the gap between restricted public resources and growing demand, particularly in the case of the financial crises and economic downturn, innovative approaches to finance transportation projects which can help the government to fairly allocate their rare resources to fund other needed public services were promoted. Private fund to finance badly needed infrastructure roads construction and deliver the subsequent service was sought. Verhoef (2007) reported that third of roads in Western Europe are privately owned. Variety of financing mechanism has been applied in the context of road implementation. Among others, concession agreement is recognised to be the most popular trend to finance road infrastructure.

### **3.3. Road Concessions**

Bousquet and Fayard (2001) identify concessions in the road projects as “*a contract under the terms of which a public authority charges a company with making the investments required to create the service at its cost, and to operate the service at its own risk, the company being remunerated in the form of a price paid by the users of the service and/or the public authority*”. The previous definition implies that the concession is a long term contract by which the private sector or concessionaire is eligible to construct, finance and operate the facility for a specific period of time- usually 20 to 30 years. The concessionaire will recover the initial cost by either one of two ways;

- direct payment by the users in the form of toll (real toll)
- Payments by the government client known as shadow toll

#### **3.3.1. Toll Concessions**

Under these arrangements, once the facility is built, the concessionaire has the duty and right to collect tolls directly from users until the concession term ends when the facility is transferred to the public sector client. In some cases where the payment by the users would not be sufficient to meet compensation of the concessionaire, the government would provide kind of subsidies depending on the construction cost, traffic forecast and level of toll (Fernandes and Viegas, 2005) as discussed in chapter Two. Users can pay toll for using the facility via variety of options such as cash, credit cards or an electronic method. The amount paid can be either a fixed or distance based toll and it is a function of vehicle type (motorcycle, car, Heavy Goods Vehicle (HGV)).

#### **3.3.2. Shadow toll Concessions**

In the case of shadow tolling arrangements, the concessionaire will remunerate the initial cost by payment made by the public sector client based on usage level and, in some cases, indicators of quality of service (accident rate, number of hours of lane closure for maintenance). From the user point of views, there is no difference between shadow toll road and other traditional roads. However, since, the payments are calculated based on road usage and the agreed rate per vehicle; demand risk is still a concern for contract parties and lenders. In all cases, the concern level is much lower

than that in toll roads where the users pay due to the uncertainty associated with users' willingness to pay.

In 2007, the number of real toll road agreements in continental Europe was four times more than the number of shadow toll ones (9 real tolls Vs 2 shadow tolls) (Kappeler and Nemoz, 2010). However, Caselli et al. (2009) suggested that real toll roads are more risky to the private sector than shadow toll projects where the private sector is eligible to government subsidies in case of project distress while there is no protection in the real toll roads which its profitability primarily depends on actual traffic. For this reason and since one of the research objectives to investigate the impacts of different factors including WTP on demand, this kind of facilities fall outside the scope of this research.

There is another kind of tolling which is known as the congestion scheme. Owing to limited space for expansion, urban centres experience increasing level of congestion. Governments have, thus, increasingly needed a means to improve the utilization of existing facilities (Kriger et al, 2006). Several governments have therefore introduced tolls on existing congested roads with the goal of reducing road use or congestion level. In the Netherlands, for instance, tolls are levied with the express intention of directing road users to other means of transport to ease road traffic conditions (Bousquet and Fayard, 2001). However, since the aim of congestion scheme is decreasing the level of congestion, the impact of demand risk is minor which makes this kind of tolling behind the scope of the research.

Since the user-paid toll road is the prevailing model for privately financed road projects and owing to the high level of demand risk profile, the real toll roads type is the major focus of this research.

### **3.4. Current Practice of Toll Roads**

The statistics from World Bank (2012) and European investment bank (EIB) (2009) suggest that many countries already have extensive experience in toll road projects. However, empirical evidence suggests that the route implementation is not straightforward. A track record of failures as a result of poor performance in terms of usage level has been detected. In many cases, predicted demand for service provided by

the facility in the feasibility phase was not eventually materialised in the operation stage leaving the project in distress as a result of shortfall in revenue. Several examples were presented in chapter two. The most documented example is the Mexican toll roads. The majority of 52 toll roads lunched between 1989 and 1994 have not met expected demand and needed to be restructured with substantial public contributions.

Several studies were devoted to explain the size of variability and deviations between forecast and actual demand as well as the potential sources of these deviations worldwide. They were simply based on a rough comparison of the projected and actual demand/revenues for different number of toll roads. Next sections consider some of these studies and summarize their findings.

The first study investigated toll road usage performance was conducted by the investment bank JP Morgan (1997). The study sample included 14 implemented toll road projects across the USA. The study compared the actual revenue of the facility to that originally forecasted. The results were presented as a percentage of actual to forecast figure. The study findings revealed that 13 of the 14 toll projects were not able to generate the predicted revenue. Three projects experienced up to 25% variations. The actual revenue for four projects was 30% less than that forecasted. The findings suggest that toll roads in the USA tend to suffer from under usage performance, particularly during the first year of operation.

Standard & Poor's (S&P's) (2002) explored 32 toll road projects all over the world, which included bridges, highways and tunnels. The study compared the actual to the forecast traffic for the opening year. The comparison results were presented as ratios of actual/forecast traffic. The study showed that the actual traffic volume for 28 of the projects was below what was initially projected (Bain et al., 2003). This core sample was extended to include 104 international toll road projects in 2005. The main results regarding the discrepancy between actual and forecasted traffic volume did not change. On average, traffic variations were about 20-30% for the first year projections. The range of actual/forecast ratios is from 0.14 (86% below what was predicted) to 1.51 (51% above that predicted) for the first year of operation as Figure 3.1 illustrates (Bain et al., 2005). The mean of the error distribution is 0.77 implying that, on average, actual traffic was 23% below the forecast levels. Based on the study results, it was concluded that inaccuracy in demand forecasting is common across the different types of

transportation infrastructures (highways, tunnels and bridges). The findings of S&P’s study are consistent with the JP Morgan study referred to above. The study showed also that there is no significant improvement after year one. Between year 1 and 5, the variation decreased from 23% to 20% on average.

Vassallo and Baeza (2007) conducted a similar study using a data set of 14 toll concessions awarded between 1971 and 2002 in Spain. The study compared the actual traffic to the traffic declared in the bid for the ramp up period. The traffic variations were estimated for the first three years of operation. The study findings showed that 13 out of the 14 projects investigated suffered from under usage performance. On average, the actual traffic was about 60% of that forecasted during the first year of operation. Further analysis of ten concessions showed that the average variations declined from 35% in the first year to 31% in the second year and to 27% in the third year. The empirical evidence of 35% variation for the first year of operation is higher but consistent with the standard and Poor’s findings (i.e 20%-30%). Based on the above result, Vassallo and Baes (2007) concluded that there is a trend towards traffic overestimation presented by the bidders of highway PPP concessions.

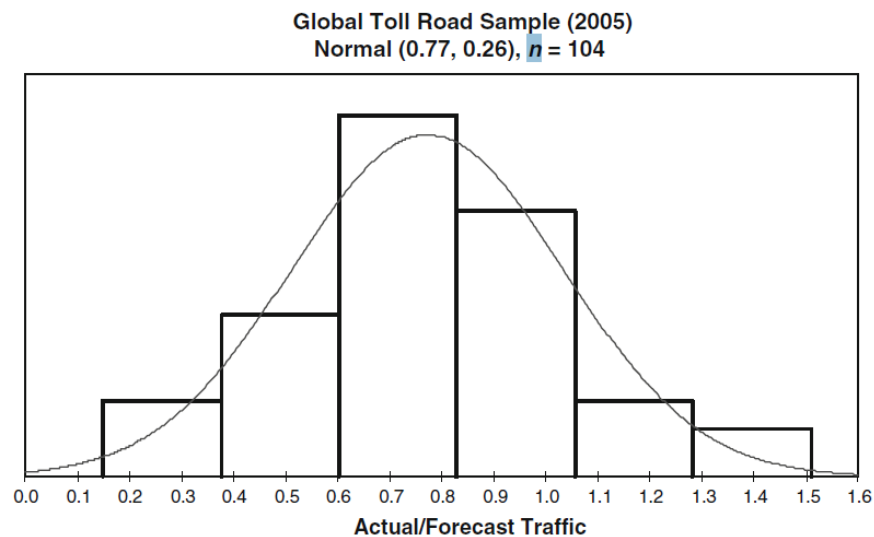


Figure 3.1: Ratio of Actual/Forecast Traffic for S&P’s Sample.  
Source: (Bain et al., 2005)

Li and Hensher (2010) conducted a comparison between actual and forecast traffic levels for 14 Australian toll roads (nine motorways, three tunnels and two bridges) implemented between 1932 and 2008. The data included actual and predicted traffic

levels for several points of time after the operation stage started. On average, for the first year of operation, the actual traffic was found to be 45 per cent below that forecasted for five projects for which data were available. This value is higher than value of S&P's (i.e. 20%-30%), but close to the study outcomes of Neass et al. (2006) (i.e.40%). However, the variations have become smaller over time. In some cases, actual figure was about 19% below forecast after 6 years of operation. These findings support Vassallo's (2007) pertinent to Spanish toll roads which provided evidence that traffic estimation tends to improve over time as discussed above. However, the improvement in the usage level could take long time and it relies mainly on the degree of land use and demographic change in the facility area.

Using data from Norway, Welde and Odeck (2011) conducted a study encompassing 25 toll roads and 25 toll free roads. The study estimated the traffic performance by comparing the actual traffic to that initially forecasted for the first year of operation. In addition, the study investigated the traffic performance for year 3 and 5 to test any possible improvement in the usage performance. As for toll roads, the results show, on average, the actual traffic is 2.5% less than predicted for the first year of operation. The results imply that variations scale is much less than that revealed in other studies as above. 24% of the projects investigated had more than 20% traffic shortfall. 40% of the projects experienced less than 20% shortfall. The average overestimation ratio has decreased to 2.1% in the year 3 for 22 projects. In year 5, it seems that actual traffic exceeded that forecasted by 2.3%. Based on the mean accuracy for toll road sample, it was concluded that traffic forecast for Norwegian toll roads is fairly accurate. Welde and Odeck (2011) attributed the demand estimation accuracy to that the planners over the years have been scrutinised in providing careful estimates for these projects. *“All projects are stress-tested for financial robustness to ensure that the risk of financial default is low, even in worst-case scenarios”*.

Most of the aforementioned empirical evidence reveals the serious deviation between actual traffic and that forecasted, particularly during the first year of operation. The variations range between 20%-30% according to standard and poor's, it is about 35% according to Vassallo and Baeza (2007) and 45% in Li and Hensher (2010) study. Prud'homme (2004) suggests that *“errors of 50 percent or more seem to be the rule rather than the exception”* in toll road projects.



The studies particularly focus on the variations in the first year of operation. However, where data are available, few of them extend the comparison and analysis for further time points after the first year. Vassallo and Baeza (2007), Li and Hensher (2010) and Welde and Odeck (2011) studies suggests some improvement in the traffic performance after the first year of operation. However, despite of these improvements, the variation at the beginning of the concession may still have serious impact on the overall project viability. Engel (2002) argues that this later improvement to demand, in most cases, may not be sufficient to compensate previous years' loss and recover the private capital investment. Welde and Odeck (2011) suggest that there is substantial risk that projects with high traffic shortfalls (up to 35%) in the first years may experience financial difficulties that necessitate loan refinancing, a prolonged payment period, increased tolls or a combination of alternatives. Demand risk is therefore significant in this kind of projects.

### **3.5. Significance of Demand Risk in Toll Roads**

While most of the risks associated with the development of toll roads are similar to those faced by other infrastructure projects such as construction risk, political risk, currency risk, and force majeure risk, toll roads face extremely high level of risk owing to the unpredictability of future traffic and revenue levels. Demand risk is a unique and real challenge for toll road schemes. For example, power projects face lower demand risk owing to a typical long-term power purchase agreement (Fisher and Babbar, 1996). Notable failures of many privately toll roads as a result of experiencing demand levels substantially below the levels required to service debt have made investors and governments aware of the significance and seriousness of demand risk.

The significance of demand traffic risk can be summarised in the following points:

- 1- The decision to implement toll financing requires raising an intensive debt; the project cash flow is the primary source for debt repayment. Since the facility cash flow is a function of demand level, the recovery of construction and operation cost and support debt payment depends heavily on the expected traffic volume. In the case of demand shortfall, actual cash flows will fall below that predicted and thus being inadequate to cover debt service. Welde and Odeck (2011) indicates that projects with significant traffic shortfalls (35% or more) is

subject to experience serious financial difficulties that require loan refinancing, prolonged payment period and higher interest rate, increased toll or a mix of previous alternatives.

- 2- In this kind of PPP projects in which the fares paid by the end users are the main source of revenue, the demand risk is entirely allocated to the private sector operator. However, in some cases and in order to allow the private sector to recover its capital investment and operational expenses, the government may share this risk with the concessionaire by providing minimum revenue guarantees, paying availability fees and issuing capital grants (Menzies and Perrott, 2010). These kinds of guarantees are likely to result in transferring the risk back to the public sector if the project fell into distress. Other risk mitigation options such as flexible-term contracts may cause transferring the risk to the end users in a form of longer concession period (as discussed earlier in section 2.4).
  
- 3- Demand shortfall provides an excuse for the concessionaire to renegotiate the concession terms and conditions. Alexander et al. (2000) suggest a tough renegotiation is an expected result of demand discrepancy once the public sector decides to employ a private company to develop and operate a toll road facility. Besides being longitudinal and costly, Engle et al. (2002) argues that these renegotiations diminish the public benefits of toll roads by limiting operator's risk of loss and reducing concessionaire's motivation to be efficient in evaluating project viability. The renegotiation of the private Mexican highway concessions contracts costed Mexican tax-payers more than \$8 billion (Engel et al., 2002). Between 1988 and 2004, 67 percent of the transportation concessions have had to be renegotiated on average after 3.1 years (Guasch, 2004). Vassallo and Baeza (2007) reported that 55% of highway concession contracts in Spain were subject to renegotiation. 50% of the contracts renegotiated ended with toll rises and 24% with extending the concession period which meant transferring demand risk to the end users.

Obviously, demand risk faced in toll roads can lead to serious financial problems, inefficient risk sharing and costly renegotiations. These intensive impacts impose the necessity of identifying the major sources of demand risk in toll roads with an ultimate aim of conducting robust demand risk assessment.

### **3.6. Sources of Variations in Traffic Demand**

In chapter two, the main factors affecting demand for service offered by PPP infrastructure projects were identified. Most of the factors identified are applicable to the toll roads as it will be illustrated in the following sub-sections. There is however some factors specifically related to the toll roads. This chapter therefore focuses on the main sources of demand variations in toll road projects particularly.

Literature offered several explanations for demand traffic variations which are mainly related to the demand estimation process. Quinet (1998) categorises the source of inaccuracy in demand forecasting as following; *inadequacy of the model structure, the inaccuracy of the available data and the uncertainty of prediction of the future value of exogenous variable*. In addition, a study by Flyvbjerg (2005) shows that there are two reasons for errors in traffic forecasting: technical mistakes in the methodology and the strategic behaviour of the bidders. De Jong et al. (2007) categorised reasons of variations in traffic demand in toll roads into: input uncertainty and model uncertainty. Input uncertainty is pertinent to the difficulty in determining the values of inputs. Model uncertainty refers to the potential error emerging from the structure of the forecasting model such as equation and parameters values. The following sub-sections discuss in details the potential sources of demand traffic variations in toll roads projects.

#### **3.6.1. Model Adequacy**

The family of four-step model is the most dominant in the traffic forecasting industry. The first comprehensive application of the four-step model traced back to the early 1950s in Chicago (USA) (Weiner, 1997). This model has been combined with land use projections and economic evaluation. The Four-step model can be described as a systematic framework for several-stages process which includes a mix of mathematical behavioural models. It is a sequential process encompasses the four following steps (Ortuzar and Willumsen, 2001):

### 1) Trip generation

In this stage of the modelling process the propensity to travel is identified. The aim of this stage is to estimate the potential number of trips at the zonal level and for variety of trip purpose in the study area. The number of trips produced from and attracted to each zone is estimated based on its economical and demographical aspects. In this context, each trip is represented as a production and an attraction implying that each trip is "counted" twice in the trip generation step.

### 2) Trip distribution

The trips produced in each zone are distributed to match the trip attracted to other zones resulting in the production of the trip matrix. Trip matrix defines total number of trips between each production-attraction pair. For example, the number of work trips produced by a specific zone is matched with work trip attractions throughout the region to estimate the number of commuting in this specific zone and to other zones. Gravity model is the most common approach used in this stage to estimate how many trips are potentially to go from each origin to each destination. This mathematical procedure considers the negative effect of travel time, cost and distance. A simple four-zone trip matrix is presented in Table 3.1. The matrix specifies the travel demands between four zones (e.g. wards, district, post code, etc.) in the network. The zones in the first column is the origins where trips originate and the zones in the first row are the destinations where the trips end. Each cell in the matrix thus represents the number of trips between an origin and destination. For example, there are 15 trips originate in zone 1 and end in zone 2, 25 trips between zone 2 and 4 and 7 between zone 4 and 2.

Table 3.1: Four-zone Trip Matrix

<b>Zone</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>Total</b>
<b>1</b>	0	15	22	13	50
<b>2</b>	10	0	17	25	52
<b>3</b>	18	27	0	14	59
<b>4</b>	2	7	23	0	32
<b>Total</b>	31	51	62	56	193

### 3) *Mode choice/Modal split*

In this stage trips are assigned to probable modes of travel such as public transit; drive alone in a car, carpooling, van or truck. The aim of this stage is to estimate the relative proportion of trips by various alternative travel modes. The attractiveness (time, cost and accessibility) and the availability are the major determinants of mode choice. This step usually uses Logit function by considering the previous attractiveness factors for each of the available mode.

### 4) *Trip assignment*

Finally, in trip assignment, trips are allocated to mode-specific networks. This step determines the route users choose to reach their destination. It specifies the number of vehicle traveling on each link. This link is usually the best alternative route through the network for each type of trip, determining the shortest way both in terms of time and distance.

The four step model has been originally designed for and widely used in estimating free toll road traffic. However, as for major toll road facilities, the common approach to forecast traffic is to begin with the traditional four step model and then adapt it to include the particular characteristics of tolled roads. Spear (2005, 2007), Kriger et al. (2006), Prozzi et al. (2009), Davidson (2011) and URS (2011) identified the main methods by which four-step models has been used to toll road demand projections which include:

- a) Option 1: Introducing tolling in the modal split (mode choice) step
- b) Option 2: Introducing tolling in the trip assignment step
- c) Option 3: Introduction tolling as an additional sub-step in the assignment step or as post processor (fifth step) outside the four step model.

Figure 3.2 illustrates a typical four step model and the integration of these three options.

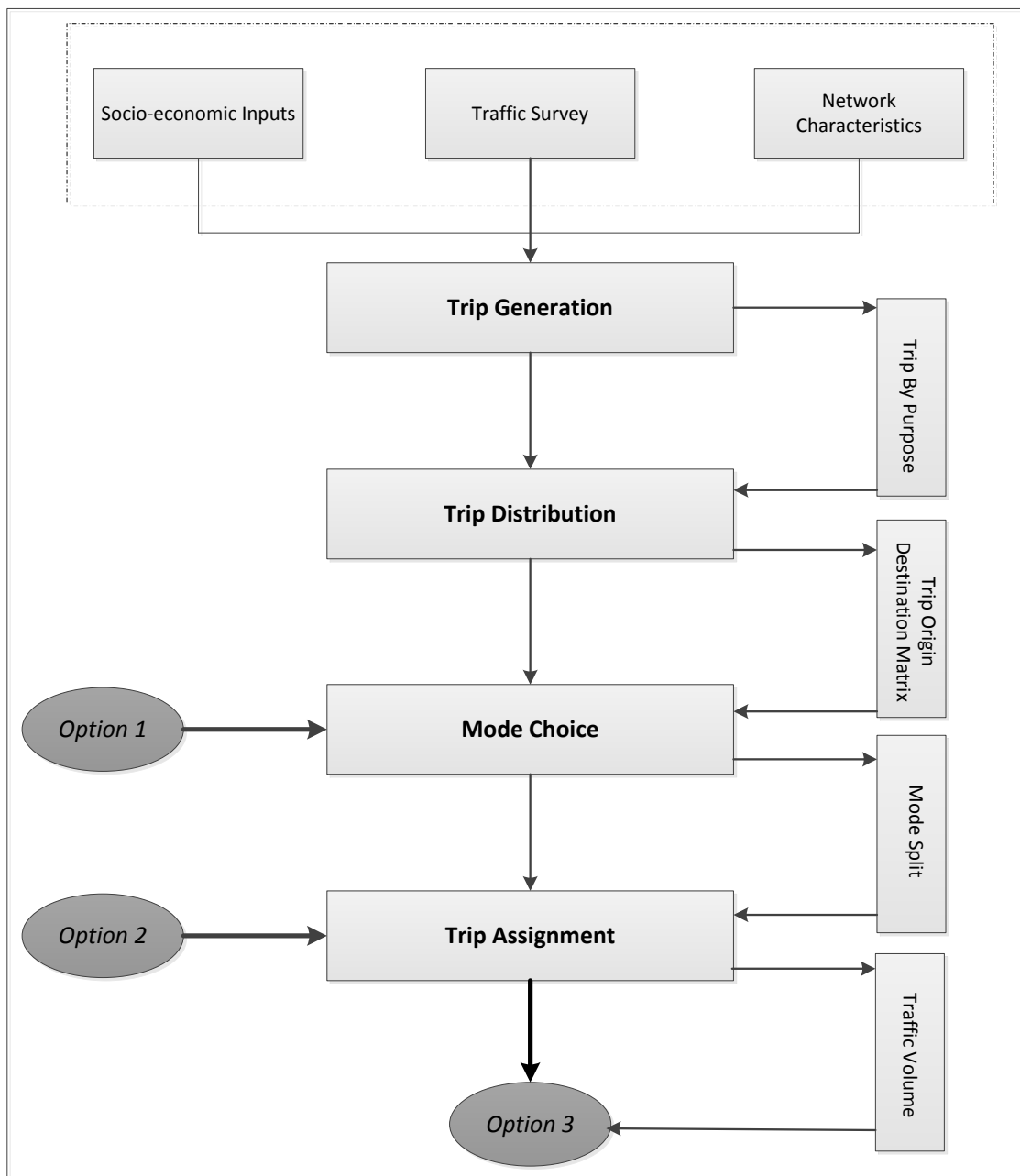


Figure 3.2: A Typical Four Step Model and the Integration of Tolling  
 Source: (adopted from Prozzi et al., 2009)

*a) Mode Choice*

The first approach is the easiest way to include tolling in the four step model. In this method, the toll road is added to other traditional modes in the model. The toll route will have the characteristics of mode choice variables such as travel time, cost and reliability. While this way of considering the toll road in the modal choice step is relatively easy, it is not without disadvantages. Simply, this way is not dynamic. For example, changes in congestion conditions on the toll free roads alternative resulting in

the assignment step cannot be account for in the modal choice step due to absence of feedback loop from the assignment step (Prozzi et al., 2009). In addition, there is a concern that the toll trips estimated in the mode choice step may not be assigned on the toll route in the next step: trip assignment stage (URS, 2011).

b) *Trip assignment-oriented approach*

There are two approaches to model tolling in trip assignment. The first approach to include tolling is to involve the toll rate as a time penalty in the trip assignment step. In this method of toll traffic estimation, a comparison between travel time on alternative routes and toll road is conducted. For example, in the case of increasing congestion on non-toll road, the travel time on this road will increase. On the other hand, the toll paid by users on the toll road will become smaller and the attractiveness of the toll road will then increases (Prozzi et al., 2009). In the absence of congestion, this model is fully deterministic. The traffic assignment model will assign the traffic to the toll road as it is part of the shortest path. The assignment can be all-or-nothing process which can lead to discontinuities in demand. Thus, the shortest link will get all relevant traffic disregarding the toll levels till a critical point where the path stops being the shortest path. At this point, the whole relevant traffic will use an alternative path causing a sudden drop of demand. In case of congestion inclusion, the traffic switches to the alternative route when the shortest path becomes congested owing to the equilibrium process. The equilibrium process can reduce discontinuities but it cannot completely eliminate. Haghani (2003) however suggested that the traffic model rarely reaches the equilibrium. In addition, it was argued that this approach of toll modelling uses an average value of time which often tend to underestimate level of demand forecasted as potential users could have a higher value of time. To solve this problem the modeller uses artificially reduced toll charge ignoring the contrary situation in which user could have lower value of time which may overestimate level of traffic. The other problem emerged is, assuming the method underestimate the traffic, how to determine the most appropriate toll discount to compensate traffic shortfall. It is obvious that this way of toll modelling can lead to kind of optimism bias.

The second approach is based on developing diversion curves. Diversion curves assign traffic between toll and non-toll routes given the travel time saving and toll rate. Figure 3.3 illustartes an example of diversion curves. This typically involves a logit function

which estimates the facilities' share of the traffic market based on relative cost and travel time between toll and non-toll routes.

The logit toll model is the most common model used to develop toll estimation (Davidson, 2011). The probability of choosing one of the routes is calculated using logit equations. It is a binomial logit choice model where the user makes choice between the best toll and the best non-toll routes based on the cost of each route. This model involves several parameters determined from behavioural data. The most common source of data is the stated preference survey. In this kind of surveys, a range of hypothetical alternatives is presented. Survey respondents will choose their preferred alternative which will provide a sample for a discrete choice calibration.

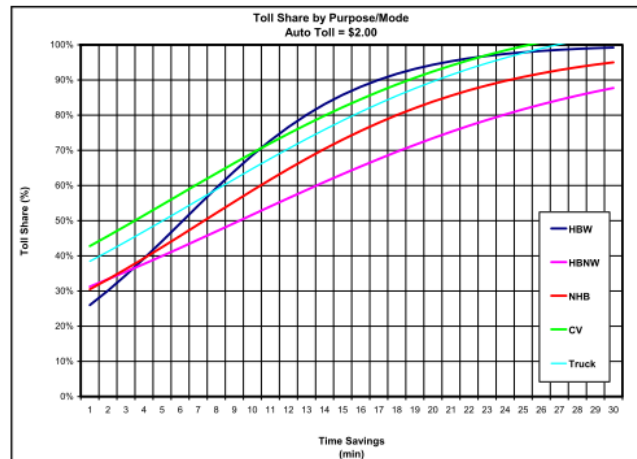


Figure 3.3: Sample Toll Diversion Curves  
Source: (URS, 2011)

*c) Additional step approach/Post processor*

This method is utilised as a fifth step within the four step model framework or applied exogenously to the output of four step model. This final approach depends mainly on comparing the toll facility characteristics (travel time, toll, etc.) to the non-toll competing facility to estimate the diversion rate out the borders of four step model.

It is not unusual that traffic forecast reports hide the way the consultant used to produce demand projections. For example, among several forecast reports reviewed by Prozzi et



al. (2009) only one has disclosed adopting the post processor to estimate the traffic demand. However, Prozzi et al. (2009) and through interviewing several traffic consultants concluded that option 2 and 3 (Figure 3.2) including logit model are the most dominant to estimate toll roads traffic projections. Davidson (2011) states that only little information is available regarding the method used to calculate toll share across Australia, it however seems that logit choice model is the most common approach. Kriger et al. (2006) found that half of the twelve toll roads surveyed used kind of diversion curve or toll elasticises based on logit model. Since the logit toll choice model dominates, the next section further discusses this method of toll modelling technique.

### *Logit model*

The logit toll model is a binomial logit choice model where the user makes choice between the best toll and the best non-toll routes based on the cost of each route.

Logit model is one application of utility theory, where people make choice based on the utility of each alternative and choosing the most preferable one. The common equation for logit choice is;

$$P_i = \frac{e^{u_i}}{\sum_j e^{u_j}} \quad (\text{Eq. 3.1})$$

For binomial choice, when there are only two alternatives to choose between, logit choice equation becomes;

$$P_1 = \frac{1}{1 + e^{u_2 - u_1}} \quad (\text{Eq. 3.2})$$

Where  $P_1$  is the probability of choosing alternative 1,  $u_1$  and  $u_2$  is the utility of alternative 1 and 2 respectively.

In case of toll roads, the utility of each alternative road can mathematically be identified in different ways and with different parameters. Value of time savings and toll are the common variables among all utility equations. One form of the utility function is the form used to estimate toll share of Hale St Link traffic;

$$U = \text{Toll} + \theta \text{ Travel time} + \gamma \theta \text{ Delay time} + \text{ASC}' \quad (\text{Eq. 3.3})$$

Where,

$\theta$  = Value of time

$\gamma$  = Delay factor

ASC constant

Using a binomial logit function and based on the parameters values of real case of Hill Street Link project in Australia, Davidson (2011) conducted a simple calculation to estimate toll share for two assumptions:

The first assumption is that the toll facility saves 16 min and the toll is \$2.

Toll Share =  $P(\text{toll}) = 68\%$

The second assumption is that the toll is still \$2, but instead of saving time it causes a delay of 16 min.

Toll Share =  $P(\text{toll}) = 12\%$

The simple calculation above suggests that even in the case where using toll road causes delays rather than saving time, 12% of the market traffic still pay money for using the road.

Based on the above calculation, it is obvious that a level of optimism bias occurs during the toll modelling process using the logit model. This model involves several parameters determined from behavioural data. The most common source of data is the stated preference survey. In this kind of surveys, a range of hypothetical alternatives is presented. Survey respondents will choose their preferred alternative which will provide a sample for a discrete choice calibration. Davidson (2009) and Bain (2009) argue that bias may occur by overestimating logit model inputs especially that extracted from stated preference survey. The stated preference survey will be discussed in the following section.

### *Stated Preference Survey*

Travel demand appraisal is usually based on data obtained by the direct observation of the travellers' behaviour or conducting survey to reveal this behaviour. This kind of surveys is called "revealed preference surveys" and depicts actual choices in terms of a set of market-based measurements of attributes for the available alternatives (Hensher et al., 1994) to reveal the preference of the respondents towards the existed options or alternatives. However, it is difficult to use this kind of survey to appraise options which do not yet exist. Alternatively, Stated Preference (SP) surveys, which describe a set of potential choices, allow the examination of hypothetical situations to uncover how

potential users value the service attributes. SP is typically used for Value of Travel Time Savings (VTTS) estimation (DfT, 2003). A typical SP survey presents a range of hypothetical choice scenarios (two or more) which made up of different attributes to be appraised by the survey respondents. The survey respondents are asked to select between different scenarios depicting different blend of cost and travel time on the toll road and an alternative route in order to estimate the utility for each of these routes. A simple example of SP choice scenario is shown in Table 3.2.

Table 3.2: An example of a Stated Preference Choice Question

<b>Option Attributes</b>	Free Road	Toll Road
Journey Time	30 minutes	15 minutes
Cost (Toll Tariff)	£0	£1
I would prefer	<input type="radio"/>	<input type="radio"/>

The table above illustrates that the toll road scenario involves a reduction of travel time by 15 minutes in conjunction with imposing £1 toll charge. The willingness to pay tolls to gain this reduction in travel time is the respondent Value of Travel Time Savings (VTTS). If a respondent chose the toll road option, that means he prefers to pay £1 to save 15 minutes. This implies that his value of time is £4 per hour.

One of the key concerns associated with the stated preference surveys is that SP data are prone to bias that emerges from the hypothetical nature of the SP scenarios where the observed preferences may not reflect an actual behaviour. In SP survey, respondents have no incentive to make a choice in an SP experiment in the same way as they would do in the real situation (Wardman, 1988, Kroes et al., 1988). Empirical evidence suggests that people tend to overstate their willingness to pay for, often by two or three times (Murphy et al., 2003). For example, a study by Harrison and Rutström (1999) showed that 34 of 39 SP observations had an average hypothetical bias of about 33.8 %. A survey by Champ et al. (2002) showed that the assigned hypothetical costs in their survey were not reliable to about 50% of their respondents. Wardman and Whelan (2001) reviewed 45 SP values from a large number of disparate studies conducted for new or improved trains. The study showed that not only the values were generally implausibly large, but they were also found to be three times higher where the purpose of the study would have been readily perceived as valuing new trains. The presence of

hypothetical bias is one of the most serious problems associated with stated preference survey. Lin et al. (1986), Kroes et al. (1988) and Bain (2009) suggest that estimating the demand based on this method necessarily needs careful interpretations, as people tend to overstate their responses under experimental conditions. Data produced from the stated preference survey was considered the key reason behind the inaccuracy of traffic forecasts for the high speed rail link between London and the channel tunnel (Financial Times, 1998).

The bias emerged from the stated preference survey data, which will eventually be used to determine the value of time and calibrate the logit choice model, will affect the logit model results and the consequent traffic estimates. Value of time is, however, not the only determinant of the traffic level; many other variable inputs are used in the process of traffic estimations. Next section discusses these variable inputs and how they affect traffic demand.

### **3.6.2. Model Inputs and Assumptions**

The methods used to forecast traffic stand on a wide range of assumptions related to the socio-economic system in addition to the facility and users characteristics. These may include assumptions relating to the population and employment growth of the area served by the facility, changes in tolls, willingness to pay and many other factors. Traffic projection, hence, involves a considerable amount of uncertainty owing to the inherent uncertainty in the model inputs and assumptions, which affect the results of the forecasting model. Chapter two introduced most of these inputs represented as factors affecting demand in PPP infrastructure in general. However, most of these factors will be re-discussed here but in the particular context of toll road projects and with further emphasis on their uncertainty. For instance, reliability may be considered one measure of quality of service provided by the toll road. In addition, there are some factors which are particularly related to toll roads such as expansion factors and induced traffic. Next sections discuss a range of factors influencing traffic in toll road projects.

### *Socio-economic factors*

The current and future demand relies on the magnitude of development in the area served by the facility. Thus, the demographic and economic aspects of the facility area can be considered one of the most significant variables when predicting the potential demand for a toll road. Inappropriate assumptions regarding the socio-economic inputs can lead to a tremendous forecasting error. Among all the socio-economic drivers, population and employment are arguably the most significant. Population growth rate is a key indicator in forecasting trip generation in a specific area. The higher is the population growth, the higher the trip generation in the area. If the actual population growth turns out to be lower/higher than that predicted, the population projection would considerably impact the traffic volume since any decrease in population would translate into lower usage. On the other hand, the employment rate is used to estimate the trip attraction. The overestimation of this rate would similarly inflate the demand projections and vice versa. Any new development will have an impact on the employment level. Land use concept is a common practice to appraise this development. The major concern regarding the land use assumption is that, in many cases, the predicted land use scenario may not be materialised leading to lower than expected demand (Kriger et al., 2006, Bain, 2009b). Uncertainty in land development is a key source of error in traffic projections (Rodier, 2003). Flyvbjerg et al. (2005, 2006) concluded that the factor of land development is one of the top stated sources of uncertainty. Rodier (2003) found that about half of the 11% of demand overestimation produced by travel demand model in California for year 2000 was due to demographic and employment projection. Pardhan and Kockelman (2001) investigated the impact of uncertainty in land use and transport modelling. The potential influencing factors included population and employment growth rate, mobility and accessibility. The analysis found that the impact of uncertain population and employment growth rate is far greater than that of mobility and accessibility factors. Thus, if the assumptions associated with growth rates are not adequately accurate to reflect changes in population and employment, it is likely to result in a different value for demand level.

Annual GDP growth is another significant indicator used in the traffic forecast studies. Experiencing higher or lower annual GDP growth rate than that assumed can have a significant impact on the toll facility performance due to the strong relationship between traffic growth and economic growth. Figure 3.4 shows the relationship between GDP

and traffic in the UK. The figure shows the consistency in change between GDP and traffic.

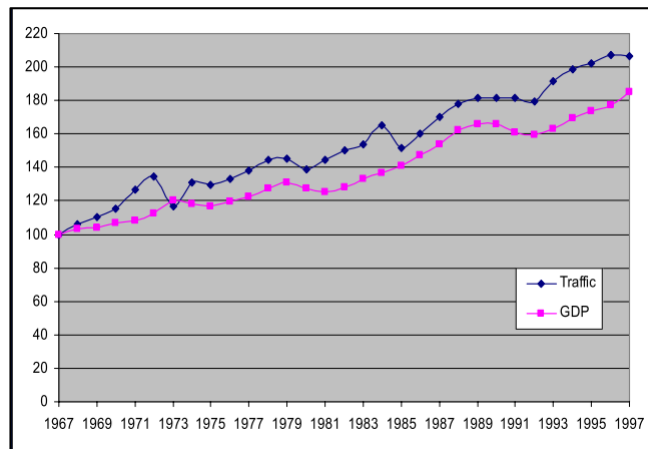


Figure 3.4: GDP versus. Traffic Growth, UK 1967-1997 (Indexed to 1967=100)  
Source: Godley (2008)

The average annual population, employment and GDP growth rates and the growth rates in five-year increments are usually used in demand forecast studies. Typically, historical growth information is the benchmark for predicting potential future growth in a specific area. To develop economic and demographic inputs and assumptions, the forecaster reviews the historical trends to estimate future growth rate (i.e. the annual population growth for previous time periods is examined to predict the future annual growth). However, a high level of uncertainty is associated with using historical value to predict future ones. Table 3.3 illustrates the variation between the predicted population growth rate used by the forecaster to predict traffic for a toll road in USA and the actual ones.

Table 3.3: Variations between Forecasted and Actual Population Growth Rate

County	Projected growth Rate (%)	Actual Growth Rate (%)
Colin County	6.4	3.9
Dallas County	1.8	0.7
Denton County	4.7	2.8

Source: (Prozzi et al., 2009)

In addition, data are sought from different regional and national organisations such as local officials, land use plans, area stakeholders, business groups, private consults, and several other governmental institutes. In many cases, several sources provide different

values for the same parameter which increases the uncertainty associated with the model inputs and assumptions.

While the level of uncertainty inherent of the socio-economic factors involved in demand forecasting is significant, the traffic demand estimated based on these socio-economic assumptions is seldom assessed against uncertainty.

#### *Willingness to Pay (WTP)*

One of the uncertain assumptions in traffic modelling is related to WTP. George et al. (2007) argue that, in countries with no history of tolling, WTP can have serious impact on toll road demand and the overall project viability as happened in Hungary. Kriger (2005) identified willingness to pay as a value of time that considers how much users value other attributes of the facility such as reliability as opposed to its availability. Average WTP can therefore be greater than actual value of time. Next sub-sections discuss the main measures of WTP.

#### *a) VTTS*

VTTS is the monetary value determined by passenger to each unit saved of travel time. It mainly assesses how toll rate affects route choice (toll route against competing non-toll route). The travel time saving offered by tolled facility and its value are at the heart of toll traffic estimation models (Bain, 2009a). It is the X-factor of toll facility projections (George et al., 2003). Boyce et al. (2005) suggest that value of time has a substantial effect on toll roads usage. Metz (2008) suggests that VTTS accounts for about 80% of the benefits of major road schemes. It is the driver for the decision to ride on the toll road rather than a competing free-toll facility (Kriger, 2005). Thus, VTTS is a critical input into demand estimation models and over/undervaluing user's time savings may cause considerable uncertainty in traffic demand estimation.

The typical way to derive value of time is based on stated preference surveys. While this kind of surveys can help to understand motorists' willingness to use toll facilities, Bain (2009) suggests that stated preference surveys are hypothetical in terms of payment and the provision of concerned service and users tend to overestimate what they would like to pay for hypothetical service. This practice makes SP surveys prone to a hypothetical

bias (Department of Infrastructure and Transport, 2011) as discussed above in section 3.6.1. Uncertainty in VTTS may also emerge from other sources. In many instances, due to time limitations, tolling modellers adopt and use value of time derived from previous studies or experience elsewhere (Kriger et al., 2006) which might not be compatible with the VTTS of potential user of the facility in question.

*b) Reliability*

Reliability can be defined as the capability of a system or a service to carry out its designed function under particular use conditions over a specific period of time (Baliwangi et al., 2007). In a transport system, reliability is a subjective aspect which relies on user's perception towards the traffic conditions on a specific route. Department for Transport (DfT) in the UK identifies reliability as the variability in travel time or journey time variability (Dft, 2012b). In other words, reliability defines how travel times vary over time (hour-to-hour, day-to-day). On a particular route, some days could be better (or worse) than others in terms of congestion, and there is some variation from average or typical conditions on any given day. Congestion can dramatically change the performance of the roadway through affecting travel speeds and time. The travelling motorists experience large performance swings, and their expectation or fear of unreliable traffic conditions affects their view of roadway performance.

Significant variations in travel time will decrease the benefits of using a particular road. Travellers are not sure about the specific trip they are about to make and how it compares to their typical or expected trip. Prolonged or missed connections and arrival at the destination either before or after the desired or expected arrival time are typical consequences (DfT, 2012b). While the motorists are sensitive to such consequences, traffic models do not usually reflect these variances in travel time and most often include only inputs of the mean value of travel time.

Reliability can be regarded as a significant factor which plays a non-trivial role in determining the demand for the toll facility. Peer et al. (2009) found that travel time reliability costs can exceed the mean travel time delay costs. In M6 toll road, reliability was evaluated at approximately similar value of time saving (AECOM, 2012). This is an evidence that travel time reliability is valued at a significant "premium" by users. DfT (2012b) therefore recommends that "Travel time variability is an increasingly



important issue. The appraisal of transport schemes or policies should aim to place a value on any changes to this journey time variability because of the extra costs it incurs on drivers and passengers. Thus, it should be taken into account in the assessment of the overall value for money of the transport project”.

Traffic modelling should therefore take into consideration the effect of such soft factor of reliability by considering its relationship with users’ WTP and assessing its impact on the level of traffic.

### *Competition*

With the increasing interest to improve road network, presence of competition is inevitable. Potential future changes to competing routes such as nearby highway extensions are significant source of uncertainty. Construction or expansion of roads will cause traffic to divert from expensive toll roads to the new less congested option. Demand estimation, thus, depends on future network changes since this kind of changes would affect congestion level. While many concession agreements include non-compete clause that protects the concessionaire from competition by prohibiting or restricting the construction of new facilities or upgrading of existing competing facilities, others do not. This risk over which the private sector has no control, needs to be well modelled as it can degrade the project success. For instance, the upgrading of the untolled competing Route 7 was considered as the main reasons for the low usage of the Dulles Greenway (USA) where the scheme concession agreement do not have any clause prohibiting the development of new adjacent facility or improvement of existing one (Iam, 2006). The uncertainty associated with the conditions of both existing and potential competing roads and the failure of the model to consider the new conditions may lead to unreliable and uncertain traffic estimate.

Conversely, complementary facilities may have opposite impacts. Chung et al. (2010) and Arndt (1998) argue that road projects are particularly concerned with the feasibility of connecting to current and future infrastructure. Considerable traffic growth may occur due to opening a new link which complements the facility. Nelson and Loke (1998) consider lack of access to the route as one of the major reasons behind defaults in the toll roads financial performance. For example, Dartford Tunnel (UK) showed only small increase in traffic volumes following the opening the second tunnel in 1990.

The main increase happened after opening M25 road which linked the facility with the national network. On the other hand, the poor usage performance of Foothill Eastern toll road (USA) was considerably attributed to the lack of appropriate access since the proposed extension of a parkway to the Foothill/Eastern toll road did not occur (George et., 2003) as originally planned.

### *Induced traffic*

Historically, economic analysis assumes that the total volume of traffic is fixed, whether or not the facility is provided. Estimates should be made to account for the effect of the provision of the facility in generating trips additional to those that would be made without providing the facility. Induced traffic can be defined as the additional traffic that is induced by the facility through mode changes, destination changes or trip frequency changes. Thus, in addition to traffic growth resulted from accelerated land development and enhanced economic growth in the adjacent area, generation of new traffic or release of latent travel demand previously suppressed needs to be accounted for. Goodwin and Noland (2003) suggest that the addition of capacity induces traffic regardless of the change in travel time. A thorough review on induced traffic conducted by The Standing Advisory Committee on Trunk Road Assessment (SACTRA) concluded that induced traffic does occur as a result of constructing new road, increasing capacity, or making improvements to existing roads leading to further traffic growth in the facility area (SACTRA, 1994). However, the level of traffic generated as a result of the provision of additional capacity is uncertain (World Bank, 2003).

### *Expansion Factors*

Most traffic estimation models produce morning peak period traffic estimates as a basis for traffic forecast. However, toll revenue estimation requires an annual estimate of demand. Morning peak estimates therefore need to be expanded to produce forecasts of average weekday traffic (AWT), annual traffic (AT) and average annual daily traffic (AADT).

First type of these expansions is generated using the weekday expansion factor which converts weekday morning peak period traffic (MPPT) to average weekday traffic

(AWT). This factor considers the relationship of morning peak period and traffic at other times of the day. Low expansion factors imply that traffic at the peak period is dominant (e.g. high percentage of work trip). On the other hand, high expansion factors imply that the road exhibits a relatively flat daily traffic. Expansion factors are typically estimated on the basis of current expansion factors observed on relevant roads.

Weekday expansion factor is not constant. Instead it changes over time. An increasing weekday expansion factor means that the traffic outside the morning period is growing faster than the traffic during the morning peak. This can result, for instance, when recreation, social and shopping trips display higher growth rates than work trips that dominate the morning peak. Historical patterns of growth observed on relevant roads are usually used to estimate the expansion factors growth rate after taking account of tolling effects.

Second type of expansion factors is the “annualisation” factor. This factor converts road’s annual average weekday traffic to the annual traffic. Subsequent division of the annual traffic by the number of days in the year gives the average annual daily traffic (AADT). Most of the roads show significant differences between traffic on weekday and traffic on Saturdays, Sundays and public holidays. Thus, annualisation factor will vary with travel trend on the weekdays relative to weekend/public holiday. A high value for the annualisation factor implies high weekend traffic relative to the weekday traffic and vice versa.

In a way similar to that used to determine weekday expansion factors, annualisation factors are estimated on the basis of traffic behaviour on relevant roads. In addition, the per annum average growth in annualisation factor is estimated based on the observed change in traffic behaviour over time.

The values of the expansion factors and the underlying growth rates are associated with a high level of uncertainty (Kriger et al., 2006; Bain, 2009 and Prozie et al., 2009). The size of variations between peak and off-peak period and between weekdays and Saturdays, Sundays and public holiday can vary greatly between roads. In addition, toll can have different impact on traffic. It is, therefore, pretty difficult to trust, use and apply expansion factors developed based on historical trends on other routes. Moreover, expansion factors vary with time with different rates. Change in land use, road

construction, and accessibility on weekdays, weekends and during the holidays can substantially affect expansion factors growth rates.

### *Ramp-up*

The toll road operation phase may start with an introductory phase or ramp-up phase. During this phase the facility utilization is minor. Ramp-up can be considered the period of the distress in the toll road project lifecycle. It is the most uncertain and risky period of the project lifecycle in terms of both demand and revenue estimation (Prozzi et al., 2009). During this period, the traffic is likely to be considerably lower than that forecasted. The reason is that it is likely to take some time for motorists to realise the benefits of using the toll facility such as time savings and reliability. By approaching the end of the ramp-up, the achievement of higher utilization may occur.

Ramp-up is uncertain and risky in terms of both duration and severity. Chung et al. (2010) suggest that toll roads in Australia such as Cross City Tunnel, Link City Tunnel and Melbourne City link confirmed that the private sector failed to predict the period of time it takes for traffic to get over the ramp-up hurdle. Rapid ramp-up period may cause the road to have a hard time meeting the expected traffic since the traffic patterns will evolve over longer duration (Bain, 2009a). In terms of severity, the low level of usage during the ramp-up period may be disastrous. Lower than projected traffic through the ramp-up period has been considered one of the major factors for demand risk and consequent need to refinance the Fothill/Estern toll road in Orang County, California, USA (Kriger et al., 2006).

### *Historical experience of Paying and public involvement in ongoing facility management*

Chapter two discussed the significance of users' experience of paying for services in infrastructure concession projects. Toll roads are not an exception. Tolling culture of the facility area is a significant driver of demand risk (Bain and Wilinkes, 2002). Demand variation is more common in countries with no previous tolling experience compared to those with tolling history (Bain et al., 2003). When the facility area has no or only little tradition of payment, the introduction of a toll road can result in low level of usage (World Bank and PPIFA, 2009). Bain and Plantagie (2003) argue that demand estimates tend to be more reliable in areas where users are accustomed to pay toll for previous toll

facility. However, experience suggests that, over the long term, motorists' willingness to pay toll augments, particularly if the road results in time savings, or improves connectivity and access (Prozzi et al., 2009). Kriger (2005) suggests that people are generally slow to accept toll road, yet the objection is gradually reduced over time implying the dynamicity of such perception.

As discussed in chapter two community engagement in setting up maintenance and safety standards and adjusting tariff is to ensure high degree of prolonged public satisfaction and use. In addition, Chung et al. (2010) suggest that the private sector is gradually realising the benefits of making the project part of the community. Initiatives such as tree planting and shutting down the road to use for run and raise money for charity are to enhance public support and use.

#### *Toll level and toll adjustment*

Introduction of toll roads means a switch from tax-payers to users for the payment responsibility. George et al. (2007) suggest that imposing fee for using roads introduces more uncertainty to the demand estimation. Toll adjustment during the operation stage can further affect traffic demand. Concession agreements give the concessionaire the right to increase toll rate over time, usually on annual basis and according to a toll increasing formula that is related to inflation. However, while increasing toll rate aims to increase the facility monetary revenue, this is not always the case. Toll rate hiking can result in considerable lower traffic volume leading to lower revenue (Cramps and Estache, 1998). Moreover, toll increase can be faced by aggressive opposition from the community. This kind of opposition has meant, in many cases, that toll has not been increased as originally planned. For instance, a strong public outcry against toll increase on the 25 April Bridge (Portugal) led to only minor increase in the level of toll (Fernandes and Viegas, 2005). In addition, in Brazil, local political pressure forced the concessionaire to charge only 50% of the original tariff in a concession in Parana (Estache et al., 2000). In such cases, operator is likely subject to specified governmental compensations.

Conversely, lower than predicted demand may push the operator to decrease imposed toll rate. For instance, it was predicted that in 1996, with an average toll of \$1.75, the

daily flow of Dulles Greenway would be 35,000 vehicles. However, only 8,500 motorists used the facility in that year. To attract more users, the toll was lowered to \$1.00 where usage increased to 23,000 riders per day, which was still less than that predicted (Lam, 2006). The failure to raise toll can have a serious impact on the financial position of the facility, particularly in the case of poor utilisation levels.

Obviously, imposed toll level and toll adjustments include a huge level of uncertainty which may impact and be impacted by the level of demand.

### *Toll collection*

The primary goals of tolling are to provide a high service quality and save time. To maintain a high standard of service, the toll system, used to collect the fees from motorists entering or exiting the toll system must be efficient at moving motorists through toll plazas at a minimum time. Time saving is a function of the toll collection method. Collecting toll manually is a common method. Toll plazas typically offers several toll booth staffed with toll collectors and involve manual cash collection. In addition, toll plazas may also offer dedicated automatic toll collection booth with automated machine using coins, credit or debit cards. The delay in toll collection caused by manual toll collection methods is considered as a major drawback of this system. The need to stop to pay tolls which prevents the uninterrupted flow and causes delays is seen as a significant impediment for using toll roads. Thus, in addition to toll payment, delay caused by collecting this toll could be another reason for opposing toll roads introduction (Baker et al., 2005).

However, introducing advanced tolling technology such as Open Road Tolling (ORT) and TAG technology wherby road users are not required to stop at a toll plaza to pay would alleviate or even remove any tolls objection resulting from toll collection delay. These systems require all motorists to register their vehicle for e-tolling, to carry tags in their vehicles and to pass the toll gates at a slower speed, but without stopping (World Bank and PPIFA, 2009). Thus, the new method has no impact on the travel time. In addition, electronic system users are usually subject to discounted toll rate for a frequent use. Bain (2009a) argues that Electronic Toll Technology (ETC) not only speeds the travel time but also decreases the motorist sensitivity to change in toll which may result

in consequent increase in demand traffic. However, the proportion of users willing to use the technology is uncertain. Lemp and Kockelman (2009) argue that uncertainty of demand may also rise owing to toll technology adoption rate. While ETC is used by more than 70% in 407 ETR (USA), which is argued to be the typical proportion for most toll roads (Prozzi et al., 2009), this percentage did not exceed 15% in the M6 toll (UK).

### *Public acceptance*

Roads have been for long viewed as public goods that government must provide. Public perceives roads as facilities paid for through tax revenue. The concept of tolling is therefore not widely accepted. About 300 years ago, aggressive rioting was the public reaction of establishing the Turnpike Trusts in 1706 in the UK. The toll-gates were destroyed, largely because the public objected to pay tolls for using roads which had previously been toll-free (Willumsen, 2005). Public's resistance forms one of the significant impediments to introducing tolling system (Fisher and Babbar, 1996). Patterns of user behaviour and the likelihood of public acceptance of such projects are uncertain. Due to this uncertainty, Mouraviev (2012) suggest that these patterns need to be carefully investigated before the beginning of a project with the help of surveys, interviews and public discussions. Chapter two discussed different method used to survey public perception and public consultation.

### *Environmental considerations*

Of particular concern to some opponents of tolling are the environmental considerations. It is one of the significant factors which could substantially affect public satisfaction of the tolled facility. Environmental approvals are a pre-set condition before the onset of any highway construction. There are several cases where environmental issues caused considerable delay or even permanent cancelation of the facility construction. Environmental impacts are unquantifiable risks (Nelson and Loke, 1998) which need to be assessed in the feasibility study.

In summary, there are several inputs and assumptions to be included in the traffic estimation models. The majority of these inputs involve level of uncertainty, dynamicity

and dependencies. However, the available forecasting models are unable to account to such features; For instance, the four-step model is unable to account to dynamicity since it is based on static settings. Kriger et al., (2006) argues that the steady-state nature of traffic forecast makes it more difficult to consider the impact of economic fluctuation on travel demand which can lead to poor forecasting performance. One of the weaknesses of traditional model is that it is based on the theoretical assumption that the urban system including land use or transportation is in a state of equilibrium (Haghani et al., 2002). In addition, these models do not have the capacity to consider uncertainty involved in most of these factors as it will be discussed later in this chapter. In addition to the uncertainty associated with the model input, the optimism bias of the values of these factors was identified as another source of demand variations. Next section discusses optimism bias in traffic forecasting.

### **3.6.3. Optimism Bias and Strategic Misrepresentation**

While technical errors (inappropriate model and inadequate model inputs and assumptions) are often introduced as the main sources for estimation errors, Flyvbjerg et al. (2008) has the perception that rationales behind traffic variation are not merely a technical problem. Flyvbjerg argues that technical errors would have a symmetrical error distribution around zero with similar proportions over and under prediction. Given this, Flyvbjerg attributes forecast errors to psychological and political-economic rationales. Psychological explanations, developed by Kahneman and Tversky (1979) and Lovallo and Kahneman (2003), account for demand overestimation in terms of optimism bias where planners overestimate project benefits by introducing scenarios of success. On the other hand, political-economic explanation, which is the source of strategic misrepresentation, developed by Wachs (1987, 1989 and 1990), considers that planners and project promoters deliberately overestimate projects benefit (generate optimistic figures). They do this in order to gain fund and approval to their project over any other potential competitors. This kind of behaviour would serve their interest in getting the project financed and built under the government purse constraints. This is most likely to happen in case of scarce resources and fund or jockeying for position. Thus, this strategic misrepresentation can be traced back to political and organisational pressure (Flyvbjerg, Holm and Buhl, 2002, 2005; flyvbjerg and Cowi, 2004 and Flyvbjerg, 2008).



In terms of traffic forecast for toll roads the main reason for producing optimistic funding is two folds. First, it is a way to use the overestimated model outcomes as a motivation for governmental acceptance and motivate government to start the project. Second, it is to attract private fund by presenting the project as favourably as possible since highly beneficial road is more attractive than one that is not. On the other hand, bidders themselves may provide optimistic traffic estimate to win the project deal. Flyvbjerg (2005), Vasallo (2007) and Bain (2009b) argue that bidding process in which the bidder with highest revenue projections and lowest cost wins could lead to the risk of overoptimistic forecast. The private sector will have more incentive to this strategic behaviour when it recognizes that the public client desperately tries to get the project succeeded by offering guarantees and subsidise and sharing risks.

In summary, literature review offered three major justifications for traffic variations: inappropriate models, inadequate inputs and assumption and optimism bias and strategic behaviour. Next section discusses the contribution of each of this justification to the uncertainty of traffic estimation and ultimately to traffic variations dilemma.

### **3.7. Traffic Estimation Uncertainty**

A study by Zhao and Kockelman (2002) tracked the uncertainty associated with modelling by four-step travel demand method. The study suggests that that uncertainty in inputs and assumptions is the major source of forecast uncertainties. Moreover, an analysis of a case study in the Netherlands by De Jong et al. (2007) suggests that the contribution of input uncertainty into the whole error is much larger than that of model uncertainty. Matas et al. (2010) and by using data pertinent to Spanish toll roads, found an empirical evidence which supports De Jong et al. conclusion. Based on the analysis, Matas et al. (2010) concluded that uncertainty of forecast depends heavily on the uncertainty about the future values of the explanatory variables and this uncertainty is the most important.

Furthermore, while a big deal has been raised regarding the presence of optimism bias and systematic selection in the toll road forecast studies, reviewing particular case studies offer no evidence proving their incidence. Prozzi et al. (2009) conducted an

investigation into four case studies in the USA; the investigation included an extensive review of traffic and revenue reports as well as the actual traffic figures. Based on the case studies reviewed, it was concluded that there was no evidence pointing to a systematic optimism bias in the traffic and revenue studies. In addition, Department of Infrastructure and Transport in Australia (2011) reviewed several toll roads studies and concluded that there “*was no proof in our case studies of deliberate systematic strategic selection*”. Osland and Strand (2010) found no support for the theory of strategic misrepresentation and argued that there are better observed explanations for the forecast variations.

Moreover, the optimism bias, if there is any, likely affects the model assumptions and inputs values through selecting optimistic values for population, employments values of time and other inputs. Department of Infrastructure and Transport in Australia (2011) reported that optimism bias may result in using higher growth rates and higher estimates of value of time. Pendyala (2005) argues that it is plausible to attribute the optimism bias documented in the traffic variations studies to optimistic input assumptions driving the forecast. The main source of error comes from WTP, VTTS, and land use. The optimism bias is also likely to occur in the absence of data for a particular variable where optimistic choice may occur (Department of Infrastructure and Transport, 2011).

Based on the aforementioned discussion, it can be concluded that traffic demand risk could be mainly attributed to the uncertainty associated with the model assumptions and inputs. One of the major issues in developing the traffic estimations pertains to the quality and integrity of the model assumptions and inputs. However, it is not easy to obtain perfect data representing the model variables and predict the actual growth (value and timing) of the model variables over long horizon which could expand to 25 years or more. Thus, in the case that future events do not match the predicted inputs or the assumptions, many unexpected outcomes would emerge. To reduce this uncertainty, experts and transport professionals recommends that multiple sensitivity analysis and probabilistic modelling of key input variables is a necessity. These two approaches will be used in this research after modelling the influencing factors taking into consideration their main features including interdependencies, dynamicity, soft factors and non-linearity of their relationships.

Demand estimation is a complex structure involving multiple interdependent variables that affect the demand internally. As discussed in chapter two, most of the factors affecting demand are interconnected. In practice, users' choice depends not only on fee levels (if any) but also on interactions of a host of factors. In toll roads for instance, it is the production of complex interactions of travel time savings, value of time and tolls (Smith et al., 2004). De Jong et al. (2007) suggest that most traffic models for transport projects ignore the correlations between the influencing variables. For instance, the willingness to pay to save time varies with income, among other things, which is, in turn, influenced by the economic conditions (boom/bust cycles).

Niles and Nelson (2001) and Haghani et al. (2003) suggest that although the mobility and dynamicity of the urban system is quite noticeable, decision makers still utilise closed and static models for modelling demand in transportation projects. Haghani et al. (2003) suggest that it is more realistic to assume that urban activities happen in the process of dynamic interactions between the various variables. Demand for service provided by PPP project through the life of the facility is subject to considerable variability. For instance, demand traffic estimation in toll road project is typically based on comparing the utility of multiple available alternatives which mainly includes toll and travel time savings. Both toll and travel time saving is not constant over time. Thus, using the traditional static models to determine toll share will often neglect an important aspects of demand influences which is dynamicity. In the same vein, traditional traffic modelling approaches produce traffic estimates on five or ten year intervals. To produce traffic for intervening years, interpolation method is usually used. Thus, these models do not accommodate year to year deviations (Bain, 2009a) resulted from influences dynamicity which could be significant. For instance, value of time is subject to annual change following changes in household incomes, among other factors. In addition, in most of the projects, private operators alter their tolls on annual basis. Therefore, the incorporation of the potential deviations is necessary to assess potential subsequent change in traffic.

In addition, the interactions among much of the demand influences often shows nonlinear trend. For example, congestion, one of the most significant determinants of quality of service provided by transportation projects, shows a non-linear function. For high levels of congestion, a small reduction in traffic volume can provide a considerable increase in speed and consequently a reduction in travel time. For instance, reducing

traffic volume from 2000 to 1800 vehicle per hour (20%) increases traffic speed by 15mph (30%). However, for lower levels of congestion, similar reduction in traffic is not likely to considerably affect the speed and travel time (Victoria transport policy institute, 2009).

Demand in PPP projects is not easy to appraise as it requires several quantitative and qualitative factors to be taken into account. Some of the most significant data required to assess the level of demand is to understand the potential users' perspectives towards the facility and their level of satisfaction in addition to several other soft factors. Most of the available models ignore this kind of soft variables when modelling demand for service. Kriger et al. (2006) suggest that it is more often than not to ignore reliability when modelling toll roads traffic. Sterman (2002) argue that omitting such qualitative factors is less scientific and less accurate than using your best judgment to estimate their values. Omitting such variables would exclude critical elements and it equals to assuming that they have zero effect (Forrester, 1961). Given this, Sterman (2002) suggests that models are grounded and validated using the widest range of data, including numerical data, archival information, and qualitative data generated from interviews, observation, and other ethnographic methods.

Most of the system in reality involves kind of delay. Complex transportation system is not an exception. The conventional solution for congestion problem is road construction. Decisions to construct a new road to relieve congestion may however, take years to make. In addition, since road construction takes time there is a delay between the construction action and the required increase in the highway capacity. The modelling tool should consider such kind of delay and its impact on traffic demand.

To assess uncertainty associated with traffic demand or demand risk, a method able to capture complexity, soft factors, dynamism of demand influences, as well as the non-linearity of their interactions in a holistic manner is an essential need.

Next section discusses the traditional methods used to assess uncertainty in traffic estimation and its limitations.

### **3.8. Modelling Uncertainty of Traffic in Toll Roads**

As discussed above most of the underlying variables of demand forecasting include a level of uncertainty which influences traffic in different ways. While such uncertainty is not trivial, in many projects it is largely overlooked by modellers and planners (Lemp and Kockelman, 2009). Duthie (2008) supports this view and suggests that not all stockholders agree with the assumed inputs and parameters values. However, most of traffic studies tend to present the traffic estimation as a deterministic figure which ignores uncertainty, suggests a level of accuracy that is probably not warranted, and ignores any possibility for potential variations or demand risk (Kriger, 2005, Clay and Johnston 2006; Litman 2009; Welde and Odeck, 2011 and Matas et al., 2010).

Based on investigation several case studies in the USA, Prozzi et al. (2009) concluded that traffic risk assessment is rarely conducted in the traffic studies. A questionnaire survey of traffic forecast practitioners by Kriger et al. (2006) indicated that only a small number of respondents conducted an assessment to evaluate traffic risk. The majority either do not conduct any risk assessment or verification, or just verify their results through simple methods such as judgments and reality checks. In addition, Kriger et al. (2006) argue that the section pertinent to the risk analysis in the forecast study reports is usually so brief and only introduces the variable considered and the resulted outcomes.

Next sections introduce the methods found in the literature or used in traffic studies to deal with uncertainty and demand risk in traffic forecasting.

#### **3.8.1. Reference Class Forecasting**

To overcome the optimism bias and misrepresentation related to the strategic behaviour of the project stockholders, Flyvbjerg (2008) introduced a reference class forecasting method in order to include this bias into the forecast.

Reference class forecasting was originally developed by Kahneman and Tversky (1979) to compensate for the bias that found in their work on decision-making under uncertainty. To apply the method to a certain project, the following three steps are required;

- Identifying a relevant reference class of past experiences which is mainly similar projects.
- Setting out a probability distribution for the selected reference class through collecting empirical data for a sufficient number of projects within the reference class.
- Comparing the project in question with the reference class distribution, in order to establish the most likely outcome for this project.

The main deficiency of this method is the large number of similar projects required to establish the probability distributions necessary to calculate the final forecasted figure. In addition, the similarity issue remains questionable, especially for those non-routine greenfield projects where it is quite difficult to find two projects with similar attributes and built in a similar environment. Quinet (1998) argues that it is difficult to compare comparable things when topic is related to traffic, the conditions of implementing a particular project is different from that defined for any other.

### **3.8.2. Judgments and Reality Checks**

This is done by conducting a rough comparison between the traffic demand projections for the facility in question and older projections for other facilities and by using simple intuition to verify the result reasonability. Technical knowledge, experience, and judgment ability are the major determinants when selecting the experts. In the context of the high uncertainty associated with forecast models inputs, judgments and reality checks becomes incapable to achieve the aim of results verification since they do not sufficiently uncover the range of possible outputs (Kriger et al., 2006). In addition, bias may arise when experts have direct or indirect interests in influencing the outcomes at hand. Their judgments may be influenced by bias consciously or unconsciously (McAndrew et al., 2009; Pronin et al., 2004.).

### **3.8.3. Sensitivity Analysis**

Few studies dealt with uncertainty by presenting several estimate based on different values for the exogenous inputs using sensitivity analysis. Sensitivity analysis is a typical way to address uncertainty via variations in key inputs. In the traffic demand

context, sensitivity analysis is a method to evaluate the impact on revenue-based demand for any given change to one input variable, when all other variables are held constant. It aims to “*quantify the degree to which actual experience could differ from assumed in the base case traffic and revenue forecast*” (George et al., 2003). It hence provides an insight into what happens if some variables values differ from the basic case. Sensitivity analysis in traffic study usually takes the form of stress tests. Stress test aims to provide an understanding of the outcomes in the context of relatively extreme conditions. In other words, the target is to generate most pessimistic and optimistic scenarios. The feasibility study of SR-520 toll facility (USA), for example, included modelling an upper and lower bound of the toll possibilities to quantify the uncertainty in the revenue forecast (Kreiger et al., 2006). However, in some cases, subjective expert opinion is used to determine a range of possible values for inputs and perform sensitivity analysis to test the impact on the outcome of hypothesised change in the estimated values of the influencing variables one by one.

Although sensitivity analysis may be a reasonably effective method, it has its limitation. One limitation is that the analysis is limited to a small number of scenarios, typically three or four. Kriger (2005), Kriger et al. (2006) and Prozzi et al. (2009) stated that modern traffic forecast studies barely include some form of limited sensitivity analysis of few key variables such as population and employment forecast and value of time. Even though such analysis can provide some insights into potential outputs, financial communities and other institution such as the National Federation of Municipal Analysts (NFMAs) consider it inadequate to uncover the range of potential outcomes. For example, stress test provides only insight into the upper and lower bounds on the outcomes ignoring the distribution of outcomes. In addition, Walker and Fox-Rushby (2001) argues that this method ignores interdependence between inputs oversimplifying the model and reducing its accuracy. Therefore, Sinha and Labi (2007) consider this method impractical to use when the aim is the assessment of the impact of change of several correlated inputs. Kriger et al. (2006) suggest that traditional sensitivity analyses conducted in most traffic studies account for a variation in only single assumption at a time. George et al. (2003) argue that most sensitivity studies conducted are uni-dimensional dealing with only one scenario such as slower economic performance or delayed development. However, this is not the case in reality where a series of events can occur simultaneously. For example, a recession in the economy can lead to a lower income and, subsequently, lower value of time and higher toll and fuel price elasticity.

Given this, institutes such as NFMAs (2005) formally recommend the analysing uncertainty by varying only one variable at a time is inadequate. Practitioners have a similar view. More than of 50% of the respondents the traffic forecast practitioner survey in the (USA) agreed on the insufficiency of this kind of sensitivity analysis (Krieger et al., 2006). Another limitation of sensitivity analysis is that it does not offer any information about the probability of events occurrence. A method which presents the variables values as probabilities or ranges and the outcomes with different levels of confidence is recommended by the financial community (Krieger et al., 2006). Prozzi et al. (2009), George et al, (2007), Dehghani and Olsen (1998) considered both sensitivity analysis and risk assessment an important step of the evaluation process for toll road and recommend more detailed risk analysis study identifying the major variables taken into account and the impact on demand projections. They mainly recommended conducting risk assessment using probabilistic method.

Furthermore, when applied, sensitivity analysis in toll roads traffic study is frequently applied to revenue estimation rather than demand estimation. Thus, the focus is on the financial indicators which are most linked to the project revenue required from the financing body. This kind of analysis usually includes demand traffic as an external influencing factor overlooking the factors impacting demand itself and having indirect but significant relationships with revenue. Analysing the sensitivity of the revenue by considering demand as independence variable ignores the elasticity of demand to toll and other influences.

The above discussion of different sensitivity analysis methods suggests the inadequacy of the methods employed and the need for a new means to assess uncertainty using multiple sensitivity analysis and probabilistic approach. In addition, as aforementioned, the methods should have the capacity to capture complexity, dynamism of demand influences as well as the non-linearity of their interactions in a holistic manner.

### **3.9. Summary**

Roads contribute to the regional and national economic prosperity by facilitating key economic development proposals and relieving traffic congestion. High level of demographic growth and congestion make public funding sources insufficient to meet



increasing demand for roads infrastructure. To fill the gap, several alternative methods have been considered. Tolling has been seen an efficient source to raise fund for introducing necessary road schemes. While tolling is considered as a reasonable solution to overcome government financial problems, the presence of demand traffic risk reduces its attractiveness. There has been increasing number of international studies focusing on demand variations issue. The studies aimed to compare actual travel level and forecasts to determine the size of variations between the two. The studies particularly focus on the variations in the first year of operation. However few of them extend the comparison and analysis for further time points after the first year. In addition, the literature offered many reasons to explain demand traffic variations such as model and input uncertainty and optimism bias. Input uncertainty proved to be the most important making long term traffic estimations subject to nontrivial degree of uncertainty. Economic and demographic factors and the particular interest of users in time saving makes uncertainty an inherent aspect of future traffic projections of any toll road scheme. The toll adjustment is also not certain. Under public or political pressure, the private operator may tend to charge a toll below the specified level in the concession agreement. Another variable bringing uncertainty to traffic estimates is the assumptions about changes to the competitive roads in the future which are based on government plans as these plans may or may not materialise in reality. While the potential variations in traffic resulted from this uncertainty is significant, uncertainty has often been overlooked or just simply assessed. In toll road projects, uncertainty analysis, if conducted, is performed by means of a methodology based on judgement and reality checks or simple sensitivity analysis where key variables are individually varied. This practice ignores the potential inter-dependencies of the variables in the system. This research hence aims to deal with the traffic demand uncertainty taking into consideration the relationships among different factors and other features of the influencing factors including dynamicity, nonlinearity, qualitative measures and delay. In addition, a probabilistic method to deal with uncertainty as recommended by financial communities and transport institutes is to be employed. Next chapter is devoted to select the most appropriate research methodology to deal with the identified problem of demand risk.

## Chapter Four: Research Methodology

### 4.1. Introduction

Research is a contribution to knowledge which relies on the subjects matter and the methodology selected to perform the study. A methodology is hence a prerequisite for carrying out any research. This chapter presents the research design aspects that should be identified for this research which include: research philosophy, research strategies and research methods. Existing research strategies are reviewed and the debates over the merits and demerits of the two major research strategies: qualitative vs. quantitative are highlighted. The chapter then illustrates where this research resides in relative to different research methodologies and justify the choice of a particular strategy. The details of the investigation leading to the selection of the research methodology which has been ultimately adopted are also highlighted. The compatibility of each research approach with the research objectives are presented and assessed.

### 4.2. Research Design

Polit et al. (2001) define a research design as “*the researcher’s overall plan for answering the research question or testing the research hypothesis*”. Parahoo (1997) identified a research design as “*a plan that describes how, when and where data are to be collected and analysed*”. The research design is the researcher plan in order to conduct a particular study. Research methodologies literature suggests different frameworks for research design. Crotty (1998) developed a model for research design in which he defined four main elements including epistemology, theoretical perspectives, methodology and method. Kagioglou et al. (2000) proposed a hierarchical model of research methodology. Within this nested approach or research modelling, the research philosophy is based at the outer ring to guide the research approaches and research techniques founded in the inner layers as shown in Figure 4.1 (Kagioglou et al, 2000). Saunders et al. (2003) proposed similar research design model but with three additional rings to the nested research model developed by Kagioglou et al. (2000). Because of the

model rings is similar to onion layers, this model was referred to as the research onion. Saunders et al. (2003) research onion is shown in Figure 4.2. Creswell (2003) proposed another framework for research design. The framework includes the intersection of three components: knowledge claims, strategies of inquiry, and specific methods.

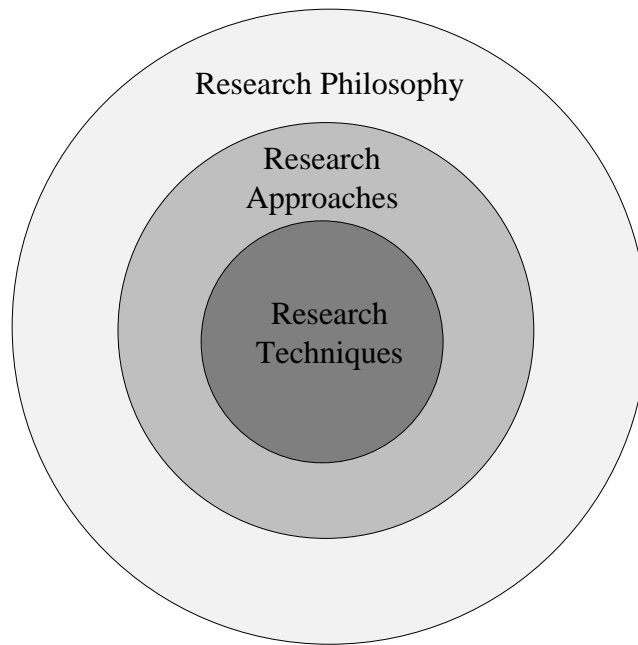


Figure 4.1: Nested Research Model (Kagioglou et al., 2000)

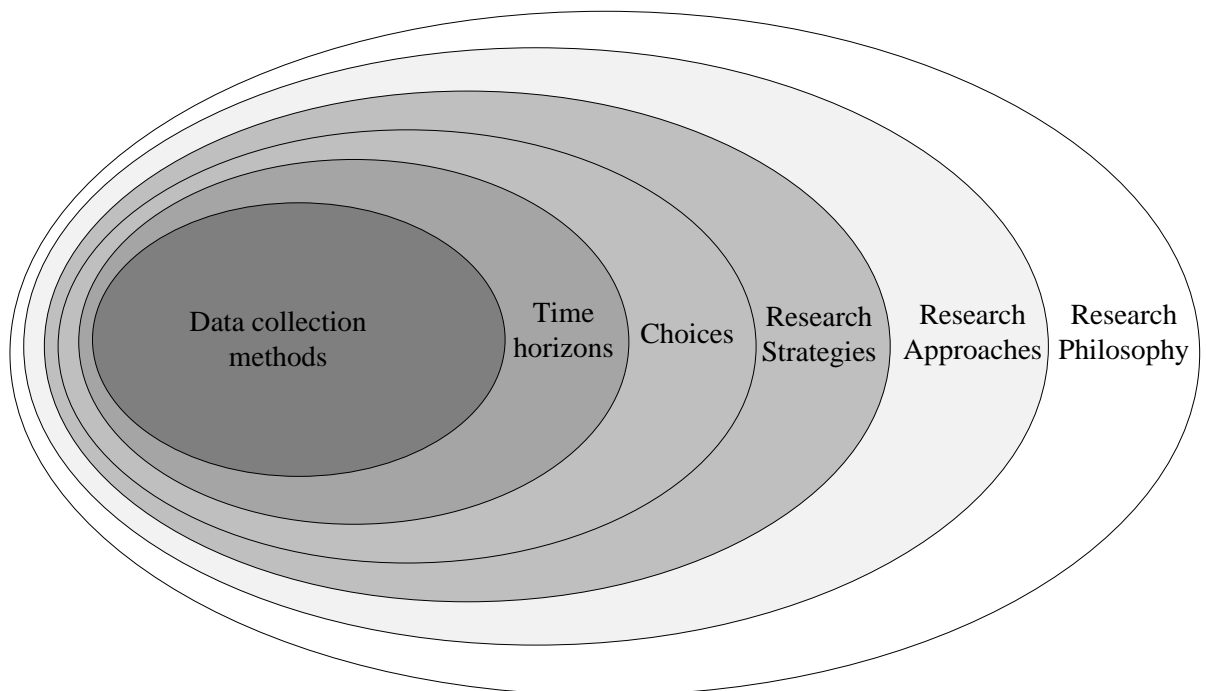


Figure 4.2: The Research Onion (Saunders et al., 2003)

Table 4.1 presents a comparison among the aforementioned four methods. Table 4.1 suggests that the components of Creswell (2003) framework are similar to that of Kagioglou et al. (2000) where the knowledge claim, strategies of inquiry and research methods in the former corresponds to the research philosophy, research approach and research techniques in the latter. "Research Approaches" component in Kagioglou et al. (2000) and Saunders et al (2003) models however refer to different concepts. The research approaches in the former's model corresponds to the research strategies in latter's.

Table 4.1: Components of the Four Research Design Models

<b>Crotty ( 1998)</b>	<b>Kagioglou et. al, (2000)</b>	<b>Saunders et. al, (2003)</b>	<b>Creswell (2003)</b>
Epistemology	Research Philosophy	Research Philosophy	Knowledge claim
Research Strategies		Research Approaches	
Methodology	Research Approaches	Research Strategies	Strategies of Inquiry
		Choices	
		Time horizons	
Method	Research Techniques	Data collection methods	Research Methods

Although this discrepancy in dividing the design process into its components, the main activities constituting the whole process are generally still the same. The following sections will be dictated to describe and explain the main pillars of the research design including research philosophy/knowledge claims, research strategies and research methods. Creswell (2003) and Kagioglou et al, (2000) research design framework will be employed as an outline for the description of the research methodology design.

### **4.3. Research Philosophy/ Knowledge Claim**

Research philosophy can be defined as the development of the research knowledge and its nature (Saunders et al., 2007). In the field of research philosophy several claims have been developed. Positivism and interpretivism (known as social Constructionism in the field of management) research theoretical perspectives are the two extremes in the social research. Between these two extremes, several approaches have been developed such as post-positivism, advocacy, idealism and realism.

Positivism assumes that social world can be explained in the same way as natural phenomenon which gives this claim the deductive aspects. It searches for general laws and cause-effect relationships by rational way (Sexton, 2003). Positivists consider personal views and values may lead to bias and they have no value to affect the research study. Positivists, thus, prefer using quantitative data. On the other hand, interpretivism consider that social life is different from the natural world. It searches for explanations of human behaviours by analysing how individuals understand their world (Sexton, 2003). It considers the researcher part of the system under study and they cannot be neutralised. Interpretivists support inductive arguments and using qualitative data (Crotty, 1998).

It is argued that in order to understand the social world, the two claims are required. The combination of these claims led to develop what so-called pragmatism (Tashakkori and Teddlie, 1998). Pragmatism is the philosophical perspective underpinning the mixed (qualitative and quantitative) methods studies. In pragmatism, it is not the methods the most important, it is rather the problem and investigators utilise all approaches to understand the problem (Rossman and Wilson, 1985). Patton (1990) stresses the significance of focusing on the research problem and employing all approaches to capture knowledge about the problem.

#### **4.4. Research Approaches/Strategies of Inquiry**

The step after selecting the knowledge claim is to decide on the strategy of inquiry. Strategy of inquiry or research approach is defined as “*The strategy, plan of action, processor design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcomes*” (Crotty, 1998). The selection of the strategy is affected by the theoretical perspective and the way in which the data will be used (deductive or inductive) (Gray, 2004). Creswell (2003) categorized research strategies into three groups: Quantitative, qualitative and mixed research strategies.

##### **4.4.1. Quantitative Research Strategies**

Quantitative research strategies focus on two main concepts: the relationship between variables and its nature and the generalisation of the research findings. Quantitative

research approaches thus aim to quantify the size of the relationships and the probability of findings generalization. Several types of quantitative strategies have been developed, out of which two are considered to be the most popular: experiments and surveys.

### *Experiments*

Experimental design occurs when the subjects (people or social systems) and conditions (events or situations) under study or investigation are manipulated by the researcher (Spector, 1981). Experiment research therefore involves the manipulation and circumstances. It sets the cause-effect relationship and conducts a comparison. The aim of carrying out experiment research is to segregate individual factors and examine their effects comprehensively, reveal new relationships and properties of the material under study and test existing theories (Denscombe, 2003). The purpose is therefor to test the impact of an action on an outcome, with controlling all other factors that likely affect that outcome (Creswell, 2003). There are three underlying aspects of conducting any experiments: controls, the identification of causal factors, and observation and measurement.

### *Survey*

The word survey refers to view comprehensively and in detail. The survey research strategy focuses on the snapshot at a given point in time. It offers a quantitative description of tendencies, attitudes, or views of a particular population by studying a sample of that population (Creswell, 2003). Survey studies usually involve questionnaires or structured interviews as ways for data collection with the aim of findings generalization from the sample under study to the whole population (Babbie, 1990). Surveys are most likely to be employed to collect data from a relatively large sample within a tight schedule (Naoum 1998).

#### **4.4.2. Qualitative Research Strategies**

Qualitative research aims at gaining insights into a problem or theory. To do so, several strategies are available. This includes ethnographies, case study, ground theory, narrative, and action research.

## *Ethnographies*

Literally, ethnography means a description of people or cultures. As a research, it is a type of qualitative research encompassing variety of methods such as observation and interviews. In ethnographic research, the researcher participates in the daily life of the group under study, watching what happens, recording what occurs and interviewing them in order to spot light on their understanding and values (Gilbert, 2009). The aim of ethnographic study is thus to gain a comprehensive understanding of the subject matter by presenting the everyday experiences of people (Fraenkel and Wallen, 2003). In this type of research, the process is flexible and the research develops based on the realities met in the field under study (Le Compte and Schensul, 1999). Ethnographic research is useful in terms of providing researcher with in-depth insights into the beliefs and values of individuals, society and organisation (Harvey and Myers 1995).

Hammersley and Atkinson (1995) identify several characteristics of ethnographic research which are;

- The research focus is exploring the nature of a certain social phenomenon, rather than testing relative hypothesis;
- The tendency to deal mainly with unstructured data
- Only or few cases are examined in detail
- The data under analysis reflect interpretation of the meanings of human actions.
- The research findings primarily take the form of verbal clarification and explanation.

## *Case Study*

Yin (1994) defines a case study as “*an empirical inquiry that investigates a contemporary occurrence within real life context, especially when the boundaries between phenomenon and context are not clearly evident*”. Case studies therefore focus on one or few instances of a certain phenomenon with a perspective of gaining comprehensive understanding of events, experience, relationships or process happening in that instance (Denscombe, 1998). The approach is particularly significant when the aim is to explore the casual relationships between a certain phenomenon and the context in which it occurs (Gray, 2004) and it is called in this case an explanatory case study. There are, however additional two kinds of case studies: exploratory and descriptive

cases. Exploratory case study investigates particular phenomenon that lacks detailed initial research. It is mainly used as an initial step of research exploring a relatively new field in which the research question has not been clearly identified. A descriptive case study, on the other hand, aims to comprehensively describe a particular phenomenon to answer a series of questions based on theoretical basis (Yin, 2003). Moreover, based on the number of cases included in a research, the case study research strategy can be categorised into single case based and multiple cases based. A single case is used if it represents a critical or a unique case. Multiple cases are incorporated with an aim to generalise the findings (Yin, 2003). In the case study approach, the researcher may use various procedures and methods (interviews, observations, surveys, etc.) to gather the required data over an extended period of time (Stake, 1995).

#### *Grounded theory*

Grounded theory approach generates theories which are grounded in the participants perspectives and then put it as the entire study conclusion (Creswell, 2003). It includes several stages of data collection and modification of categories of information (Strauss and Corbin, 1998).

#### *Narrative research*

Narrative research is a type of qualitative research in which an entire life story is investigated, generated from the set of interviews, observation, and documents. Narrative research employs different methods for analysis such as choosing and organising documents, creating field notes, and/or selecting sections of interview for close examination (Riessman, 2005).

#### *Action research*

Action research is identified as a “*tradition that links processes of inquiry to the lives of people as they come to grips with the problems and stresses that beset them in their day-to-day lives*” (Stringer, 1996). It thus seeks to realize both research and practical objectives by relating the principle of theory and practice (Baskerville and Wood-



Harper, 1996). A significant aspect of action research is a tight relationship between the researcher and the sample under study. Somekh (1995) argued that action research rejects the principle of a two-phase process in which the study is conducted first by researcher and then the knowledge produced is applied by practitioners as a separate second stage. These two processes of research and action are rather incorporated. Action research can use different techniques for data collection such as case studies, questionnaire surveys, structured and unstructured interviews, participant observation recordings, and document analysis.

#### **4.4.3. Mixed Method Research Strategies**

The core aspect of the mixed method is collecting both qualitative and quantitative data and the integration of these data sets. Creswell (2003) identifies three different types of mixed method strategies: sequential, concurrent and transformative procedures. Sequential procedures are used with the intent of elaborating on or expanding the outcomes of one method with another. The researcher may start by using a qualitative method and follow it up with a quantitative one or vice versa. In the concurrent procedures, the researcher combined qualitative and quantitative information aiming at offering a thorough understating of the subject matter. He gathers both kinds of data at the same time. Transformative procedures are sequential or concurrent procedures combined by using a theoretical lens. The theoretical umbrella or lens may be a gender, class or life style.

#### **4.5. Research Techniques/Data Collection Methods**

A significant key component of any research design model is the methods of data collection. Research, in general, entails gathering of data or information that are then analysed in order to increase understanding or expand knowledge (Naoum, 1998). Whether the required data is specified in advance of the study or to be generated from the participants in the study determines the type of data collection method. In addition, the type of required data (numeric or textual) also influences the choice of the research technique (Creswell, 2003). There are several methods available for data collection such as observation, interviews and questionnaire.

#### **4.6. Research design as Philosophy, Strategies, and Methods: Approaches to Research**

The three components discussed above, philosophy or knowledge claim, the strategies, and the methods all contribute to a research design that tends to be quantitative, qualitative, or mixed (Creswell, 2003). In the field of construction management, much debate has been conducted about the suitability and superiority of one over another. This issue generated substantial debate in the nineteenth of the last century where strong arguments were raised for or against the two major research paradigms (Raftery et al 1997; Seymour et al, 1997; Runeson, 1997; Seymoure and Rooke, 1995). One group calls for rejection of the rationalistic quantitative research (Seymour et al., 1997) and support interpretive qualitative research. The other, however, supports the idea of defining the problem and employs the most suitable research method (Raftery, et al 1997 and Runeson, 1997).

##### **4.6.1. Quantitative vs. Qualitative Methodologies**

Research methodologies may be based on qualitative, quantitative or mixed approaches. Punch (2000) discriminated between quantitative and qualitative research in terms of type of the empirical data. He defines quantitative research as an empirical research in which the data is in the form of numbers while qualitative research is an empirical research in which the data is not in the form of numbers. Berg (2001) also distinguished between them suggesting that quantitative research referred to the measures and counts, while qualitative research referred to the definitions, concepts, meanings, metaphors, symbols and depiction.

From a different angle, Creswell (2003) defines quantitative strategy as an approach in which the researcher mainly use positivist views to develop knowledge and utilises methods such as experiments and surveys for gathering data based on predetermined tools that generate statistical data. The research findings from a sample are then be generalized to the population. Qualitative strategy, on the other hand, is an approach in which the researcher uses constructivist views to generate knowledge. He employs method of inquiry such as ethnographies and case studies for data collection.

The quantitative method is based on the supposition that there is only one reality, while the qualitative approach supposes that many equally feasible realities are available. These realities are built from the perspectives of many individuals. The aim of a quantitative study is to decrease the difficulty by emphasising parts of the reality and then overseeing and monitoring the features of phenomenon. On the other hand, the aim of qualitative research is to investigate simple realities so that a full understanding of the problem can be obtained (Csete and Albrecht, 1994).

Moreover, quantitative research is described as showing a deductive relationship between theory and research (Bryman, 2004). The researcher introduces a theory, collect data to test and verify it, and use the finding to confirm or disconfirm it (Creswell, 2003). The theory is hence the research focus. It is the foundation for the research question and hypothesis and the basis for data collection. Quantitative strategy is based on specified, well-defined research questions, conceptual frameworks and strong designs connecting the variables, and highly structured data. The quantitative method therefore involves an in-depth and comprehensive review of the literature in order to provide a solid foundation for the research question and hypotheses. It hence establishes the research tightly within a theoretical body of relative literature. Therefore, the literature is deductively utilised as a framework for the research questions with the aim of verifying a theory rather than developing it (Creswell, 1994). However, in the qualitative research, the research design inductively aims to develop patterns from detailed categories or themes. Qualitative research is hence towards theory generation that helps explain a phenomenon rather than towards theory testing as in the case of quantitative method (Rudestam and Newton, 2001). In the qualitative research, the theory is, therefore, the end point of the research. The research starts by collecting data and categorizing it into themes. The themes are then developed into theories that compared to the available literature. It is an inductive process of constructing from the data to generalised theory (Creswell, 2003). Qualitative method is more diverse and the research questions, the design structure and the data uncover as the empirical work carries on (Punch, 2000). It is emergent rather than firmly prefigured. Variety of features emerges during a qualitative study. The research questions and the data collection process might change based on the encountered circumstances. These features of an unfolding research model make it difficult to prefigure qualitative research at an early stage (Creswell, 1998). Qualitative research is therefore exploratory and seeks to build a theory. Morse (1991) suggests that this kind of strategy is primarily

useful when the topic is new and has not been examined before with a specific group or in the case that available theory cannot be applied with a certain group. Maxwell (1996) presented the qualitative and quantitative approaches as the causal relation between x and y as follows: While quantitative strategy seeks to explain "*whether and to what extent variance in x causes variance in y*", the qualitative strategy tend to answer the question "*how x plays a role in causing y, what the process is that connects x and y*".

Furthermore, in quantitative research, the research is regarded as the neutral collector of facts. He is detached from the social world. The research orientation concentrates on outsider objective researcher. On the other hand, the inquirer in the qualitative research is seen as a part of the studied world and needs to interact with others. The researcher's own background (personal, cultural and historical experience) shapes his interpretation. The research orientation hence concentrates on an insider view (Fitzgerald and Howcroft, 1998). This deep engagement of researcher introduces a variety of strategic, ethical, and personal issues into the qualitative research process (Locke et al., 2000). Quantitative research focuses on the group and uses a quantitative method to generalise. Qualitative research focuses on the individual and use qualitative methods to understand the experience (Fitzgerald and Howcroft, 1998). The inquirers therefore employ small sample and assess them to comprehend the views of large people (Kasi 2009).

Table 4.2 presents a comparison between quantitative and qualitative approaches.

Table 4.2: A Comparison between Quantitative and Qualitative Approaches

<b>Quantitative Research</b>	<b>Qualitative Research</b>
Numerical data	Textual data
Analysis	Description
Confirmatory	Exploratory
A predetermined research design	An emergent research design
Large-Scale study	Small-Scale study
deductive	Inductive
Researcher detachments	Researcher involvement

In the real world of research however things do not fall neatly into these two categories and the two approaches are not mutually exclusive. Wing (1998) highlights the importance of qualitative methods in addressing the problems, but argues that they

should not be focused on exclusively. This is because an empirical study can be quantitative and qualitative, but it requires involving analysis and description. Thus, he deems that there is no single research approach which is suitable to all studies. The debate over which approach is more appropriate for a particular research study has therefore coincided with an interest of combining both approaches together when conducting research (Punch, 2000).

#### **4.6.2. Mixed Method**

Mixed method term is used to bring together quantitative and qualitative research (Bryman, 2004, 2006, Creswell, 2003). It may therefore involve theory inductively or deductively. It is mainly governed by pragmatic perspective. This kind of methods has a long history (Gilbert, 2009). However, quantitative and qualitative research integration has been increasingly adopted since the early of 1980s (Bryman, 2004). Mixed method is an approach in which the investigator gathers both numeric information and text information so that the final database involves both quantitative and qualitative data (Creswell, 2003). It is argued that the integration strategy helps combine both strategies strengths and weakness offset. Kelle (2001) suggests that mixed method enhances the research findings accuracy and the level of confidence in them. Creswell (2003) suggests that collecting quantitative and qualitative data for a certain research proves benefits to best understand the research problem.

Hammersley (1996) introduced several ways in which quantitative and qualitative research paradigm can be integrated, this includes:

Triangulation: the use of quantitative research to corroborate qualitative research outcomes or vice versa. It includes measuring a particular phenomenon in two or more different ways in order to increase level of measurement accuracy (Gillbert, 2009).

Facilitation: the employment of one research strategy to help achieving research using the other one.

Complementary: The use of the two research strategies to take advantages of the combination of different aspects of investigation. It is mainly used to investigate and examine different aspects of a particular phenomenon (Green et al., 1989).

It is important to mention that the choice of a particular strategy over another when designing research is governed by the major objectives of the study and the expected outcomes. The research questions are the major drivers to select the strategy rather than which strategy is best (Punch, 2000). Creswell (2003) defined research problem, personal experience and audience as the major criteria for selecting an appropriate research methodology.

## **4.7. Research Methodology Adopted**

### **4.7.1. Statement of the Research Aim**

The problem of the research as stated in chapter one is about investigating the causes of demand variations/demand risk in PPP concession infrastructure projects. Demand risk can cause costly renegotiations and serious financial problems. These intensive impacts of demand risk impose the necessity of robust demand risk assessments considering the particular aspects of its influences. A thorough review of the relative literature in chapter two and chapter three helped identify and understand the influencing factors of demand variations. Understanding the nature of these factors and how they interact and ultimately affect demand helps robustly assess this risk to reduce the impact of demand risk on the project viability. The aim of the research is to develop a dynamic model to assess demand risk in PPP projects over the operation period. The model will provide a tool to quantify the effect of different underlying factors on the demand level and help evaluate changes in demand over the project life cycle.

### **4.7.2. Selection of the Research Method**

Yin (2003) proposed a method to select the most appropriate strategy among five major research strategies: experiments, surveys, archival analysis, histories and case studies. The selection is controlled by three main criteria: form of the research question, control of behavioural events and focuses on contemporary events as shown in Table 4.3.

Table 4.3: Relevant Situations for Different Research Strategies

Research Strategy	Form of Research Question	Requires Control of Behavioural Events	Focuses on Contemporary Events?
Experiment	How? Why?	Yes	Yes
Survey	What? How? Where? How many? How much?	No	Yes
Archival records	What? Who? Where? How many? How much?	No	Yes/No
History	What? How? Why?	No	No
Case Study	What? How? Why?	No	Yes

Source (Yin, 2003)

Hedrick et al. (1993) categorises the research questions as who, what, where, how, and why (cited in Yin, 2003). Yin (2003) suggested that there are two possibilities for “what” question. The first one is exploratory what questions. Exploratory study is typically conducted to develop pertinent hypotheses and propositions for further inquiry. For this kind of what questions, any of the five research strategies can be used (e.g. an exploratory survey, an exploratory experiment, or an exploratory case study). The second type of what questions take a form of how much or how many type of inquiry. Survey or archival records analysis is preferred strategies than others. On the other hand, Yin (2003) noted that how and why questions are more explanatory since they “deal with operational links needing to be traced over time rather than mere frequencies or incidence.” Histories, case studies, and experiments are favoured strategies than others.

As shown in Table 4.3, Yin (2003) further differentiated among various research strategies based on the extent of the researcher’s control over behaviour and the degree

of focus on contemporary events. For example, histories are a preferred strategy for how and why questions when there is no access or control. This mainly because the historical methods deal with past events when no relevant persons are alive to report and the researcher relies on primary and secondary documents and cultural and physical artifacts. Moreover, the case study method is preferred in examining contemporary events when the relevant behaviour cannot be manipulated. Even though case studies and history strategies can overlap, case study is stronger than historical methods in dealing with a full range of evidence sources such as documents, interviews and observations beyond what available in the case of histories. Experiment strategy is finally conducted when researcher “*can manipulate behaviour directly, precisely, and systematically*”.

Yin (2003) concluded that there are large overlaps among these strategies and added “*to some extent, the various strategies are not mutually exclusive*”. Multiple strategies can be relevant to any given study.

As discussed in chapter one and earlier in this chapter, the research aims at developing a dynamic model to assess demand risk by investigating and assessing how different factors are jointly affect demand for service provided by PPP infrastructure projects. These factors are of both qualitative and quantitative nature and they interact with each other. The research therefore probes demand as the outcome of complex interactions of variety of qualitative and quantitative factors. The study objectives thus involve identifying, understanding, mapping and measuring these factors and their complex relationships to assess how they affect demand. Given this, none of the approaches introduced in the previous sections and Table 4.3 is alone able to fulfil the full list of the research objectives. A mixed of research methods is therefore employed.

The first objective of this study is to identify the key influences of demand. This is a “what” question to explore the demand risk phenomenon inherent of concession contracts. There is no researcher access to or control of actual phenomenon. The recent studies in the field have employed case study research approach (Prozzie et al., 2009) to investigate the phenomenon. Creswell (2003) suggest that in the case that the problem is identifying factors affecting outcomes or understanding the best predictors of outcomes, the quantitative approach is the best. Table 4.3 suggests that surveys and archival record analysis are significant for this kind of research. Literature survey and questionnaire



survey are thus considered applicable to achieve this objective. A survey of the existing literature helps collect secondary data that are used to identify the key factors influencing demand for service provided by PPP projects. The gathered secondary data offer a list of demand risk factors. To build more confidence in this list, it is however further validated using a quantitative research approach by employing questionnaire survey technique targeted individuals and organisations with experience in PPPs. Because of the complex nature of the demand risk factors, the gathered data was analysed by using conventional statistical methods and Analytic Network Process (ANP) as it will be further discussed in chapter six.

The second research objective is how the interrelationships among the identified factor can be mapped and modelled. This is a “How” question to explain the phenomenon by identifying the relationships between demand risk factors and their interactions. There is no researcher access to or control of actual phenomena. Table 4.3 suggests that case studies, historical analyses, experiment, and surveys are the preferred approaches to deal with the issue of concern. However, before selecting the method to collect the required data, it is important to choose the best way to measure and map the relationships. To measure relationships between variables, there are two key approaches: correlation analysis and causal analysis.

Correlation analysis investigates the amount of correlation between two variables or more by studying the joint variation between them. There are two main types of correlation statistical analysis: bivariate and multivariate. Bivariate methods such as Karl Pearson's and simple regression analysis concern with investigating the relationship between only two variables. The research in question aims to study how different factors interact with each other and ultimately influence level of demand which may include the interdependencies among several variables rather than only two variables. This resulted in excluding the bivariate methods from the further consideration. Multivariate technique is able to study the relationship between more than two variables. This technique is considered suitable to study problems when there are dependent variables as function of several explanatory or independent variables. The disadvantage of this method is that it cannot determine how the correlation is indicative of a causal relationship which is extremely significant in this research to study how change in different factor cause change in other factors of the system and in demand. In addition, this method is not always able to identify the non-linear relationships between

variables which is the case for most of the demand influences as discussed in chapter three. Therefore, the multivariate method is also excluded from further consideration.

On the other hand, causal analysis aims to study how one or more variables influence changes in another. There are two key methods used by researchers to build the causal relationships: causal path analysis (CPA) and System Dynamics (SD). CPA is a technique “*to examine the causal processes underlying the observed relationships and to estimate the relative importance of alternative paths of influence*” (Asher, 1983). CPA offers a graphical and empirical way to represent and estimate the relationships in an assumed theory. It offers a way to estimate the causal effect that one variable has on another using experimental data. The main disadvantages of the method are that the effect of the variables included is additive. In other words, there is no interaction between these variables which is contrary to the case of complex system. In addition, no path may go backward eliminating the possibility of feedback causation which is often the case in the complex systems. The demand estimation process is complex owing to the variety of its influences (economic, social and technical) and their interrelations. The previous limitations of CPA when dealing with the complex systems introduced a barrier to use it in the research.

The other method is SD method which has a high capacity to deal with complex systems and accommodates all the above disadvantages. Therefore, SD is used for demand modelling and simulation. Causal Loop Diagram (CLD) offered by SD is first used to map and model the different factors and relationships considered in this study. To identify these relationships, a qualitative strategy of literature survey and the interview survey (as it is one of the preferred methods in Table 4.3) is employed to fulfil this objective. A survey of the literature is undertaken to capture the secondary data from the exiting studies, which offers the insights into the relationships among different demand influences. These data is translated into cause-effect diagrams using CLD tool offered by SD modelling software. To build more confidence into the drawn diagrams of mapped factors, the opinions of experienced PPP stakeholders are sought using an interview survey. The collected data helps reform the drawn diagrams and produce validated causal loop diagrams. The interviews with PPPs stakeholders are further discussed in chapter six. In addition, the nature of the relationships between identified factors imposed using System Dynamics (SD) method for simulation. As discussed in chapter three, the demand influencing factors are in flux, mix of qualitative and

quantitative and interact in a complex way. Sterman (2000) suggests that out of the formal modelling approaches, SD has the most evolved guideline for presenting, analysing and explaining the dynamics of complex systems. SD is a well-established method to describe and simulate complex systems (Forrester 1969, 1971). In addition, most of the relationships between the factors are non-linear. System dynamics models are typically developed of high-order, nonlinear formulas representing the decision rules of the agents, natural processes, and physical structures pertinent to model purpose. Moreover, delay is another aspect of these relationships. SD is one of the best methods to accommodate such feature. Next chapter will discuss in more details the SD modelling method.

The third objective of the study aims at quantifying the relationships among the demand factors. This is a “how much” question to measure the effect of each factor on others. There is no researcher access to or control over actual phenomena. Table 4.3 suggests that survey and archival record are the preferred methods. Thus, mix of qualitative and quantitative strategy is used. For the relationships for which numerical data are available, archival records are accessed to gather the required data. Historical data are then processed using regression analysis technique to generate the required equation representing the concerned relationships. For those relationships where numerical data are not available, interview surveys with experts in toll road projects are conducted to quantify the concerned relationships. Subjective beliefs, perceptions, experience, personal judgment of the experienced participants are used to develop the required relationships.

The fourth objective of the study is to validate the developed model in terms of structure and behaviour. The validation process is mainly based on the nature of the model. SD model validation is typically based on a wide range of tests as well as many sources of data such as mental models, reports and archival documents. The SD model is validated using several tests for which system dynamics software offers a mechanism to perform. The validation process also includes interviews with stockholders in PPP projects. In addition, the findings of the model are validated by comparing the results to real time series data.

The last research objective is assessing and simulating the effects of change in different factors on level of demand. Since each PPP project is unique in terms of demand

influences values, conducting the simulation requires first determining the values of these variables affecting demand externally. To do so, a case study project is applied to demonstrate the development of the proposed approach. Case study depends on the subjective use of unreliable intuition for assessing the complex structure generating from the initial depiction of the real system (Forrester, 1994). SD is a tool to convert real life case into a simulation model. Williams (2001) advised the combination of case study and simulation methods in order to improve the understanding of stakeholders pertinent to changes in requirements over time. Single case study approach has been selected to conduct this phase of research since it is the best way to investigate a unique case (Yin, 2003). Using single case study is a common practice when developing SD model (Forester and Senge, 1980; Graham et al., 1982). Jang (2011) used a single case study to develop a SD decision model for concessionaire selection in the PPP Project Procurement. Krumbeck and Killen (2010) employed a case study with the Royal Australian Navy (RAN) to examine the applicability of SD as a potential tool for the management of project portfolio interdependencies. In this research, using the case study helps test the validity of SD as a tool for assessing demand risk in PPP projects. The combination of the SD and case study helps contrast the qualitative bias of case studies with the quantitative features of system dynamics modelling. Wynkoop (1992) suggests that the integration of quantitative and qualitative helps understand how the behaviour of different variables affects a particular phenomenon which is one of the objectives of conducting this research.

#### **4.8. Summary**

This chapter discussed the basic concepts related to the research methodology. It introduced different models that can be used for designing a particular research study. Three key components including research philosophy, research strategies and research methods were explained. Different research strategies such as experiments, survey research, ethnographic research, case studies, and action research were considered. A comprehensive comparison of qualitative, quantitative and mixed research strategies were also conducted as the basis for the research methodology selection. The chapter is then dictated to select and present the most suiting research methodology for the fulfillment of the research objectives. The subject matter and the research objectives offered the basis to the choice of research methodology to employ. The demand system

is complex owing to the variety of its influences and their interactions. SD technique was thus selected based on the research problem nature and research objectives. Next chapter discuss in detail the system dynamics method.

## Chapter Five: System Dynamics

### 5.1. Introduction

In order to demonstrate the outcomes of the research, it is important to consider the approaches employed for carrying out the study and the data collection. Chapter four concluded by selecting the System Dynamics (SD) method as the most suitable method to model the problem in concern. This chapter presents an overview of the SD method. The SD model development process is discussed. Most of the knowledge required to develop system dynamics models exists in the mental models of system's stakeholders. Therefore, knowledge elicitation from its sources requires engaging participants from the real system to capture the relevant information necessary to build the model. The chapter thus outlines the data collection methods adopted to capture this knowledge.

### 5.2. System Dynamics

System Dynamics (SD) is a technique to study problems with complex nature and time dependent. It is one of the most suitable approaches to deal with causal structure governing the behaviour of complex systems. SD is a way to include all relevant factors, cause-effect relationships, time delay and feedback loops which factor in the unexpected behaviour of the complex system. Wolstenholme (1990) identify SD as “*a rigorous method for qualitative description, exploration and analysis of complex system in terms of their process, information, organisational boundaries and strategies, which facilitates quantitative simulation modelling and analysis for the design of system structure and control*”. The definition implies that SD modelling includes two main phases: Qualitative System Dynamics and Quantitative System Dynamics. While the former is mainly based on creating cause-effect diagrams (section 5.5.1), the latter is devoted to quantitative computer simulations. In short, SD is a graphical and mathematical approach for understanding and analysing complex dynamic systems.

### **5.3. Background of SD**

System dynamics was invented by Jay W. Forrester at MIT in late 1950s. The SD philosophy and methodology was explained in Forrester seminal book *Industrial Dynamics* (Forrester, 1961). The hand simulation was first converted into computer modelling when Richard Bennett, a colleague of Forrester in MIT, created the first compiler known as “SIMPLE” (Simulation of Industrial Management Problem with Lots of Equations) which later was extended by Jack Pugh into DYNAMO. Within ten years of SD invention, SD applications grew from industrial problems to include several other fields such as the management of research and development, commodity cycles, urban stagnation and decay, and the dynamics of growth in a finite world. In late 1970s microcomputer became available, and in the early 1980s Micro-DYNAMO (Pugh-Roberts, 1982) became also available to the interested public. Roberts et al. (1983) published a text book detailing the SD approach and its application in variety of fields such as biology, psychology, physics, ecology, economic and mathematics. Since then, more powerful SD modelling software were developed such as PowerSim, STELLA, ithink, and Vensim. SD method has regarded applications in a wide range of areas such as social (Forrester, 1969, 1971) business (Sterman, 2000), environmental systems (Vezjak et al. 1998, Ford, 1999) and several other fields.

#### **5.3.1. Application of SD in PPP Field**

As discussed in chapter two, PPP has increasingly become a preferred procurement model for the delivery of infrastructure projects. PPP structure and implementation is of dynamic and complex nature. It is dynamic owing to the long duration of this kind of contracts where key project parameters such as cash flow show a dynamic behaviour. In addition, it is complex due to the involvement of different types of stakeholders and risks over the different project phases.

Nyagwachi and Smallwood (2008) used SD method to develop a model for PPP projects planning and implementation in South Africa. The model purpose is to clarify the complexity of the causal relationships within the PPP system and illustrate the general processes used to implement PPP projects. Li (2008) developed a SD model to assess the applicability of PPP financing model for a particular project. The model aimed at offering a tool to help making a decision on reliable and reasonable financial

agreement which eases the pre-contract negotiation between the contract parties. In the SD model, the applicability was considered a stock accumulating by three flows representing the potential benefits gained by the public, private and social sectors.

Khanzadi et al. (2011) proposed a fuzzy system dynamics-based method to determine the concession period in PPP transportation projects. Integrating the fuzzy logic theory considered the existing uncertainties associated with the concession period determinants. A conceptual SD model of Net present Value (NPV), traffic volume, operation cost and maintenance cost were developed and applied on a highway project where the NPV and concession period were determined as fuzzy numbers.

Jang (2011) proposed a modelling approach that used a SD technique for the decision of concessionaire selection in PPP projects. The SD model helped estimate the effects of risks interaction on project NPV over time. The model was built to define how efficiently the risk effects can be reduced and the NPV performance can be improved. Then by using appropriate stochastic analyses, different values of NPV among different bidding proposals can be compared and the PPP concessionaire with the best NPV performance can be selected.

Xu et al. (2012) proposed a SD based model to determine an appropriate concession price for PPP highway projects. The model aimed to calculate the basic price of a PPP project based on quantifiable pricing parameters. The model involved two categories of parameters: cash outflow (cost) parameters and cash inflow (benefit) parameters. To deal with the uncertainty associated with prices, a price adjustment model based on Case Base Reasoning (CBR) technique was utilised.

### **5.3.2. Application of SD in Transportation Modelling**

One of the early applications of SD was in transportation modelling. Parthasarathi (1974) proposed a SD model for urban public transit operations. The model aimed at revealing the dynamic nature of the complex interactions among different elements of the urban transportation system by investigating the cause and effect relationships of these elements. In addition, the model intended to evaluate various decisions which may lead to optimize of the urban transportation system. Hirsh (1977) offered an urban bus



transit model. The model aimed at evaluating a wide range of impacts emerged from the bus transit operating policies. Wadhwa and Demoulin (1978) applied SD to model the economic and transport planning for the area of North Queensland in Australia. The SD model helped evaluate variety of transport policies and their impacts on economic development and performance of the transport system. Gunaman (1984), Charlesworth (1985; 1987), and Charlesworth and Gunawan (1987) proposed different SD models for urban road traffic taking into consideration traffic flow, network geometry, and driver's behaviour. Abbas (1990) used SD to model the management system for the road projects. The aim of the models was to understand the dynamicity of road system and assess different strategies available for the road development (reported by Liu, 2007).

Haghani et al. (2003) introduced a system dynamic model to assess the transportation system performance. The model included seven sub models: population, migration, household, job growth-employment-land availability, housing development, travel demand and traffic congestion. The model was tested on data from Montgomery County (USA). The model outcomes showed the significance of SD in dealing with complex land use/transportation system.

Altamirano (2006) introduced a system dynamics model to capture the institutional context in which road projects are developed. The purpose of the model was to indicate what contracting model is likely to be applied and which ones are likely to succeed in view of meeting the public values and demands.

Liu (2007) proposed an integrated fuzzy SD model to assess the effect of various travel demand management interventions in a particular area. The aim of the model was to understand the complex behaviour of influenced transportation-socioeconomic systems. Fuzzy set theory was employed to account for, represent and operate the linguistic variables encountered in the modelling process. In the SD model, travel demand dynamics was assumed to be generated by two main activities: work travel and social networking. Factors such as population, tourism and employment growth were assumed to be exogenous factors that affect demand. While the model did not provide the expected results, the method was considered useful to evaluate various travel demand management strategies.

Qian et al. (2006) proposed a SD model to evaluate the roads congestion problem in Shanghai. The model purpose was to understand the complex relationship between road demand and supply. The simulation results showed that several alternative policies, rather than increasing road supply, such as promoting public transportation should be emphasised to solve congestion problem.

Xu et al. (2012) combined SD and Multiobjective Programming (MOP) to develop an integrated model for analysing the transportation system of garden cities. For the modelling process, SD method was first used to develop the CLDs and Stock and Flow diagrams (SFDs), MOPs was then employed to get the optimum values of the sensitive variables in the model and input them into the SD model for simulation. The integrated model was applied to a representative city, Chengdu (China), one of the world modern garden cities. The simulation results help make sensible decisions regarding transportation structure and transportation development mode in the modern garden city.

Shepherd (2013) proved the validity of employing SD in the travel demand field. Shepherd demonstrated the equivalence between the standard SD goal-seeking structure and disequilibrium travel demand model. SD approach was used to assess demand response to changes in generalized cost and to model the toll operators' decision to adapt toll level. The SD model was utilised to assess alternative toll-setting strategies whereby one operator may act aggressively to increase its share of the market while maximizing profit.

#### **5.4. Application of SD in the Current Research**

While system dynamics has been used in the area of PPP, none of the previous research investigated the significance of risks met in the operation stage particularly that related to demand risk. Moreover, while a wider range of studies using SD were conducted in the field of transportation, none of the research assessed the significance of traffic demand risk in toll road projects. To fill the gap, this research aims to develop a SD model to assess demand risk in PPP road projects.

Since its inception, SD has been extensively employed for purposes of demand modelling. FOSSIL2 is an U.S energy supply and demand model to provide projections for energy policy analysis developed in seventies of last century (Naill, 1992 cited in Balnac et al., 2009). Since then, SD has been widely used to estimate demand in different fields. Filho and Schuch (1998) developed SD-based model for electricity long-term forecasting demand. Lyneis (1998) employed SD to develop a demand-supply forecasting model for the commercial jet aircraft industry. Sadeghi et al. (2001) used SD in industrial companies forecasting of the technology by prediction of market needs to help policy makers defining market opportunities and threats. Zhang et al., (2008a), Zhang *et al.* (2008b) and Zhai *et al.* (2009) adopted SD to forecast the total water demand of Tianjin city, Linkong city and Tianjin Polytechnic University (China) respectively. Balnac *et al.* (2009) employed SD to provide Mauritian policy makers with power demand-supply model which can describe the Mauritian power system. Sun et al. (2010) employed SD to simulate the trend of gas demand and supply between 1990 and 2050.

Before further explaining the application of SD model in the current research, it is important to highlight the main SD principles used in the modelling process.

## **5.5. SD Modelling Principles**

### **5.5.1. Causal Loop Diagrams (CLDs)**

As discussed above SD is a useful methodological tool for defining and representing the key factors of a system and the ways they interact. CLD is an important tool of SD that captures the structure of the system. CLDs are visual representations of the interactions and feedback loops between different factors which help propose and capture the sources' problems (Andy and Minato, 2003). It is mainly used to map the cause-effect relationships between different variables within the system. The CLDs, representing the hypothesis of the model, depict how each factor can affect the model outcome directly or through other intermediate variables as well as the effect that one variable has on others. They show clearly the direction and kind of causality among different variables in the system (Love et al., 1999). A relationship between two variables ( $x_1$ ) and ( $x_2$ ) is represented by an arrow (Figure 5.1). The arrow starts from the "cause" variable ( $x_1$ ) and goes into the "effect" variable ( $x_2$ ). For each relationship, the link between the two

variables is noted as positive if an increase in the variable at the tail of the arrow (x1) causes an increase in the variable at the head (x2). This relationship is noted as negative if an increase in (x1) causes a decrease in (x2).

One significant aspect of SD causal diagram is the feedback loop. The presence of feedback loops is the characteristic which gives the system its dynamic nature (Meadows and Robinson, 1985). Feedback loops can be positive or negative. While variables in the positive or reinforcing loop (R) increase or decrease indefinitely, variables in the negative or balancing loop (B) stabilize over time as it will be discussed later in section 5.5.3.

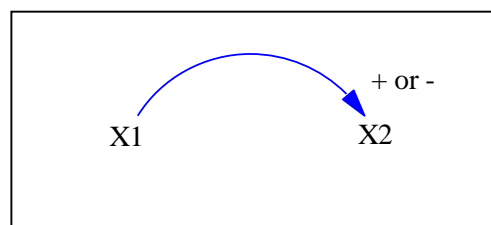


Figure 5.1: Cause-Effect Relationship

The causal relationships among system elements expressed in CLDs represent the Dynamics hypothesis. This qualitative representation of the system relationships constitutes the basis for the subsequent quantitative description of the model represented by the stock and flow diagram.

### 5.5.2. Stock and Flow Diagrams (SFDs)

The Causal Loop Diagrams (CLDs) present the system structure qualitatively. They show how different variables interact with each other. In addition to CLDs, stock and flow diagrams are ways of representing the structure of a system with more detailed information. They contain all the necessary information to determine the dynamic behaviour of a system. SFDs are the first step in building the simulation model because they help define types of variables that are important in studying the system behaviour (Vensim guide). Variables could be stock, flow, rate or constant. In these diagrams, stocks are represented by rectangles, inflows and outflows are represented by arrows, where the flows themselves are represented by valves; and clouds represent the sources or sinks of the flows. Stocks or levels are essential to observe behaviour in a system;

flows or rates cause stocks to change. Stocks thus accumulate over time due to discrepancy between inflow and outflow as shown in Figure 5.2 and mathematically in Eq. 5.1.

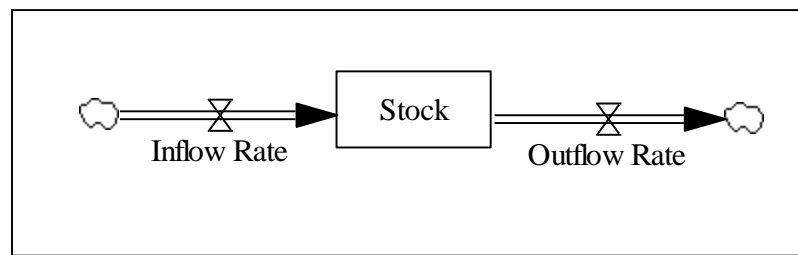


Figure 5.2: Stock and Flow Structure

$$\frac{d(\text{stock})}{dt} = \text{inflow}(t) - \text{outflow}(t) \quad (\text{Eq. 5.1})$$

SFDs are the basis of the quantitative SD model or computer simulation model. In this stage of SD modelling, the simulation equations of the relationships in the stock and flow diagrams are developed. Further details of the SD model equations development are provided in chapter six.

### 5.5.3. Patterns of Dynamic Behaviour

The feedback structure in the SD system has several types of dynamic behavior. The fundamental modes of behavior are exponential growth, goal seeking and oscillation. These three patterns are generated due to the presence of three corresponding types of loops. Exponential growth occurs due to a positive reinforcing loop, goal seeking occurs due to a negative self-balancing loop and oscillation occurs due to a negative feedback loop with time delay. A delay is a process where outputs lag behind the inputs in some ways (Sterman, 2000). It is one of the common behaviours of real systems. The flow of physical materials and non-physical information takes time. For instance, Package delivery may takes days, and full understanding of a new notion may take years (Albin, 1998). The time delay in a causal relationship between two variables implies that the cause leads to an effect, but not instantaneously. Coyle (1996) argues that the delay is an important element of the system and has a significant effect on the dynamics. A delay in systems makes cause and effect less evident since nothing occurs to the output (effect) until the delay time has elapsed. The late response resulted from delay creates a difficulty to reach a desired state which increase the behaviour dynamicity and complexity. Next sub-sections discuss the three patterns of dynamic behaviour.

### ***Exponential growth***

Exponential growth behaviour occurs as a result of a self-reinforcing feedback loop represented by “R” or “+” in the CLDs. The change in one of the variable in the system leads to a positive change in the other variable. The change in the latter will feed back and cause positive change in the former. The positive effect is thus reinforced. Figure 5.3 illustrates an example of this kind of growth. The Net Increase Rate raises the State of the System. The increase in the State of the System raises the Net Increase Rate. The best example describing the exponential growth is the feedback loop between the net birth rate and the population. When the net birth rate increases, population will increase. As the population increases, the net birth rate also increases leading to exponential growth (Figure 5.4).

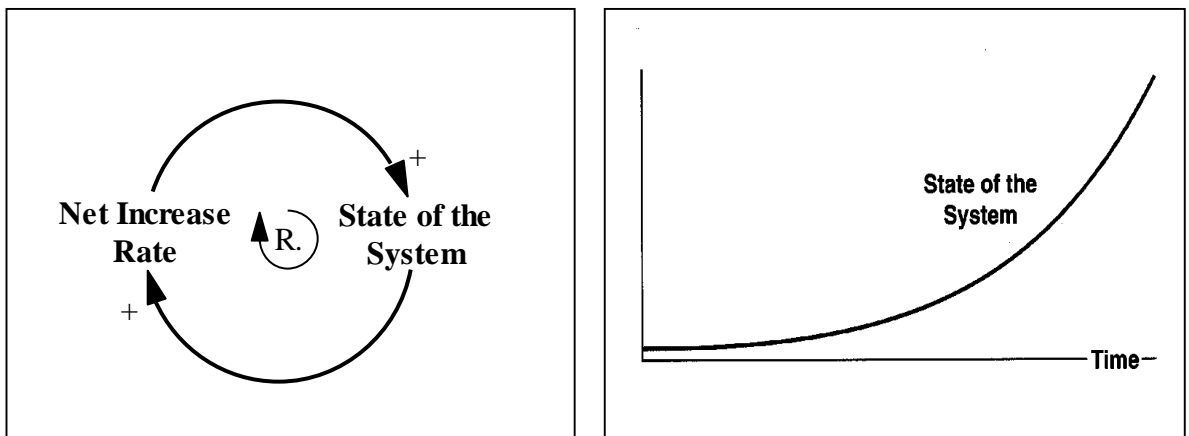


Figure 5.3: The Structure (Reinforcing Feedback Loop) and Behaviour of the Exponential Growth , Source (Sterman, 2000)

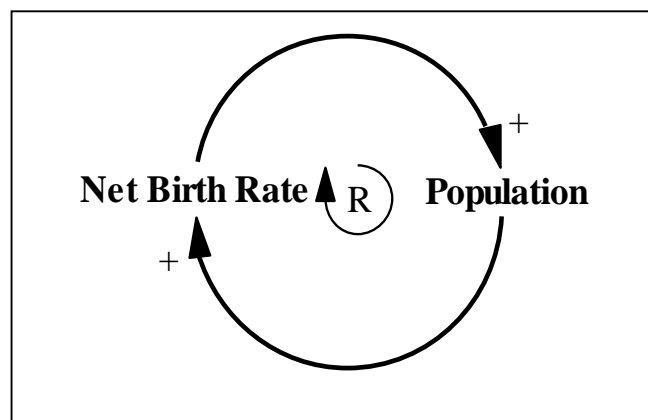


Figure 5.4: An Example of Exponential Growth Structure

**Goal seeking**

Goal seeking behaviour occurs as a result of a negative self-balancing loop represented by “B” or “-” on the CLDs. The negative feedback loop tries to bring the State of the System to the goal or desired state (Figure 5.5). The level of the discrepancy between the actual and desired state determines the corrective action required to bring the state of the system back to the goal. The state of the system is again compared with the desired state and based on the level of discrepancy, another corrective action is taken. Over time, the state of the system approaches the goal while the discrepancy falls.

Figure 5.6 shows an example of goal seeking structure. In this example the state of the system is the current room temperature. The goal is the desired room temperature. Based on the temperature gap, the decision maker will allow heat to flow into the room to adjust its temperature till the room temperature eventually becomes equivalent to that desired and the temperature gap is zero.

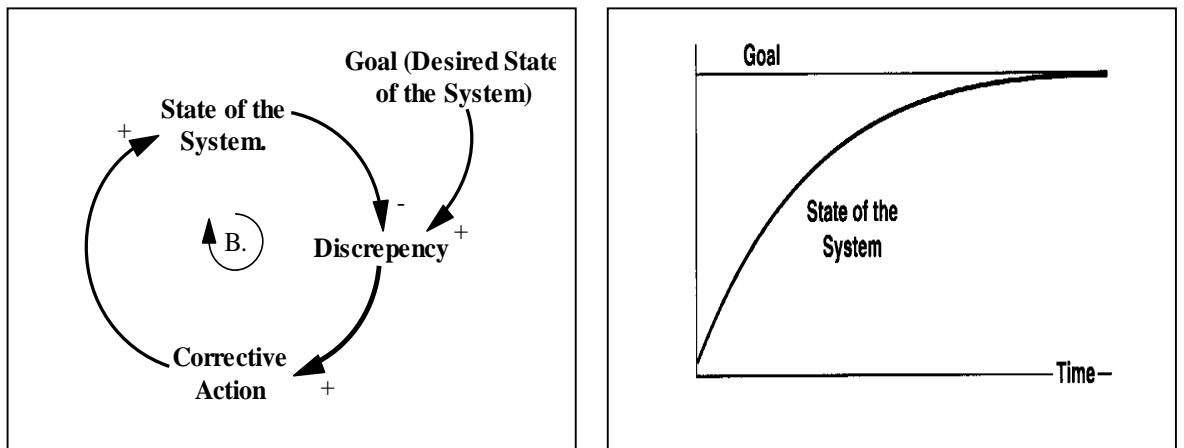


Figure 5.5: The Structure (Self-Balancing Feedback Loop) and Behaviour of the Goal Seeking, Source (Sterman, 2000)

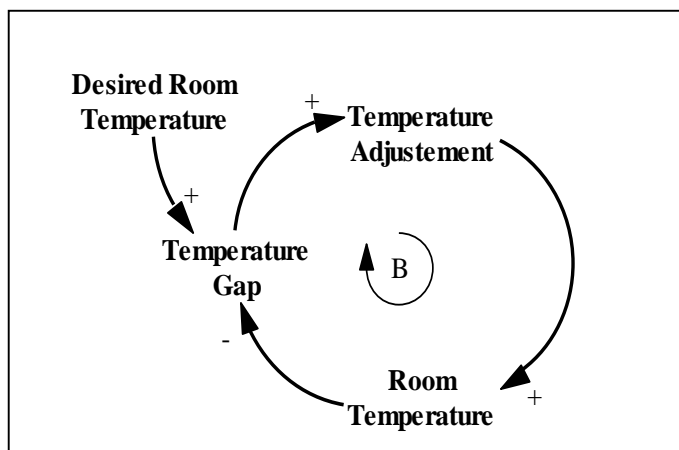


Figure 5.6: An Example of the Goal Seeking Structure

### Oscillation

Oscillation behaviour occurs in the case that there is a delay in the negative feedback loop. Except the delay, the loop is similar to the goal seeking loop. The self-balancing loop tries to move the system toward the goal. However, due to the delay, the system does not reach the goal instantly. The self-balancing loop keeps trying to take the system toward the goal. This leads the state of the system to overshoot and undershoot the goal and so on. As shown in Figure 5.7, the delay could occur in any link of the negative loop. An example of this fundamental mode is the inventory oscillation. It takes time for a factory to procure labour force in responding to new production plan to increase the inventory. This delay in the initiation of the corrective action (labour procurement) has its effect on the State of the System (inventory) as illustrated in Figure 5.8.

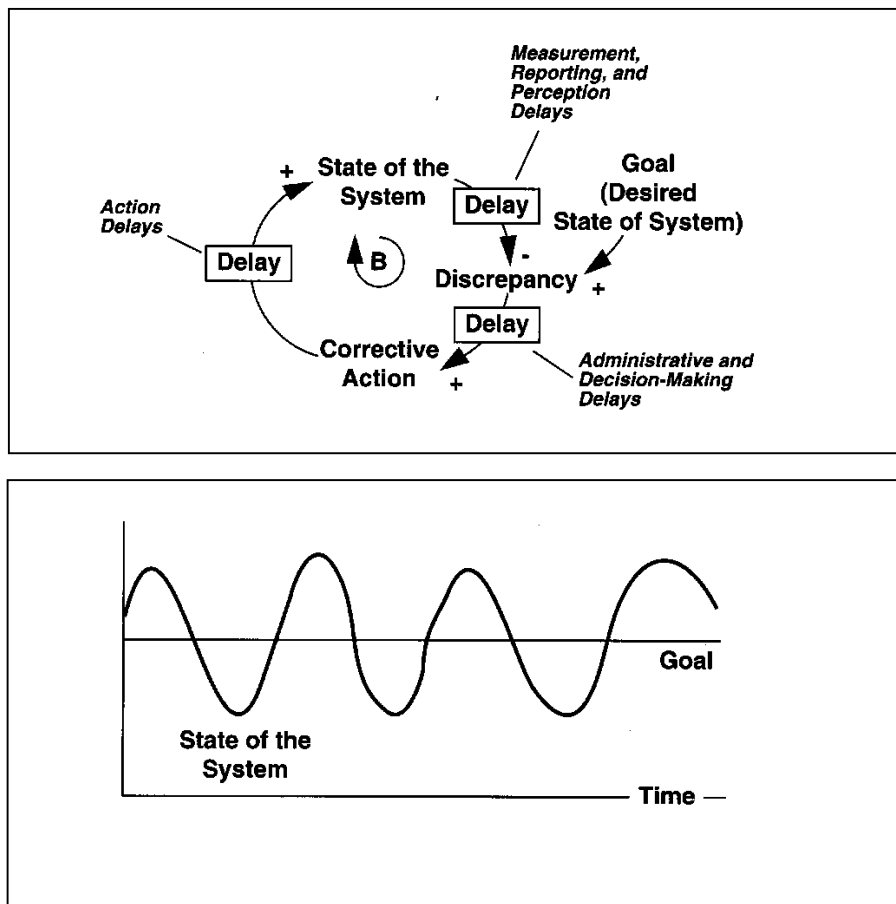


Figure 5.7: The Structure (Self-Balancing Feedback Loop) and Behaviour of the Oscillation, Source (Sterman, 2000)



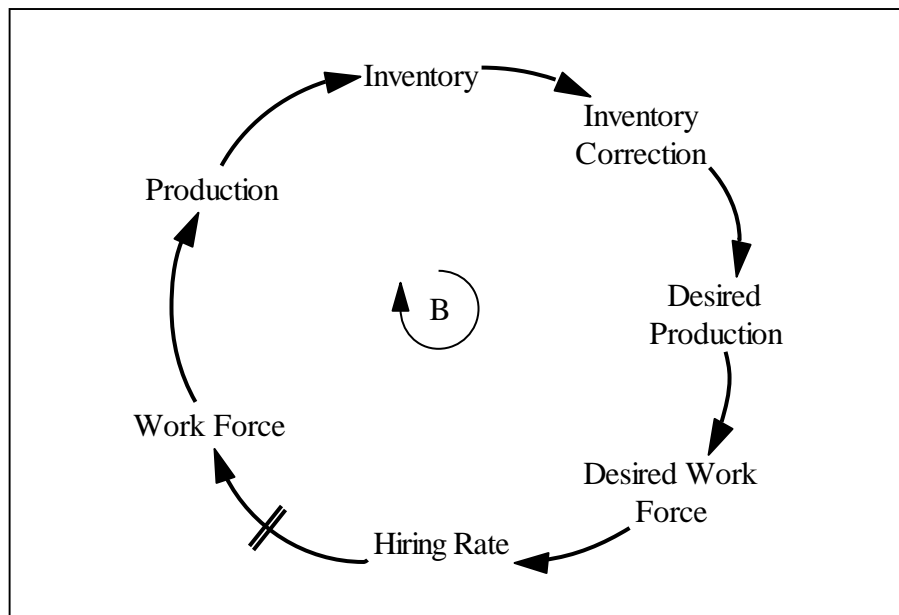


Figure 5.8: An Example of the Oscillation Structure

#### 5.5.4. Non-linearity

Non-linearity is an inherent aspect of social and physical system behaviour (Forrester, 1994). Any time elements of a system interfere, cooperate, or compete, nonlinear interactions is the normal result. Effect is seldom proportional to cause, and what occurs locally in a system often does not apply in distant regions (other states of the system) (Sterman, 2002). Infrastructure systems are characterized by high degree of connectivity and complexity. Bettis and Prahalad (1995) suggest that such complex systems usually show nonlinear behaviour. For instance the relationship between congestion and travel time on a specific link is non-linear. In modelling such system, alternatives to mere linear models are thus required. Hitt et al. (1998: 25) suggest “*inputting linear and rational attributes to nonlinear problems will only lead to erroneous strategic actions*”. System dynamics is grounded in the theory of nonlinear dynamics theory (Sterman, 2002). One of the most significant aspects of SD is its capacity to provide an analytic solution for complex and nonlinear system (Forrester 1991). It is well known to its ability to describe and formulate nonlinear relationships.

#### 5.5.5. SD Modelling Process

SD is a mathematical and diagrammatical modelling technique that is employed to treat complex-nature problems through building and rebuilding of system structure. System

dynamics literature suggests different conceptual frameworks for system dynamic-based modelling process. Wolstonholm (1990) divides the modelling process into three stages, Randers (1980) grouped the activities of the modelling process in 4 stages, Kwak (1995) and Sterman (2000) grouped them into five, Robert et al. (1983) into six and Richardson and Pugh (1981) into seven different stages. Although this discrepancy in dividing the modelling process into its components, the main activities constituting the whole modelling process are generally still the same. Table 5.1 provides insights on this difference.

In general, SD modelling includes two main stages: Qualitative System Dynamics or model conceptualization and Quantitative System Dynamics. For instance, SD modelling process developed by Sterman (2000) is divided into five stages as suggested by Table 5.1. The first two stages concern Qualitative System Dynamics or model conceptualization while the other three stages constitute Quantitative System Dynamics. While the former is mainly directed to identify the problem and to create causal loop diagrams, the latter is devoted to quantitative computer simulation. In all previous frameworks, the real world will first be interpreted into description, the description leads into equations and simulation to understand the dynamic behaviour. It thus convert real situation into a simulation model.

## **5.6. Demand Risk Model Development**

Sterman (2000) states that there is no formal procedure to follow for successful modelling. Thus, given the nature of the research problem, the research adopt a SD modelling process which includes problem identification, model conceptualization, model formulation, model simulation, model validation, and model application. The modelling process along with the method used for collecting data in each stage is represented in Figure 5.9 and detailed in the next sub-sections. In addition, Table 5.2 summarises how the identified data collection and modelling methods are used to satisfy the research objectives.

Table 5.1: System Dynamics Modelling Process across the Classic Literature

Randers (1980)	Richardson and Pugh (1981)	Robert et al (1983)	Wolstenholme (1990)	Kwak (1995)	Sterman (2000)	Ranganath and Rodrigues (2008)
Conceptualization	Problem Identification	Problem definition	Diagram conceptualisation and analysis	System Understanding	Problem articulation	Problem Identification and definition
Formulation	System Conceptualisation	System conceptualization		Conceptualisation	Dynamic hypothesis	System Conceptualisation
	Model formulation	Model Representation	Model Formation	Formulation	Model formulation	
Testing	Analysis of model behaviour	Model behaviour	Simulation phase (1)	Model Validation	Testing	Simulation and Validation
	Model evaluation	Model evaluation				
Implementation	Policy analysis	Policy analysis and model use	Simulation phase (2)	Policy Analysis	Policy formulation and evaluation	Policy analysis and improvement
	Model use or implementation					Policy Implementation

### **5.6.1. Problem Identification**

The first stage, as shown in Figure 5.9, identifies the research problem. This is achieved by reviewing existing literature in the area of PPPs and toll roads. The research problem has been established in Chapter one.

### **5.6.2. Model Conceptualization**

The second stage is the model conceptualisation. This involves identifying those factors that have a major influence on the output and mapping them by creating the causal loop diagrams (CLDs). In light of the steps and instructions provided by Richardson and Poug's (1991) guidelines for building causal loop diagrams, the CLDs of the factors influencing demand in PPP projects are created. This process requires understanding of the relationships between those factors which describe the behaviour pattern over time. The justification of any of these causal relationships can be done through direct observation, reliance on accepted theory, hypothesis and assumption, and statistical evidence (Coyle, 1996). For each of the links, the relationship is indicated as positive or negative based on the SD principles discussed above. The feedback loops are then identified and labeled. Besides being a useful representation of the structure of the system, CLDs constitute the platform for developing the stock and flow diagrams in the next stage of the modelling process. However, before the CLDs can be converted into stock and flow diagrams, they need to be verified by the experts in the field of the study which will be further discussed in the next chapter.

### **5.6.3. Model Formulation**

Mapping the causal links and feedback loops by CLDs is not adequate to establish the dynamic behaviour of the system. Therefore, stock and flow diagrams are developed. Stock and flow diagrams help define types of variables that are important in causing behaviour change. Stocks or levels are the essential components which generate the system behaviour; flows or rates cause stocks to change. For example, population in the CLDs is replaced by the more operational formulation of inflow and outflow that rely on the value of the stock (population) and a fractional rate (growth rate). In addition, stock and flow diagram is more sophisticated than CLDs. For instance, demand in the

stock and a flow diagram is segregated into three types of demand or traffic: commuting, business and social. By this way it is possible to integrate the distinctive drivers' values for each segment of the demand model such as value of time.

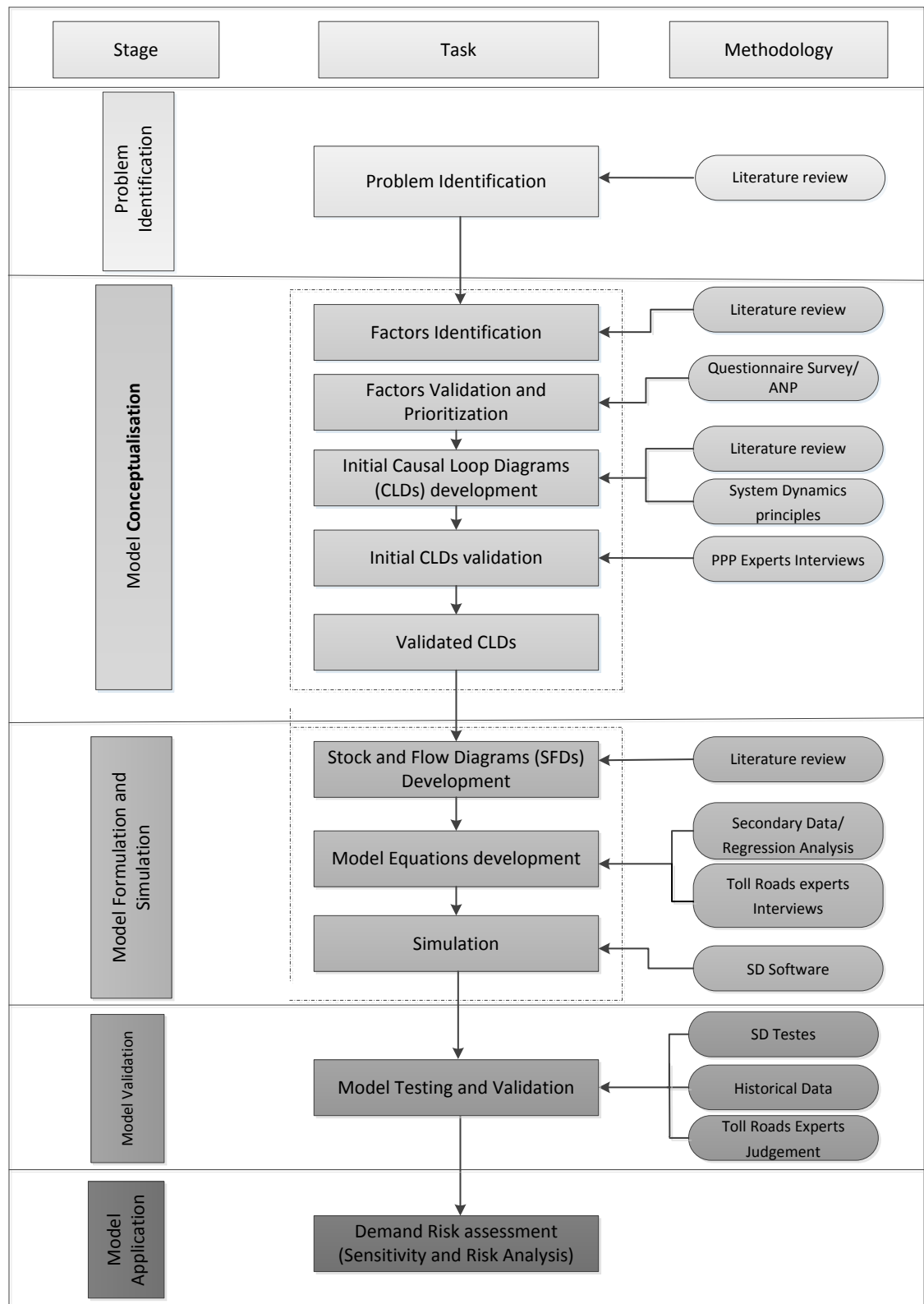


Figure 5.9: The Main Stages, Activities and Data Collection Methods involved in developing the SD Mode

Table 5.2: Thesis Objectives and the corresponding Data Collection and Analysis Methods

Method Objectives	Data Collection Method				Modelling		
	Questionnaire	Interview	Case study	Secondary Data	ANP	Regression Analysis	SD
Objective 1	√				√		
Objective 2		√					√
Objective 3		√	√	√		√	√
Objective 4		√		√			√
Objective 5		√	√				√

Both causal loop diagrams and stock and flow diagrams are not simulation models. They only describe the interrelations among the model variables. Simulation models require representing all the links among the model variables appearing in a diagram by algebraic relationships. These algebraic relationships determine the behaviour of the model. For instance, an insight into the impact of the underlying factors on the demand requires examining the dynamic behaviour of the model. In order to examine the variables behaviour over time, it is necessary to quantify the relationships among the model variables and then simulate the model.

SD model equations can be estimated in three different ways: from first-hand knowledge of a process, from data based on individual relationships in a model, and from overall system behaviour (Richardson and Pugh, 1981). Typically a blend of these three approaches is used. The relationships between some variables can simply be determined by basic mathematical formula. However, there are still several relationships which cannot easily be quantified. In such cases, the variables relationships are formulated by either extrapolation or expert judgment. Thus, to successfully accomplish this process for the proposed model, variety of data sources needs to be accessed. This includes archival research, observations and mental database.

System dynamics relies heavily on numerical data to build the model (Luna-Reyes and Anderson, 2003). The main use of this data is to statistically quantify model

relationships. Peterson (1980) proved the usefulness of statistical techniques when building SD model equations. For the proposed model, the variables for which historical data are available, the equations are estimated through Ordinary Least Square (OLS) or regression analysis using the corresponding time series data.

However, most of the time series data required to build this kind of econometric model is difficult to get or even not available (Sterman, 2000). Therefore, professional judgments and experts perceptions become of particular importance. In the context of PPP road facilities, there is only limited data to support good evaluations of the impacts of various kinds of factors on traffic behaviour, particularly in the case of absence of projects with similar characteristics. Therefore, some of the model equations were estimated using the method employed by Ford and Sterman (1998) and explained in Sterman (2000). According to Sterman (2000), this method of equations elicitation can be used with individuals or small group of practitioners. For the proposed model, five experts are individually interviewed (section 5.7.3) at the aim of eliciting the knowledge required to build the model equations, along with the available numerical data. The elicitation process employed to set the proposed model equations includes three stages positioning, description, and discussion as recommended by Sterman (2000). The positioning phase sets the context and aim of the interview and describes the model purpose and the relationships to be quantified. The description phase aims at eliciting expert knowledge and transforming it into a usable form by using kind of worksheets already prepared for the expert. In this stage, the expert perceptions about behavioural influences are gleaned to specify the shape and values of the model relationships represented as graphs. Since the experts have detailed information about the traffic behaviour under various circumstances through their observations and measurements, the interviewees identified the curve shape they thought best describes and the values best specify the effect of various independent variables on other dependent ones as it will be discussed in chapter seven. Finally, and in the discussion phase, the experts justify the rationale underlying their estimates of each relationship. Eventually, this data obtained from experts' mental models is incorporated into the model formulation. The developed SD simulation model equations are detailed on chapter seven and listed in full in Appendix A.

In addition, to determine the values of the soft variables such as public consultation and effect of environmental considerations, three interviews with M6 toll road (the case

study used to demonstrate the model application) stakeholders were conducted. The interviewees were from the private sector, public sector and a consultant. All the three interviewees have engaged in the operation of the facility, so they have the required knowledge to develop the values of the variables.

#### **5.6.4. Model Simulation**

Simulation of the model begins after the equations pass some logical criteria such as: all variables are being identified and attached to values, none is defined more than once, and there are consistent units of measure (Forrester, 1991). Simulation is the task of obtaining an abstract model from a real case with the purpose of comprehending the effect of modification and the impact of initiating particular strategies on the situation. It is a rigorous activity where major influences are defined and manipulated to examine their effects on the outcomes (Coyle, 1996). The major purpose of the simulation is thus to understand what will occur for a certain situation under certain assumptions. Through the computer simulation, and by assuming that the system structure generates particular behaviour, SD-based model enables the imitation of a potential behaviour of the system under particular circumstances. System dynamics software offers a mechanism to easily perform this process.

Vensim SD software has been used in the research in concern. Vensim is simulation software which is used for developing, analyzing, and packaging dynamic models. Vensim was developed around the mid-1980s by Ventana Systems for use in consulting projects. The software was then commercially available in 1992. The software contains several tools for model representation, analysis and testing. To build a SD model, Vensim offers an array of symbols used in creating SD model sketches as it will be shown later in Chapter six and Seven. The modelling outcomes can be represented both numerically and graphically. Vensim has the capability of connections to data and sophisticated calibration methods, instant output with continuous simulation in SyntheSim, flexible model publication and model analysis, including optimization and Monte Carlo simulation.

Chapter eight examines in details the simulation process of the SD model and its outcomes.



### **5.6.5. Model Validation**

Model validation is a significant feature of any model-based methodology. A valid model means “well suited to a purpose and soundly constructed” (Coyle, 1997). The goal of our research is to provide practitioners with a model which offers sources, explanations and assessments for potential variations in the future demand. The practitioners in the study area are hence the ablest to identify its usefulness. The validation process therefore includes interviews with stakeholders in the toll road field. In addition, SD model validation is drawing on a wide range of tests as well as many sources of data such as reports and archival documents. The SD model is validated using a combination of tests such as boundary adequacy and structure assessment for which system dynamics software offers a mechanism to perform. In addition, the findings of the model are validated by comparing the results to real time series data. Validation process is further detailed in chapter nine.

### **5.6.6. Model Application**

After ensuring that the model is valid in terms of structure and behaviour, the model is used to assess demand risk in PPP road projects as it will be discussed in chapter ten.

Next section discusses the data collection method involved in the modelling process.

## **5.7. Data Collection**

Figure 5.9 provides an insight into the main stages included in the model development process and indicate the method used for data collection in the modelling process. Most of the knowledge required to build system dynamics models exists in the mental models of the system stakeholders (Forrester, 1992). Therefore, knowledge elicitation from its sources requires engaging participants from the real system to capture the relevant information necessary to build a reliable model. Experts are the ablest to identify the problem structure as they have the wider, better-quality of relevant knowledge and information. Forrester (1992) identified three kinds of knowledge sources which help

build SD models, namely; numerical, written and mental. Among these three types of knowledge sources, Forrester argues that mental models are the richest.

Knowledge elicitation from mental models of system stakeholders can be done individually or from a panel of experts. While focus group is the most common when eliciting information from a group of experts, several methods are available to elicit information from individuals such as questionnaires, interviews, and workbooks (Vennix, 1990). As for the model in concern, different methods of data collection are used. The following sub-sections discuss the data collection methods involved in the interactive model development process.

### **5.7.1. Literature Review**

Sterman (2000) recommends accessing stakeholders databases and written databases when identifying a problem. A written database is a significant source of data since it contains both mental data and interpretations for other sources of information (Forrester, 1992). Therefore, for the model in question, examining the available written documents was a significant source of data. The principal sources of data were journal papers, conference papers, textbooks, work and research papers and professional and official government reports. Based on the data generated, the problem is explored and the main influencing factors and their relationships are defined.

### **5.7.2. Questionnaire**

In addition to the literature review, the factors identification process included accessing stakeholder mental database by distributing an on-line questionnaire. The aim of the questionnaire is two folds: first, to validate the collected data and supplement further data or factors, and second to prioritize the identified factors to exclude any insignificant factor. One of the main advantages of questionnaire survey is the capacity to cover a wide geographical area. PPP approach has become an international trend as discussed in chapter two. The method has been adopted by many governments around the world for delivering major infrastructure. The potential questionnaire respondents are hence widely dispersed and gaining wide range of their views requires such tool. In addition, the questionnaire can offer a quick and low-cost way for collecting data.

Oppenheim (1992) argues that, although the postal questionnaire offers less control over the persons answering the questions and the way in which they answer, they form a considerable structured, reliable method for collecting data in which all the respondents are presented with similar questions and in a similar order. Moreover, questionnaire survey grants the participants enough time to reflect on the questions (Sekaran, 1992; Brook, 1977). Questionnaire survey has been frequently used in the area of risk in PPP projects in general (Li et al., 2004; Salman et al., 2007) and risk ranking in particular. Askar and Gab-Allah (2002) used a questionnaire survey to rank different types of risks in PPP projects. The questionnaire used a scale from 0%-100% to rate and rank risk factors. Tang et al (2007) and Toan and Ozawa (2008) used a similar approach but by employing a Likert scale instead.

For this research, potential demand risk factors extracted from the literature have been incorporated into the questionnaire survey. The target respondents were primarily personnel from the public and private sectors who had already been involved in PPP schemes. This approach of employing questionnaire as a method of knowledge elicitation from individuals when developing SD model, especially when the expert group are geographically dispersed, as in our case, is corroborated by Vennix (1990, 1992). The questionnaire survey questions and findings are further discussed in chapter six.

Questionnaire survey is used to rate and measure the relative importance of each influencing factor. Since the factors affecting demand risk have some kind of interdependencies and interact with each other in a complex manner, questionnaire finding analysis aimed at prioritizing the influencing factors should consider their complex interactions. Given this normal methods of data analysis are not sufficient. An Analytic Network Process (ANP) based technique for prioritizing demand risk factors in the PPP infrastructure concession is hence developed. ANP is a useful method to deal with complex systems that involve dependence. ANP makes it possible to deal systematically with the interactions and dependencies among the factors in a decision system (Bayazit and Carpak, 2007). To make complex risky decisions, Saaty (2008) argues that not only judgments but also structures that represent the best understanding of the flow of influences are required. The ANP method used in this research contained both the quantitative and qualitative factors of the demand risk revealed during the literature review and questionnaire survey sent to the experts in the PPP projects.

The method offered an approach to prioritize each of the risk factors identified in four main steps:

- (1) Hierarchic structure development
- (2) Pairwise comparisons
- (3) Determining priority weighing
- (4) Providing of final priorities

ANP method and its findings pertaining to the research are more detailed in chapter six.

### **5.7.3. Interview**

Interviews technique is often utilised to survey the experiences, views and beliefs of individuals. Interviews help researcher to set up relationships with the interviewees and gain their cooperation. They permit clarify ambiguity and gain deep understanding by asking for further information. Interviews can be conducted in person (face-to-face) or via telephone or other kinds of communication technologies such as Skype. There are three fundamental types of interview data collection technique. Interview can be structured, semi-structured or unstructured. A structured interview has a pre-determined fixed set of questions with very small possibility to ask additional questions. Conversely, unstructured interviews are undertaken with little or no organisation and no control on scope and length of the response. Raiden et al. (2008) argue that structured questions do not permit participants to expand on their knowledge. On the other hand in unstructured interviews, the interviewer has no control on either the questions or the answers provided and in this case the responses are much more complex to analyse. The in-between semi-structured interviews encompass several major questions that identify the areas to be explored with the possibility of seeking further clarifications and explanations (Fellows and Liu, 2003). Blumberg et al. (2005) suggest that this latter kind of interview is aimed at accessing and understanding the views of the participants on the topic of concern and to identify the possibility that the participant may confirm the information the interviewer has.

SD model development requires accessing expert knowledge and learning their views regarding the model structure. Their insights are crucial for eliciting and developing the

model equations. In addition, interviewees' confirmation and disconfirmation is frequently required during the modelling process. For instance, experts need to confirm or reject the model relationships in the CLDs validation process. Semi structure interviews were therefore incorporated as a major technique for collecting data.

Three rounds of face to face, semi-structure interviews are conducted. The first round aims at CLDs validation, the second is conducted with the aim of equations elicitation and the third round aims at model validation. Face to face interviews offered a chance to access and understand experts' views and tacit their mental knowledge.

The first round of interviews is conducted in the conceptualisation stage (Section 6.3). Sterman (2000) suggests that knowledge elicitation by stakeholders' interviews is an effective approach to collect data necessary to model conceptualization. In this round, nine experts have been interviewed to validate the proposed CLDs. Based on the results of the whole interviews and by revisiting, comparing and combining the interviewees' comments, the CLDs have been further refined and updated to agree validated CLDs which constitute the conceptual model. Second round of the interviews is aimed at building the model equations (Section 5.6.3, Section 7.3 (e.g. Section 7.3.2 and Figure 7.4)). Expert judgment is elicited to determine the mathematical relationships by conducting semi-structure interview with practitioners in toll roads field. Five face to face interviews, each of which is about two hours in length, with experts in toll roads are undertaken. The final round of interviews aims to validate the quantitative model (Section 9.3). They thus focussed on the presentation and discussion of the final model and its outcomes. The interviews are structured around a number of main questions concerning the model structure, the base case run results, and some scenarios. Each interview begins with presenting the method for model development and implementation. The interviews last between one and two hours in length. In terms of number, literature shows that a range of 5 to 20 experts was used (Linkove et al., 2006; Morgan and Henrion, 1990). As a rule of thumb, Cooke et al. (2000) recommend using eight experts and at least four experts for a particular subject. For the model in concern, five interviews with experts in toll roads are undertaken to validate the model. Interviews results will be further discussed in chapter six and chapter nine.

#### **5.7.4. Case Study**

SD literature shows that case study has been frequently used to validate quantitative SD simulation models (Senge and Forester, 1980; Graham and Morecroft et al., 1982). As discussed in the previous chapter, a case study is an empirical examination of a contemporary phenomenon within its life context (Yin, 2003). Employing case study strategy allows making benefit from triangulation of multiple sources of data (Saunders et al., 2003). Based on the number of cases included in a research, the case study research method can be categorised into single case based and multiple cases based. Since toll roads have very different characteristics, as discussed in chapter three, investigating toll roads on case by case basis may offer reliable justification for encountered demand traffic variation. Prozzie et al. (2009) conducted a detailed study to isolate the main source of demand variations in the USA by employing multiple case study strategy. Because of the availability of this type of projects in the USA (more than 150 projects), several toll roads (5 case study were included) with similar characteristics in terms of scope, area and demographic and transportation were studied.

However, in the UK, the experience of toll road is still immature. M6 toll road is the first privately financed road in the country (except major bridges and tunnels). Thus, in order to investigate the sources of poor usage performance of toll roads, a single case study strategy is used. M6 toll road is employed as an explanatory case study. The data is collected from published document and interview with relevant professionals. Documents reviewed include reports, news release, research articles as well as the facility website. A number of interviews are conducted with different stakeholders, including: government officials, organisational representatives, financial consultants and the road operators. For instance, three interviews were conducted with M6 toll road stakeholder to determine the values of the soft variables included in the model as discussed above section 5.6.3.

#### **5.7.5. Secondary Data**

Further to aforementioned techniques, collecting data from other sources turned out to be important. To develop the model equations, for instance, several methods are employed such as regression analysis, extrapolation and expert judgment. Secondary data, which is mainly quantitative time series data, is required to build some of the

model equations. The data is collected from different official organisations such as Department for Transport and National Office of Statistics.

The gathered data is used to undertake the statistical analysis of the model relationships and develop some of the model equations. Multiple regression analysis is used to develop the equations using the secondary data collected. Multiple regression analysis is a statistical technique which employs several explanatory variables to estimate a response dependant variable. It thus helps model the relationship between the independent and dependent variables.

### **5.8. Summary**

The aim of this chapter was to provide information about the specific approaches and tools embraced to deal with the research problem. SD method was thus investigated and discussed. The chapter reviewed the literature related to using the SD in PPPs and transport filed. The chapter then provided a detailed explanation of major principles and features of SD method. The modelling process using SD method was presented. The chapter detailed how different methods of data collection were used for the modelling process. Next chapter discusses the first modelling stage “model conceptualization.

## **Chapter Six: Model Conceptualisation**

### **6.1. Introduction**

Chapter two presented the main factors affecting demand for service provided by PPP infrastructure projects. Literature review was the main source of data for factors identification. While literature offered a rich list of factors influencing demand, further investigation of these factors is carried out using a questionnaire survey approach. Since the aim of SD modelling is to model the main and most relevant elements of the problem rather than modelling the entire system, the survey also aims to identify those most important factors by asking the respondent to rate them. The rated factors are then subject to a prioritization process. The prioritization process helps identify the most critical factors so that they can be given more attention and be subject to further analysis. This chapter reports the findings of the questionnaire survey along with the method used to analyse the data gathered. The chapter thus addresses the first objective of this study. The second part of the chapter is assigned for mapping the relationships among these factors. This process is an important step of the conceptualisation stages of system dynamics modelling. A set of cause-effect or Causal Loop diagrams (CLDs) are developed to depict how the factors are related and affect demand.

### **6.2. Factors Validation and Prioritization**

Reviewing the relating literature led to produce a list of core factors affecting demand in PPP infrastructure projects. However, validating the identified factors is essential. The full range of the factors is therefore incorporated into a questionnaire survey and distributed to PPP projects stakeholders online.

Table 6.1 shows the list of factors affecting demand as identified by the literature review.



Table 6.1: A list of the Factors affecting Demand Identified based on the Literature

<b>Factors</b>	<b>Source</b>
1- Users' wealth	Edward,1996; Bansall and Kelly, 2005
2- Public acceptance	Pahlman, 1996; Abdul-Aziz, 2001; Calvo and Cariola , 2004
3- Historical experience of paying	Bain, 2002, 2009.
4- Public involvement in ongoing facility management	Baxandall et al., 2009; Estache et al.,2000; Ballance and Taylor, 2005
5- Willingness to pay	Edward,1996; Delmon, 2005; Mugabi and Kayaga, 2010
6- Quality of service	Abdul-Aziz, 2001; Debande, 2002
7- Level of fee	Hodge, 2000; Thomas et al., 2003; Lemos, 2004; Raje et al.,2004a, b; Zhou et al., 2008; Choi et al., 2010; Menzie and Perotte, 2010; Kwak et al., 2009; Yu et al., 2013
8- Quality of service provided by competitive facilities	Harding, 2005; Baxandall et al., 2009
9- The fee for using alternative facilities	Harding, 2005. Eboli and Mazzulla, 2008.
10. Level of public benefit delivered by the facility (e.g. Time savings)	Rydin and Pennington, 2000; Illsley, 2003
11- Project location and environmental considerations	Walker and Smith, 1995; Debande, 2002;
12- Availability of supportive facilities	Zhou et al., 2008; Cabral and Junior, 2010; Choi et al., 2010; Menzie and Perotte, 2010; Thomas et al., 2003; Yu et al., 2013.
13- Infrastructure market access rules (e.g. Non-compete clause)	Baxandall et al., 2009
14- Competition	Walker and Smith, 1995; Lang, 1998; Lemos, 2004; Delmon, 2005; Shen and Wu, 2005; Cabral and Junior, 2010; Choi <i>et al.</i> , 2010; Menzie and Perotte, 2010; Thomas et al., 2003; Yu et al., 2013
15- Employment	Chiu and Bosher, 2005
16- Population	Lang, 1998; Delmon, 2005.
17- GDP	Zhou et al., 2008; Yu et al., 2013.

A convenient sampling technique was used to identify the survey respondents and data collection. Naoum (1998) stated that the sampling method must ensure that the attributes of the sample are similar to those of the population from which it is taken and should be a true representative of that population. Frankfort et al. (1996) stated that “*a sample is said to be representative if the analysis made on its sampling units produce results similar to those that would be obtained had the entire population been analysed*”. Therefore, it was essential to clearly define the target population based on the objectives of the study. The research mainly concerns PPPs problem. Therefore it is essentially to involve participants who are engaged in PPP schemes from both the public and private sector. The main survey targets were thus selected from the database of people who are involved in PPP projects, which was compiled in PPP LinkedIn groups. This was added to another database from a variety of sources (e.g. Internet, PFI journals). This method of sampling helped to select a specific, targeted audience and know that the sample is valid and respondents meet the defined criteria of engaging in PPP schemes.

The survey was designed and sent using an online tool (survey monkey) to facilitate its distribution. The questions provided boxes’ choices where the respondents were asked to choose the relevant box or boxes. The questionnaire is divided into two main parts as shown in Appendix B: the first part deals with general information about the respondents such as the type of agency working for and years of experience. The second part of the questionnaire mainly aimed to identify the significance of each included risk factor. To do so, a rating system was adopted. Likert scale has been used as a rating system for the criticality of each factor in the questionnaire. The questionnaire respondents were asked to list the significance of potential risk identified on a scale of 1-5, where 1 represents “not significant” factor and 5 represents an “extremely significant”. The respondents are also asked to add to the list of factors any other factors if not presented in the original list and rate it.

200 questionnaires were distributed to people perceived to be involved in PPP projects via email. A total of 37 completely filled questionnaires have been received and included in the analysis. The response rate is about 19%. This rate is higher than that of other studies in the field of PPP such as Li et al. (2005) (12%) and IPPR consultant (2000) (9.6%). In addition, 17 questionnaires were partially filled and as a result have been excluded from the analysis.

Table 6.2 presents a summary of information on the respondents who completed the questionnaire. The table shows the respondents' information in terms of organisation type (public and private sector) and year of experience.

Table 6.2: Respondents' Experience and Associated Organisation

Year of Experience	Public	Private	Financial Community	Consultancy	Total
0-5	2	-	-	2	4
5-10	3	9	1	3	16
10-20	5	4	1	2	12
>20	2	3	-	-	5
Total	10	16	2	9	37

The results suggest that 43% of the questionnaire respondents belong to the private sector, 27% is of the public sector, 24% is from consultants and 6% are working in financial organisations. 43% of the respondent have between 5-10 years of experience in the field of PPP, 32% have between 10-20 years, 14% have more than 20 years and 11% have less than 5 years of experience in the PPP field. This indicates that the respondents have significant experience in the field of PPPs.

In the second part of the survey the PPP stakeholders are asked to rate and measure the relative importance of each influencing factor. In addition, they are asked to add any new factor to the list. Based on the questionnaire survey results, it was concluded that the literature review provided a complete list of factors affecting demand since no new factors were added by the questionnaire respondents. The survey results in terms of the relative importance of the demand factors of PPP are listed in Table 6.3. For the identified factors, the mean values have a range from the lowest value of 2.69 (Public involvement in ongoing facility management) to the highest value of 4.17 (WTP)). From these results, no major difference is observed between the factors means. In addition, no factor mean value scores fell into the fairly significant (<2.5) category which shows that all the factors are important. Therefore, all factors should be considered for SD modelling.

Table 6.3: Demand Risk Factors Means based on the Questionnaire Survey

<b>Factors</b>	<b>Mean</b>
Users' wealth	3.54
Public acceptance	3.32
Historical experience of paying	3.60
Public involvement in ongoing facility management	2.69
Willingness to pay	4.17
Quality of service	4.03
Level of fee	4.03
Quality of service provided by competing facilities	3.80
The fee for using alternative facilities	3.86
Level of public benefit delivered by the facility (e.g. time savings)	3.72
Project location and environmental considerations	3.31
Availability of supportive facilities	3.37
Infrastructure market access rules (e.g. Non-compete clause)	3.49
Competition	4.08
employment	3.54
Population	3.57
GDP	3.37

Most of the factors affecting demand are interdependent and they interact with each other in a complex manner. For instance, GDP influences population and level of employment. User wealth affects WTP. Because of this interdependency, the factors that are less important individually might turn out to be more important when evaluated collectively (Karpak and Topcu, 2010). In this context, ranking the factors should consider this complexity. Therefore, the factors should not be ranked only based on their means and further analysis has to be conducted to consider these interdependencies. Therefore, Analytical Network Process (ANP) is used to prioritize interrelated factors according to their importance from the project stakeholder perspectives.

### **6.2.1. Factor Prioritization Using ANP**

ANP is a flexible method to prioritize factors of complex nature by breaking down the problem into a systematic network of interrelated-factors. Karpak and Topcu (2010)

developed ANP model to prioritize the measures of success and the antecedents for Turkish small to medium sized manufacturing enterprises. Khan and Faisal (2007) used ANP to prioritise and select appropriate municipal solid waste disposal methods. Cheng and Li (2005) employed ANP to prioritise a set of construction projects by using a five level project selection model.

In the context of this research, the ANP method offers an approach to prioritize the risk factors in four main steps:

- (1) Hierarchic structure development
- (2) Pairwise comparisons
- (3) Determining priority weighing
- (4) Providing of final priorities

“Super Decisions” a sophisticated and user friendly software (Saaty, 2001a), is used to run the ANP exercise.

### ***1) ANP hierarchical structure***

To perform the prioritization process, the identified and validated demand influencing factors are grouped in three main clusters: user characteristics, facility characteristics and area characteristics as shown in Table 6.4. Classification of elements into clusters can be done according to their homogeneity (Sadeghi et al., 2012). For market share problem, for instance, the clusters might include the system players such as customers, service, economics, advertising and goods (Saaty, 2005). Accordingly, the demand risk factors have been thus decomposed to a set of manageable clusters based on the players in the demand system so that each pair-wise comparison measures the relative importance or strength of the factors within a cluster by using a ratio scale. The main aim of this categorization is to divide the factors into groups whose elements are similar and comparable. This categorisation will ensure that factors under a specific category share similar properties. The constructed ANP model for prioritizing demand risk factors thus includes three clusters as shown in Figure 6.1. Once the ANP structure is developed, the pair wise comparison metrics can be established.

Table 6.4: A List of Demand Risk Clusters and Factors

cluster	Code	Factors
<b>Users characteristics</b>	U1	Users' wealth
	U2	Public acceptance
	U3	Historical experience of paying
	U4	Public involvement in ongoing facility management
	U5	Willingness to pay
<b>Facility Characteristics</b>	F1	Quality of service
	F2	Level of fee
	F3	Quality of service provided by competitive facilities
	F4	The fee for using alternative facilities
	F5	Level of public benefit delivered by the facility (e.g. Time savings)
	F6	Project location and environmental considerations
	F7	Availability of supportive facilities
	F8	Infrastructure market access rules (e.g. Non-compete clause)
	F9	Availability of alternative facilities (competition)
<b>Area Characteristics</b>	A1	Employment
	A2	Population
	A3	GDP

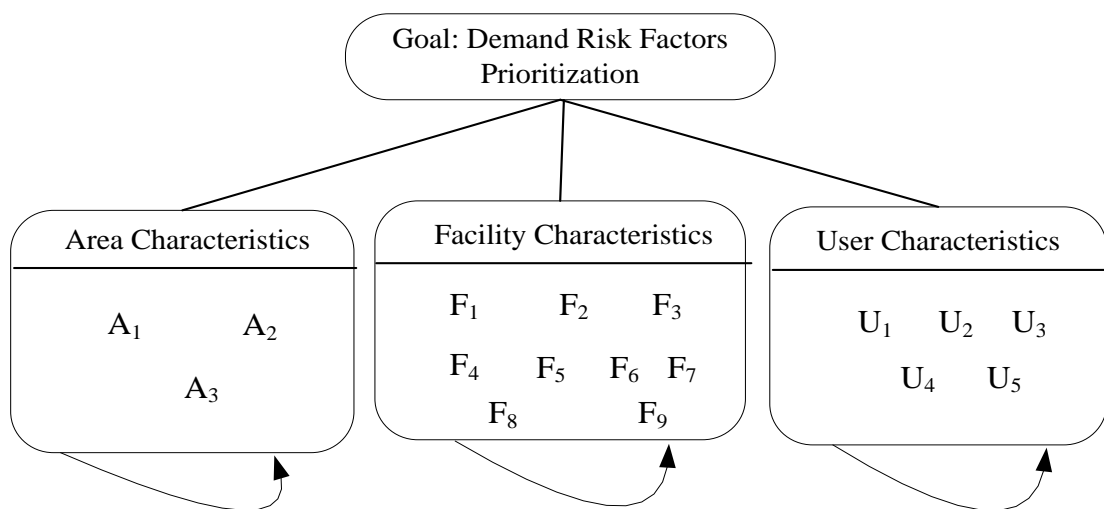


Figure 6.1: ANP Network Structure for Factors Affecting Demand for Service Provided by PPP Projects.

## 2) *Pairwise comparison matrices*

A pairwise comparison is a numerical representation of the relationships between two factors that shows which factor is more significant according to a higher criterion (Khan and Faisal, 2007). The ANP methodology is thus used to convert the respondents' evaluations to numerical values that can be processed and compared over the entire range of the problem. The essence is that human judgments and not just the underlying information can be used in performing the assessments.

The constructed ANP hierarchy is used to compare the factors to one another in pairs within each cluster based on their normalised means identified in Table 6.3. The ANP fundamental scale of Pairwise Judgment (Satty 2005, Zhen et al., 2011) as shown in Table 6.5 was used for the comparison exercise. A score of 1 indicates that the two factors have equal importance where a score of 9 indicates dominance of the factors under consideration over the comparison factor. Once the pairwise comparison is conducted, the vector corresponding to the maximum eigenvalue of the constructed matrices is computed to obtain priority vector. The priority values are further normalised to obtain priorities of the concerned factor. A consistency ratio is used to provide numerical assessment to check the consistency of pairwise comparison, if the calculated ratio is less than 0.10, consistency is considered to be satisfactory. If  $CR \leq 0.1$ , it means respondents' judgments satisfy the consistency. If not, then that means the experts have conflicting judgments. The inconsistent elements in the comparison matrix have to be identified and revised; otherwise, the result of risk assessment and decision analysis is unreliable.

For the three matrices of user characteristics, facility characteristics and area characteristics, the CR was 0.001, 0.00 and 0.002 respectively. The three values are less CR threshold of 0.1. The pairwise matrices can then identify the relative weight of the identified demand risk factors considering the dependencies among these factors.

Table 6.5: Pairwise Judgement Scale

Scales of pairwise judgment	Comparisons of pair indicator scores <sup>a</sup>
1=equal	1:1
2=equally to moderately dominant	2:1, 3:2, 4:3, 5:4
3=moderately dominant	3:1, 4:2, 5:3
4=moderately to strongly dominant	4:1, 5:2
5=strongly dominant	5:1

<sup>a</sup>Scores for indicators based on questionnaire survey; scales for scoring each indicator: 1= not significant; 2 = fairly significant; 3 = significant; 4=very significant; 5 = Extremely significant

### 3) *Determining risk priority weighing*

In making the comparisons in the previous step, concrete data about the factors derived from respondents' mean values were used for judgments about the factors' relative meaning and importance. A numerical weight or priority is thus derived for each factors of the hierarchy as shown in Table 6.6 to Table 6.8 allowing diverse and often incommensurable factors to be compared to one another in a rational and consistent way. All calculations to determine the priorities of the factors in the network were computed by Super Decisions software.

### 4) *Providing of final priorities*

#### a) *User Characteristics*

As shown in Table 6.6, historical experience of paying is ranked as the most important factor influencing demand risk in PPP infrastructure projects in terms of users characteristic. Demand is impacted by user familiarity with user charge-based facilities. Public are not used to pay for government for providing infrastructure service (especially in developing countries). When there is no tradition of paying for public service, the introduction of new facility could be faced by reluctance from the potential users which would negatively impact demand. Ranked second is user willingness to pay. Willingness to pay is an important factor in the evaluation stage of any project to be procured as a concession scheme. Bain (2009) has stated the uncertainty over the user willingness to pay toll in toll road projects, especially when those toll are higher than average, is one of the major drivers for demand risk. User wealth is ranked as the third factor in the prioritization list. Affordability or public capacity to pay for the



service provided is a key. It is therefore of utmost importance to recognize the target population receiving the service in terms of their wealth. Public involvement in ongoing facility management is ranked as the fourth important factor. Infrastructure projects are inherent to the daily lives of users and they can have enormous implication on quality of life (Baxandall et al., 2009). Public engagement in long term facility management is therefore necessary to ensure coherent planning over long period of time. Community engagement in setting up maintenance and safety standard and adjusting tariff is to ensure high degree of prolonged public satisfaction. And finally, public acceptance is the last important factor in user characteristic group.

#### *b) Facility Characteristics*

Per analysis for the facility characteristics cluster in Table 6.6, the fee for using the facility plays the most important role. Public typically choose the cheapest alternative where one is available. Therefore, to guarantee a constant demand for service provided by a project the tariff should be set at a reasonable level. Evidence shows that a very high tariff is off putting to potential users. In the UK, the public outcry against the high tariff for the Manchester Metrolink project has led to contract termination (Menziez and Perrott, 2010). Quality of service provided by the competing facility is ranked as the second important factor in the prioritization list. The quality of service offered by alternative facilities to which the users could switch from the concerned facility is a significant factor which could affect willingness to pay, particularly in the case of free alternative service. It is argued that the level of satisfaction relating to service offered by each alternative influences willingness to pay for using others. The third important factor is the access rules to the infrastructure market. This kind of rules can affect the level of competition. The most common form of market access rules is the non-compete clause included in some toll road concession agreements. Toll roads experience around the world shows these kinds of projects contract terms frequently contain clauses that limit government ability to build or upgrade adjacent facilities in ways that could damage demand and the private sector ability to recover its capital investment. For example, the non-compete clause included in the concession agreement prevented Indiana municipality (USA) from building or expanding an adjacent road of the east-west toll road for at least 55 years (Baxandall et al., 2009). The reason is that building a new facility or rehabilitating an existing one can seriously diminish the viability of the project as a result of tough competition. Level of fee for using competing facility is

other aspect of competition and is ranked fourth. The demand level for a service responsively changes when a change in price takes place in other competing one. This change in demand is widely known as a cross elasticity of demand. For instance, demand for Crydon Tramlink (UK) declined due to decreasing bus fares on competitive roads to Croydon system (Harding, 2005). Level of competition (number of competing facilities) and benefit from using the facility (e.g time saving in case of toll roads) are the fifth and sixth important respectively. Public perception toward paying fee depends, to large extent, on the benefit gained from utilising the facility. In toll road project, for example, it is important to understand that the public willingness to pay tolls relies first on the time saving benefit. WTP is the subjective value of time in terms of monetary cost for savings in travel time (Eboli and Mazzulla, 2008). The seventh important factor in facility characteristics is quality of service. Demand volume is extremely sensitive to the quality of service (Debande, 2002). Quality of service is a major driver for willingness to pay. User awareness of low service quality would be a reason for reduced WTP and consequent reduction in demand. Facility location and environmental consideration and availability of supportive facilities are ranked as the least important factors.

### *c) Area Characteristics*

The last cluster analysed is the area characteristics which include three factors: employment, population and GDP. Table 6.8 shows that the most important factor in this cluster is the employment followed by population. While introducing infrastructure facility to a specific region would augment employment opportunities and enhance the productivity of the area, the level of employment itself would in turn enhance the usage of the facility. In addition, changes in population number and distribution over the course of few years can create tremendous change in demand. When the population of facility surrounding areas grows, this is likely to be reflected in the level of the facility usage. Finally, GDP reflecting the national economic conditions is ranked as the least important factor influencing demand in PPP infrastructure projects in the cluster of area characteristics.

Table 6.6: Pairwise Comparison with respect to User Characteristics (UC)

Factor	UC	U1	U2	U3	U4	U5	weights	Rank
Users' wealth	<b>U1</b>	1	2	1	2	1	0.250	<b>3</b>
Public acceptance	<b>U2</b>	1/2	1	1/2	1	1/2	0.125	<b>5</b>
Historical experience of paying	<b>U3</b>	1	2	1	2	1	0.250	<b>1</b>
Public involvement	<b>U4</b>	1/2	1	1/2	1	1/2	0.125	<b>4</b>
WTP	<b>U5</b>	1	2	1	2	1	0.250	<b>2</b>
<b>Total</b>							1.000	

Table 6.7: Pairwise Comparison with respect to Facility Characteristics (FC)

Factor	FC	F1	F2	F3	F4	F5	F6	F7	F8	F9	Wight	Rank
Quality of service	<b>F1</b>	1	1	1	1	1	2	2	1	1	0.125	7
Level of fee	<b>F2</b>	1	1	1	1	1	2	2	1	1	0.125	1
QS provided by competitive facilities	<b>F3</b>	1	1	1	1	1	2	2	1	1	0.125	2
The fee for using alternative facilities	<b>F4</b>	1	1	1	1	1	2	2	1	1	0.125	4
public benefit	<b>F5</b>	1	1	1	1	1	2	2	1	1	0.125	6
Project location and environmental issues	<b>F6</b>	1/2	1/2	1/2	1/2	1/2	1	1	1/2	1/2	0.063	8
Availability of supportive facilities	<b>F7</b>	1/2	1/2	1/2	1/2	1/2	1	1	1/2	1/2	0.063	9
Market access rules	<b>F8</b>	1	1	1	1	1	2	2	1	1	0.125	3
Availability of alternative facilities (Competition)	<b>F9</b>	1	1	1	1	1	2	2	1	1	0.125	5
<b>Total</b>											1.000	

Table 6.8: Pairwise Comparison with respect to Area Characteristic (AC)

Factor	AC	A1	A2	A3	Weights	Rank
Employment	<b>A1</b>	1	1	2	0.40	1
Population	<b>A2</b>	1	1	2	0.40	2
GDP	<b>A3</b>	1/2	1/2	1	0.20	3
<b>Total</b>					1.00	

The previous tables showed that the analysis using ANP provided an insight into the priorities of the demand risk factors. The tables provided also the weights assigned to each factor which constitute the basis for the prioritization process. ANP analysis shows that the factors within each category have close if not similar weight values indicating the relative significance of all the included factors. Given this, it can be concluded that the survey and ANP analysis results show that all identified factors are important and none of them can be excluded from the modelling procedures, as will be conducted using the SD method.

Next sections of this chapter present the way used to map the relationships among the identified factors and explains how each of these factor would affect demand.

### **6.3. Causal Loop Diagrams (CLDs) Development**

The relationships among all the factors identified in the previous section are mapped using CLDs. In light of the steps and instructions provided by Richardson and Poug's (1981) and Kim (1992) guidelines for building causal loop diagrams, the initial causal loop diagrams of factors influencing demand in PPP projects are created by the modeller.

The following hints offered by the aforementioned guidelines were taken into consideration when developing the CLDs;

- a) Noun or noun phrase rather than variable are used to represent the model elements.
- b) The action in the diagram is represented by arrows and not element.
- c) The definition of any element should clarify which direction is up for the variable. For instance, the "public satisfaction" rather than "public attitude towards the project".
- d) It is preferable to select element name which reflect the positive sense. For instance, "growth" rather than "declination".
- e) Arrows imply the direction of causation rather than time sequence. For instance, the positive causal link from  $X_1$  to  $X_2$  doesn't mean  $X_1$  occurs before  $X_2$ , it rather means if  $X_1$  increases,  $X_2$  increases.

- f) During the construction process for CLDs links, unexpected side effects occurring in addition to the drawn influences need to be taken into consideration. This may lead new links to appear in the diagram to represent these side effects.
- g) Differentiation between actual and perceived states of a process which may requires including both the actual and perceived value of the variable.
- h) Including intermediate element when the causal link between two elements requires a lot of explaining.
- i) Diagrams need to be kept as simple as possible.
- j) The elements in the diagram are variables which can go up or down with measuring scales that are compatible with each other.

Once these initial CLDs were developed, they were validated by experts and professionals in PPP projects. This method of employing a preliminary model then engaging the experts in the more advanced stage of creating the CLDs (rather than the case where one starts from scratch) is supported by several SD researchers such as Hart et al. (1985), Morecroft et al. (1992) and Vennix et al. (1992) because it helps reduce the time invested by the participants and, at the same time, enhance the participant influence on the conceptual model (Vennix et al., 1992). The experts incorporated in the modelling process are in occupation related to PPP projects. In this context, the experts are selected on the basis of availability and on their extensive experience of working in the relevant field. They have an in-depth knowledge about the major reasons behind demand variations, the impact on users, public and private partners and the potential actions to alleviate its negative consequences. The experts were approached individually. A series of semi-structured interviews with nine experts were conducted. Table 6.9 shows the organisations type, academic qualification and years of experience of the engaged experts.

Each of these meetings began with a preliminary depiction of the research aim and objectives, a general overview of system dynamics as an adopted methodology, and the expected meeting outputs. The interviewees were then asked to review each of the demonstrated diagrams to: (1) add or drop variables (cause, effect, or intermediate), (2) verify the existence and direction of each relationship in the diagram and (3) point out any missing relationships.

Table 6.9: CLDs Validation Respondents Profile

<b>Sector</b>	<b>Academic Qualification</b>	<b>Years of Experience in PPPs</b>
Public	PhD	20-25
Public	PhD	20-25
Public	PhD	20-25
Public	PhD	20-25
Public	PhD	10-15
Public	PhD	0-5
Private	PhD	15-20
Private	PhD	10-15
Private	Master	10-15

The abovementioned questions aiming at CLDs validation cover the major criteria that determine the validity of CLDs. These criteria include clarity, quantity existence, cause sufficiency, additional cause possibility, predicted effect existence, tautology, connection edge existence and cause-effect reversal (Burns and Musa, 2001). During the course of the interview, the relative significance of the factors and relationships among factors were discussed. The interviewees identified few new variables to be included in the model as they indicated that some intermediate factors were missing and they need to be added to a number of CLDs. For instance, net migration was suggested as an intermediate factor between economic growth and population in the socio-economic sub-model. It is important to mention that these intermediate factors do not affect the prioritisation results of the major factors affecting demand since they are sub-factors under those major factors. They are only added to make the CLDs representation clearer. In addition, refinements to few relationships were suggested.

Based on the results of the these interviews and by revisiting, comparing and combining the interviewees' comments, the CLDs have been further refined and validated to establish the whole conceptual model as shown in Figure 6.2, 6.4, 6.5, 6.6 and 6.7. The following sections will discuss each of the developed CLDs.

### **6.3.1. Socio-economic CLD**

There is such an agreement that the investment in public infrastructure has an important and positive impact on economic growth. Ashaure (1989) assures the importance of the infrastructure investment in economic growth indicating that core infrastructure such as

highways are a principal player in augmenting any economy. Munnell (1992) stressed that public investment has a significant positive impact on the economic growth. . Lau and Sin (1997) estimate the elasticity of output to the public investments to be 0.11 indicating the positive influence of infrastructure investment on economic growth. Gramlich (1994) argues that schemes such as highways could provide high return comparing the minor or negative impact of any maintenance scheme.

Introducing a new infrastructure projects can have its local and systematic impacts. While systematic impacts can influence all potential users of the facility, local impacts affect those people in the vicinity area (Kananoglou et al., 1998). In the local impacts context, introducing infrastructure facility to a specific region would bring significant benefits. It would augment employment opportunities and enhance the productivity of the area due to enhancing additional economic activities (agriculture, manufacturing, construction) by which a significant proportion of employment and income can be triggered. This will finally result in a positive impact on the local economy in general. For instance, constructing a new highway will lead to many fuel and service stations, firms, retail stores, warehouses and restaurants being emerged along and in the proximity of the facility. It can also contribute to the development of agriculture, tourism, industry and other sectors. Ernst and Young (2008) reported that toll roads in Sydney contributed \$1.8 billion Real Gross State Product (RGSP) to the New South Wales (NSW) economy in 2007, or 0.55% of NSW RGSP. Moreover, the realisation of the second Peace Bridge between Canada and USA was declared to facilitate \$29 billion in trade and contribute to construct an international trade complex in the adjoining area (McQuaid and Greig, 2010). Similar situations were identified in the UK. Holvand and Preston (2005) identified nine studies conducted in the UK that examine the relationships between road projects and local economic growth. One of these studies by Linneker and Spence (1996) reported that building M25 had a positive impact on demand for labour. Skye Bridge has been considered beneficial for the Isle of Skye local economy (McQuaid and Greig, 2010). Pineda (1991) argues that the main economic benefit of the bridge would be the increase in the number of tourists flowing to the island which would result from reducing the congestion at the ferry. Infrastructure developments have therefor their positive impacts on the local economy through enhancing economic growth and increasing productivity and profitability (Debande, 2002).

The emerging amenities have their positive impacts on the local population and their income as they create additional job opportunities and attract new people to the facility area. While increasing level of economic activities will trigger simultaneous growth in the community and cause increasing per capita income, there is no doubt that this increasing will also have its effect on demand for the service provided by the infrastructure facilities in the area.

The economic context in which the facility is to be operated has its impact on the demand level. The future facility demand and revenues rely, to large extent, on the development of the facility area or land use aspects (Bain, 2002). Infrastructure projects are generator of economic activities as discussed above. The facility users could play a significant role in shifting economical resources to the facility area leading to a substantial economic growth. Growth in economic would increase employment and demand for labours and can cause change in demographics in terms of number and distribution during a period of time. This demographic change in the course of few years can create tremendous change in demand. When the facility surrounding areas grow in terms of population, this will be reflected as a growth in facility usage (Chiu and Bosher, 2005).

Socio-economic CLD, as shown in Figure 6.2, shows many feedback loops. The first one which is a reinforcing loop R1 [local economic growth, labour supply/employment, demand, alternative facilities- local economic growth] where the economic growth in the facility area will trigger more job opportunities attracting more employees and labour to this area which consequently will increase the level of demand. However, continuous increase in demand resulting from more job opportunities will create a need for another facility to relief inordinate pressure on the concerned one. This new built project will eventually contribute in the economic growth. However, it should be noted that constructing another facility in the area is most likely to negatively affect the demand for the service provided by the concerned facility (B1-loop). The second reinforcing loop is R2 [local economic growth, net migration, population, demand, alternative facilities, local economic growth] where the economic growth will enhance migration to the facility area which will enhance the population growth resulting finally in demand growth. R3 loop [local economic growth, user wealth, WTP, demand, alternative facility, local economic growth] shows that economic growth will enhance user wealth resulting in increasing purchasing power and WTP of the potential users



which will have positive impact on level of demand. R4 loop [local economic growth, labour supply/employment, local economic growth] is the final reinforcing loop where the growth in economy will attract employees and labour to the facility area causing further growth in the local economy.

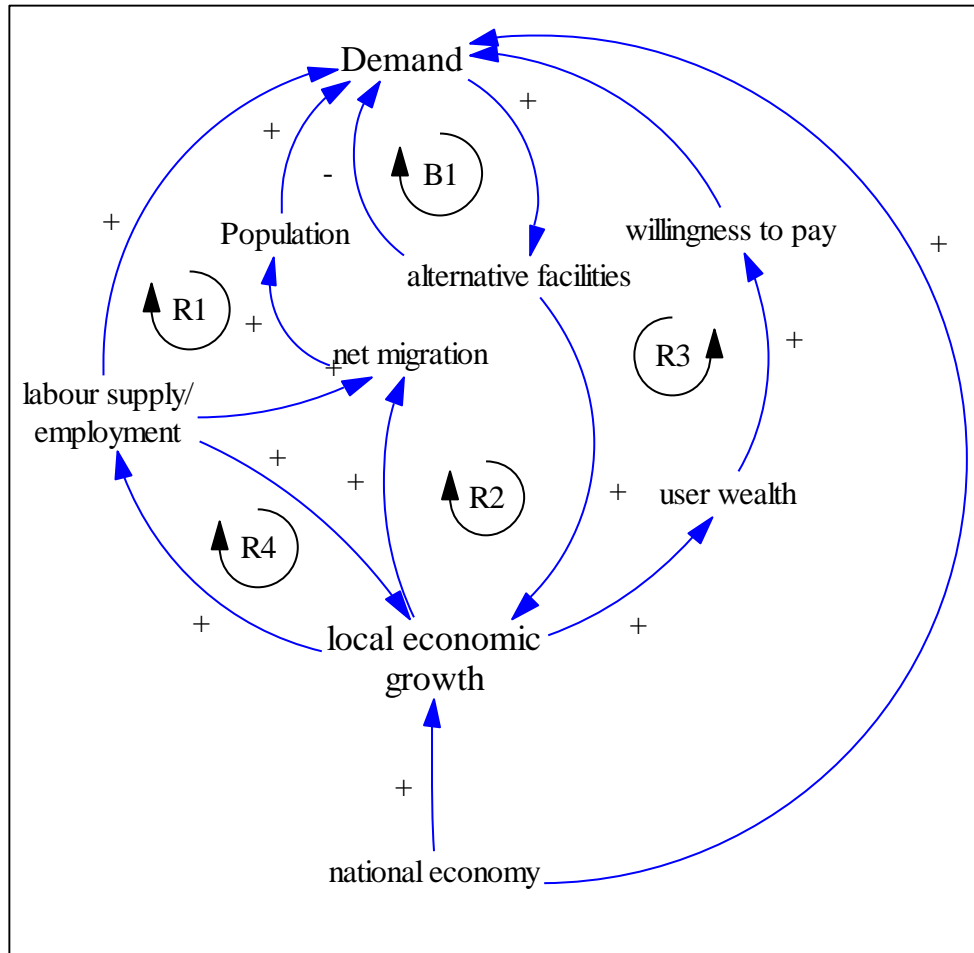


Figure 6.2: Socio-economic Causal Loop Diagram

### 6.3.2. Public Satisfaction CLD

Since user's perception is a main driver for service demand and consequently for project viability in concession projects, the significance of public satisfaction emerges as a key driver for project success.

In 80's, many governments around the world started employing privatisation to deliver infrastructure projects as a way to raise fund and take advantage of private sector management efficiency. However, political opposition and public outcry were a response for the privatisation in many cities (Siemiatycki, 2009). A survey by the National Association of Realtors in the USA showed that two-thirds of Americans oppose employing the private sector to build and operate roads (Baxandall et al., 2009). This negative attitude of community regarding the privatisation is likely to have its impacts on the financial status of PPP projects. For instance, the serious public opposition for some PPP projects in the Lao PDR was one of the major problem encountered projects partners (Pahlman, 1996). Levey (1996) considers the same reason a cause for the failure of some PPP projects in the United States. Abdul-Aziz (2001) argues that public worries regarding PPP arrangements have been reflected in difficulties encountered by some of the PPP sewerage system which caused, at the end, to concession termination after 7 years out of 28 year concession contract. Russell et al., (2000) suggest that privatisation of City link (Australia) project has been the probable cause of diverting 15-37% of traffic to the adjacent roads. In the UK when the proposals of toll road were launched in 2007, the people outcry against it, expressed on the Government 'downing Street' website, was the bigger ever met. On this website, more than 1.8 million voted against the idea of real toll (Berry and Blum, 2011). In addition, community unfamiliarity with real toll roads in the UK led to mass protests by the public against introducing user fee on the bridge to the Hebridean Island of sky (Scotland). Continuous public opposition led the Scottish government eventually to renationalising the scheme and abolishing the charge in 2004 after only 9 year of its concession period.

To avoid public opposition against this kind of project which is most likely to damage the project viability, consultation is a key. Flyvbjerg et al., (2003) argue that community consultation and engagement in decision-making is crucial to raise public support for a project and making the planning process accountable. The major aim of this kind of consultations is to inform the public about the project and seek their sights and comments on the project proposal and any other options available. Public consultation gives the community an opportunity to take part in the project formation by contributing in the assessment and formulation of the project design. This process makes the public feel that their views are appreciated and taken into account, especially when feedback about the consultation process is provided to the contributors before making the last

decision (Illsley, 2003). Only by this way the support for the facility can be built. On the other hand, consultation process would help to address and avoid any misunderstanding and negative insight among the public regarding the prospected facility. In addition, concealing the charge the user is being about from the public can aggravate the public negative attitude towards the facility. In Malaysia, public outcry has arisen due to the charge from the private promoter for wastewater project. The government was obliged to review the charge level twice to appease public. The review led to lower user fee by injecting public fund in the privatised project (Abdul-Aziz, 2001).

Moreover, while environmental issue is important when planning for any infrastructure projects, its significance becomes more serious in the case of PPP projects because it is likely to represent an additional excuse for public outrage. Potential environmental damage and social impacts resulting from the project development defuses public dissatisfaction leading to public denial and rejection for using the facility (Rydin and Pennington, 2000). In transportation projects, for instance, several environmental issues would emerge causing public dissatisfaction. Examples of these issues include increasing greenhouse emission and deteriorating air quality as a result of developing a facility which bring more traffic to the area. Thorough strategy for public participation and communication to enable the public to express views regarding any social and environmental concerns relating to the projects and the use of more environmentally-friendly materials while developing the project would enhance public support and avoid any unforeseeable implications. In addition, attention should be paid to protecting natural heritage and other environmental aspects such as scenery and wildlife in the project area (Siemiatycki, 2011; OMEGA, 2011).

Figure 6.3 provides insight into the factors influencing public satisfaction of PPP infrastructure. Public acceptance causal diagram shows that there are two main factors affecting public satisfaction. Each of these factors positively affects public satisfaction. The first factor is public acceptance emerged mainly from public consultation. The other is goodness of project location and environmental consideration. An increase in any of this measure will lead to subsequent increase in the level of public satisfaction and demand.

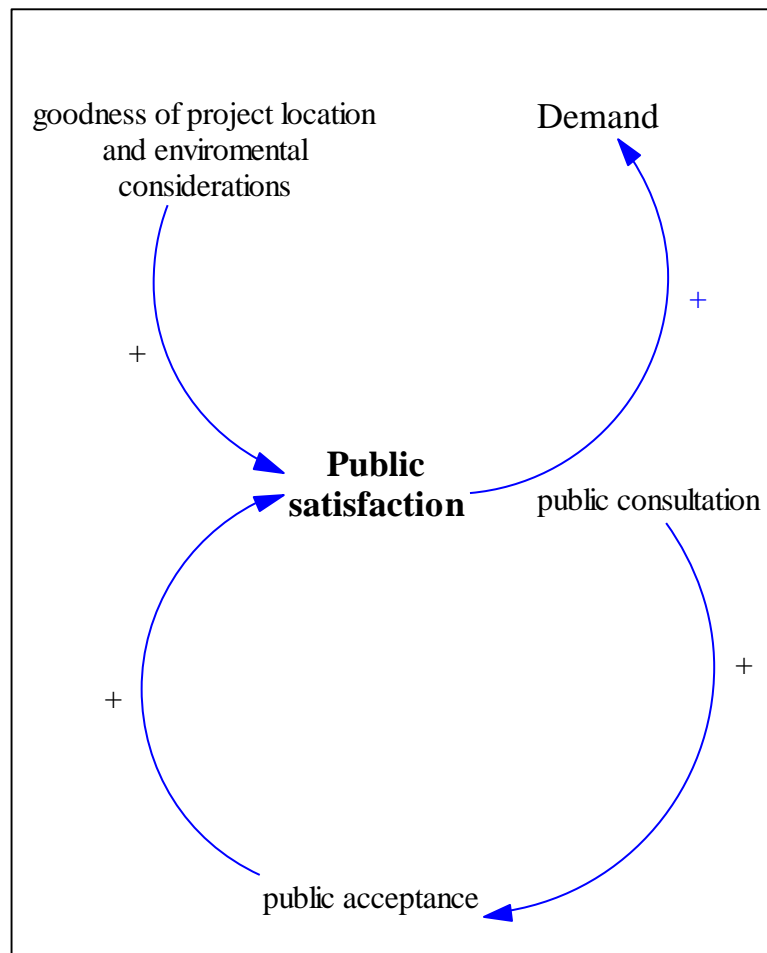


Figure 6.3: Public satisfaction Causal Loop Diagram

### 6.3.3. Willingness to pay CLD

Willingness to pay is an important factor in the evaluation stage of any project to be procured as a concession scheme. Willingness to pay reflects the level of fee that user is ready to pay against the service offered by the facility. It is one of the major drivers for demand.

Willingness to pay is a function of several factors. Users' willingness to pay is limited by their wealth. Public has different attitudes toward tariff paying due to differences in earnings (Bain, 2002). If a high proportion of the considered population is unable to afford the service cost, the project is likely to be in financial distress. Affordability is therefore a significant factor that demand estimation need to consider. Users are sensitive to income effects (Trujillo *et al.*, 2000). Zhang and Kumaraswamy (2001) argue that in PPP revenue-reliant projects, users' affordability should be a determinant

for the level of tariffs imposed for using the service. When pricing a new service, a balance should be struck between the tariff determined based on the project cost and that estimated based on user affordability and his willingness to pay (Trujillo *et al.*, 2000).

WTP and level of demand for service provided by PPP facilities is extremely sensitive to the quality of service (Debande, 2002). *The WTP in terms of service quality attributes represents a quantitative measure of the monetary cost that the user would pay for improving some qualitative service aspects* (Eboli and Mazzulla, 2008). In transportation sector, for instance, users' willingness to pay depends on the ability of the facility of providing better services in terms of reliability, safety, lower accidents rates, and elimination of congestion and delay. Service quality reflects the public expectations towards some service aspects. WTP is higher if the service quality is better, but lower if the price increases and the quality remains poor. User awareness of low service quality would be a reason for reduced WTP. In the transportation sector, several studies have been conducted to assess WTP linked to improvement of service quality such as reducing road accidents (Iraguen and Ortuzar, 2004) and improving the paved road surface (Walton *et al.*, 2004).

On the other hand, the quality of service offered by alternative facilities to which the users could switch from the concerned facility is another measure, which could affect intention to pay. People are willing to pay some amount for quality improvement. This implies that improvement in quality of services provided by a competing facility that lead to offering service which is better than concerned facility's service has a negative impact on willingness to pay. It can be argued that the level of satisfaction relating to service offered by each alternative will influences willingness to pay for the other. In terms of transportation projects, for instance, WTP for using toll roads will decrease if the quality of service on competing free roads improved (e.g. less congestion, higher speed, etc.) (Baxandall *et al.*, 2009).

Public perception toward paying fee depends, to large extent, on the benefit gained from utilising the facility. Willingness to pay will be greater when the built facility provide benefits for potential users compared to other service available. In toll road project, for example, it is important to understand that the public willingness to pay tolls relies first on the time saving benefit (Kriger, 2006, Bain, 2009, Prozzi *et al.*, 2009). In this case,

WTP is the subjective value of time in terms of monetary cost for savings in travel time (Eboli and Mazzulla, 2008).

Moreover, one of the key drivers of WTP is level of fee for using the facility in concern. In case of toll road, for instance, tolls imposed to use the road were seen by many as a potential deterrent to more public for using the facility. A survey study targeted the tourists visiting Highlands, showed the 15% of the respondents cited the high toll level as the main reason for not considering Skye a choice for tourism destination. 11% of the respondents, who already had been to Skye, mentioned that they would not go there if they have heard about the toll charge in anticipation (System Three, 1996). Section 6.5.5 further discusses the effect of level of fee.

R1 reinforcing loop in Figure 6.4 shows that when the level of fee increases, the public WTP decreases which will cause decreasing in demand. Declination in demand may lead the concessionaire to increase the fee for using the facility to compensate shortfall in revenue where the loop starts again. B1 balancing loop indicates that when the level of fee decreases, WTP will increase which will motivate the concessionaire to increase the fee. In addition, WTP causal loop diagram shows that there are a set of factors which positively affect willingness to pay for the service provided. These factors include quality of service, benefit from using the facility and user wealth. On the other hand the diagram shows that there are many other factors negatively affecting user's willingness to pay such as service quality and level of fee of other competing facility.

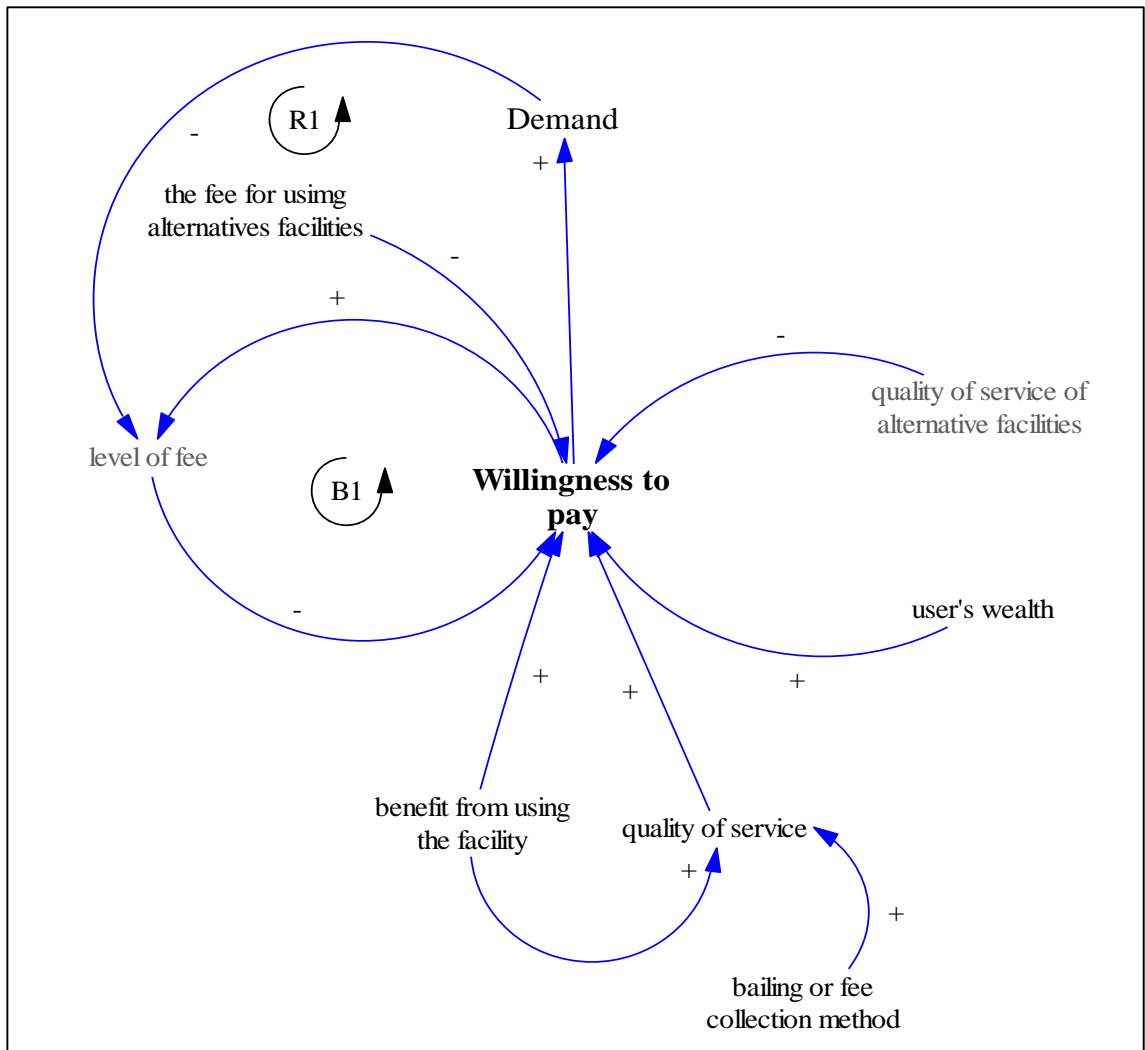


Figure 6.4: Willingness to Pay Causal Loop Diagram

#### 6.3.4. Competition CLD

For PPP infrastructure facilities, one of the main determinates of the efficiency of the investment is the ability to repay the debit within the predetermined time frame. However, this is not straightforward in this specific kind of projects. Complex issues would emerge which could make the facility usage and revenue under the desired level leading the whole deal to become a high-profile failure.

It is often difficult to consider the facility in isolation of surrounding environment or other adjacent facilities. Improvement to an existing facility or building a new one can seriously diminish the viability of the project as a result of tough competition. Dulles green toll road in Virginia (USA) is a common example of projects in which the private sector went bankrupt due to tough shortfall in usage and revenues a result of

construction adjacent competing facility (Price, 2001). The absence of non-compete clause preventing building such facility from the concession agreement was the reason behind the project failure.

Nevertheless, PPP experience around the world shows that PPP contract terms frequently contain such clauses that limit government ability to build or upgrade adjacent facilities in ways that could damage demand and the private sector ability to recover its capital investment. The Government Accountability Office (2008) reported, *“in highway public-private partnerships the public sector may lose some control over its ability to modify existing assets or implement plans to accommodate changes over time”* (quoted in Siemiatycki, 2009). For example, the non-compete clause included in the concession agreement prevented Indiana municipality (USA) from building or expanding an adjacent road of the east-west toll road for at least 55 years (Baxandall et al., 2009). In addition, in SR91Express toll lane (US), this non-compete clause in the partnership agreement prevented the government from constructing additional lane to alleviate renewed congestion within a 1.5 mile “absolute protection zone” in the region of SR91(Price, 2001). These non-compete clauses can be considered as an assurance from the government for the private sector that actual demand will meet that projected by controlling the service quality of the competing facility. In Colorado, one agreement contains condition which imposes decreasing the speed limits on local roads to lessen the probable competition for the private toll road (Baxandall et al., 2009). This example shows how quality of service on competing facility (speed) may affect level of demand for a particular facility.

In addition, the fee for using the competing facilities may play a significant role in shaping demand. In Croydon TramLink (UK), it was predicted that the project will carry 25 million patronages per year. However, only 60% of the predicted passenger volume has used the link within the first five years of operation. TramLink general manager attributes this shortfall to decreasing bus fares and increasing local bus service on competitive roads to Croydon system (Harding, 2005). Thus, Transport for London has been obligated to reimburse the private sector due to demand shortfall resulting from its own policy which affected private operator demand-based revenue and expected profit.



While an improvement to a competing facility would deteriorate demand, the impact of other amenities can go so diverse way changing the sign of correlation between the concerned facility and others. This kind of supportive facilities is key to enhance demand. In many cases, the public body is asked to develop certain assets to support service and guarantee the minimum demand for the project (Debande, 2002). In transportation, for instance, the construction of supportive assets most likely allows improving the access to the facility in question. An improvement in the bus service and road infrastructure is likely to increase demand for train or for subway when it works as a feeder as happened in Brazilian North-eastern cities (Trujillo *et al.*, 2000) and Eurotunnel. Moreover, Ruster (1997) attributes the lack of demand for the many of Mexican toll roads to the absence of contiguous sections that would integrate the toll roads into the main network which highly deteriorated the attractiveness of these toll roads.

Competition causal loop diagram shows two balancing loops. The first one is B1 [demand- number of alternative facilities- competition-demand] where high level of demand for service will increase the need for building new alternative facilities. The reaction for demand increase may not occur immediately and the decision to build new facility takes several years. The ultimate increase in the number of alternative facilities will enhance the competition. This also includes kind of delay due to the time required to build the facility. The competition from other facilities negatively affects demand for service provided by the concerned one. The level of access to the infrastructure market is typically controlled by the government. More flexibility in the access to the infrastructure market causes increase in the number of alternatives which will enhance the competition. This increase in the level of competition will form a motivation for the government to ease market access (B2). Decrease of quality of service provided by the competing facilities over time increases the willingness to pay for the facility in concern which will subsequently increase the level of demand. The figure also shows that availability of supportive facilities will be a trigger for high level of demand.

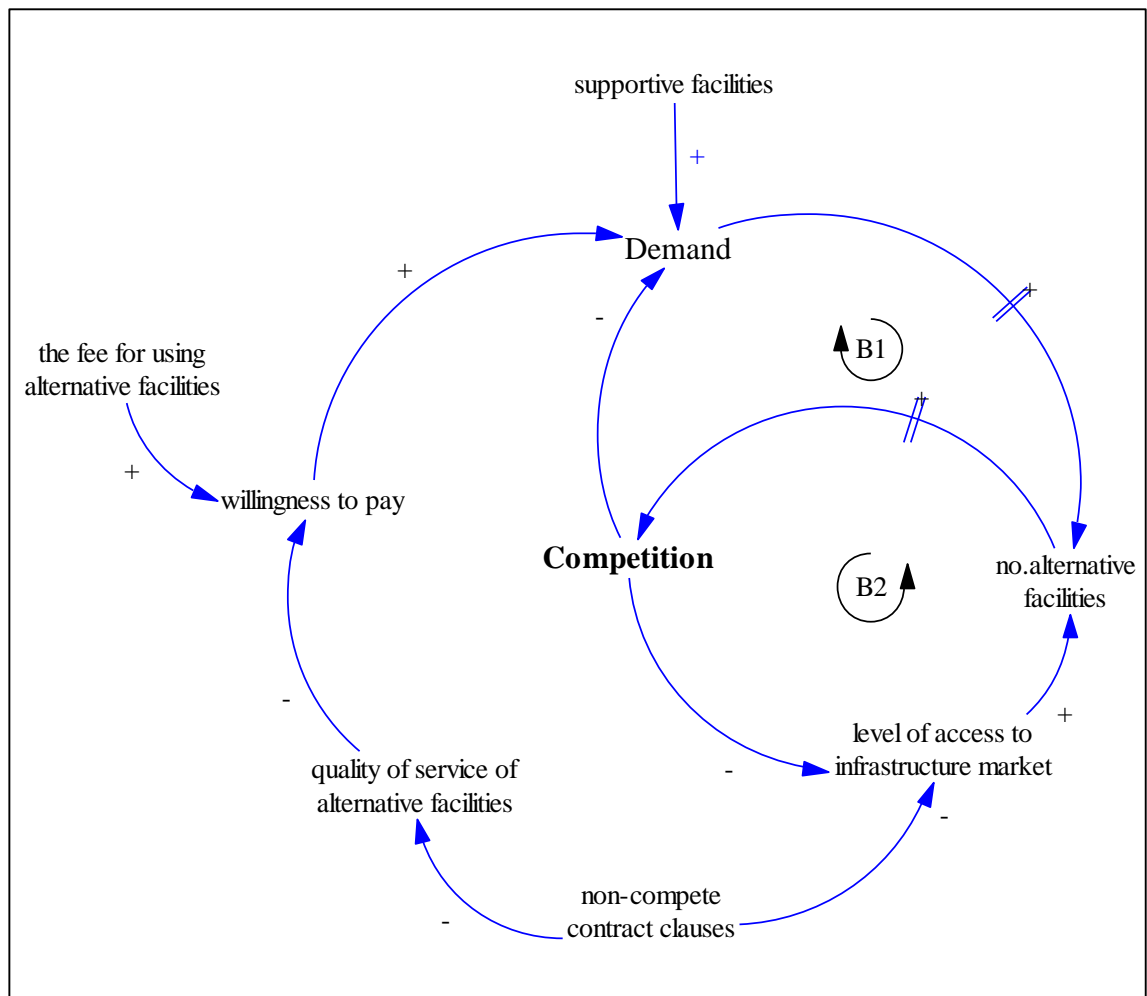


Figure 6.5: Competition Causal Loop Diagram

### 6.3.5. Level of fee CLD

A study by Zhang (2005) showed that an appropriate tariff and suitable adjustment formula is the most significant out of the 10 sub-success factors under sound financial package of PPP critical success factor. For user-based projects to be financially viable, the total revenue collected from users overall the concession period should cover the project cost plus expected profit. The project cost typically includes construction cost, operation and maintenance costs and cost of capital involving the interest on loan and dividends on equity raised to finance the project by the private company. The price at which the service is provided is essential to the private operator profit. There is therefore a great incentive for the private sector to fix the price as high as possible. However, the high tariff is likely to negatively affect demand level. In the case of the

toll roads, for instance, a high-level toll will definitely cause traffic diversion to any available alternative leaving the facility under-used.

Employing PPP to deliver infrastructure projects imposes a serious need to understand the trade-off between the financial and economic viability of the facility in concern. In many cases, the expensive construction program and the private sector willingness to fasten repayment of the debt service and gain high profit led to levying high tariffs. This high level of fee is likely to have a negative impact on the demand for service offered by the facility. In Sydney Airport railway Link (Australia), for instance, the high ticket price was the main reason for low patronage observed. The ticket cost for using the railway was roughly three times as expensive as other lines. However, while private sector is worry about their profit and risk, the major concern of the user is the service price and quality which can seriously affect the user's WTP and demand (Trujillo et al., 2000). Given this, the fee level imposed for using the facility should strike a fair balance between achieving a reasonable return to the concessionaire and being compatible with the quality of service provided (Zhang and Kumaraswamy, 2001).

PPP infrastructure projects are complex and they are associated with risk overall the project lifecycle. In the case of the private infrastructure investment the risk-reward profile is one of the most important considerations when establishing the scheme contract. A higher risk project is more costly due to greater expected return by the private concessionaire to remunerate the additional risk. Pricing these risks will be directly reflected in service pricing. Given this, the risks that are expected to be met and the operator to take on are an important measure when determining the level of fee. Any risk to be borne or being met will be translated into a risk premium which will be added to the project cost (Zhang. and Kumaraswamy, 2001). The construction risk in the channel tunnel project, for instance, has led to double the project construction cost (Langford and Retik, 1996). Since it is common to employ cost-reflecting price strategy in financially free-standing projects to determine the level of fee, the high construction cost for this project was subsequently translated into a high fee for using the facility.

Concession projects could rarely be completely self-financing (Debande, 2002). In many cases the private sector is unable to raise the entire fund necessary to develop the facility, entailing government financial contribution to finance the project development. In the case of Mexican toll road program, for instance, the government grants forms

19% of the total investment (World Bank, 1997). In addition to a loan to be repaid from tolls within 30 years, the UK government provided a grant of £4.65 million to build the Forth Road Bridge (FSB, 2010). This grant would allow the project cost to be shared between facility users and government ensuring reasonable level of user fee. However, when the government is unable to provide this kind of subsidies and as a way to reduce its financial contributions, the public sector would accept setting high tariff for using the facility or, otherwise, establishing so long concession period to extend the revenue generation period leaving the public interests comprised in both cases. In addition, if the private company's revenue falls short as a result of usage underperformance, the requirement for revenue deficit grant is not unlikely. Otherwise, increasing the fare charge would be an expected solution. In Skye Bridge, for instance, the agreement permitted the private company to increase the toll charge by 30 percent if there is any shortfall in traffic utilizing the bridge compared to that forecasted (NAO, 1997).

In addition, level of fee for using other alternative facility is a measure when deciding on level of fee. In sky bridge (Scotland) for example, it was targeted that the toll should be no higher than the ferry fares (Select Committee on Public Accounts, 1998).

Level of fee CLD in Figure 6.6 shows several loops. The first balancing loop B1[ level of fee, WTP, demand, level of fee] shows that the increase in level of fee will lead to decreasing in the willingness to pay. This decreasing in user's willingness to pay will lead to equitable decrease in the level of demand. Demand decline will push the operator to increase level of fee to compensate the shortage in facility revenues. The operator reaction towards demand shortfall does not however occur promptly. As for R2 reinforcing loop [level of fee, WTP, demand, demand for alternative facility, fee for using alternative facility], any decrease in the level of fee will mean increasing in demand for the facility in concern and will be translated as decrease in the demand for any other alternative facility. The demand declination of the alternative facility will lead the operator of that facility to increase the fee to compensate the loss in revenue. This behaviour of alternative facility operator will motivate the concerned facility operator to increase the fee as well which would finally cause demand diversion to the alternative facility when the fee for using the facility in concern becomes more than that for using the alternative one. In some cases and to ensure reasonable level of user fee, the government would provide grants to the private sector as discussed above. This kind of grants will lead to decrease the level of fee imposed for using the facility causing

subsequent increase in the demand. This increase in demand would help to decrease the amount of any further payment required from the government as B2 balancing loop suggests [grants, level of fee, WTP, demand, grants]. User fee causal loop diagram also suggests that there are several other factors affecting level of fee such as cost of capital, discount rate, project cost and expected rate of return.

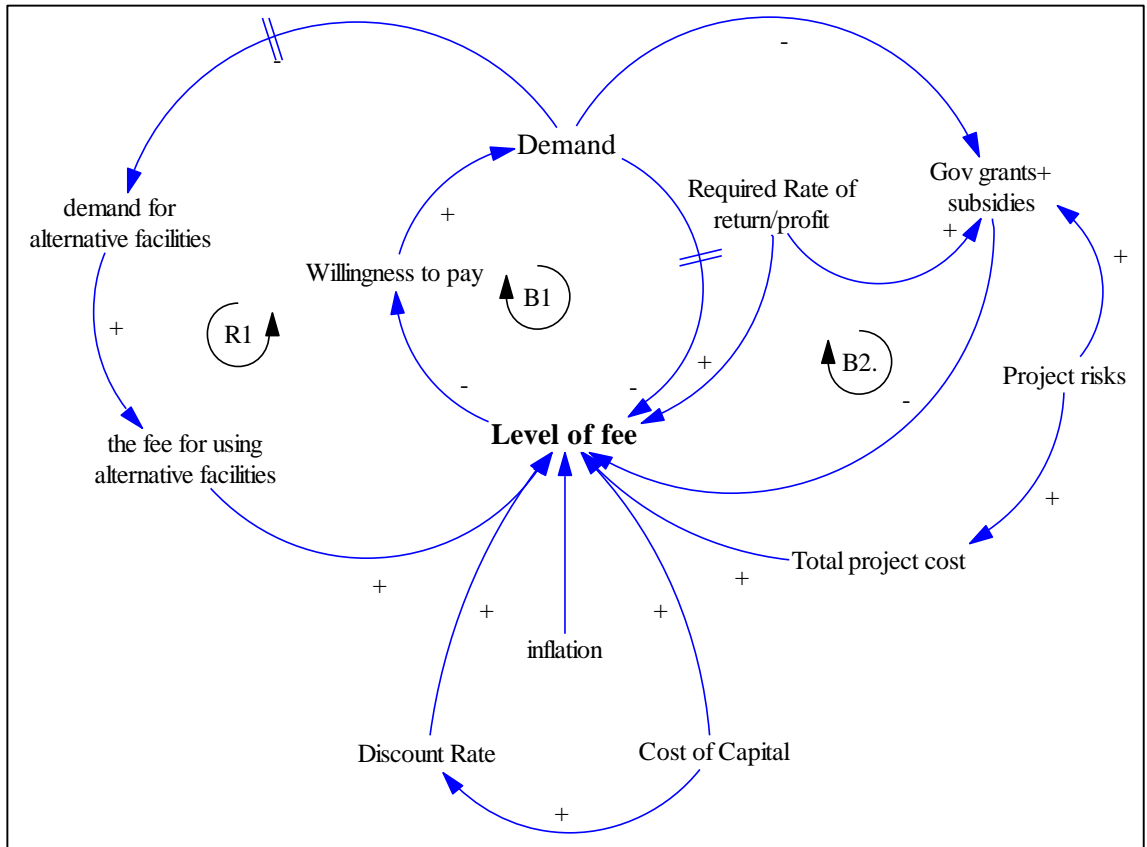


Figure 6.6: Level of Fee Causal Loop Diagram

### 6.3.6. High Level Conceptual Model

Finally, figure 6.7 shows how the previous CLDs interact with each other and affect demand. R1 reinforcing loop [level of fee, WTP, demand, level of fee] suggests that increasing fee will decrease WTP which will ultimately decrease demand. Reduction in demand will push the facility operator to increase the fee where the loop starts again. R2 [level of fee, competition, demand, level of fee] implies that increasing fee will increase competition from other facilities which will decrease demand. Reduction in demand will push the facility operator to increase the fee. B1 balancing loop suggests that increasing demand leads to build a new facility or expand an existed one which will

increase competition and decrease demand for the facility in concern. In addition, the figure shows that socio-economic factors, public satisfaction, historical experience of paying and public involvement in ongoing facility management affect demand positively.

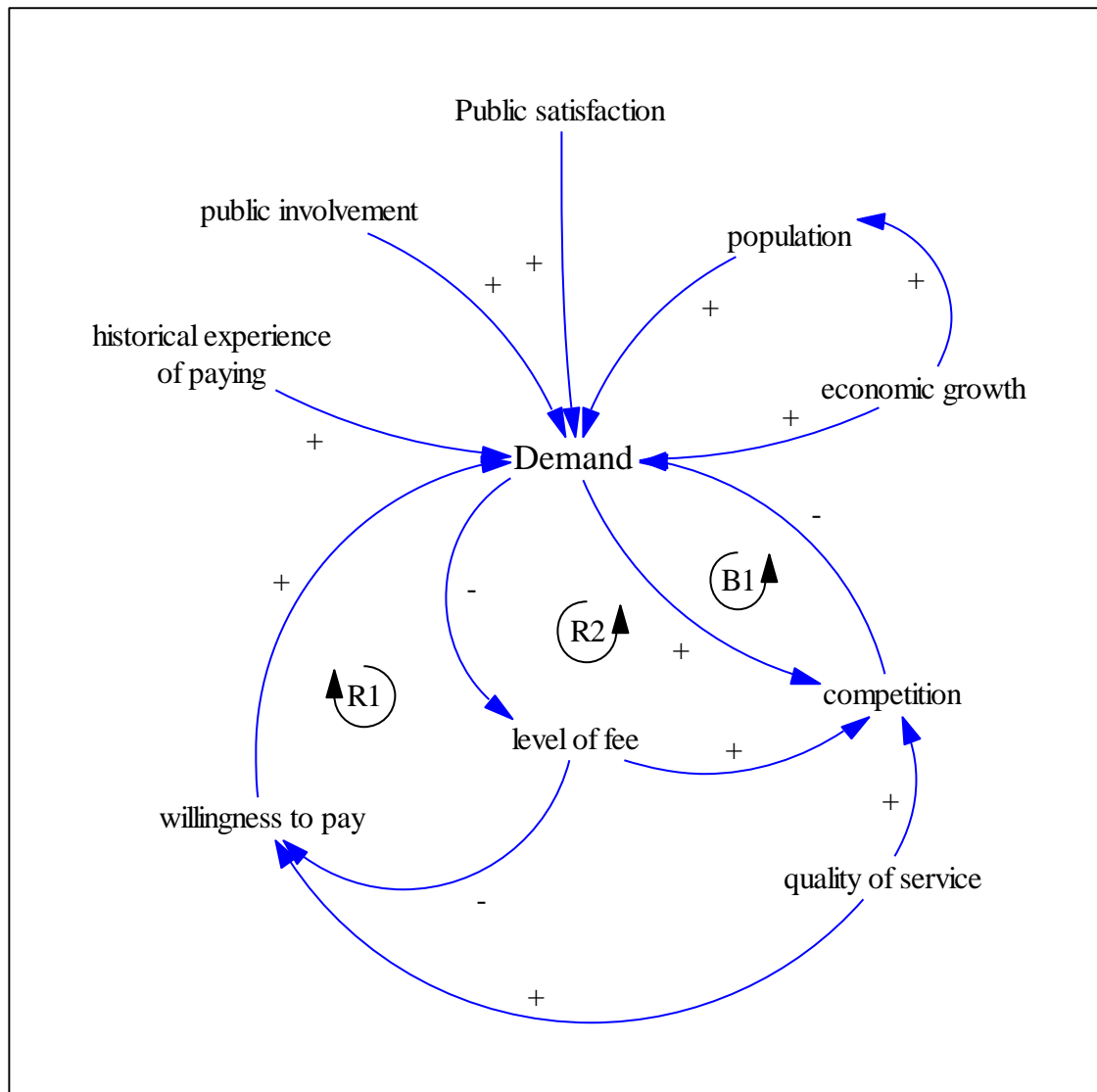


Figure 6.7: High Level Conceptual Model of Demand in PPP infrastructure Projects

#### 6.4. Summary

This chapter outlines the method used to validate, prioritise and map the major factors affecting demand in PPP projects. A comprehensive list of all the identified factors in chapter two was incorporated in a questionnaire survey to gain stakeholder views regarding the significance of the included factors. Since factors affecting demand

interact with each other in a complex manner, prioritizing the influencing factors should consider their complex interactions. Thus, the rated factors via the questionnaire survey were prioritized using the ANP method. The prioritization process showed that all the identified factors are equally important and their impact on demand should be subject to further investigation. Demand is complex and dynamic. Several inter-related qualitative and quantitative factors need to be accounted for. A method which considers this particular nature of factors affecting demand was considered. The system dynamics method by which different factors affecting demand were modelled in a holistic means was used. The concept of system dynamics has been employed to build up a set of causal loop diagrams. The CLDs explain the effect of underlying factors on level of demand. These diagrams will form the basis for developing the simulation model in next chapter.

## **Chapter Seven: Model Formulation**

### **7.1. Introduction**

The first stage in this research explored the factors affecting PPP facility demand (Chapter two and three). Chapter six identified how these factors interact with each other using Causal Loop Diagrams (CLDs). CLDs are qualitative models which describe the causal nature of demand influences. CLDs are however unable to capture the quantitative features of the system. This chapter therefore focuses on the formulation of the quantitative model using Stock and Flow diagrams (SFDs)<sup>2</sup> offered by the SD modelling technique. It develops a SD quantitative simulation model for demand risk assessment. The chapter mathematically explains the relationships between the variables in the SD model. It first offers an overview of the model boundaries and sub-models. The structure of the model developed for this research using SFDs and the quantifying process including the major model equations are then presented and discussed.

### **7.2. Model Overview**

Before formulating the model, it is important to decide on which variables to be included in the simulation model, i.e. the boundary of the model. This step of the model development may eliminate some variables and causal relationships which are outside the scope of the model. The procedure will make the model simpler and easier to understand.

After defining the model boundary, the sub-models diagram, which shows a general view of the model, is developed. The model structure using SFDs is then built and the

---

<sup>2</sup> In the context of this research, the CLDs were developed for the demand risk in PPP projects in general whereas the SFDs are particularly developed for PPP toll roads.



equations describing the model relationships are established. Next sub-section presents the model boundaries chart and the model sub-model diagram.

### **7.2.1. Model Boundary Chart**

When creating a SD model, an important step is to settle on the model boundary. The model boundary determines what is considered to belong to the model and what is not. Forrester (1975) suggests that if a component can be excluded without jeopardizing the purpose or the behaviour of the model, then that component can be dismissed and the model boundary can be established more narrowly. On the other hand, the boundary should be set such that no component excluded from the model is necessary to represent the behaviour of interest (Abin and Forrester, 1997). If omitting a component causes a misrepresentation of the model behaviour, the model boundaries have to be drawn broadly to include this component. System dynamics focuses on endogenous explanation for a specific real system. The word “endogenous” means arising from within. An endogenous theory generates the dynamics of a system through the interaction of the model variables. By determining how the system is structured and the rules of its variables interaction, it is simple to describe the system behaviour created by those rules and to explain how the behaviour might change in the case of changing the structure and rules. On the other hand, “exogenous” means “arising from without” or from outside the boundary of the model. An exogenous theory aims to explain the dynamic of variables pertinent to other variables whose behaviours are assumed (Sterman 2000).

The previous chapter introduced all the factors influencing demand which have been identified through the literature review and confirmed by the questionnaire survey. The aim was to develop a complete list of all the factors affecting demand. In the context of the model purpose, and after further examination, the model boundary has been set. There are several variables that are not directly relating to the purpose of the model but may affect other variables in the model exogenously. Given this, the model boundary was determined by accounting for areas which are essential and relevant to the purpose of the model. Thus, the scope of the model is specified by categorizing the variables into endogenous, exogenous and excluded variables.

The model boundary chart as shown in Table 7.1 lists which variables are included endogenously, which are exogenous and which are excluded from the model. The table shows that the majority of variables are endogenous. For instance, toll rate, time saving and WTP are tightly linked to the toll share and other variables. On the other hand, several exogenous variables control the model behaviour. They describe elements of the national and regional economy such as demographic variable and variables about employment and GDP growth. Variables describing the facility in concern and the competing facility characteristics are also exogenous. A number of variables are omitted, such as migration. It is well known that the total population of a community is controlled by natural changes (births and deaths) and migration (in and out). These two variables are explanatory variables that are not tightly related to the study purpose but they affect other important variables which are the area population and employment growth. A population growth rate which aggregately accounts for all growth drivers (migration, birth and death) has been used instead of explicitly representing all the growth drivers in the model. Employment is dealt with in a similar way. All the variables determining initial toll level such as construction cost, cost of capital, discount rate and projects risks are also considered to be out of the model boundaries since they are not relevant to the operation stage over which the model is run

Table 7.1: Model Boundary Chart of the Demand Risk Assessment Model

<b>Endogenous</b>	<b>Exogenous</b>	<b>Excluded</b>
Population	Population growth rate	Migration
Employment	Employment growth rate	Discount rate
GDP	Corridor traffic growth rate	Cost of capital
	adjustment factor (CAF)	
Regional traffic	Induced traffic rate	Project risks
Regional traffic growth rate	Environmental considerations and project location	Rate of return
Corridor Traffic	Public consultation	
Corridor traffic growth rate	Toll change rate	
Public acceptance	Toll Adjustment factor (TAF)	
Effect of environmental consideration and project location	VTTS change rate	
Users satisfaction	Rival V/C change	
Potential users	ETC normal travel time	
Toll	Non-ETC normal travel time	
Value of Travel Time Savings (VTTS)	ETC normal travel time	

Table 7.1: *continue*

<b>Endogenous</b>	<b>Exogenous</b>	<b>Excluded</b>
WTP	Rival normal travel time	
Effect of qualitative factors/reliability	Weekday expansion factor change rate	
Rival V/C	Annualisation factor change rate	
Travel Time of ETC users	ETC users change rate	
Rival travel time	Proportion of Heavy Goods Vehicle (HGVs)	
Travel time savings of Non-ETC users	Congestion threshold	
Travel time	Rival toll change rate	
Rival travel time	Subsidies related to revenue level	
Effect of V/C on travel time	Fixed subsidies	
Effect of rival V/C on rival travel time	Effect of change in maintenance and operation cost	
Travel cost of ETC users	Effect of demand on maintenance and operation cost	
Travel cost of Non-ETC users	Other effects on maintenance and operation cost	
WTP effect of ETC users	HGVs toll	
WTP effect of non-ETC users	Ramp-up effect	
ETC users toll share	Improvement effect on rival V/C	
Non-ETC toll share	Investment effect on rival V/C	
Effect of historical experience of paying		
Effect of public involvement		
Effect of fuel price		
ETC-demand		
Non-ETC demand		

Endogenous	Exogenous	Excluded
Weekday expansion factor		
Annulisation factor		
Morning Peak period traffic		
Annual Average weekday traffic		
change in maintenance and operation cost		
Traffic revenue		
HGVs revenue		
Governmental subsidies		
Rival toll		
Improvement		
Investment		
Needs to decrease congestion		
Rival V/C change rate		
Rival V/C flow		

### 7.2.2. Sub-models Diagram

Sub-models diagram is a helpful technique to understand the overall model structure. A sub-model diagram shows the overall architecture of the model (Sterman, 2000). It shows the flow of materials and information and linking the sub-models to each other. It thus communicates a general view of the model. Based on the CLDs developed in chapter six and after considering the particular variables of the traffic estimation process explained in chapter three, the model can be divided into a number of sub-models.

Figure 7.1 illustrates the sub-models of the traffic demand model. The figure describes how the sub-models interact with each other and ultimately affect demand. The model is structured around six sub-models. These are socio-economic, public satisfaction, Willingness to Pay (WTP), toll rate, expansion factors and competition sub-models. The expansion factors sub-model is a toll roads-specific sub-model which converts peak period traffic demand into daily and annual traffic. In addition, the diagram shows the key outputs of the model including corridor traffic, satisfaction ratio, potential users, toll share, peak period traffic, Annual Average Daily Traffic (AADT) and revenue.

Chapter three discussed the process of conducting traffic estimation study. Based on this discussion, the traffic demand sub-models are linked in the consequences illustrated in Figure 7.1.

The figure shows that traffic estimation is based on the socio-economic conditions which crystallise the corridor traffic. Given the satisfaction ratio, the number of the facility potential users is a proportion of the corridor traffic. Toll sub-model and competition sub-model feed into WTP sub-model where all together determine the toll share of the facility of its potential users. Since the model generates the traffic for the peak period, expansion factors sub-model is an additional sub-model which converts the peak period traffic into Annual Average Daily Traffic (AADT). Multiplication of the AADT by the toll produces the potential revenue from traffic.

Based on the model structure represented by the sub-model diagrams, next sections will focus on the formulation of the simulation model and setting up the model equations.

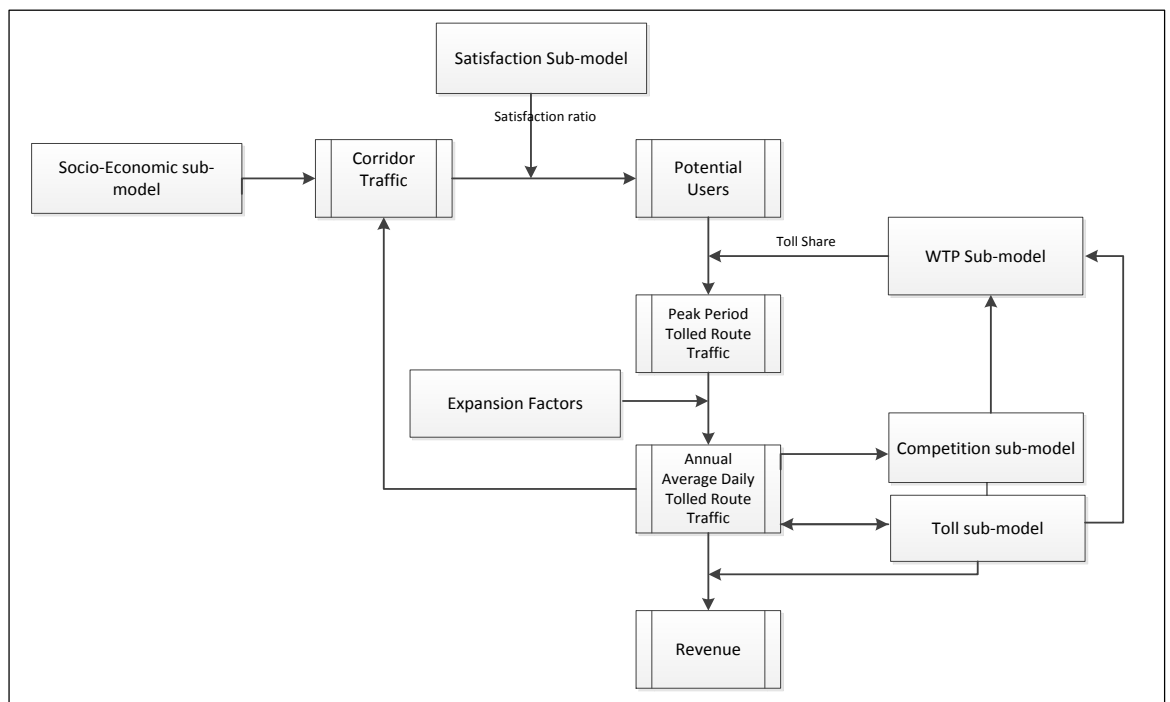



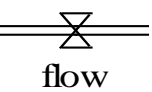


Figure 7.1: Sub-Models Diagram

### 7.3. Model Formulation

Model formulation is one essential step of SD modelling. Model formulation is primarily about developing Stock and Flow Diagrams (SFDs) based on the mental model represented by CLDs. Comparing to the CLDs presented in chapter six, SFDs are more sophisticated method to represent the system structure. It is a tool which helps visually distinguish between the various components of the system, and shows how these components change by including certain symbols each of which refers to a certain type of the model components. Table 7.2 shows the components of SFDs.

The first step in building SFDs is to determine which of the system variables are stocks and which are flows. The distinction between stocks and flows is essential for understanding the source of dynamicity in the system. Stocks can be seen as bathtubs that accumulate physical or informational flow over time. On the other hand, flows can be seen as pipe and faucet fill-up or drain the tube (Radzicki, 2009). Auxiliaries are variables that can affect flows and/or affect each other. Of these auxiliaries, there are constant variables which are typically set from outside (exogenous values).

Table 7.2: Symbols used in Stock and Flow Diagrams

Symbol	Components	Description
	Level/stock	Variable that can accumulate as a result of flows
	Valves	A variable represents rates of change and it influences the model levels
	Clouds	It represents the boundaries of the problem or system and could be source or sink
<variable>	Shadow variable	It represents an alias for another variable on the diagram. It is useful for reducing diagram complexity.
	Link	A connector that link each two variables

In spite of the fact that the SFDs are developed based on the validated causal loop diagrams, it is easy to notice that the appearance and organisation of the variables is different. This can be explained as;

- Employing different symbols (i.e stock, flow, rate and auxiliary) to describe the variables in the stock and flow diagram requires organising the model in different way.
- Stock and flow diagram is more detailed than CLDs, therefore, new intermediate variables may be added.
- The variables are linked together by mathematical formulas; therefore the diagram should be shown to enable creating the equations (Mohammed, 2007).

The SFDs are the basis of the simulation model. Simulation model is the mathematical representation of the system that can be employed to simulate the behaviour of the system by means of computer software. In the simulation mathematical models, all physical and information flows and connections, symbolized visually in SFDs, are mathematically determined using different methods. For the demand risk model, time series data, general knowledge about the system and the expert knowledge gained from the elicitation process discussed in chapter five (section 5.6.3 and section 5.7.3) are the main methods used to formulate the model. Table 7.3 summarizes the general information of the experts engaged in the whole model formulation.

Table 7.3: Model Formulation Respondents Profile

<b>Sector</b>	<b>Academic Qualification</b>	<b>Years of Experience in PPPs</b>
Public	PhD	20-25
Public	PhD	10-15
Public	PhD	0-5
Private	Master	20-25
Consultant	PhD	15-20

Table 7.3 indicates the years of experience of the interviewees to ensure that those interviewed have involved and have deep knowledge on issues relating to demand risk in toll road projects. The result indicates that the interviewees have an average of about 16.5 years of experience on the concerned issue. From the foregoing background

information of experts participated in the formulation process, it can be concluded that the formulation will be made by relevant and qualified experts whose inputs to the formulation can be useful and reliable.

In addition, the system constants representing the exogenous variables are numerically represented by the model inputs as will be discussed in the next chapter.

Next sub-sections discuss in some details the development of SFDs and the formulation of the proposed simulation model. A complete list of the model equations is provided in Appendix A.

### **7.3.1. Socio-economic Sub-model**

To determine the traffic on a particular route, it is important to consider the wider traffic in the route corridor from which the route traffic materialise. The corridor traffic is the function of the socio-economic conditions. The corridor traffic is therefore the key output of the socio-economic sub-model.

Total traffic on a particular route or in a specific region (regional traffic) can easily be divided into two main categories, national and local traffic. National traffic may constitute a significant proportion of transport network system. There are many factors affecting the national traffic such as income and Gross Domestic Product (GDP). On the other hand, local traffic is a significant variable determining the viability of service based infrastructure roads. Regional economy drivers such as population, employments are obviously the main feeder for roads traffic. Roads gain from the contentious growing in regional population and employment levels resulted from different forms of land use. Land use would include new residential, commercial, industrial and retail developments. The addition of any new development will affect regional population and employment. Therefore, a detailed analysis of the economic and demographic factors is of particular importance. These variables representing economic (GDP and employment) and demographic (population) aspects as the main drivers for different kinds of travel were included in the model. Each of these three variables was modelled as a stock element accumulating from a single flow controlled by a growth rate as shown in Figure 7.2, Eq. 7.1, Eq. 7.2 and Eq.7.3.



$$\text{Employment} = \text{INTEG}(\text{employment growth, initial employment}) \quad (\text{Eq.7.1})$$

$$\text{Population} = \text{INTEG}(\text{population growth, initial population}) \quad (\text{Eq.7.2})$$

$$\text{GDP} = \text{INTEG}(\text{GDP growth, initial GDP}) \quad (\text{Eq.7.3})$$

Growth rate for each of these three variables is exogenously projected based on the historical growth trend. The reason behind that is that the factors influencing the change in GDP, population or employment growth rate are outside the boundaries of the model as discussed in Section 7.2.1. Historical data for population and employment growth rate were extracted from statsWales and ONS data set between 1994 and 2012. Historical data of GDP growth rate of the UK between 1994 and 2012 were captured from International Monetary Fund (IFM) data set. Table 7.3 shows a sample of data.

Table 7.4: Sample Data for UK GDP, West midlands Population and Employment

Variable	Unit of Measurements	Minimum	Maximum	Mean	Standard Deviation
GDP	£ Billion	961.407	1449.861	1252.983	161.55
Population	People	4.076*10 <sup>6</sup>	4.426 *10 <sup>6</sup>	4.193.42*10 <sup>6</sup>	0.99*10 <sup>6</sup>
Employment	People	2.316*10 <sup>6</sup>	2.513*10 <sup>6</sup>	2.425.68*10 <sup>6</sup>	0.05*10 <sup>6</sup>

Due to the strong linear relationships between GDP, population, employment (see Appendix C), the effect of socio-economic factors on regional traffic was assumed to be a linear function of regional population, employment and national GDP as illustrated in Eq. 7.4. Haghani (2003) used similar method to develop the relationships between traffic and socio-economic factors. Zhai et al. (2009) also employed a liner functions to describe the relationships between demand for water and socio-economic factors.

$$\text{Regional Traffic} = \alpha * \text{population} + \beta * \text{employment} + \gamma * \text{GDP} + \delta \quad (\text{Eq.7.4})$$

The parameters  $\alpha$ ,  $\beta$ ,  $\gamma$  and  $\delta$  measure how regional traffic responds to changes in the employment, population and GDP. The parameters are area-specific. The value of these parameters need, hence, to be estimated before using the model. The estimation process is explained in the next chapter.

### *Corridor Traffic*

Corridor traffic is the total traffic on the routes that run parallel to the facility and from which the facility market is materialised. The corridor traffic was modelled as a stock accumulating from a flow which is controlled by the corridor traffic growth rate and the induced traffic rate. Corridor traffic growth rate is the function of regional traffic growth rate. Regional traffic growth rate is estimated based on changes in regional traffic. To adjust regional growth rate into the corridor one, a corridor adjustment factor (CAF) was used (Eq.7.5). The CAF is based on the historical trends of traffic growth in the corridor in question. In other words, the more crowded the corridor area in relation to the whole region, the higher is the CAF. In the SD model, this variable will also account for any event which could contribute to enhance the corridor traffic. This may include providing a link (constructing new roads and expanding network) connecting the toll facility to a non-toll route which is likely to feed into the facility or help divert traffic from a specific route to the route in concern. This kind of complementary facilities enhances the connectivity of the corridor within the system and could provide additional time saving leading to new traffic using the facility. CAF is exogenously estimated based on historical data and by using the formula;

$$CAF = \text{average corridor traffic growth rate} / \text{average regional traffic growth rate} \quad (\text{Eq.7.5})$$

In the SD model, corridor traffic growth rate function has then been mathematically modelled as following;

$$\text{Corridor Traffic growth rate} = \text{regional traffic growth rate} * CAF \quad (\text{Eq.7.6})$$

In addition, growth in the corridor traffic can occur due to the induced traffic resulted from introducing the facility. Since it is normal that building a new road will induce trips that would yet have to happen otherwise as discussed in chapter three, this factor was necessarily considered in the model.

The corridor traffic in the SD model was divided into three segments based on the trip purposes which are: commuting traffic, social traffic and business traffic. The reason behind this segmentation is the different traffic types have different behaviours toward using toll routes mainly due to their different value of time. By segmenting the traffic

by trip purpose, the model can incorporate some degree of value of time variation among different types of traffic. It can subsequently reflect the varied behaviour of traffic.

$$\text{Corridor traffic [traffic segmentation]} = \text{INTEG} (\text{corridor traffic growth [traffic segmentation]} - \text{users satisfaction flow [traffic segmentation]}, \text{initial traffic [traffic segmentation]}) \quad (\text{Eq. 7.7})$$

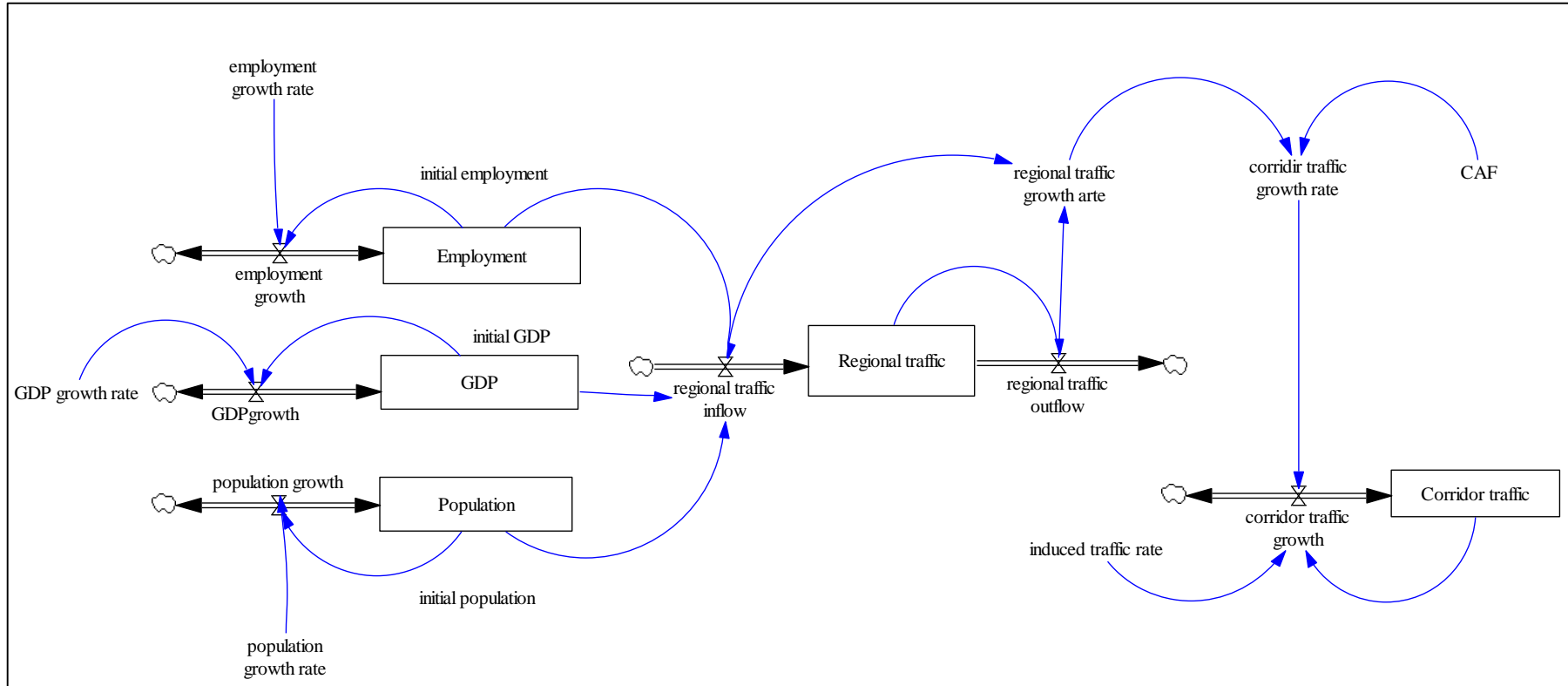


Figure 7.2: Socio-economic Sub-model

### 7.3.2. Public satisfaction sub-model

As discussed in chapter two and three, public outrage was the reason for low usage of several PPP projects. The more the satisfied people are, the higher the facility usage is. Public satisfaction sub-model assesses the level of public satisfaction and the satisfaction level is the key output of the sub-model. These satisfied motorists represent the potential users or the market from which the facility traffic materialises.

The proportion of the overall traffic in a travel corridor that potentially rides the facility depends on the level of public satisfaction with the facility in concern. In the demand model, the level of public satisfaction was modelled as a flow which has been referred to as “users satisfaction flow” as shown in Figure 7.3. There are two major factors affecting public satisfaction as represented by Eq.7.8, namely: 1) project location and environmental considerations and 2) public acceptance.

$$\text{Users satisfaction flow [traffic segmentation]} = \text{effect of project location and environmental consideration} * \text{public acceptance} * \text{Corridor traffic [traffic segmentation]} \quad (\text{Eq.7.8})$$

The effect of project location and the environmental consideration on the level of users’ satisfaction has been estimated based on the experts’ perceptions according to the method described in chapter five (Section 5.6.3). The project location and the environmental considerations variable is measured on a scale between 0 and 10 where 0 implies absence of any considerations and 10 implies full considerations were taken into account. On the other hand, the effect the project location and the environmental considerations on level of public satisfaction is measured also on a scale between 0 and 1, where 0 indicates to disastrous effect or none of the motorists is satisfied and 1 implies no effect or full satisfaction. The professional judgements helped to determine the value and shape best describing this qualitative relationship as shown in Eq. 7.9 and Figure 7.4.

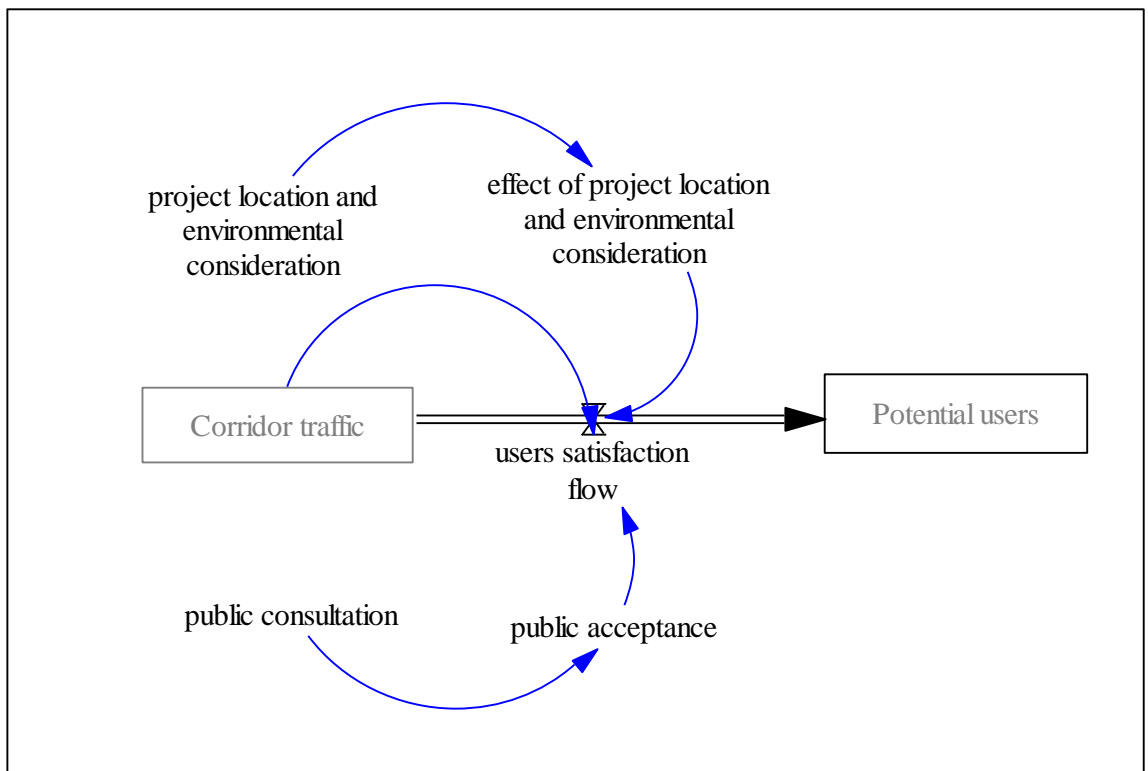


Figure 7.3: Public satisfaction sub-model

The interviews with experts in toll roads showed that minor consideration of the environmental impacts of the facility slightly impacts level of motorists’ satisfaction. Absence of the environmental consideration (referred to by 0) decreases the public satisfaction by only 10% where 90% of the public is still satisfied and willing to use the facility. The satisfied proportion of all the motorists in the corridor increases to 100% when all potential considerations are taken into account (referred to by 1).

$$\begin{aligned}
 & \text{effect of project location and} & \text{environmental} & \text{consideration} = \text{with lookup}(\text{project location} \\
 & \text{and} & & \text{and} & \text{consideration}) \\
 & ((0,0.9),(10,1) ) & & & \text{(Eq.7.9)}
 \end{aligned}$$

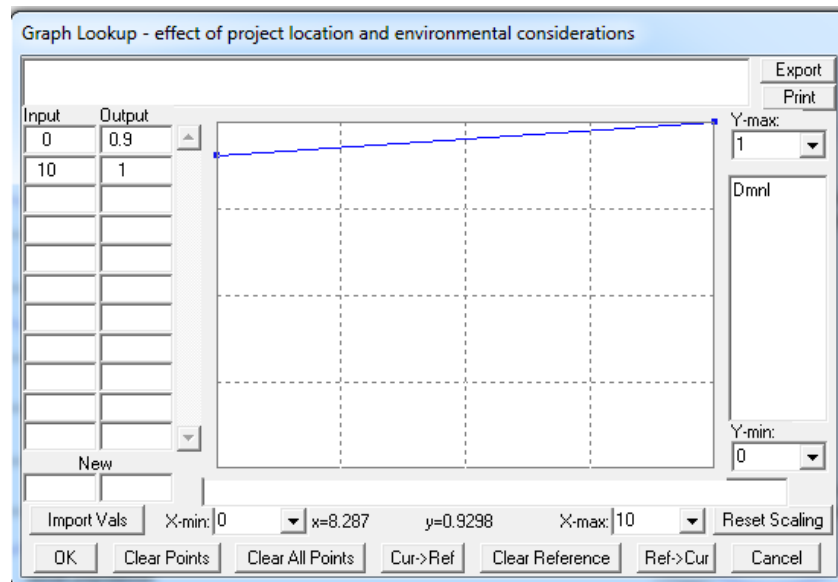


Figure 7.4: Effect of project Location and Environmental Consideration Lookup

Anti-toll attitude, especially in regions where toll facilities are new, is likely to lead to a negative reaction which may affect the facility usage. To eliminate public opposition against this kind of projects, consultation is highly recommended. The effect of public consultation for a proposed facility on the level of public acceptance has been determined by the transportation expert judgments too as follows in Eq.7.10;

$$\text{Public acceptance} = \text{with lookup (public consultation)} \\ ((0,0.9),(10,1)) \quad (\text{Eq.7.10})$$

The equation implies that absence of any kind of consultation decreases public acceptance and by only 10% and 90% of the motorists is still satisfied by the facility. Conversely, public consultation cancels any kind of dissatisfaction and 100% of the corridor motorist will potentially use the facility.

As shown in Figure 7.3, user satisfaction flow feeds into the potential users stock. The potential users stock constitutes the entity of users from which the facility traffic share will be derived.

### 7.3.3. WTP sub-model

WTP sub-model determines the toll share or the proportion of the facility users based on plethora of variables discussed below. The multiplication of toll share by potential users determines the number of the facility users.

Before discussing the WTP sub-model, it is important to introduce the types of users in terms of the used toll collection method because they have different values of WTP. As the volume of traffic increases the manual method of toll collection becomes inefficient. The need to stop for paying tolls interrupts the traffic flow on the highway and increases the subsequent risk of delays. To improve the toll collection, the majority of toll roads have turned to operate an electronic payment system known as “Electronic Toll Collection” (ETC) or “Tag”. The system works by users having a Tag attached to their windscreen. It includes a microchip that is automatically read by sensors fixed on the toll plaza which makes the toll barrier rises, and the motorist can proceed without delay. Thus, using this kind of ETC avoids the need of the motorists to stop and subsequently speeds their travel (larger time savings). In addition, to attract more motorists to use the system, ETC users usually receive a particular discount of toll rate above other users. For instance, the ETC users of Northwest Austin Turnpike Elements (USA) receive 10% discount in comparison to non-ETC users (Prozzi et al., 2009).

The availability of different types of toll collection methods and the discrepancy of input values for some variables such as travel time and toll rate between ETC and non-ETC users imposes the need to segregate the users of the facility in the model into ETC and non-ETC users (users who pay cash or by cards) as shown in Figure 7.5.

Evidence shows that motorists, both ETC and Non-ETC users, are responsive to fluctuations in the fuel price (Goodwin, 1992; Johansson and Schipper, 1997; de Jong and Gunn, 2001; Graham and Glaister, 2002; Mata and Raymond, 2003). The increase of fuel price may lead people to make corresponding adjustments to these higher prices by making fewer trips or converting to other kinds of transportation modes. This effect of fuel prices on users’ behaviour implies that traffic flows in road lanes decrease when fuel prices increase which is known as traffic elasticity to fuel price.



Given the potential effect of change of fuel prices on traffic flow, it was essential to consider the elasticity impacts of traffic levels with respect to fuel prices in the SD model as shown on Figure 7.4. The proposed model represents the change in traffic resulting from fuel price changes by a flow between ETC demand and non-ETC demand stocks and the potential users' stock asset as shown in Figure 7.5.

There are several methods to calculate elasticities. The simplest form of these methods is called the "shrinkage factor". The shrinkage factor is a simple linear function and is defined as the percentage change in demand caused by a percentage change in price relative to the original demand and price. While this method is simple and easy to use, it is only accurate for relatively small changes in price. A more accurate method is the "arc elasticity". The arc elasticity reflects the change in demand resulting from each 1% change in price. The price change, thus, encompasses several accumulated changes (Pratt, 2003). Because of its accuracy, the latter method has been used to measure change in demand resulting from change fuel price. The formula for arc elasticity is an exponential function of fuel price elasticity and the amount of change in fuel price as shown by Eq.7.11

$$\text{Effect of FP on demand} = 1 - [(1 + \text{change in fuel price})^{\text{demand elasticity to FP}}] \quad (\text{Eq.7.11})$$

Evidence shows that the ETC users' proportion relative to overall toll transactions is most likely to grow over time as motorists transfer from paying cash or by card into using Tag. For instance, the number of ETC transactions in 407 ETR (USA) has increased from 300,000 in 1999 to 857,000 in 2007 (Prozzi, 2009), which implies a considerable growth in ETC usage level. The estimation of ETC flow (or as known ETC market share) is typically based on a review of ETC usage at other toll facilities operating in similar conditions. ETC market shares over years are interpolated. SD model reflects this phenomenon by assuming gradual increase in ETC usage over the road's lifecycle. The change has been modelled as a flow from non-ETC users stock to ETC users stock as shown in Figure 7.5 and Eq.7.12.

$$\text{ETC growth [traffic segmentation]} = (\text{"Non-ETC Demand"}[\text{traffic segmentation}]) * \text{ETC users growth rate} \quad (\text{Eq. 7.12})$$

As discussed above, ETC users enjoy more time saving and pay less. The discrepancy of input values for some variables such as travel time and toll rate between ETC and non-ETC users impose the need to include two WTP sub-models. The first one concerns the ETC users (Figure 7.6) and the second concerns the non-ETC users (Figure 7.7). Since these two sub-models are identical except in their input values and some minor aspects, the following section describes only one of these sub-models (ETC users) with an appropriate reference to any difference between the two sub-models when necessary.

Toll share, the ultimate outcomes of WTP sub-model, constitutes the rate of users potentially diverted to use the facility in concern. To determine the proportion of traffic that is likely to ride the toll route, the benefit of using the facility needs to be estimated. This is mainly achieved by comparing the benefits gained from using the facility to other available alternatives. Toll share is, therefore, the result of the interactions between the competitive aspects from other alternative facilities. For example, when the private operator increases the toll rate, a portion of traffic will divert to a free-toll road or any cheaper available alternative. However, because the low level of service typically provided by the free-toll road and the time savings offered by the toll road facility, the traffic level on the toll road could be recovered again. The proposed SD model considers toll share as a function of WTP and other factor describing historical behavioural and public involvement in ongoing facility management influences as defined by equation 7.13 below. The following sub-sections will discuss these factors.

$$ETC \text{ user toll share [traffic segmentation]} = WTP \text{ effect of ETC user [traffic segmentation]} * \text{effect of historical experience of paying [traffic segmentation]} * \text{effect of public involvement [traffic segmentation]} \quad (\text{Eq. 7.13})$$

#### *7.3.3.1.WTP effect*

The effect of WTP on toll share is a nonlinear function. This function has been determined based on the professional judgement in the way discussed in chapter five and algebraically expressed as in Eq.7.14:

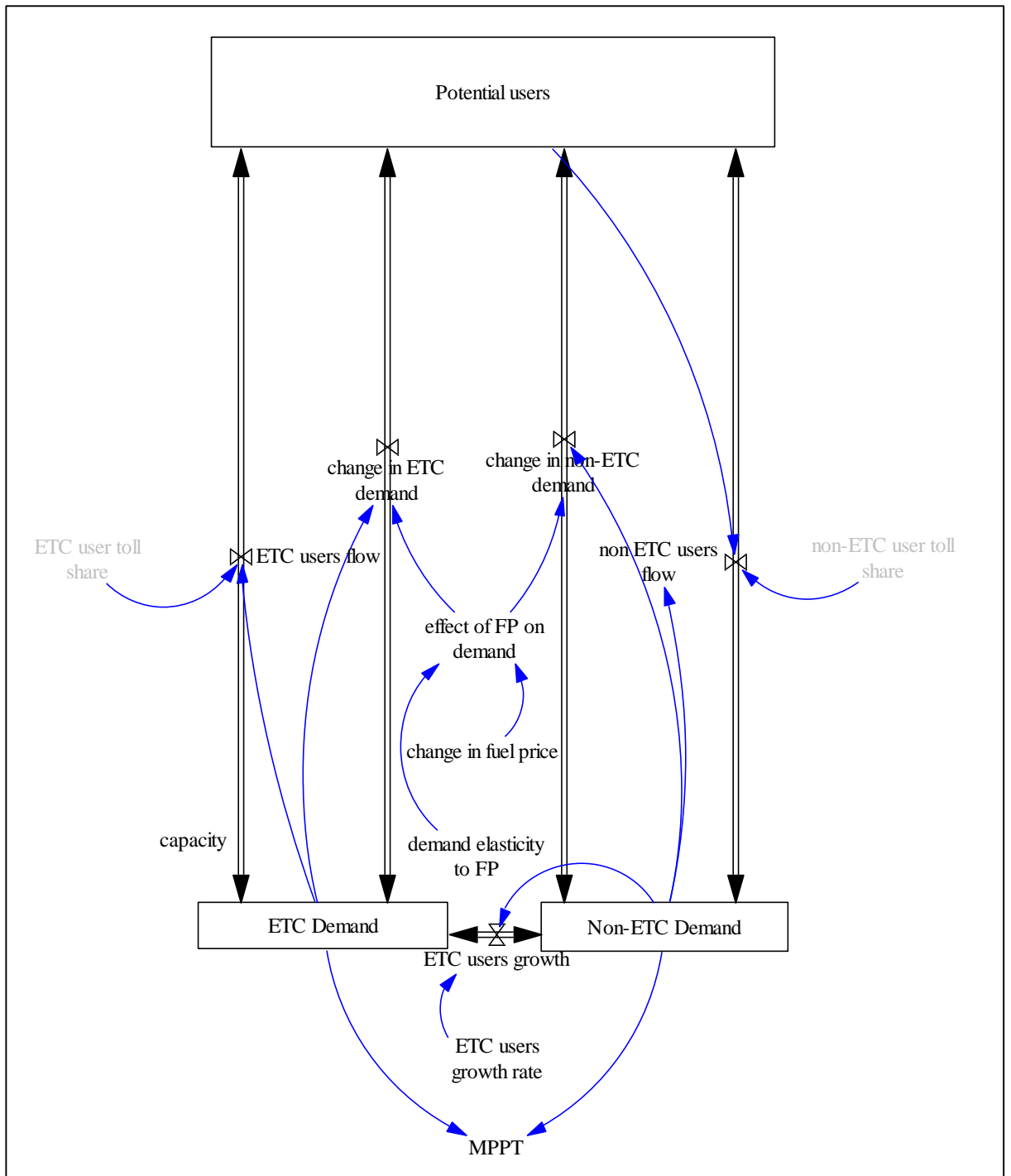


Figure 7.5: Division of Toll Facility Users based on Toll Collection Method

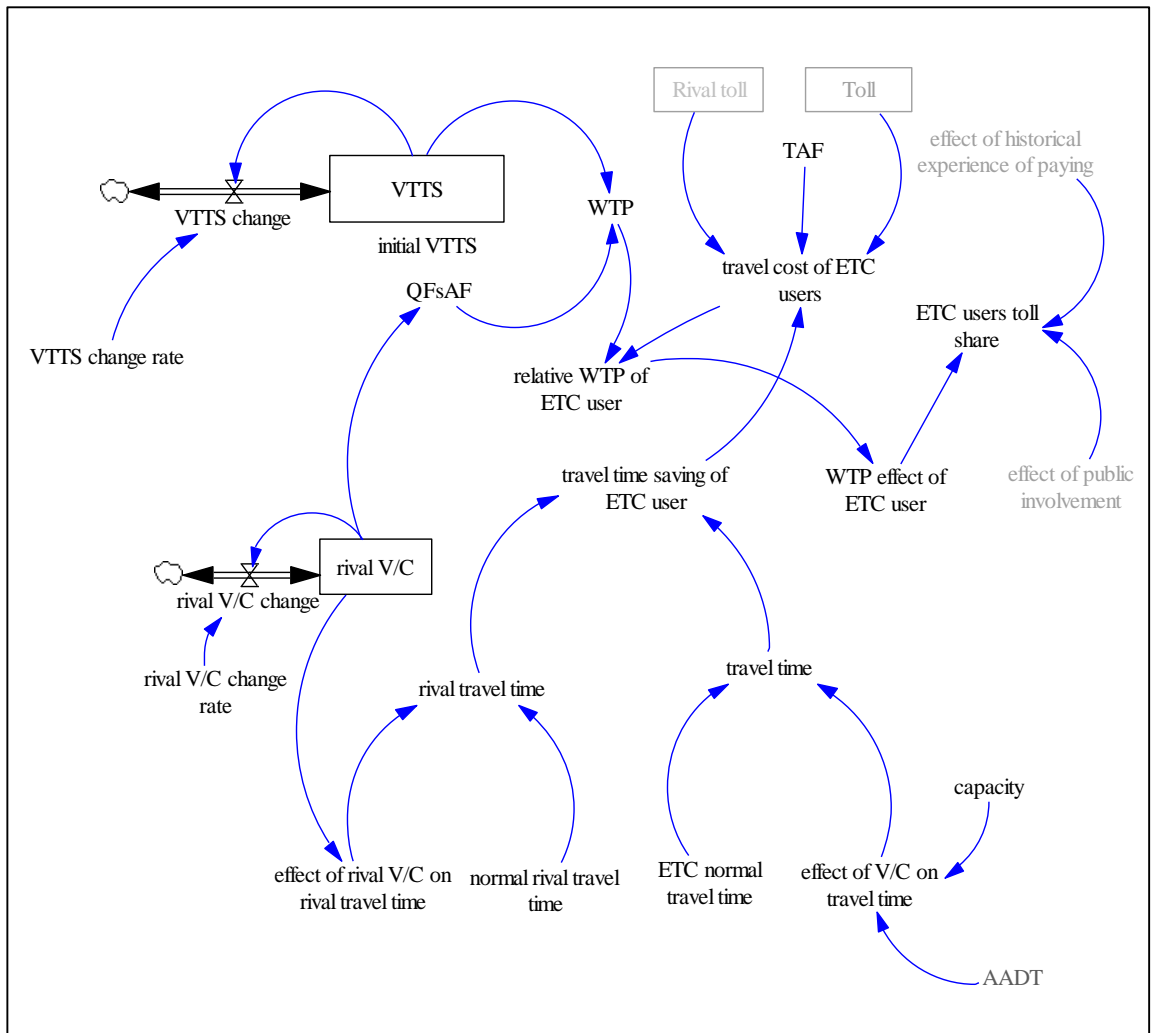


Figure 7.6: WTP Sub-Model for ETC Users

$$WTP \text{ effect for ETC users [traffic segmentation]} = WITH \text{ LOOKUP (relative WTP of ETC users [traffic segmentation])} \quad (\text{Eq. 7.14})$$

### Relative WTP

Travel time savings are the driver for the decision to ride on the toll route rather than a competing route. Value of Travel Time Saving (VTTS) reflects what the user is really willing to pay for saved time. Traditional transport facility evaluation models usually use a simple WTP which places emphasis on VTTS only ignoring other qualitative factors such as reliability. WTP necessarily needs to account for qualitative factors which can change project evaluation results. The SD model accounts for this kind of qualitative travel conditions by allowing for VTTS to fluctuate by a suitable percentage (Qualitative Factors Adjustment Factor (QFsAF)) producing altogether a WTP value.

The value of this factor has been determined based on travel conditions on the rival route. Volume to capacity ratio (V/C) has been taken as a proxy for the route conditions.

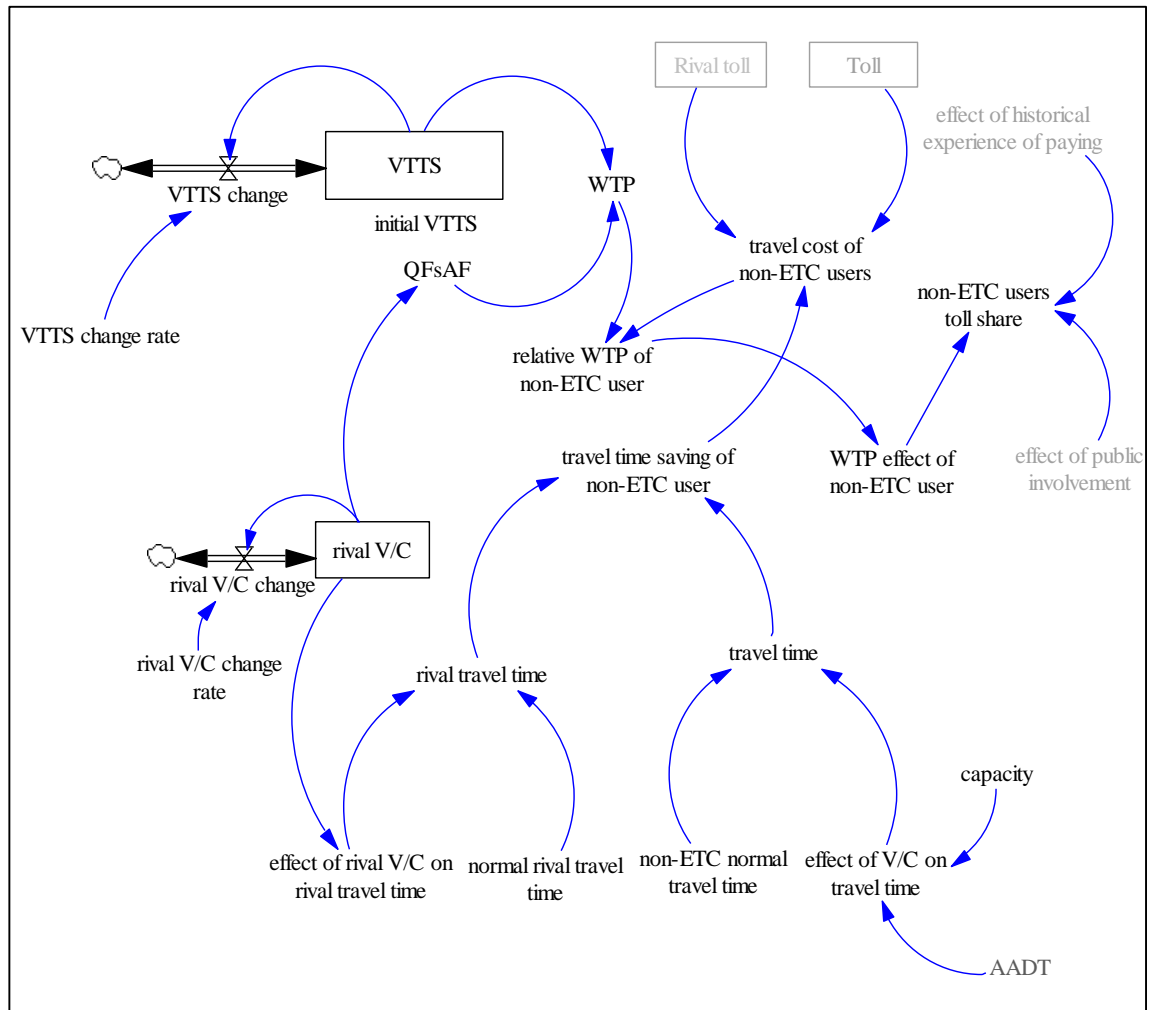


Figure 7.7: WTP Sub-Model for Non-ETC users

For example for high Level Of Service (A-C) on the competing route (rival V/C <0.5), QFsAF is equal to 1 and for lower level of service (D) (rival V/C >.85), the QFsAF=2 (Victoria Transport Policy Institute, 2009).

$$WTP [traffic segmentation] = VTTS [traffic segmentation] * QFsAF \quad (Eq.7.15)$$

$$QFsAF = f(rival V/C) \quad (Eq.7.16)$$

The interaction among the variables WTP and toll is the major determinant of toll share and is referred to in the SD model as relative WTP. Relative WTP is formulated as follows;

$$\text{Relative WTP for ETC users [traffic segmentation]} = \frac{\text{WTP [traffic segmentation]}}{\text{travel cost for ETC users}} \quad (\text{Eq. 7.17})$$

$$\text{Relative WTP for non-ETC users [traffic segmentation]} = \frac{\text{WTP [traffic segmentation]}}{\text{travel cost for non-ETC users}} \quad (\text{Eq. 7.18})$$

Where;

$$\text{Travel cost for ETC users} = (\text{TAF} * \text{Toll} - \text{Rival toll}) / \text{travel time saving of ETC user} \quad (\text{Eq.7.19})$$

$$\text{Travel cost for non-ETC users} = (\text{Toll} - \text{rival toll}) / \text{travel time saving of non-ETC users} \quad (\text{Eq.7.20})$$

As mentioned above ETC user is usually subject to discounted toll. Toll Adjustment Factor (TAF) in Eq. 7.19 is used to accounts for this discount.

The toll for using the facility presented on the right hand side of Eq. 7.19 and Eq.7.20 is often estimated based on the project cost side and its determinants are outside the model boundaries. Toll will be discussed in more detail in the toll sub-model section. Rival toll on the other hand is the toll for using the competing facility and it is an exogenous variable too. It is important to note that most of the competing facility in the real world is free, therefore in most cases the value of rival toll equals to zero.

*Travel time saving*

Travel time saving refers to the difference between the estimated typical travel time on the toll route and the other alternative as shown in Eq.7.21 and Eq.7.22;

$$\text{ETC users travel time saving} = \text{rival travel time} - \text{ETC users travel time} \quad (\text{Eq.7.21})$$

$$\text{Non-ETC users travel time saving} = \text{rival travel time} - \text{non-ETC users travel time} \quad (\text{Eq.7.22})$$

As time saving is a function of the traffic level on the roads, this value needs to be revised repeatedly over time to reflect the change in traffic conditions on roads over time. Travel time saving is influenced with the level of service on the two routes. Therefore, a measure of level of service was included to express the change in congestion over time. Volume to capacity ratio (V/C) has been taken as a proxy for level of service since travel time on a road heavily relies on traffic congestion. The relationship between travel time and congestion allows the model to respond to the increase in travel time as a result of increasing in the traffic level and congestion. Based on Rijn (2004) and on Harwood et al. (1999), V/C was initialised on a quantitative scale between 0.35 (high level of service) and 1 (low level of service). This effect of V/C (and rival V/C) on travel time is a nonlinear relationship which has been sketched as a graph shown in Figure 7.8 that was validated also by professional judgements as shown in Eq.7.23 and Eq.7.24:

$$\text{Effect of V/C on travel time} = \text{with lookup (V/C)} \quad (\text{Eq.7.23})$$

$$\text{Effect of rival (V/C) on rival travel time} = \text{with lookup (rival V/C)} \quad (\text{Eq.7.24})$$

Integrating this factor in the model will reflect the effect of improvements to alternate highway in the facility area on diverting the traffic away from the toll facility. Rival V/C also reflects any temporary road works and maintenance which may increase V/C ratio on the road due to smaller capacity.

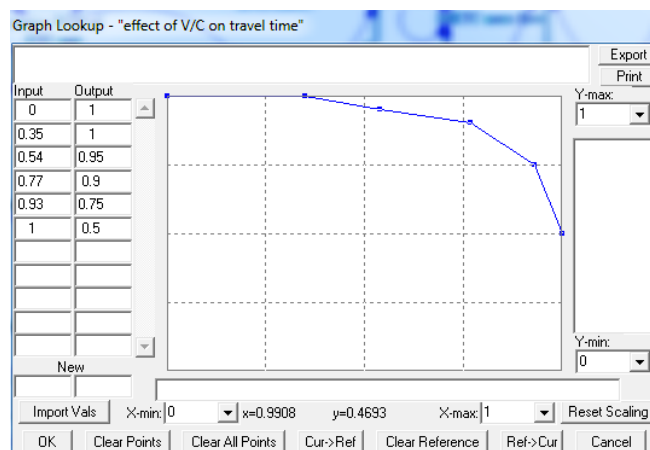


Figure 7.8: Effect of V/C on Travel Time Lookup

### *7.3.3.2. Effect of historical experience of paying and public involvement*

As shown in Eq. 7.12, the effect of historical experience of paying for toll road facilities on user behaviour has been considered for estimating toll share. When there are no traditions of paying for such public infrastructure, the introduction of toll facility could be faced by reluctance of the assumed users which would negatively affect demand. In such cases, the historical experience of paying is limited so the model should reflect the initial absence of this experience which can gradually increase reflecting the positive perception toward the benefits gained (e.g. time savings) from using the facility. Based on the discussion with the experts, it was suggested to measure the effect of historical experience on a scale between 0.7 and 1. It was agreed that in the case where users have previous experience with toll road then the effect will be equal to 1 (i.e there is no effect on toll share). However, in the opposite case (when users have no previous experience), the effect will gradually increase from 0.7 in the first year of operation to 1 in the fourth year according to the experts perceptions.

Similarly, the public involvement effect on toll share has been estimated based on the expert judgments. A value of 0.7 indicates absence of any public involvement in the ongoing facility management while value of 1 indicates a satisfied level of public involvement.

### **7.3.4. Toll sub-model**

Toll rate for using the facility over time is the ultimate output of toll sub-model. Toll will feed into the WTP sub-model as one significant determinant of user's WTP.

Demand is sensitive to change in toll rate. For most toll roads, toll rate is adjusted annually in accordance with an indexation or acceleration formula. The Retail Price Index or Consumer Price index which reflects inflation is usually a main part of this formula. Contrary, some facilities may have their tolls cut in accordance with deflation. Some concessions give the private operator the right to set and alter the tolls across the project duration. Others, however, may include a clause that provides governmental consent of toll increases or compensation arrangements in form of subsidies if that



authorization is withheld. Especially, when toll increases face a strong public outcry as occurred in the 25 April Bridge (Portugal) which led to only minor increase in the level of toll (Lemos et al., 2004). This kind of compensation is not always received by the operators immediately. Sort of delay is, therefore, expected. Moreover, toll hiking could occur due to higher than predicted operation and maintenance (O&M) cost which results from high traffic flowing on the road. Based on these factors, toll change can be determined.

For the proposed model, toll itself was modelled as a stock accumulating from toll change flow and was mathematically expressed Eq.7.25;

$$Toll = INTEG (toll\ change, initial\ toll) \quad (Eq.7.25)$$

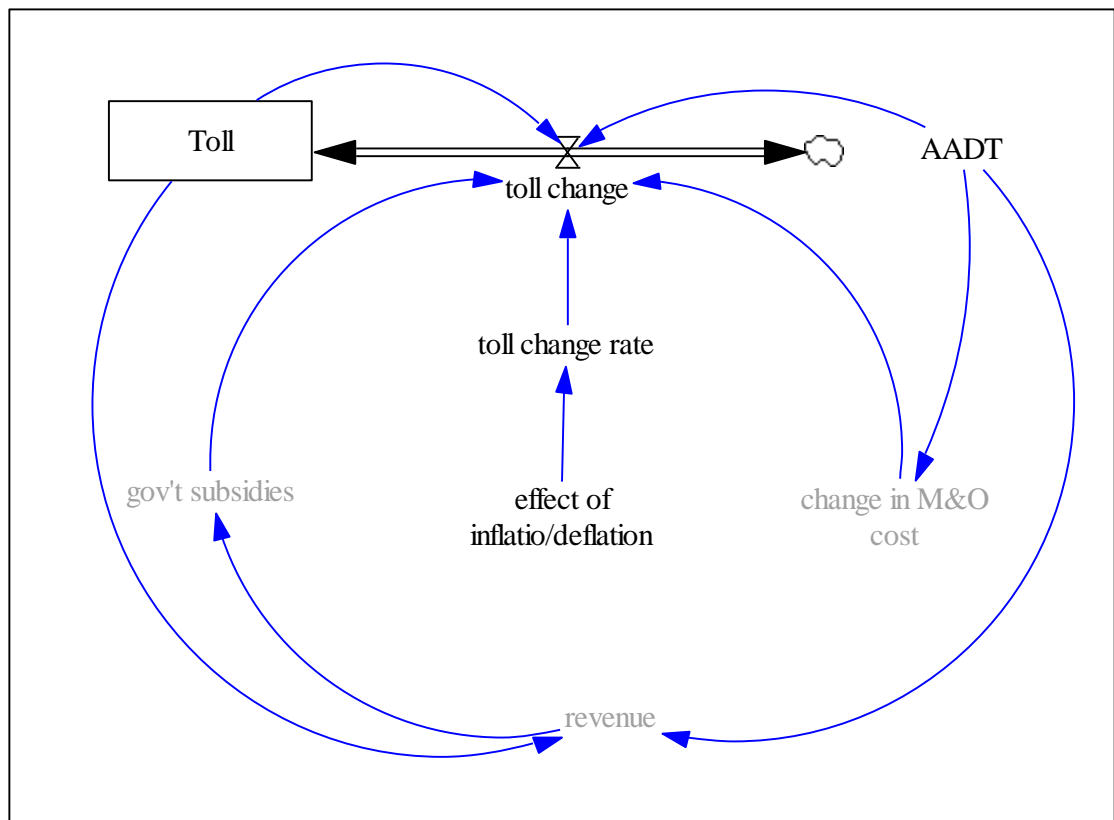


Figure 7.9: Toll Sub-model

### 7.3.5. Expansion Factors Sub-model

Weekday expansion and annualisation factors are the key outputs of expansion factors sub-model. Both factors will be used to convert peak period traffic to annual figures.

As discussed in chapter three, a typical travel demand model usually focuses on predicting weekday peak hour or peak period travel estimate as a basis for traffic forecast. However, these estimates are then expanded to produce forecasts of Average Weekday Traffic (AWT), Annual Traffic (AT) and Average Annual Daily Traffic (AADT). Therefore, appropriate factors which convert or expand peak period estimates into daily and annually estimates need to be developed and then applied. The typical method to develop those factors is traffic trend observations as discussed in chapter three.

There are two main types of expansion factors; first type is the weekday expansion factor which converts the weekday Morning Peak Period Traffic (MPPT) to Average Weekday Traffic (AWT). This factor considers the relationship between the morning peak period and traffic at other times of the day. The second type is a factor which converts average weekday traffic into annual or annualisation factor. Since the level of traffic on weekends and special holidays varies from that on the week days, this factor needs importantly to account for this difference in the expected traffic level of weekends and holidays.

Since both previous factors account for the variability in traffic, they are not constant. They change over time following the change in traffic behaviour. In the proposed model, those two factors were modelled as stock accumulating over time as a result of certain growth rate as shown by Eq.7.26 and Eq.7.27.

$$\text{Weekday expansion factor} = \text{INTEG} (\text{weekday expansion factor change, initial Weekday expansion factor})$$

(Eq.7.26)

$$\text{Annualisation factor} = \text{INTEG} (\text{annualisation factor change, initial annualisation factor})$$

(Eq.7.27)

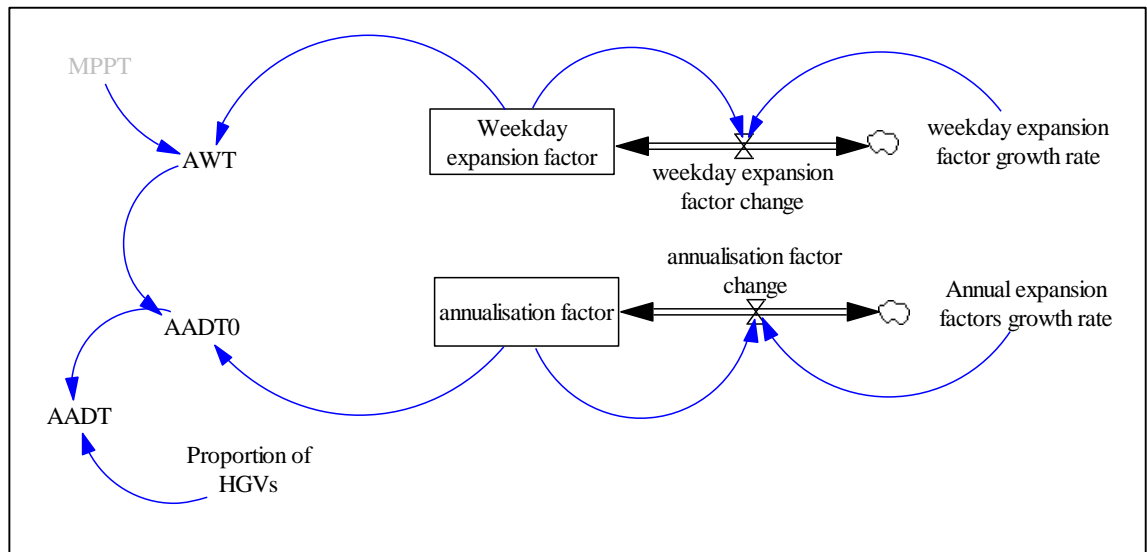


Figure 7.10: Expansion Factors sub-model

AWT and Annual Average Daily Traffic were then estimated using the following functions;

$$AWT = MPPT * \text{Weekday expansion factor} \quad (\text{Eq.7.28})$$

It is important to indicate that AWT in the SD model accounts for passenger car only. HGVs traffic has different peak period from that of passenger cars. Since the truck peak hour do not coincide with that of cars, it is difficult to use the same model to estimate HGVs usage. The common way to include trucks is to factor the personal vehicle according to the observed traffic mix (Kriger et al., 2006). Thus the Annual Average daily Traffic for passenger cars only (AADT0) was first calculated as in Eq. 7.29:

$$AADT0 = AWT * \text{annualisation factor} / 365 \quad (\text{Eq.7.29})$$

HGVs were then factored of AADT0 to find out the AADT as in Eq. 7.30:

$$AADT = AADT0 * (1 + \text{HGVs proportion}) \quad (\text{Eq.7.30})$$

### 7.3.6. Competition Sub-model

The aim of this sub-model is to account for any new facility or improvement to an existing one. The effect of the construction and/or improvement on the level of congestion in the facility corridor is the key output of this sub-model. The effect will be reflected in rival V/C ratio, one of the drivers of WTP.

One of the most influential factors on demand is the construction of new alternative that did not originally exist or improvement to an existing one. Building new road project in the corridor should be taken into account because demand traffic on toll routes is affected by new entrants to the market which may cause diverting traffic away from the tolled road.

When users experience an increase in the level of congestion as a result of increasing traffic in the travel corridor which exceeds the amount of available capacity, there is a growing pressure on the government to reduce congestion. This pressure may finally lead to a road construction or expansion which, after a time delay of several years, results in more capacity. However, in case of toll road, this issue is not straightforward. Free market entry causes a nominal profit for concessionaire. Thus, to protect the profit level, the concessionaires usually seek a kind of protection shell by introducing a contract condition that restrains new competitors from entering the market. Non-compete clause is the most common form of these conditions which inhibits accessing the infrastructure market in facility corridor. Thus, to invest in a new road, two conditions need to be available, presence of high congestion level in the travel corridor and absence of non-compete clause which allows the entrance to the infrastructure market, as the Eq.7.31 suggests;

$$\text{Investment} = \text{DELAY (need to decrease congestion, 5)*access to infrastructure market} \quad (\text{Eq.7.31})$$

The right hand side of Eq.7.31 indicates to the presence of delay in the action to reduce level of congestion. Due to funding constraints, decision makers' response to decrease congestion may not occur instantly and the construction of the new facility takes time. The existence of delay in making decision to decrease congestion as well as the time

required for the facility construction does not allow the direct increase in the competing capacity, thus delay of average 5 years was built in Eq.7.31.

The first part of the right hand side of Eq.7.31 represents the first condition related to the level of congestion in the corridor and is given by Eq.7.32.

Equation 7.32 implies that when the overall traffic in the travel corridor exceeds the amount of the available capacity, the policy maker needs to expand the system to accommodate this traffic. Thus, to precede with the investment or improvement, the V/C ratio on both the toll road and any other available competing road needs to be higher than a particular threshold determined by the policy makers.

$$\text{need to decrease congestion} = \text{IF THEN ELSE}(\text{"V/C"} \geq \text{congestion threshold} : \text{AND: "rival V/C"} \geq \text{threshold 0}) \quad (\text{Eq.7.32})$$

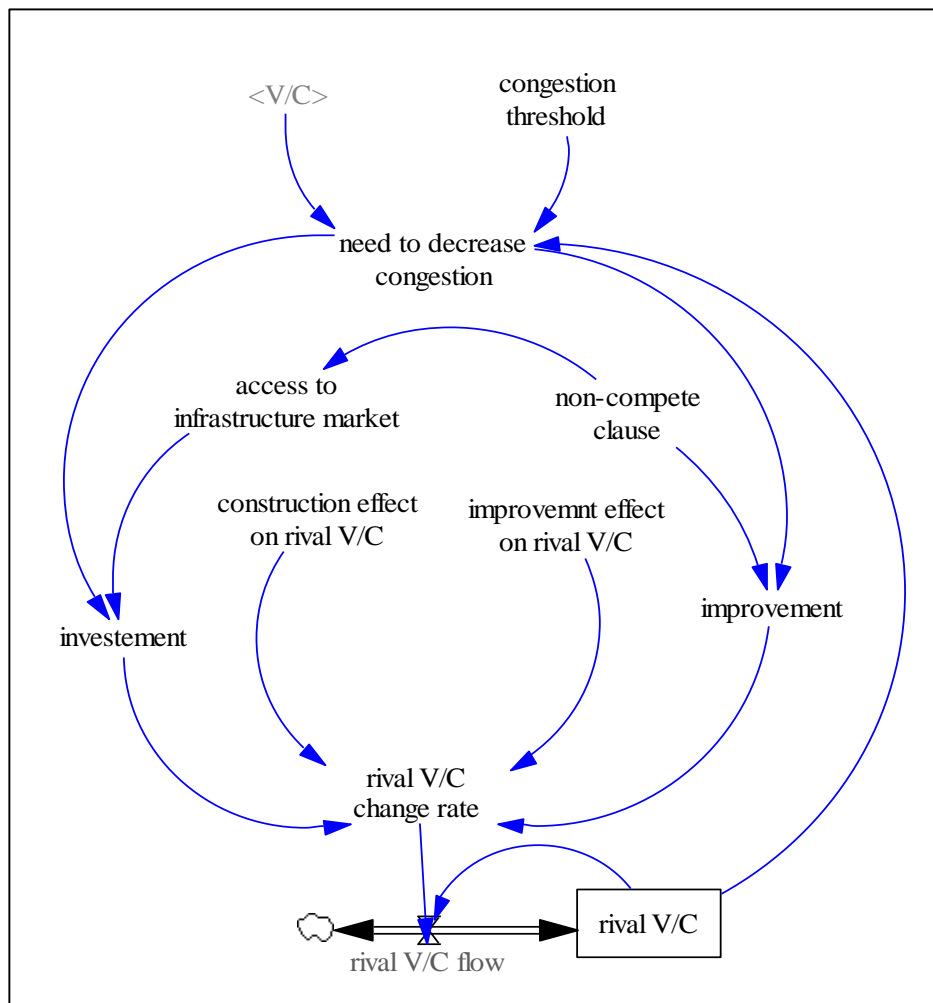


Figure 7.11: Competition Sub- Model

The second condition is expressed in the Eq.7.33. In Eq.7.33, “non-compete clause”=1 indicates to presence the contract condition which prohibits the access to the infrastructure market. In this case, the access to infrastructure market is expressed as “access to infrastructure market”=0. Otherwise, when the access is allowed (indicated as “access to infrastructure market” =1), new facility may be built if the first condition is met. In this case, the corridor capacity is expanded, congestion and rival V/C is amended which is likely to affect the toll share of the facility and level of traffic on the tolled facility.

$$\text{access to infrastructure market} = \text{IF THEN ELSE}(\text{"non-compete clause"}=1, 0, 1)$$

(Eq.7.33)

#### **7.4. Summary**

This chapter outlined the development of the simulation model. It started by providing an overview of the general model structure including the model boundaries and sub-models. The chapter postulated the variables to be included in the simulation model and the nature of the relationships among them. It presented the development of SFDs which forms the basis of the simulation model. It finally detailed the formulation process of the model relationships based on the literature and qualitative information extracted from experts and by using the formulation techniques readily available in the software used for simulation “Vensim”. The model is functioned by estimating numerical values for the constant (exogenous) variables and using these input values to generate outputs, as it will be illustrated in the next chapter.

## **Chapter Eight: Model Simulation (The Case of M6 Toll Road)**

### **8.1. Introduction**

As discussed in the previous chapter, the aim of the simulation model is to assess how the change in the demand risk factors would change demand behaviour over time. This chapter depicts how the developed SD model, can be applied on a specific case study. The objective of the application is to show how the model can provide an estimation of the demand for the facility over its lifecycle. The model uses data from M6 Toll road in the north east of the West Midlands conurbation (UK). The chapter will first examine the development background of the road including planning, construction and operation aspects. The value of the model variables required to perform the simulation will be then identified. The simulation results are presented at the end of this chapter.

### **8.2. Project Profile**

This section discusses some significant aspects of the facility in relation to planning, construction and operation.

#### **8.2.1. Planning and Construction**

The M6 through the west midland conurbation is one of the major roads in the UK and one of the busiest. The road, known as the backbone of Britain, is a north-south motorway connecting M1 at J19 in Rugby to Carlisle at the A74 (M) (HA, 2013). M6 motorway is considered one of the most congested roads in the Western Europe (World Bank and PPIAF, 2009). It carries up to 170,000 vehicles a day with peak journey times estimated at up to 71 minutes for a 23 minute journey by November 2003 (Ellis and Caceres, 2011). To relieve congestion on M6, proposals for a new publicly funded motorway was put for consultation in 1985 and the preferred route was announced by DfT in March 1986 (HA, 2009). However, publicly funded road had been a mere

proposal for several years. After issuing the Green Paper “New roads by new means” which allows private funding and operating of roads and using toll to compensate the concessionaire in 1989, the government decided to offer the road as a privately financed scheme in the same year. Three consortia presented their bids to the concession. Midland Expressway Ltd (MEL) (itself owned by Macquarie Atlas Roads) won the competition, and the concession was signed in 1992.

The Design, Build, Finance, Operate (DBFO) concession agreement establishes the private company obligations. Midland Expressway Ltd (MEL) must build and finance the road without recourse to government fund or guarantees. The concession period is 53 years, encompassing 3 years of construction and 50 year of operation. The concession gives MEL the right to run the toll road and collect toll revenue from the road for 50 years until 2054 in return for operating and maintaining it.

M6 toll road went through the normal highway process in the UK including consultation, publication of draft orders, receiving objections and a public inquiry. In June 1993, MEL, the M6 toll concessionaire, published the route draft proposal, environmental statement and concession statement. Public views were then invited. By April 1994, over 7,800 objections were received (DfT, 1994). A wide range of local resident groups, action groups, local and national industrial and commercial bodies expressed their objection to the project. A public enquiry was held between June 1994 and October 1995 to become the longest public inquiry into a road scheme in the UK. Friends of Earth (2003) reported that the consultation process into M6 toll road scheme brought over 10,000 objection letters and the resulting public inquiry was the longest ever the UK has seen. However, a go-ahead for the project was issued in 1997. After an elongated process to secure land acquisition, the project reached financial close in 2000 with a £685 million (Ellis and Caceres, 2011).

A consortium of major contractors including Carillion, Alfred McAlpine, Balfour Beatty and AMEC (together known as CAMBBA) won the contract to design and build the road in 2000 and earth work started in 2001. The M6 toll road cost around £485 million to build, and the total project cost reached about £980 million. A debt financing of £685 was provided by a group of commercial banks and institutional lenders. The rest of the total cost was put as equity by the consortium. M6 toll ultimately opened in



December 2003 as the first privately financed tolled motorway in the UK (except major bridges and tunnels). A structure of the M6 toll road concession is shown in Figure 8.1.

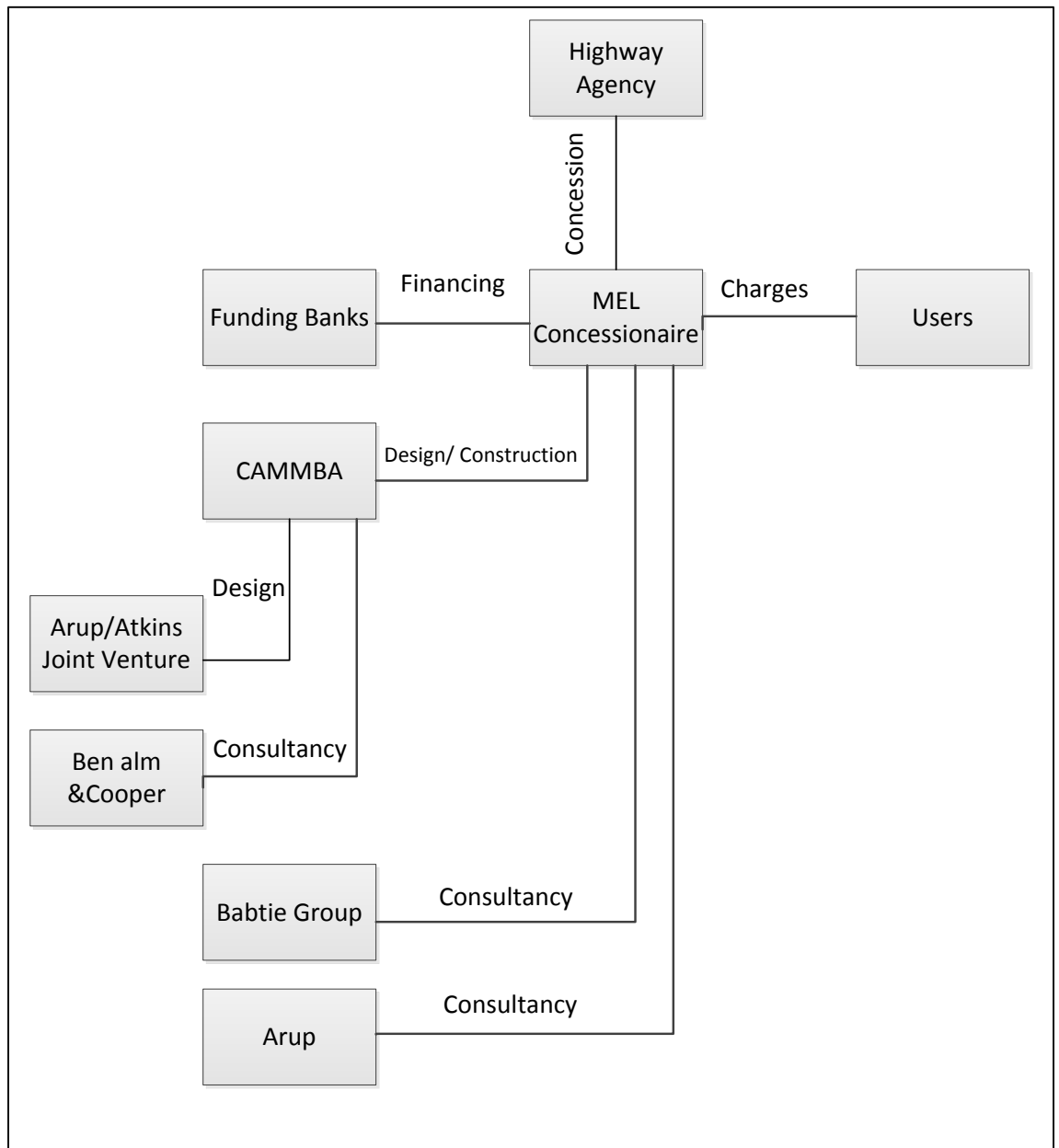


Figure 8.1: M6 Toll Concession Structure

The M6 Toll, also known as the Birmingham North Relief Road (BBNR), is a 27-mile (43 Km) long dual three-lane route with a design capacity of 100,000 cars a day through the West Midlands conurbation and its location in a national context is shown in Figure 8.2. The road which runs to the north east of Birmingham was proposed to provide an alternative to the most congested part of M6 linking junction 11a of the M6

near Cannock, to Junction 3a at Coleshill. M6 toll runs close to and in parallel of other routes such as A5, A38 and A446.



Figure 8.2: Location of the M6 Toll Motorway within England  
Source: (HA, 2009)

Users can join the toll facility at the south end, at either junction 3a of the M6 or just prior to junction 9 from the M42. At the north end, they can join at junction 11a of the M6. Motorists can also access and exit the M6 Toll at various points along the route. There are 8 junctions (known as tolls), and one Motorway Service Area (MSA) situated at Norton Canes (HA, 2009) as illustrated in Figure 8.3.

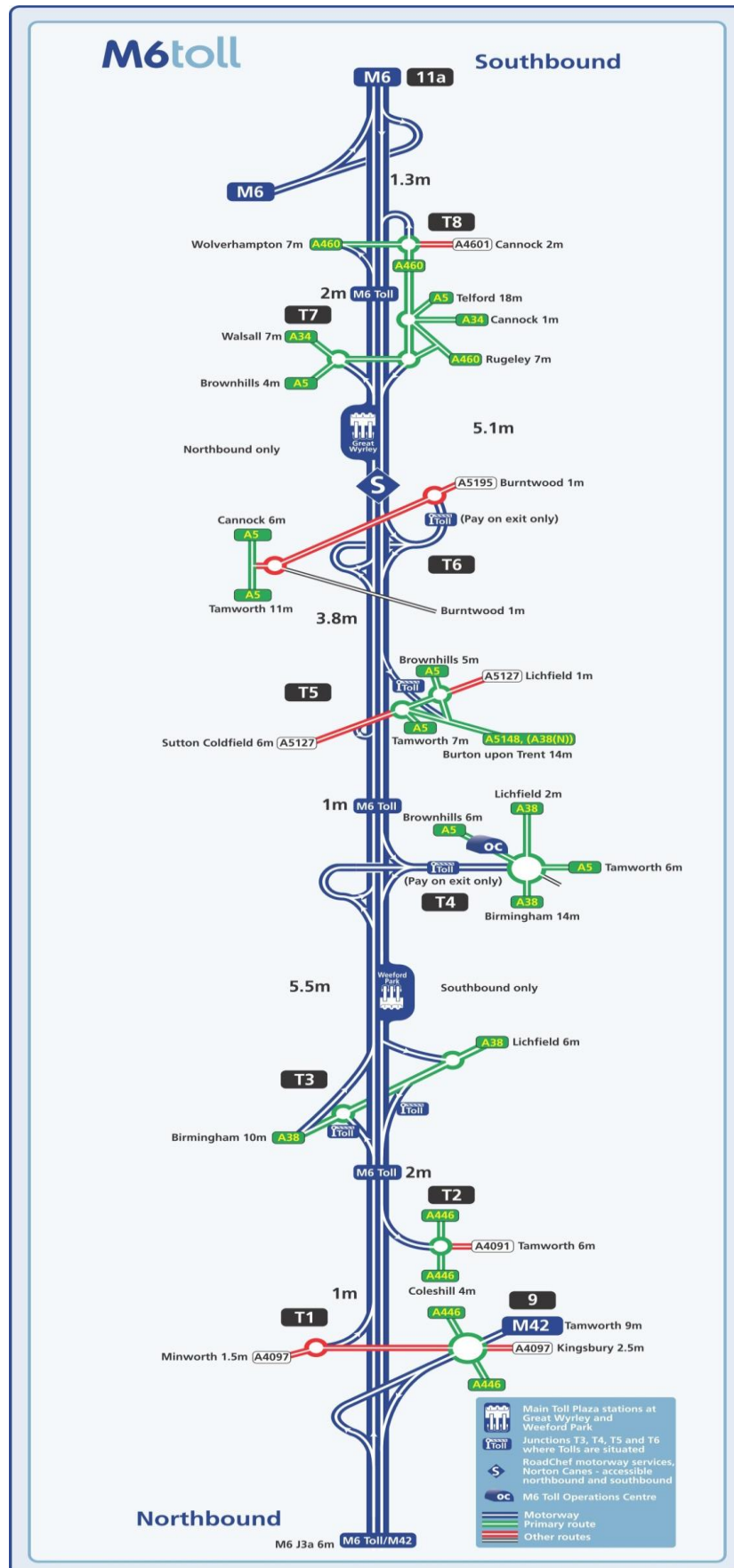


Figure 8.3: Tube Style Map of M6 Toll road  
 Source: www.m6toll.co.uk

## 8.2.2. Operation

The operation of M6 toll road was examined in the following aspects;

- 1) Toll policy, toll rate and adjustment mechanism
- 2) Toll collection methods
- 3) Traffic and financial performance

### *1) Tolls Policy, toll rate and adjustment mechanism*

At the aim of attracting users, MEL developed its proposals on the basis of providing the level of service for which users would be most prepared to pay (DfTb, 1994). The concession terms give MEL the right to set and alter the tolls overall the project duration in response to the market conditions. A summary of the actual toll rate by vehicle classification and year of operation is shown in Table 8.1.

Table 8.1: Summary of M6 Toll Pricing

Date introduced	Mon-Fri (06:00-23:00) (Standard Charge)		Night (23:00-06:00)		Sat-Sun (06:00-23:00)	
	Car	Lorries, coaches, large Vans	Car	Lorries, coaches, large Vans	Car	Lorries, coaches, large Vans
2004	£3.00	£6.00	-	-	-	-
2005	£3.50	£7.00	-	-	-	-
2007	£4.00	£8.00	-	-	-	-
2008	£4.50	£9.00	£3.50	£8.00	-	-
2009	£4.70	£9.40	£3.50	£8.00	£4.50	£9.00
2010	£5.00	£10.00	£3.50	£8.00	£4.50	£9.00
2011	£5.30	£10.60	£3.80	£8.60	£4.80	£9.60
2012	£5.50	£11.00	£3.80	£8.60	£4.80	£9.60
2013	£5.50	£11.00	£3.80	£8.60	£4.80	£9.60

Source: compiled from (HA, 2005, HA, 2009, M6 Toll website, OMEGA, 2009)

The M6 toll, as most of the tolled facilities, charges different tolls according to the type of vehicles. From 2004 to 2009 MEL adopted a regular toll rate for the whole day where motorists were charged the same toll rate for peak and off-peak (overnight and weekends) periods. During the last four years, MEL adopted different toll rate schedule

where a discounted toll rate was set for off-peak period as shown in Table 8.1. However, since the traffic is running fairly freely during these periods on non-tolled M6 road, the modest toll discount for overnight and weekend use does not seem to offer an incentive to use the M6 Toll link.

As for Heavy Goods Vehicles (HGVs), since the outset of the operation stage, heavy goods operators showed unwillingness to pay the levied £10. The HGVs toll was, therefore, reduced to £6 in June 2004, six months after the project opening (Ellis and Caceres, 2011). Since then, HGVs pay approximately two times higher tolls than cars. The chief executive of the west midlands Passenger Transport Authority (Centro) considers the trucks toll so expensive and it is putting off drivers of riding M6 toll link (Calder, 2013).

Between 2004 and 2013, MEL imposed several toll adjustments. The standard day tariff was increased in 2005 to £3.50 for cars and £7 for HGVs. The current toll for cars (£5.5) and HGVs (£11) has increased by 83% from the 2004's tolls of £3 and £6 respectively. Each adjustment involved an increase in toll between £0.2 and £0.5 for cars and £0.4 and £1 for HGVs.

Unfortunately, there is no data available with respect to the toll rate that was initially used to forecast traffic in the planning stage. MEL maintained many of the key sections of the concession agreement confidential and data pertinent to the initial toll adjustment mechanism are not available. It is not obvious whether MEL had in its bid an original toll policy which is different from that applied.

The UK's first pay-to-use motorway, M6 Toll, is proving drivers unwillingness to pay. A survey by the Commercial Motor/Michelin Business Monitor in 2004 revealed that only 25% of the operators surveyed use the M6 toll. The majority of them think that a reasonable fee for the toll would be between £1 and £3. A call to cut tolls and road renationalisation has been raised.

## *2) Toll collection*

The toll collection method of M6 toll road was designed to ensure the most time saving in order to attract users who have the option of free alternatives. Thus, an open toll system which requires drivers to stop once was established. Toll points were set at a number of entries and exits and at two toll plazas. Users can, thus, join the route at different junctions and pay either on exit or at a toll plaza (M6 toll website, 2013). In this system, drivers entering from different junctions are charged a fixed amount to pass a toll barrier.

Tolls can be paid by cash, credit or debit cards or via electronic toll collection (ETC) transponder. Payment can be made at manned booths by cash, credit or debit cards; or at automatic booths using coins, credit or debit cards (M6 toll website, 2013).

The electronic toll collection is another payment option which allows drives to pay in advance of their trips. To use this option, an electronic TAG which is a small physical device fitted to the windscreen of the vehicle is required (Figure 8.4). At toll plazas, drivers need to choose and run a TAG relevant lane (Figure 8.5). As the vehicle pass toll booth, TAG which includes a microchip will be read. Providing the motorist account contains credit, the toll barriers will be opened and the motorist continues without delay. The toll amount will then automatically be deducted from the user's registered TAG account. Thus, ETC enables the motorist to drive along their route without stopping at the toll booths to pay toll as all bailing is electronic. To do so, motorist need to register their vehicles for e-tag and establish an account with the private operator of M6 toll. To open an account, a balance which at least equals to the cost of ten trips is required. This kind of electronic system allows for free and smooth flowing for traffic which assists in eliminating congestion and reduces the amount of time spent on the road.

Since 2005, TAG users on M6 toll have a 5% discount per trip. However, they need to pay £1 monthly as a lease fee (HA, 2009).

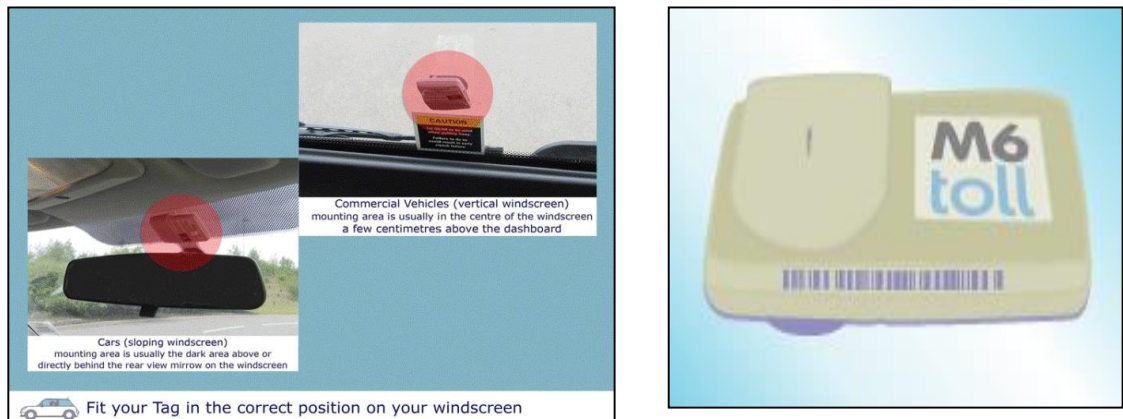


Figure 8.4: M6 Toll TAG device



Figure 8.5: The Dedicated Tag Lane on M6 Toll

### 3) Traffic and revenue performance

The main aim of M6 toll road scheme is to provide a free-flowing route as an alternative route to avoid the heavily congested section of the M6 between junctions 4 and 11. As a pay-to-use road, motorists would only pay to use it if it offered faster and more reliable journey than that experienced on its free competing M6 route. M6 Toll traffic forecasts

were generated through a combination of conventional transport planning methods and the application of market research techniques, in a two stage process. A conventional traffic model was first used to forecast flows on the M6 Toll as if it was a free road. The no-toll flow was then factored down to account for the effect of imposing a toll, on the basis of demand curves derived from the market research. The market research methods encompass interview surveys of drivers using service areas on the parallel routes, household interviews of local motorists, and interviews with commercial transport managers. Interviewees were asked how likely they would use the M6 toll if it were free, and at various levels of tolls (Adams, 1992; Hawkett, 1995).

MEL, the project operator, never published any data relating to the original forecast of traffic volume. However, some contradictory figures are available. Steer Davies Gleave group suggested that about 70,000 vehicles per day would be using the road within a year of opening, and 80,000 after three years (Wellings and Lipson, 2008 Cited in OMEGA, 2009). DfT (1994b) published a sample data from forecast showing that BNRR's level of usage between Chasewater/Burntwood–Shenstone in 2011 would be 68000 vehicles per day. Alternatively, figures published in 1993 show projections based on the year 2011 of between 36,500 and 54,500 vehicles a day using the toll road (OMEGA, 2009). Similar figures have been published in the M6 Toll Five Year after Study (2009).

In middle 2013, the DfT published an updated traffic study for M6 toll usage prepared by AECOM (2012). The study is based on the early real usage of M6 toll road. One year after opening, MEL made updates to the M6 toll demand model's input parameters which reflect the M6 toll actual level of usage and the actual road characteristics such as time savings and toll. The model enhancements led to produce an updated toll share curve and the traffic demand figures have been adjusted accordingly.

The actual usage number, provided by the MEL and obtained from the M6 toll road website, indicates that in the first year of operation there were about 46,000 vehicles using the route on an average day. One year after, in 2005, the number of users of the M6 Toll dropped slightly to average about 45,000. The year 2006 regarded an increase in users where more traffic had diverted from the M6. This increase to traffic coincided with major improvements and maintenance on the parallel M6. The annual average daily users counted to 48,300 vehicles. Since that time, the average level of usage has



dramatically declined. The annual average daily number of motorists was again on decrease in the subsequent two years with an average of 45,900 and 40,500 users per day in 2007 and 2008 respectively. Five years on, the usage level in 2009 has further decreased to 38,500 vehicles per day. Since then, level of usage has seen further declination for the last successive years. The annual average of users per day in 2012 was only 35,000 users per day.

The growth of traffic on the parallel M6, contrary to the regional negative trends seen on other highways, suggests that there has been an obvious reassignment of M6 toll traffic back onto the M6 since 2005. It seems that so many users who had previously selected the M6 Toll went back to ride other free alternatives for their journeys.

Light vehicle or cars constitutes the majority of the traffic flow on M6 toll link. According to the data available from the DfT website with respect to west midland region, cars account for more than 90% of the total toll transactions. HGVs traffic is more lagging behind. In the first year of operation about 2500 lorries used the road. In the subsequent years, on average day, no more than 1550 Lorries used the M6 toll (Figure 8.6). The proportion of HGVs at most sections of the M6 Toll is shown to be around 7% of the overall traffic (OMEGA, 2009). On contrast, trucks proportion on the M6 road is around 30% (OYA, 2005). Centro's Chief executive reported that nine out of 10 trucks use the M6 road. Unfortunately, there is no released data about the forecasted figure of trucks usage and it is not clear how much the actual usage by HGVs is different from that initially forecasted. However, Wellings and Lipson (2008) reported that "*goods vehicles were originally envisaged to be a major source of revenue but many haulage companies have boycotted the toll road*". The survey by the Commercial Motor/Michelin Business Monitor in 2004 showed that more than 50% of operators who had used the M6 Toll road when the fee was £6 said that they will abandon it when the price increase to £7. Actual data on Figure 8.6 support the survey results. While about 2450 HGVs used the road in 2004 where the toll was £6, only about half of this figure (1330) used the road in 2005 when the facility toll was raised by £1.

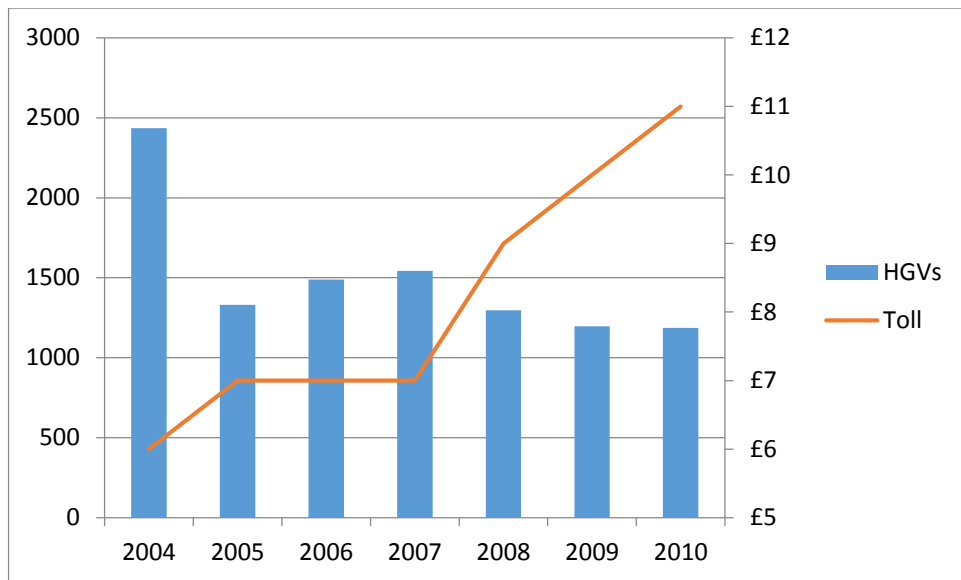


Figure 8.6: HGVs Usage against HGVs Toll

Assuming the 70,000 vehicles a day forecasted to use the route, it can be seen that just half of this number have used the road in 2012. Overall years of operation, the annual average number of motorists riding the road is greatly below the traffic levels forecasted before the road was built. On the other hand, more than 125,000 motorists are riding the free alternative M6 road leading to heavy congestion.

The M6 toll facility has been open for over 9 years. The annual monitoring reports do not show good financial performance. The most recent annual report mentioned: *“Underlying performance continues to be impacted by the continuing weak economic conditions in the United Kingdom”*. MEL, M6 toll operator, is loaded with a bank debt which due by 2015. The company owes more than 1 billion as a debt to banks. To meet lender requirements, MEL needs to pay over two-third of the debt. However, the poor usage performance suggests that the asset is running out of money to meet its liabilities and the firm is renegotiating loans with its creditors (Lavanchy, 2013). This poor financial performance suggests a high possibility that the concession agreement will be subject to renegotiation and could be taken over in the case of financial distress.

### 8.3. Parameter Estimation

As discussed in the previous chapter, the parameters or the coefficients needed for the socio-economic sub-model equations are area-specific parameters. It is, thus, important to determine the values of these parameters before using the model. For socio-economic aspects, it is important to capture the relevant relationships between population, employment, GDP and traffic using observations related to the facility area. Thus, the socio-economic sub-model has been calibrated using the data pertinent to M6 toll road where values of west midland's population and employment as well as the national GDP-related parameter are estimated using statistical data.

In chapter Seven, the regional traffic was formulated as a linear function of population and employment in the facility area and national GDP as follows;

$$\text{Regional Traffic} = \alpha * \text{population} + \beta * \text{employment} + \gamma * \text{GDP} + \delta$$

The parameters  $\alpha$ ,  $\beta$ ,  $\gamma$  and  $\delta$  measure how regional traffic responds to changes in the employment, population and GDP.

The 1994-2012 time series data available for west midland working age population and employment, national GDP and regional traffic on the motorways were used. Working age population and employment of the west midland region were obtained from StatsWales and ONS. UK GDP data was obtained from IFM website. Regional traffic was calculated based on motorway traffic data of west midland obtained from DfT data base. From the time series data collected, it was possible to quantify the model relationships econometrically. The equation coefficients were estimated through Ordinary Least Square (OLS) estimation using the corresponding historical data.

Estimating this relationship by using linear regression gave significant results. The results of the estimated model show that all the coefficients have the expected sign and that they have been estimated with a reasonable degree of reliability.

Table 8.2 shows the estimated coefficients for regional traffic equation. In addition, the table shows two other values:  $R^2$  value and F value.  $R^2$  is coefficient of determination. It is a measure of the amount of variability in the data accounted for by the regression model.  $R^2$  varies between 0 (none of the variability is explained), and 1 (all of the variability is explained). If  $R^2=1$ , the model has perfect predictability, if  $R^2=0$ , the

model has no predictive capability. On the other hand, F is a test for statistical significance of the regression equation. It is used to decide whether the independent variables have significant capability to predict the dependent variable. F statistic tests for the significant linear regression relationship between the response variable and the predictor variables. Testing the statistical significance using F-Test is achieved by advancing a “null hypothesis” (H0) and an alternative hypothesis. The null hypothesis states that all the parameters are equal to zero ( $\alpha = \beta = \gamma = 0$ ). The alternative hypothesis (H1) states that at least one of the parameters is different from zero and they are linearly related to the dependent variable. The “null hypothesis” is rejected if level of discrepancy (p-value) is less than 0.001.

For the model in concern,  $R^2$  value indicates that 98% of the growth in regional traffic on the motorways can be explained by change in population, employment and GDP. In addition, large value of the F-test statistic (102.8) and P-value (less than 0.001) provides strong evidence against the null hypothesis. There is strong evidence that parameters are not equal to zero and the model has significant predictive capacity.

Table 8.2: Estimation of the Coefficients of Traffic Equations

<b>Variable</b>	Population ( $\alpha$ )	Employment t ( $\beta$ )	GDP ( $\gamma$ )	Constant ( $\delta$ )	$R^2$ value	F value	P-value
<b>Coefficient</b>	0.007	0.024	0.021	-33.48	98%	102.8	0.000

#### 8.4. Model Input

The time horizon of the model is 30 years (2004 to 2033). The model time horizon is in line with most PPP concession contracts’ period. This period is long enough to analyse potential changes in users’ behaviour patterns, policy measures, facility conditions, and external environment. For M6 toll road, the previous operation period of 9 years (2004-2012) provides the model behaviour which will be used as reference mode for future behaviour. The simulation will help gain the potential behaviour of the traffic demand over the remaining period of the project operation (21 years).

To run the proposed SD model, a value for each of the constant variables over the model time horizon needs first to be determined and then assigned. Some of the

proposed SD model variables are soft variables such as public consultation and historical experience of paying, to determine the values of these variables, three interviews with M6 toll stakeholder were conducted as discussed in chapter five. The following sections present how the values of these variables were set up.

#### **8.4.1. Population, Employment and GDP Growth Rate**

The growth rate of the socio-economic sub-model variables including population and employment at the regional level, as well as national GDP, are the corresponding historical data for years 2004-2012. For the rest of the model horizon of 21 years, the historical trends were assumed to continue in the future. The average values of the annual growth rate during the last 18 years (1994-2012: the time series data available and used to develop the regression analysis model) are calculated. An average of 0.004, 0.0037 and 0.021 was therefore used as a future value for working age population, employment and GDP growth rate respectively.

#### **8.4.2. Corridor Traffic**

As discussed in chapter seven, corridor traffic includes the total traffic on the routes that run parallel to the facility and from which the facility market is materialised. This can easily be divided into two types of traffic: through traffic and intermediate traffic. Through traffic passes through the whole facility. Since the major facility traffic is through traffic, it is the focus of the SD model. Intermediate traffic is the traffic using only a section of the facility. This type of traffic forms only a much smaller portion (10-15%) of the whole traffic (AECOM, 2012). Thus, it was not expressly modelled and is added as proportion of the overall traffic based on the available data.

Of the through traffic, only passenger cars which constitute more than 90% of the M6 toll traffic were modelled. The reason is two folds. The data available suggests that traffic re-routing into the M6 Toll is predominantly light vehicles where cars represent more than 90% of the entire traffic (AECOM, 2012). HGVs do not represent more than 7% of the traffic on any section (UCL, 2010; AECOM, 2012). While this proportion could affect the facility revenue owing to the considerably high toll rate, its impact on the overall usage performance which is the focus of this research, is trivial. Given this,

more emphasis has been placed on demand of the high proportion of light vehicle riding the road. Furthermore, as discussed in Section 8.2.2, the majority of traffic models and this generic SD model are based on estimating the number of road users during the peak periods on average weekday which is then converted it to AADT. However, the HGVs traffic has different peak period from that of passenger cars. It is, therefore, difficult to use the same model to estimate HGVs usage. Thus, HGVs were not expressly modelled. Instead, they were added as a proportion of the overall traffic based on the available data as well and as discussed in section 7.3.5.

A base year traffic picture constituting the initial values of corridor traffic was interpolated from the aggregate trip matrix for through traffic developed by the AECOM (2012) available from DfT publications. The value representing the initial corridor traffic input into the SD model was disaggregated based on the available percentage of the trip purpose into three types: commuting, social, and business car passenger. The values used for commuting, social and business segment are: 7593, 12590, 26826 users per year respectively.

#### **8.4.3. Corridor Adjustment Factor (CAF)**

The interviews with M6 toll road stakeholders indicated that the corridor traffic experienced similar value of growth rate to the regional one. Thus, value equivalent to 1 was assigned to CAF.

#### **8.4.4. Induced Traffic Rate**

As illustrated in the previous chapter, in addition to the original traffic growth, induced traffic could be a very strong determinant of the facility level of usage. Induced traffic rate accounted for these trips would not be done without the presence of the road. For M6 toll, it was suggested that “The M6 Toll has generated extra traffic in the region. The number of vehicles on the M6 corridor increased from 144,000 in November 2003 before the M6 Toll opened, to 160,000 in November 2004” (UCL, 2010). However, since the model make use the corridor traffic figures developed in 2005, it was assumed that these traffic figures considered this increase in traffic and consequently it was

considered in the model by default. Thus the value of induced traffic rate was assumed to be equivalent to zero.

#### **8.4.5. Public Consultation**

As discussed in chapter two, three and seven, public consultation is a significant factor which affect public satisfaction and level of use. This is a soft factor whose value was determined based on the expert judgment. On a scale between 1 and 10, the M6 toll stakeholders were asked to determine which value suits best the M6 toll related consultation process where value of 10 indicates an excellent consultation process. Based on their views, an average value of 8 (very good consultation process) was assigned to this constant variable.

#### **8.4.6. Project Location and Environmental Considerations**

While M6 toll construction required relocation of several recreation facilities, the impact of M6 toll on community was considered to be nominal. The proposed scheme passes between existing settlements rather than through them.

A detailed environmental assessment was performed and published before the public inquiry. M6 Toll road environmental statement showed the mitigation measures to minimise the impact of the facility construction on the surrounding area. Mitigation measures included tree planting, wildlife protection and pollution and noise reduction. However, in addition to the objections relating to the toll order, most of the objection letters drawn from the official consultation process raised concern regarding the potential impacts of the road construction on local areas and side roads. For instance, objections specifically covered matters such as environmental impacts (noise and air pollution, impact on wildlife and ecology, impact on recreational value of countryside) and loss of green (DfT, 1994b).

It seems that these kinds of objections as well as the pressure from environmental group were a motivation to the private concessionaire to precisely evaluate the potential environmental impacts of the scheme and provide further environmental mitigation measures. The consortium decided to use environmentally-friendly routes, anti-noise road building materials (noise reducing asphalt) and to establish and develop significant landscaping along the route where about one million trees were planted along the road.

Moreover, further mitigations were carried out to protect flora and fauna. In addition, downward directed lighting has been used to reduce lighting impacts (DfT, 1994b).

To quantify how the project location and environmental considerations might affect public satisfaction, M6 toll stakeholders were again asked to describe the M6 project location and environmental considerations on scale between 1 and 10. An average value of 9 (very good level of considerations) has been assigned to this variable in the SD model.

#### 8.4.7. Toll and Toll Change

As discussed above, only passenger cars were explicitly modelled in the SD model. Cars toll rates were therefore used as an input to the model. During the last years MEL has offered a modest discount for off- peak period use. Since the traffic is running fairly and freely during these periods on the non-tolled M6 road, the modest toll discount for overnight and weekend use does not seem to offer an incentive to use the tolled M6 link. The model, therefore, used a standard toll charge (peak period rate) as all-day rate for the whole modelled period. This assumption could result in slightly lower traffic volume.

M6 road toll rates have been raised frequently since it opened to traffic in 2004. For modelling purposes, an initial toll rate of £3 was used. Between 2005 and 2013, this value was raised every year with a similar rate to the actual increase in the toll rate extracted from different sources of data as shown in Table 8.3. Standard toll charges on weekdays now stand at £5.50 and £11 for cars and HGVs respectively. For the base case run, the average observed growth was extrapolated into the future. Starting from 2014, the toll rate was, thus, assumed to be raised by £0.35 per year.

Table 8.3: Toll Change Rates Used in the Model

Date introduced	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Standard Toll	£3.0	£3.5	£3.5	£4.0	£4.5	£4.7	£5.0	£5.3	£5.5	£5.5

Source: (HA, 2005, 2009, M6 toll website)



#### **8.4.8. Toll Adjustment Factor (TAF)**

Since Tag users are entitled to pay a 5% discounted rate, the toll value applied into the ETC users in the model was 95% of non-ETC users' toll.

#### **8.4.9. Value of Travel Time Saving (VTTS)**

VTTS is a multi-dimensional distribution which varies according to trip purpose and income level. While the SD model has the capacity to include up to eight subscripts for VTTS, due to data availability limitations, VTTS was only differentiated on the basis of trip purpose. Different groups of users have different VTTS; the relative importance of VTTS was expressed in the model by dividing the VTTS variable into three subscripts attached to three values of time saving. Thus, all the members of a group undertaking similar kind of trips (commuting, social or business) will be assigned the same value of time which is different from other groups' values. Thus, three different values of time savings of £9.21, £13.71 and £16.16 for commuting, social and business trips respectively for year 2004 were used in the SD model. These values were extracted from the AECOM (2012) report developed based on the real use of M6 toll road. The VTTS values were estimated based on revealed preference survey for M6 toll users.

According to Transport Analysis Guidance (TAG) unit 3.5.6 (DfT, 2012), VTTS grows in line with the income with an elasticity of 0.8. The measure of income used is GDP per head. VTTS was thus annually upgraded in line with change in GDP per head as recommended by TAG unit 3.5.6 (DfT, 2012).

#### **8.4.10. Rival V/C**

M6 Toll was originally designed as a scheme to relieve the heavily congested parallel section of M6 between junction 4 and junction 11. Traffic on the M6 road is close to saturation over extensive and lengthen period of the day (Adams, 1992). In addition, the traffic on other local routes in the M6 corridor exhibits similar characteristics (Adams, 1992). The data available from DfT as well as the M6 toll road stakeholders and toll roads experts interviewed in the course of model development indicated that V/C ratio on the untolled M6 (i.e. rival V/C) is close to 1. A value of 0.94 was assumed and used

in the model. This value was subject to change over time to reflect the increasing traffic and the roadwork on the M6 untolled road.

#### 8.4.11. Electronic Tag Usage

The SD model breakdowns the traffic according to the type of payment. Based on the payment type, M6 toll road users can be divided into two types, users paying manually (Non-ETC Users) and users paying using Tag technology (ETC users).

Figure 8.7 shows the growth of Tag users over time. Although the number of M6 toll road users is decreasing, the number of Tag users has slightly increased between 2005 and 2008. The proportion of the Tag users of the entire number of M6 toll users has increased from 7% in 2005 to 13% in 2008. However, according to the M6 toll operator, this number stood at 15%.

By using this information it was possible to estimate the input value for the ETC change rate variable in the SD model representing the change in the ETC market share for different modelled years.

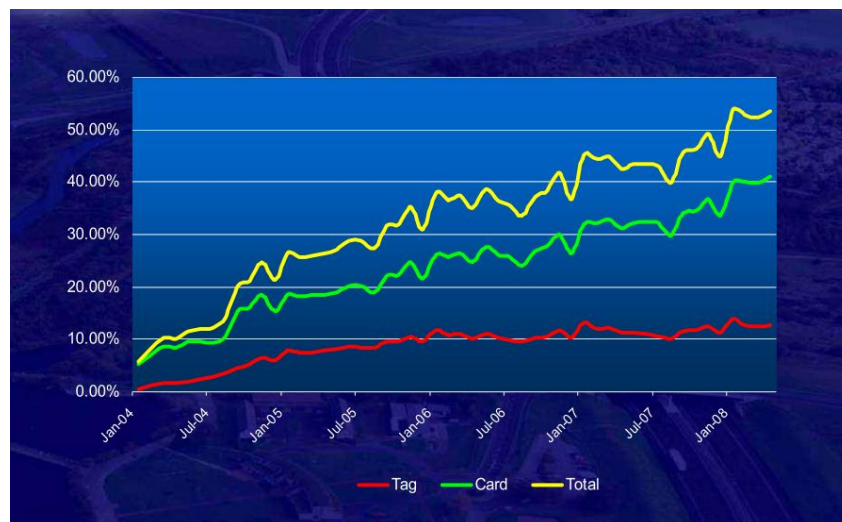


Figure 8.7: TAG Users Vs M6 Toll Users

#### **8.4.12. Normal Travel Time and Rival Normal Travel Time**

In the SD model, “normal time” is the travel time required to pass a specific distance in the free flow conditions. For M6 toll, it is the travel time between the start and finish points of the route. Since Tag users are not required to stop, they enjoy more time saving. Thus, we need to differentiate two normal times, non-ETC users’ normal time and ETC users’ normal time. By using the data available from AECOM modelling report (2012), values of 22.2 and 21.2 minutes for non-ETC users and ETC users were used in the model respectively. In the AECOM report, these figures were estimated based on the actual travel time on M6 toll in the free flow condition.

Rival normal travel time, on the other hand, is the travel time between junction 3A and junction11A (start and finish points of M6 toll) on the untolled M6 road. Using the same data source (AECOM, 2012), a value of 24 minutes for rival normal time was used in the model.

#### **8.4.13. Historical Experience of Paying**

M6 toll road is the first privately financed road in the UK. Potential users were assumed to be not familiar with this kind of facility. Historical experience of paying is, thus, assumed to be equivalent to zero.

#### **8.1.1 Expansion Factors**

As discussed in Chapter Seven, the majority of traffic models are based on estimating the number of road users during the peak periods on an average weekday since it is the most important periods affecting the project level of usage. The annual traffic is then estimated by applying expansion and annulaisation factors based on the analysis of observed relationships between peak period and the entire traffic on regional and national levels. An alternative method is to explicitly model the peak periods in addition to several other periods throughout the day. The available data imply that the M6 toll road model was based on this method and it is not clear how peak period traffic was converted into AWT and AADT. Since there is no expansion factor developed for the M6 toll road which is used to convert the initial traffic during the peak period on

average week day into AADT, this SD model directly uses the data available with respect to AADT in the facility corridor and produces the M6 toll share of this traffic. This procedure revokes the need for using the expansion factors sub-model. Thus, both weekly and annualisation factor were considered to be equivalent to one with null growth rate.

#### **8.4.14. Change in Fuel Price**

Based on the trends of the pump of road fuel given in the Department of Energy and Climate Change (DECC) Quarterly energy prices publication, between 2004 and 2012, the fuel price increased from 76.2p in 2004 to 132.9p in 2012. This represents an average annual growth of about 6p. For modelling purpose, an annual average change in the prices for a litre of unleaded petrol in the United Kingdom of £0.06 was used for the period between 2004 and 2012. Based on longer historical data (1994-2012), the average value of £ was 0.045 used to predict the future.

#### **8.4.15. Ramp-up**

The interview with the M6 toll road stakeholders concluded the ramp-up period for M6 toll did not last more than 2 years. The SD model therefore assumed 2 years ramp-up period.

#### **8.4.16. Non-compete Clause**

The concession between MEL and the DfT does not have any agreement prohibiting the improvement of existing roads such as untolled M6 road or even development of a new free road nearby. Non-compete clause variable value is, thus, assumed to be equivalent to zero.

#### **8.4.17. Guarantee**

The M6 toll road is 100% private sector funding. MEL built and financed the facility without recourse to government fund or guarantees.

#### **8.4.18. Rival Toll**

Since the major competing route, M6 road, is a free facility, initial value of rival toll and change in rival toll were set at zero.

The values of all the exogenous variables used in the SD model to estimate the M6 toll traffic demand are included in Appendix A.

### **8.5. Base Case Run**

The socioeconomic aspects of the facility area are one of the most significant variables when estimating the current and future demand for a toll road. Annual growth rates of population and employment at regional level as well as national GDP were input into the model as discussed above in section 8.4.1. Figure 8.8 through Figure 8.10 show how the three socio-economic variables employment, population and GDP (y-axis) evolve over the time horizon of the SD model (x-axis). The model outputs illustrate the behaviours of the west midlands population and employments as well as the UK GDP.

The model results shown in Figure 8.8 suggest that west midland population (16-85 years) is on a continuous upward trend. The results indicate that the population will grow to about 4.8 million in 2033. This represents an average annual growth of 0.47%. Between 2011 and 2021, the results suggest a growth of 4.1%. This figure is a bit lower than 5% growth between 2011 and 2021 suggested by the data available from NOS for over 16 west midland population. This variation is mainly attributed to the difference in the data set used. The model used population between 16-85 years while the data available from NOS is for all population over 16 years.

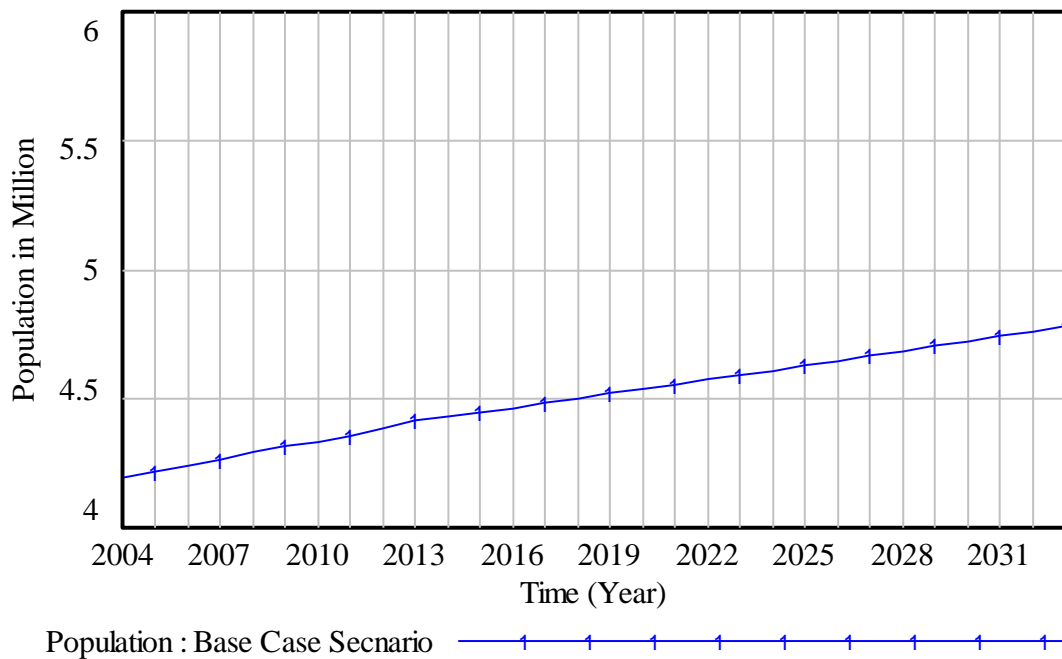


Figure 8.8: Population Growth in the Base Case Scenario

$$\text{Population} = \text{INTEG}(\text{population growth}, \text{initial population})$$

Figure 8.9 also shows general upward trend for the west midlands employment. However, the figure shows a downwards trend between 2008 and 2009. This can mainly attributed to the negative growth in the employment rate due to the downturn in the UK economy during the same period. The model shows that the west midland employment of 2.46 million grows to 2.73 million by 2033. This figure shows an annual growth of 0.37% on average. This growth rate is much less than 0.5% between 2015 and 2020 0.6% between 2020-2025 employment growth rate predicted by Cambridge Econometrics Local Economy Forecasting Model (LEFM) for west midland. The variation is mainly attributed to the differences in the models assumptions. The proposed model used the employment historical growth as a basis for predicting future. (LEFM) considered potential change in the economic conditions in the west midlands area.

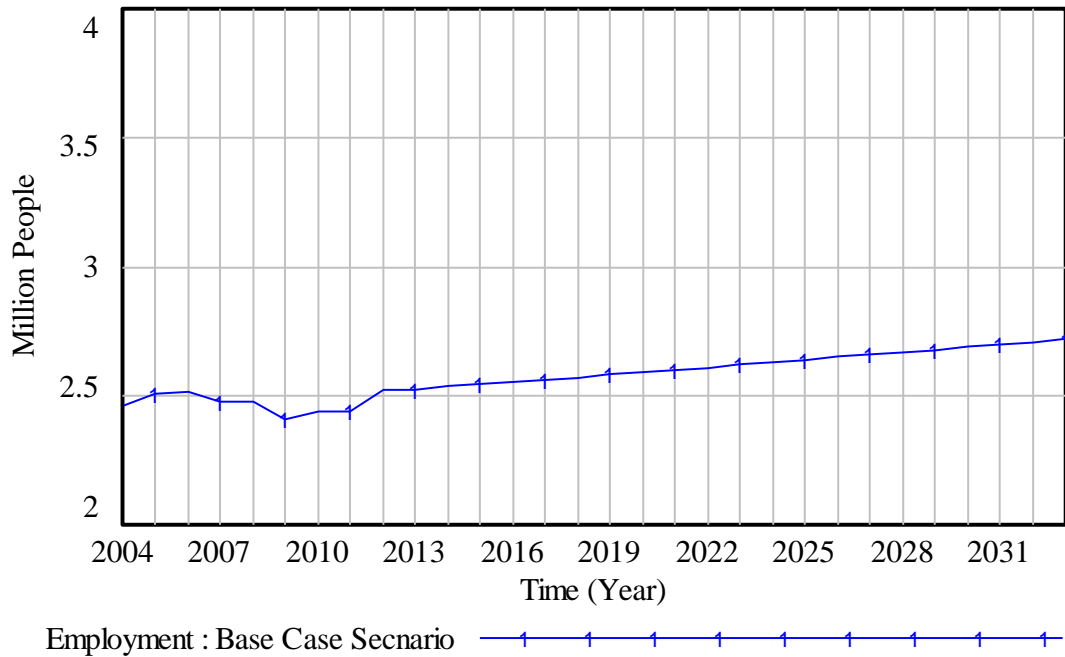


Figure 8.9: Employment Growth in the Base Case Scenario

$$Employment = INTEG (employment\ growth, initial\ employment)$$

The third socio-economic variable used in the model is GDP. Figure 8.10 shows the trend of the UK GDP over 30 year the model horizon. After a tiny downward trend between 2007 and 2009 due to the recession, the GDP showed a continuous upwards trend till the year 2033. The model shows that the UK GDP will grow to £2,208 billion by 2033. The GDP data available from IMF is only till 2017 and indicates that by that year UK GDP will grow to £1611 billion. This figure is higher than that generated by SD model for the same year of £1576. The main reason is that the model assumes conservative GDP growth rate (0.021%) in the future based on the historical trends including the recession growth rates while the published average GDP growth rate is about 0.25%.

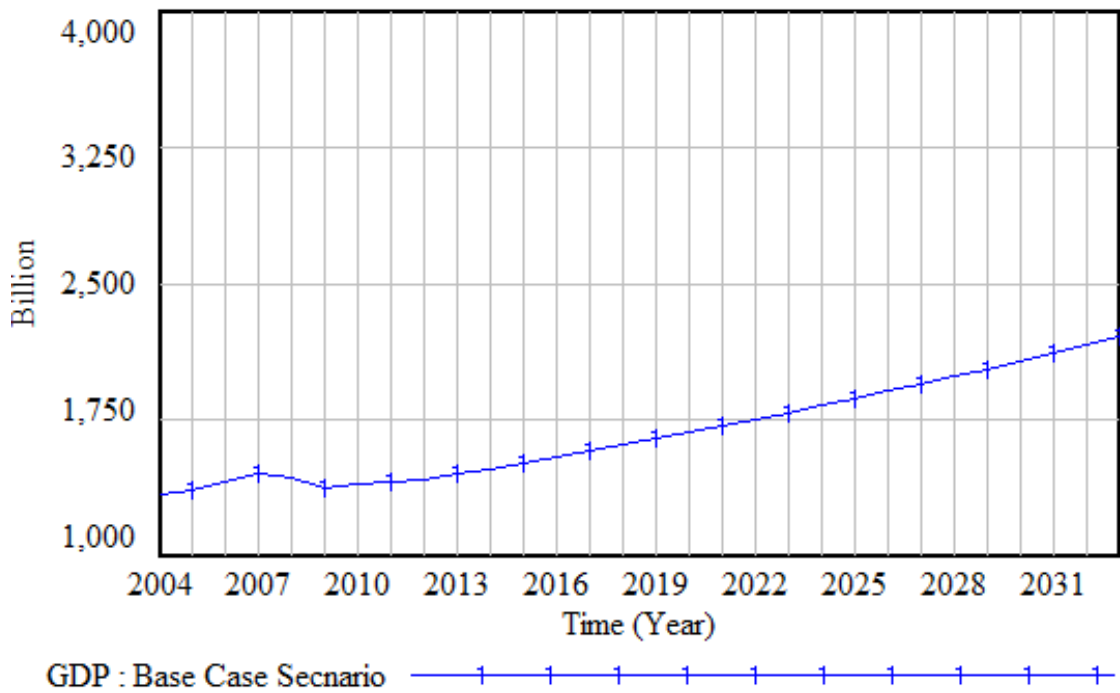


Figure 8.10: GDP Growth in the Base Case Scenario

$$GDP = INTEG (GDP \text{ growth}, \text{initial GDP})$$

Based on socio-economic variables, the model generated the pattern of the west midland average annual regional motorway traffic over time. Figure 8.11 shows how the regional traffic evolves over the time horizon. The model results suggest that the trend of regional traffic follows an upward trend with small downward slope between 2008 and 2009 resulted from the negative trends during the recession period. The results indicate that the average annual regional traffic on the motorways in west midlands increases from about 83 million in 2004 to about 112 million in 2033. This figure suggests an annual traffic growth of about 1.2% on average.

The model performance between 2004 and 2011 shows that the regional traffic grows from 83 to 85.11 million users respectively. The actual traffic data calculated based on the traffic data extracted from DfT database suggest that regional traffic of West midlands motorways grows from 82.8 to 85.13 between 2004 and 2011. Obviously, the results of the model are consistent with the historical data where the model generated almost exactly the actual regional traffic of west midlands motorways.



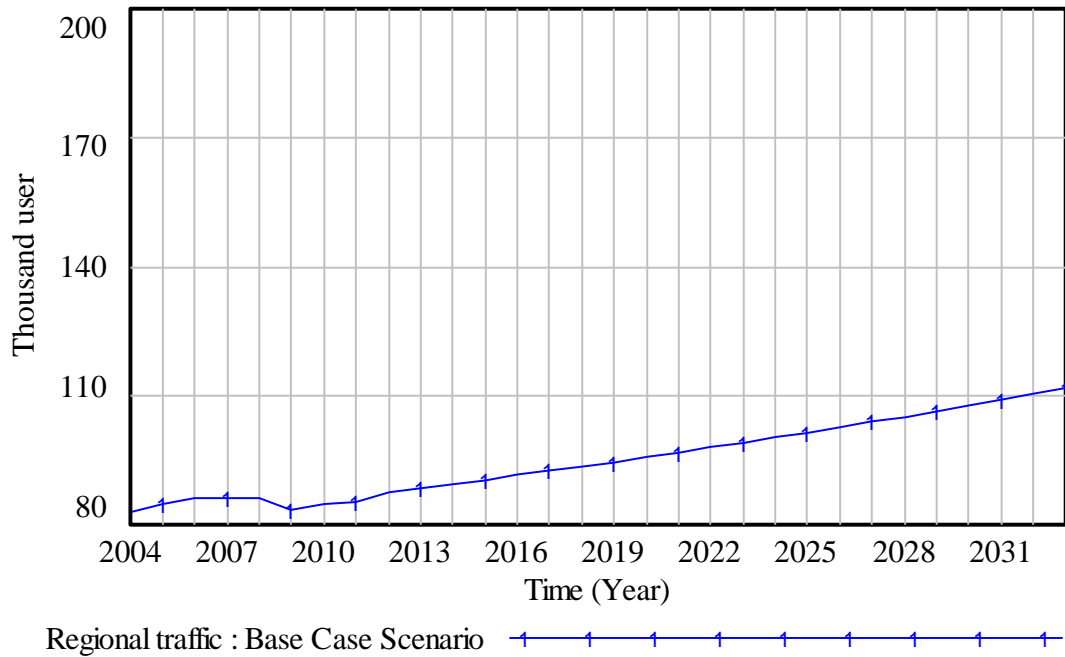


Figure 8.11: Regional Traffic Behaviour in the Base Case Scenario

$$Regional\ traffic = -33.479 + 0.021 * GDP + 0.007 * Population + 0.024 * Employment$$

Figure 8.12 and Figure 8.13 illustrate how the VTTS and WTP behaviour develop over time. As discussed in Section 8.4.2 and Section 8.4.9, the SD model distinguished between various traffic segments (i.e. commuting, social and business) that form the potential traffic of the facility. This was mainly because each segment has a different value of time saving and WTP, and consequently a different response to toll level. It can be concluded that the three categories exhibit similar behaviour over the time horizon.

The VTTS in Figure 8.12 shows an upward trend for the three traffic segments over the 30 years similar to that of UK GDP. This is because the assumption that the VTTS for the three segments of traffic will grow in line with GDP grow. Between 2004 and 2033, the VTTS of commuting, social and business trips grows from £9.22, £13.73 and £16.18 to £12.91, £19.22 and £22.66 respectively. These figures represent an annual growth of 0.13% on average. The 2005 VTTS value of commuting, social and business trips is £9.4, £14 and £16.5 respectively. These values are equivalent to the values suggested by EACOM (2012) study and used to develop the M6 toll demand model.

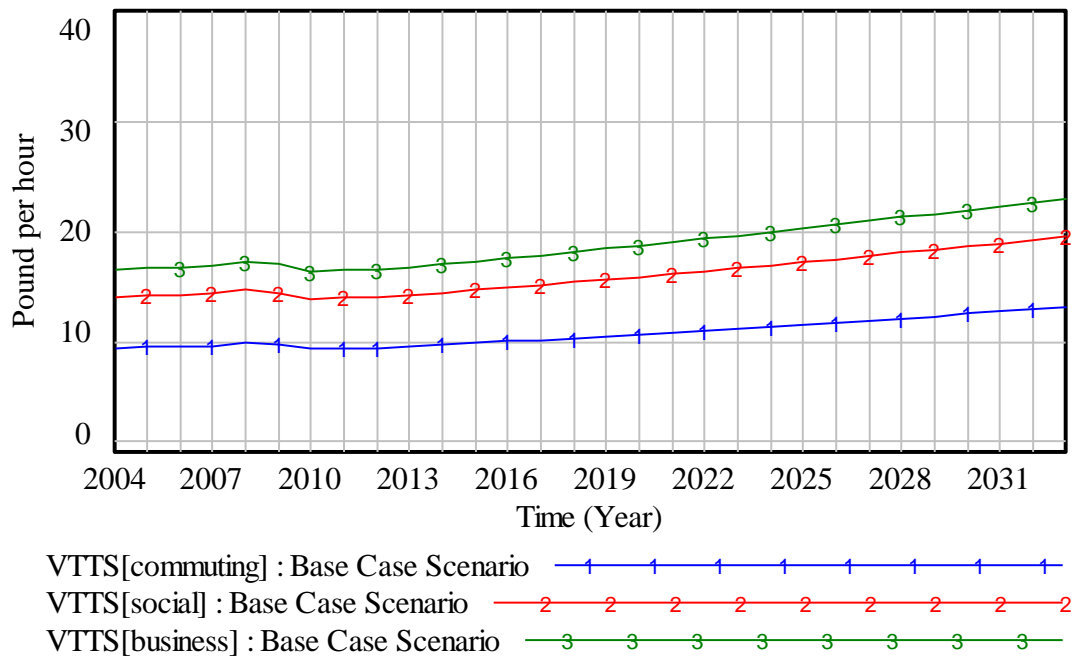


Figure 8.12: VTTS in the Base Case Scenario

$$VTTS [traffic segmentation] = INTEG (VTTS change [traffic segmentation], initial VTTS [traffic segmentation])$$

Figure 8.13 shows the behaviour of WTP variable over the model time horizon. Obviously, WTP shows upwards behaviour similar to that of VTTS. As discussed in Chapter Three, VTTS is one of the most determinants of WTP in addition to some soft variables such as reliability. The result shows that WTP of commuting, social and business traffic increases from £18.42, £27.44 and £32.34 to £25.82, £38.45 and £45.31 by 2033, respectively. This is twice higher than the VTTS. The double factor reflects the effect of reliability on WTP value. This value is consistent with the value reported by EACOM (2012) that the M6 toll users value reliability as equivalent to 11 minutes. The time saving offered by the M6 Toll is nearly 10 minutes. Obviously, M6 toll road users approximately value the reliability equally to time saving. WTP value which encompasses time saving and reliability values is thus approximately double the time saving value.

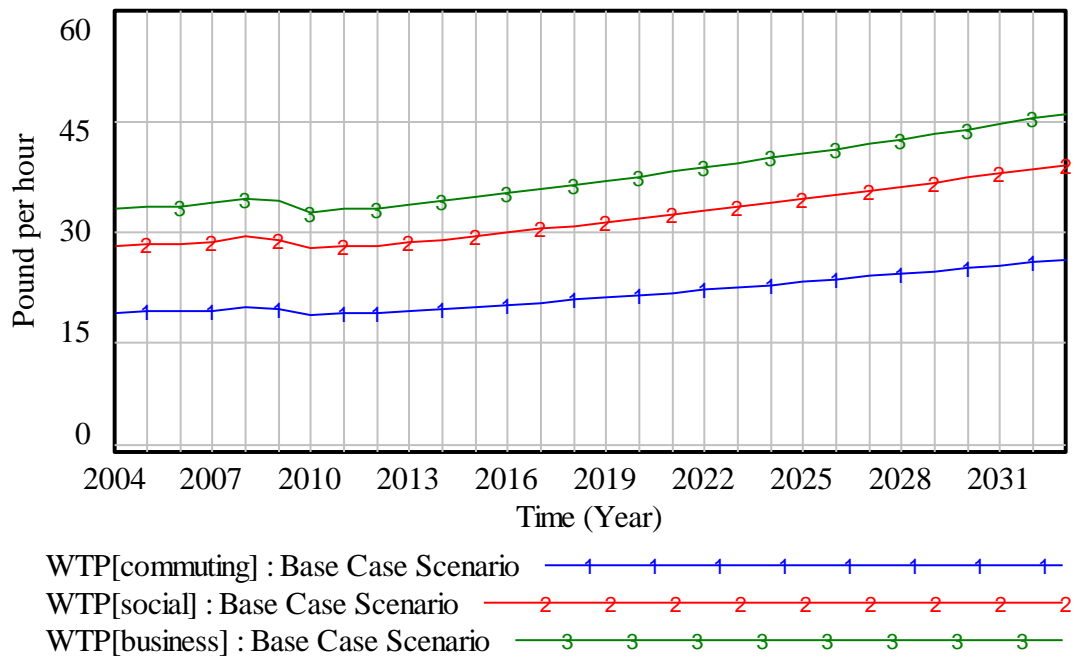


Figure 8.13: WTP in the Base Case Scenario

$$WTP[traffic\ segmentation] = effect\ of\ QF[traffic\ segmentation] * VTTS[traffic\ segmentation]$$

Figure 8.14 shows the behaviour of toll rate over the model time horizon. The simulation was run for the actual toll rate of the past nine years of the operation period. The average historical increase of £0.35 annually was extrapolated into the future. Given this, the graph shows an upward trend with constant slop from year 2013. The results suggest that toll rate increases from £3 in 2004 to £12.5 in 2033 which implies an annual growth of about 10 % on average.

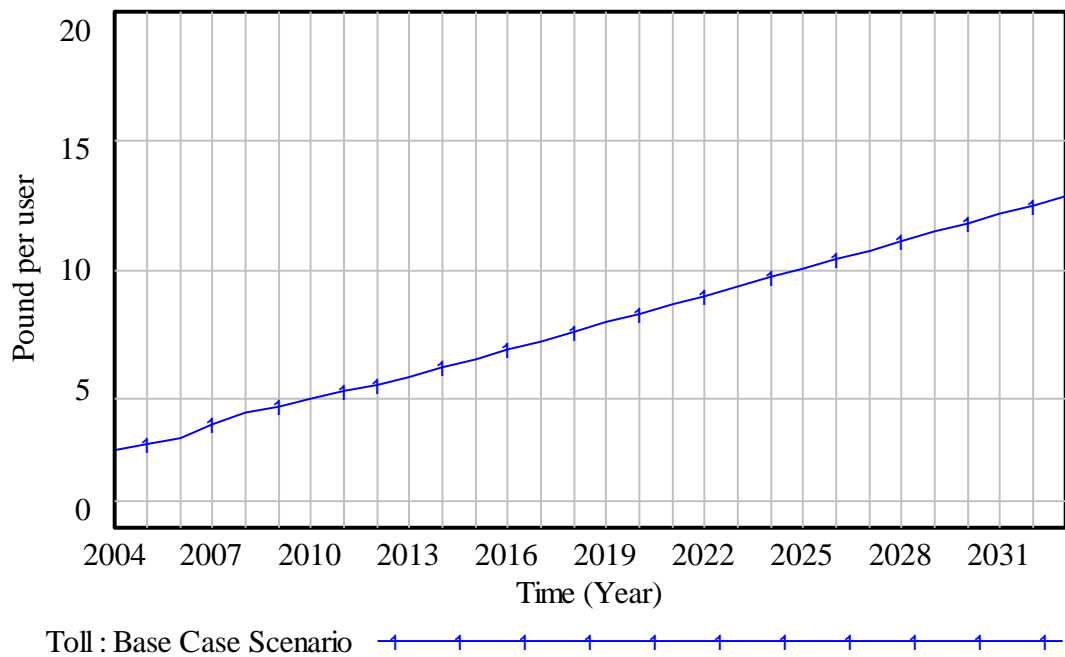


Figure 8.14: Toll Rate in the Base Case Scenario

$$Toll = INTEG (toll\ change, initial\ toll)$$

The overall impact of the opening of the M6 Toll can mainly be assessed by looking at time savings of journeys on the parallel M6. Since the M6 toll road is still operated under the free-flow conditions, the time saving is mainly determined by the congestion conditions on the untolled parallel. Figure 8.5 shows the travel saving experienced by the non-ETC users of M6 toll facility who constitute the majority of M6 toll market. The figure shows two main peaks in travel saving in year 2006 and year 2010 which reflects the congestion resulted from major roadwork and maintenance on the parallel untolled M6 during these years. Thereafter, the results shows an upwards trends until 2033. The increase in travel time saving is a direct consequence of the expected increase in traffic level and congestion on the parallel M6 over the next period of the facility operation. On average and between 2014 and 2033, the travel time saving offered by M6 toll is expected to grow by an annual value of 2.6%.

According to the data available for 2004 and 2005, a simple comparison of the journey times on M6 toll and M6, the average weekday journey time savings are 12 minutes northbound and 7 minutes southbound (M6 traffic monitoring study, 2005). Thus, Harrison (2005) identified additional time saving achieved by using the M6 Toll of

approximately 10 minutes (UCL, 2010). This value is consistent with value of time saving of 0.168 hour (i.e. 10.08 minutes) generated by SD model for 2005.

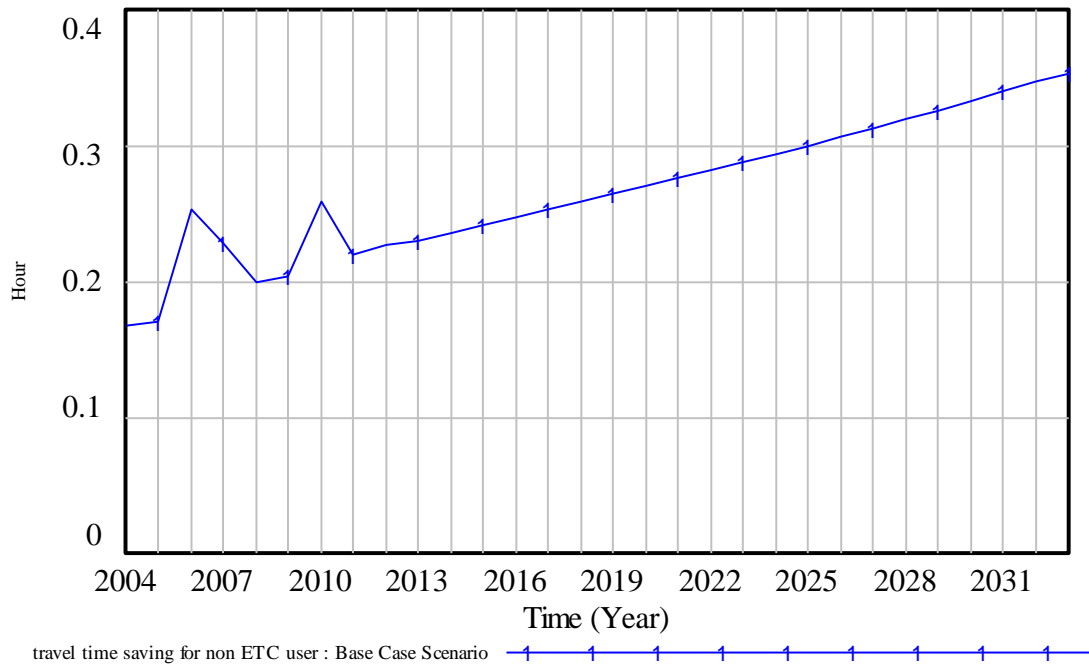


Figure 8.15: Travel Time Saving of Non-ETC Users

$$\text{travel time saving for non ETC user} = \text{rival travel time} - \text{"non-ETC travel time"}$$

Given the values of WTP (value of time and reliability), the travel time saving, toll and other variables, the model generated the toll share for each market segment as illustrated in Figure 8.16. The toll share for each segment allocates a proportion of corresponding through traffic to the M6 Toll.

The toll share graph shows two peaks in 2006 and 2010 in corresponding to the higher time saving offered by the facility in these years. This higher toll share implies a higher portion of the traffic in the corridor is willing to use the facility. The predicted toll share for the rest of the model time horizon suggests almost constant trend. By 2033, the toll share of commuting, social and business trips will be 22%, 62% and 72% respectively. Between 2013 and 2033, these figures represent an average growth of -0.8%, -0.54% and -0.35%. This slight but negative growth in toll share can mainly be interpreted as the growing in WTP and travel time saving is not able to offset the suggested increase of toll rate.

The value of toll share generated by the model for 2005 (when toll rate is £3.5) of 22%, 74% and 80% is reasonably consistent with value generated by the logit curve developed for M6 toll road by AECOM (2012). For 10 minutes time saving and toll rate of £3.5, the calibrated logit curve approximately estimated toll share of commuting, social and business through traffic as 19%, 77% and 80% respectively. The model results are slightly different for commuting and social traffic toll share. This can mainly be attributed to the differences in the models structure, variables, and equations. For instance, the AECOM model, used the delay function to find time saving. This model used instead a non-linear function to depict the effect of congestion on travel time. In addition, the modelling and calibrating process between the two models are also different.

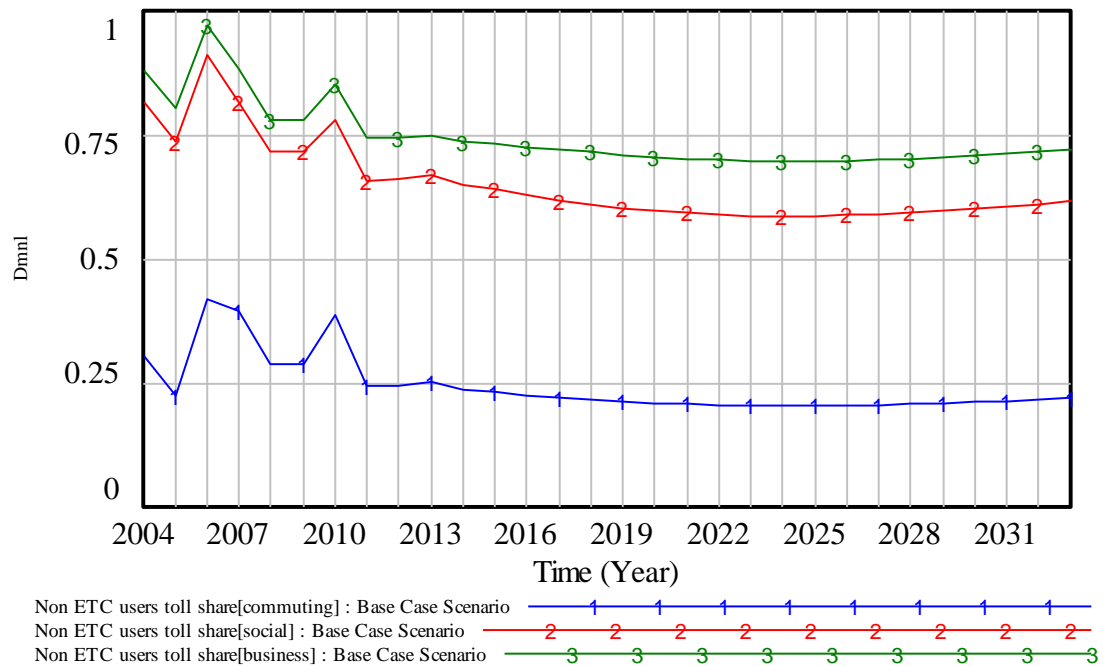


Figure 8.16: Non-ETC Users Toll Share

*Non ETC users share [traffic segmentation]=effect of historical experience of paying on WTU[traffic segmentation]\*"WTP effect of non-ETC users"[traffic segmentation]\*public involvement effect[traffic segmentation]*

Since Tag users are not required to stop when using the facility, they enjoy slightly higher time savings. In addition, they are entitled to a 5% discounted rate on the toll. Due to this higher time savings and cheaper service, the toll share of ETC users is

higher as illustrated in Figure 8.17. The toll share for 2033 is about 25%, 63% and 73% for ETC users against 22%, 62% and 72% for non ETC users.

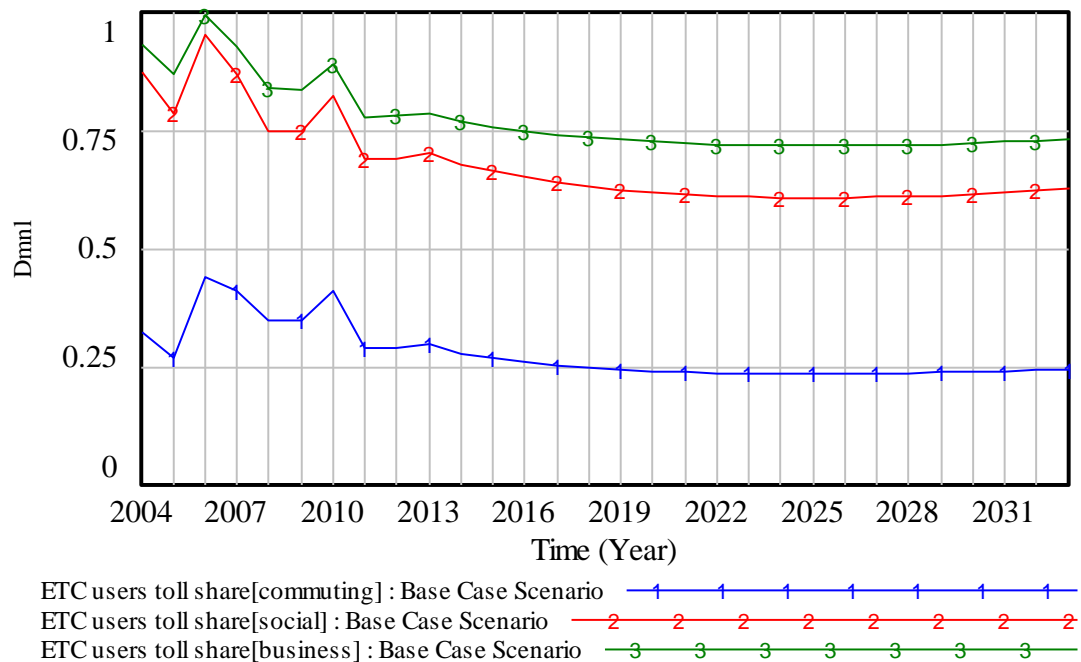


Figure 8.17: ETC Users Toll Share

*ETC users share [traffic segmentation]=effect of historical experience of paying on WTU[traffic segmentation]\*"WTP effect of ETC users"[traffic segmentation]\*public involvement effect[traffic segmentation]*

Given the value of toll share for each traffic segment generated by the model and the proportion of each segment of the through traffic identified in Section 8.4.2, the model generated the level of commuting, social and business traffic using the M6 toll road. Figure 8.18 and Figure 8.19 show the level of traffic demand by non-ETC users and ETC users respectively. The model results show a declination in non-ETC users met by an increase in ETC users between 2004 and 2010. This is mainly attributed to an increased number of non-ETC users converted to use TAG technology between 2005 and 2010 (as explained in Section 8.4.11). However, based on the data available, the conversion level was constant at 15% after 2010. The M6 toll road operator confirmed in the course of the interviews that ETC users do not exceed 15 % of the total M6 toll road traffic. As shown in the figure, in 2010, the ETC traffic is around 4860 users. On the other hand, the non-ETC traffic is about 28471. This is a ratio of  $4860/(4860+28473)$  which is approximately 15%.

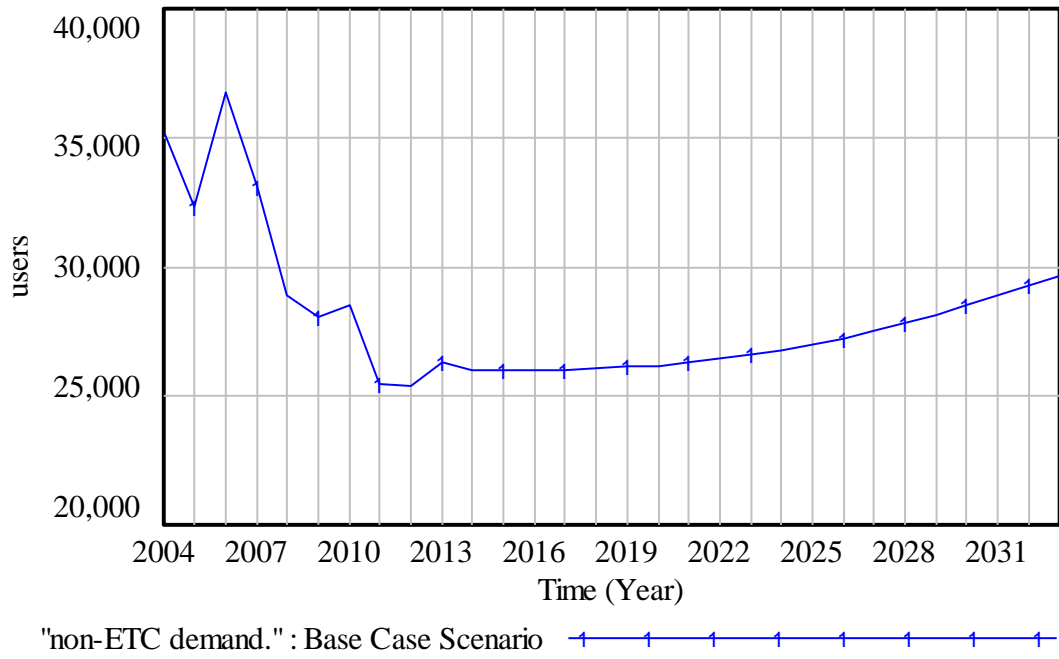


Figure 8.18: Non-ETC Traffic Demand

$$\text{non-ETC demand.} = \text{sum}(\text{"Non-ETC Demand"}[\text{traffic segmentation!}])$$

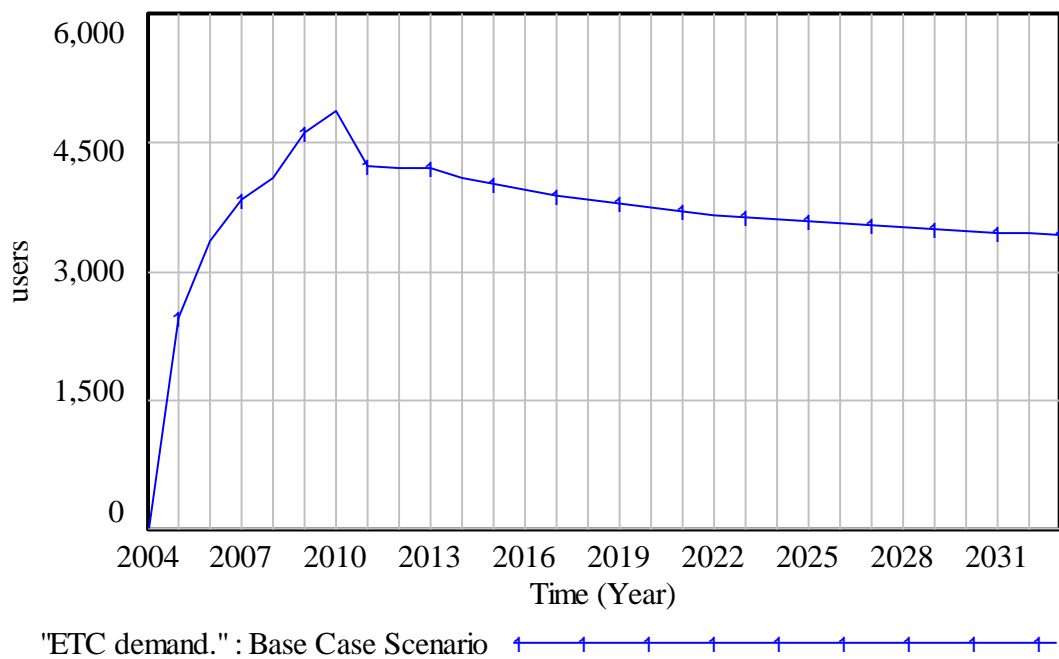


Figure 8.19: ETC Traffic Demand

$$\text{ETC demand.} = \text{sum}(\text{ETC Demand}[\text{traffic segmentation!}])$$



Figure 8.20 shows the level of demand (non-ETC and ETC users) for each of the three traffic segments.

Figure 8.20 shows that the business trips constitute the majority of M6 toll trips. This is followed by the social trips and then the commuting trips. This is totally consistent with the data available from AECOM (2012) and from the M6 toll stakeholders' interviews outcomes. While MEL initially considered that M6 toll is to meet the needs of both long-haul and regional road users, with local users primarily benefitting from the congestion relief to the other alternative roads (DfT, 1994), commuting traffic turned out to form only minority of the M6 toll traffic. M6 toll is mainly long haul route for social and business trips with this traffic constituting more than 80% of the total traffic. The interviews outcomes indicated that most of M6 toll traffic is long haul traffic; it is the traffic coming from Manchester, Glasgow and southwest of Scotland through to London. The minority of M6 toll traffic is local. Few small towns are surrounding the route such as Cannock and Lichfield with total population around 70000 to 80000, so the local movements are not great.

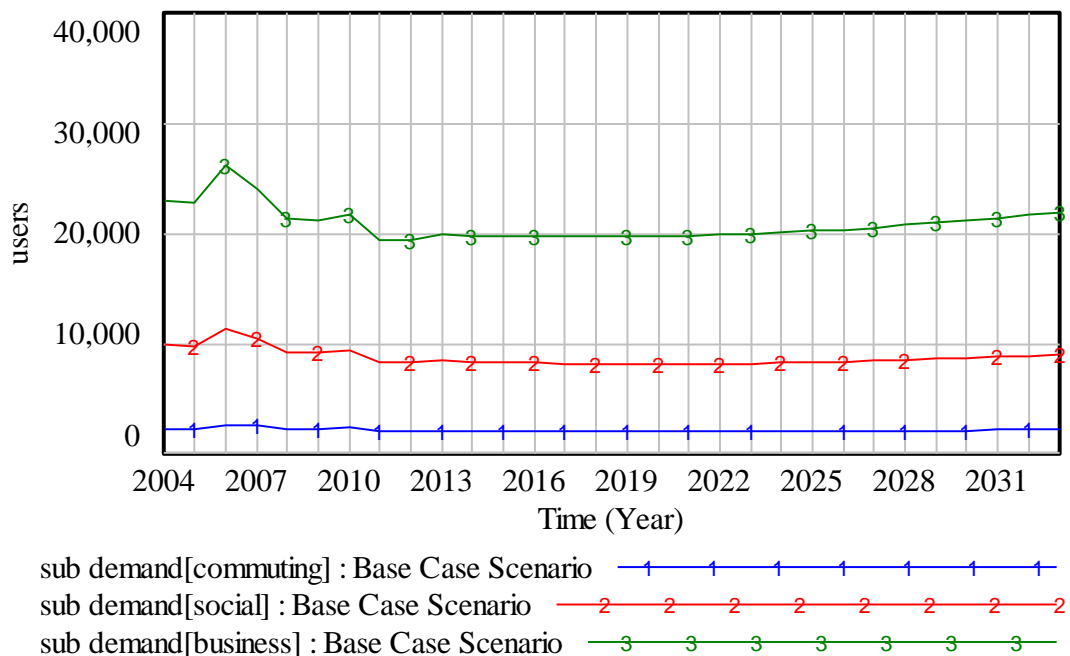


Figure 8.20: Demand for Different Traffic Segmentations in the Base Case Scenario

$$sub\ demand[traffic\ segmentation] = ETC\ Demand[traffic\ segmentation] + "Non-ETC\ Demand"[traffic\ segmentation]$$

The SD model then accumulated the outputs of the traffic segments shown in Figure 8.20 to estimate the total demand of the toll route. The total demand is represented by Annual Average Daily Traffic (AADT) in the SD model and it is the main output of the model. Figure 8.21 shows the base case scenario behaviour of the model pertinent to AADT. The results of the base case run shows how the traffic develops over time with respect to the input values presented in the previous sections. The results show a major peak in AADT in 2006. This is mainly attributed to an increase in M6 toll traffic resulted from converting the traffic from parallel untolled M6 during the roadwork's and maintenance in the same year. There is a smaller peak in 2010. The data from DfT indicated that the traffic decreased from 124.2 thousands in 2009 to 122.5 thousands in 2010 between junction 9 and junction 10, the part of untolled M6 parallel to M6 toll, indicating traffic conversion to other roads. On the other hand, the M6 toll traffic increased by more than 1200 between 2009 and 2010. The graph shows approximately a stable trend then after.

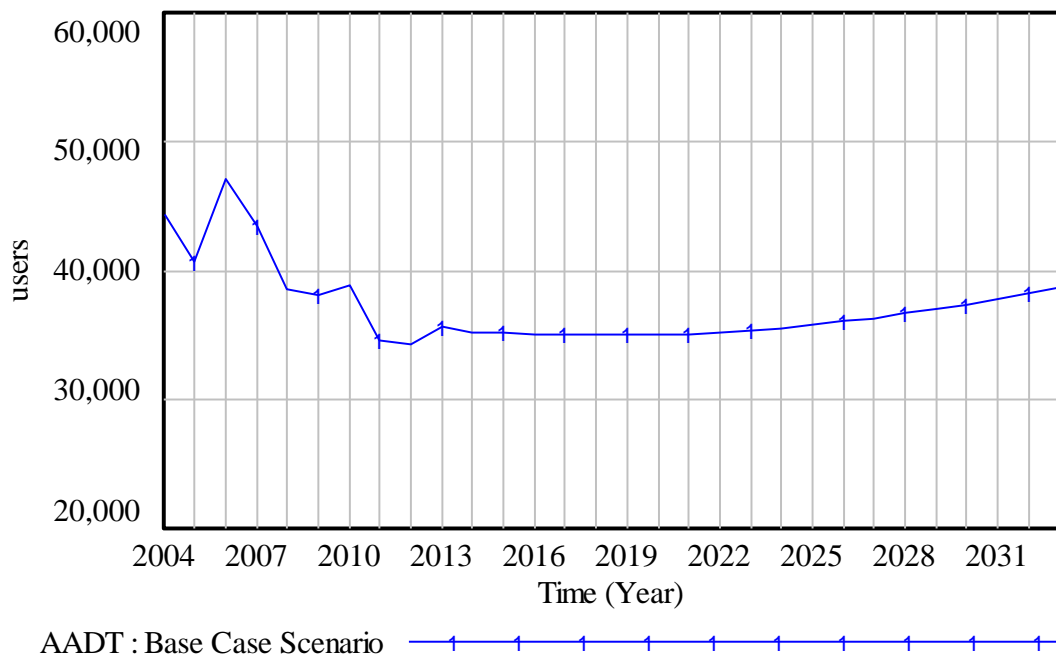


Figure 8.21: Total Traffic Demand in the Base Case Scenario

$$AADT = AADT_0 * (1 + \text{proportion of intermediate traffic}) * (1 + \text{Proportion of HGVs})$$

Figure 8.21 indicates that in the first year of operation (2004) M6 Toll managed to attract around 45000 users who mainly diverted from M6 competing route. In the 2006, M6 toll has regarded an increase in passengers when M6 road was subject to major road works and maintenance which causes traffic diversion. While roadworks and maintenance on M6 led to a higher usage level of M6 toll in 2006, the long-term impacts seems to be different. It seems that the road maintenance led to major improvements on the competing M6 route. Since 2006 the usage level of M6 toll has gradually reduced to less than that seen on initial opening. This negative pattern of traffic change since 2006 suggests the traffic has diverted back to M6 road. Particularly, the growth of traffic on the parallel M6 coincided with the negative regional growth trends on other highways in the west midlands. In 2012, the model outcomes show that only about 35000 motorists used the facility. This figure is about 25% below that figure seen on the road in the first year of operation and 19% lower than that in 2010. The model predicted a higher usage in year 2013 which mainly attributed to constancy in toll price against continuous increasing in VTTS and congestion on the free alternative.

The SD model outputs reflect the likely behaviour of road traffic in the future. The results show that over the next 21 years, the expected increase in VTTS, congestion, socio-economic variables will barely be able to offset the assumed increase in tolls. By 2033, the AADT on M6 toll is about 39000 users per day. While this figure is a bit higher than the current usage, it is lower than that figure shown in the first year of operation. The facility level of usage shows a slow increase over time. As one would expect, the proportion of motorists intending to use the toll facility decrease as the toll levied to use the facility increases. However, the increase in VTTS, GDP and congestion on M6 seem to be able to meet the assumed increase in toll. Raising tolls to higher level is likely to put people off and decrease level of usage. Chapter Ten will illustrate the likely trend of traffic in the future under different toll adjustment and other different conditions. This includes, for example, the likely behaviour of users when they are faced with different possible tolls or different congestion level.

Given the level of traffic, toll of passenger car, toll of HGVs and ramp-up effect, the model can estimate the toll revenue or the traffic revenue. It is important to notice that this revenue does not form the total project revenue. Project revenue may include other type of revenue such as revenue from fuel station and other facilities on the main route.

Figure 8.22 shows the revenue variable behaviour over time. The results show a slow increase in the revenue in the first two years due the assumed rump-up effect. The figure shows a peak in revenue in 2006 due to higher traffic in this year. Due to declination in traffic, revenue in 2012 is 6% lower than that in 2010. The revenue in 2033 is a bit over £183 million. This figure is about 165% higher than the figure of the year of 2012. However, the revenue then increases steadily year on year in line with traffic. In general, the revenue shows patterns similar to that of traffic demand as expected.

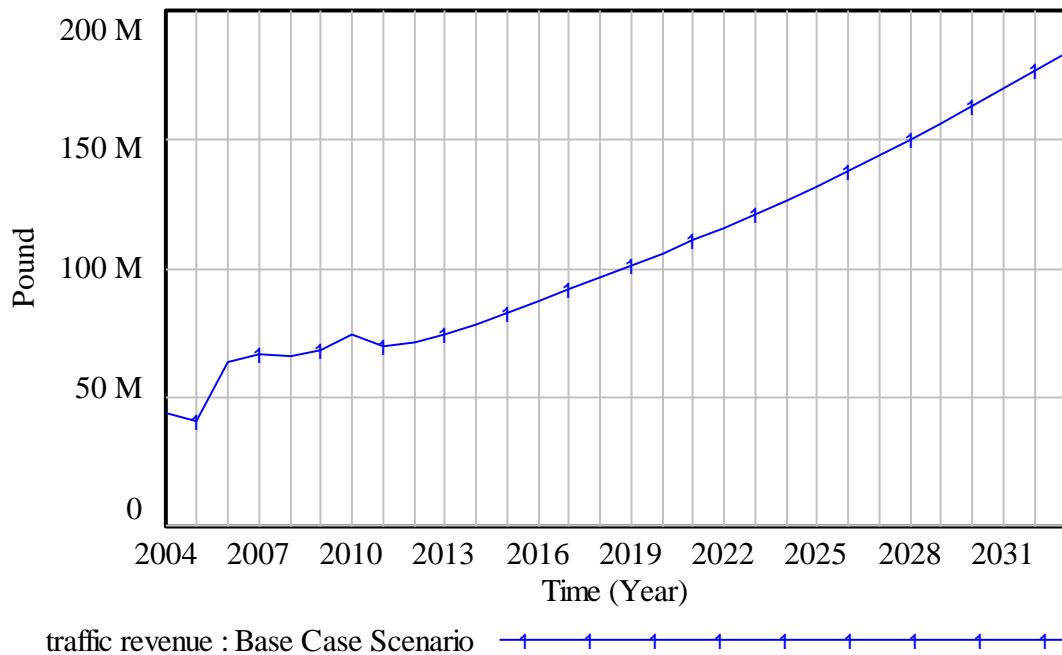


Figure 8.22: Toll or Traffic Revenue

$$\begin{aligned}
 \text{traffic revenue} = & ((\text{AADT0} * (1 + \text{proportion of intermediate traffic}) * \text{Toll} + \text{HGVs} \\
 & \text{revenue}) * \text{ramp up effect}) * 365
 \end{aligned}$$

## 8.6. Summary

This chapter illustrated the SD model simulation. Although the model can be used for any toll road, in this study it was calibrated against M6 toll road (UK). The implementation of the case study in the software “Vensim” demonstrated how the model can be used. The model was run for this specific facility and the input values for the model were obtained from the M6 toll documents and stakeholders. Based on the existing data of socio-economic factors, the model produced fairly sound figures for the regional traffic. Using the overall economic and demographic growth rate in West Midlands over the next 21 years and the projected economic and demographic trends,

the model also predicted the potential future values. Toll share was estimated using WTP, travel time saving toll rate and other variables in the model. The model then estimated the current and most likely future usage of the facility. By comparing the SD model results with the data available, the SD model showed a reasonable conformance with the observed traffic demand. Further comparisons are conducted in the model validation stage discussed in the next chapter. Next chapter will validate the model structure and examine its behaviour so that a range of potential events and trends which are likely to influence traffic demand on M6 Toll can be tested.

## **Chapter Nine: Validation and Model Testing**

### **9.1. Introduction**

Validation is an important aspect of simulation based models. Model outcomes validity is heavily based on the validity of model itself. The previous chapters presented the model structure and the model base case outputs. This chapter will examine the model structure and use the base case outputs to validate and test the model behaviour. The chapter therefore presents a range of tests which helps assess the robustness of the proposed model with respect to its structure and behaviour. The purpose of these tests is to further calibrate and validate the model so that it can be used for sensitivity, policy and risk analysis as will be discussed in the next chapter.

### **9.2. Model Validation**

Model validation is a core element of any model development process like SD and is a critical measure for the model quality and viability. While verification means checking the reality of the model, validation refers to ensuring that the model supports the objective truth (Sterman, 2000). However, due to the fact that the models are based on several limiting assumptions, no model is an exact representation of reality. Given this, Sterman (2000) argues that it is impossible for any model to be verified and validated. Forrester (1961) therefore prefers to use the term “significance” rather than “validity” and suggests that the validity should be judged by the model’s appropriateness for a particular purpose. Forrester (1992) argues that there is no way to prove validity of a theory which claims to represent real-life behaviour. Only a degree of confidence can be achieved in a model which is a compromise between adequacy, time, and cost. Model validation is thus the process of establishing confidence in the soundness and usefulness of a model with respect to its purpose (Forrester and Senge, 1980). In this context, validation aims to assess the usefulness of the model.

Unlike correlational or data driven models for which validation is only based on the aggregate output behaviour, causal descriptive models (e.g. system dynamics) validation is based on the validity of the internal structure of the model beside reproduction of the real behaviour (Barlas, 1996). For this kind of models, it is not enough to reproduce the real system behaviour, but also to explain how this behaviour is generated. SD model validation thus includes two broad type of validation: structure validation and behaviour validation. Structure validation means ensuring that the model adequately captures and represents the real system considering the purpose of the model. Behaviour validation, on the other hand, is to ensure that the model outcome behaviour is close to the real system behaviour.

There are a number of tests to assess the validity of SD models in terms of structure and behaviour. The typical testes of model validation which are extensively applied by current research in the area of SD include;

1. Structure-oriented test: boundary adequacy tests, structure assessment tests, dimensional consistency tests, parameter assessment tests and extreme condition analysis tests.
2. Behaviour-oriented test: Behaviour reproduction tests and sensitivity analysis.
- 3.

Table 9.1 summarizes these tests by exhibiting the purpose of the test and the recommended tools to conduct it. These tests will be conducted for the proposed model and discussed in Section 9.4 and Section 9.5.

### **9.3. Participations in the Model Validation**

Since validation means usefulness in regard to a particular purpose as discussed above, model validation would necessarily involve subjective and qualitative aspects. Barlas (1996) argues that judging the validity of a model ultimately involves judging the validity of its purpose which is primarily a qualitative process. Model validation cannot be merely objective, it should rather include semi-formal and subjective components (Forrester, 1961; Forrester 1968; Forrester and Senge 1980; Andersen 1980; Meadows 1980; Richardson and Pugh 1981; Sterman 1984; Barlas & Carpenter 1990; Lane 1995 and Barlas, 1996). The information required for validating the model structure particularly is

Table 9.1: SD Validation Tests

Test	Purpose of Test	Recommended Tools and Procedures
<b>Structure tests:</b>		
Boundary Adequacy Tests	Whether the important concepts and structures for addressing the problem are endogenous to the model.	Using model boundary chart, causal diagrams and stock and flow diagrams. Use interview, workshops, archival material and literature review
Structure Assessment	Whether the model structure is consistent with relevant descriptive knowledge of the system and whether the model conforms to basic physical laws.	Using causal loop diagrams, stock and flow diagrams. Using interview and workshops to solicit expert opinion and archival materials.
Dimensional Consistency	Whether each equation in the model dimensionally corresponds to the real system.	Using dimensional analysis software.
Parameter Assessment	Whether the parameters in the model are consistent with relevant descriptive and numerical knowledge of the real system.	Using statistical methods to estimate parameters. Using judgemental method based on interview, expert opinion, focus group and archival materials.
Extreme Condition Analysis	Whether the model respond plausibly when parameters are assigned extreme values.	Testing response to extreme values of each input, alone and in combination.
<b>Behaviour tests:</b>		
Behaviour Reproduction	Whether the model is plausibly able to reproduce behaviour pattern displayed by the real system and whether the model generate various modes of behaviour observed in the real system.	Calculating statistical measures of correspondence between model outcomes and available data (e.g. $R^2$ , MAPE). Comparing model output and data qualitatively including model of behaviour and shape of variables.
Sensitivity Analysis	Whether the plausible shifts in parameters values lead the model to behave implausibly	Perform univariate and multivariate sensitivity analysis.

(Adapted from Sterman, 2000)



merely qualitative and need to be captured from the experts' mental modes. Churchman (1973) states "*a model is realistic to the extent that it can be adequately interpreted, understood and accepted by other points of views*". The model suitability to its purpose is largely a matter of its acceptability to the client (Coyle, 1996). Therefore, the participation of stakeholders of toll roads was regarded crucial for validating the proposed SD model.

As discussed in chapter six, a series of interviews with PPP experts was conducted in order to verify the CLDs or the qualitative SD model. However, another series of semi-structured interviews with seven experts in toll roads were conducted to validate the quantitative simulation model. Experts were mainly selected based on their experience. This would ensure that the opinions and perceptions gathered would soundly assess the model validity and usefulness. The experts engaged in the validation process were mainly from industry (private and public) with hands-on experience in toll road projects. One academic also participated in the exercise because of his experience in both toll roads and SD. Table 9.2 shows the profile of the respondents who took part in the validation exercise.

The experts from the industry were from the public (17%), private (17%), consultancy (33%) and modelling (33%) sectors. In terms of academic qualification, 28% of the participants have a bachelor degree, and 43% have a master's degree and 29% have a PhD. The average year of experience in their sectors is 15 years. Only one of the experts interviewed has experience in the SD field. Technical knowledge in terms of understanding the background of the problem at hand as well as the wide experience of the chosen experts guaranteed a high level of judgmental ability.

The interview started with a brief description of the research problem, aim and objectives. The aim of the validation was also made clear to the participants. To achieve the validation task, the experts were presented with the model structure, a collection of the model outputs from the base case run and some scenarios. Therefore, the experts had a chance to review both the model structure and its outputs. The experts were asked to assess the model and evaluate its behaviour in terms of;

- Clarity of purpose: Whether the model fulfils the intended function for which it has been built,

- Conceptually valid: relationships among variables are theoretically and empirically compelling, and
- Behaviourally valid: behaves in a reasonable manner.

Generally, the experts confirmed that the model is appropriate as a tool for demand traffic risk assessment. They also ascertain the logical structure of the model and its applicability.

Table 9.2: Validation Respondent Profile

<b>Sector</b>	<b>Academic Qualification</b>	<b>Years of Experience</b>
Industry/Private sector	Bachelor's degree	20-25
Industry/Consultant	PhD	20-25
Industry/Consultant	Bachelor's degree	20-25
Industry/Public	Master's degree	5-10
Industry/Modeller	Master's degree	10-15
Industry/Modeller	Master's degree	5-10
Academia	PhD	10-15

The following sections discuss the main test conducted to validate the proposed SD model and how the input from the interviewees assessed the model validity.

#### **9.4. Structure-oriented Tests**

The aim of the structure-oriented tests is to ensure that the model structure adequately replicates the real system with respect to its purpose. The model should include the relative elements of the real system (Barlas, 1996). This section introduces in details the tests conducted to assess the SD model validity with respect to its structure as recommended by Sterman (2000). All the tests listed under structure oriented test in Table 9.1 were applied to evaluate the validity of the demand SD model.

##### **9.4.1. Boundary Adequacy Tests**

Boundary adequacy test assesses the appropriateness of the model boundary for the problem in question (Sterman, 2000). It therefore aims to assess whether the structure of

the model includes all the relevant elements and satisfies the purpose for which the model was built.

For the research in question, in the conceptualisation stage of the model development process, the CLDs were created based on the literature review. The model elements and cause-effect relationships were then assessed and validated to ensure the model boundary is adequate and appropriate for the purpose at hand, as illustrated in chapter six. Nine preliminary interviews with PPP experts and practitioners were conducted in the first round of interviews to validate these CLDs as discussed in chapter six. The feedback from the interviewees suggested that the model captured the important factors and the significant relationships related to demand for service provided by PPP projects. The inputs from the experts ascertained that no significant concepts were omitted with respect to the model purpose.

Moreover, the model boundary charts shown in Table 7.2, is one of the useful tools to conduct the boundary adequacy test. The table shows which variables were excluded, which variable were exogenous inputs, and which variables were endogenously calculated in the SD model. Reviewing relative literature and archival materials and then conducting the second round of interviews with key experts, discussed in Chapter Five (Section 5.6.3) and Seven (Section 7.3), were the main source for identifying the model boundary. The expert interviews helped ensure explicit identification of the model boundary and guarantee the model boundary is adequate and appropriate for the purpose at hand.

#### **9.4.2. Structure Assessment Tests**

Coyle and Exelby (2000) consider validation as the assurance that the model structure meets the purpose of which it has been built. As in Table 9.1, structure assessment test means comparing the model structure with the structure of the real system. To pass the test the model must not contradict with the knowledge of the real system (Forrester and Seng, 1980). For instance, a system model relationship should not contradict or conflict with an established real relationship. Sterman (2000) recommends that modellers should test their model structure as they build it. Structure assessment test was thus done during the modelling process: first, in the conceptualisation stage (CLDs validation) and then

in the formulation stage (stock and flow diagrams) and ultimately at the validation stage.

The inputs from the experts were the main way to assess the validity of the model structure. The experts and practitioners of the real system were asked to evaluate the qualitative model structure as discussed in chapter six (CLDs validation) and the quantitative model structure as discussed above in section 9.3. The feedback from the validation participants in both the qualitative (CLDs) and quantitative (stock and flow diagrams) model structure concluded that the SD model structure adequately captures the information underlying the real system. The important variables and relationships were included and ideally represented in the model.

In addition, in the course of the validation stage interviews, besides the variables and relationships, some of the model equations were inspected and assessed to ascertain that they do not conflict with or violate physical laws.

#### **9.4.3. Dimensional Consistency Tests**

The aim of this test is to ensure that the measurement units of all the variables and constants involved in each mathematical equation of the model are dimensionally consistent (i.e. in (unit) = out (unit)). The dimensional consistency of the SD model in question was assessed using Vensim automated dimensional analysis function. The software automatically checks the units of all the variables included in the model. The dimensional analysis showed that there is no unit error and all the variables and equations are consistent.

#### **9.4.4. Parameter Assessment Tests**

Parameter assessment test means comparing model parameters to observations of the real life to determine whether the parameters correspond conceptually and numerically to the real system (Forrester and Seng, 1980). To evaluate the model parameters, Sterman (2000) suggests using statistical and judgemental methods (Table 9.1). The values assigned to the parameters of demand SD model are sourced from the available numerical data and existing knowledge. Table 9.3 lists some of the model parameters including the socio economic sub-model parameters (GDP growth, population growth

and employment growth) and toll change, their values and the source. The table shows that the values assigned to each parameter of the SD model are within the range of actual values.

Table 9.3: Some SD Model Parameters, Values and Sources

Parameter	Period	Values	Source
Population Growth rate	2004	0.0069	ONS, StatsWales,
	2005	0.0052	
	2006	0.0049	
	2007	0.0049	
	2008	0.0046	
	2009	0.0044	
	2010	0.0071	
	2011	0.0067	
	2012	0.0067	
	2013-2030	0.0037	
Employment Growth rate	2004	0.019	ONS, StatsWales,
	2005	0.002	
	2006	-0.013	
	2007	0.000	
	2008	-0.028	
	2009	0.130	
	2010	0.000	
	2011	0.035	
	2012	0.000	
	2013-2030	0.004	
GDP Growth rate	2004	0.021	International Monetary Fund (IMF)
	2005	0.026	
	2006	0.035	
	2007	-0.001	
	2008	-0.044	
	2009	0.021	
	2010	0.007	
	2011	0.008	
	2012	0.02	
	2013-2030	0.021	
Toll change	2004	0.5	M6 toll website, Five Year After report (FYA)
	2005	0.5	
	2006	0	
	2007	0.5	
	2008	0.2	
	2009	0.3	
	2010	0.3	
	2011	0.2	
	2012	0	
	2013-2030	0.35	

#### 9.4.5. Extreme Conditions Analysis

Extreme condition test assesses the model robustness under the extreme values of its parameters. Robustness means the model behaves plausibly disregarding how extreme the inputs are (Sterman, 2000). For instance, the demand for service should fall to zero when the tariff is extremely high. Extreme conditions test therefore requires assigning extreme values to some of the model parameters and comparing the model outcomes behaviour to the observed or anticipated behaviour of the real system under similar extreme conditions.

For the model in concern, extreme condition tests were conducted by establishing upper and lower limits for some exogenous variables, with all other variables remained constant. For instance, the model was evaluated based on its response to extreme values of toll change and VTTS change rate. Toll change was varied between £0 and £2 per year and VTTS change rate between -5% and 5%. The impact of change was assessed using the toll share variable. Toll share is the most significant variable in the model since it determines the facility share of the corridor traffic based on toll and value of time and some other variables in the model. The simulation results showed that the model outcome behaviour related to toll share variable is plausible under the assumed extreme conditions for toll change and VTTS change rate as shown in Figure 9.1 through Figure 9.4.

Under lower level of toll, it is expected the toll share of the facility will increase over time. Under the assumption of toll change is equivalent to zero; the toll rate will stand for £5.5 over the next period of operation stage. Fixed toll share combined with increased VTTS will results in higher toll share as illustrated in Figure 9.1. On the other hand, high increase in toll rate will decrease the toll share as shown in Figure 9.2. This increase in VTTS will not be able to meet the higher increase in toll rate and the demand decline constantly.

On the contrary, when VTTS grows much faster than toll rate, this will increase the facility toll share and enhance the overall demand as shown in Figure 9.3. Figure 9.4 shows the opposed situation where VTTS decline steadily over time with combined increase in toll rate for using the facility which leads to steep declination in toll share.



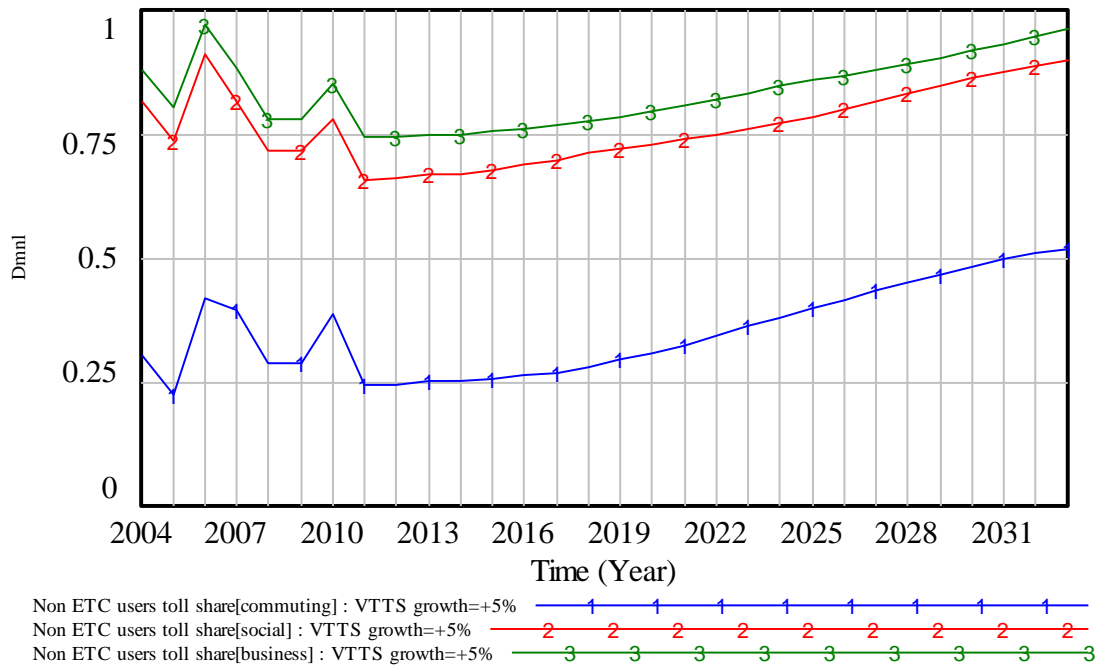


Figure 9.3: ETC Users Toll Share under VTTS Change Rate of +5%

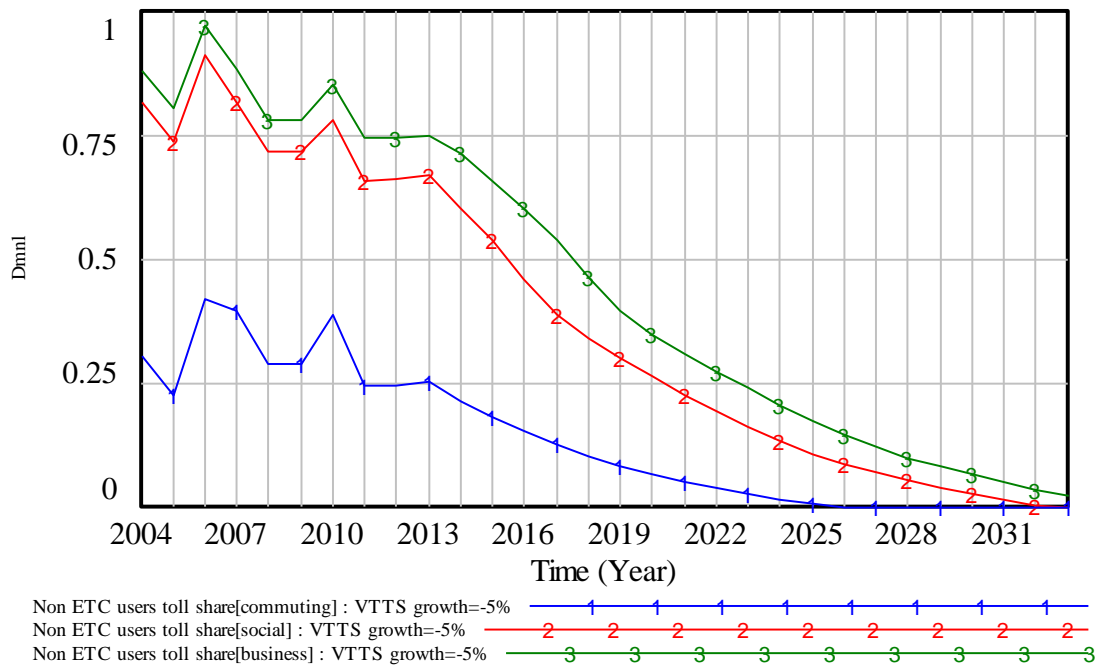


Figure 9.4: ETC Users Toll Share under VTTS Change Rate of -5%



## **9.5. Behaviour-oriented Tests**

Once confidence has been established in the validity of the model structure, certain tests are applied to measure how the model can accurately reproduce the pattern exhibited by the real system behaviour. Behaviour oriented test aims to test the model capacity to replicate the real system behaviour (Barlas, 1996). Two key tests were conducted to assess whether the demand SD model outcome behaviour is adequately close to the observed and anticipated real system behaviour. These tests include: behaviour reproduction test and sensitivity analysis.

### **9.5.1. Behaviour Reproduction Tests**

The aim of this test is to measure how the model can accurately reproduce the behaviour pattern displayed by the real system. The test helps to reveal flaws in the structure and parameters and assess if the model fits for purpose (Sterman, 2000) by using historical data. Forrester (1992) suggests that numerical data is useful in two ways: firstly, determining some parameters values and secondly as a way for model validation where the model outcomes could be compared with real time series data. Sterman (2000) supports the previous statement and suggests that when numerical data is available, it is important to assess the model ability to replicate historical data. To do so, statistical significance is the most appropriate technique in testing the accuracy of the model behaviour (Barlas, 1996). The most widely reported statistical measure is the coefficient of determination  $R^2$  and the Mean Absolute Percent Error (MAPE).  $R^2$  measures the fraction of variance of the data explained by the model.  $R^2$  is between 0 and 1.  $R^2=1$  means the model exactly replicates the actual data. Smaller  $R^2$  means there is a variance between the simulated and the observed values. MAPE is one of the broadly used error measures to assess the average error between the simulated and actual data (Sterman, 2000). It is a relative measure which expresses errors as a percentage of the actual data. Lower value of MAPE is preferable as it indicates that smaller percentage errors are produced by the model. Lewis (1982) suggests that a MAPE value less than 10% indicates that the model prediction is highly accurate and a value between 10% and 20% indicates to good prediction.

To validate the model in concern against behaviour reproduction, the base case run of the model presented in Chapter Eight was compared to relative real data by performing

a pattern analysis of the model outcomes and the corresponding real data. The real data available for some of the model variables were used to test the ability of the model to reproduce real system behaviour over the last period of the M6 toll project operation. The real data for the regional traffic and the (AADT) were used. The historical data of the regional traffic from 2004 to 2012 extracted from DfT and the historical data of M6 toll demand traffic obtained from the road operator were used to conduct the test. The test results for the simulated and the actual data, for the regional traffic and M6 toll AADT are shown in Figure 9.5 and Figure 9.6 respectively.

The pattern analysis of the two variables showed that the goodness of fit ( $R^2$ ) was 0.94 and 0.95 for regional traffic and M6 toll AADT respectively. This shows how well the SD model fits and replicates the actual data. Obviously, the model exhibited similar mode of behaviour to that exhibited by the actual data. In addition the mean absolute percentage error (MAPE) of 0.68% for regional traffic and 3.43% for M6 toll AADT shown in Table 9.4 are considered small. In addition, the maximum value of MAPE of the model outcomes in terms of regional traffic and AADT is 1.46% and 9.1% are still adequate as well. This can conclude that the model adequately replicate the real system. This by implication means that the SD model can plausibly predict the anticipated outcomes and it passes the test.

Table 9.4: Model Fit Statistics

<b>Model</b>	<b>R-squared</b>	<b>MAPE%(Mean) (mean)</b>	<b>MAPE% (Maximum)</b>
Regional Traffic	0.94	0.68	1.46
(AADT)	0.95	3.4	9.1

*MAPE= Mean Absolute Percentage Error*

Regional traffic generated by the model is compared by regional traffic data extracted from DfT department (curve marked as 2 in Figure 9.5). The comparison shows how well the model replicated the regional traffic.  $R^2$  value of (0.94) indicates that the model well estimated the regional traffic based on the values of the socio-economic factors (Population, employment and GDP).

AADT generated by the model is compared with actual traffic demand extracted from M6 toll road website (Line marked as 2 in Figure 9.6). This comparison

shows that the modelled traffic is slightly lower than the actual figures. This could be attributed to using a standard level of toll for the whole day rather than using a discounted toll rate for off-peak periods and weekends. However, the difference is trivial and the model accurately replicated the behaviour of the actual traffic.  $R^2$  value (0.95) indicates that the model estimation is fairly sound. Bearing in mind the nature and constraint of data, overall SD model exhibited a reasonable conformance with the observed traffic level. The model outcomes are not only following the trend of the actual traffic but also lying within the ranges of actual figures.

The original demand forecast of M6 toll road was around 70,000 users per day for the first year of operation as discussed in Chapter Eight. The actual traffic in this year is about 45,700 users. The absolute percentage error between the forecasted and the actual figures is around 53%. The proposed SD model predicted 44,400 users in the first year of operation. The absolute percentage error between the SD model estimation and the actual figures is around 2.8%. This result indicates how optimistic the original M6 toll road projection is. In addition, this gives support to the developed model since it predicted the toll traffic demand much more accurately.

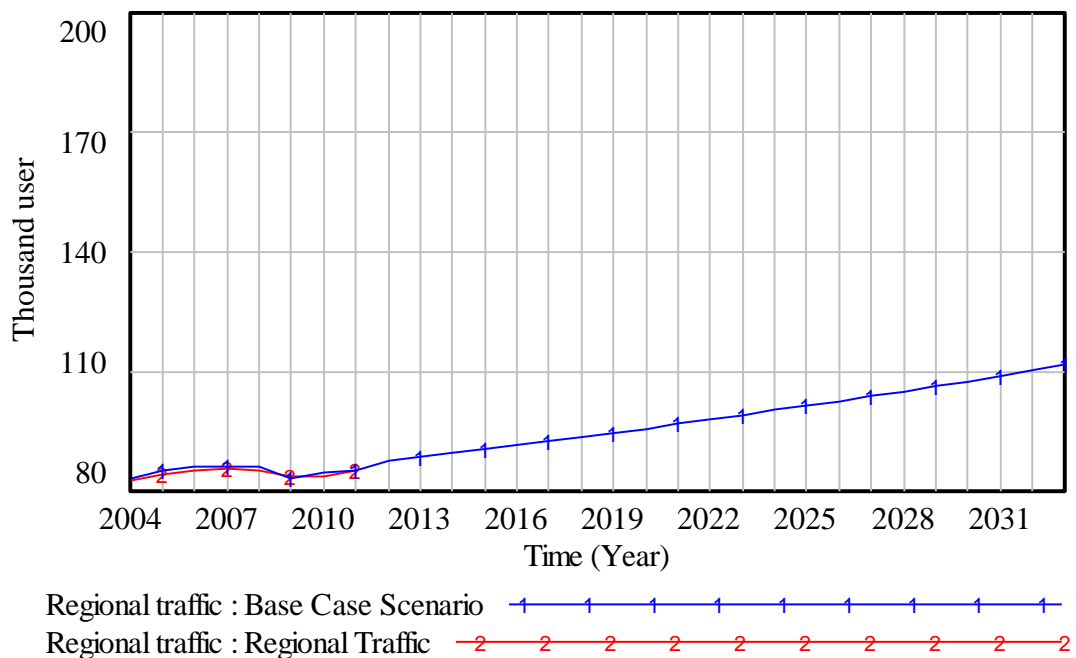


Figure 9.5: Regional Traffic in the Base Case Scenario against the Actual Data

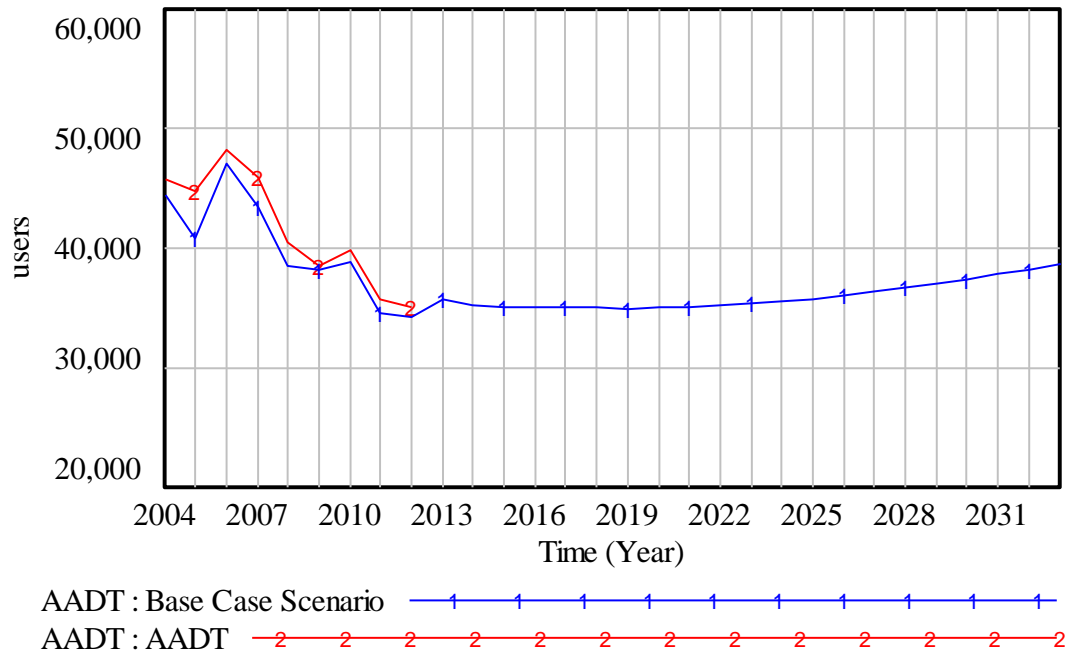


Figure 9.6: Total Traffic Demand in the Base Case Scenario against the Actual Data

### 9.5.2. Sensitivity Analysis

Sensitivity analysis examines whether the model outputs change reasonably when the model assumptions change over plausible level of uncertainty (Sterman, 2000). It therefore seeks to ensure that the model behaves reasonably in response to the main aspects of the real system. As discussed in chapter three, the uncertainty associated with the demand influences could be significant and should be assessed. Sensitivity analysis will therefore be employed to test the SD model in question. To do so, the uncertainty associated with the value of the model variables should be first identified as discussed in Section 3.6.2 in Chapter 3.

The sensitivity analysis test for the proposed model was conducted by assessing the effect of changing the values of the model variables on the model outcomes. The variables were varied simultaneously in a similar way to that reported by Rahmandad and Sterman (2012). The analysis considers two of the model variables: GDP growth rate and employment growth rate over three values each, which reflect the changes to the economic conditions. The two variables are varied around their base values of 0.021 and 0.0037, respectively, as shown in Table 9.5. The full factorial analysis yields a

total of nine scenarios. The analysis runs multiple iterations for each of these scenarios to calculate the corresponding outcome for the regional traffic and the AADT. T-test was conducted to assess the model sensitivity by comparing each scenario outputs with the base case run outputs for regional traffic and AADT. Table 9.5 reports the mean and standard deviation resulted for the regional traffic and the AADT for each scenario. The results show that all the scenarios compared with base case are statistically different. An asterisk indicates that the mean is statistically different, at p- value <0.05, from the base case results based on the t-test.

The test showed that the tested (uncertain) variables affect the SD model behaviour. Further sensitivity analyses will be conducted and elaborated in the next chapter to assess the impact of other factors on the level of demand individually and simultaneously.

Table 9.5: Results of Behavioural Sensitivity Analysis

GDP Growth Rate		Employment Growth Rate		
		0.0027	0.0037	0.0047
0.011	Regional Traffic	95.73(3.85)*	96.42(4.21)*	97.13(4.59)*
	AADT	36297 (776)*	36557(913)*	36819(1056)*
0.021	Regional Traffic	99.86(6.24)*	100.55(6.61)	101.25(6.98)*
	AADT	37824(1703)*	38082(1847.2)	38343(1994)*
0.031	Regional Traffic	104.55(9.16)*	105.25(9.52)*	105.95(9.9)*
	AADT	39538(2838)*	39793(2981)*	40052(3127)*

## 9.6. Summary

The purpose of this chapter is to provide an overview of the model validation process. A series of tests for the SD model were run to investigate the model validity in terms of its structure and behaviour. The tests revealed that both the model structure and behaviour are adequately valid with respect to the model purpose. The model structure test

indicated that the model sufficiently reflects the real system and it is endogenously valid. The behaviour reproduction test revealed that the model is capable of reproducing the behaviour of the SD model variables. The entire validation process did not show any limitations which renders the SD model unusable for the purpose of demand risk assessment. The next chapter discusses how the valid SD model will be used to assess the demand traffic sensitivity and risk.

## **Chapter Ten: Model Application - Sensitivity and Risk Analysis**

### **10.1. Introduction**

Chapter Eight discussed the base case scenario which includes the most likely behaviour of the Average Annual Daily Traffic (AADT) on the M6 toll road. However, as discussed in Chapter Three, most of the factors affecting traffic demand and included in the model are associated with a high level of uncertainty. Any change in one or more of these factors will be translated into a subsequent change in the traffic demand. To assess the uncertainty associated with these influencing factors and its impact on demand; this chapter employs the base case run and introduces sensitivity and risk analysis to examine its behaviour when variations in the assumptions underpinning the key variables occur. Sensitivity and risk analysis are two significant means when dealing with uncertainty. The two methods were performed to gauge uncertainty associated with annual deterministic estimates of demand traffic level generated by the SD model. Two types of sensitivity analysis were conducted: univariate sensitivity analysis (one variable a time) and multivariate sensitivity or scenarios (a combination of variables). Risk analysis, on the other hand, was conducted using Monte Carlo simulation.

Sensitivity analysis seeks to quantify the effects brought to an outcome by variations in the input variables. In Chapter Nine, one exercise of sensitivity analysis was conducted as one of the tests to validate the model behaviour. This chapter, however, introduces wider range of sensitivity analysis aiming to test the uncertainty associated with most of the model inputs. The sensitivity analysis involves the variation of one input by a deterministic value (i.e. simple/univariate sensitivity analysis) or a combination of inputs (i.e. multivariate sensitivity analysis/scenario analysis) to the SD model and the model outputs is then assessed. Thus, the impact on the level of demand resulted from different conditions is evaluated based on input exposed to variations. The risk analysis, on the other hand, evaluates the probability that the outcome will attain a specific value and the variability of this outcome when compared to a specific estimate. Risk analysis is conducted by Monte Carlo simulation. Monte Carlo Simulation assigns a random

value for each input. It thus explains how likely the resulting outcome will be. Next sections will discuss in details the sensitivity and risk analysis conducted in this research.

## **10.2. Univariate Sensitivity Analysis**

To perform univariate sensitivity analysis, a number of selected parameters are varied one at a time. To test the behaviour of the model, the value of a parameter is thus changed while the others remain constant. This provides an indication of the sensitivity of the demand value to each variable. In addition, this sensitivity analysis helps locate the most sensitive/critical parameters in the model.

Chapter Seven presented all the variables included in the model. Out of these variables, the constant variables or parameters which are subject to uncertainty and affect future demand are tested. The parameters list includes; population growth rate, employment growth rate, GDP growth rate, CAF, Value of Travel Time Saving (VTTS) change rate, toll change, rival V/C change and proportion of Heavy Good Vehicles (HGVs). By doing so, the sensitivity of demand to various changes in conditions (e.g. economic conditions) and policy (e.g. toll change) can be tested.

The base case run established in Chapter Eight will be used as the base case scenario. All aforementioned parameters will be varied by  $\pm 100\%$  of their original value (i.e. base case scenario values) with an interval of  $\pm 10\%$  constantly throughout the last 20 years of the model time scale. After changing one parameter value at a time, a new value of AADT is recorded. The resulting outcomes with respect to AADT will be compared to the base case scenario. The analysis is repeated on the other parameters similarly. Next sub-sections present the sensitivity analysis tests conducted for the different model parameters.



### **10.2.1. Population Growth Rate**

Censuses are the main way to collect information about population. In the UK, census is conducted every ten years. During these ten years, the populations are obtained by interpolation and future populations are predicted based on the historical data. The estimation is therefore subject to potential errors and uncertainty. To account for such uncertainty, a simulation is performed by changing the value of the input parameter associated with population growth rate between -100% and +100% of the base case with an interval of 10% while keeping the other parameter unchanged. The results of this test are shown in Table 10.1 and Figure 10.1 which illustrates the change in AADT as a result of upper (100%) and lower (-100%) bound change in the population growth rate.

The sensitivity runs show that the population growth rate of the west midland region has a minor effect on the M6 Toll traffic. The upper and lower values of changes in the population growth rate have resulted in +2.56% and -2.55% in AADT in 2033 respectively. These effects are quite small which may be referred to the fact that motorways riders are mainly long haul passengers rather than commuting. Commuters typically reflect the level of usage by the regional population. Commuters form a minor segment of the corridor traffic and M6 toll traffic. In addition, the interview with M6 toll stakeholder revealed that M6 toll is located in an environment of so many small underprivileged towns which raises the question of affordability. The area housing average price is well below the UK one. People classification stands at D level, this class is barely able to offer toll. Introducing the toll into west midland area forms a real barrier for those of low incomes people to drive the facility which also help explain the low effect of change in population growth rate on the motorway traffic.

Table 10.1: Sensitivity Analysis results for the impact of Population Growth Rate on AADT

The change in population growth rate	Value of population growth rate	Percentage of change in traffic
+100%	0.80%	2.56%
+90%	0.76%	2.42%
+80%	0.72%	2.14%
+70%	0.68%	1.89%
+60%	0.64%	1.60%
+50%	0.60%	1.33%
+40%	0.56%	1.06%
+30%	0.52%	0.80%
+20%	0.48%	0.52%
+10%	0.44%	0.26%
-10%	0.36%	-0.26%
-20%	0.32%	-0.52%
-30%	0.28%	-0.78%
-40%	0.24%	-1.03%
-50%	0.2%	-1.29%
-60%	0.16%	-1.57%
-70%	0.12%	-1.88%
-80%	0.08%	-2.12%
-90%	0.04%	-2.40%
-100%	0	-2.55%

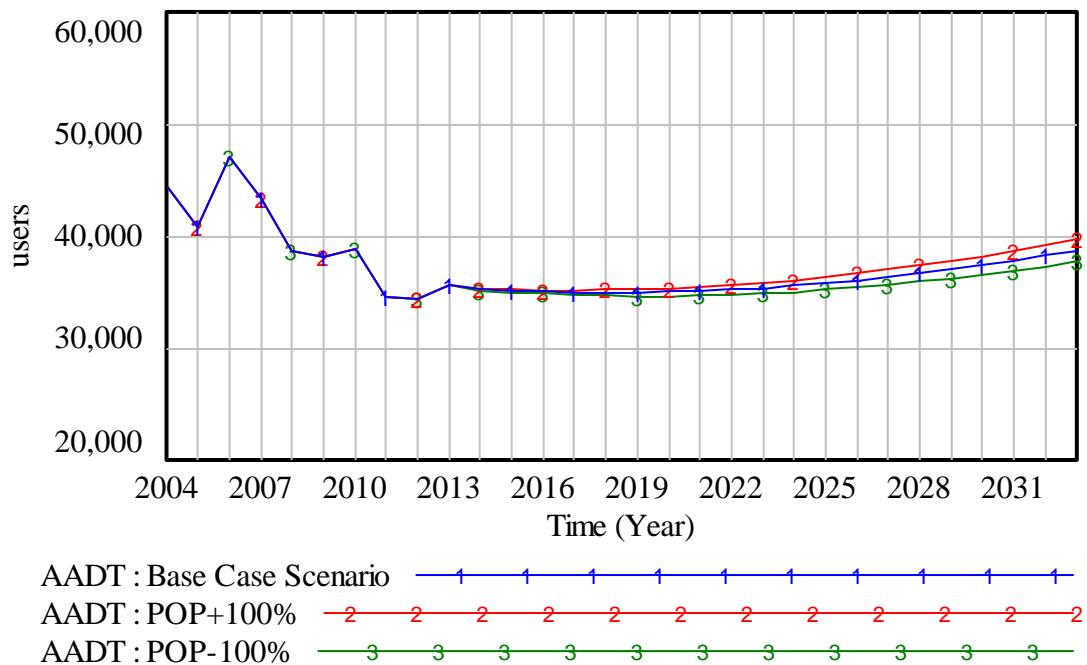


Figure 10.1: Impact of Change in Population Growth Rate on AADT

### 10.2.2. Employment Growth Rate

There are typically different views on the likely employment trends in the future, particularly due to different prospects regarding the future growth in the economy and potential land use plans. This leads the employment growth rate to be subject to a level of uncertainty. This test provides an indication about the model outputs when the employment growth rate is different from the rate of the base case scenario. The range of change in employment growth rate is assumed to be between -100% and +100% with 10% interval.

The results of the test are shown in Table 10.2 and graphically in Figure 10.2. The results suggest that there is a higher level of sensitivity to the employment growth rate than that to the population growth rate. As shown in Figure 10.2, a 100% increase and decrease in the employment growth rate causes a cumulative change of +5.00% and -4.3% in AADT in 2033 respectively. While it is common that traffic on tolled motorways is sensitive to the evolution of regional economic activities, M6 toll shows slight sensitivity to change in employment growth rate. The fact that M6 toll is mainly long haul route and commuters are minority may again explain the low sensitivity of AADT to change in employment growth rate.

Table 10.2: Sensitivity Analysis results of the impact of Employment Growth Rate on AADT

The change in Employment growth rate	Value of Employment growth rate	Percentage of change on AADT
+100%	0.74%	5.00%
+90%	0.70%	4.70%
+80%	0.67%	3.38%
+70%	0.63%	3.04%
+60%	0.59%	2.86%
+50%	0.56%	2.37%
+40%	0.52%	1.89%
+30%	0.48%	1.41%
+20%	0.44%	0.94%
+10%	0.41%	0.47%
-10%	0.333%	-0.47%
-20%	0.296%	-0.93%
-30%	0.259%	-1.39%
-40%	0.222%	-1.84%
-50%	0.185%	-2.30%
-60%	0.148%	-2.75%
-70%	0.111%	-3.19%
-80%	0.074%	-3.64%
-90%	0.037%	-4.08%
-100%	0	-4.30%

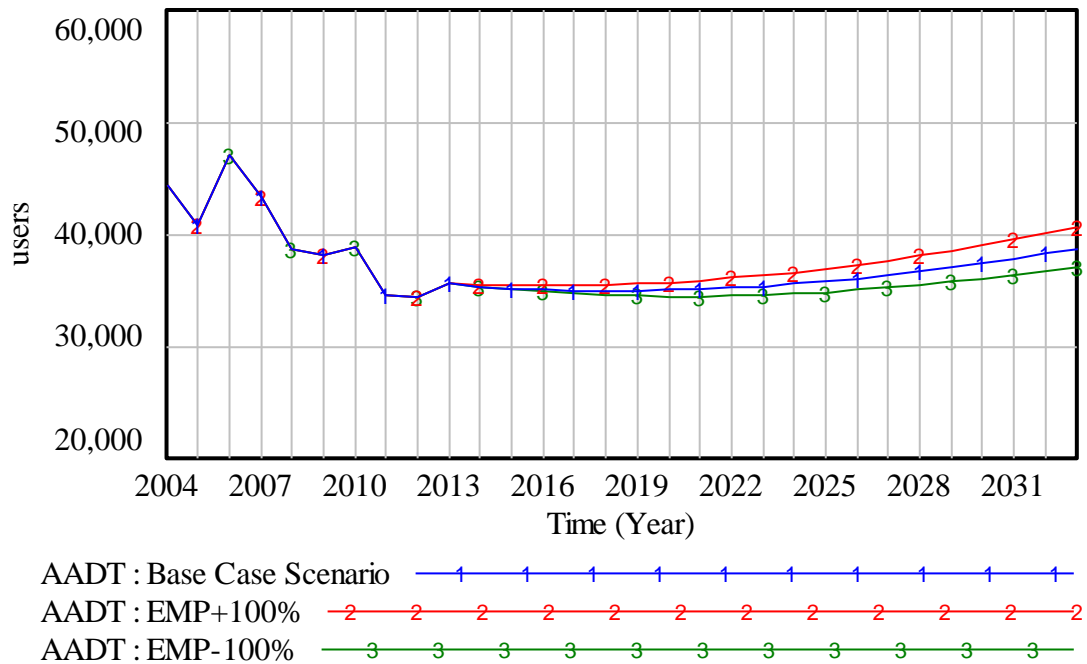


Figure 10.2: Impact of Change in Employment Growth Rate on AADT

### 10.2.3. GDP Growth Rate

Gross Domestic Product (GDP) is the economic variable used to capture the national evolution of the economic activities. There are different degrees of confidence about the capacity of a national economy to grow at a certain rate in the future. In Chapter Eight, the model assumed the historical trend will continue in the future and made use of an average annual GDP growth in the UK of 2.13% for the period from 2013 to 2033 to reflect the country economic performance. In this chapter and for the sensitivity analysis purpose, the GDP growth rate is subject to changes between -100% and +100% as compared to the base case with an interval of 10%.

The results of this test are shown in Table 10.3 and Figure 10.3. The sensitivity runs outputs suggest that doubling the GDP growth rate will lead to about 22% increase in AADT by 2033. On the other hand, decreasing GDP growth rate by 100% leads to about 16% decrease in AADT. This figure is more than 8 times that of the population rate and more than 4 times of that of employment rate. The test outcomes suggest that traffic shows a much higher sensitivity to national GDP than that to regional population and employment. As discussed above, M6 toll is mainly long haul route where social

and recreational trips as well as business trips constitute the majority of M6 toll traffic. These kinds of trips are best represented by GDP identified at the national level. Given this, traffic on M6 toll roads would be highly sensitive to the change in the performance of the national economy since it represents the large portion of its traffic. The sensitivity analysis results are also in full agreement with the interviews output of M6 toll stakeholders. Most of the interviewees attributed the less than predicted usage performance during the last period of the operation stage to the recession in the UK economy. One of them commented “*I would think it [recession] is inhabited the long distance growth*”. Another added “*The impact of recession was frankly devastating.*” The downturn in the UK economy was considered to have significantly affected the road performance.

Table 10.3: Sensitivity Analysis results of the impact of GDP Growth Rate on AADT

The change in GDP growth rate	Value of GDP growth rate	Percentage of change in traffic
+100%	4.60%	22.01%
+90%	4.37%	20.73%
+80%	4.14%	17.04%
+70%	3.91%	13.44%
+60%	3.68%	11.93%
+50%	3.45%	9.50%
+40%	3.22%	7.10%
+30%	2.99%	6.69%
+20%	2.76%	4.37%
+10%	2.53%	2.14%
-10%	2.07%	-2.06%
-20%	1.84%	-3.04%
-30%	1.61%	-4.93%
-40%	1.38%	-5.76%
-50%	1.15%	-7.52%
-60%	0.92%	-9.19%
-70%	0.69%	-10.81%
-80%	0.46%	-11.36%
-90%	0.23%	-13.85%
-100%	0	-15.52%

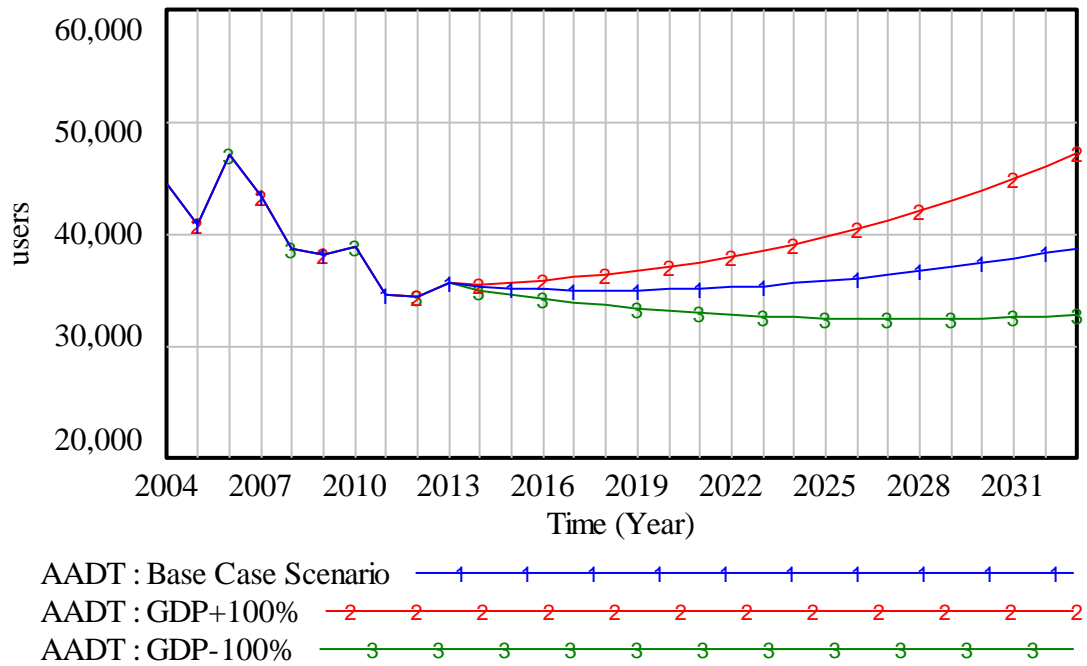


Figure 10.3: Impact of Change in GDP Growth Rate on AADT

#### 10.2.4. Corridor Traffic Growth

As discussed in chapter seven and eight, Corridor Adjustment Factor (CAF) is used to adjust the regional growth rate into the corridor one and its value is determined based on the historical trends of the traffic growth in the corridor. This factor simply reflects the growth in the corridor traffic. Changes to the value of this factor are therefore translated into similar changes in the corridor traffic growth. Corridor traffic may show different behaviour than that of regional one due to any kind of developments or amount of sprawl in the land use associated with the corridor area which may affect the corridor traffic more than the regional one. Land use data may contain errors owing to the fact that they are based on sample rather than the whole population. In addition, translating the land use scenario into values to be assigned to the model input is another source of uncertainty. Moreover, the government policy pertinent to land use may change in the future adding further uncertainty to the future level of demand. Given this, it was important to study the sensitivity of AADT to this factor.

The CAF sensitivity analysis results show that M6 toll traffic is significantly sensitive to corridor traffic growth rate. A +100% and -100% change in the corridor traffic growth rate, represented by +100% and -100% in CAF, resulted in approximately 26% and -23% change in AADT respectively as shown on Table 10.4 and graphically in Figure

10.4. The results suggest that the rate of growth of corridor traffic is critical to the M6 toll traffic. The implication of this test is significant to the policy makers. The plans of the land use or connective roads which may directly affect the corridor traffic are of particular importance to enhance the toll road usage.

Table 10.4: Sensitivity Analysis results of the Impact of Corridor Traffic Growth on AADT

The change in CAF	Value of CAF	Percentage of change in traffic
+100%	2	26.30%
+90%	1.9	24.03%
+80%	1.8	22.89%
+70%	1.7	20.82%
+60%	1.6	17.79%
+50%	1.5	14.81%
+40%	1.4	11.87%
+30%	1.3	8.80%
+20%	1.2	5.80%
+10%	1.1	2.87%
-10%	0.9	-2.80%
-20%	0.8	-4.53%
-30%	0.7	-8.21%
-40%	0.6	-7.76%
-50%	0.5	-13.38%
-60%	0.4	-15.87%
-70%	0.3	--18.69%
-80%	0.2	-20.01%
-90%	0.1	-21.28%
-100%	0	-22.71%

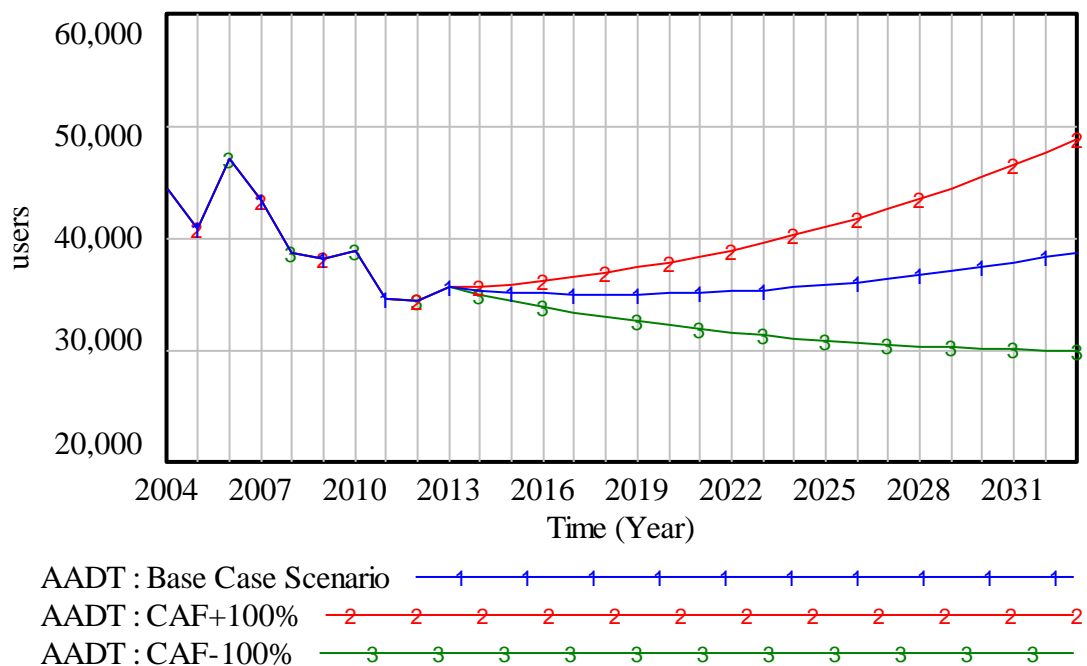


Figure 10.4: Impact of Change in Corridor Traffic Growth on AADT

### 10.2.5. Value of Travel Time Saving (VTTS) Growth Rate

As discussed in Chapter Three, VTTS is the monetary value determined by passengers to each unit saved of the travel time. VTTS is a function of the user wealth. The change in the income and the overall wealth make it so important to estimate VTTS over the whole period of the operation stage. In Chapter Eight, VTTS was assumed to grow in line with the GDP as recommended by Transport Analysis Guidance (TAG) (DfT, 2012). GDP growth rate prediction, however, is subject to a degree of uncertainty as discussed above. It was therefore important to assess the impact of change in VTTS growth rate on the level of toll traffic.

Table 10.5 summarises the results of testing the sensitivity of the future AADT to changes in the VTTS growth rate. In addition, Figure 10.5 graphically shows the results of 100% increase and decrease in the VTTS growth rate. The results suggest that AADT is relatively sensitive to change in VTTS growth rate. For 2015, the range of percentage change resulting from 100% increase and 100% decrease in VTTS growth rate is +1.5% and -1.4 % respectively. For 2025, the range of percentage change resulting from 100% increase and 100% decrease in VTTS growth rate is about 10% and -13%. For 2033, a 100% increase in the growth rate yields about 16% cumulative increase in AADT. Much less increase of 10 % in VTTS led to cumulative effect of about 1% increase in AADT by 2033. However, decreasing in VTTS has higher effect on AADT. With a 100% declination in VTTS cases, AADT declines by about 22% in 2033. This is mainly attributed to the non-linear relationships used in the model.

VTTS assesses how toll rate affects route choice (toll route against competing untolled route). The higher growth in VTTS against constant toll rate thus indicates that motorists' value the time saved higher than the toll paid for using the facility. The implication of this is higher toll share and subsequent increase in the usage level of toll facility. Thus, the higher the VTTS will be, the more rigid is the demand.



Table 10.5: Sensitivity Analysis results of the impact of VTTS Growth Rate on AADT

The change in VTTS growth rate	Value of VTTS growth rate	Percentage of change in traffic
+100%	3.20%	15.79%
+90%	3.04%	13.58%
+80%	2.88%	12.56%
+70%	2.72%	11.07%
+60%	2.56%	10.30%
+50%	2.40%	8.52%
+40%	2.24%	6.89%
+30%	2.08%	4.37%
+20%	1.92%	2.36%
+10%	1.76%	0.90%
-10%	1.44%	-1.23%
-20%	1.28%	-6.53%
-30%	1.12%	-9.65%
-40%	0.96%	-12.58%
-50%	0.8%	-14.87%
-60%	0.64%	-16.3%
-70%	0.48%	-17.98%
-80%	0.32%	-18.73%
-90%	0.16%	-20.05%
-100%	0	-21.65%

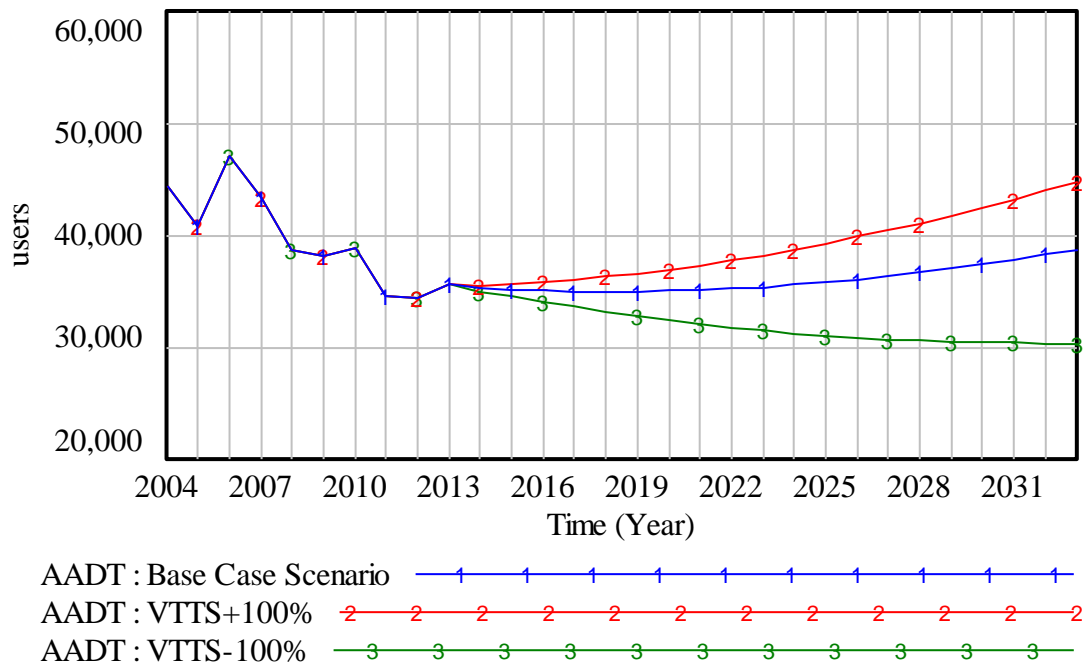


Figure 10.5: Impact of Value of Travel Time Savings Growth on AADT

### 10.2.6. Change in Toll Rate

Toll is a significant force which considerably influences demand for toll route. Toll is typically altered over time, often in response to market conditions. This is, however, not always the case. The toll adjustment is not certain. In many instances, the private operator may charge a toll which is below the level specified in the concession agreement if the demand is well under predicted to attract more users. In addition, political and social opposition may place restrictions on the concessionaire ability to increase tolls as initially specified in the concession agreement. A toll road concession in Parana (Brazil) was affected by such political interference. In this case, the local government forced the concessionaire to charge only 50% of the original tariff (Estache et al., 2000). Economic and financial analysis of toll roads should therefore necessarily consider the failure to increase tolls for several years. To address such uncertainty, the potential growth in level of toll is varied within the range of -100% through to +100% of the original value used in the base case run with an interval of 10%.

Table 10.6 summarises the results of testing the sensitivity of the AADT to the changes in the toll growth. In addition, Figure 10.6 shows the AADT response to change of upper bound (+100%) and lower bound (-100%) in toll growth. The results show that traffic is relatively sensitive to the level of toll imposed to use the toll route. For 10% increase in the assumed growth in toll rate, the results indicate about -0.28% decrease in traffic level in 2014 and 3.6% by 2034. This 10% increase in the toll growth implies 0.6% increase in the £5.85 toll imposed to use the toll route in 2014. The 0.6% increase in the toll level therefore produces -0.28% change in AADT. This implies short term elasticity to toll level of -0.47. This elasticity value is in the range of -0.21 to -0.83 reported by Matas and Raymond (2003) study on demand elasticity on toll roads in Spain. In addition, the result shows (Figure 10.6) that 100% increasing in toll growth (an annual increase of £0.7 instead of £0.35) constantly throughout the next 20 years caused AADT to decrease by 2.8 % in 2014 , 24% in the year 2024, and 31% in the year 2033. On the other hand, reducing toll growth resulted in higher traffic using the road as expected. A constant 100% decrease per year (Freezing toll at £5.5) in toll growth led to cumulative increasing over time to about 38% in the level of usage in 2033. This is due to the fact that reducing the toll rates will induce travel demand.

Toll rate has a direct effect on traffic revenue. Figure 10.7 shows the change in revenue generated from traffic under 100% variations (increase and decrease) in toll change. The 100% reduction in toll decreases toll revenue by 35% in 2033. On the other hand, increasing toll change by 100% resulted in only 9% subsequent increase in toll revenue. The implication of the test is that increasing toll does not necessarily lead to similar increase in revenue. Revenue is the function of toll and demand. Toll increase puts the motorist off and most probably leads to reducing in demand level. When the declination in demand is high, the increase in toll won't be able to compensate the shortage in revenue resulted in the demand declination. Toll adjustment policy should therefore consider the declination in demand resulted from increase in toll and its impact on the facility revenue.

Table 10.6: Sensitivity Analysis results of the impact of Toll Change on AADT

The change in Toll growth	Value of Toll growth	Percentage of change in traffic
+100%	£0.70	-30.99%
+90%	£0.67	-27.69%
+80%	£0.63	23.37%
+70%	£0.60	-21.82%
+60%	£0.56	-19.07%
+50%	£0.53	-15.31%
+40%	£0.49	-12.53%
+30%	£0.46	-9.47%
+20%	£0.42	-6.61%
+10%	£0.39	-3.60%
-10%	£0.315	3.18%
-20%	£0.28	6.53%
-30%	£0.245	9.85%
-40%	£0.21	12.83%
-50%	£0.175	23.29%
-60%	£0.14	29.74%
-70%	£0.105	33.54%
-80%	£0.07	35.90%
-90%	£0.035	36.73%
-100%	£0	37.75%

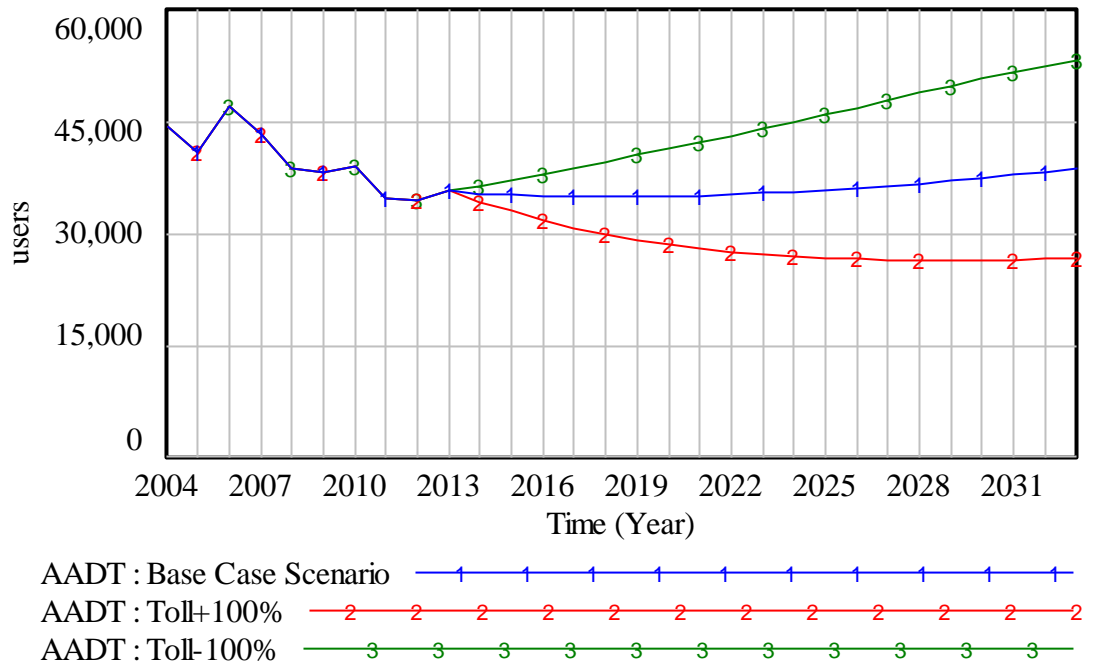


Figure 10.6: Impact of Change in Toll rate on AADT

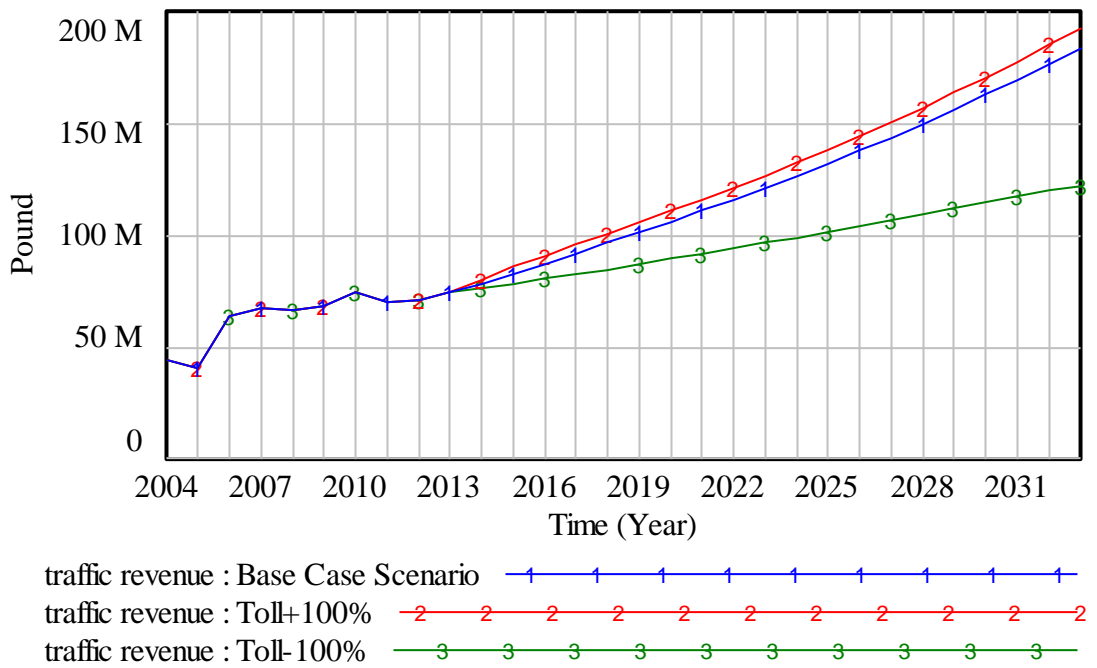


Figure 10.7: Impact of Change in Toll rate on Traffic Revenue

### 10.2.7. Rival V/C Change

Another variable which brings uncertainty to the level of traffic on toll roads is the assumptions about changes to the competitive roads in the future which are mainly based on government plans. In view of potential changes in the circumstances over the prolonged contract period, the government may reserve the right to undertake competitive roads improvements. These plans may or may not materialise in reality. If these plans will be in place, in most cases the resulted improvements to roads may have a negative impact on the usage of tolled facility. It is therefore crucial to analyse the patterns of traffic on the toll route due to changes in the characteristics of the competitive routes in the corridor over the project life. The sensitivity analysis helps address such kind of uncertainty. The potential improvements to competitive route is reflected in the SD model by decreasing the future value of rival V/C which reflects lower level of congestion on the untolled competitive route due to such improvements or capacity expansions. The opposite case of higher level of congestion due to higher traffic growth rate is also addressed. The implications of both cases are reflected by changing the rival V/C between -100% and 100%.

The results of this test are shown in Table 10.8 and Figure 10.8. The results indicate that the effects on traffic are relatively significant. The cumulative declination in AADT is about 29% due to 100% decrease in V/C ratio growth rate on untolled M6. This can be interpreted as if the congestion on the untolled M6 road remains with the same level currently experienced by the motorists due to any kind of road expansion, for instance, the traffic on M6 toll will decrease by 29% by year 2033. This can mainly be attributed to the increase in toll rate. In the shorter time, the sensitivity test suggests that the traffic will be decreased by 9% in the year 2020, 17% in the year 2025 and 24% in the year 2030. On the other hand, the cumulative increase in AADT is about 25% due to 100% increase in congestion growth on the untolled M6. The implication of the test is that failures to upgrade the competitive untolled M6 road would have a positive effect on M6 toll since it results in further redistributions of trips to M6 toll. The more congested the alternative road is, the higher the time saving of using the toll route is, and so the higher is the level of traffic.

Table 10.7: Sensitivity Analysis results of the impact of Rival V/C on AADT

The change in rival V/C growth	Value of Rival V/C growth	Percentage of change in traffic
+100%	0.30%	25.39%
+90%	0.285%	21.53%
+80%	0.27%	18.18%
+70%	0.255%	15.84%
+60%	0.24%	12.26%
+50%	0.225%	9.80%
+40%	0.21%	9.09%
+30%	0.195%	6.77%
+20%	0.18%	4.49%
+10%	0.165%	3.32%
-10%	0.135%	-3.22%
-20%	0.12%	-5.34%
-30%	0.105%	-7.36%
-40%	0.09%	-10.88%
-50%	0.075%	-13.52%
-60%	0.06%	-16.03%
-70%	0.045%	-18.60%
-80%	0.03%	-23.28%
-90%	0.015%	-26.87%
-100%	0	-28.98%

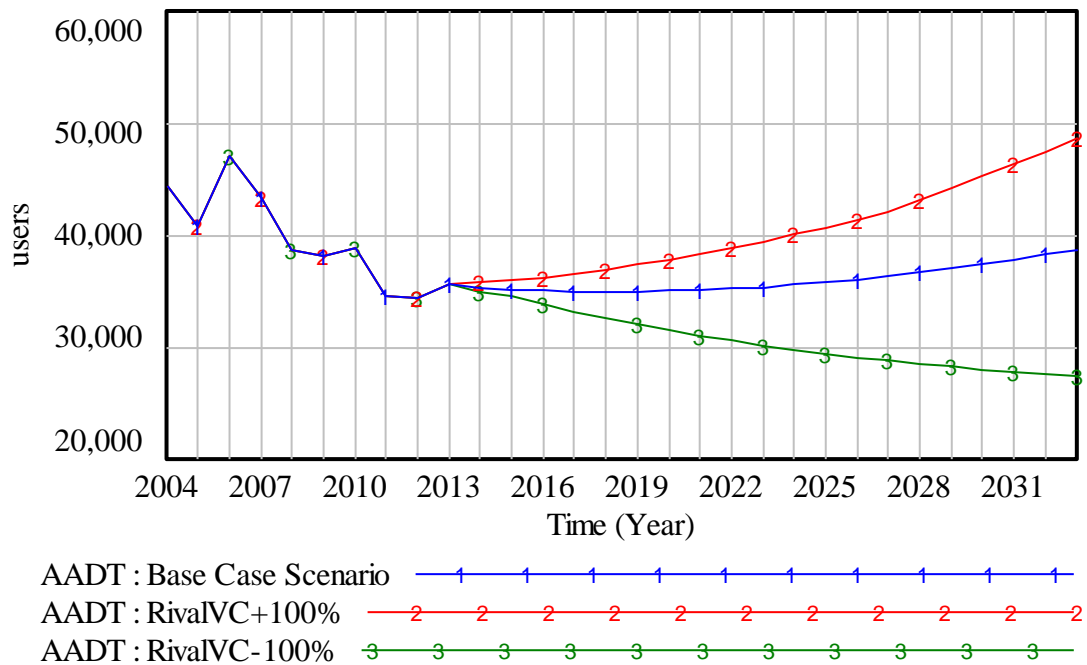


Figure 10.8: Impact of Change in Rival V/C on AADT

### 10.2.8. Change of Fuel Price

Raising fuel prices may play a significant role in reducing the volume of traffic on a particular road. Motorists may adjust to other transportation modes or resort to car-pooling to save in the cost of transportation. As above, fuel price was subject to change between -100% and +100% with an interval of 10%.

The sensitivity test outcomes of the toll road traffic to the change of the fuel price are shown in Table 10.8 and graphically in Figure 10.9. The results show that the immediate effect of a 100% increase in the price of fuel, holding everything else constant, will cause about 0.7% declines in traffic in 2014 and 7% in 2024. Over time, a sustained increase of 100% in price would eventually reduce traffic by about 11% by year 2033. On the other hand a 100% decrease increases traffic by 12% by 2033.

Table 10.8: Sensitivity Analysis results of the impact of Change of Fuel Price on AADT

The change in Fuel Price	Value of change in Fuel Price	Percentage of change in traffic
+100%	9p	-12.33%
+90%	8.55p	-19.00%
+80%	8.1p	-17.17%
+70%	7.65p	-15.28%
+60%	7.2p	-13.32%
+50%	6.75p	-11.29%
+40%	6.3p	-9.19%
+30%	5.85p	-7.07%
+20%	5.4p	-4.76%
+10%	4.95p	-2.42%
-10%	4.05p	2.52%
-20%	3.64p	5.12%
-30%	3.15p	7.84%
-40%	2.7p	10.65%
-50%	2.25p	13.45%
-60%	1.8p	16.29%
-70%	1.35p	19.21%
-80%	0.9p	22.24%
-90%	0.45p	25.38%
-100%	0	10.66%

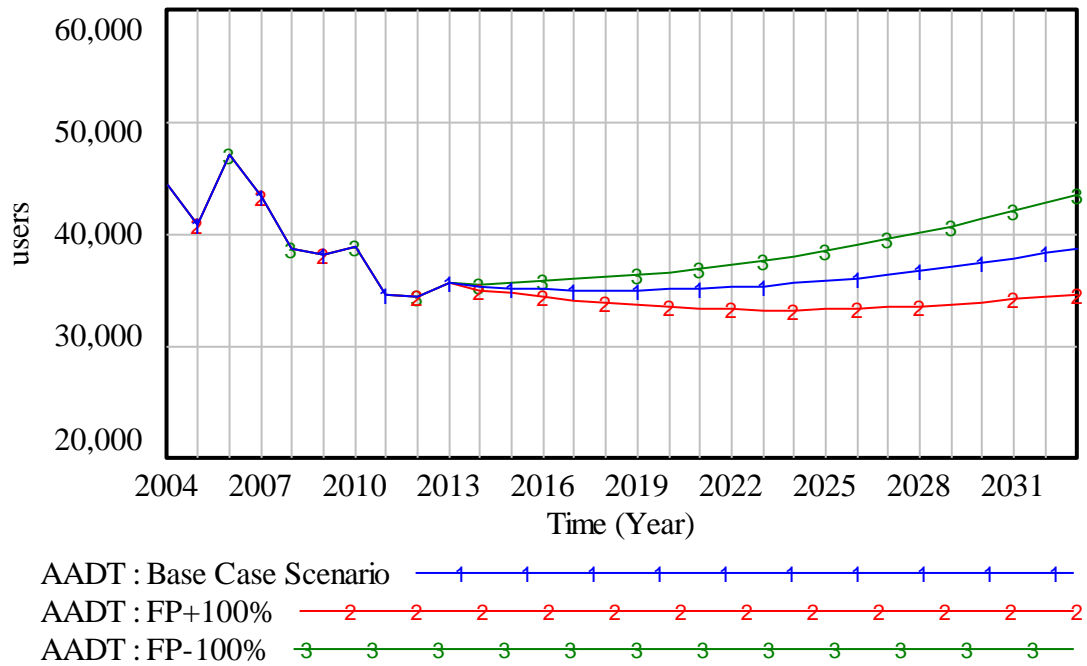


Figure 10.9: Impact of Change of Fuel Price on AADT

### 10.2.9. Proportion of Heavy Good Vehicle (HGVs)

As discussed in Chapter Eight, HGVs form an insignificant proportion of traffic on the M6 toll. On contrast, trucks proportion on the competing M6 road is around 30% of the traffic flow. Several attempts were made to attract more haulage companies to use the M6 toll such as reducing the tolls for lorries in July 2004 from £10 to £6 and offering one month free-pass on the M6 toll. Given the uncertainty associated with the proportion of HGVs potentially using the route, sensitivity test was conducted. The average value of HGVs proportion used to produce the base case scenario was changed from -100% through to +100% with 10% interval.

The results of the sensitivity tests related to 100% increase and decrease in HGVs proportion are shown in Figure 10.10. As discussed in Chapter Seven and Chapter Eight, AADT was factored to include the proportion of HGVs. Due to this modelling method, it is expected that 100% increase or decrease in HGVs proportion will lead to similar increase or decrease in AADT. Given this, the results were only shown graphically in Figure 10.10. The results suggest that the effects of change in HGVs proportion on the model outcome in terms of AADT are small. The model outcomes show that the usage level of M6 toll route declines by only 4% when the HGVs is



decreased by 100% and increases by a similar percentage when the HGVs increases by 100%.

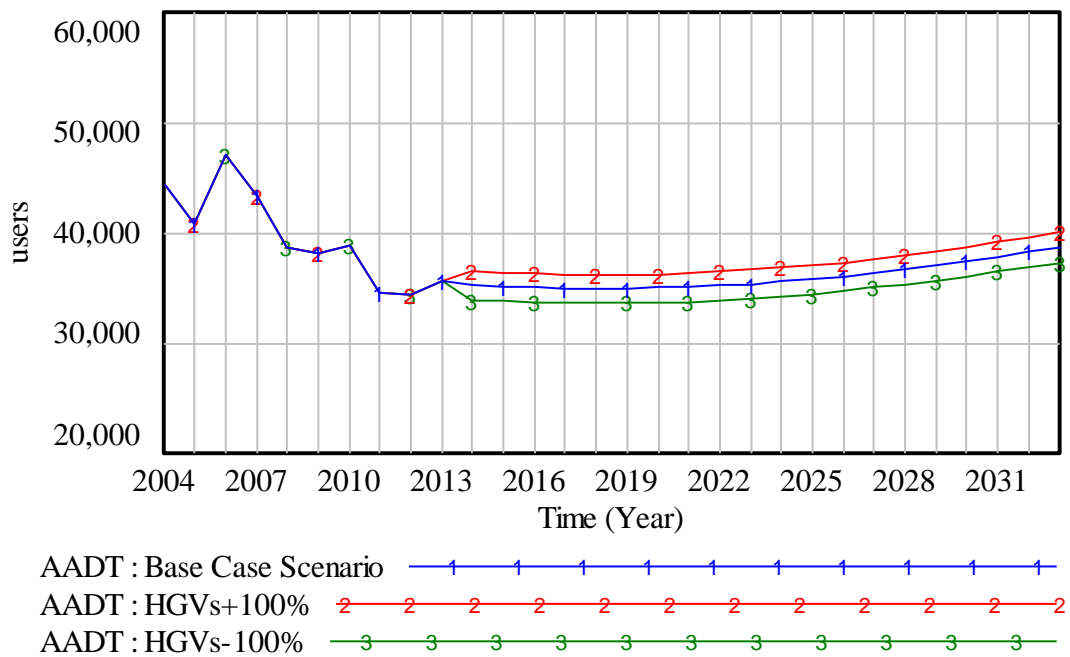


Figure 10.10: Impact of Change in Heavy Good Vehicles on AADT

As discussed above in Section 10.2, besides being useful to better understand the model outcome behaviour under different conditions and policies, sensitivity analysis is significant to locate the sensitive variables of the model. One of the purposes of conducting several rounds of sensitivity analysis is to reveal which variables have a considerable effect on the outcome behaviour. Based on this, the conditions that actually impact significantly on the model output can be identified, so that more attention can be paid for it. Next section is therefore devoted to rank the above-tested model variables based on their significance to the demand traffic level using tornado diagram.

### 10.2.10. Summary of Univariate Sensitivity Analysis

The sensitivity analysis tests conducted above helped identify the effect that each variable has on AADT of the toll route over the model time scale. To gauge and assess

the significance of the effect of different variables included in the sensitivity analysis on AADT, tornado diagram was developed.

Tornado diagram is a useful tool to gauge the significance of different variables on an outcome. It is a chart which shows how an output varies with change in a set of inputs once at a time. The diagram offers a graphical technique to present the varying effects of different variables. It therefore allows comparing sensitivity analysis results for numerous input variables.

Figure 10.11 shows a tornado diagram for AADT based on the univariate sensitivity analysis of SD model variables. The chart reports the variations in the output as a result of 100% decrease and increase in the tested variables. The vertical line at the horizontal scale “0” in the graph represents the value of AADT generated in the base case scenario which corresponds to the input variables established at their base values (i.e. no sensitivities involved). The length of the bars on the tornado diagram corresponds to the influence of 100% variable change on the AADT in 2033. In the diagram, the variables were ranked based on their down side effect on AADT so that the variable which mostly reduces AADT is exposed first and the variable which caused least decrease in AADT was ranked last (red bars). The diagram therefore helped highlight, locate and rank the greatest contributors to the AADT output. In addition, the figure shows that the variables ranking in terms of the upside effects on AADT (blue bars) resulting from 100 change is a bit different. This is mainly because the nonlinear relationships between the variables in the SD model. It was chosen, however, to rank the variables based on their down side effects leading to decrease traffic demand since less than expected demand is the norm in traffic on toll roads and it jeopardizes the project viability.

The results of the entire sensitivity analysis, represented by means of tornado diagram, suggest that the effects of variations in toll on the traffic are the most significant. A 100% increase in toll change rate led to a 31% decrease in AADT. Moreover, changes in congestion on untolled alternative represented by rival V/C seems to have important consequences on AADT too. A 100% decrease in V/C ratio on the untolled route leads to a 29% decrease in AADT which suggests that the variable is a key contributor to the level of traffic on the proposed route. Besides, the effects of traffic growth in the facility corridor represented by CAF causes the third greatest variations in AADT. Traffic is decreased by about 23% for corresponding 100% decrease in CAF. Ranked fourth,

VTTs change rate also contributes significantly to AADT. The variable has a consequence as high as 22% on AADT. The sensitivity analysis results as shown on the tornado diagram also indicate a significant sensitivity to GDP growth rate which ranked fifth. A 100% reduction in GDP growth rate variable caused 15% reduction in AADT. Change in fuel price, which ranked sixth, also has non-trivial effect on AADT. A 100% increase in fuel price change led to about a 10% decrease in AADT on the tolled route. HGVs variations impact is not very high since the proportion of HGVs is small. Finally, the results show that the departures in both employment and population growth rate have small impacts on AADT. The traffic may decrease by about 4.3% and 2.6% in correspondence to a 100% decrease in employment and population growth rate respectively. The results indicate that employment growth rate and population growth rate on the regional level are not significant figures in projection of future travel on M6 toll. The model outcome in terms of AADT appears to be relatively insensitive to change in these variables. In addition, from the results, it can be concluded that GDP contributed more significant results than population and employment. The impact of GDP growth rate is about 6 times higher than that of the population and three times higher than that of employment.

The insights gained from the sensitivity analysis lead to a set of conclusions about the important driving variables of model behaviour. In addition, the findings of sensitivity analysis suggest that there is a range of policy prospects that may influence the pattern of traffic. On the one hand, toll rate has a significant effect on traffic development over time. Increasing toll will put off the user and shift traffic from the toll route to the untolled competing route. The toll route will be underused whereas traffic will shift to the untolled motorway with the consequent increase in congestion. The costs of traffic diversion might be significant to the private sector because of its possible negative impact on the project revenue. In addition, while improvements to alternative untolled roads imply higher demand in the short term, tolled motorway will face a wider range of behavioural possibilities in the long term. Toll route users may opt to the free alternative as a result of potential improvement in their travel time on the untolled motorway leaving the toll facility underused in the longer term.

While the simple univariate sensitivity analysis is useful in demonstrating the impact of the change in one variable on the model output, this kind of sensitivity does not often reflect the reality. In the real world more than one variable varies at the same time since

several events and multiple actions may occur at once. Therefore, it is more sensible to examine the impact of two or more different variables varying simultaneously. The systematic variation of several uncertain variables together creates scenarios which better describe potential futures. Next section will discuss scenario analysis or multivariate sensitivity analysis.

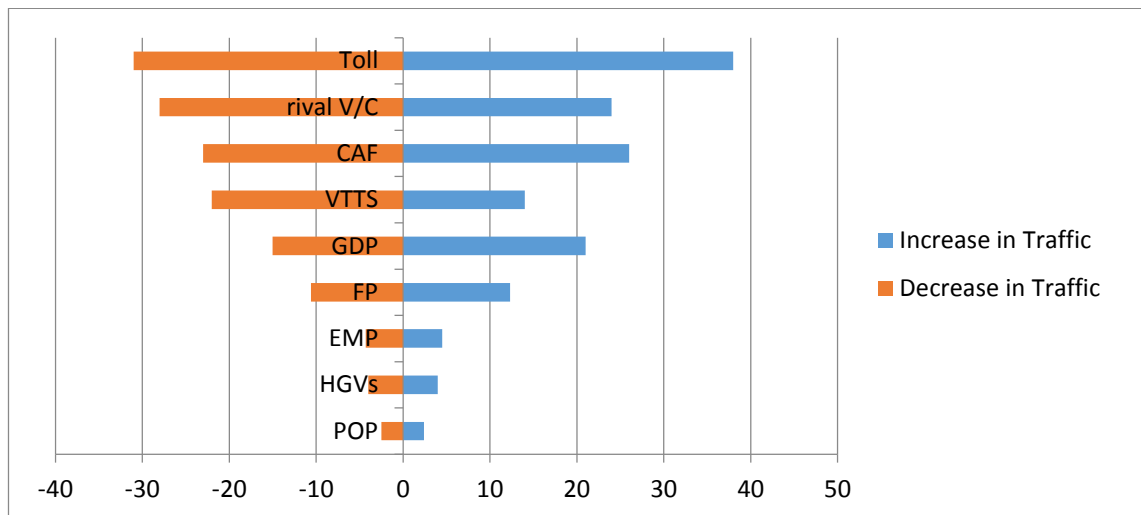


Figure 10.11: Tornado Diagram of Different Variables Influencing AADT

### 10.3. Scenario Analysis/Multivariate Sensitivity analysis

Scenario analysis is a tool to assist in understanding and analysing the impacts of possible future events on a specific outcome or a set of outcomes. Scenarios typically include a set of explicit 'if-then' rules that explore the consequences of a range of influenced assumptions to reveal the impact of each potential combination of values. Section 10.2.10 concluded that toll, VTTS, Rival V/C as well as GDP growth rate are the most important factors affecting traffic demand. In addition, the interviews with M6 toll road stockholders discussed in chapter nine identified economic conditions, toll, untolled M6 conditions as the most important drivers for M6 toll traffic. Given this, scenarios which consider different potential combinations of these factors are introduced. Next sub sections present various possible scenarios and analyse the SD model outcomes behaviour in terms of AADT under the assumptions of these scenarios.

### **10.3.1. Scenario 1: Better Economic Conditions**

The interviews with M6 toll road stakeholders (discussed in chapter five) identified downturn in economy as one the most significant factors which affected the facility level of usage. This scenario therefore tests the impact of potential improvement to the UK economy on the AADT of M6 toll road. Based on the GDP projection provided by DfT, the GDP will grow by 3% in 2015. This figure is 40% higher than the average growth used for the base case scenario. Given this, this scenario assumes improvement to the UK economy by 40% than the percentage assumed for the base case scenario and by common sense in the value of travel time savings. In addition, investigating the relationships between GDP growth rate and employment growth rate for the data available (1994-2012) suggests that the rate of change of GDP growth rate and employment growth rate is linked. Thus, a growth of 40% is also applied to employment growth rate. The scenario also assumes a 10% increase in the fuel price can be applied as a result of better economic conditions.

Figure 10.12 shows the model outputs of scenario 1. The results show that the assumed improvements to the UK economy lead to similar improvements to the facility level of usage. Under this scenario's assumptions, the traffic will increase by 0.8% in 2015, 4.6% in 2020, 8.7% in 2025 and 13.4% in 2030. The 40% higher than the assumed in the base case can result in approximately 15% cumulative increase in the AADT of M6 toll road by year 2033.

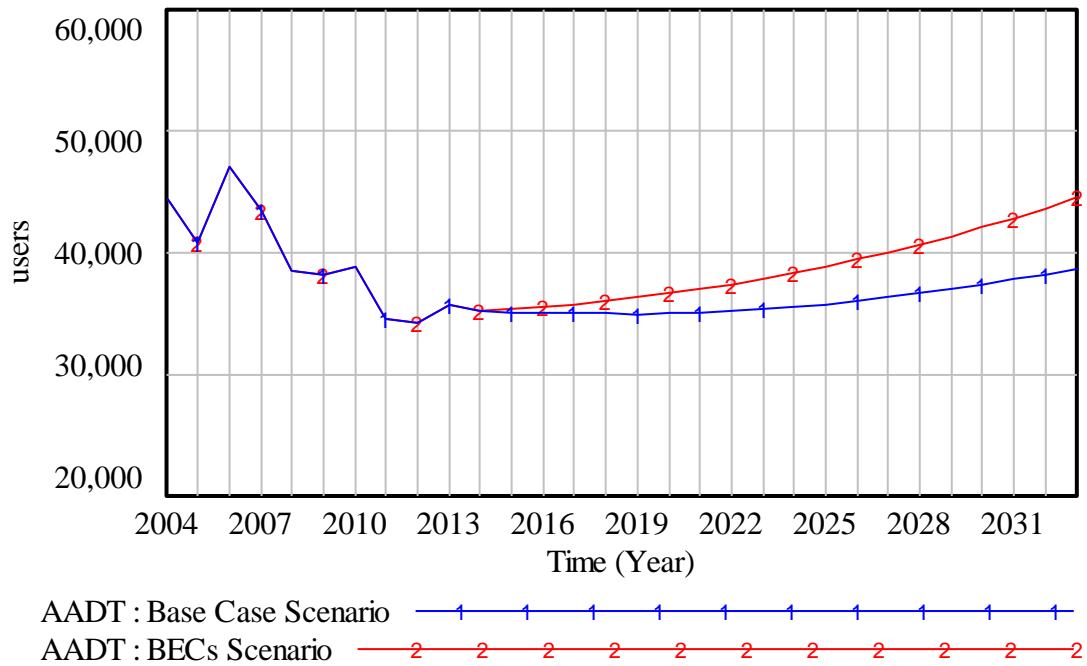


Figure 10.12: Traffic Demand under Better Economic Conditions Scenario

### 10.3.2. Scenario 2: Better Economic Conditions and Higher Change in Toll

This scenario assumes similar improvement to the UK economy to that assumed in scenario 1 (i.e. 40% higher than the assumed in the base case GDP, VTTS, and employment growth rate and 10% higher change in fuel price). However, the private sector operator will react to these improvements in the economic conditions by adjusting the toll for using the facility by £0.5 per year (an increase equivalent to that of the initial period of operation) instead of £0.35 assumed in the base case run. The purpose of this experiment is to show how sensitive the traffic reacts to increase in toll under better economic conditions.

The test outcomes are shown in Figure 10.13. The results indicate that under this scenario the traffic demand is almost equivalent to that under base case scenario over the next 20 years. The scenario thus outlines potential conditions and policies under which the road may reserve current level of use. The declination of traffic resulting from increasing the toll by £0.5 per year instead of £0.35 seems to almost meet the increase in traffic resulting from improvement in the economic conditions shown in the scenario1. In 2030, the variation in traffic between the base case scenario and scenario 2 roughly equals to zero. The highest variation is 3% in 2020. A major implication of this

scenario is identifying the economic conditions under which the private operator can increase toll with higher rate. It also addresses how policies have to be designed by the private sector to stabilize current traffic level.

### 10.3.3. Scenario 3: Higher Toll and Higher Congestion on the Untolled Alternative Facility

The presence of an alternative route plays a key role in determining the usage of toll route. The presence of juxtaposed untolled route makes demand extremely sensitive to price since motorist has another option to ride. In addition, the quality of service on this alternative may increase this sensitivity. The higher the speed on the alternative road, the more sensitive the demand is. This Scenario assumes an annual increase in the toll rate of £0.45 instead of £0.35 assumed in the base case scenario. Due to an expected diversion of the traffic to the free alternative, this increase in toll rate assumed to be combined with a higher increase in traffic and congestion on the rival M6 of 50% than that in the base case assumptions.

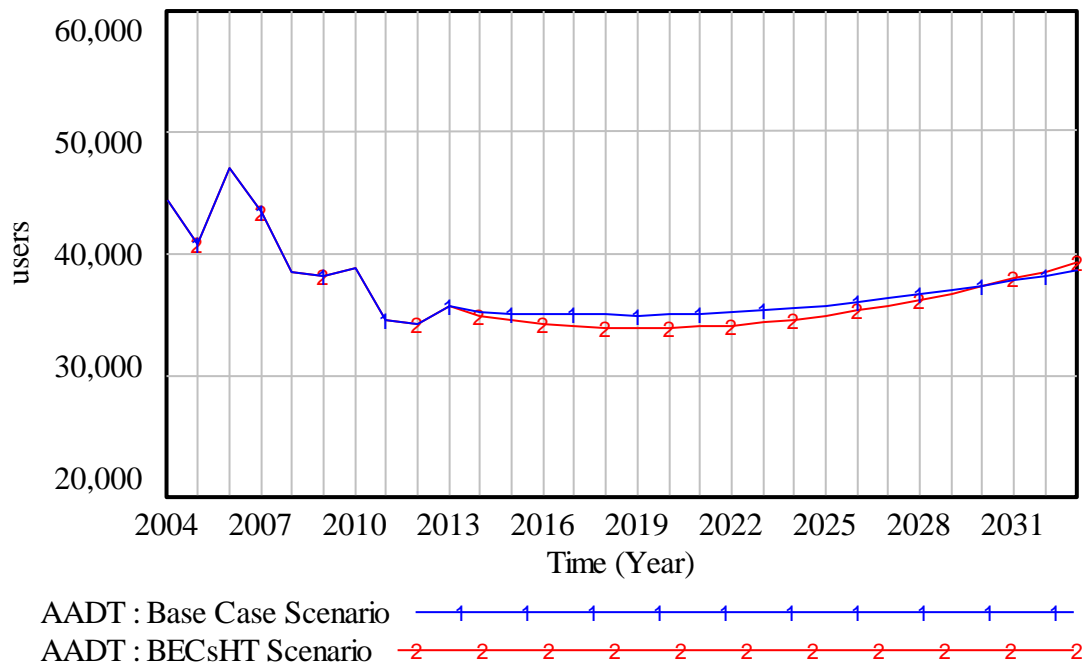


Figure 10.13: Toll Road Traffic Demand under Better Economic Conditions and Higher Toll Scenario

Figure 10.14 shows the model outcomes of this scenario. The results show that AADT correspond to this test with slight departure comparing to the base case run outcome. The higher toll put off the motorists and shift traffic from the toll motorway to the untolled one. The increase in congestion on untolled road results in an increase in travel time on the M6. Consequently, M6 toll afford faster travel for the motorists with subsequent increase in travel time savings. Higher time savings will attract more motorists to use the toll route and produce a positive shift in toll traffic level. In this scenario, the potential increase in traffic on M6 toll route resulted from higher congestion on untolled M6 is approximately met by the declination in traffic resulted from higher toll rate. The largest shift produced by this scenario is in 2018 (year 15). The variations between the base case and scenario 3 outcomes are as high as 2%. In this year, the increase in traffic resulted from congestion on untolled M6 seems to be unable to meet the decrease resulted from the higher toll rate. The toll is still a bit expensive for the potential users. However, over time, the variations decrease to nearly reach zero by 2027 where the increase in toll will totally meet the increased in congestion. However, continuous increase in congestion will attract users again where a positive variation of 1.5% occurs in 2033.

The demand elasticity to toll here is much less than that identified in the univariate sensitivity analysis. The traffic is approximately inelastic to change in toll. This mainly attributed to the worse conditions on the untolled M6. The implication of this scenario is that travel demand is shown to be less sensitive to monetary costs when the alternative shows higher level of congestion (bad service quality). Therefore, it can be concluded that the decisions about the toll level on the motorways should not be independent from the congestion conditions on the alternative routes.

This scenario shows that pricing have important consequences in terms of traffic allocation between roads. The effects of toll increase/reduction occur at network level. A toll increase may increase the congestion on the alternative motorway and therefore this should be taken into account when evaluating changes in toll rates. On the other hand, this scenario implies that the decisions about the toll level are not independent from the governmental policy in terms of improvement transport infrastructure. Improvement will decrease level of congestion on the free alternatives, which implies more elastic demand toward toll rate.



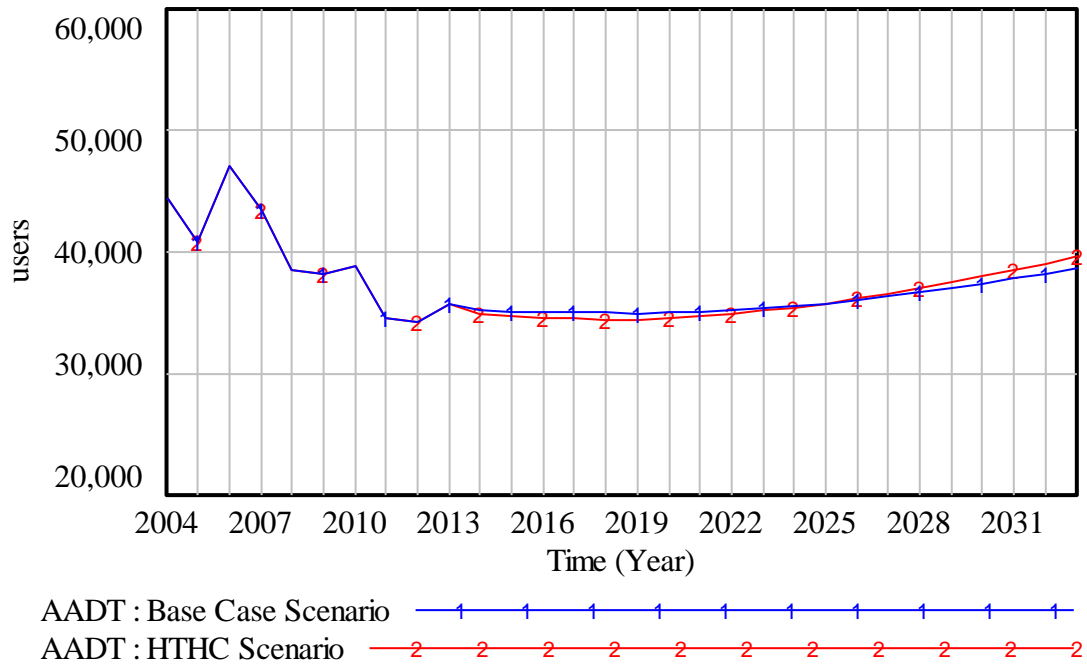


Figure 10.14: Toll Road Traffic Demand under Higher Toll with Higher Congestion on untolled Alternative Facility Scenario

#### 10.3.4. Scenario 4: Freezing Toll and Higher Change in Corridor Traffic

In 2013, there was a call to renationalise the M6 toll road. However, being a public road does not necessary mean withdrawing toll, but it potentially means setting a specific level of toll as happened in Orange toll road in USA or freezing the toll at the nationalisation time level. Under this scenario, it was therefore assumed freezing the toll rate at the current price of £5.5. In addition, the scenario assumed improvements to the land use in the corridor area where the area may experience an amount of sprawl as a result of cheaper toll. This will bring more traffic into the corridor. Thus, an increase in corridor traffic and consequently untolled M6 traffic of 10% was also assumed.

The results of this scenario are presented in Figure 10.15. Obviously, the positive effect of freezing toll, increasing corridor traffic combining with increased congestion on M6 joined to produce a corresponding increase in the traffic. In comparison to the base case scenario, AADT shows higher increase over time. The percentage change in AADT for the 2015 and 2025 is 6% and 30% respectively. In 2033, AADT is about 41% higher than that in the base case scenario. Higher traffic in the corridor means higher market

from which M6 toll traffic share will be materialised. In addition, the higher corridor traffic would increase the traffic using untolled M6. As above, M6 toll afford faster travel speeds for the motorists who would prefer to take advantage the faster travel trips in comparison to congested untolled M6 since heavier traffic slows travel speeds. The higher time benefits will therefor attract more motorists to use the toll route with subsequent increase in traffic level. In addition, motorists enjoy relatively cheaper toll rate than that in the base case scenario which also contribute to increase AADT.

While univariate and multivariate sensitivity is useful in demonstrating the impact that a deterministic change in parameters has on the main outcomes, it is not practical in representing the occurrence likelihood of the inputs values and level of confidence in the model outputs. The method is incapable of presenting the probability of event occurring. It is best suited for handling risks that take the form of discrete outputs. Therefore, risk analysis is considered a useful methodology to deal with uncertainty, which will be discussed in the following section.

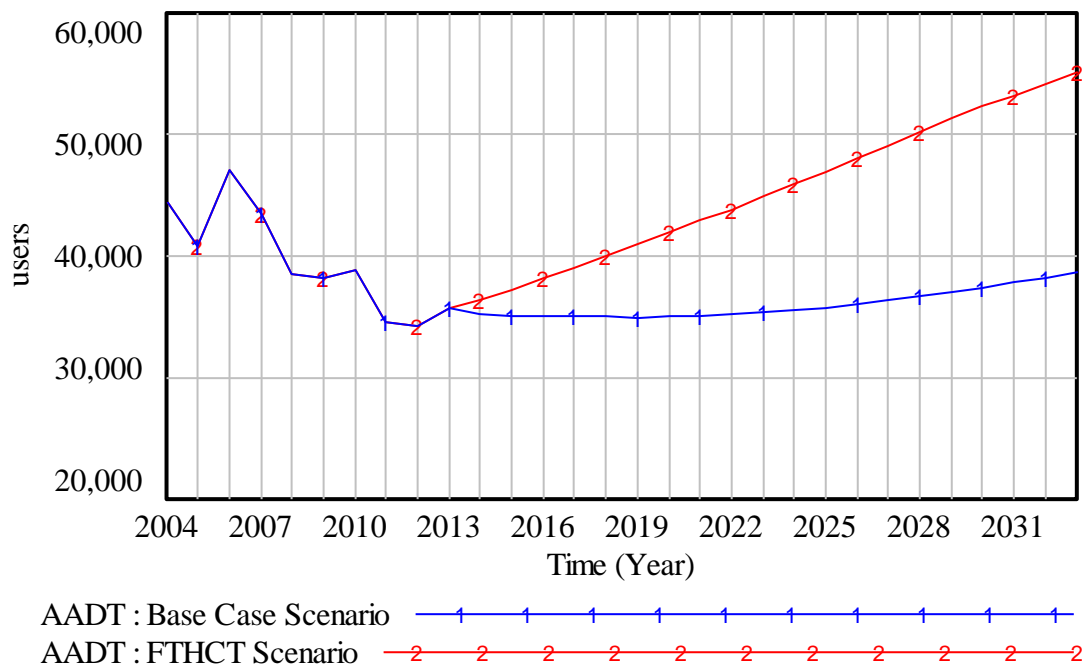


Figure 10.15: Toll Road Traffic Demand under Frozen Toll and Higher Corridor Traffic Growth Scenario

#### **10.4. Risk Analysis**

Sinha and Labi (2007) distinguish between uncertainty and risk noting that uncertainty is the case where the input values are not known with certainty and their probability distributions are also unknown whereas risk is the case where the range and distribution of potential input values are known. For risk analysis purpose, it is thus necessary to associate to each variable a probability distribution defined in a precise interval of values. It includes quantifying the level of uncertainty related to a particular variable within a reasonable range of values. Risk analysis therefore helps identify a range of outcome values with a confidence bounds considering the variation in the inputs values within their respective probability distributions. In this research, to conduct risk analysis, Monte Carlo simulation was performed.

##### ***Monte Carlo Simulation***

While in deterministic methods each parameter is assigned a specific discrete value, Monte Carlo simulation allows assigning distributions to the model exogenous variables. It is a probabilistic calculation that uses random number generators to draw samples from the assigned probability distributions. The method thus considers a number of values for each variable selected randomly within their respective probability distributions. During the simulation, the randomly chosen values for uncertain variables are used to generate a distribution of possible case scenarios (De Marco, 2011). While scenario analysis (Section 10.3) help assess the effects of discrete variables, Monte Carlo simulations help examine the consequences of continuous variables. It thus provide fuller picture of the potential risk by generating hundreds of possible outcomes. The main objective of Monte Carlo simulation is to reveal the effect of multiple uncertainties on the output of interest. It assesses the likelihood and potential effect of an event on the outcome.

To perform Monte Carlo simulation, it is crucial to define and assign probability distributions for the sensitive variables in the model. Given the probability distribution for these variables, a combined probability for the outcome can then be estimated. The following sub-sections explain in detail the process of conducting Monte Carlo simulation in this study.

### *Defining and assigning probability distributions for the model variables*

This step of the analysis aims to establish the probability distribution of variables values. A probability distribution identifies the range and shape of the interval over which the variable is likely to vary representing the uncertainty in the variables values. The distribution provides a measure of the uncertainty associated with the input value in the form of a standard deviation. The probability distributions are typically derived on the basis of historical or sample data or by using empirical distribution (Lam and Tam, 1995). Input distributions of the traffic demand related variables were identified based on the historical data available for each of the model parameters.

SPSS software was used to apply a probability fitting and infer the probability distribution of the relative exogenous variables. To check whether the data follow a specific distribution (i.e. normal distribution), numerical and visual outputs of probability fitting were investigated. Numerical outputs were assessed using Skewness, Kurtosis and Shapiro-wilk tests. Visual outputs including histograms and the Q-Q plots are also investigated to examine if the data follows a normal distribution.

Skewness measures symmetry of the data set or distribution. The skewness for a normal distribution equals to zero. Kurtosis measures whether the data are peaked or flat relative to a normal distribution. In terms of normality, both Skewness and Kurtosis measures divided by their standard errors (i.e. Z-value) should be as close to zero as possible and within the interval [-1.96 and 1.96] (Cramer, 1998; Field, 2009; Doane and Seward, 2011). Shapiro-Wilk is a “goodness-of-fit” test which examines whether a particular distribution is not significantly different from one hypothesized (i.e. a normal distribution). The null hypothesis for Shapiro-Wilk test assumes that the data is normally distributed. The null hypothesis is rejected if p-value is less than 0.05 (Shapiro and Wilk, 1965, Razali and Wah, 2011).

The histogram (frequency distribution) and Q-Q plot (quantile-quantile plot) are used for checking normality visually (Field, 2009). Histograms are used to represent the probability distribution of a continuous variable. It is particularly useful for displaying both the skewness and kurtosis of data. Being used for normality tests, the histogram should show that the data approximately have a normal curve. Q-Q plot, on the other

hand, is a graph of the percentiles of standard normal distributions against the corresponding percentiles of the identified data. In the case that the data roughly follow a normal distribution, the plot should be approximately a straight line with positive slope. Next sub-sections present the normality test conducted for the proposed SD model variables.

#### *Employment Growth Rate*

The first data set investigated is the data associated with the employment growth rate exogenous variable. For this variable, the time series data is available from 1994 to 2012. The first two tests conducted were Skewness and Kurtosis. Table 10.10 shows the results of these tests. The results show that the values of measures (standard error) for skewness are -0.202 (0.536) and for kurtosis are 0.098 (1.038) for the employment growth rate data. These values generate Z-values of -0.377 for skewness test and 0.094 for kurtosis test. Z-value indicates that the data insignificantly depart from zero and it is in range of [-1.96 and 1.96]. The tests show that the data are little skewed and kurtotic but it does not differ significantly from normality and it is safe to assume that the employment data are normally distributed in terms of skewness and kurtosis tests.

The other test conducted was Shapiro-Wilk test. As for the employment growth rate data, the test showed that p-value equals 0.976 which is above 0.05 as shown in Table 10.10. The null hypothesis is thus not rejected and the data is approximately normally distributed in terms of Shapiro-Wilk test also.

In terms of visual outputs, graphically figures generated by the software for employment growth rate data were examined. Inspecting the histogram of employment growth rate data, shown in Figure 10.16, implies that the data approximately have a normal curve. In addition, Figure 10.17 shows the associated Q-Q plot. As for employment growth rate data, obviously, most of the dots are along the straight line which indicates that the data is normally distributed.

Based on the numerical and visual inspection introduced above, it was concluded that the employment growth rate data is normally distributed. Employment growth rate is thus assumed to follow a normal distribution with the projected employment growth rate of 0.37% as a mean and 1.5% as a standard deviation.

In a similar way, the data of Population growth rate, GDP growth rate, VTTS growth rate, change in fuel price and Heavy Goods Vehicle proportion were investigated. Table 10.10 shows the results of the normality tests for these variables. The results show that the values of measures (standard error) for skewness and for kurtosis. These values generate Z-values which indicate that the data insignificantly depart from zero. The tests results thus indicate that the data are little skewed and kurtotic but it does not differ significantly from normality and it is safe to assume that the variables data are normally distributed in terms of skewness and kurtosis test.

The Shapiro-Wilk test for the variables data, shown also in Table 10.10, indicate that p-values for the all variables are above 0.05 and the null hypothesis is thus not rejected. This test therefore also suggests that the data is approximately normally distributed.

Besides, the visual inspection is also conducted for all the variables. The examination into the histograms representing the data for each variable implies that the data approximately have a normal curve. In addition, the Q-Q plot indicates that the data is approximately normally distributed. The visual outputs of the tested variables are included in Appendix D.

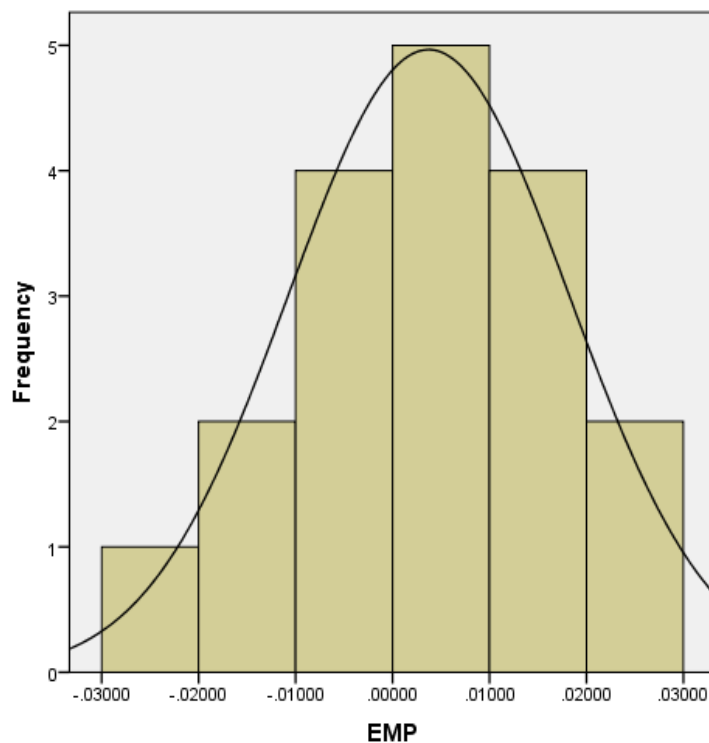


Figure 10.16: Histogram and Normality Curve of Employment Growth Rate

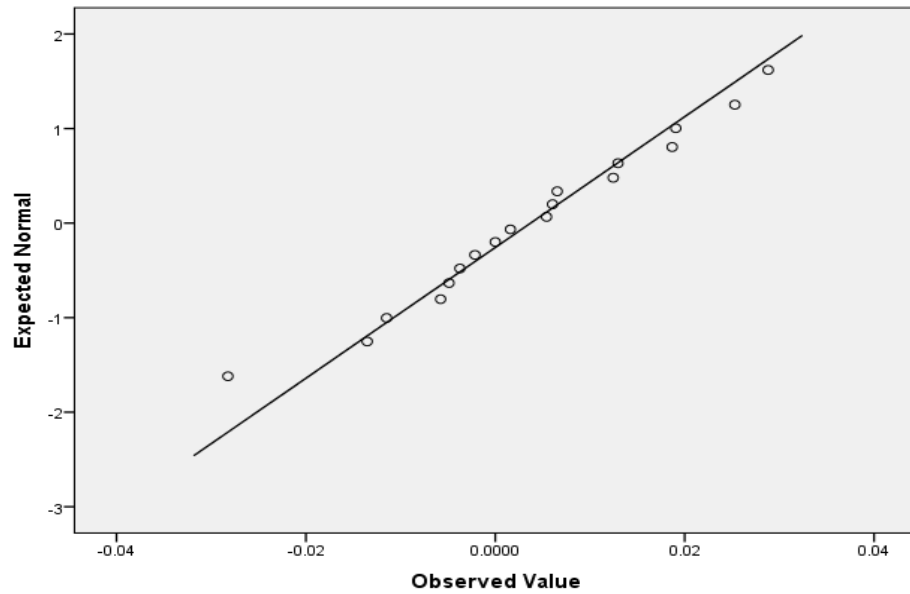


Figure 10.17: Q-Q Plot of Employment Growth Rate

Table 10.9: Normality Tests for Population Growth Rate Variable

Variable		Mean	Std. D	Skewness Test		Kurtosis Test		Shapiro-Wilk Test
				Measure	Std.Error	Measure	Std.Error	p-value
EMP	Growth Rate	0.037	0.015	0.202	0.536	0.098	1.038	0.976
GDP	Growth Rate	0.0213	0.021	-0.036	0.536	-0.341	1.038	0.07
VTTS	Growth Rate	0.016	0.012	-1.024	0.524	0.592	1.014	0.06
Change in FP		4.5	9.5	0.045	0.536	1.428	1.038	0.33
Proportion of HGVs		0.04	0.004	0.973	0.752	0.365	1.481	0.400

### *Toll Change*

Over the last period of the operation stage, MEL, the private operator MEL imposed several toll adjustments. The toll adjustment involved an increase in toll between as low as £0.2 in 2008 and as high as £0.5 in 2004. In addition, the toll was frozen twice in 2006 and 2012 (£0 change). Given this, change in toll charge was assumed to follow a uniform distribution with a minimum value of 0 and maximum value of £0.5.

### *Rival V/C Change*

As discussed in Chapter Seven and Eight, rival V/C variable represent level of congestion on the alternative road. It therefore reflects change in level of traffic on M6 untolled facility along with temporary decreasing in capacity resulted from maintenance and roads works. Unfortunately, there is no representative data which reflect change in the value of this variable. Change in rival V/C was therefore assumed to be uniformly distributed with a minimum value of -0.15% and a maximum value of 0.45%.

### *CAF*

CAF was assumed to follow a uniform distribution with a minimum value of 0.5 and a maximum value of 1.5.

Table 10.10 summarizes the probability distribution of exogenous variables specified to be included in this analysis

Table 10.10: The Probability Distributions of the Exogenous Variables

Variable	Distribution	Mean	Standard Deviation
Employment Growth Rate	Normal	0.0037	0.015
Population Growth Rate	Normal	0.004	0.002
GDP Growth Rate	Normal	0.021	0.21
Value of Time Growth Rate	Normal	0.016	0.012
Fuel Price	Normal	4.5p	9.5p
HGV	Normal	0.04	0.004
Rival V/C	Uniform	-	-
Toll Change	Uniform	-	-
CAF	Uniform	-	-



*Estimating the combined probability of the outcomes*

After having established the probability distribution of the exogenous variables, the resultant variables probability distributions were the inputs to the analysis in “Vensim” software. 10,000 Monte Carlo simulations were performed which allows simultaneously changing the values of the identified exogenous variables along the bounded distribution. The probability distribution of the AADT of the facility was thus calculated with its confidence bounds over the period of the model time scale as shown in Figure 10.18.

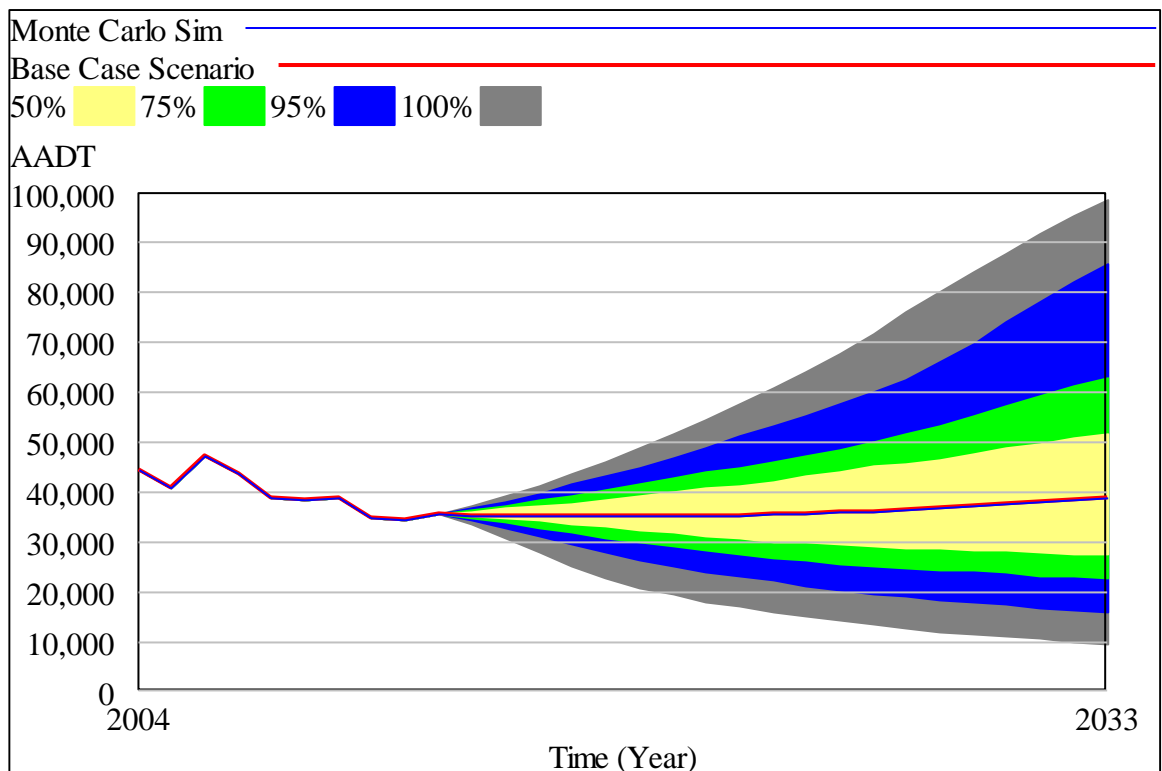


Figure 10.18: Monte Carlo Simulation of AADT

The results provide illustrative information about the impacts of variables change on the model outputs. Figure 10.18 shows the results of risk analysis with respect to confidence bounds. The method combined the effects of the variations in the identified and assessed variables on the overall demand estimate. The spread AADT values in term of 50%, 75%, 95% and 100% confidence bounds are shown over the entire time scale of the model. The increasing spread in the range boundary indicates increasing the uncertainty of AADT over time. The outer bounds of uncertainty (100%) show the maximum and minimum values that the AADT can take. The area in between indicates

the range of outcomes in 10,000 simulations when the parameter are randomly varied around its values.

The mean value of AADT in 2033 is about 39,000 users within a range of {17,000: 85,000} at 95% confidence level. The maximum and minimum values of AADT are approximately 97,000 users for the best case and 10,000 users for the worst case in year 2033. The best case of 97,000 users occurs if the conditions work to perfection (ex. Highest VTTS growth rate= 3.2%, highest GDP growth rate= 5.1%, lowest toll change=£0, and lowest change in fuel price= -17p). However, the worst case is happening if the lowest VTTS growth rate= -1.3%, lowest GDP growth rate =-2.1%, highest toll change=£0.5, and highest change in fuel price=25.4p occur. The best case occurs when low level of toll and high growth of value of time which leads to a high level of toll share for the facility combining with high growth in GDP, employment and population. On the other hand, the worst case results from downturn in the economy leading to slow growth in the GDP, employment and VTTS combining with excessive increases in toll charge. During the last few years, M6 toll has poor usage performance. The interviews with some of the project key stakeholders indicated that the bad conditions faced the UK economy during the last few year was the main driver. The variability of the GDP and consequently the VTTS combined with increasing the toll level has significantly influenced the AADT trend over the project operation period. If the economic downturn continues in the future, the traffic may dive toward the worst case shown in Figure 10.18.

However, these two extreme situations are not the most likely scenario. Monte Carlo simulation also generates several confidence intervals for the model scenarios. A wide range of values are thus spread between the best and worst case values. For instance, there is a 50% chance that AADT will be between 28,000 and 51,000 users and 75% chance that AADT will be between about 25,000 and 62,000 users in year 2033.

Obviously, the risk analysis method yielded a distribution of values for AADT (e.g. 10,000 to 97,000 users in 2033) rather than a point estimate. In addition, it also estimated the confidence upon which these values may occur (there is 50% chance that the traffic is 51,000 users in 2033). Providing such estimates of the expected values and the confidence level are likely to lead to better decisions since decision-makers get a realistic picture of the uncertainty in AADT value. This creates overall risk profiles by

providing the probability of achieving a specific estimate. For instance, there is less than 5% chance that the demand exceeds 75,000 users per day. If the private sector cannot yield the required revenue with less than 75,000 users per day, this may guide to not move ahead with the investment or to postpone the investment.

Such risk analysis results can also be used by the project stakeholder to make varieties of decisions that might affect the level of demand for a project. It helps the private operator to decide on how much they can increase toll and when they can do so. For instance, increasing toll by £0.5 annually, considering the economic conditions, would significantly affect the level of demand and may reduce the traffic to the worst case of 10,000 users per day. The decision makers should therefore consider the negative implications increasing the toll or evaluate the risks of toll increase. On the other hand, risk analysis also helps investigate how different changes to land use resulted from planning policies in the area may affect toll traffic. Higher corridor traffic growth resulted from such land use may increase traffic to the upper bound of 97,000 if the other factor works with their best conditions. Risk analysis therefore provides a basis for evaluating the potential risk as an important step of risk management strategy.

For M6 toll road, if such analysis was conducted early in the project life cycle, it would have helped make more informed decisions. The key issue is the probability of reaching the expected level of use, because this value is the input to the financial analyses. For instance, it was expected that 70, 000 users will use M6 toll. The risk analysis shows that there is low confidence (less than 20%) that the project will meet this level of demand. The implication of the analysis would be that the government would have considered sharing demand risk along with the private sector, for instance. Particularly because the analysis shows that the demand is influenced by various factors such as economic factors, competing and complementary facilities over which the private sector has no control. These factors are primarily controlled by the public sector. The private sector control over demand risk is thus partial and can influence the demand traffic only by imposing reasonable toll and providing better services. Therefore, such analysis would have led to demand risk to be shared between public and private sectors early in the project life cycle.

## 10.5. Summary

This chapter introduced the sensitivity and risk analysis conducted for the proposed model. The sensitivity of demand was analysed with respect to changes in the underlying assumptions using univariate, scenarios and Monte Carlo simulation. The univariate sensitivity allowed testing the sensitivity of the model outcomes behaviour to a plausible range of uncertainty in the values of the input variables. The variables were tested on the basis of one at a time within a 10% interval for a total range of  $\pm 100\%$ . The results of the univariate sensitivity analysis was summarised and presented using tornado diagrams. Tornado diagram graphically helped to show the correlation between variations in different model inputs and the corresponding variation in the outputs. The univariate sensitivity tests represented by the tornado diagram indicated that toll has the most important impact on traffic flow. The conditions on the untolled alternative route represented by V/C and Corridor traffic growth rate were ranked second and third respectively. Employment and population were ranked last. In addition, several scenarios were tested to explore the effects of varying multiple variables simultaneously. Monte Carlo simulation was conducted by assigning probability distributions to the model variables. Monte Carlo simulation then estimated the level of uncertainty in the model outcome as a function of the assumed uncertainty in the model inputs. The method therefore yielded more informative output than the deterministic method. It provided the potential level of use of the facility over the model time scale with a particular probability. Identifying the probability of demand reaching particular levels in specified years plays an important role in the financial analysis and investment decisions.

## **Chapter Eleven: Conclusions and Recommendations**

### **11.1. Introduction**

The aim of this research is to develop a system dynamic based model to assess the demand risk for service provided by PPP projects. The model was particularly used to assess traffic demand risk in toll road projects as one significant type of PPP projects. It was employed to assess demand risk by analysing the potential effect of changes in the key interrelated factors that influence the usage level. This chapter highlights the findings from this research and how the research objectives were achieved. The chapter then highlights the research contributions. The research limitations are then presented. Recommendations for further research conclude the chapter.

### **11.2. Achievement of the Research Objectives and General Conclusions**

**Objective 1:** *To identify the key factors affecting demand for services provided by PPP projects*

Chapter two and three demonstrated the outcomes of this objective. Section 2.8 presents the key factors affecting demand for service provided by PPP infrastructure projects. These factors include socio-economic factors, public satisfaction, willingness to pay, historical experience of paying, public involvement in ongoing facility management, competition from alternative facility and level of fee.

Socio-economic factors involve demographic and economic aspects which may affect the facility level of use. These are typically represented by population, employment and GDP. Demand risk in PPP projects can be substantial if the project is not back up by reasonable growth in these factors. The downturn in the economy and the local recession can cause serious reduction in demand levels. Public satisfaction is another driver for demand. Political opposition and public outcry were the responses of the privatisation in many cities. This negative attitude of community regarding the

privatisation is likely to have its impacts on the level of use and financial status of PPP projects. Public consultation is therefore considered as a key to boost public satisfaction. In addition, uncertainty over the user willingness to pay tariff is one of the major drivers of demand risk. WTP is the function of several factors such as quality of service, level of fee, quality of service and level of fee of other alternative facility. Moreover, the demand to use a particular PPP facility is significantly affected by the paying culture. In countries with historical experiences of such practices, it is less difficult to accept and use a new PPP scheme which requires users to pay for the public service. Public engagement in long term facility management, setting up maintenance and safety standard and adjusting tariff is another factor to ensure high degree of public satisfaction and use. Furthermore, building a new competing facility and/or rehabilitating an existing one can seriously affect demand and diminish the viability of a project. Besides, to guarantee a constant demand for a project the tariff for using the facility should be set at a reasonable level. High tariff for using the facility is the main reason for financial troubles because it can put off the potential users.

To build more confidence in the identified factors, 200 questionnaires were distributed to people perceived to be involved in PPP projects via email. A total of 37 completely filled questionnaires have been received and included in the analysis. The response rate was about 19%. Based on the questionnaire survey results, it was concluded that the literature review provided a complete list of factors affecting demand since no new factors were added by the questionnaire respondents.

**Objective 2:** *To identify the relationships between these factors and how they ultimately affect demand*

Chapter two, three, six and seven covered this objective. The literature review in chapter two and three were used to identify the relationships among the above-identified factors by reviewing the relevant literature. The relationships were investigated for each of the demand factors in terms of the direct cause, direct consequence and intermediate variables. For instance, tariff should not be excessively high because of its strong relationship to the public willingness to pay which extremely affects demand. Willingness to pay itself is a function of tariff, quality of service, tariff and quality of service of alternative facilities.

Chapter Six then presented the method used to map these relationships using system dynamic technique. Five causal loop diagrams, that address interdependencies and interactions, were developed which include: socio-economic, public satisfaction, WTP, competition, and level of fee CLDs. These diagrams show how different factors affect each other and ultimately affect demand. To ensure reliability, the proposed CLDs were validated by experts and professionals in the field of PPP projects. A series of semi-structured interviews with nine experts were conducted. The interviewees identified some intermediate variables to be included in a number of the CLDs. In addition, refinements to few relationships were suggested.

Based on the literature review conducted in chapter three and the CLDs developed in chapter six, chapter seven presented the stock and flow diagrams for factors affecting traffic in toll road projects. Six sub-models were developed which include: socio-economic sub-model, satisfaction sub-model, WTP sub-model, competition sub-model, toll sub-model and expansion factors sub-model. These sub-models constitute the basis for the quantitative simulation model.

**Objective 3:** *To quantify the established relationships between influencing factors and demand and develop a dynamic simulation model*

Chapter seven was used to fulfil this objective. All CLDs have been symbolized visually in the stock and flow diagram which were mathematically quantified using quantitative and qualitative data sources. To develop the model equations, several methods were employed such as regression analysis, expert judgment and conclusions from literature review.

Regression analysis was used for variables that have historical records with the corresponding time series data. This method was mainly used to develop the relationship between regional traffic on the west midland motorways and west midland population, employment and UK GDP in the socio-economic sub-model.

In addition, the judgments of experts gained through the elicitation process were a significant source of data for quantifying the relationships between several of the model variables. Five interviews with experts in the toll road field were conducted.

Relationships such as the effect of consultation on public satisfaction and the effect of historical experience of paying on toll share were developed based on the experts' judgements. Literature was also a significant source to develop many of the model relationships.

When all the model equations were developed, a case study of M6 toll road was used to demonstrate the model application which is considered the base case scenario. Chapter eight discussed the results of the model simulation for the base case scenario. The base case scenario served as the base scenario for other simulation runs for different conditions and policies conducted on the model and presented in chapter ten.

**Objective 4:** *To validate the developed model in terms of structure and behaviour*

Chapter nine covered this objective by providing an overview of the model validation process. A series of tests for the SD model were run to investigate the model validity in terms of its structure and behaviour. Qualitative and quantitative data were used to complete the validation process. The model structure test indicated that the model sufficiently reflects the real system and it is endogenously valid. The behaviour reproduction test revealed that the model is capable of reproducing the behaviour of the SD model variables.

**Objective 5:** *Using the developed model to assess demand risk in toll road projects over the operation period*

Chapter ten was used to fulfil this objective. The chapter extensively discussed the univariate and multivariate sensitivity analysis, as well as risk analysis to illustrate the use of the model.

Several tests of univariate sensitivity analysis were conducted. Most of the model constant variables including population growth rate, employment growth rate, GDP growth rate, CAF, Value of Travel Time Saving (VTTS) change rate, toll change, rival V/C change and proportion of Heavy Good Vehicles (HGVs) were subject to sensitivity analysis. For each variables, 20 tests were conducted where the variable was varied by  $\pm 10\%$  of their original value (i.e. base case scenario values) up to  $\pm 100\%$  change. After changing one variable value at a time, a new value of the Annual Average Daily Traffic (AADT) was recorded. The resulting outcomes with respect to AADT were compared



to the base case scenario. The univariate sensitivity analysis helped to identify the effect that each variable has on AADT of the toll route over the model time scale.

Multivariate sensitivity analysis, on the other hand, helped in assessing the impact of several variables on demand simultaneously. Four scenarios were assessed. The first scenario is “Better Economic Conditions”. This scenario describes the impact of better economic conditions on the level of demand. The second scenario is “Better Economic Conditions and Higher Change in Toll”. This scenario combines the first scenario conditions with increasing the toll change to £0.5 instead of £0.35 assumed in the base case scenario. The third scenario is “Higher Toll and Higher Congestion on the Untolled Alternative Facility”. The scenario assumed an annual increase in the toll rate of £0.45 instead of £0.35 assumed in the base case scenario and a higher increase in congestion on the rival M6 by 50% than that assumed for the base case scenario. The final scenario “Toll and Higher Change in Corridor Traffic” assessed the case of the road rationalisation. The scenario assumes freezing the toll rate at the current price of £5.5 and an increase in the corridor traffic and untolled M6 traffic by 10%.

Finally risk analysis was conducted using Monte Carlo simulation. To perform Monte Carlo simulation, probability distributions were identified and assigned for each of the constant variables in the SD model. The distributions were identified and developed based on the time series data available for each of these variables.

The following gives the summary of findings and conclusions from the sensitivity and risk analysis:

The results of the univariate sensitivity analysis showed that the effects of variations in toll on the traffic are the most significant. A 100% increase in toll change rate leads to 31% decrease in AADT. Ranked second is the changes in congestion on untolled alternative represented by rival V/C. A 100% decrease in V/C ratio on the untolled route leads to a 29% decrease in AADT. The effects of traffic growth on the facility corridor represented by CAF causes the third greatest variations in AADT. Traffic is decreased by 23% for the corresponding 100% decrease in CAF. Ranked fourth, VTTS change rate has a consequence impact as high as 22% of the AADT. GDP is ranked fifth where a 100% reduction in GDP growth rate caused 15% reduction in AADT. A 100 increase in fuel price, which ranked sixth, leads to about 10% decrease in AADT on the tolled

route. HGVs proportion, employment growth rate and population growth rate were ranked last with less than 5% effect.

As for the multivariate analysis, the results of the first scenario show that 40% increase in GDP growth rate, employment growth rate, VTTS growth rate and 10% increase in fuel price cause about 15% increase in AADT. The results of second scenario suggest that no significant change occurred and the traffic demand is almost equivalent to that under the base case scenario. The scenario thus outlines the potential conditions under which the road may reserve current level of use. The results of the third scenario show that the variations in demand are tiny where the increase in demand resulting from the increase in congestion on the untolled alternative facility seems to meet the decrease in traffic resulting from higher toll. In comparison to the base case scenario, scenario four result in AADT to be about 41% higher in 2033. The positive effect of freezing toll, increasing corridor traffic combined with the increased congestion on the M6 produce a corresponding increase in the traffic.

The results of the risk analysis show that the mean value of AADT is about 39,000 users with a confidential level of 95% and a range of {17,000:85,000}. The maximum and minimum values of AADT are approximately 97,000 users for the best case and 10,000 users for the worst case in year 2033.

Given the sensitivity and risk analysis results, it can be concluded:

- Toll is the most significant factor driving traffic demand for toll road projects. This result is in line with the ANP results where level of fee was ranked first under the facility characteristics cluster. In addition, level of fee was ranked third out of the 17 factors listed in the questionnaire survey data.
- The planned annual increase in toll level of £0.5 will negatively affect level of traffic demand unless an improvement in the economic conditions occur.
- Since Monte Carlo simulation estimated the level of uncertainty in the model outcome as a function of the assumed uncertainty in the model inputs, the method yielded more informative outputs than the deterministic method.

Identifying the probability of demand reaching particular levels in specified years plays an important role in the financial analysis and investment decisions.

### **11.3. Originality of the Research and Contribution to Knowledge**

The originality of this research lies in providing a dynamic model to assess demand risk in PPP projects. This was done by the application of system dynamic as a modelling technique to represent the complex structure of demand system. In addition, the structure of the developed model is generic and can be considered for many cases. The general perception about the system behaviour is embodied in the structure of the model. The special case is only represented by the values of constant variables.

The previous studies on demand risk highlighted the variations between forecast and actual demand and identified some of the influencing factors. None of these studies however analysed the structure or the mechanism of such influence. A particular objective of this research is to understand the complex structure of the demand system. The system thinking principles were used to represent the complex interrelationships among different factors using CLDs and to produce a qualitative model of the relationships among demand risk factors. This extends the knowledge base of systems thinking and system dynamics to the area of demand risk in PPP projects. In addition, while the study applied the quantitative model on toll roads only, the CLDs and the qualitative model constitute the base for modelling demand for other types of infrastructure such as rail transport, airline, energy and waste water.

Moreover, the quantitative model provides the toll roads practitioners with a tool for assessing demand risk. The developed model helps assess the dynamic change in demand over time resulting from changes in the influencing factors. System dynamics modelling of traffic demand system helps understand and analyse the performance patterns resulted from uncertain traffic factors. Assessing the potential impact of such factors early in the project lifecycle enhances the quality of decision making regarding the investments and for the operational purposes. The model is also a decision making tool which is used to investigate the feasibility of implementing the proposed facility. It provides a basis to determine whether the proposed facility deserves further investigation. Risk analysis process facilitates an informed decision by proving the

probability of reaching an expected level of use and assessing the impacts of changes in the model variables and assumptions. This research therefore deals with a major area where improvement can be made to obtain more efficient and reliable decisions.

It can also be used as a pre-feasibility demand estimation tool which provides a kind of benchmark against which estimations from other tools can be compared as recommended by Boyce and Bright (2003), procedure which can increase the reliability of preliminary estimates.

As discussed in chapter one, the model is intended to serve as demand risk assessment and evaluation tool which can be used by several parties as follows:

- Public sector, which is responsible for considering and planning the facility and other complementary and/or competing facilities.
- Private sector, who is in charge of construction, financing and long term operation of the facility
- Financial communities which sell the capital debt.
- Credit rating agencies which evaluate the underlying credit quality and are the most interested in risk assessment.
- Demand modellers who are responsible for providing demand estimation.

#### **11.4. Recommendations for Practice**

The research results suggest that evolving risk analysis process in demand estimation should be a pre-request. Given the inherent uncertainties in demand influencing factors, quantification of demand uncertainties is extremely important. The typical point estimate of demand and revenue are no longer sufficient. Public and private sectors as well as financial community such as bond investors and rating agencies should consider more rigorous sensitivity/risk assessment in PPP projects. Combined sensitivity analysis and risk analysis is highly recommended since it is reasonably effective for accommodating risk in demand level.

The sensitivity analysis helps to:

- Demonstrate impacts of changes to inputs
- Determine most and least influential inputs

On the other hand, risk analysis helps to:

- Quantify uncertainties in inputs
- Determine impacts of inputs on output
- Analyse output sensitivities
- Quantify uncertainties of the output

Using this method will help to assess if the investment worthwhile. All organizations should therefore base their investment decisions on a range of values rather than one single estimate of demand and revenue. It is important to determine to which extent the changes in assumptions affect the viability of the scheme.

### **11.5. Limitation of the Research**

A comprehensive research is reflected by the fulfilment of its aim and objectives. Meanwhile, developing a research project depends on a range of assumptions which limit its applicability. The limitations of this research upon which further development can be made are as follows:

- The model is used to study the behaviour of through traffic over time only. Intermediate traffic was included as a proportion of the toll facility traffic based on the data available. The implication of this practice is the assumption that intermediate traffic has a similar behaviour to that of through traffic and change at the same rate. Intermediate traffic may have different behaviour due to different segmentation or different conditions on the alternative roads.
- No particular model was developed for truck utilisation estimation. Rather, truck is also assumed as a percentage of car traffic which is the typical method in developing traffic estimation. In the SD model, HGVs was assumed to follow the historical trend. While in the case of M6 toll road, the proportion of HGVs is quite small and slightly affect the total use of the facility, HGVs may represent a higher proportion in other cases. Developing a separate model to study the different factors influencing HGVs behaviour would increase the model's reliability.

- The model development and application were limited to some extent because of data availability. Limitations because of data include:
  - The SD model is an aggregate model to assess the wholesale impact of change on the influencing variables. In the SD model, for each traffic segment, single value of VTTS regardless of the users' income was used. This implies that all the motorists belonging to the same segment value their time the same. However, motorists' response to changes in toll depends on their wealth and is not usually as similar as it is assumed. While the SD model has the capacity to represent such differences by categorising the motorists into different bands based on their income, limited information is available regarding the percentage of users in terms of their income band within each traffic segment. An average value for each of the traffic segmentations was therefore used, and it is in this way that the results must be interpreted.
  - Demand models typically predict peak period demand and then expand to daily and annual estimates using proper expansion factors. However, the developed SD model estimates toll demand directly starting from annual travel in the corridor, as the data for peak period travel only and the expansion factors are not available at the time of the study.
  - Rival V/C and CAF were assumed to follow uniform distributions. More data is required to investigate whether they follow different kind of distributions.
  - The full evaluation of the model was limited to data availability. While actual traffic data on M6 toll in the past nine years were accessible on the operator website, accessibility to sources or data pertinent to the original traffic projections and studies does not exist. Documents related to projected traffic or the associated assumptions are considered as extremely confidential. Thus, it was impossible to evaluate the future performance of the model owing to the absence of the corresponding forecasted figures. The model was only evaluated by comparing part of its outcomes to the actual usage performance in the past.

## **11.6. Recommendations for Further Research**

This research lays the foundation for using the system dynamic technique in the area of demand risk assessment. Further research can be conducted on the basis of the developed SD model as follows:

- The qualitative or the conceptual model in this research is developed for a typical PPP project and not for the exact development of toll road projects. The general factors impacting on demand for service provided by PPP facilities are embodied in the model structure. The application of the qualitative model may therefore extend to develop quantitative simulation models for other kind of infrastructure projects such as rail transport, airline, energy, and waste water facilities.
- The quantitative simulation model is developed for a typical toll road project and not for the specific case of M6 toll road. The general aspects and factors affecting demand for toll road traffic are included in the model. M6 toll was thus used to demonstrate the model use, validation and application. More case studies are therefore suggested for further validation of the model results.
- Beside the developed model, a separate model which takes into consideration the factors affecting the HGVs demand is recommended. The two models can work together to generate the overall demand of the facility and to thoroughly assess the demand risk.

## References

- Abd Karim, N. (2011). Risk Allocation in Public-Private Partnership (PPP). Project: A Review on Risk Factors. *International Journal of Sustainable Construction Engineering & Technology*, 2(2), pp 8-16.
- Abdul Rashid, K. (2007). Private Finance Initiative (PFI): Concept and method of procurement for construction projects with specific reference to Malaysia. International Islamic University Malaysia.
- Abdul-Aziz, A. (2001). Unravelling of BOT scheme: Malaysia's Indah water consortium. *Journal of Construction Engineering and Management*, ASCE, 127(6), 457-460.
- Adams, M. G. W. (1992). Birmingham Northern Relief Road, The UK's First Tolloed Motorway. In: *proceedings Financing transport infrastructure, 14-18 September 1992 Manchester. PTRC Transport, Highway, and Planning*, 103-124.
- AECOM, (2012). *M6T Research Study: Modelling Report*. Birmingham: AECOM.
- AECOM. (2007). Case Studies of Public-Private Partnerships for Transportation Projects around the World – Task Order 05-00. US Department for Transport, Federal Highway Administration (FHWA), HPTS.
- Akintoye, A. and Chinyio, E. (2005). Private Finance Initiative in the Healthcare Sector: Trends and Risk Assessment. *Engineering, Construction and Architectural Management*, 12(6), 601-16.
- Akintoye, A., Beck, M., Cliff, H., Chinyio, E. and Asenova, D. (2001). The financial structure of private finance initiative projects, *Proceedings: 17th ARCOM Annual Conference*, Salford, 1, 361-369.



- Akintoye, A., Beck, M., Hardcastle, C., Chinyio, E. and Assenova, D. (2001). *Framework for Risk Assessment and Management of Private Finance Initiative Projects*. The School of Built and Natural Environment, Glasgow Caledonian University.
- Akintoye, A., Hardcastle, C., Beck, M., Chinyio, E. and Asenova, D. (2003). Achieving best value in private finance initiative project procurement, *Construction Management and Economics*, 21(5), 461-70.
- Alexander, I., Estache, A. and Oliveri, A. (2000). A Few Things Transport Regulators Need to Know about Risks. *Utilities Policy*, 9(1):1–13.
- Alfen, H. W. and Bauhaus-Universitate Weimar. (2009). *Public Private Partnership in Infrastructure Development: Case Studies from Asia and Europe*. Bauhaus-Universitate Weimar, Weimar, Germany.
- Altamirano, M. A. (2006). Modeling the Evolution of National Road Procurement Strategies.  
<http://www.systemdynamics.org/conferences/2006/proceed/papers/ALTAM306.pdf>
- American Society of Civil Engineers (ASCE). (2005). Raising the Grades: Small Steps for Big Improvements in Americas Failing Infrastructure.
- Andersen, D. F. 1980. How Differences in Analytic Paradigms Can Lead to Differences in Policy Decisions. In *Elements of the System Dynamics Method*, ed. J. Randers. Portland, OR: Productivity Press.
- Andi, S. and Minato, T. (2003). Representing causal mechanism of defective designs: a system approach considering human errors. *Construction Management and Economics*, 21, 297-305.
- Arndt, R. H. (1998). Risk Allocation in the Melbourne City Link Project. *The Journal of Project Finance*, 4(3), 11-24.

- Aschauer, D. A. (1989). Is public expenditure productive? *Journal of Monetary Economics*, 23, 177–200.
- ASECAP. (2000). Available at: [http://www.asecap.com/pdf\\_files/BROCHURE.PDF](http://www.asecap.com/pdf_files/BROCHURE.PDF)  
[Accessed 19 November 2012].
- Asher, H. D. (1983). *Causal modelling*. (2nd ed.)Newbury Park, CA: Sage.
- Askar, M. M. and Gab-Allah, A. A. (2002). Problems Facing Parties Involved in Build, Operate, and Transport Projects in Egypt. *Journal of Management in Engineering*, 18 (4), 173-178.
- Babbie, E. R. (1990). *Survey Research Methods*. Belmont, CA: Wadsworth.
- Baccarini, D. (1996). The Concept of Project Complexity: a Review. *International Journal of Project Management*. 14(4), 201-204.
- Baeza, M. A. and Vassallo, J. M. (2010). Private Concession Contracts for Toll Roads in Spain: Analysis and Recommendations. *Public Money & Management*, 30, 299-304.
- Bain, R. and Wilkins, M. (2002). The Credit Implications of Traffic Risk in Start-Up Toll Facilities, Standard & Poor's, London. Available at: [http://www.infrastructureaustralia.gov.au/publications/files/Traffic\\_Risk\\_in\\_start\\_up\\_toll\\_facilities\\_2002.pdf](http://www.infrastructureaustralia.gov.au/publications/files/Traffic_Risk_in_start_up_toll_facilities_2002.pdf) [Accessed 4 March 2011].
- Bain, R. and Plantagie, J. W. (2003). Traffic Forecasting Risk: Study Update 2003. Standard & Poor's, London .
- Bain, R. and Plantagie J. W. (2004). Traffic Forecasting Risk: Study Update 2004. Standard & Poor's, London .
- Bain, R. and Polakovic, L. (2005). Traffic Forecasting Risk Study 2005: Through Ramp-Up and Beyond. Standard & Poor's, London .

- Bain, R. (2009a). Error and Optimism Bias in Toll Road Traffic Forecasts. *Transportation*, 36(5), 469-482.
- Bain, R. (2009b). *Toll Road Traffic & Revenue Forecasts – An Interpreter’s Guide, Credit Risk Analysis*. Seville: Publication Digitals SA.
- Bain, R. (2009c). Review of Lessons from Completed PPP Projects Financed by the EIB. European Investment Bank.
- Baker, Public Financial Mangement (PFM). CRA International, and Fitzgerald & Halliday. (2005). Toll Feasibility Study. Virginia. Virginia Department for Transport US Department for Transport, Federal Highway Administration.
- Balcombe, K. G. and Smith, L. E. D. (1999). Refining the Use of Monte Carlo Techniques for Risk Analysis in Project Planning. *Journal of Development Studies*, 36, 113-135.
- Baliwangi, L., Arima, H., Artana, K. B. and Ishida, K. (2007). Risk Modification through System Dynamics Simulation. *Proceedings of the 18th conference on Proceedings of the 18th IASTED International Conference: modelling and simulation*. Montreal, Canada: ACTA Press.
- Ball, R., Heafey, M. and King, D. (2003). Risk Transfer and Value for Money in PFI Projects. *Public Management Review*, 5(2), 279 – 290.
- Ballance, T. and Taylor, A. (2005). Competition and Economic Regulation in Water: The Future of the European Water Industry. IWA Publishing, London UK.
- Balnac, K., Bokhoree, C., Deenapanray, P., Bassi, A.M. (2009). A System Dynamics Model of the Mauritian Power Sector. Albuquerque, New Mexico, USA.
- Barlas, Y. (1996). Formal Aspects of Model Validity and Validation in System Dynamics. *System Dynamics Review*, 12, 183-210.

- Barlas, Y. and S. Carpenter. (1990). Philosophical Roots of Model Validation: Two Paradigms. *System Dynamics Review* 6(2): 148-166.
- Barlow, J. and Gaiser, M. (2008). The private Finance initiative, Project form and Design Innovation: The UK's Hospitals Programme. *Research Policy*, 37(8), 1392-1402.
- Baskerville, R. and Wood-Harper, A. T. (1996). A critical perspective on action research as a method for information systems research. *Journal of Information Technology*, 11, 235-246.
- Baxandall, P., Wohlschlegel, K. and Dutzik, T. (2009). Private Roads, public costs: the facts about toll road privatization and how to protect the public. US, U. S PIRG Education Fund.
- Beato, P. (1997). Road Concessions: Lessons Learned from the Experience of Four Countries. Department of Sustainable Development, Inter-American Development Bank. Available at: <http://www.iadb.org/sds/doc/1205eng.pdf> [Accessed 24 October 2011].
- Beidleman, C. R., Fletcher, D. and Veshosky, D. (1990). On Allocating Risk: the Essences of project Finance, *Sloan Management Review*, 47-55.
- Bel, G., and Fott, J. (2007). Comparison of Recent Toll Road Concession Transactions in the United States and France, *Proceedings the 75 the Annual Meeting of the International Bridge, Tunnel and Turnpike Association*, Vienna.
- Berg, B. L. (2001). *Research Methods for the Social Sciences*. Boston: Allyn and Bacon.
- Berry, S. and Blum, R. (2011). Briefing on the Risks of Toll Road Investment in the UK. *Campaign for Better Transport*.

- Bayazit, O. & Karpak, B. (2007). An analytical network process-based framework for successful total quality management (TQM): An assessment of Turkish manufacturing industry readiness. *Int. J. Production Economics*, 105, 79–96
- Bettis, R. A. and Prahalad, C.K. (1995). The Dominant Logic: Retrospective and Extension. *Strategic Management Journal*, 16 (1), 5-14.
- Bing, L., Akintoye, A., Edwards, P. and Hardcastle, C. (2005). Perceptions of positive and negative factors influencing the attractiveness of PPP/PFI procurement for construction projects in the UK: Findings from questionnaire survey” *Engineering, Construction and Architectural Management*, 12 (2), 125-148.
- Birnie, J. (1999). Private Finance Initiative (PFI), UK Construction Industry Response. *Journal of Construction Procurement*. 5(1), 5-14.
- Bitrán, G. A. and Valenzuela, E. P. (2003). Water Services in Chile: Comparing Private and Public Performance. World Bank, Washington, DC.
- Blumberg, B., Cooper, D.R, and Schindler, P.S. (2005). *Business Research Methods*. Berkshire: McGraw-Hill Education.
- Bloomberg, M., Rendell, E. and Schwarzenegger, A. (2011). Building America’s: Future Falling Apart and Falling Behind. Transportation Infrastructure Report 2011.
- Bonsall, P. and Kelly, C. (2005). Road User Charging and Social Exclusion: The Impact of Congestion Charges on At-Risk Groups, *Transport Policy*, 12(5), 406-418.
- Booz & Co. (2012). Review of HS1 Demand Forecasts. London. HS2 Limited.
- Bousquet, F. and Fayard, A. (2001). Road Infrastructure Concession Practice in Europe”. Policy Research Working Paper, WPS 2675. Washington, DC: World Bank.

- Boyce, A. and Bright, M. (2003). Reducing or Managing Forecasting Risk in Privately Financing Projects. *Proceedings European Transport conference 2003*.
- Boyce, D. and Zhang, F. (1997). Calibrating Combined Model of Trip Distribution; Model Split and Traffic Assignment, *Transportation Research Record*, National Academic Press, Washington, 1-5.
- Bryman, A. (2004). *Social Research Methods*. (2nd edition). Oxford: Oxford University Press.
- Bryman, A. (2006). Integrating quantitative and qualitative research: How is it done? *Qualitative Research*, 6, 97-113.
- Bureau of Infrastructure, Transport, and Regional Economics. (2011). Review of Traffic Forecasting Performance: Toll roads. Department of Infrastructure and Transport, Australian Government.
- Burnes, J. and Musa, P. (2001). Structural Validation of causal loop diagrams. *SD conference*. Atlanta.
- Cabral, S. and Junior, F. S. S. (2010). Addressing the Demand Risk in PPP for the FIFA World Cup Stadium: A Real Approach. Chaire EPPP. Available at: [http://www.chaire-eppp.org/files\\_chaire/cabral\\_silvajr\\_football\\_conf\\_PPP\\_2010.pdf](http://www.chaire-eppp.org/files_chaire/cabral_silvajr_football_conf_PPP_2010.pdf). [Access at 9 April, 2011].
- Calder, S. (2013). Overpriced and underused: M6 toll road is going nowhere fast. *BBC*.
- Calvo, M. and Cariola, E. (2004). Analysis of the Privatization Process of the Water and Sanitation Sector in Chile. UNRISD. Available at: <http://www.unrisd.org/unrisd/website/projects.nsf/0d098d9016856d2080256e>

[b300388f39/b9983741a6570e17c1256f41003d599a/\\$FILE/dcalvo.pdf](http://www.southwalesdevelopmentplan.org/wp-content/uploads/2013/02/20130201-Jobs-For-Cast-Briefing-Note-CE-Scenario-Assumptions-2011131.pdf)

[Accessed 12 April 2011].

Cambridge Econometrics (2013). Assumptions for the Baseline and ‘Smart Efficiency and Growth’ Scenarios for Worcestershire Districts. A briefing note for Worcester City Council and Partners Available at: <http://www.swdevelopmentplan.org/wpcontent/uploads/2013/02/20130201-Jobs-For-Cast-Briefing-Note-CE-Scenario-Assumptions-2011131.pdf> [Accessed February 14 2013].

Carpintero, S. and Raphael B. (2012). Private Toll Roads: Lessons from Latin America, *Proceedings 2012 International Conference on Traffic and Transportation Engineering*. ICTTE Belgrade, November 29-30th.

Carpintero, S., Vassallo, J. and Soliño, A. (2013). Dealing with Traffic Risk in Latin American Toll Roads. *Journal of Management in Engineering*, 10.

Celebi, D., Bolat, B. and Bayraktar, D. (2009). Light Rail Passenger Demand Forecasting by Artificial Neural Networks. *International Conference on Computers & Industrial Engineering, 2009*.

Champ, P.A., N.E. Flores, Brown, T.C. and Chivers. J. (2002). Contingent Valuation and Incentives. *Land Economics* 78(4): 591–604.

Chang, M., Imura, H. (2002). Development Private Finance Initiative (PFI) for Urban Environment Infrastructure in Asia, Institute for Global Environment Strategies.

Chen, Z., Li, H., Hong, R., Xu, Q. and Hong J. (2011). Total Environmental Risk assessment for international hub airport projects. *International Journal of Project Management*, 29(7), 856-866.

Cheng, E. and Li, H. (2005). Analytic Network Process Applied to Project Selection. *Journal of Construction Engineering and Management*, 131(4), 459–466.

- Cheung, E., Chan, A. And Kajewski, S. (2009). Enhancing value for money in public private partnership projects: Findings from a survey conducted in Hong Kong and Australia compared to findings from previous research in the UK. *Journal of Financial Management of Property and Construction*, 14 (1). 7-20.
- Chiu, T. Y. C. and Bosher, C. B. (2005). Risk sharing in various public private partnership (PPP). arrangements for the provision of water and wastewater services. *Conference on Public private Partnerships-Opportunities and Challenges*, Hong Kong. The University of Hong Kong. 22 February 2005.
- Choi, J., Chung, J. and Lee, J. (2010). Risk Perception Analysis: Participation in China's Water PPP Market" *International Journal of Project Management*, 28, 580-598.
- Chrisney, M. D. (1996). Financing Trends for Private Infrastructure in Latin America and Caribbean. *The Financier*. 3(1).
- Chung, D., Hensher, D. A. and Rose, J. M. (2010). Toward the betterment of risk allocation: investigating risk perceptions of Australian stakeholder groups to public-private-partnership toll road projects. *Research in Transportation Economics*, 30 (1), 43-58.
- Churchman, C. (1973). Reliability of models in the social sciences. *Interfaces*, 4(1): 1- 12.
- Clay, M. J. and Johnston, R. A. (2006). Multivariate Uncertainty Analysis of an Integrated Land Use and Transportation Model: MEPLAN. *Transportation Research Part D*, 11, 191-203.
- Cooke, N. J., Salas, E., Cannon-Bowers, J. A., and Stout, R. (2000). Measuring team knowledge. *Human Factors*, 42, 151-173.
- Coyle R. G (1997). System Dynamics at Bradford University: A Silver Jubilee Review. *System Dynamics Review*, 13(4), 311-321



- Coyle, R. G. (1996). *System Dynamics Modelling, A Practical Approach*, London, Chapman & Hall.
- Cramer, D. (1998). *Fundamental Statistics for Social Research*. London: Routledge.
- Crampes, C. and Estache, A. (1998). Regulatory Trade-Offs in the Design of Concession Contracts. *Utilities Policy*, 7(1).
- Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, CA: Sage.
- Creswell, J. W. (2003). *Research Design: Qualitative, Quantitative and Mixed Methods Approaches*. 2nd edition. Thousand Oaks, CA: Sage.
- Creswell, J. W. (1994). *Research Design: Qualitative and Quantitative Approaches*. Thousand Oaks; London: Sage.
- Crotty, M. (1998). *The foundations of social march: Meaning and perspective in the research process*. London: Sage.
- Cruz, C. O. and Marques, R. C. (2013). Exogenous Determinants for Renegotiating Public Infrastructure Concessions: Evidence from Portugal. *Journal of Construction Engineering and Management*, 139 (9), 1082-1090.
- Csete, J. M. and Albrecht, R. R. (1994). The Best of Both Worlds: Synthesizing Quantitative and Qualitative Research in The Medical Setting. *Primary Care Research Methods and Statistics Conference*, San Antonia, Texas.
- CURACAO. (2009). Deliverable D2: State of the Art Review: Coordination of Road User Charging Administrative Issues (CURACO). European Commission FB6.
- Davidson, P. (2011). Modelling Toll Roads-Where Have We Gone Wrong?. *Australasian Transport Research Forum*, Australia, December.

- De Jong, G. and Gunn. H. (2001). Recent Evidence on Car Cost and Time Elasticities of Travel Demand in Europe. *Journal of Transport Economics and Policy* 35, 137–160.
- De Jong, G., Daly, A., Pieters, M., Miller, S., Plasmeijer, R. and Hofman, F. (2007). Uncertainty in traffic forecasts: literature review and new results for The Netherlands. *Transportation*, 34(4), 375-395.
- Debande O. (2002). Private Financing of Transport Infrastructure: An Assessment of The UK Experience. *Journal of Transport Economics and Policy*, 36(3), 355-387.
- Dehghani, Y. and Olsen, W. (1998). Potential Pitfalls in Forecasting Travel Demand for Toll Roads: Experience in the US and Overseas. TRB Paper 99051.
- Deng, F. (2004). Expert and Decision Support System Approached for Construction Project Funding and Cash Flow Management for Large Infrastructure Projects. PhD Dissertation, Department of Civil, Structure and Environmental Engineering, The State University of New York at Buffalo.
- Delmon, J. (2005). *Project Finance, BOT Projects and Risk*, The Hague: Kluwer Law.
- Denscombe, M. (1998). *The Good Research Guide*. Buckingham: Open University Press.
- Department of Energy and Climate Change (DECC) (2012). Quarterly energy prices publication. Available at:  
<https://www.gov.uk/government/collections/quarterly-energy-prices> [Accessed 4 September 2012].
- Department of Infrastructure and Transport, (2011). An investigation of the Causes of Over-Optimistic Patronage Forecasts for Selected Recent Toll Road Projects. Available at:

[http://www.infrastructure.gov.au/infrastructure/public\\_consultations/files/attach\\_c\\_gdh\\_report.pdf](http://www.infrastructure.gov.au/infrastructure/public_consultations/files/attach_c_gdh_report.pdf). [Accessed 9 July 2012]

Dettmer, H. W. (1997). *Goldratt's Theory of Constraints: A Systems Approach to Continuous Improvement*, Wisconsin, ASQ Quality Press.

Dey, P. K. and Ogunlana, S. O. (2004). Selection and Application of Risk Management Tools and Techniques for Build-Operate-Transfer Projects. *Industrial Management & Data Systems*, 104, 334-346.

DfT (1994). *Trunk Roads in England: 1994 Review*. TSO, London.

DfT (1994). *Birmingham Northern Relief Road Statement of Reasons for the Public Inquiries*.

DfT, (2003). *Values of Travel Time Savings in the UK*, White Rose Consortium,

DfT. (2011). *Transport Statistics Great Britain 2011*, [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/9002/modal-summary.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/9002/modal-summary.pdf) [Accessed 13 May 2012].

DfT. (2012a). *Transport Statistics Great Britain 2012*. Available at: [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/36545/Transport\\_statistics\\_great\\_britain\\_-\\_2012\\_summary.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/36545/Transport_statistics_great_britain_-_2012_summary.pdf) [Accessed 9 June 2012].

DfT. (2012b). TAG Unite 3.5.6: *Values of Time and Vehicle Operating Costs*.

Doaen, D.P. and Seward, L. E. (2011). Measuring Skewness. *Journal of Statistics Education*, 19(2), 1-18.

Duffield, C.F. (2005). PPPs in Australia, in Jefferies, M (2009). *Using Public Private Partnerships (PPPs) to Procure Social Infrastructure in Australia*. *Engineering, Construction and Architectural Management*, 16 (5), 415-437.

- Duthie, J., Voruganti, A., Kockelman, K. and Waller, S. T. (2008). Uncertainty Analysis and its Impacts on Decision-Making in an Integrated Transportation and Gravity-Based Land Use Model. In: *Proceedings the 88th Annual Meeting of the Transportation Research Board*, Washington, D.C.
- Eboli, L. and Mazzulla, G. (2008). Willingness-to-Pay of Public Transport Users for Improvement in Service Quality. *European Transport*, 38, 107-118.
- Edler, J. and Georghiou, L. (2007). Public Procurement and Innovation: Resurrecting the Demand Side. *Research Policy*, 36, 949–963.
- Edward A. L. (1996). Key Features of Successful BOT. *Proceedings of the Seminar on BOT in the Water Supply Sector*. Beijing, China, 22-23 October.
- EIB. (2007). A Renewed Policy for EIB Lending To The Transport Sector. European Investment Bank.
- Ellis, S. and Caceres, V. (2011). M6 Birmingham Expressway: The quest for leverage continues. Available at: <http://www.docstoc.com/docs/70646812/M6-Birmingham-Expressway>. [Accessed February 3, 2012].
- Engel, E., Galetovic, A. and Fischer, R. (2002). A New Approach to Private Roads. *Regulation*, 25(3).
- Engel, E., Fischer, R. and Galetovic, A. (2003). Privatizing highways in Latin America: Is it possible to fix what went wrong?. *Economia*, 4(1), 129–143.
- Engel, E., Fischer, R. and Galetovic, A. (2006). Renegotiation without Holdup: Anticipating Spending and Infrastructure concessions. NBER Working Paper 12339, National Bureau of Economic Research, Cambridge, MA.
- EPEC. (2012). The Guide to Guidance, How to Prepare, Procure and Deliver PPP Projects. European Investment Bank.

- Estache, A., Guasch, J. L., Iimi, A. and Trujillo, L. (2008). *Multidimensionality And Renegotiation: Evidence from Transport-Sector, Public-Private-Partnership Transactions In Latin America*, Policy Research Working Paper No. 4665, World Bank, Washington, DC.
- Estache, A., Juan, E. and Trujillo, L. (2007). *Public Private Partnerships in Transport*. World Bank, Washington, DC.
- Estache, A., Romero, M. and Strong, J. (2000). *The Long and Winding Path to Private Financing and Regulation of toll roads*. World Bank.
- Evenhuis, E. and Vickerman, R. (2010). *Transport Pricing and Public-Private Partnerships in Theory: Issues and Suggestions*. *Research in Transportation Economics*, 30 (1), 6-14
- Fayard, A., Gaeta, F. and Quinet, E. (2005). *French Motorways: Experience and Assessment*, in Giorgio Ragazzi and Werner Rothengatter (eds.), *Procurement and Financing of Motorways in Europe*. Oxford: *Elsevier*, 2005, 93-105.
- Fayard, A. (2004). *Analysis of Highway Concession in Europe*, *Conference on Highways: cost and regulation in Europe*, University of Bergamo – Italy, March 2004.
- Fayard, A., Gaeta, F. and Quinet, E. (2004). *French motorways: Experience and assessment*, *Conference on Highways: cost and regulation in Europe*, University of Bergamo, Italy, March 2004.
- Fedderke, J. W., Perkins, P. and Luiz, J. M. (2006). *Infrastructural Investment in Long-Run Economic Growth: South Africa 1875-2001*. *World Development*, 34, 1037-1059.
- Fellows, R and Liu, A. (2003) “*Research methods for construction*”. 2ed. London: Blackwell Science Ltd.

- Fernandes C. and Viegas J. M. (2005). Portuguese Experience in Motorway Concessions with Real and Shadow Tolls. *Research in Transportation Economics*, 15, 157-174.
- Field A. (2009). *Discovering statistics using SPSS*. 3 ed. London: SAGE.
- Financial Times (1998). High Speed Rail, the Future in Stated Preference Techniques and Consumer Decision Making: New Challenges to Old Assumptions. 18April  
(<https://dspace.lib.cranfield.ac.uk/bitstream/1826/664/2/SWP0200.pdf>)
- Fisher, G. and Babbar, S. (1996). Private Financing of Toll Roads. RMC discussion paper series; no. 117. World Bank, Washington, D.C.
- Fitzgerald, B. and Howcroft, D. (1998). Towards Dissolution of the IS Research Debate: From Polarisation to Polarity. *Journal of Information Technology*, 13 (4), 313-326.
- Flyvbjerg, B. (2008). Curbing Optimism Bias and Strategic Misrepresentation in Planning: Reference Class Forecasting in Practice. *European Planning Studies*, 16 (1), 3-21.
- Flyvbjerg, B., Bruzelius, N. and Rothengatter, W. (2003). *Megaprojects and risk: An anatomy of ambition*. New York: Cambridge University Press.
- Flyvbjerg, B., Holm, M. K. S. and Buhl, S. L. (2006). Inaccuracy in Traffic Forecasts. *Transport Review*, 26(1).
- Flyvbjerg, B., Holm, M. K. S. and Buhl, S. R. L. (2005). How (In)accurate Are Demand Forecasts in Public Works Projects? *Journal of the American Planning Association*. Routledge.
- Ford, A. (1999). *Modelling the Environment*. Washington, DC, USA: Island Press,

- Ford, D. N. and J. D. Sterman. 1998. Dynamic modeling of product development processes. *System Dynamics Review* 14(1): 31, 68
- Forrester, J.W, 1991, *System dynamics and the lessons of 35 years*, De Greene, K.B, The Systemic Basis of Policy Making in the 1990s, Sloan School of Management, MIT, Boston, MA.
- Forrester, J. W. (1994). System Dynamics. Systems Thinking. and Soft OR. *System Dynamics Review*. 10(2-3): 245-256.
- Forrester, J. W. (1992). Policies, Decisions and Information Sources for Modelling, *European Journal of Operational Research*, 59, 42-63.
- Forrester, J. W. and Senge, P. M. (1980). Tests for Building Confidence in System Dynamics Models. *TIME Studies in the Management Science* 14, 209-228.
- Forrester, Jay W. (1975). *Collected Papers of Jay W. Forrester*. Portland, OR: Productivity Press. 284 pp. Forrester, Nathan B. 1973. *The Life Cycle of Economic Development*. Portland, OR: Productivity Press.
- Forrester, J. W. (1971). *World Dynamics*. Cambridge, Massachusetts, MA, USA: Wright-Allen Press.
- Forrester, J. W. (1969). *Urban Dynamics*. Portland, OR: Productivity Press
- Forrester, Jay W., (1968). *Principles of Systems*. (2nd ed.). Portland, OR: Productivity Press.
- Forrester, J. W. (1961). *Industrial Dynamics*. MIT Press: Cambridge, Massachusetts
- Fox, J. and Tott, N. (1999). *PFI Handbook*, Jordan Publishing, Bristol.
- Frankfort-Nachmias, C. and Nachmias, D. (1996). *Research Methods in the Social Sciences*. New York: Worth Publishers.

- Fraenkel, J. R. and Wallen, N. E. (2007). *How to Design and Evaluate Research in Education*, (5th ed.). New York: McGraw-Hill.
- Friends of the Earth. (2003). Briefing in Advance of the M6 Toll Opening. Available at: [http://www.birminghamfoe.org.uk/bnrr/Toll\\_opening\\_briefing.htm](http://www.birminghamfoe.org.uk/bnrr/Toll_opening_briefing.htm) [Accessed Apr, 2013].
- Froud, J. (2003). The Private Finance Initiative: Risk, Uncertainty and State. *Accounting, Organisation and society*, 28, 567-589.
- FSA. (2010). The Severn Bridge: Taking its Toll on The Economy?
- Gable, G. G. (1994). Integrating Case Study and Survey Research Methods: an Example in Information Systems. *European Journal of Information Systems* 3(2), 112-126.
- George, C. (2003). Bliss, Heartburn, and Toll Road Forecasts. Fitch Ratings. Fitch Ratings. New York, USA.
- George, C., Trommer, S. McDermott, M. Zurita, G. Lewis, C. Monnier, L. Streeter, W. Lopez, E. and Fuenalida. C. (2007). Global Toll Road Rating Guidelines. Fitch Ratings. New York, USA.
- Gilbert, A. (2009). Disciplinary cultures in mechanical engineering and materials science: Gendered/gendering practices?. *Equal Opportunities International*, 28 (1), 24 - 35
- Goodwin, p. (1996). Empirical Evidence on Induced Traffic. *Transportation*, 23 (1), 35-54
- Goodwin, p. and Noland, R.B. (2003). Building New Roads Really Create Extra Traffic. *Applied Economic*, 35(13), 1451-1457.



- Goodwin, P. B. (1992). A Review of New Demand Elasticities with Special Reference to Short and Long Run Effects of Price Changes. *Journal of Transport Economics and Policy*, 26, 155–169
- Graham, A. K., Morecroft, J. D., Senge, P. M. and Sterman, J. D. (1992). Model Supported Case Studies for Management Education. *European Journal of Operational Research*. 59(1), 151-166.
- Graham, D.J. and Glaister. S. (2002). The Demand for Automobile Fuel: A Survey of Elasticities. *Journal of Transport Economics and Policy*. 36, 1–26.
- Gramlich, E. (1994). Infrastructure Investment: A Review Essay. *Journal of Economic Literature*, 32.
- Gray, D, E. (2004). *Doing research in the real world*. London: Sage.
- Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a Conceptual Framework for Mixed-Method Evaluation Designs. *Educational Evaluation and Policy Analysis*, 11, 255-274.
- Grimsey, D. and Lewis, M. K. (2002). Evaluating the Risks of Public Private Partnerships for Infrastructure Projects. *International Journal of Project Management*, 20 (2), 107–118.
- Guasch, J. L. (2004). *Renegotiating infrastructure concessions: Doing it right*. World Bank, Washington, DC.
- Guasch, J. L., Laffont, J. and Straub, S. (2007). Concessions of infrastructure in Latin America: Government-led renegotiation. *Journal of Application. Economic* 22(7), 1267–1294.
- Guasch, J. L., Laffont, J. and Straub, S. (2008). Renegotiation of concession contracts in Latin America Evidence from the water and transport sectors. *International Journal of Industrial Organisation*, 26(2), 421–442.

- Guasch, L. (2001). Concessions and Regulatory Design: Determinants of Performance-Fifteen Years of Evidence, mimeo, World Bank and University of California, San Diego.
- Haghani, A., Lee, S. Y. and Byun, J. H. (2003). A System Dynamics Approach to Land Use/Transportation System Performance Modelling Part I: Methodology. *Journal of Advanced Transportation*, 37(1): 1-41.
- Halcrow Group. (2004). A Tale of Three Cities: Urban Rail Concessions in Bangkok, Kuala Lumpur and Manila. Asian Development Bank, Japan Bank for International Cooperation, and World Bank East Asia and Pacific Infrastructure Study, Washington, DC.
- Hall, D., Corral, V., Lobina, E. and de la Motte, R. (2004). Water privatisation and restructuring in Asia-Pacific. *Public Services International (PSI) Unit for its Asia-Pacific meeting*, Changmai, Thailand, December 2004.
- Hall, D., Lobina, E. and de la Motte, R. (2005). Public Resistance to Privatization in Water and Energy. *Development in Practice*, 15(3&4)
- Hammersley, M. (1996). The Relationship between Quantitative and Qualitative Research, in J Richardson (ed.). *Handbook of Qualitative Research Methods for Psychology and the Social Sciences*, Leicester, British Psychological Society Books.
- Hammersley, M. and Atkinson, P. (1995). *Ethnography: Principles in Practice*. London and New York: Routledge.
- Harding, R. (2005). Memorandum by Tramtrack Croydon. Integrated Transport: The Future Of Light Rail And Modern Trams In Britain. Select Committee on Transport. Written Evidence. House of Commons.
- Harrison, G. W. and Rutström, E. E. (1999). Experimental Evidence on the Existence of Hypothetical Bias in Value Elicitation Methods,' in Smith, V. L., ed,

Handbook of Results in Experimental Economics. New York: Elsevier Science.

Hart, S., Boroush, M., Enk, G. and Hornick, W. (1985). Managing Complexity through Consensus Mapping: Technology for the Structuring of Group decisions". *Academy of Management Review*, 10, 587-600.

Harvey, L. and Myers, M, D. (1995). Scholarship and practice: the contribution of ethnographic research methods to bridging the gap. *Information Technology and People*, 8 (3), 13-27

Harwood, D., Glauz, W. and Elefteriadou, L. (1999). Roadway Widening Costs for Geometric Design Improvements to Accommodate Potential Larger Trucks. *Transportation Research Record*. Issue 1658.

Hawkett, D. (1995). Forecasting for the Birmingham Northern Relief Road. *The Journal of the Transport Economist*. 22 (2). 22-29.

Hensher, D. A. (1994). Stated Preference Analysis of Travel Choices: The State Of Practice. *Transportation*, 21(2), 107–133.

Hensher, D. A. and Puckett, S. (2005). Road User Charging: The Global Relevance of Recent Developments in The United Kingdom, *Transport Policy*. 12, 377-383.

Heravi, G. and Hajihosseini, Z. (2012). Risk Allocation in Public–Private Partnership Infrastructure Projects in Developing Countries: Case Study of the Tehran Chalus Toll Road." *Journal of Infrastructure Systems*, 18(3), 210–217.

Highway Agency website <http://www.highways.gov.uk/our-road-network/our-network/key-roads/m6/> [Accessed 22 August 2011].

Highway Agency. (2009). Post opening Project Evaluation, M6 Toll, Five Years after Study, DfT.

Highway Agency. (2005). Post Opening Project Evaluation, M6 Toll after Study: Traffic and Safety Summary. DfT

HM Treasury. (1997). Partnerships for prosperity. London: HMSO.

HM Treasury. (2003). PFI: Meeting the Investment Challenge. London, UK.

HM Treasury. (2006). Value for Money Assessment Guidance. London, UK.

HM Treasury (1995). Private Opportunity, Public Benefit: Progress the Private Finance Initiative, the Stationery Office, London

Ho, S. P. (2004). Model for Financial Renegotiation in Public Private Partnership Projects and Its Policy Implications: Game Theoretic View. *Journal of Construction, Engineering, and Management*, 130(1), 94–104.

Hodge, G. A. (2004). The Risky Business of Public Private Partnerships. *Australian Journal of Public Administration*, 63 (4), 37-49.

Holvad, T. and Preston, J.M. (2005). A Review of the Empirical Evidence on the Additional Benefits of Road Investment. Deliverable D1 of the Rees Jeffrey Road Fund Study Road Transport and Additional Economic Benefits, November 2005.

Horner, R. (1999). Public Private Partnership, the Way forward. Irish Banking Review summer 1999, 25-35. Available at: <http://transweb.sjsu.edu/mtiportal/research/publications/documents/02-03.pdf>. [Accessed 12 March 2012].

ICF International Venner Consulting, CH2M Hill, and the University of Florida (2008), Guide to Estimating Environmental Costs. American Association of State Highway and Transportation Officials (AASHTO), October, 2008.

Illsley, B. M. (2003). Fair Participation: A Canadian Perspective. *Land Use Policy*, 20, 265-273.

Infrastructure PPP in Asia, [online] Norton Rose. Available at: <<http://www.nortonrose.com/knowledge/publications/2006/pub8505.aspx?page=11030&lang>> [Accessed 17 April 2011].

IPPR. (2000). Summary of Responses to Call for Evidence - Consultation on Public Private Partnerships. Available at: <http://www.ippr.org.uk>. [Accessed January 2011].

Iraguen, P. and Juan De Dios, O. (2004). Willingness-To-Pay for Reducing Fatal Accident Risk in Urban Areas: An Internet-Based Web Page Stated Preference Survey. *Accident Analysis and Prevention*, 36, 513-524.

Ive, G., Edkins, A., and Millan, G. (2000). The Role Of Cost Saving and Innovation in PFI Projects, Thomas Telford, London.

Jain, D. A., Joshi, U. C. and Varshney, A. K. (2000). Short-Term Water Demand Forecasting using Artificial Neural Networks: IIT Kanpur Experience. *15th International Conference on Pattern Recognition, 2000*.

Jang, S. G. (2011). A Concessionaire Selection Decision Model Development and Application for the PPP Project Procurement. PhD Thesis, *School of Management*. University of Southampton.

Jayaseelan, R. and Tan, M. (2006). PFI-Cure for All Ills. The Edge Malaysia, 72-74. WORLD Bank, 1997.

Jefferies, M. and McGeorge, D (2009). Using public-private partnerships (PPPs) to Procure Social Infrastructure in Australia? *Engineering, Construction and Architectural Management*, 16 (5), 415-437.

- Jefferies, M. and McGeorge, D. (2009). Public-Private Partnerships: A Critical Review of Risk Management in Australian Social Infrastructure Projects. *Journal of Construction Procurement*, 14(1), 66-80.
- Jin, X. H. and Doloi, H. (2008). Interpreting Risk Allocation Mechanism in Public Private Partnership Projects: An Empirical Study in a Transaction Cost Economics Perspective. *Construction Management and Economics*, 26(7), 707–21.
- Jin, X. H. and Zhang, G. (2011). Modelling Optimal Risk Allocation in PPP Projects Using Artificial Neural Networks. *International Journal of Project Management*, 29(5), 591-603.
- Johansson, O. and Schipper, L. (1997). Measuring the Long-Run Fuel Demand of Cars. *Journal of Transport Economics and Policy*, 31, 272–292.
- Kagioglou, M., Cooper, R., Aouad, G. and Sexton, M. (2000). Rethinking Construction: The Generic Design and Construction Process Protocol'. *Journal of Engineering Construction and Architectural Management*, 7 (2), 141-154.
- Kahneman, D. and Tversky, A. (1979). Prospect theory: An analysis of Decisions under Risk, *Econometrica*, 47, 313–327.
- Kanaroglou, P. S. Anderson, W. P. and Kazakov, A. (1998). Economic impacts of highway infrastructure improvements Part 1. Conceptual framework. *Journal of Transport Geography*, 6, 203-210.
- Karpak, B., Topcu, I. (2010). Small Medium Manufacturing Enterprises in Turkey: An Analytic Network Process Framework for Prioritizing Factors Affecting Success. *Intentional Journal of Production Economics*, 125 (2010) 60–70.
- Khanzadi, M., Nasirzadeh, F., and Alipour, M. (2012). Integrating system dynamics and fuzzy logic modeling to determine concession period in BOT projects. *Automation in Construction*, 22, 368–376.

- Kaplan, B. and Duchon, D. (1988). Combining Qualitative and Quantitative Methods in Information Systems Research: a Case Study. *MIS Quarterly* 12(4), 51-586.
- Kappeler, A. and Nemoz, M. (2010). Public private partnerships in Europe – before and during the Recent Crisis. Economic and Financial Report No. 2010/04, European Investment Bank, July.
- Kasi, P. (2009). *Research: What, Why and How? A Treatise from Researchers to Researchers*, 1st Edition. Bloomington: AuthorHouse.
- Ke, Y., Wang, S. and Chan, A. (2010). Risk Allocation in Public-Private Partnership Infrastructure Projects: Comparative Study. *Journal of Infrastructure Systems* 16(4): 343-351.
- Kelle, U. (2001). Sociological Explanations between Micro and Macro and the Integration of Qualitative and Quantitative Methods, Forum: *Qualitative Social Research (FQS)*. 2(1)
- Khadaroo, I. (2008). The actual evaluation of school PFI bids for value for money in the UK public sector. *Critical perspective on accounting* 19, 1321-1345.
- Khan, S. and Faisal, M. N. (2008). An Analytic Network Process Model for Municipal Solid Waste Disposal Options, *Waste Management*. 28, 1500–1508.
- Khotanzad, A., Afkhami-Rohani, R., Lu, T.L., Davis, M.H., Abaye, A. and Maratukulam, D. (1997). ANNSTLF- A Neural Network Based Electric Load Forecasting System," *IEEE Trans. on Neural Networks*, 8 (4), 835-846.
- Kikeri, S. and Kolo, A. (2005). Privatization: trends and recent developments, World Bank. Report NoWPS3765.

- Kim D. H. (1992). Guidelines for Drawing Causal Loop Diagrams, the Systems Thinker, 3(1), 5-6.
- Kruger D. (2005). Traffic and Revenue Forecasting for Roads and Highways: Concerns, Methods and a Checklist for Practitioners , paper prepared for Expert Forum on Road Pricing and Travel Demand Modelling, November 14-15, Alexandria, VA.
- Kruger, D., S. Shiu, and S. Naylor. (2006). Estimating Toll Road Demand and Revenue – A Synthesis of Highway Practice. NCHRP Synthesis 364, Transport Research Board. Washington, D.C. USA.
- Kroes, E.P. and Sheldon, R.J. (1988). Stated Preferences Methods: An Introduction. *Journal of Transport Economics and Policy*, 22, 1, 11-25.
- Krumbeck Brook and Killen Catherine (2010). A System Dynamics Approach for Strategic Analysis of Project Portfolio Interdependencies, Australian Institute Project Management (AIPM), Australia, 1-10.
- Kwak, Y. H., Chih, Y. Y. and Ibbs, C. W. (2009). Towards a Comprehensive Understanding of Public Private Partnerships for Infrastructure Development. *California Management Review*, 51 (2), 51-78.
- Kwak, S. (1995). Policy analysis of Hanford tank farm operations with system dynamic approach, Ph.D thesis, Department of Nuclear Engineering, Massachusetts Institute of Technology, Cambridge, Mass.
- Lam, K. (2006). Operation of Toll Roads, Bridges and Tunnels in Selected Places Central, Hong Kong: Research and Library Services Division, Legislative Council Secretariat.
- Lam, W. and Tam, M.L. (1998). Risk Analysis of Traffic and Revenue Forecasts for Road Investment Projects. *Journal of Infrastructure Systems*, 4 (1), 19–27.



- Land Transport New Zealand. (2007). Risk Analysis. Appendix A13 of 'Economic Evaluation Manual: Volume1,' Land Transport New Zealand. <http://www.nzta.govt.nz/resources/economic-evaluation-manual/volume-1/docs/eem1-amendment-1-pages.pdf>
- Lane, D. C. (1995). The Folding Star: A Comparative Reframing and Extension of Validity Concepts in System Dynamics. Proceedings of International System Dynamics Conference, Tokyo, Japan, Vol. 1: 111-130.
- Lang, H.P. (1998). *Project finance in Asia*, Amsterdam: Elsevier
- Lavanchy, R. (2013). M6 Toll: the owners head for next exit. Available at: <https://infrastructurepunk.wordpress.com/2013/09/24/m6-toll-the-owners-head-for-next-exit/> [Accessed 13 May 2013].
- Lau, S. H. P and Sin, C. Y. (1997). *Public Infrastructure and Economic Growth: Time Series Properties and Evidence*, Economic Record, 73.
- Le Vine, S. and Jones, P. 2012, On the Move, Making Sense of Car and Train Travel Trends in Britain, RAC Foundation, Dec, 2012.
- Le Compte, M. D. and Schensul, J. J. (1999). *Designing and conducting ethnographic research*. Walnut Creek, CA: AltaMira
- Lemos, T., Eaton D., Betts M. and de Almeida L.T. (2004). Risk management in the Lusoponte Concession-a Case Study of the Two Bridges in Lisbon, Portugal. *International Journal of Project Management* 22(1), 63-73(11).
- Lemp, J. and Kockelman, K. (2009). Understanding and Accommodating Risk and Uncertainty in Toll Road Projects: A Review of the Literature. *Transportation Research Record*, 2132, 106-112.
- Levy, S. M. (1996). *Build, Operate, Transfer*, New York: Wiley.

- Lewis, C. D. (1982). *Industrial and business forecasting methods: A practical guide to exponential smoothing and curve fitting*. London: Butterworth Scientific.
- Li, B. (2003). Risk Management of construction public private partnership” in Cheung, E., Chan, A. And Kajewski, S. (2009). Enhancing value for money in public private partnership projects : Findings from a survey conducted in Hong Kong and Australia compared to findings from previous research in the UK”, *Journal of Financial Management of Property and Construction*. Vol. 14 No. 1, 2009 pp. 7-20.
- Li, B., Akintoye, A., Edwards, P. and Hardcastle, C. (2005). The allocation of risk in PPP/PFI construction projects in the UK. *International Journal of Project Management*, 23, 25–35
- Li, B. and Ren, Z. (2009). Bayesian technique framework for allocating demand risk between the public and private sector in PPP projects. *IEEE*, 837-841.
- Li, Z., and Hensher, D. A. (2010). Toll roads in Australia: an overview of characteristics and accuracy of demand forecasts. *Transport Reviews*. A Transnational Transdisciplinary Journal. 30(5), pp. 541-569.
- Li, Y., Yuan, Z., Cao, S., Ding, Y. and Hu, P. (2008). Application of Combined Traffic Demand Forecasting for Comprehensive Transport Corridor. *NCM '08. Fourth International Conference on Networked Computing and Advanced Information Management*, 2008.
- Li, H-B. (2007). System Dynamics Application to PPP Financing. *2007 International Conference on Wireless Communications, Networking and Mobile Computing*, 4982–85.
- Lin, S., Pioches, A. and Stander, P. (1986). Estimating Sales Volume Potential for Innovative Product with Case Histories, In: *Proceeding of 1986 ESOMAR Congress*, Monte Carlo.

- Linkov, I., Satterstrom, F. K., Kiker, G., Seager, T. P., Bridges, T., Gardner, K. H.; Rogers, S. H.; Belluck, D. A. and Meyer, A. (2006). Multi-Criteria Decision Analysis: A Comprehensive Decision Approach for Management of Contaminated Sediments, *Risk Analysis*, 6(1), 61-78.
- Linneker, B. J. and Spence, N. A. (1996). Road Transport Infrastructure and Regional Economic Development: The Regional Development Effects of the M25 London Orbital Motorway, *Journal of Transport Geography* 4 (2):77-92.
- Litman, T. (2009). *Transportation Cost and Benefit Analysis, Techniques, Estimates and Implications*. Victoria Transport Policy Institute (VTPI).
- Liu, S., Triantis, K. P. and Sarangi, S. (2010), A Framework for Evaluating The Dynamic Impacts of A Congestion Pricing Policy for A Transportation Socioeconomic System. *Transportation Research Part A: Policy and Practice*, 44, 596-608.
- Liu, H., Deng, T. and Zhang, H. (2009). Research on Forecasting Method of Urban Water Demand Based on Fuzzy Theory. 2009. *FSKD '09. Sixth International Conference on Fuzzy Systems and Knowledge Discovery, 2009*.
- Liu, S. (2007). Three Essays on Travel Demand Management Strategies for Traffic Congestion Mitigation *Faculty of Virginia Polytechnic Institute*. State University. PhD: 547
- Liu, X. Q., Ang, B. W. and Goh, T. N. (1991). Forecasting of electricity consumption: a comparison between an econometric model and a neural network model. 1991 *IEEE International Joint Conference on Neural Network, 1991*.
- Locke, L. T., Spirduso, W. W. and Siverman, S. J. (2000). *Proposals that Work*. Thousand Oaks: Sage.

- Loosemore, M., Raftery, J., Reilly C. and Higgon, D. (2006). *Risk Management in Projects*. London: Taylor & Francis.
- Lovallo, D .and Kahneman, D. (2003). Delusions of Success: How Optimism Undermines Executives' Decisions, *Harvard Business Review*, 56-63.
- Love, P., Mandal, P. and Li, H. (1999). Determining the Causal Structure of Rework Influences in Construction. *Construction Management and Economics*, 17, 505-517.
- Lowe, J. and Whitworth, T. (1996). Risk Management and Major Construction Projects, *CIB W65 (in conjunction with W92). International Symposium for the Organization and Management of Construction: Shaping Theory and Practice*, Glasgow, Scotland, pp. 891-899.
- Luna-Reyes, L. F. and Andersen, D. L. (2003). Collecting and Analysing Qualitative Data for System Dynamics: Methods and Models. *System Dynamics Review*, 19, 271-296.
- Lyneis, J. M. 1998. System Dynamics in Business Forecasting: A Case Study of the Commercial Jet Aircraft Industry. *Proceedings of the 1998 International System Dynamics Conference*, Quebec, Canada.
- M6 Toll, UK. (2012). Available at: <https://www.m6toll.co.uk/> [Accessed 12 January 2012].
- Mackie, P., Nellthorp, J., and Laird, J. (2003). Toolkit for the Economic Evaluation of World Bank, Transport Projects Institute for Transport Studies, University of Leeds.
- Marques, R. C. and Berg, S. (2010). Revisiting the strengths and Limitations of regulatory contracts in infrastructure industries. *Journal of Infrastructure System*, 16(4), 334–342.

- Matas, A., Raymond. J. L. and Ruiz, A. (2003). Demand Elasticity on Tolled Motorways. *Journal of Transportation and Statistics*. V6, N2/3.
- Matas, A., Raymond. J. L. and Ruiz, A. (2010). Traffic Forecasts under Uncertainty and Capacity Constraints. Paper presented at the WCTR Conference, Lisbon, Portugal.
- Mackie, P., Nellthorp, J. and Laird, J. (2003). Toolkit for the Economic Evaluation of World Bank Transport Projects, Institute for Transport Studies, University of Leeds.
- Maxwell. J. (1996). *Qualitative research design: An Interactive Approach*. Thousand Oaks, CA: Sage.
- McAndrew, C., Smith, J. L. and Thompson, R. (2009). The Impact of Reservation Prices on the Perceived Bias in Expert Appraisals of Fine Art: Controlling for Latent Censoring of Transaction Prices. Social Science Research Network, Working Paper Series. Available at: <[http://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=1327026](http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1327026). [Accessed October 10, 2012].
- McKinsey (2008). How Investors Can Get More Out of Infrastructure, “The McKinse Quarterly”, First Quarter 2008.
- McKinsey Global Institute, (2013). Infrastructure Productivity: How to Save \$1 Trillion a Year.
- McQuaid, R.W. and M. Greig. (2002). *An Assessment of the Economic Impact of the Skye Bridge Tolls*, Research Report, Inverness: Highland Council.
- McQuaid, R.W. and M. Greig (2002b). *An Assessment of the Economic Impact of the Skye Bridge Tolls*, Research Report, Inverness: Highland Council. [https://dspace.stir.ac.uk/bitstream/1893/17595/1/skye\\_bridge\\_final\\_report.pdf](https://dspace.stir.ac.uk/bitstream/1893/17595/1/skye_bridge_final_report.pdf) [accessed May 8, 2011].

- McQuaid, R.W. and M. Greig (2010). The Bridge to Skye, Scotland. *Island Study Journal*.
- Meadows, D.H., Robinson, J.M. (1985). The Electronic Oracle: Computer Models and Social Decisions. John Wiley and Sons, New York.
- Medda, F. (2007). A game theory approach for the allocation of risks in Transport Public Private Partnerships. *International Journal of Project Management* 25, 213-218.
- Megens, P. (1997). Construction Risk and Project Finance –Risk Allocation as Viewed by Contractors and Financiers. *The International Construction Law Review*,14(1), 5-32.
- Menzies, I, and Perrott, C (2010). Private Sector Participation in Urban Rail: Getting the Structure Right, Note No. 54. Washington DC: PPIAF. Available at: <http://www.ppiaf.org/ppiaf/sites/ppiaf.org/files/publication/Gridlines-54-PSP%20in%20Urban%20Rail%20-%20IMenzies%20CMandri-Perrot.pdf> [Accessed 13 April, 2011].
- Metz, D. (2008). The myth of travel time saving, *Transport Reviews*, 28, (3), 321-336.
- Meyer, J, and Gomez-Ibañez.J. (1993). Going Private: The International Experience with Transport Privatization. Washington, D.C.: The Brookings Institution.
- Midland Expressway Limited (MEL). (2005). Interim Financial Statements (unaudited) for the six months ended 31 December 2005.
- Monod, J., (1982). The private sector and the management of public sector drinking water supply. Washington. World Bank.
- Morecroft, J. W. and Van Der Heijden, M. (1992), Modelling the oil producers — Capturing oil industry knowledge in a behavioural simulation model. *European Journal of Operational Research*, 59, 102-122.

- Morgan, M. G. and Henrion, M. (1990) *Uncertainty: A Guide To Dealing With Uncertainty In Quantitative Risk And Policy Analysis*, Cambridge, UK: Cambridge University Press.
- Morse, J. M. (1991a). On Funding Qualitative Proposals [Editorial]. *Qualitative Health Research*, 192, 147-151
- Mouraviev, N. (2012). Risk Management in Public-Private Partnerships and Research Agenda for Transitional Countries. *IJMBS*, 2, 37-41.
- Msiza, I. S., Nelwamondo, F. V. and Marwala, T. (2007). Artificial Neural Networks and Support Vector Machines for Water Demand Time Series Forecasting. *IEEE International Conference on Systems, Man and Cybernetics, 2007*.
- Mugabi, J. and Kayaga, S. (2010). Attitudinal and Socio-Demographic Effects on Willingness to Pay for Water Services and Actual Payment Behaviour. *Urban Water Journal*, 7, 287-300.
- Munnell, Alicia H. (1992), Policy Watch: Infrastructure Investment and Economic Growth. *The Journal of Economic Perspectives*, 6 (4).
- Murphy, J., Stevens, T. and Weatherhead, D., (2003). *An Empirical Study of Hypothetical Bias in Voluntary Contribution Contingent Valuation: Does Cheap Talk Matter?* University of Massachusetts, Amherst. Working Paper,
- Naess, P., Flybjerg, B. and Buhl, S. (2006). Do road planners produce more ‘honest numbers’ than rail planners? An analysis of accuracy in road-traffic forecasts in cities versus peripheral regions. *Transport Reviews*, 26(5): 537–555
- NAO (2003). PFI: construction performance Rep.NoHC371, The stationery Office, London.
- Naoum, S, G. (1998). *Dissertation research and writing – For construction students*. Butterworth-Heinemann, Oxford, U.K.

- Nelson, G and Loke, H. (1998). Evaluating Toll Road Risks. Dominion Bond Rating Service Ltd (DBRS). Available at: <http://www.dbrs.com/research/101400/evaluating-toll-road-risks-archived.pdf> [Accessed 19 November 2011]
- Ng, A. and Loosemore, M. (2007). Risk allocation in the private provision of public infrastructure. *International Journal of Project Management*, 25, 66-76.
- Ng, S. T., Xie, J. Z., Cheung, Y. K., and Jefferies, K. (2007a). A Simulated Model for Optimizing the Concession Period of Public Private Partnerships Schemes. *International Journal of Project*, 25, 791-798.
- Ng, S. T., Xie, J., Skitmore, M. and Cheung, Y. K. (2007b). A Fuzzy Simulation Model for Evaluating the Concession Items of Public-Private Partnership Schemes. *Automation in Construction*, 17, 22-29.
- Nicholas, A. (2012). Private Investment in Large Transport Projects Increases during the First Semester of 2011, Concentrated in India and the Road Sector. World Bank, Washington, DC. World Bank.
- Niles, H, Nelson, D (2001). Identifying Uncertainty in Forecasting of Travel Demand. *Global Telematics*.
- Norton Rose, (2006). Asia PPP – a survey of the infrastructure sector, October 2006
- Nyagwachi and Smallwood, (2008). South Africa PPP Project, A System Dynamics Model for Planning and Implementation. *26th System Dynamics Conference Proceedings*, Athens, Greece.
- OECD (2007), Infrastructure to 2030, Volume 2: Mapping Policy for Electricity, Water and Transport. ISBN Number: 978-9264031319.
- OECD (2008). Public-Private Partnerships: In Pursuit of Risk Sharing and Value for Money. ISBN Number: 9789264042797



- Osland O, and Strand A. (2010). The politics and institutions of project approval - a critical-constructive comment on the theory of strategic misrepresentation. *European Journal of Transport and Infrastructure Research*, 10(1): 77–88
- OMEGA. (2009). Project profile, UK, M6 toll road. UCL. London. Available at: [http://www.omegacentre.bartlett.ucl.ac.uk/studies/cases/pdf/UK\\_M6\\_PROFI\\_LE\\_021210.pdf](http://www.omegacentre.bartlett.ucl.ac.uk/studies/cases/pdf/UK_M6_PROFI_LE_021210.pdf) [Accessed 9 October 2012]
- Oppenheim, A. N. (1992). *Questionnaire design, interviewing and attitude measurement*. London: Pinter
- Ortúzar, J. D. D. and Willumsen, L. G. (2003). *Modelling Transport*. Chichester, Wiley.
- Ouyahia, M. (2006). *Public-Private Partnerships for Funding Municipal Drinking Water Infrastructure: What are the Challenges?* PRI Project, Sustainable Development, Canada. Discussion Paper.
- Pahlman, C. (1996). Build-Own-Operate-Transfer (BOOT). Private Investment in Public Projects...Or Just More Public Subsidies for the Private Sector? *Watershed*, 2(1), 49-52.
- Parahoo. K. (1997). *Nursing Research Principles, Process and Issues*. London: Macmillan.
- Parker, D. and Hartley, K. (2003). Transaction costs, relational contracting and public private partnerships: a case study of UK defence. *Journal of Purchasing & Supply Management* 9, 97–108.
- Patton, M. Q. (1990). *Qualitative Evaluation and Research Methods* (2<sup>nd</sup> ed.). Newbury Park, CA: Sage.
- Peer, S., Koopmans, C. and Verhoef, E. (2009) Predicting Travel Time Variability for Cost-Benefit Analysis. In: proceedings of *Value of Travel Time Reliability*

*and Cost-Benefit Analysis International Meeting. International Transport Forum, Vancouver,*

- Pendyala, R. M. (2005). Modelling Pricing in the Planning Process, paper prepared for Expert Forum on Road Pricing and Travel Demand Modelling, November 14-15, Alexandria.
- Perrott, C. and Menzies, I. (2010). Private Sector Participation in Light Rail Metro Transit Initiatives, The World Bank and Public-Private Infrastructure Advisory facility (PPIAF).
- Peterson DW. 1980. Statistical tools for system dynamics. In J Randers (ed.). 1980. Elements of the System Dynamics Method. Cambridge, MA: Productivity Press: 226-242.
- Pieda (1999). *Skye Bridge: Socio-Economic Impact Evaluation*, Edinburgh: Scottish Executive.
- Pitt, M. And Collins, N. (2006). Practice Briefing: The private finance initiative and value for money” *Journal of Property Investment & Finance* (24) 4, 363-373.
- Polit, D. F. Beck, CT and Hungler, B. P. (2001). *Essentials of Nursing Research: Methods, Appraisal and Utilization*. 5th edition. Philadelphia: Lippincott Williams & Wilkins.
- Pradhan, A. and Kockelman, K. (2001). Uncertainty Propagation in an Integrated Land Use-Transportation Modelling Framework: Output Variation via UrbanSim, In: *proceedings 81st Annual Meeting of the Transportation Research Board*. US.
- Pratt, R. (2003). Traveler Response to Transportation System Changes: An Interim Introduction to the Handbook: Appendix A: Elasticity Discussion and Formulae.
- Price, W. T. (2001). An Odyssey of Privatizing Highways: the Evolving Case of SR 91. *Public works management and policy*, 5, 259-269.

- Pronin, E., Gilovich, T. and Ross. L. (2004). Objectivity in the Eye of the Beholder: Divergent Perceptions of Bias in Self versus Others. *Psychological Review*, Vol. 111, No. 3, 781-799.
- Prozzi, J., Flanagan, K., Loftus-Outway, L., Porterfield, B., Persad, K., Prozzi, J. A. and Walton. C. M. (2009). Actual vs. Forecasted Toll Usage: A Case Study Review. Centre for Transportation Research. The University of Texas. Austin, Texas.
- Prud'homme, R. (2004). Infrastructure and Development. World Bank. Available at: [http://www.rprudhomme.com/resources/Prud\\$27homme+2005a.pdf](http://www.rprudhomme.com/resources/Prud%27homme+2005a.pdf)
- Public Works Financing. (2000). "2000 International Major Projects Survey". Reinhardt Communications Corp., Westfield, NJ, Vol. 144.
- Pugh-Roberts Associates. (1982). *User Guide and Reference Manual for Micro-DYNAMO System Dynamics Modeling Language*. Reading, MA, Addison-Wesley.
- Punch, Keith (2000). *Developing effective research proposals*. London: Sage Publication.
- Qian, Y. Zhong, J. Yuan. J. (2006). Investigating traffic congestion in Shanghai: a system dynamics approach. *International Journal of Services Operations and Informatics*, 1 (4), 363–379.
- Quiggin, J. (2004). Risk, PPPs and the Public Sector Comparator. *Australian Accounting Review*, 14, 51-61.
- Quinet, E. (1998). *Principles d'Economic des Transport*, Paris, Economica.
- Radzicki, M. (2009). System Dynamics and its Contribution to Economics/Economic Modeling. *Encyclopedia of Complexity and Systems Science*. Robert A. Meyers, ed. Berlin: Springer -Verlag.

- Raftery, J., McGeorge, D. and Walters, M. (1997). Breaking up methodological monopolies: a multi-paradigm approach to construction management research. *Construction management and economics*, 15, 291 – 297.
- Rahmandad, J. and Sterman, J. (2012). Notes and Insights: Reporting guidelines for simulation-based research. *System Dynamics Review*, 28, 396–411.
- Raje, F., Grieco, M., Hine, J. and Preston, J. (2004a). Transport, Demand Management and Social Inclusion: The Need for Ethnic Perspectives. Ashgate: Aldershot.
- Raje, F., Grieco, M. and McQuaid, R. (2004b). Edinburgh Road Pricing and the Boundary Problem: Issues of Equity and Efficiency. A report to the Scottish Economics Policy Network, Edinburgh.
- Randers, J. (1980). *Guidelines in model conceptualization, in elements of the System Dynamics method*. MIT Press, Cambridge, 117-139.
- Ranganath, B. J. and Rodrigues, L.L.R. (2008). System dynamics: Theory and case studies, I.K. International Publishing House Pvt. Limited, New Delhi.
- Rasouli, S. and Timmermans, H, (2012), Uncertainty in travel demand forecasting models: literature review and research agenda. *Transportation Letters: the International Journal of Transportation Research*, 4 (1), 55-73.
- Razali, N. M. and Wah, Y. B. (2011). Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson Darling tests. *Journal of statistical Modelling and Analytics*, 2(1), 21 – 33.
- Reilly, J. (2005). Cost Estimating and Risk- Management for Underground Projects. *Proc. International Tunneling Association Conference*, Istanbul, May 2005.
- Reilly, J. and Brown, J. (2004). Management and Control of Cost and Risk for Tunneling and Infrastructure Projects. In *Proceedings International Tunneling Association Conference*, Singapore.

- Richardson, G. (1991). *Feedback Thought in Social Science and Systems Theory*. Philadelphia, PA, University of Pennsylvania Press.
- Richardson, G. and Pugh, A. (1981). *Introduction to System Dynamics: Modelling with DYNAMO*, Cambridge, MIT Press.
- Riessman, C. K. (2005). Narrative Analysis. In: *Narrative, Memory & Everyday Life*. University of Huddersfield, Huddersfield, 1-7.
- Rijn, J. (2004). ROAD CAPACITIES. In developmet. Available at: <http://www.indevelopment.nl/PDFfiles/CapacityOfRoads.pdf> [Access 23 May 2012]
- Roberts, N. Anderson, D., Deal, R., Grant, M. and Shaffer, W. (1983), *Introduction to Computer Simulation: A System Dynamics Modeling Approach Reading*, Addison-Wesley.
- Rodier, C. J. (2003). Verifying the Accuracy of Regional Models Used in Transportation and Air Quality Planning. Mineta Transportation Institute (MTI). Report 02-03, College of Business, San Jose State University.
- Rodney, W. and Gallimore, P. (2002). Risk Assessment in PPP Schemes for Primary Health Care. *Facilities*, 20(1& 2), 52-60.
- Rossmann, G. B. and Wilson, B. L. (1985). Numbers and words: Combining quantitative and qualitative methods in a single large-scale evaluation study. *Evaluation Review*, 9, 627–643
- Rouboutsos, A. and Macario, R. (2013). Guest Editorial: Public private partnerships in transport: theory and practice, *Built Environment Project and Asset Management Journal*, 3 (2), 160-164.

- Roumboutsos, A., Farrell, S., Liyanage, C. and Macário, R. (2013). *COST Action TU1001: Public Private Partnerships in Transport: Trends & Theory P3T3*. COST. 2013 Discussion Papers Part II Case Studies.
- Roy, S., Marg, K. S. K. and Mohapatra, P. K. J. (2000). Causality and Validation of System Dynamics Models Incorporating Soft Variables: Establishing an Interface with Structural Equation Modelling In: 2000 system dynamics conference, 2000 University of Bergen, Norway.
- Ruane, S. (2000), Acquiescence and opposition: the private finance initiative in the National Health Service. *Policy & Politics.*, 28 (3), 411-24.
- Rudestam, K. and Rae N. (2001). *Surviving Your Dissertation: A Comprehensive Guide to Content and Process* (2end edition). Los Angeles: Sage
- Runeson, G. (1997). The Role of Theory in Construction Management Research: Comment. *Construction Management and Economics*, 15, 299-302.
- Russell, E. W., Waterman, E. and Seddon, N. (2000). Audit Review of Government Contracts: Contracting, Privatisation, Probity and Disclosure in Victoria 1992–1999, An Independent Review .
- Ruster, J. (1997). Retrospective on the Mexican Toll: Road Program (1989-94). The World Bank Group Finance, Private Sector, and Infrastructure Network. Available at: [https://openknowledge.worldbank.org/bitstream/handle/10986/11573/multi\\_page.pdf?sequence=1](https://openknowledge.worldbank.org/bitstream/handle/10986/11573/multi_page.pdf?sequence=1) [Accessed at 23 April 2011].
- Rydin, Y., Pennington, M., (2000). Public Participation and Local Environmental Planning: the Collective Action Problem and the Potential of Social Capital. *Local Environment* 5 (2), 153–169.
- Saaty, T.L., (2008). Decision Making with the Analytic Hierarchy, *Process.Int. J. Services Sciences*, 1(1), p.83-98.

- Saaty, T. L. (2005). Theory and applications of the analytic network process: Decision making with benefits, opportunities, costs, and risks. PA: RWS
- Saaty, T.L. (2001). Decision making with dependence and feedback: the analytic network process, RWS Publications, Pittsburgh, 23-25
- Sadeghi, M., Rashidzadeh, M. and Soukhakian, M. (2012). Using Analytic Network Process in a Group Decision-Making for Supplier Selection, *Informatica*, 23(4), 621–643.
- Sader, F. (2000). Attracting Foreign Direct Investment into Infrastructure: Why is it so Difficult, The International Finance Cooperation and World Bank, Washington, D.C.
- Salman, A. F.M, Skibniewski, M. J., Basha, I. (2007). “BOT viability model for large-scale infrastructure projects.” *Journal of Construction Engineering and Management*, ASCE / January.
- Saunders, M. Thornhill, A. and Lewis, P. (2007). Research methods for business students, 4th Edition. London: Financial Times Prentice Hall.
- Saunders, M., Lewis, P., and Thornhill, A. (2003). *Research method for business students*, 3rd edition. New York: Prentice Hall
- Schwartzs, G. (1995). Privatization in Eastern Europe. Privatization Policy and Performance, P. Cook and C. Kirkpatrick, eds., Prentice- Hall/Harvester Wheatsheaf, New York, 31–47.
- Sekaran, U. (1992). Research Methods for Business, John Wiley & Sons, New York, NY.
- Select Committee on Public Accounts. (1998). Achievement of the Department's Objectives. Available at:  
<http://www.publications.parliament.uk/pa/cm199798/cmselect/cmpublicacc/348/34804.htm> [Accessed 26 Nov 2011].

- Sexton, M. (2003). A supple approach to exposing and challenging assumptions and path dependencies in research, International Postgraduate Research Conference April 2003, Available at: [http://www.research.scpm.salford.ac.uk/bf2003/sexton ke nY ote. Pdf](http://www.research.scpm.salford.ac.uk/bf2003/sexton%20keynote.Pdf) [accessed 12 Feb 2013].
- Seymour, D. (1997). The role of theory in construction Management: A call for debate. *Construction management and Economic*, 15(1), 117-9.
- Seymour, D. and Rooke, J. (1995). The Culture of the Industry and the Culture of Research. *Construction management and economics*, 13, 511 – 523.
- Shapiro, S. S. and Wilk, M. B. (1965). An Analysis of Variance Test for Normality (Complete Sample). *Biometrika*. 52(3/4), 591-611.
- Shen, L., Plattan, A. and Deng, X. (2006). Role of public private partnerships to manage risks in public sector projects in Hong Kong. *International Journal of Project Management*, 24, 587–594.
- Shen, L. Y. and Wu, Y. Z. (2005). Risk Concession Model for Build/Operate/Transfer Contract Projects. *Journal of Construction Engineering & Management*. American Society of Civil Engineers.
- Shen, L. Y., Wu, W. C. and Ng, S. K. (2001). Risk Assessment for Construction Joint Ventures in China. *Journal of Construction Engineering & Management*, 127(1), 76-81.
- Siemens Financial Services. (2007). Public infrastructures and private funding Financial Solutions for the Energy, Industry and Healthcare Sectors. Available at: [http://finance.siemens.com/financialservices/global/en/press/studies/documents/study\\_2007\\_public-infrastructure-private-funding.pdf](http://finance.siemens.com/financialservices/global/en/press/studies/documents/study_2007_public-infrastructure-private-funding.pdf) [Accessed 11 October 2012]



Siemiatycki, M. (2009). Delivering Transportation Infrastructure through Public-Private Partnerships: Planning Concerns. *Journal of the American Planning Association*, 76, 43-58.

Silva, F. (2000). Toll roads: recent trends in private participation. Public policy for the private sector; Note no. 224. Washington, D.C. The World Bank. <http://documents.worldbank.org/curated/en/2000/12/1346419/toll-roads-recent-trends-private-participation> [Accessed 13 May 2012]

Sinha, K. and Labi, S. (2007). *Transportation Decision Making: Principles of Project Evaluation and Programming*. Wiley.

Smith, D., Chang-Albitres, C., Stockton, W. and Smith, C. (2004). Estimating Revenues Using a Toll Viability Screening Tool, Federal Highway Administration, College Station, Tex., 9–21.

Somekh, B. (1995). The contribution of action research to development in social endeavours: a position paper on action research methodology, *British Education Research Journal*, 21(3): 339-55.

Spear, B. D. (2005). A Summary of The Current State of The Practice in Modeling Road Pricing. paper presented at Expert Forum on Road Pricing and Travel Demand Modeling. Virginia, USA, May 2005. Available at: [http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_syn\\_364.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_364.pdf) [Accessed 22 May 2012].

Spector, P. E. (1981). *Research designs*. Newbury Park, CA: Sage Publication.

Spicer, M. (2006). BTS Skytrain Case Study – The experience of Bangkok’s first private mass-transit concession. International Finance Corporation (IFC). Presented at the WB Transport Learning Week 2006.

- Spock, L. (1998). *Synthesis of highway practice 262: Tolling practices for highway facilities*. Washington, D.C., Transportation Research Board, National Academy Press.
- Stake, R. (1995). *The Art of Case Study Research*, Thousand Oaks, CA: Sage Publications
- Standing Advisory Committee on Trunk Road Assessment (SACTRA). (1994). *Trunk roads and the generation of traffic*. Dept of Transport (Great Britain).
- Sterman, J. (2002). All Models are Wrong: Reflections on Becoming a Systems Scientist: 2002 Jay W. Forrester Award Address *System Dynamics Review*, 18(4), 501-531.
- Sterman, J. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*, USA, Jeffrey J. Shelstad.
- Strauss, A., and Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. (2nd ed.). Thousand Oaks, CA: Sage.
- Stringer, E.T. (1996). *Action research: A handbook for practitioners*. Thousand Oaks, CA: Sage.
- System Three (1996). *Skye Bridge Tolls Tourism Study*, Edinburgh: Scottish Office.
- Tang, W., Qiang, M., Duffield, C.F., Youg, D.M., and Lu, Y. (2007). Risk management in the Chinese construction industry, *J. of Const. Engg. and Management*, 133 (12), 944-956.
- Tashakkori, A. and Teddlie, C. (1998). *Mixed methodology: Combining qualitative and quantitative approaches*. Thousand Oaks, CA: SAGE Publications.
- Taylor, J. C., Robideaux, D. R. and Jackson, G.C. (2003). *The U.S.-Canada Border: Cost Impacts, Causes, and Short to Long Term Management Options*, U.S.

Department of Transportation. Available at:  
<http://www.gvsu.edu/cms3/assets/C6D78A67-0AEF-0264-A38619EC6FB0793A/CanadaUSBorderCostsReport052103-pdf091905.pdf>  
[Accessed May 8, 2011].

Thomas, A. V., Kalidindi, N. and Ananthanarayana, K. (2003). Risk Perception Analysis of BOT Road Project Participants in India. *Construction Management and Economics*, 21, 393-407.

Tiong, R. L .K. (1990). BOT Projects: Risks and Securities, *Construction Management and Economics*, 315-28.

Toan, T. N. and Ozawa, K. (2008). Stakeholders' perception on risks of BOT infrastructure projects in Vietnam. *CIB W107 Construction in Developing Countries International Symposium*, 16 – 18 January 2008, Trinidad & Tobago.

Treasury Task Force (1997). Treasury Taskforce Guidance, Partnerships for Prosperity, The Private Finance Initiative, HMSO, London.

Treasury Task Force (1999). How to construct a Public Sector Comparator, Treasury Taskforce, Private Finance, Technical Note No. 5.

Trujillo, L., Quinet, E. and Estache, A. (2000), Forecasting the Demand for Privatized Transport: What Economic Regulators Should Know, and Why? Policy Research Working Paper Series: 2446, The World Bank.

ULI and Ernst & Young (2013). Infrastructure2013: Global Priorities, Global Insights. Washington, D.C.: Urban Land Institute.

URS. (2011). "Toll Road Modeling Techniques. "Mricopa Association of Governments. Arizona." Available at:  
[http://www.azmag.gov/Documents/TRANS\\_2012-02-08\\_Toll-Road-Modeling-Techniques.pdf](http://www.azmag.gov/Documents/TRANS_2012-02-08_Toll-Road-Modeling-Techniques.pdf). [Accessed 6 November 2012]

- US DOT, (1995), Trends and Forecasts of Highway Costs, <http://www.fhwa.dot.gov/policy/hcas/final/three.htm>
- US DOT. (1995). Status of the Nation's Surface Transportation System: Condition and Performance. Washington, D.C
- Vanelslander, T., Chomat, G., Roumboutsos, A, and Bonnet, G. (2014). "Cross-sectoral Comparison of Concessions in Transport Urban, Road and Port pre-fuzzy Assessment". *BEPAM*, 4 (1), 22-39.
- Vassallo, J. M. and Baeza, M, A. (2007). Why Traffic Forecasts in PPP Contracts are Often Overestimated. European Investment Bank, Luxembourg, Research Paper.
- Vega, A.O. (1997). Risk Allocation in Infrastructure Financing. *Journal of Project Finance*, 3(2), 38-42.
- Vennix, J. A. M. (1996). Group Model Building. Facilitating Team Learning Using System Dynamics, Chichester, Wiley.
- Vennix, J. A. M. and Gubbels, J. W. (1992). Knowledge elicitation in conceptual model building: A case study in modeling a regional Dutch health care system. *European Journal of Operational Research*, 59, 85-101.
- Vennix, J. A. M., Gubbels, J. W., POST, D. & Poppen, H. J. (1990). A structured approach to knowledge elicitation in conceptual model building. *System Dynamics Review*, 6, 194-208.
- Verhoef, E. T. (2007). Second-best road pricing through highway franchising. *Journal of Urban Economics*, 62(2), 337-361.
- Verougstraete, M. and Enders, I. (2014). Traffic Demand Risk: The case of Bangkok's Skytrain (BTS). *Public-Private Partnerships-Case Study*,

Economic and Social Commission for Asia and Pacific (ESCAP)-United Nation.

Vežjak, M., Savšek, T. and Stuhler, E.A. (1998). System dynamics of eutrophication processes in lakes. *European Journal of Operational Research*, 109(2), 442-451.

Victoria Transport Policy Institute. (2009). Transportation cost and Benefits Analysis Techniques, Estimates and Implications. Victoria Transport Policy Institute. Victoria, Canada.

Viegas, J. M. (2010). Questioning the Need for Full Amortization in PPP Contracts for Transport Infrastructure. *Research in Transportation Economics*, 30, 139-144.

Wachs, M. (1987). Forecasts in Urban Transportation Planning: Uses, Methods and Dilemmas. *Climatic Change*, 11, pp. 61-80.

Wachs, M., (1990). Ethics and advocacy in forecasting for public policy. *Business and Professional Ethics Journal*, 9(1-2), 141-157.

Wachs, M., 1989, When Planners Lie with Numbers. *Journal of the American Planning Association*, 55(4), 476-479 .

Walker, D. and Fox-Rushby J. (2001). Allowing for Uncertainty in Economic Evaluations: Qualitative Sensitivity Analysis. *Health Policy and Planning*. 16:435–443.

Walker, C. and Smith, A. J. (1995). Privatized Infrastructure: The Build Operate Transfer, London: Thomas Telford.

Walton, D., Thomas, J. A. and Cenek, P. D. (2004). Self and others' willingness to pay for improvements to the paved road surface. *Transportation Research Part A*, 38, 483-494.

- WANG, X.-P. & MENG, M. (2008) Forecasting electricity demand using Grey-Markov model. *International Conference on Machine Learning and Cybernetics, 2008*.
- Ward, J. and Sussman, J. (2005). Analysis of the Malaysian Toll Road Public-Private Partnership Program and Recommendations for Policy Improvements. MIT Engineering Systems Division Working Paper No. ESD-WP 2005-09.
- Wardman, M. (1988). A comparison of revealed preference and stated preference models of travel behaviour. *Journal of Transport Economics and Policy*, 22, 1, 71-91.
- Wardman, M. and Whelan, G. (2001). Valuation of improved railway rolling stock: A review of the literature and new evidence. *Transport Reviews* 21 (4). 415-448.
- Weiner, E. (1997). *Urban Transportation Planning in the United States: An Historical Overview* (fifth edition), Report DOT-T-97-24, US Department of Transportation, Washington, DC.
- Welde, M. and Odeck, J. (2011). Do planners get it right? The accuracy of travel demand forecasting in Norway. *EJTIR*, 1(11).
- Wellings, R and Lipson, B. (2008). *Towards Better Transport*. Policy Exchange. Available at: [http://www.policyexchange.org.uk/publications/category/item/towards-better-transport-funding-new-infrastructure-with-future-road-pricing-revenue?category\\_id=24](http://www.policyexchange.org.uk/publications/category/item/towards-better-transport-funding-new-infrastructure-with-future-road-pricing-revenue?category_id=24) [Accessed 20 April, 2013]
- Willumsen, L. (2005), London congestion charging and urban tolling in Chile: contrasts and lessons on fairness and project finance. PIARC seminar on Road Pricing with Emphasis on Financing, Regulation and Equity. April 2005, Cancun, Mexico.
- Wolstenholme, E. F. (1990). *System Enquiry – a System Dynamics Approach*, Wiley.

- Woodward, D.G. (1992). Risk management of BOOT projects, *Project*, 10-11.
- World Bank (1997). A Retrospective on the Mexican Toll Road Program (1989–94). Available at: <http://rru.worldbank.org/Documents/PublicPolicyJournal/125ruste.pdf> [Accessed 23 Oct 2011].
- World Bank. (2001). World Development Report 2001, Washington D.C.
- World Bank with PPIAF. (2009). Toolkit for Public-Private Partnership in Roads and Highways, available at: <http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTTRANSPOR T/0,,contentMDK:22759355~pagePK:210058~piPK:210062~theSitePK:3371 16,00.html> [Accessed 11 April, 2011]
- World Bank, 2003, Treatment of Induced Traffic: Toolkit for the Economic Evaluation of World Bank Transport Projects. Institute for Transport Studies, University of Leeds, 2003. <http://www.its.leeds.ac.uk/projects/WBToolkit/Note6.htm>
- Wynekoop, J. (1992). Strategies for implementation research: combining research methods, in DeGross, J., Bostrom, R. and Robey, D. (Eds). Proceedings of the Thirteenth International Conference on Information Systems, Dallas, Texas, pp. 185-193.
- Xu, J. Yang, J. and Yao. L. (2012). Transportation Structure Analysis Using SD-MOP in World Modern Garden City: A Case Study in China. *Discrete Dynamics in Nature and Society*.
- Ye, S. and Tiong, R. L. K. (2003). Tariff Adjustment Frameworks for Privately Financed Infrastructure Projects. *Construction Management and Economics*, 21, 409-419.

- Yin, R. K. 1994. *Case study research: design and methods*, 2nd edition. Sage Publications Inc, Thousand Oaks, USA.
- Yin, K. R. (2003). *Case Study Research: Design and Methods*, Sage, Thousand Oaks, CA, 2003b,3rd edition
- Yu, C. Lam, C. K., Yung, P. (2013). An Investigation to the Influential Factors of Concession Period Length of Tunnel Project under BOT Contract. *Journal of Management in Engineering*,
- Yuan, J. F., Skibniewski, M.J., Li, Q. and Shan, J. (2010). The driving factors of China's public –private partnership projects in metropolitan transportation systems: public sector's viewpoint. *Journal of Civil Engineering and Management*, 16(1), 5-18.
- Yuan, J., Skibniewski M. J. and Li , Q. (2009). Performance objectives selection model in public-private partnership projects based on the perspective of stakeholders. *Journal of Management in Engineering*. 26, 89-104
- Zerah, M. and Harrison, K. (2001). The Buenos Aires concession. Case Studies. Water and Sanitation Program. Available at: [http://www.wsp.org/sites/wsp.org/files/publications/sa\\_buenos.pdf](http://www.wsp.org/sites/wsp.org/files/publications/sa_buenos.pdf). [Accessed April 10, 2011].
- Zhai, C., Zhang, H. And Zhang, X. (2009). Application of System Dynamics in the Forecasting Water Resources Demand in Tianjin Polytechnic University. *Artificial Intelligence and Computational Intelligence*, 2009. AICI '09.
- Zhang, H., Zhai, C. And Zhang, X. (2008a). Forecasting Water Resources Demand Based on Complex System Dynamics: A Case Study of Tianjin City. *Future BioMedical Information Engineering, 2008. FBIE '08. International Seminar on Future Biomedical Information Engineering*.
- Zhang, X., Zhang, H. And Zhao, X. (2008b). A System Dynamics Approach for Developing Zone Water Demand Forecasting: A Case Study of Linkong



Area. *Intelligent Information Technology Application, 2008. IITA '08. Second International Symposium on Intelligent Information Technology Application.*

Zhang, W. R., Wang, S. Q., Tiong, R. L. K., Ting, S. K. and Ashley, D. (1998). Risk Management of Shanghai's Privately Financed Yan'an Donglu Tunnels. *Engineering, Construction and Architectural Management*, 5 (4), 399-409.

Zhang, X. (2005). Critical Success Factors for Public Private Partnerships in Infrastructure Development. *Journal of Construction Engineering & Management*. American Society of Civil Engineers.

Zhang, G. P. (2003). Time Series Forecasting Using a Hybrid ARIMA and Neural Network Model. *Neurocomputing*, 50, 159-175.

Zhang, X. Q. and Kumaraswamy, M. M. (2001). Procurement Protocols for Public-Private Partnered Projects, *ASCE*.

Zhao, Y. and Kockelman, K.M. (2001). The Propagation of Uncertainty through Travel Demand Models: An Exploratory Analysis. *Annals of Regional Science* 36, 909-921.

Zhou, J., Chen, X. G. and Yang, H. W. (2008). Control Strategy on Road Toll Pricing under a BOT Scheme. *Systems Engineering - Theory & Practice*, 28, 148-151.

Zou, P. X. W., Wang, S. and Fang, D. (2008). A Life-cycle Risk Management Framework for PPP Infrastructure Projects. *Journal of financial Management of Property and Construction*, 13, 123-142.

## **Appendix A**

### **Model Equations**

$AADT = AADT0 * (1 + \text{proportion of intermediate traffic}) * (1 + \text{Proportion of HGVs})$

Units: users

$AADT0 = AWT * \text{annualisation factor}$

Units: users

$\text{access to infrastructure market} = \text{IF THEN ELSE}(\text{"non-competite clause"} = 1, 0, 1)$

Units: Dmnl

$\text{annualisation factor} = \text{INTEG}(\text{annualisation factor change}, 1)$

Units: Dmnl

$\text{annualisation factor change} = \text{annualisation factors change rate} * \text{annualisation factor}$

Units: Dmnl

$\text{annualisation factors change rate} = 0$

Units: Dmnl

$AWT = \text{sum}(\text{MPPT}[\text{traffic segmentation!}]) * \text{Weekday expansion factor}$

Units: user

$CAF = \text{IF THEN ELSE}(\text{Time} < 2013, \text{CCAF}, \text{FCAF})$

Units: Dmnl

$\text{capacity} = 100000$

Units: user

$CCAF = 1$

Units: Dmnl

CE=-0.16

Units: Dmnl

CETC (change in ETC)=IF THEN ELSE(Time=2004, 0.07, IF THEN ELSE(Time=2005, 0.02, IF THEN ELSE(Time=2006, 0.02, IF THEN ELSE(Time=2007, 0.02, IF THEN ELSE(Time=2008, 0.02, IF THEN ELSE(Time=2009, 0, 0))))))

Units: Dmnl

CFP (current change in fuel price)=0.06

Units: Pound

change in ETC demand[traffic segmentation]=effect of FP on demand\*ETC Demand[traffic segmentation]

Units: user

change in fuel price=IF THEN ELSE(Time <2013, CFP, FFP)

Units: Pound

change in maintenance and operation cost=IF THEN ELSE((AADT)<=Normal demand, IF THEN ELSE("other source of M&O cost"=0, 0, "high demand M&O cost"), "high demand M&O cost")

Units: Pound

"change in non-ETC demand"[traffic segmentation]=effect of FP on demand\*"Non-ETC Demand"[traffic segmentation]

Units: user

change in rival toll=(rival toll change rate)\*(Rival toll)

Units: Pound

congestion threshold=0.9

Units: Dmnl

corridor traffic growth rate=CAF\*regional traffic growth rate

Units: Dmnl

Corridor traffic [traffic segmentation] = INTEG (corridor traffic growth [traffic segmentation]-users satisfaction flow [traffic segmentation], initial traffic[traffic segmentation])

Units: user

corridor traffic growth[traffic segmentation]=(corridor traffic growth rate + induced traffic rate)\*(MPPT[traffic segmentation] +Potential users[traffic segmentation]+Corridor traffic[traffic segmentation])

Units: user

demand elasticity to FP=IF THEN ELSE(Time<2013, CE, FE)

Units: Dmnl

Ecurrent (current employment growth rate)= GET XLS DATA ( 'Datasets.xlsx' , 'Datasets' , 'A' , 'E' )

Units: Dmnl

"effect of expansion on rival V/C"=IF THEN ELSE(investment=1, effect of investment, IF THEN ELSE(improvement=1, effect of improvement, 1))

Units: Dmnl

effect of FP on demand=1-(1+change in fuel price)^demand elasticity to FP

Units: Dmnl

effect of historical experience of paying on WTU [traffic segmentation]=IF THEN ELSE (historical experience of paying[traffic segmentation]=1,1, 0.7 +RAMP (0.1, 2004, 2007))

Units: Dmnl

effect of improvement=1

Units: Dmnl

effect of investment=1

Units: Dmnl

effect of project location and environmental considerations= WITH LOOKUP (project location and environmental considerations,([(0,0)-(10,1)],(0,0.9),(10,1) ))

Units: Dmnl

effect of QF (qualitative factors)[traffic segmentation]= (IF THEN ELSE("rival V/C"<0.5, 1, IF THEN ELSE("rival V/C">=0.5:AND:"rival V/C"<0.77, 1.34, IF THEN ELSE("rival V/C"

>=0.77:AND:"rival V/C"<=0.84, 1.68, IF THEN ELSE("rival V/C">0.84, 2, 2))))))

Units: Dmnl

"effect of rival V/C on rival travel time"= WITH LOOKUP ("rival V/C",([(0.3,0)-(1.3,1)],(0.35,1),(0.54,0.95),(0.77,0.9),(0.93,0.77),(1,0.5),(1.1,0) ))

Units: Dmnl

"effect of V/C on travel time"= WITH LOOKUP ( "V/C",([(0,0)-(1,1)],(0,1),(0.35,1),(0.54,0.95),(0.77,0.9),(0.93,0.75),(1,0.5) ))

Units: Dmnl

Efuture (Future employment growth rate)=0.0037

Units: Dmnl

Employment= INTEG (employment growth, initial employment)

Units: Thousand users

employment growth=Employment\*employment growth rate

Units: Thousand users

employment growth rate=IF THEN ELSE(Time<2013, Ecurrent, Efuture)

Units: Dmnl

ETC Demand [traffic segmentation]= INTEG (ETC user flow[traffic segmentation]+ETC users flow[traffic segmentation]-change in ETC demand [traffic segmentation], 1)

Units: users

"ETC demand."=sum(ETC Demand[traffic segmentation!])

Units: users

ETC toll share [traffic segmentation]=(WTP effect of ETC user[traffic segmentation]\*effect of historical experience of paying on WTU[traffic segmentation])\*public involvement effect[traffic segmentation]

Units: Dmnl

ETC normal travel time=0.353

Units: Hour

ETC user flow [traffic segmentation]= ("Non-ETC Demand"[traffic segmentation])\*ETC users change rate

Units: users

ETC users change rate=IF THEN ELSE (Time<2010, CETC, FETC)

Units: Dmnl

ETC users flow [traffic segmentation] = (ETC inflow[traffic segmentation]-ETC users toll share [traffic segmentation])\*ETC Demand[traffic segmentation]

Units: user

facility type=0

Units: Dmnl

facility type effect=IF THEN ELSE(investment=1, IF THEN ELSE(facility type=1, 1, 0), 0)

Units: Dmnl

FCAF=1

Units: Dmnl

FE (Fuel elasticity)=-0.16

Units: Dmnl

FFP( Future fuel price)=0.045

Units: Pound

fixed subsidies=0

Units: Pound

GDPcurrent=GET XLS DATA ('Datasets.xlsx', 'Datasets', 'A', 'G')

Units: Dmnl

GDP= INTEG (GDP growth, initial GDP)

Units: Billion

GDP growth rate=IF THEN ELSE (Time<2013, Gcurrent, Gfuture)

Units: Dmnl

GDPgrowth=GDP growth rate\*GDP

Units: Billion

Gfuture=0.0213

Units: Dmnl

gov't subsidies=IF THEN ELSE(subsidies related to revenue level=0, 0, IF THEN ELSE(fixed subsidies<>0, fixed subsidies, IF THEN ELSE((traffic revenue)>=expected revenue, 0, (expected revenue-traffic revenue))) )

Units: Pound

Hcurrent(HGVs)= GET XLS DATA ( 'Datasets.xlsx', 'Datasets', 'A', 'H' )

Units: Dmnl

Hfuture(HGVs)=0.04

Units: Dmnl

HGVs revenue= (Proportion of HGVs)\*AADT\*HGVs toll

Units: Pound

HGVs toll= INTEG (HGVs toll change, 6)

Units: Pound per user

HGVs toll change=HGVs toll change lookup

Units: Pound

HGVs toll change lookup=IF THEN ELSE(IF THEN ELSE(Time=2004, 1, IF THEN ELSE(Time=2005, 1, IF THEN ELSE(Time=2006, 1, IF THEN ELSE(Time=2007, 0.4, IF THEN ELSE(Time=2008, 0.6, IF THEN ELSE (Time=2009, 0.6, IF THEN ELSE(Time=2010, 0.4, IF THEN ELSE(Time=2011, 0, IF THEN ELSE (Time=2012, 0, 0.7))))))))))

Units: Pound

"high demand M&O cost"=0

Units: Pound

historical experience of paying[traffic segmentation]=0,1,1

Units: Dmnl

improvement=IF THEN ELSE(access to infrastructure market=1, 1, 0)

Units: Dmnl

induced traffic rate=0

Units: Dmnl

initial employment=2463

Units: Thousand users



initial GDP=1337.78

Units: Billion

initial population=4191

Units: Thousand users

initial potential users[traffic segmentation]=7366,12210, 26022

Units: user

initial rival toll=IF THEN ELSE(facility type effect=0, 0, initial rival toll value)

Units: Hour

initial rival toll =0

Units: Pound

initial toll=3

Units: Pound

initial traffic[traffic segmentation]=227,377, 804

Units: user

initial VTTS [traffic segmentation]=9.22, 13.73, 16.18

Units: Pound per hour

investment=IF THEN ELSE(access to infrastructure market=1:AND:need to decrease congestion

=1, 1, 0)

Units: Dmnl

MPPT[traffic segmentation]=sub demand [traffic segmentation]

Units: user

need to decrease congestion=IF THEN ELSE("V/C">=congestion threshold: AND: "rival V/C">=congestion threshold, 1, 0)

Units: Dmnl

non ETC users flow[traffic segmentation]=IF THEN ELSE(Time=2004, non ETC users inflow[traffic segmentation]\*Potential users [traffic segmentation], ((non ETC users inflow[traffic segmentation]-Non ETC users toll share [traffic segmentation])\*"Non-ETC Demand"[traffic segmentation])+non ETC users inflow [traffic segmentation]\*users satisfaction flow[traffic segmentation])

Units: user

"non-compete clause "=1

Units: Dmnl

"Non-ETC Demand"[traffic segmentation]= INTEG (non ETC users flow[traffic segmentation]-"change in non-ETC demand"[traffic segmentation]-ETC user flow[traffic segmentation], 2)

Units: users

"non-ETC demand."=sum("Non-ETC Demand"[traffic segmentation!])

Units: users

"non-ETC normal travel time "=0.37

Units: Hour

"non-ETC travel time"="non-ETC normal travel time"/"effect of V/C on travel time"

Units: Hour

Non ETC users share [traffic segmentation]=effect of historical experience of paying on WTU[traffic segmentation]\*"WTP effect of non-ETC users"[traffic segmentation]\*public involvement effect[traffic segmentation]

Units: Dmnl

"other source of M&O cost "=0

Units: Pound

Pcurrent=GET XLS DATA ('Datasets.xlsx' , 'Datasets' , 'A' , 'P' )

Units: Dmnl

Pfuture=0.004

Units: Dmnl

Population= INTEG (population growth, initial population)

Units: Thousand users

population growth=Population\*population growth rate

Units: Thousand users

population growth rate= IF THEN ELSE(Time<2013, Pcurrent, Pfuture)

Units: Dmnl

Potential users [traffic segmentation]= INTEG (change in ETC demand[traffic segmentation]+ "change in non-ETC demand"[traffic segmentation]+users satisfaction flow[traffic segmentation]-ETC users flow[traffic segmentation]-non ETC users flow[traffic segmentation], initial potential users[traffic segmentation])

Units: user

project location and environmental considerations=9

Units: Dmnl

Proportion of HGVs=IF THEN ELSE (Time<2013, Hcurrent, Hfuture)))

Units: Dmnl

proportion of intermediate traffic=IF THEN ELSE(Time<2013, 0.125, 0.125)

Units: Dmnl

public acceptance= WITH LOOKUP (public consultation, ((0,0)-(1,1)],(0,0.9),(10,1) ))

Units: Dmnl

public consultation=8

Units: Dmnl

public involvement effect[traffic segmentation]=0.7,1,1

Units: Dmnl

ramp up effect=IF THEN ELSE(Time=2004:OR:Time=2005, 0.8, 1)

Units: Dmnl

Regional traffic= INTEG (regional traffic inflow-regional traffic outflow,  
79.4)

Units: Thousand users

regional traffic growth rate=(regional traffic inflow-regional traffic outflow)/regional  
traffic outflow

Units: Dmnl

Regional traffic =-33.479+0.021\*GDP+0.007\*Population+0.024\*Employment

Units: Thousand users

relative WTP of ETC user[traffic segmentation]=WTP[traffic segmentation]/travel cost  
of ETC users

Units: Dmnl

relative WTP of non ETC user[traffic segmentation]=WTP[traffic segmentation]/travel  
cost non ETC user

Units: Dmnl

rival normal travel time=0.4

Units: Hour

Rival toll= INTEG (change in rival toll, initial rival toll)

Units: Pound

rival toll change rate=0

Units: Dmnl

rival travel time=rival normal travel time/"effect of rival V/C on rival travel time"

Units: Hour

"rival V/C change"=IF THEN ELSE( Time<2013, Vcurrent, Vfuture\*"effect of expansion on rivalV/C"  
)

Units: Dmnl

"rival V/C"= INTEG ("rival V/C change",0.94)

Units: Dmnl

sub demand[traffic segmentation]= ETC Demand[traffic segmentation]+"Non-ETC Demand"[traffic segmentation]

Units: users

subsidies related to revenue level=0

Units: Pound

TAF=0.95

Units: Dmnl

Tcurrent=IF THEN ELSE(Time=2004, 0.5, IF THEN ELSE(Time=2005, 0, IF THEN ELSE(Time=2006, 0.5, IF THEN ELSE(Time=2007, 0.5, IF THEN ELSE(Time=2008, 0.2, IF THEN ELSE (Time=2009, 0.3, IF THEN ELSE(Time=2010, 0.3, IF THEN ELSE(Time=2011, 0.2, IF THEN ELSE(Time=2012, 0, 0))))))))))

Units: Pound

Tfuture=0.35

Units: Pound

Toll= INTEG (toll change, initial toll)

Units: Pound

toll change=(((-gov't subsidies+change in maintenance and operation cost)/((AADT0)\*Toll))\*Toll+(toll change rate))

Units: Pound

toll change =IF THEN ELSE(Time<2013, Tcurrent, Tfuture)

Units: Pound

traffic revenue=((AADT0\*(1+proportion of intermediate traffic)+HGVs revenue)\*ramp  
up effect\*365

Units: Pound

travel cost non ETC user=(Toll -Rival toll)/travel time saving for non ETC user

Units: Pound

travel cost of ETC users=(TAF\*Toll-Rival toll)/travel time saving ETC user

Units: Pound

travel time=ETC normal travel time/"effect of V/C on travel time"

Units: Hour

travel time saving ETC user=rival travel time-travel time

Units: Hour

travel time saving for non ETC user=rival travel time-"non-ETC travel time"

Units: Hour

users satisfaction flow[traffic segmentation]=effect of project location and  
environmental considerations\*public acceptance\*Corridor traffic[traffic segmentation]

Units: Dmnl

"V/C"=((AADT)/(capacity)

Units: Dmnl

Vcurrent=IF THEN ELSEGET XLS DATA ('Datasets.xlsx' , 'Datasets' , 'A' , 'V' )

Units: Dmnl

Vfuture=0.0015

Units: Dmnl

VTcurrent=GET XLS DATA ('Datasets.xlsx' , 'Datasets' , 'A' , 'VT' )Units: Pound per hour

VTfuture=0.016

Units: Dmnl

VTTS [traffic segmentation] = INTEG (VTTS change [traffic segmentation], initial VTTS[traffic segmentation])

Units: Pound per hour

VTTS change [traffic segmentation]=VTTS[traffic segmentation]\*VTTS change rate

Units: Pound per hour

VTTS change rate=IF THEN ELSE (Time<2012, VTcurrent, VTfuture)

Units: Dmnl

Weekday expansion factor= INTEG (weekday expansion factor change, 1)

Units: Dmnl

weekday expansion factor change=weekday expansion factor change rate\*Weekday expansion factor

Units: Dmnl

weekday expansion factor change rate=0

Units: Dmnl

WTP[traffic segmentation]=effect of QF[traffic segmentation]\*VTTS[traffic segmentation]

Units: Pound per hour

WTP effect of ETC user [traffic segmentation] = WITH LOOKUP ((relative WTP of ETC user[traffic segmentation]), ((0,0)(5,1)],[0.2,0),(0.464832,0.1253),(0.636086,0.245614),(0.831804,0.3704),(1.0030

6,0.52193),(1.3211,0.697368),(1.33333,0.70614),(1.76147,0.855263),(2.23853,0.93859  
6),(2.48318,0.97807),(2.82569,1),(3,1),(3.7156,0.995614),(5,1) )

Units: Dmnl

"WTP effect of non-ETC users"[traffic segmentation]= WITH LOOKUP (relative WTP  
of non ETC user[traffic segmentation]),  
([(0,0)(5,1)],(0.2,0),(0.464832,0.1253),(0.636086,0.245614),(0.831804,0.3704),(1.0030  
6,0.52193),(1.3211,0.697368),(1.33333,0.70614),(1.76147,0.855263),(2.23853,0.93859  
6),(2.48318,0.97807),(2.82569,1),(3,1),(3.7156,0.995614),(5,1) )

Units: Dmnl



## **Appendix B**

### **Questionnaire Survey**

Dear Sir/Madam,

I am working on a research project which aims to develop a model for demand risk assessment in PPP infrastructure projects, carried out in the **School of the built Environment, Heriot-Watt University, Edinburgh, UK**.

I would be so grateful for your assistance in this research work. I have produced the attached questionnaire to capture information regarding the factors affecting demand for service provided by PPPs.

The questionnaire has been designed such that it will not take much time to complete. Your response to this questionnaire would be crucial to my research. I look forward to your comments, and appreciate it if I could further discuss this research with you.

Your response is highly appreciated and the information or data collected will be treated with confidentiality.

I am happy to share the outcomes of this study with you, if you are interested in getting the final results.

If you have any enquiries on the survey please do not hesitate to contact me.

Many thanks for your cooperation.

Yours faithfully

*Rajaa Alasad  
PhD Student  
Room WA 3.37 William Arrol Building  
School of Built Environment  
Heriot-Watt University  
Edinburgh EH14 4AS  
Scotland, UK  
Email: [Ra280@hw.ac.uk](mailto:Ra280@hw.ac.uk)  
Tel: +44(0) 131 451 4402*

Public-Private Partnership (PPP) method has increasingly become a favoured approach to procure public infrastructure projects. PPP arrangements, in which the revenues are derived directly from the end users, are widely used for delivering infrastructure projects. The success of these projects depends heavily on the demand for the service they offer, which places demand risk on the top of project's risk list. The aim of this research is to develop a model for demand risk assessment in PPP projects based on the identified factors.

### **Part One: General Information**

1. Which sector do you work for

- Public/ Government
- Private
- Financial Community
- Consultancy

2. Your experience in your field (year)

- Less than 5
- Between 5 and 10
- Between 10 and 20
- More than 20

**Part Two: General Information**

The following provides a checklist of factors affecting demand in PPP infrastructure (e.g transportation) projects. Please tick how significant each factor is in determining demand for service provided by the facility. Using a scale of 1-5 where 1= not significant; 2=fairly significant; 3= significant; 4= very significant; 5= extremely significant.

Please add any new factors you think can influence demand and tick the corresponding level of significance in determining demand volume.

Factors	N.S	F.S	S	V.S	E.S
Users' wealth	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Public acceptance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Historical experience of paying	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Public involvement in ongoing facility management	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Willingness to pay	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Quality of Service	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Level of fee	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Quality of service provided by competing facilities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
The fee for using alternative facilities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Level of public benefit delivered by the facility (e.g. time savings)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Project location and environmental considerations	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Availability of supportive facilities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Infrastructure market or access rules (e.g. non-compete clause)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Availability of alternative facilities (competition)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Employment in the facility area	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Population of the facility	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
GDP	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Other (please specify and rate)

.....  
 .....

## Appendix C

### Linear relationships between socio-economic factors and Traffic

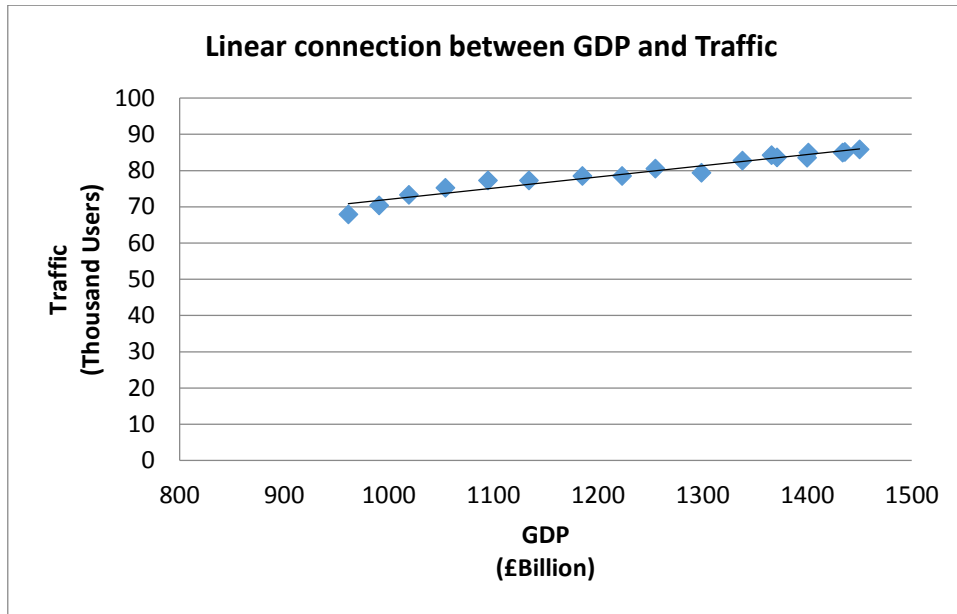


Figure C.1: Linear relationship between GDP and Traffic

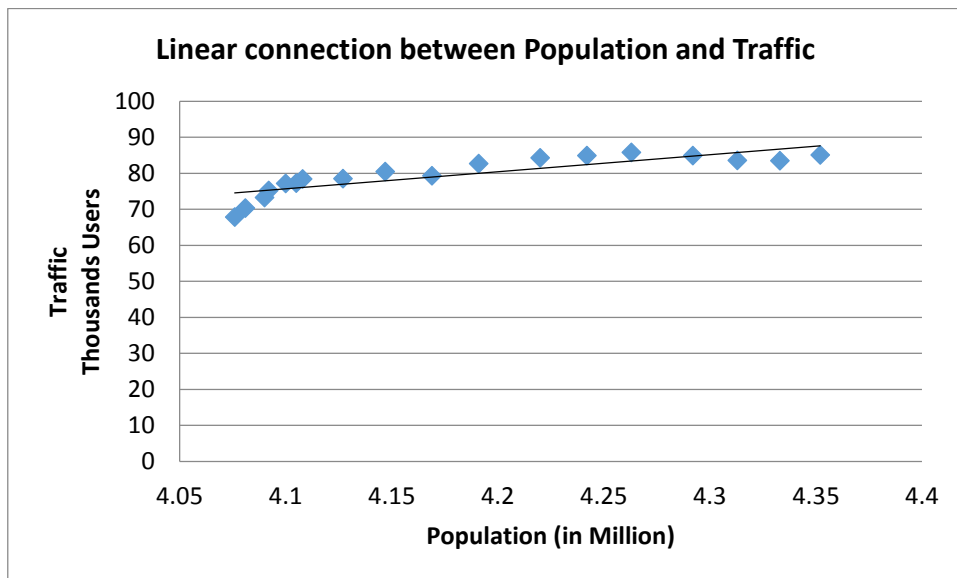


Figure C.2: Linear relationship between Population and Traffic

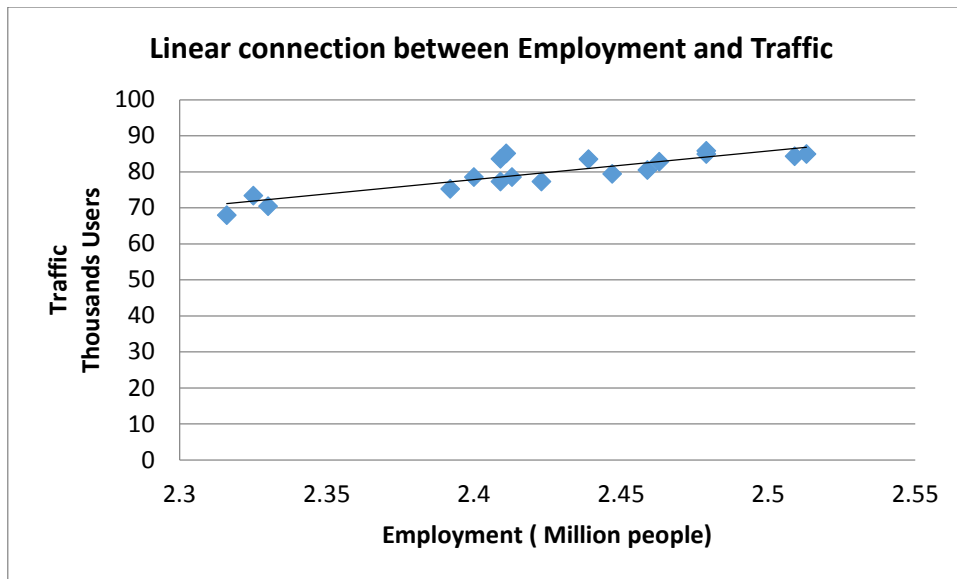


Figure C.3: Linear relationship between Employment and Traffic

## Appendix D

### Normality Visual Tests

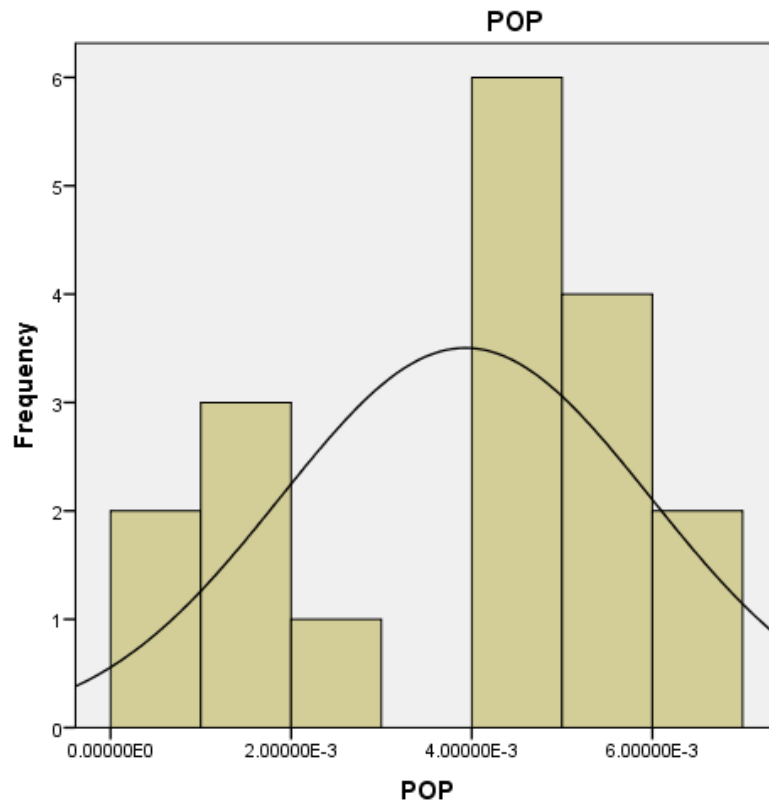


Figure D.1: Histogram and Normality Curve of Population Growth Rate

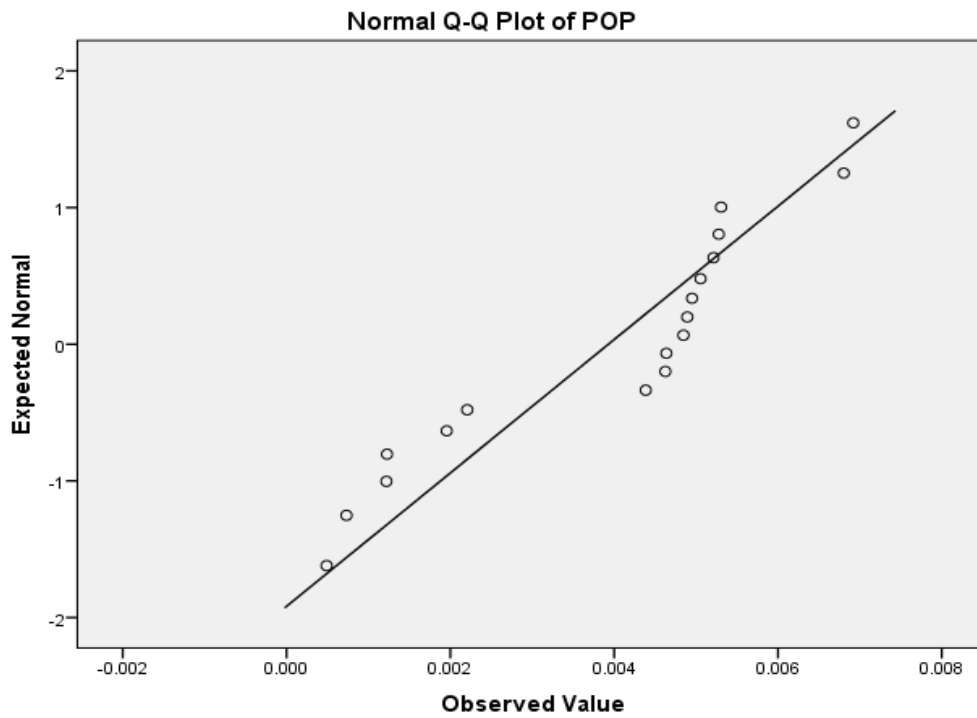


Figure D.2: Q-Q Plot of Population Growth Rate

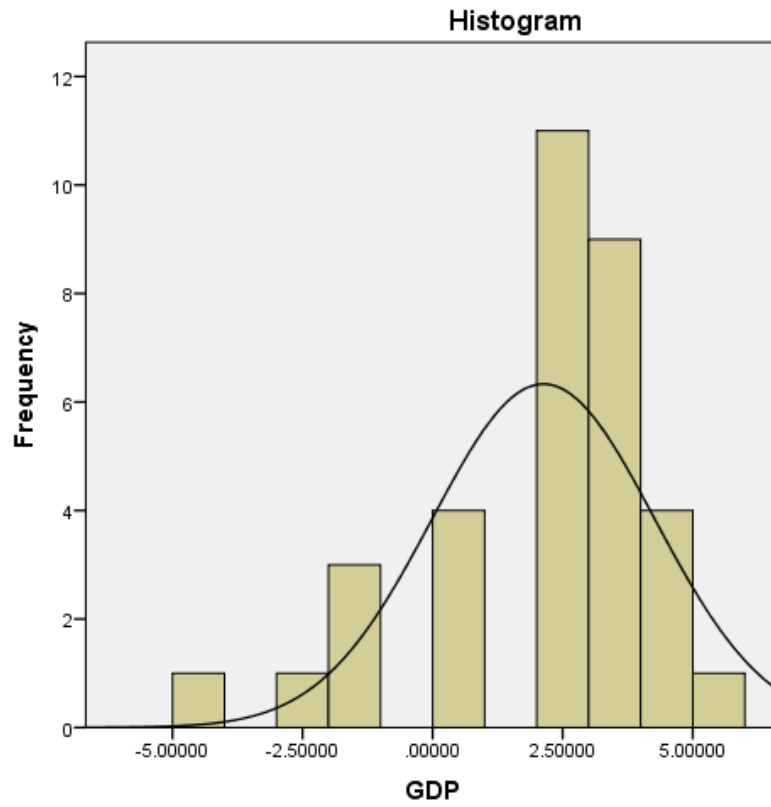


Figure D.3: Histogram and Normality Curve of GDP Growth Rate

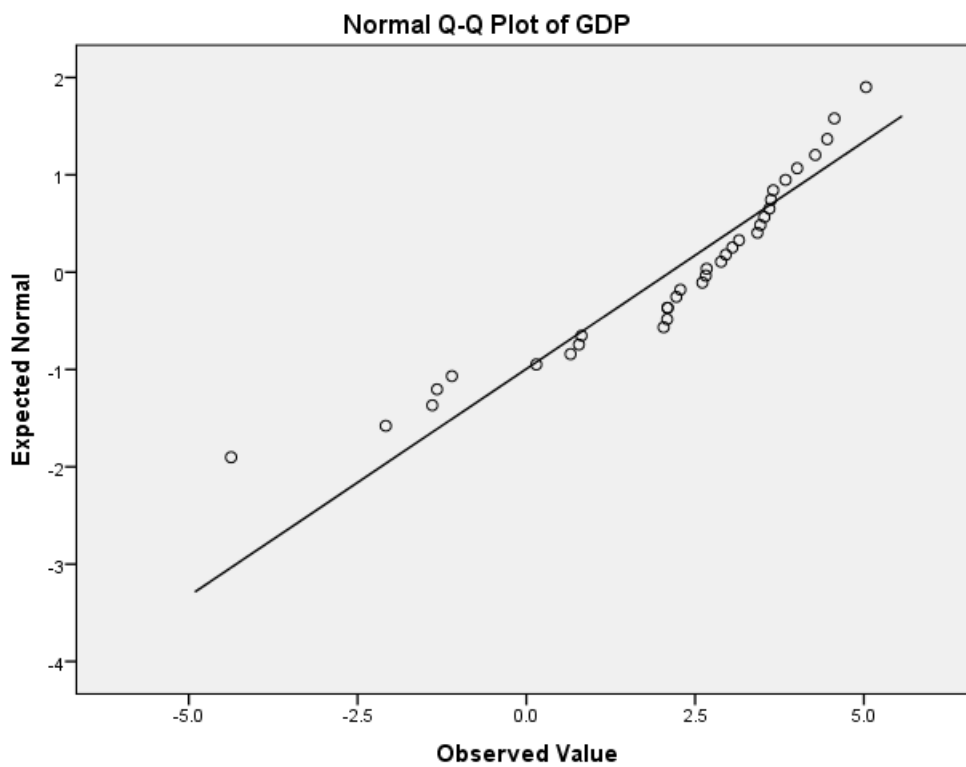


Figure D.4: Q-Q Plot of GDP Growth Rate

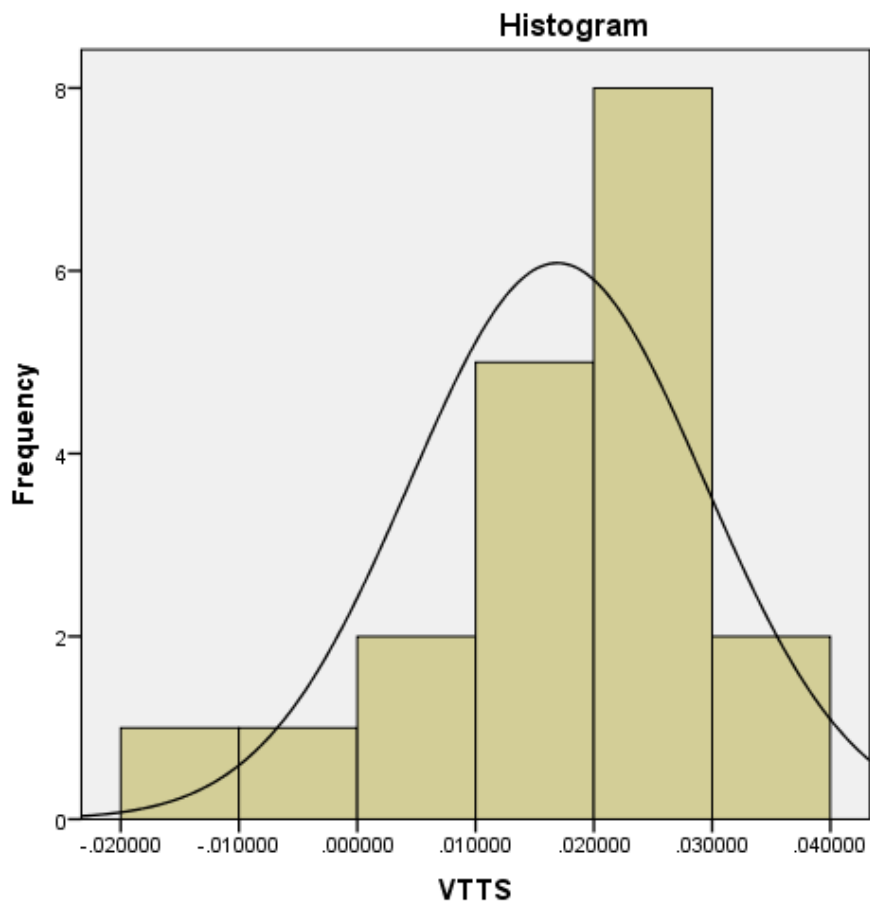


Figure D.5: Histogram and Normality Curve of VTTS Growth Rate

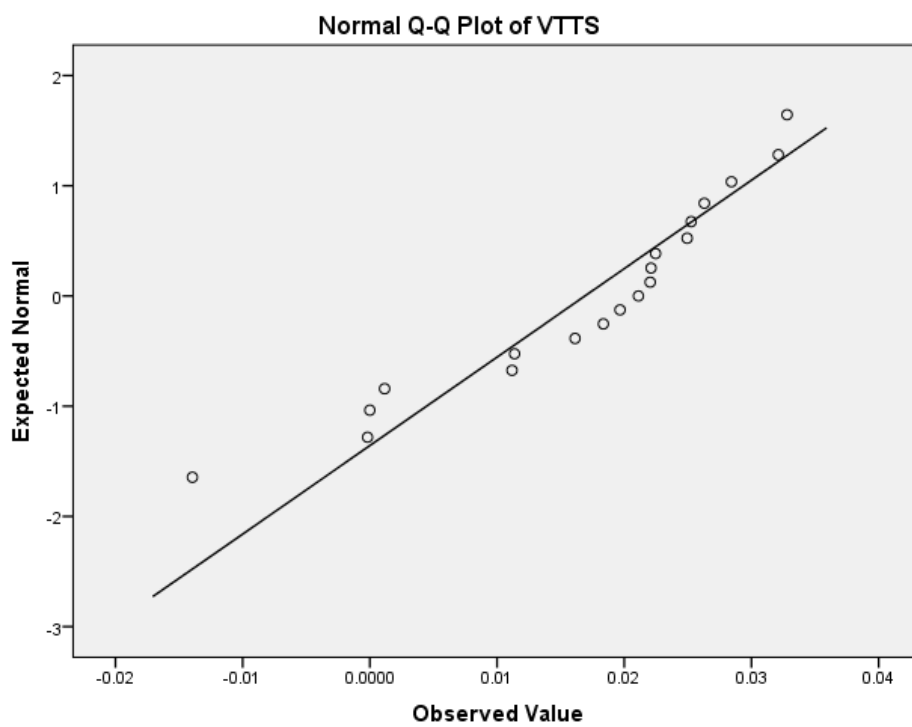


Figure D.6: Q-Q Plot of VTTS Growth Rate



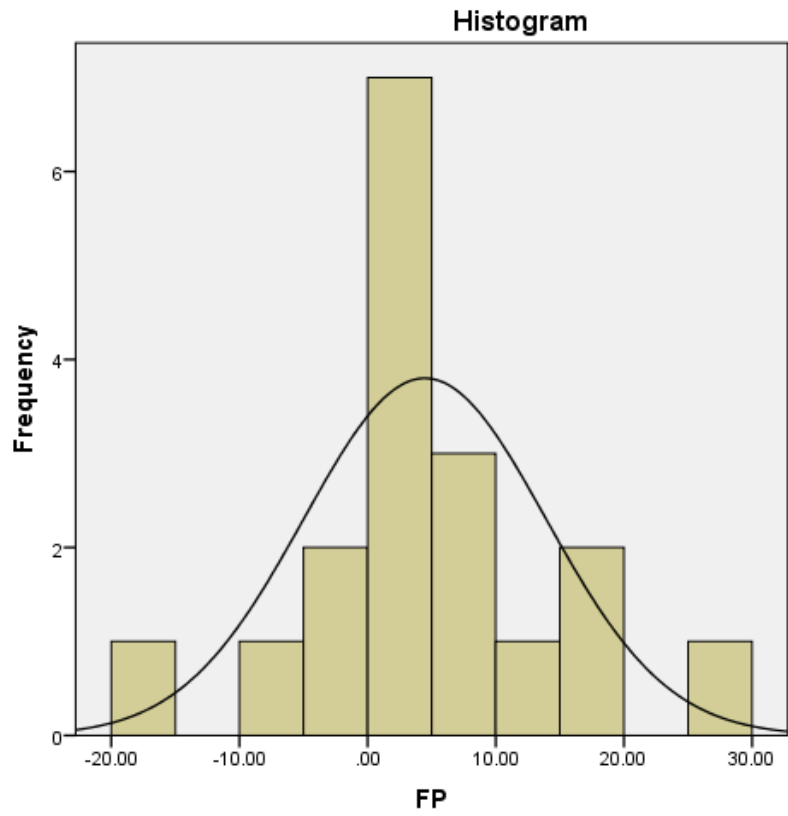


Figure D.7: Histogram and Normality Curve Change in Fuel Price

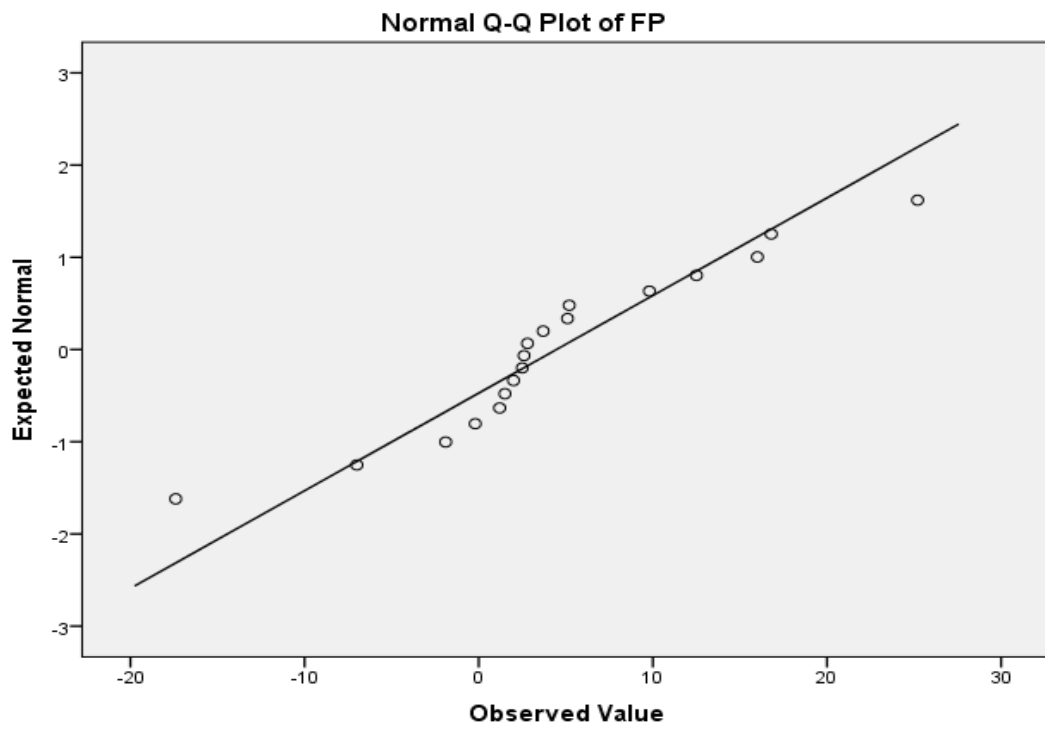


Figure D.8: Q-Q Plot of Change in Fuel Price

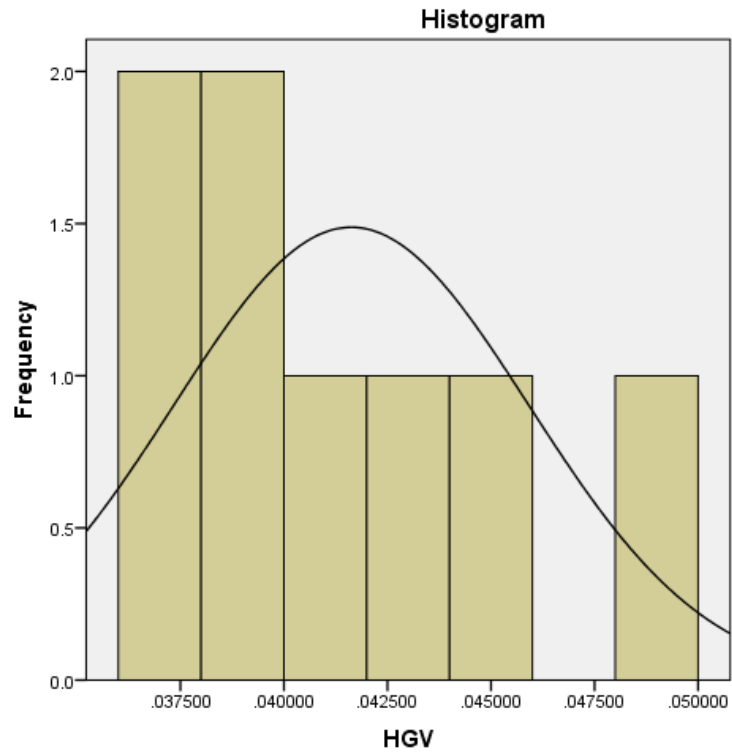


Figure D.9: Histogram and Normality Curve of Proportion of HGVs

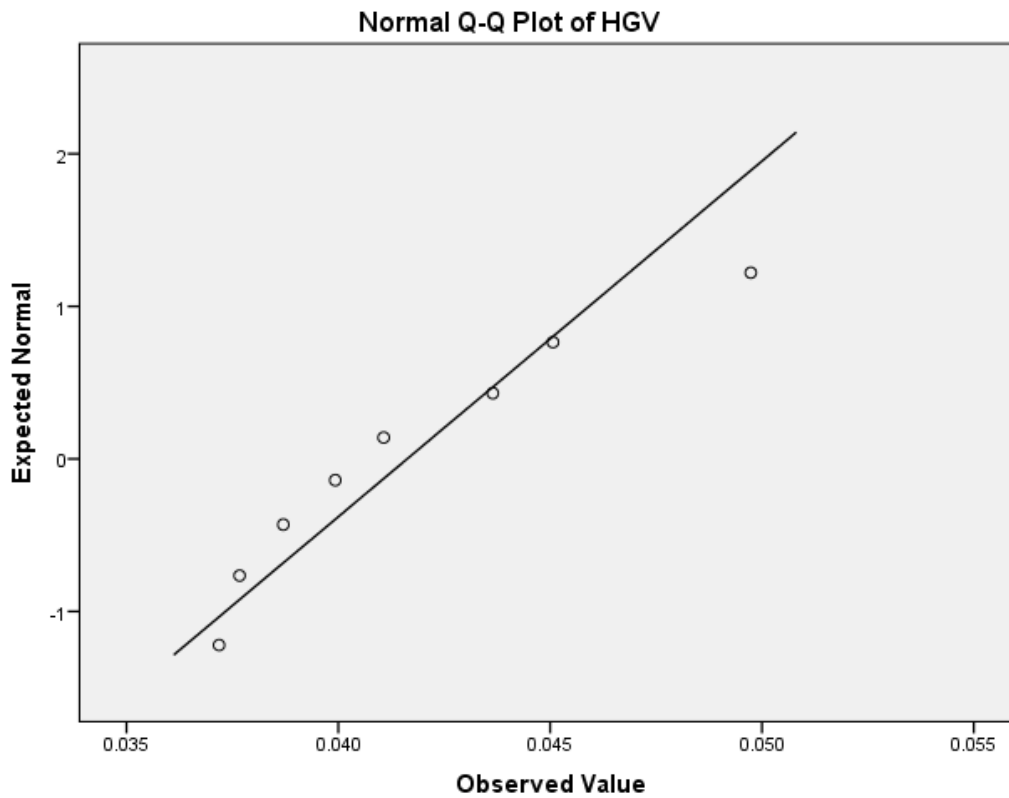


Figure D.10: Q-Q Plot of Proportion of HGVs