MODELLING ROAD DEVELOPMENT COST AND BENEFITS DUE TO CHANGES IN LAND VALUES

By

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Abstract

Road networks play an important role in the development of countries from economic and social points of view. Their impacts may be considered as primary (i.e. solving network congestion and decreasing travel time and cost for road users) and secondary (i.e. increasing the industrial and agricultural outputs, increasing job opportunities, increasing household income and tax, increasing values of land, and changing use of land).

This study focused on the correlation between the primary and the secondary impacts of an inter-urban road development by means of a comprehensive investigation and clarification of the relationship between the road users' benefits and changes in land values (CLVs). Its methodology is aimed at coupling the conventional cost benefit analysis (CBA) with an economic impact analysis (EIA) and avoiding the double counting of their results.

The secondary impacts of road development concentrated on the changes in land values. These changes were modelled using a new logarithmic model developed to improve the understanding of the impact of an inter-urban road development on the affected land. The model related the percentage change in land values with four independent variables: the distance from the road; the land use; the land area; and the time that has elapsed since the completion of the roadworks. The selection of the model's form, its variables, its validity, its sensitivity and its overall performance were tested systematically. The model performed satisfactorily in all tests and it was subsequently used in parallel with the Highway Development and Management tool (HDM-4) model.

The CBA was carried out using the HDM-4 with a case study of a road development scheme in the UK. For a period of 30 years, a comparison was carried out to examine the similarities in the trends of the road users' benefits and the CLVs.

The HDM-4 was systematically adjusted using data gathered from a number of UK sources and its performance was tested accordingly with an independent study. Subsequently, it was used to calculate the road users' cost savings (RUCSs) associated with the case study considered. The land values change model was then used to calculate the development of the land values adjacent to the road development scheme; which were compared with the RUCSs. Three main periods were found through this comparison; which were denoted by the change in the trend of the RUCS' distribution over the analysis period. The first period is from year 0 (year of the road's opening) to year 3; the second period is from year 4 after the road's opening to year 19; the last period starts from year 20 and finishes at the end of the analysis (year 30).

The primary and secondary impacts in the first and the third periods of analysis behaved inversely. These two mentioned periods represent about half the whole period of analysis; while the rest of the analysis period showed similar behaviour for the CLV and the RUCS, i.e. both of them increased in spite of the difference in their magnitudes. It was found that the factors affecting the degree of their similarity were traffic volume and the response of the network users to the new road, associated with the increased accessibility obtained from such a road. In addition, the limitation of the developed model of CLVs in terms of the variables used and particularly in their maximum and minimum values also affects the degree of similarity.

The methodology proposed may be used by road appraisers to acquire a broader view of all the impacts of road development.

DEDICATION

To my beloved mother and father, who were always so patient and understanding, it would not have been possible without their prayers and motivational words

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CLVs	changes in land values
CBA	cost benefit analysis
EIA	economic impact analysis
HDM-4	Highway Development and Management tool
RUCSs	road users' cost savings
DfT	Department for Transport
IRC	The Indian Roads Congress
ICE	Institution of Civil Engineering
TRB	transportation research board
DETR	Department of the Environment, Transport and the Regions
EEA	European Environmental Agency
CBD	central business district
DCLG	Department for Communities and Local Government
GIS	geographical information system
TTCBD	Travel time to CBD
PPR	Persons per room
CT	Commuting time
MI	Median Income
DtC	Distance to cities
DtR	Distance to rail
PD	Population density
Hs	Household size
DtH	Distance to highway

PW	Percent white
Sm	Street miles
DtA	Distance to Atlanta
SF_{Impr}	Square footage of improved structure.
$X_{i, Impr}$	Vector of variables related to such improvements (i.e., a constant term, a time trend, use-type indicator variable; and age of structure).
SF_{Land}	Square footage of land area.
$X_{j, Land}$	Vector of variables related to land valuation (i.e., a constant term, a time trend and parcel location variables)
WBTN	Western Brisbane Transport Network
OLS	ordinary least squares
LUTI	land use transport interaction models
TOMM	time oriented metropolitan model
PLUM	Productive Land Use Model
ITLUP	Integrated Transportation and Land Use Package
LILT	Leeds Integrated Land Use Transport Model
IRPUD	Institute of Spatial Planning of the University of Dortmund
CA	cellular automata
MEPLAN	Marcial Echenique & Partners' software package
PECAS	Production, Exchange, and Consumption Allocation System.
CATLAS	Chicago Area Transportation and Land Use Analysis System
NYMTIC-LUM	NYMTIC Land Use Model
DELTA	Development, Employment, Location, Transition and Area quality
Ramblas	Regional planning model based on the micro-simulation of daily activity patterns

ILUMASS	Integrated Land-Use Modelling and Transportation System Simulation
UrbanSim	Urban simulation model
ILUTE	Integrated Land Use, Transportation, Environment
FAO	Food and Agricultural Organization of the United Nations
TMR	Transport and Main Roads
WMO	World Metrological Organization
COBA	Cost Benefit Analysis Model
FTM	Fixed trip matrix
VTM	Variable trip matrix
TUBA	Transport User Benefit Appraisal
dTIMS	Deighton's total infrastructure management system
RTIM	Road Transport Investment Model
PCLV	percent changes in land values
RACs	Road agency costs
RUCs	Road user costs
P_1-P_2	Difference in cost of trip
V_1-V_2	Difference in volume of traffic
CoV	Coefficient of variation (=standard deviation/mean)
t	t-statistics
n	Samples size
α_1	1
α_2	3.3
HDM-III	Highway Design and Maintenance Standards Model
VFM	vehicle fleet manager

RD	Road deterioration
MIE	Maintenance and improvement effects
SEC	socio-economic costs
VOC	vehicle operating cost
TTC	travel time cost
PCSE	passenger car space equivalence
ESALF	equivalent standard axle load factor
LGVs	light goods vehicles
VOC	vehicle operating cost
TTC	travel time cost
AC	accidents’ cost
r	discount rate
TE	Trading Economics
DT	Diverted traffic
IT	Induced traffic

CHAPTER ONE
INTRODUCTION

1.1 Background

Roads play an important role in the economy of countries and their development (Wilkie et al., 2000; Garber and Hoel, 2009); there is a need to calculate the total cost required for the development of a road project and the total benefits aggregated from such a project (Hanley and Spash, 1993). These are analysed using conventional CBA models (economic evaluation tools) which deal with the monetary equivalents (Small, 1998) of all the consequences of a road project to all members in a society (Boardman et al., 2006; Mackie, 2010). They have been used for seven decades (Lakshmanan, 2011) to help the road appraiser (decision maker), i.e. economist, road planner and politician (Gkritza et al., 2008; Mouter et al., 2013) to choose the best option for investing in roads' infrastructure (Boardman et al., 2006; Robinson, 2008). However, the CBA models do not consider the effect the road project has on the values of the adjacent land (Mackie, 2010; Transportation Research Board (TRB), 2010). Yet, there are a number of models of another type of economic analysis, termed EIA that can be used to calculate the impact of a road project on the economy of a well-defined area (Gkritza et al., 2008), including the change in the values of the affected land (TRB, 2010; Kockelman et al., 2002; Lavee, 2015; Chang, 2006). These economic impacts are the end result of the road's direct impact on road users and non-users. There is no integration to date of the CBA model with the EIA model, but there are many studies considering the double counting of the project's cost and benefits (TRB, 2010; Department for Transport (DfT), 2016c; Mackie, 2010; Banister and Berechman, 2001). Moreover, of course there is merit to integrate these models to attain a more comprehensive appraisal view of all the general economic growth that in turn may change the ranking in the project's options and choose the best option for investing in roads' infrastructure (Melo et al., 2013).

1.2 Primary Impacts of Road Development

The impacts resulting from the road development (Sloman et al., 2017) may be broadly divided into primary impacts and secondary impacts. The primary impacts are associated with solving network congestion and decreasing travel time and cost for road users (Dft, 2016c; Anas, 1984; Boarnet et al., 2008; Parkinson, 1981; Mackie, 2010; Litman and Colman, 2001; Levkovich et al., 2015); these in turn increase the accessibility obtained from the new road for the movement of people and goods to their destination point (Litman and Doherty, 2009; Banister and Berechman, 2001; Weisbrod, 2008; Parkinson, 1981; Litman, 2017b; Garber and Hoel, 2009; Kockelman et al., 2002). These primary impacts of road development should be considered with regard to five engineering objectives: economic, accessibility, safety, political and environmental (Ratner and Goetz, 2013; Nelson, 1982; Morosiuk et al., 2006; Nellthorp and Mackie, 2000). These may be analysed using conventional CBA, which is a decision framework widely used by government agencies (Lee, 2000) for economic evaluation of road investments (Litman, 2006; Lakshmanan, 2011). It can assist in considering the desirability of the project's options, based on their net benefits (Robinson, 2008; Litman, 2017c; Bennett, 1995), which are the result of subtracting the total costs required for the development of the road project (expenditures) from the total benefits aggregated from such a project (revenues) (Hanley and Spash, 1993); and then assist in choosing the option that has the greatest net benefits.

Benefits obtained from road development can be summarized into road user benefits and social benefits (The Indian Roads Congress (IRC), 1993; Mackie, 2010). The road user benefits include the saving of transport costs for road users (Archondo-Callao, 2008;

Mackie, 2010); while the social benefits include the benefits that are related to environmental standards, health, education and the economic development of a society (IRC, 1993).

1.3 Secondary Impacts of Road Development

In the UK, the government has usually linked the increase of industrial and agricultural outputs, the regeneration of an old area, an increase in job opportunities, increases in household income and tax, increased values of land and changes of the use of land to the provision of road development (Institution of Civil Engineering (ICE), 2011). These economic impacts result as a secondary impact of road development (Gillespie, 1998; Banister and Thurstain-Goodwin, 2005; Lavee, 2015; Parkinson, 1981; Angel et al., 2011; Bertaud, 2012; Chandra and Thompson, 2000), due to increasing the economic activities of nearby land (Sloman et al., 2017; Department of the Environment, Transport and the Regions (DETR), 1999; Lakshmanan, 2011). Generally, investing in a road project has widely been used to encourage the economic development of a society (Melo et al., 2013), which may be calculated using appropriate EIA models. Due to their differences, each one of these secondary impacts requires an individual examination. It was therefore felt necessary to focus on one of these impacts, the changes in land values, as the transportation benefits from these changes have largely been ignored. It was felt that these CLVs result from the RUCSs, the primary impacts of road development (Litman and Colman, 2001); and that they are just transformations from these savings and therefore it is important not to double count them as they are obtained from the same development (TRB, 2010).

The increase of the land values and changes in the land use may lead to a geographical expansion (Angel et al., 2011; Bertaud, 2012; European Environmental Agency (EEA), 2016; Rogers, 2016; Aurbach, 2003; Litman, 2003) and can extend 30-40 miles away from the central business district (CBD) in large cities (Lang, 2003; Hartshorn and Muller, 1989).

Different models have been proposed to determine the impact the road investment has on the adjacent land. These models may be divided into two approaches: the first that focuses on the relationship between the transportation investment and the change in land use; and the second approach models the impact of the urban road investments on the values of the adjacent land.

1.4 Problem Definition

The feasibility study of a transportation project does not take into account the value of the land that is used to build the transportation project, or often gives it a low price at a constant rate (Litman, 2017b; Litman and Doherty, 2009), unless there is a need for land acquisition (Delucchi, 2005; Ketcham and Komanoff, 1992). Moreover, the change in the values of land or the change in its use due to road development have not been considered in the conventional CBA (Roth, 1996; FAO, 2007; Litman, 2016a). In the UK, the British guidelines for a transportation appraisal (Dft, 2013a) very briefly cover the change in land values as an economic impact of road projects (Börjesson et al., 2014b). This is due to the road appraisers who considered these changes in land values as transformations from the road's primary benefits and are already combined with the RUCSs (Litman and Colman, 2001). Studying the change in land use is important because such a change would generate traffic (Mackett, 1993; Kockelman et al., 2002; Chang, 2006). Although the change in land values and the changes in land use have been found to be significant factors in the road appraisal process, it seems that to date there is no model that takes into account explicitly these changes over the long term of a road's life, especially for inter-urban road. Furthermore and to date, there is no study that compares the primary and the secondary impacts of road development over a long period of analysis. To this end, this study proposes a model of CLVs as an impact of an inter-urban road development. This model will seek to improve the understanding of the road development effect on the adjacent land and then compare its results with the primary impact of the same development. Its results may be used to support road planners, road economists, politicians and road appraisers in the road appraisal process, to aid the appraisal tool CBA and to choose the right option for investing in road infrastructure.

1.5 Research Aim and Objectives

1.5.1 Aim

The aim of this research is to develop a methodology that could jointly consider conventional CBA with EIA for the appraisal of road development schemes and as a consequence, acquire a comprehensive tool capable of quantifying the total impact of road transport on the economy.

1.5.2 Objectives

The following objectives may be defined to achieve this aim:

1. To focus on the relationship between road network development and changes in the values of the adjacent land.

2. To develop a model capable of capturing these CLVs for inter-urban roads, as part of a wider economic impact analysis methodology.

3. To evaluate the prediction ability of the developed model using real data.

4. To compare qualitatively and quantitatively the CLVs predicted by the developed model with the results of a CBA model, with the view to examine whether they follow similar trends.

5. To provide a more comprehensive road appraisal methodology by using both CBA and EIA concepts and without double counting costs and benefits incurred from the road project.

1.6 Thesis Layout

To meet the aim and objectives, this thesis is presented in eleven chapters, as follows:

Chapter Two presents a literature review of the secondary impacts of road development and of appraisal methods and associated software. It reviews: the two main approaches used when studying the relationship between transportation investment and land use or land value; an overview of land use types; the principles of cost benefit analysis, its robustness and the principles of economic impact analysis; the transportation economic rules; the features of HDM-4 and other similar models used for the economic evaluation of road projects; and finally, a comparison between these models.

Chapter Three describes the methodology of this research, developed to compare the primary impacts of an inter-urban road development with the secondary impacts resulting from the same project over the long term. This chapter outlines the primary impacts of road development, the usage of HDM-4 software, generated traffic, the secondary impacts of road development and in particular, the changes in land values.

Chapter Four presents the modelling development process for the changes in land values' model. It illustrates the process of choosing the independent variables for this model, the variables' range, data used to produce the model and the statistical test used to choose the number of samples needed to develop this model.

Chapter Five gives the building process for the two resulting model forms for the change in land values' linear and non-linear models. It also outlines the different analyses used to ascertain the most accurate model of land values, such as analysis of error, analysis of goodness of fit and the sensitivity analysis.

Chapter Six introduces the process of verifying the proposed model to evaluate its prediction ability using real data from the UK. It illustrates the methodology used in the model verification, data description and a discussion of the results obtained.

Chapter Seven presents the case study used to achieve the goal of this research, the characteristics of this case study and the reasons behind this choice, to complete the application tasks of this research. This chapter also describes the new methodology developed in this study to apply the developed model to obtain these changes in land values as a secondary impact of an inter-urban road development over the long term. The results obtained from the model's application have been shown in this chapter.

Chapter Eight reviews the use of HDM-4 to aid the acquisition of the primary impacts of road development. It presents an overview of the HDM-4 software and its conceptual structure; the modelling of the road user cost in such software; the key input data used and its impacts on the HDM-4 calculation; the results of the project analysis of HDM-4 and the accuracy of the obtained results.

Chapter Nine offers a comparison of the primary and secondary impacts of road development over a long analysis period. It outlines the concepts of CBA and EIA, data issues, the comparison of primary and secondary impacts of road development over the long analysis period and a detailed discussion about the results obtained from this comparison.

Chapter Ten presents the discussion of this research.

Chapter Eleven gives the conclusions obtained from this study and suggestions for future work.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter presents a literature review of the secondary impacts of road development and of appraisal methods and associated software. It is organized as follows: the first section reviews the approaches used when studying the relationship between transportation investment and land use or land value. The second section overviews the types of land use. The third section reviews the principles of CBA, its robustness and the principles of EIA. The features of HDM-4 software and other similar models used for road project economic evaluation are summarised in the fourth section; which is followed by a comparison of the models.

The expected outcome from this literature is to review the models of a road project's impact on the value of affected land, variables used in these models, their limits and the relationship between each variable and the land value. Another outcome from such literature is to understand the principles for each CBA and EIA and the difference between these two analyses. In addition, this chapter summarizes the different types of CBA models and the comparison between these models that helps when selecting the most appropriate model to complete the requirements of this study.

2.2 Relationship between Transportation Investments and Land Use and Value

There are generally two approaches used to study the impact of transportation projects on the affected land, i.e. land which has access points to such projects. The first approach is the perspective of the economists who deal with the changes in land values; while the second approach is that of the transportation engineering planners who deal with the changes in land use. The difference between these two perspectives is that change in land use leads to a change in the value of such land; but a change in land value does not necessarily mean that there is a change in the use of that land, because the value of land may be changed even if there is no change in the land use. In addition, there is a difference with regards to the generated traffic; the change in land use can help in predicting the traffic generated due to such change, while changes in land values cannot help in traffic estimation because even if there is a change in land value that does not mean that there is a change in land use.

2.2.1 Effect of Transportation Investment on Land Values from the Economist's Perspective

The impacts of changes in the transportation infrastructure on the value of adjacent property have been a significant issue for urban economists since the late 1970s (Chernobai et al., 2011). These impacts were considered for road investments and for rail investments.

A road development project may solve network traffic congestion and, as a result, decrease travel time and travel costs (Levkovich et al., 2015; Dft, 2016c; Banister and Berechman, 2001; Parkinson, 1981; DETR, 1999). This may lead to an increase in the accessibility of the surrounding land (Banister and Berechman, 2001), which in turn may result in an increase in the values of such land (Chandra and Thompson, 2000; Giuliano, 1989; Anas, 1984; Kockelman et al., 2002; Chang, 2006; Huang, 1994; Landis et al., 1995). Huang (1994) reported that there are two simultaneous effects but opposing at the same time. The first effect is the increase in the accessibility of the affected land, which makes these lands more attractive and as a result increases their values. The second effect is the decrease in the willingness to pay for the same affected land, which in turn resulted in decreasing their values. The second effect would minimize the first effect, which in turn resulted in decreasing the net benefits to the values of the affected land.

To date, a number of studies have been carried out to assess the impact of road transport investment on land values, as represented by property prices (Sanchez, 1993; Siethoff and Kockelman, 2002; Kockelman et al., 2002; Sanchez, 2004; Neelawala et al., 2010; Chernobai et al., 2011). Sanchez (1993) investigated the impact of highway location on property prices of residential land use in 18 counties in Atlanta in 1990. Data from more than 480 samples of property values were used, in conjunction with a geographical information system (GIS) application to determine the impact of highway location on property prices in the metropolitan area. The results of this research confirmed the significant impact road investment had on residential property prices in Atlanta. A regression model for changes in property value was obtained by Sanchez and is as follows:

$$\begin{aligned}\boldsymbol{Ln\ value} = {} & 12.167 - 0.0082(\boldsymbol{TTCBD}) - 0.098(\boldsymbol{PPR}) - 0.0158(\boldsymbol{CT}) + 0.00002(\boldsymbol{MI}) \\ & + 0.0055(\boldsymbol{DtC}) + 0.0098(\boldsymbol{DtR}) + 0.00003(\boldsymbol{PD}) - 0.3648(\boldsymbol{Hs}) + 0.0076(\boldsymbol{DtH}) \\ & + 0.0017(\boldsymbol{PW}) - 0.025(\boldsymbol{Sm}) - 0.0084(\boldsymbol{DtA})\end{aligned} \quad \ldots(2.1)$$

Where:

TTCBD	=	*Travel time to CBD*	***PD***	=	*Population density*
PPR	=	*Persons per room*	***Hs***	=	*Household size*
CT	=	*Commuting time*	***DtH***	=	*Distance to highway*
MI	=	*Median Income*	***PW***	=	*Percent white*
DtC	=	*Distance to cities*	***Sm***	=	*Street miles*
DtR	=	*Distance to rail*	***DtA***	=	*Distance to Atlanta*

Another study by Siethoff and Kockelman (2002) focused on commercial land use in Northwest Austin, Texas. It examined the impact of expanding the US-183 road width from four lanes to six lanes on the property values for a period of 18 years from 1982 to 1999. Using records of land tax assessment, especially of that real estate which had frontage on the road, in addition to 10% of random estate samples within half a mile from the highway, over a period of eighteen years, it gauged the impact of increasing road capacity on the value of the real estate. Three individual models were proposed to describe this: (a) a total value model, (b) an improvement value model and (c) a land value model, shown in Eq. (2.2), (2.3) and (2.4) respectively:

$$TotValue = \beta_0 + SF_{Impr}\sum_i(\beta_{i,Impr}X_{i,Impr}) + SF_{Land}\sum_j(\beta_{j,Land}X_{j,Land}) + u \qquad R^2=0.61 \ldots\ldots (2.2)$$

$$ImpValue = \beta_0 + SF_{Impr}\sum_i(\beta_{i,Impr}X_{i,Impr}) + u, \qquad R^2=0.87 \ldots\ldots (2.3)$$

$$LandValue = \beta_0 + SF_{Land}\sum_j(\beta_{j,Land}X_{j,Land}) + u, \qquad R^2=0.32 \ldots\ldots (2.4)$$

Where:

SF_{Impr}	=	*Square footage of improved structure.*
$X_{i,Impr}$	=	*Vector of variables related to such improvements (i.e., a constant term, a time trend, use-type indicator variable; and age of structure).*
SF_{Land}	=	*Square footage of land area.*
$X_{j,Land}$	=	*Vector of variables related to land valuation (i.e., a constant term, a time trend and parcel location variables).*

Furthermore, Sanchez (2004) used two scales of aerial photography, in conjunction with a GIS application, to show the effect of an increase in highway capacity on urban development in Oregon between 1970 and 1990. More than 42000 observations collected from fifteen cities in Oregon ranged in terms of the number of population, from 997 persons to 44757 persons to determine the pattern of urban development. A logit regression model was produced to predict the percentage change in land use as an impact from road projects. Sanchez (2004) concluded from his study that about 41.6% of land located up to 1.6 km from road projects next to urbanized areas, were upgraded to urban use. However, for road projects that were next to the boundaries of an urbanized area, the percentage of upgraded land decreased to about 31.4%. These results were due to the fact that lands near urbanized areas were closer to formerly developed land more than lands near the boundaries of urbanized areas. A logit regression model was produced to predict the percentage change in land use as a result of the road projects, successfully predicting about 84% of land conversion for all the cities used in the study.

Neelawala et al. (2010) investigated the impact of two road-widening projects on the surrounding property values. The two projects used were part of the *Western Brisbane Transport Network* (WBTN) in Australia. More than 600 observations during the period 1992-2009 were collected from areas up to 2 kilometres distant from the two sites. These were then used in regression analysis to determine the impacts of the two projects. The main finding of this study was that the impact of transportation projects on land values varies according to the size of the road development, i.e. the larger the project size, the bigger the effect on property prices. Moreover, by using ordinary least squares (OLS) *analyses* they found that property buyers were willing to spend more money, around 2.82% per kilometre distant, to be further away from the road project, due to the negative externalities of road development, such as noise, emissions, and vibration. The regression analysis model developed is shown below:

$$\begin{aligned} LOG\boldsymbol{CPC} = &-69.96509 + 0.037437(\boldsymbol{DIS}) - 0.001759(\boldsymbol{AGE}) + 0.037066(\boldsymbol{BD}) \\ &+ 0.123929(\boldsymbol{BTH}) - 0.049093(\boldsymbol{CARPORT}) + 0.000114(\boldsymbol{SIZE}) \\ &+ 7.08E\text{^}(-05)\ (\boldsymbol{MHI}) - 0.002164(\boldsymbol{PARK}) - 0.057222(\boldsymbol{SCHOOL}) \\ &+ 0.031409(\boldsymbol{SMAR}) + 0.042069(\boldsymbol{YR}) + 0.149691(\boldsymbol{LOGUCV}) \\ &- 0.022597(\boldsymbol{OBORN}) + 0.001194(\boldsymbol{CBD}) - 0.207261(\boldsymbol{DUMMY}) + \varepsilon \end{aligned} \quad ...(2.5)$$

Where:

CPC	=	*Corrected property price*	***DIS***	=	*Distance to proposed transport corridor*
MHI	=	*Monthly household income*	***CBD***	=	*Distance to central business district*
AGE	=	*Age of the properties*	***SMAR***	=	*Distance to nearest supermarket*
UCV	=	*Unimproved capital value*	***SCHOOL***	=	*Distance to the nearest state school*
OBORN	=	*Overseas born population*	***YR***	=	*The year of sale variable*

More recently, Chernobai et al. (2011) studied the influence of a highway extension on the prices of surrounding houses in metropolitan Los Angeles over a period of eleven years. A regression model was produced to relate the prices of houses built in lands of commercial use to their characteristics, including size, age, distance from road, area and time since the road works have been completed. A combination of a *standard regression model* and a *spline regression technique* was used to study the nonlinear relationship between real estate prices and both distance from the road project and time from the road works' completion.

For rail investment, there is a similarity between the analysis of the impacts of inter-urban roads and rail projects; both have full control of access to them. In other words, inter-urban roads connect cities and only have access points near cities, as well as other access points elsewhere along these roads. The same can be said for rail projects, which have a limited number of access points i.e. train stations. As a result, numerous studies have attempted to clarify the impacts of rail investments by considering property prices such as the studies carried out by Damm et al. (1980), Forrest et al. (1996), Henneberry (1998), Hess and Almeida (2007), Du and Mulley (2007), Du and Mulley (2012), Cervero and Murakami (2009), Topalovic et al. (2012), Chatman et al. (2012), Dziauddin (2009), Pan (2013), Dziauddin et al. (2015), Blainey and Preston (2010), Gatzlaff and Smith (1993), Agostini and Palmucci (2008) and Lee and Sohn (2014). However further investigation was beyond the scope of this research.

2.2.2 Relationship between Transportation Investment and Land Use from the Transportation Planner's View

Although modelling the relationship between transportation investment and changes in land use is a difficult process, different models have attempted to describe this relationship in urban regions by integrating a four-step travel forecasting model with a land use model to evaluate the impact of road development on land use and vice versa (Iacono et al., 2008; Woudsma et al., 2008). These models are called land use transport interaction models (LUTI models). The first attempt was made in the USA (Wegener, 2004) in the 1950s (Batty, 1979); but the first urban land use simulation model which was called the Model of Metropolis, was developed by Lowry (1964) and presented in the early 1960s (Iacono et al., 2008). This model was based on spatial interaction and it was developed for the Pennsylvania region (Iacono et al., 2008). Some researchers tried to make some changes to Lowry's model. Garin (1966), for example, recast the model by providing a matrix representation; while Crecine (1964) presented a time oriented metropolitan model (TOMM), which is an improved derivative of Lowry's model and disaggregates the population into groups (Iacono et al., 2008). Models which depended on a spatial interaction theory continued to enhance the existing models until the mid 1980s; this was the first presentation of econometric models. While the first presentation of microsimulation models was in the early 1990s. Figure 2-1 shows the chronological development of the models used to describe the relationship between land use and transportation projects (Iacono et al., 2008).

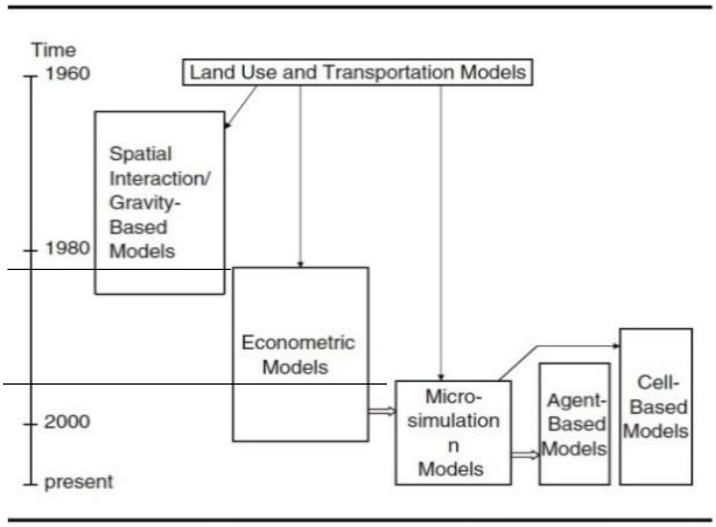
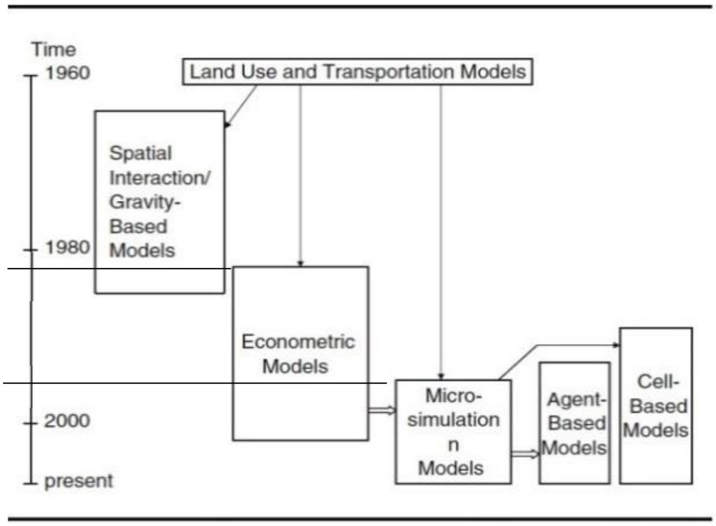


Figure 2- 1: Chronological Development of Land Use and Transportation Models (after Iacono et al., 2008).

It is clear from Figure 2-1 that three main groups of simulation models may be defined: 1- *spatial interaction/gravity-based models*; 2- *econometric models*; and 3- *microsimulation models* (Iacono et al., 2008). Each group contains a number of models. The spatial interaction models include Model of Metropolis, TOMM, PLUM, ITLUP/METROPILUS, LILT and IRPUD. The econometric models include CATLAS, MEPLAN, TRANUS, MUSSA, METROSIM, NYMTIC-LUM, DELTA and PECAS. The microsimulation models cover ILUTE, ILUMASS, Ramblas, UrbanSim, and cellular models (Iacono et al., 2008). A summary of the three groups of models, references, distinguishing features, advantages and shortcomings, is shown in Table 2-1.



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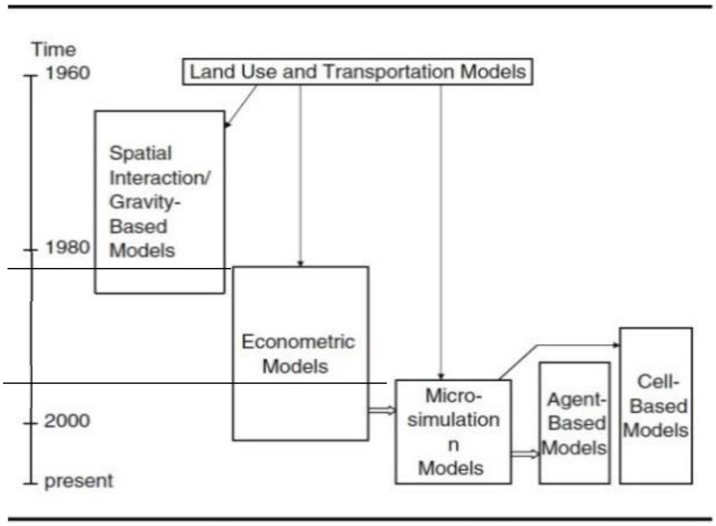

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Table 2- 1: Summary of Land Use Transport Interaction Models (adopted from Iacono et al., 2008)

	Model	Reference	Distinguishing Features	Advantages	Shortcomings
Spatial Interaction/Gravity based models	Model of Metropolis	Lowry (1964), Garin (1966)	-First recognized operational land use model for urban regions. -Couple the models of both land use and a travel forecast to present a network flow; Garin provided matrix representation.	-	-Static models with no capability to capture the dynamics of the relationship between transportation investment and land use in urban regions. -Data hungry and complex models (Lee, 1973). - Land price has not been represented in any of these models. -Zones are highly aggregate and they lacked spatial information (Lee, 1973). -Poorly forecasting for the change in land uses due to inadequate theory for representing the transportation-land use relationship (Batty, 1979).
	TOMM	Crecine (1964)	TOMM: Time Oriented Metropolitan Model -An improved Lowry's model by disaggregating the population into groups; incorporation of inertia effects in activity allocation.		
	PLUM	Goldner (1971)	PLUM: Productive Land Use Model (Goldner, 1971) -Replaced standard gravity model with intervening opportunity model; use of county-specific dispersion parameters.		
	ITLUP/ METROPILUS	Putman (1983)	ITLUP: Integrated Transportation and Land Use Package -First complete software package for integrated modelling; improved calibration techniques; improved network model with multiple modes; incorporation of congestion effects in activity allocation. -METROPILUS, a new package that includes the GIS software to develop the presentation of an outcome.		
	LILT	Mackett (1983)	LILT: Leeds Integrated Land Use Transport Model -Combines a land use model with the four-step travel model; uses an accessibility function; includes sub-model regarding the car ownership; includes a land use model; which has the capability to handle demolition and the change of occupancy and vacancy rates.		

	IRPUD	Wegener (1982)	IRPUD: Institute of Spatial Planning of the University of Dortmund (Wegener, 2011). -Contains seven separate sub-models; microsimulation of land use; use of differing spatial scales for sub-models; separates discretionary and non-discretionary travel.		
Econometric Models (Regional Econometric Models or Land Market Models)	**Model**	**Reference**	**Distinguishing Features**	**Advantages**	**Shortcomings**
	MEPLAN	Echenique et al. (1969), Echenique et al. (1990)	MEPLAN: Marcial Echenique & Partners' software package (Echenique et al., 1990) -Incorporation of spatial input-output model with economic evaluation component; able to forecast commercial trip generation; travel treated as a derived demand.	-The use of random utility theory and the improving of discrete choice modelling for individual behaviour have permitted the insertion of economic evaluation components in some of the models and also the measures of improved accessibility that depend on utility functions. -The introduction of models that are built around an economic model allowed for the inclusion of commercial travel in forecasts and the treatment of travel as a derivative demand.	-Most of the models are still aggregate to a high level, despite the disaggregation used in the calibration methods. -Static models with no capability to represent the dynamic relationship of transportation project and land use. -In MUSSA, households have been disaggregated at a level that is adequate to operate them in a static microsimulation format, where a typical sample is used within a micro analysis for applications of short-term forecasts. However, for
	TRANUS	De La Barra (1989)	-Development supply model simulates choices of developers; sophisticated travel model with combined mode-route choice.		
	PECAS	Hunt and Abraham (2005)	PECAS: Production, Exchange, and Consumption Allocation System. -Regional econometric model with microsimulation of land development at the parcel level; ability to couple with an activity-based travel model and to apply at supra-regional level.		
	CATLAS	Anas (1982)	CATLAS: Chicago Area Transportation and Land Use Analysis System Anas and Arnott (1994). -Improved representation of economic agents and decision making; explicit treatment of housing markets; economic analysis capabilities.		
	MUSSA	Martinez (1992)	-Incorporation of bid-rent framework for land, floor space markets; detailed representation of transit network in travel model; high level of household type disaggregation.		

	METR-OSIM	Anas and Arnott (1994)	-Model extended to consider the market of commercial real estate; addition of dynamic housing market model		long-run forecasts the application should be up dated to represent the dynamics for both individuals and environments.
	NYMTIC-LUM	Anas (1998)	NYMTIC-LUM: NYMTIC Land Use Model (Anas and Associates, 2002) -Endogenous determination of housing prices, floor space rents and wages; high level of spatial disaggregation suitable for transit and land use policy evaluation.		
	DELTA	Simmonds (1999)	DELTA: Development, Employment, Location, Transition and Area quality. -Microsimulation of demographic changes; treatment of quality in the market for space.		
Microsimulation Models (dynamic models)	**Model**	**Reference**	**Distinguishing Features**	**Advantages**	**Shortcomings**
	Ramblas	Veldhuisen et al. (2000)	Ramblas: Regional planning model based on the micro-simulation of daily activity patterns (Veldhuisen et al., 2000a) -Entirely rule-based model framework; designed to simulate very large populations.	-Solve many of the shortcomings related to earlier large-scale modelling efforts and such models represent significant change	-The inadequate representation of land use (Change 2006) and their
	ILUMASS	Moeckel et al. (2003); Strauch et al. (2003)	ILUMASS: Integrated Land-Use Modelling and Transportation System Simulation (Moeckel et al., 2003) -Descendent of IRPUD model; incorporates microscopic dynamic simulation model of traffic flows and goods movement model; designed with environmental evaluation sub-model.		

	UrbanSim	(Waddell et al., 2003)	UrbanSim: Urban simulation model (Waddell et al., 2003). -Land use model incorporating microsimulations of demographic processes land use development; parcel-level land use representation; high level of household type disaggregation; open-source software developed for general use.	processes in cities with the required detail. -Microsimulation methods are mainly effective for modelling systems that are complex and have dynamic status such as urban systems.	limited features due to their simplicity.
	ILUTE	(Salvini and Miller, 2005)	ILUTE: Integrated Land Use, Transportation, Environment (Salvini and Miller, 2005) -Comprehensive urban system microsimulation model; structured to accurately capture temporal elements urban change; activity-travel model includes household member interactions; disequilibrium modelling framework.		
	Cellular Models	Batty (1997); Batty (2005)	Cell-based models and particularly those based on cellular automata (CA) theory (Batty, 1997; Batty, 2005). -The compatibility of CA models with GIS, remote sensing data and associated visualization capabilities make them particularly suitable for land use modelling applications. The relative ease and flexibility with which they can be modified to describe processes of change.	-Models that provide greater simplicity and a clearer representation of the dynamics of land use change using cell-based representations of regions have merged within the past two decades as an increasingly attractive land use modelling alternative.	-Their simplicity is a significant limitation.

Another study focused on LUTI models was that of Wegener (2004), where twenty models were used for a comparison review. Some of the above mentioned models were included in this comparison, although some others were not.

Simulation models that have been proposed for use in the United Kingdom include the following (Mackett, 1991):

- **LILT model** Leeds Integrated Land Use Transport model. It was developed by Mackett (1983) as a spatial interaction model that represented "the relationships between transport supply (or cost) and the spatial distribution of population, housing, employment, jobs, shopping and land utilization" (Mackett, 1993). This model linked the Lowry land use model and the conventional four-step travel forecasting model (Iacono et al., 2008; Mackett, 1993; Rohr and Williams, 1994).

- **MEPLAN model** Marcial Echenique and Partners' software package (Echenique et al., 1990). It was developed by *Marcial Echenique and Partners*. Besides the application of this model in Leeds, it was also applied as an econometrical model in Bilbao and Dortmund (Echenique et al., 1990). One of its most important applications was for completing the planning criteria for the construction of the *Channel Tunnel between England and France* (Rohr and Williams, 1994), as its structure makes it appropriate for modelling both intra-urban and inter-urban projects (Iacono et al., 2008).

- **DELTA model**, this new package to model land use (Simmonds, 1999), was a form of an econometric model framework for urban use and was developed by *David Simmonds Consultancy* and the Institution for Transport Studies (ITS) of the University of Leeds between 1995-96 (Simmonds, 1999).

2.3 Land Use

The term land use refers to the main activities to which the land is dedicated such as industrial, residential, agricultural, urban greenspace, other greenspace, woodland, infrastructure and inland water (Wightman, 2013).

Land use is not static; it depends on people's activities. A transportation investment is normally required to develop and change the use of the land in question (Dft, 2014a; Mackett, 1993; Chandra and Thompson, 2000; Kockelman et al., 2002; Moore and Thorsnes, 1994; Sanchez, 2004; Giuliano, 1989).

Furthermore, the price of land is related to its use, which is in turn affected by different market forces, policies and economic, social and environmental development (FAO, 2007; Litman, 2016a).

Transportation investment increases land activities that result in raising its value and may change its use (Damm et al., 1980; Huang, 1994; Landis et al., 1995; Kelly, 1994; Banister and Thurstain-Goodwin, 2005; Levkovich et al., 2015). Conversely, the development of land generates traffic, which increases the demand for transportation investment. Therefore, there is a two-way interaction (Mackett, 1993; Kockelman et al., 2002; Chang, 2006).

There are many types of land use categories. Each category has a unique value, which is affected by its different types of activities (Litman, 2016a). Table 2-2 shows the land uses and associated values across England.

Table 2- 2: Land Values for Different Land Uses across England (after Wightman, 2013)

	Hectares	£ per ha land value	Total land value £
Business property	86,895	328,0453	£285,055,000,000
Residential	715,284	2,047,760	£1,464,729,766,246
Agricultural	8,925,000	£10,000	£89,250,000,000
Woodland	1,295,000	£1,000	£89,250,000,000
Inland water	343,620	£0	£0
Urban greenspace	106,550	£0	£0
Other greenspace	1,247,612	£1,000	£1,247,612,000
Infrastructure	327,237	£0	£0
Other	185,173	£1,000	£185,172,921
ENGLAND	13,232,271		£1,841,762,551,167

Road transport projects have many impacts on land use. In general, these impacts can be divided broadly into: direct impacts and indirect impacts (Litman, 2016a), as illustrated in Figure 2-2.

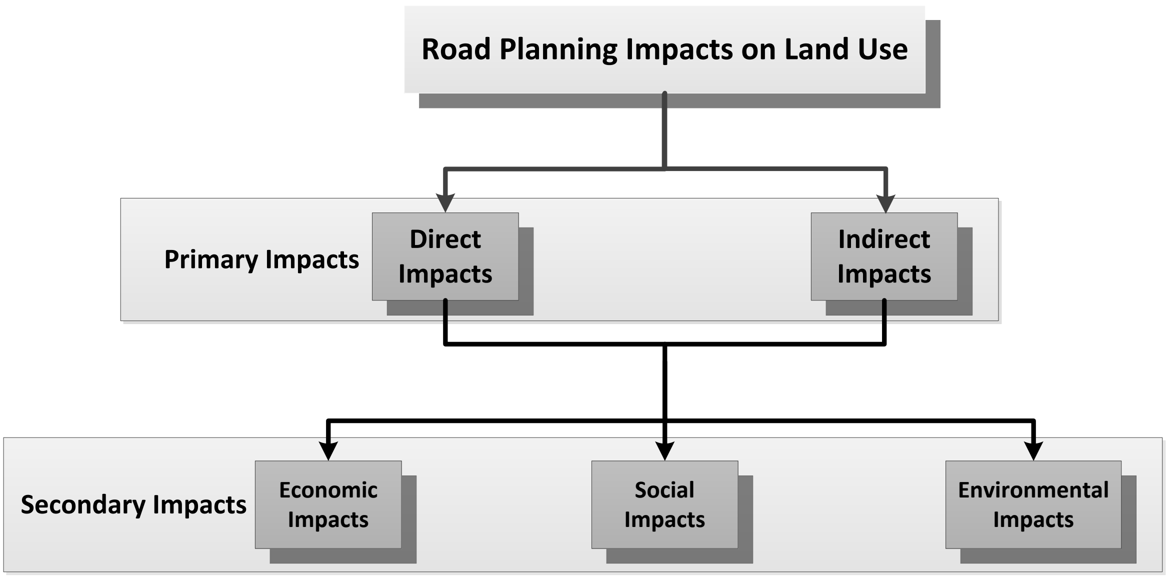


Figure 2- 2: Road Project Impacts on Land Use

The land area dedicated to the transportation project is directly impacted. Increased transportation accessibility produces indirect impacts (Banister and Berechman, 2001), which results in decreased travel time and travel cost for different locations (Kelly, 1994; Boarnet et al., 2008; Parkinson, 1981). All these direct and indirect impacts may lead to secondary impacts, which may be economic, social and environmental (Litman, 2016a). On the other hand, TRB (2010) reported that economic impacts can be considered as the outcome from the projects' direct impacts on road users and non-users.

A detailed presentation of the above impacts may be found elsewhere (Litman, 2016a). However, this research focuses on the following economic impacts: changes in land values, changes in land use accessibility, changes in crash damages and changes in transportation costs.

2.4 Scheme Appraisal Method

A scheme appraisal method is the decision-making process used to choose the best option for a project needed to solve an existing problem (Garber and Hoel, 2009); which may be an increase in the number of accidents or in the magnitude of traffic volume. Each option is a unique solution to such a problem and also has a unique cost and benefits. To check the viability of the proposed options, a comparison should be made between all the project's options with the base case; and then they should be ranked according to their net benefits. The optimum option can then be chosen (Transport and Main Roads (TMR), 2011; Robinson, 2008).

The fundamental part of the appraisal process is to select criteria that are related to the stated goal and on which the comparison will depend (Garber and Hoel, 2009). Different criteria such as economic, financial, environmental, safety and social factors may be included in the appraisal process, to check the viability of the proposed options; and to ensure that sufficient returns (benefits) would result from such an investment (Robinson, 2008; World Metrological Organization (WMO), 2007; Garber and Hoel, 2009). In the UK (ICE, 2011; Nellthorp and Mackie, 2000), five objectives are required for transport: environment, safety, economics, accessibility and integration. Each objective has sub-objectives. This study focuses on economic objectives, which include land regeneration and increase in the value of the land and also any change in the use of land due to the provision of a road development project and transport user benefits. As a result, it was felt appropriate to make a model capable of determining the changes in land values as an impact of a road development project and then use the results of this model to compare with the road user benefits resulting from such a project.

2.4.1 Cost Benefit Analysis

CBA is a technique that is widely used in economic evaluation (Litman, 2006; Arrow et al., 1996); it can assist in choosing the optimum project option by comparing the benefits derived from a transportation project with the costs required to implement such a project (Robinson, 2008). The subtraction of the costs from the benefits produces the net benefit; while dividing the benefits by the costs produces the CBA (WMO, 2007; TMR, 2011; Mackie, 2010).

There are some rules that should be taken into account when making an estimation of both costs and benefits for any project (Robinson, 2008; WMO, 2007):

- The estimation of costs and benefits is made on the same basis over time, i.e. no inflation in price for both costs and benefits (inflation should be removed).

- The estimation of costs and benefits is made after adjustment for the time related changes in the value of money (they should both be predicted at present values) (Garber and Hoel, 2009).

- Care should be exercised so that there will be no double counting for cost or benefits in such a holistic approach (TRB, 2010; Dft, 2016c; Banister and Berechman, 2001).

- Present both the CBA and EIA individually and do not add the results together (TRB, 2010).

As a result, it was felt important to take all these points into account when comparing the changes in land values as a secondary impact of a road development project with the road user benefits as a primary impact resulting from such a project.

2.4.2 Robustness of CBA

There are two main types of CBA (Boardman et al., 2006): ex ante CBA and ex post CBA. Both of them are a conventional CBA but the difference between them is related to the time of conducting the calculation. The ex ante CBA is conducted before starting the roadworks, i.e. while the project is under consideration; while the ex post CBA evaluates the project's viability at the end of its life. The value obtained from the ex post CBA is broader than that obtained from the ex ante CBA and can contribute to an overview of whether such a project is worthwhile (Boardman et al., 2006). The reason behind this is due to the dependence on real values of costs and benefits (observations) and not just on estimations about them, used for the ex ante CBA. There is a third type of CBA, which is conducted during the project's life but it is less used compared with the two main types of CBA (Boardman et al., 2006). To this end, the principal type of CBA for accuracy is the ex post analysis; while the less accurate type is the ex ante CBA (Boardman et al., 2006).

To date, a number of studies have been carried out to assess the robustness of CBA (Alder and Posner, 2000) as slight changes in input may lead to completely different results. Börjesson et al. (2014a) for example, confirmed the robustness of CBA results and recommend the use of CBA to obtain ranked options.

However, another study about CBA (Börjesson et al., 2014b) states that, although the relationship between transportation development and the adjacent land improvement is important (Levkovich et al., 2016; Banister and Thurstain-Goodwin, 2005), induced demand (induced traffic) due to changes in land use resulting from transportation development is not included in conventional CBA.

De Jong et al. (2007) focused on studying the uncertainty in CBA resulting from errors of transport models, i.e. traffic forecasting models. The uncertainty was considered in terms of input uncertainty and model uncertainty. The latter was, in turn, due to the model formulae, or to not using the true values of parameters but estimations instead. They also found that the uncertainty in CBA resulting from errors in assumptions for transport models was much more than that resulting from transport modelling errors.

In addition, Mackie and Preston (1998) with examples from the UK, identified more than twenty potential errors in road project appraisals, which are related to input data, models used, unclear objectives, incorrect definition, systems of urban dynamics, wrong assessment of project life and double counting of benefits derived from a project's options. To overcome these, they suggested, amongst other items, to use an input data of good quality to examine the project's success.

2.4.3 Economic Impact Analysis versus CBA

Economic effects are one of the secondary impacts of a road development project; which are due to different factors, such as changes in transportation costs, changes in people's behaviour that increase business, increased tourism, increased market connectivity, development of land and increased desirability of the area under study (Linneker and Spence, 1996; TRB, 2010).

EIA may be seen as a determination of how a transportation project would affect the economy of a well-defined area, which can be measured in terms of the variation in number of jobs, increasing personal income, increasing the land value and changing the use of land (TRB, 2010; Kockelman et al., 2002; Lavee, 2015; Chang, 2006).

On the other hand, CBA is an analysis that may be used to compare between a project's options and subsequently rank them in terms of their costs and associated benefits (Robinson, 2008). These two types of analysis seem to complement each other to make the project more convincing for investment in road infrastructure (Melo et al., 2013). However, the main differences between CBA and EIA may be considered in terms of their geographic scope, their direct benefits and their follow-on benefits (TRB, 2010), as shown in Figure 2-3:

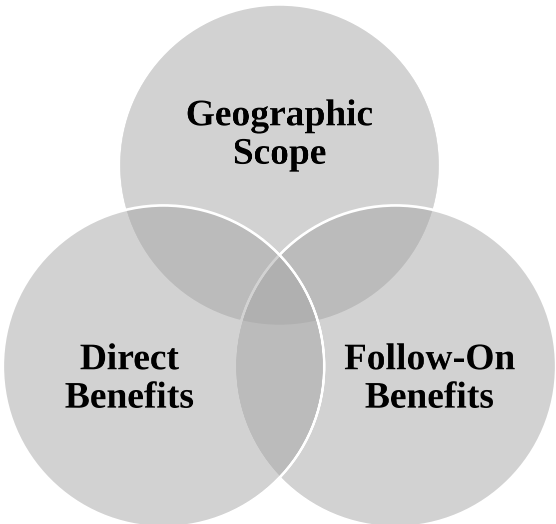


Figure 2- 3: Main Differences between CBA and EIA

- Geographic scope: EIA analyses the changes in economic activity in a defined area, while CBA takes in its analysis a broader view than EIA (TRB, 2010). A CBA is used to determine the project option's social welfare effects by measuring the benefits derived from such an

option for all road users and non-users (despite their living place or working place) (TRB, 2010).

- Direct benefits: CBA has a wider scope of the direct impact of road investment than EIA. In other words, the primary effects of a road development project such as meeting economic, safety, financial and environmental engineering objectives may be assessed by CBA to determine the viability of the project (Lakshmanan, 2011; Gkritza et al., 2008; Morosiuk et al., 2006; Eliasson et al., 2015); but EIA focuses on the impacts the road project has on the economy of the region.
- Follow-on benefits: (TRB, 2010) separates the impacts from the transportation investment into three types: direct impacts, indirect impacts and induced impacts. The indirect impacts and induced impacts can be considered as follow-on impacts of road investment (Mohring, 1993) and are included in the EIA; while CBA analyses only the direct impacts of such an investment. As a result, EIA analyses a wider view of consequent benefits than CBA.

This study broadly focuses on comparing CBA with EIA by taking the transportation economics rules into account and by presenting each of them individually, without double counting the cost or benefits and without adding the results together. A CBA deals with the primary effects of road development such as overall costs and benefits of the road project; while an EIA deals with the secondary effects of such a project.

2.4.4 Generated Traffic

It is important to mention that due to a road project, reduced transportation costs encourage road users to change their activities in a number of ways (Mackie et al., 2005; Mackie, 1996; Goodwin, 1996; Parkinson, 1981): alter the route of travel, alter the mode of travel, alter the travel time, alter the trip frequency, alter the destination point to another more reachable point and generate new trips.

This generated traffic consists of diverted traffic (re-assigned traffic) and induced traffic (terms used to describe the additional volume of traffic as an increased number of trips or vehicle miles travelled due to change in land use) (Goodwin, 1996; Litman and Colman, 2001; Litman, 2017a). The diverted traffic is the change in the route of travel, i.e. the traffic volume that exists but uses other routes; while induced traffic is a term used to describe any change of the following: mode of travel, destination point, travel time and trip frequency, and the additional volume of traffic either as an increased number of vehicle trips or vehicle miles travelled due to changes in land use (Mackie et al., 2005; Mackie, 1996; Kockelman et al., 2002; Litman and Colman, 2001). Up to six months into the second year of a project, all the generated traffic is diverted traffic; while from the second half of year two onwards, all the generated traffic is due to induced traffic (Litman and Colman, 2001). Failing to correctly estimate generated traffic results in faulty prediction of traffic volume and about 50% overestimation in the calculation of benefits resulting from road development, compared to the real benefits (Williams and Yamashita, 1992; Mackie et al., 2005).

Estimating the traffic volume over the long term leads to four types of errors: exclusion, forecasting, measurement and valuation errors (Boardman et al., 2006). The exclusion error involves ruling out some impact types due to them being thought of as unnecessary; while the forecasting error is due to the difficult prediction of some technological changes, which in turn increases with the complexity of the project (Boardman et al., 2006). The third type of error is the measurement error, which is dependent mainly on the quality of the equipment or technology used. Such a type of error has received little attention compared with the attention received by the other types of errors (Boardman et al., 2006). The fourth type of error is the valuation error; which is much greater than other types of errors because of the estimating of the values of the project's impacts. On the other hand, (Zhao and Kockelman, 2002) reported that the future prediction of a transportation model involves a lot of uncertainty, due to two reasons: uncertainty in the input used and uncertainty in the model building (De Jong et al., 2007; Zhao and Kockelman, 2002). In addition, (De Jong et al., 2007) have reviewed 21 studies on uncertainty in modelling the traffic forecasting volume; the models used in their study have covered the time horizon from 1980 until 2005 as shown in Appendix A Table A.1.

2.5 CBA Models

2.5.1 HDM-4

The piece of software, HDM-4 is widely used to investigate the economic value derived from road investment (Bennett, 1995). It includes formulae to calculate vehicle operating costs under different road conditions (Litman, 2017c). Moreover, it includes all the functions necessary for road management (Aswathy et al., 2013) to address areas such as policy and planning, works programming, preparation and operation (Kerali et al., 1998). Different reports comprise the output from running HDM-4: including a report for traffic, deterioration and works' effects; road user effects; environmental effects; cost streams; economic evaluation and multi criteria analysis. Reports are produced for each option considered for the road project. The primary effects of such options may be assessed by an appropriate analytical tool such as HDM4, *the world's de facto* standard for road project appraisal. Using such a tool, a number of investment options may be compared and subsequently ranked in terms of their costs and associated benefits. Moreover, HDM-4 can be used by a wider range of users such as governments, consultants and agencies and for both developed and developing countries.

2.5.2 Other Similar Models

A number of other models have been developed for CBA. These include:

1) COBA Cost Benefit Analysis Model

The Department for Transport developed the COBA computer programme (Builder, 2014) in the 1970s to conduct conventional CBAs for urban trunk and all major interurban roads. This programme has been used in England and Wales for 30 years (Bull, 2003; White et al., 2001). The COBA programme used the fixed trip matrix (FTM) assumption; which means it used the same matrix for origin and destination in both a do-nothing case and a do-something case. The method used is a link-based appraisal and internal supply model to calculate travel costs (White et al., 2001). It only has the ability to deal with quantified and monetised elements (Willis et al., 1998); COBA cannot deal with "the environmental, social or wider economic impacts of a project and is confined to use in road projects" (Vickerman, 2007).

2) URECA

This programme was released in 1988 by the DfT for urban road assessment (Bull, 2003), but it is less widely used than COBA. Like COBA, URECA used the FTM assumption, but both programmes have been modified to deal with the variable trip matrix (VTM). The URECA programme used a link-based method and "input from a traffic assignment model" to calculate travel costs (White et al., 2001).

3) TUBA Transport User Benefit Appraisal

The full version of the TUBA programme was released in 2001 by the UK government (White et al., 2001) and is used to calculate the induced traffic benefits, depending on the *matrix-based Rule of Half approach* (Dft, 2016), i.e. benefits derived from generated traffic are approximately half the benefit per trip of that obtained by the original road user (Small, 1998). The TUBA programme has the flexibility to use both FTM and VTM matrix-based appraisals;

it can be used for *single or multi-mode transport projects* (White et al., 2001), but is most commonly used for multi-modal studies (DETR, 2000).

4) dTIMS Deighton's total infrastructure management system

This analysis software was adopted in New Zealand in 1999 and has been followed by a new version, dTIMS CT, in 2004. The dTIMS software was developed to select the best decisions for New Zealand's maintenance plan (Henning et al., 2006). The pavement deterioration models used in the dTIMS software are based on the HDM-III and HDM-4 models. Henning et al.'s study (Henning et al., 2006) is the first study focused on calibrated HDM deterioration models for New Zealand's conditions.

5) RTIM Road Transport Investment Model

This model was used to simplify the economical appraisal process for road projects in developing countries (Cundill and Withnall, 1995). The model is simple and consists of some spreadsheets that take the user through the economic appraisal stages. The model is easy to use on a personal computer, offers help facilities, offers checking for data input and offers graphical representation for the output result. The model can be used to determine the more economic status by offering a comparison between the road expenditure for two cases; road maintenance and road improvement, with the vehicle operating costs over the project analysis period (Cundill and Withnall, 1995).

2.5.3 Comparison of CBA Models

A comparison of HDM-4 version 2, COBA, URECA and TUBA models can be achieved as shown in Table 2-3. Seven points have been used to compare the four programmes: the developing company, year of first usage, who used such a model, type of trip matrix, road type, the ability to deal with multi criteria analysis and type of transport project that uses such a model. It is important to mention that dTIMS and RTIM models have not been included in Table 2-3 due to the use of these models in New Zealand and some developing country, respectively.

Table 2- 3: Comparison of CBA Models

	HDM-4 Version 2	**COBA**	**URECA**	**TUBA**
Developed by	World Bank	DfT	DfT	DfT
First use	2005	1970s	1988	2001
Used by	Government, consultants, agencies and different studies	UK government	UK government	UK government
Type of trip matrix	FTM	FTM	FTM	FTM or VTM
Road type	Any type of road	Urban trunk and all major interurban roads in England and Wales	Urban roads	Trunk roads
Multi criteria analysis	Can deal with	Cannot deal with	Cannot deal with	Cannot deal with
Type of transport project	Road projects	Road projects	Road projects	Single- or multi-mode transport projects
Limitations	- Used FTM only -Can be used for road projects only	-Cannot deal with multi criteria -Limited number of users (UK government only)	-Cannot deal with multi criteria - Limited number of users (UK government only) -Used for urban roads only	-Cannot deal with multi criteria -Limited number of users (UK government only) -Used for trunk roads only

As a result from the above comparison, it was felt appropriate to use HDM-4 to calculate the primary impacts of road development due to its capability to analyse any type of road projects and also due to its popularity worldwide.

2.6 Summary

An extensive review of the literature concerning the primary and secondary impacts from road development projects and their measurements has been performed. Such a literature review revealed that:

1- The secondary impacts from a project can be measured by EIA models in terms of increasing the value of the land and changing its usage. There is a difference between these two concepts because changes in the land use can give an estimation of the traffic volume that would use the road network after road development; while changes in land values cannot give any estimation about traffic volume forecasting. Thus, the reason behind using the existing two approaches to study the impacts of road development on the affected land is demonstrated. These studies can be divided into those conducted by economists that concentrated on the changes in the values of the adjacent property; and those conducted by transportation planners which concentrated on the changes in land use.

2- The problems with the models conducted from these two approaches, mentioned above, are that they are developed for urban roads only. To this end, it was felt appropriate to develop a model capable of describing the changes in land values as a function of key parameters such as time and space.

3- On the other hand, such a road development would generate traffic due to a decrease in travel time and travel costs (Levkovich et al., 2015; Parkinson, 1981). Up to six months into the second year of road development, all the generated traffic is diverted traffic; while from the second half of year two onwards, all the generated traffic is due to induced traffic (Litman and Colman, 2001).

4- Faulty estimation of generated traffic would overestimate the calculation of benefits resulting from road development, lead to the wrong ranking for a project's options and a wrong decision as a result.

5- Reviewing the programs that can be used for economic analysis of a road project confirmed that HDM-4 has a special capability to assess the primary effects of road investment (Litman, 2017c). Using such a tool, a number of investment options may be compared subsequently and ranked in terms of their costs and associated benefits but care should be given to some important rules relating to both costs' and benefits' estimation for a road development project (Robinson, 2008; WMO, 2007). These rules are related to money inflation and double counting of both costs and benefits.

6- Finally, it was felt appropriate to establish whether CBA and EIA demonstrate similar quantifying impacts or have similar trends. In addition, it is necessary to clarify whether the conventional CBA captures all quantifiable benefits, but this comparison task is complex.

CHAPTER THREE
METHODOLOGY

3.1 Introduction

The overall aim of this research is to make a comparison between the primary effects of a road development project and the secondary effects of changes in land values, with a view to examine whether they may follow similar trends and as a result, provide a more comprehensive appraisal tool for road investments.

After the completion of the road works, the values of lands increase as a result of increasing accessibility and decreasing RUCs. The rate of their changes decreases with time. These transportation benefits of CLV as an impact from road development have largely been ignored. This is due to the argument that impacts on land values over the long-term i.e. 30 years are already combined with RUCSs (Litman and Colman, 2001) and are merely transformations of transport benefits. (Martínez and Araya, 2000) concluded that, in order to evaluate a transportation project, appraisers should use transportation-land-use models, which take into account the combined impact of transport on land use and vice versa.

The impacts of changes in the transportation infrastructure on the value of adjacent property have been a significant issue for urban economists; however, their developed models have focused mainly on the impacts of urban roads on property values, especially residential or commercial property value. These models were regression models which give the price of a property depending on its attractiveness, i.e. the number of rooms, the number of bathrooms, the distance to the CBD, the distance to the nearest road. In other words, the variables used in such models may be used for a changes in land values' model. In addition, the developed models have focused on the impacts from different road investment, i.e. the impacts of urban road expansion or road extension projects.

For the models that have been developed by transportation planners, these models have attempted to describe the relationship between transportation investments and changes in land use in urban regions (Iacono et al., 2008). As a result, all the models developed by the two approaches chiefly have concerned urban roads.

To address this gap, this study seeks to integrate the above two approaches by producing a model capable of calculating the changes in land values as an impact of inter-urban road development and link it with the output of conventional road project appraisal models. The proposed model may ultimately benefit all parties involved in, or affected by, road projects; including land-owners, engineers, economists and decision makers working to make the best choice between a project’s options.

Such a model would then enable a comparison to be made between the CLVs and the benefits obtained from generated traffic over the project period of analysis. These benefits can be calculated using an appropriate analytical tool. However, care should be exercised so that there will be no double counting in such a holistic approach. The overall approach of this process is shown in Figure 3-1.

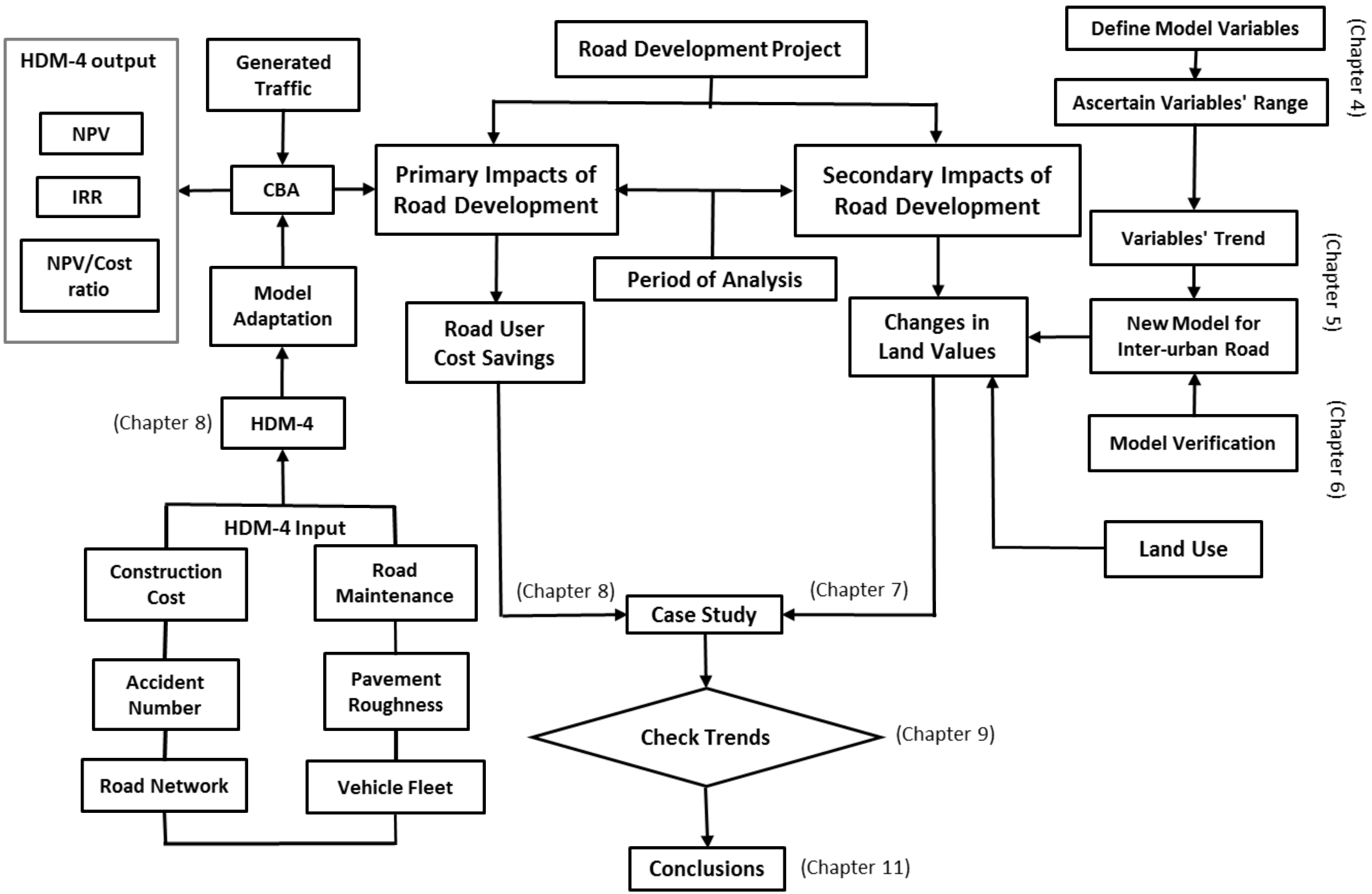


Figure 3- 1: Proposed Outline of the Methodology for this Study

The research methodology shown in Figure 3-1 broadly consists of comparing two parts. The first part focuses on modelling the economic impacts of an inter-urban road development, with regard to the CLVs. As a consequence, it was felt necessary to choose independent parameters for the model that could reflect better the road transport characteristics of an inter-urban road. In addition, it was important to specify the maximum and minimum numbers for each parameter chosen. To this end and after proposing the theoretical model, such a model should be verified to evaluate its predictability using real data of land values obtained from the Zoopla website.

The second part of this study consists of calculating the changes in the primary effects of an inter-urban road development, such as the benefits from generated traffic RUCSs derived from such a project. These benefits will be calculated using an appropriate analytical tool: such as HDM-4, due to the capability of this software to conduct the economic analysis of road investment and especially the conventional CBA over a long term of up to 50 years.

There are two main innovations resulting from this study: (a) a model calculating percent changes in land values (PCLV) as an impact of inter-urban road development; and (b) a comparison between the CLVs and the RUCSs.

To this end, this chapter is structured as follows: an outline of the primary effects of a road development project; HDM-4, its ability and limitation; and an overview about the issues associated with generated traffic is also given. Then, a description of the secondary effects of a road development project and in particular, the CLVs is presented. Finally, this chapter deals with the project analysis period.

3.2 Primary Effects of Road Development Project

In general, the primary effects of a road development project concern solving congestion problems and decreasing travel time and number of accidents, which in turn decreases the cost for road users. Each road development project has some options and different criteria associated with each option; these may be included in the appraisal process to ascertain the viability of the options. These primary effects may be calculated using an appropriate analytical tool which has the capability to conduct CBA and compare and rank the project's options in terms of their costs and associated benefits (Robinson, 2008; Mackie, 2010). Although there are different types of CBA (see Appendix B), they are all dependent on the calculation of costs needed to implement the project (Robinson, 2008) and to maintain the road network, and the benefits derived from such a project for all road users and non-users (TRB, 2010).

There are two types of costs (Aswathy et al., 2013): road agency costs (RACs) and road user costs (RUCs). The RACs include the capital costs of road development and the recurrent costs of maintaining the road. The RUCs are the summation of vehicle operation costs, travel time costs and accident costs. For each year in the project analysis period, any saving in these mentioned costs associated with the difference between a do-something case and a do-nothing case (base case) may be considered as a benefit from such a project option.

The comparison between each project's option (do something case) with the base case is dependent on the costs needed for this project option and the benefits derived from such an option. Therefore, the project's options should be ranked depending on the net benefits resulting from these options; and then the optimum option should be chosen i.e. the option with the maximum net benefit.

3.2.1 Highway Development and Management (HDM-4)

HDM-4 was developed by the World Bank (Kerali et al., 2006; Ko et al., 2016) and has the ability to investigate the economic value derived from a project's options. This ability is due to its inclusion formulae to calculate costs and benefits under different road conditions (Litman, 2017c). There are three types of CBA models embedded in HDM-4: (a) net present value (NPV); (b) internal rate of return (IRR); and (c) NPV/cost ratio. Although the same project's option may be achieved using the three models, the result can be presented in different ways (Garber and Hoel, 2009). The HDM-4 can be considered as a most advanced tool to complete the requirements of this study. In spite of that, HDM-4 uses the FTM assumption (Mackie et al., 2005), which means it uses the same matrix for origin and destination in both a do-nothing case and a do-something case. The FTM has historically, always been used in economic appraisals, due to its simplification of reality while giving an acceptable approximation for road schemes (COBA 9 Manual, 1993a cited in Mackie, 1996). However, an important conclusion reached by Mackie's study, which has been accepted by the UK Department for Transport, stated that a VTM is required for the appraisal of major roads; this requires the use of a different matrix for origin and destination in both a do-nothing case and a do-something case. Consequently, using a programme that depends on a VTM may provide more accurate results than the HDM-4. However, this problem has been overcome in this study.

3.2.2 Generated Traffic

Generated traffic can be classified from the perspective of traffic associated with the project and that associated within the entire multi-modal transport system as shown in Table 3-1.

Table 3- 1: Traffic Classification by Behavioural Response (Mackie et al., 2005)

<table>
<tr><th rowspan="2">Behavioural response</th><th colspan="2">Classification from the perspective of</th></tr>
<tr><th>Traffic associated with the project</th><th>Traffic within the entire multi-modal transport system</th></tr>
<tr><td>No change in behaviour</td><td>Base load/ traffic</td><td rowspan="6">Normal load/ traffic</td></tr>
<tr><td>Route change (same origin and destination after route change)</td><td>Re-assigned or diverted traffic</td></tr>
<tr><td>Mode change</td><td rowspan="5">Induced traffic</td></tr>
<tr><td>Destination change</td></tr>
<tr><td>Time of travel change</td></tr>
<tr><td>Trip frequency increase</td><td rowspan="2">Generated traffic</td></tr>
<tr><td>Generated or new (e.g. from different land use patterns)</td></tr>
</table>

In this study, only the traffic associated with the project, which includes base traffic, diverted traffic and induced traffic, has been taken into account. Different percentages of generated traffic, diverted traffic and induced traffic have been adopted in recent studies, as shown in Table 3-2. These differences are due to the amount of saving in transport costs derived from the road development.

Table 3- 2: Percentages of Generated Traffic from Different Studies (Rodier et al., 2001; Litman, 2017a)

Author	Short-term	Long-term (3+ years)
Wood (1994)		50-100%
Goodwin (1996)	28%	57%
Johnson and Ceerla (1996)		60-90%
Hansen and Huang (1997)		90%
Fulton, et al. (2000)	10-40%	50-80%
Marshall (2000)		76-85%
Noland (2001)	20-50%	70-100%

In this study and to obtain the diverted traffic and induced traffic, average percentages of generated traffic for both diverted traffic and induced traffic shown in Table 3-2 have been used to obtain the RUCS of the generated traffic.

Benefits derived from generated traffic are approximately half the benefit per trip of that obtained by the original road user (Small, 1998), as illustrated in eq. (3.1) (Robinson, 2008):

$$\boldsymbol{Benefit} = 0.5\,(\boldsymbol{P_1} - \boldsymbol{P_2})(\boldsymbol{V_2} - \boldsymbol{V_1}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where:

$\boldsymbol{P_1 - P_2}$ =	*Difference in cost of trip*
$\boldsymbol{V_2 - V_1}$ =	*Difference in volume of traffic*

Eq. (3.1) has been adopted in this study to calculate the benefits obtained from generated traffic, which may be used later in the comparison with the proposed model of changes in land values.

3.3 Secondary Effects of a Road Development Project

The primary impacts of road development projects lead to a number of secondary impacts which can be divided mainly into social, economic and environmental impacts (Garber and Hoel, 2009; Litman, 2016a).

The changes in the economic activities of the affected area by the road project may include an increase in the value of the land, a change in the use of the land, an increase of industrial and agricultural outputs, the creation of jobs and an increase in individual incomes (TRB, 2010; Kockelman et al., 2002; Lavee, 2015; Chang, 2006; Angel et al., 2011; Bertaud, 2012). These impacts are the results from different factors; such as changes in transport price, changes in people's behaviour that develop business, increased tourism activity, increased market connectivity, induced development of land and increases in the attraction and expansion in the affected areas (TRB, 2010).

Historically, the growing and development of cities is related to transportation investments (Muller, 2004). This development spreads outwards as the transportation facility decreases the time needed for the journeys and increases their speed (Janelle, 2004).

3.3.1 Changes in Land Values

The concept of the value of land is in practice associated with the market price of the land, which, in turn, is associated with the use of the land (Litman, 2016a). The use of land is in turn affected by policies and different types of activity: such as economic, social and environmental (FAO, 2007; Litman, 2016a).

Lands served by a transportation project may become more attractive than other areas and more valuable than previously (Kockelman, 1997; Mikelbank, 2004; Kockelman et al., 2002; Giuliano, 1989; Huang, 1994). As a result, the transportation infrastructure may be considered to be the main factor that spurs on the development of land (Chandra and Thompson, 2000; Kockelman et al., 2002; Damm et al., 1980; Huang, 1994; Landis et al., 1995), because it increases the economic activities on the land that result in raising its value and may change its usage (Banister and Thurstain-Goodwin, 2005; Bertaud, 2012; Levkovich et al., 2015).

The changes in land use and land value may generate additional traffic, which increases the traffic volumes in the transportation facilities (Wegener, 2004; Moore and Thorsnes, 1994; Sanchez, 2004). As a consequence, the relationship between road development and change

in land use is considered to be a two-way relationship (Kockelman et al., 2002; Chang, 2006; Mackett, 1993) and has received much attention in recent years (Banister and Thurstain-Goodwin, 2005; Huang, 1994; Landis et al., 1995; Levkovich et al., 2016), as shown in Figure 3-2.

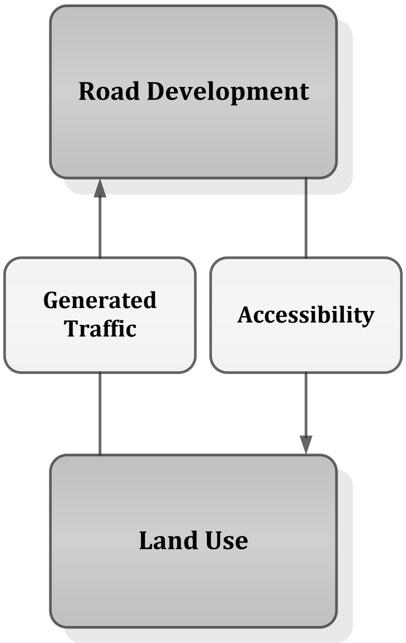


Figure 3- 2: Simplification of the Road Development-Land Use Relationship

A two-way relationship means that the road development project would increase the accessibility to the adjacent land, which would decrease travel times and costs for road users; this in turn would increase the economic activities in these regions, causing a change in the land use and then a change in the value of such land. This could generate more traffic, leading to an increase in the traffic volume on the transport system (Iacono et al., 2008).

It may be seen from reviewing the literature that there is no model that can explicitly address the impacts from inter-urban roads. In addition, there is a need to choose suitable parameters for the model that could reflect better the road transport characteristics of inter-urban roads

and use these parameters to develop a model capable of describing the CLVs. This study will therefore seek to address this issue by identifying the most widely used and representative parameters of the task in hand, assess their suitability and range using data from the literature and ultimately identify a model capable of quantifying the CLVs as an impact of a road development project.

3.4 Project Analysis Period

The primary and secondary impacts of an inter-urban road project will be analysed long term, starting from the completion of the road works onwards. The primary impacts represented by the benefits derived from generated traffic will be obtained using HDM-4, which has the ability to conduct an economic evaluation of the project's options for up to 50 years, starting from the beginning of the road works. For secondary impacts, which are represented by the changes in land values, an EIA model such as the PCLV model, will be utilized in this study to analyse the project's economic impacts for the long term (for up to 30 years) starting from the beginning of the road works. A 30 year has chosen to examine the similarities in the trends of the road users' benefits and the CLVs. This period is within the allowable limit of service life for road infrastructure reported by Odoki et al. (2012).

3.5 Summary

This chapter presented a methodology to compare the primary impacts of an inter-urban road development project with secondary impacts resulted from such a project over the project analysis period. The primary impacts represented by the RUCS obtained from the generated traffic, which will be calculated using an appropriate analytical tool, i.e. HDM-4, and the secondary impacts represented by the CLVs. To achieve this, it is important to develop a model capable of calculating the CLVs as an impact of inter-urban road development.

The proposed methodology is expected to provide a better understanding for the comparison of the primary effects of an inter-urban road development and one of its secondary economic impacts for long term analysis period. In addition, this study seems to be important to trigger further research on the CLV as an impact of such a project.

CHAPTER FOUR
MODEL DEVELOPMENT

4.1 Introduction

To estimate the secondary impacts of road development on CLVs, a new statistical model should be developed to capture these changes for inter-urban roads as all the recent studies of the change in land value mainly concerned urban roads and focused on one type of land use.

The model building process may be summarized in four major steps: choosing the model form, selecting and testing the data, producing the model, verifying the model prediction ability (Montgomery and Peck, 1992).

In this chapter, the first section gives an overview of the form that will be used in this study to model the changes in the values of lands affected by road development. The second section describes the process of choosing the independent variables for the proposed model. The third section outlines the range of each chosen variable intended to be used to produce the model. The fourth section deals with the data used to produce the model; and the statistical test considered for selecting the sample size needed for generating the data used for producing the CLV model. Model verification is presented in the consequent chapter.

4.2 Model Form

Selecting a model form that fits the data is the first step of the model development process. Models developed in recent studies were used to determine the impact of road investment on property values, especially those of residential or commercial use. Regression models were used extensively in these studies to represent the phenomena in question. Such models may be based on multiple regression analysis (ordinary least square), which is a statistical method focusing on the relationship between the dependent and independent variable(s) (Kennedy and Neville, 1986; Allison, 1999). Despite the number of statistical methods, introduced in the last 30 years which achieved similar goals to that obtained by regression analysis; the latter proved its simplicity and popularity due to ease of understanding and use (Allison, 1999). In addition, multiple regression analysis proved its usefulness for modelling prediction purposes because it is designed to make the least percentage of error (Allison, 1999).

To this end, this study seeks to develop a model of CLVs using multiple regression analysis. Step-wise multiple regression models will be used to fit the data to the required level of accuracy and to determine these CLVs as a secondary impact of an inter-urban road development.

To produce the model in question, it was felt appropriate to review the literature to choose both the independent variables and determine the likely maximum and minimum values for each chosen variable; in addition to the maximum and minimum value of the dependent variable, which is the CLVs.

4.3 Choosing the Independent Variables

The second step of the model development process is to choose appropriate independent variables and use them to produce a model capable of capturing the CLVs as a secondary impact of an inter-urban road development.

Models from the literature associate the value of land with its market price; which, in turn, is connected to the use of the land. Subsequently, this study will use the market price of the land as a proxy for its overall value. As a consequence, it was felt necessary to choose independent parameters for the model that could reflect better the road transport characteristics of inter-urban roads. Different studies, which concerned land value, such as Sanchez (2004); Siethoff and Kockelman (2002); Kockelman et al. (2002); Neelawala et al. (2010); Chernobai et al. (2011) were considered in order to obtain the common variables used in most of these studies as shown in Table 4-1.

Table 4- 1: Dependent Variables and Common and Uncommon Independent Variables Used in Recent Studies

	Project	**Dependent Variables**	**Independent Variables**									
			Common variables					**Non-common variables**				
			Area	**Distance from road**	**Time after project completion**	**Land use**	**Age of building**	**Total no. of rooms in property**	**Distance to nearest highway /city centre**	**Population growth rate**	**City population**	**Distance to CBD**
Chernobai et al. (2011)	Highway extension	House value (price)	√	√	√		√	√				
Siethoff and Kockelman (2002)	Roadway capacity expansion	Improvement value (price)	√	√	√	√	√					
		Land value (price)	√	√	√							
		Total value (price)	√	√	√	√	√					
Sanchez (2004)	Increase in highway capacity	Land use change (%)		√	√	√			√	√	√	
Kockelman et al. (2002)	Highway capacity expansion	Improvement value (price)	√	√	√	√	√					
		Land value (price)	√	√	√							
		Total value (price)	√	√	√	√	√					
Neelawala et al. (2010)	Widening of existing road corridors	Property value (price)	√	√	√		√	√				√

*UGB: Urban Growth Boundary

In Table 4-1, the project, the dependent variable and the independent variables used in the studies have been reported. The independent variables have been divided into common variables and non-common variables. The common variables were the area, the distance from road, the time after project completion, the land use and the age of the building; while the non-common variables were the total number of rooms in the property, the distance to the nearest highway, the distance to the city centre, the population growth rate, the city population and the distance to the CBD.

It is important to mention that the model forms that were used in some of the recent studies have not been reported; only the variables used, their ranges and trends were presented. As a result, the statistical model forms that were used in these studies have not been included in Table 4-1. From the common variables, the age of the building was not used in this study as one of the independent variables, as the age of the infrastructure was felt to be included in the variable of the time after road works completion. As a result, only four independent variables from the five common variables shown in Table 4-1 were chosen to be used in this study. These variables are the distance from the road, time after project completion, land use and land area; while the dependent variable is the PCLV representing growth or shrinkage.

4.4 Variables' Range

To build the model of CLV, data for the chosen variables was needed but this data was not available in the short period of analysis. Therefore, proxy data, which is artificial data but representative of actual conditions was used instead. Thus, it was important to review the maximum and minimum values for each variable chosen in Table 4.1, plus the relationship of each independent variable with the dependent variable should be examined. As a result and based on the literature examined, it was found that the chosen variables could vary as follows:

4.4.1 Percentage of Change in Land Value

Sanchez (2004) determined the urban development in Oregon using a technique of aerial photography, with the aid of a GIS application for three different years (1970, 1980, and 1990). The land was classified as urban when any residential, commercial, or industrial activity was observed in the photographs, or if the land was close to an urban centre. It was found that about 41.6% of land located up to 1.6 km from road projects next to urbanized areas were upgraded to urban use. However, for road projects that were next to the boundaries of urbanized areas the percentage of upgraded land was about 31.4%. The difference in the two mentioned percentages was due to the fact that lands near urbanized areas were closer to the lands that had previously been developed more than the lands near the boundaries of the urbanized area. Another important study was that of Huang (1994) who investigated the literature and concluded from many land use studies that lands located next to transportation projects were developed with a percentage of increase in their values, ranging from 0% to more than 30% above their original price. As this study deals with an inter-urban road and to ensure that the chosen range will cover the ranges mentioned in the above two studies, a range from 0% to 40% was used to produce the model of this study.

4.4.2 Distance

Chernobai et al. (2011) studied land values, using real estate prices, located up to 4.8 km from a highway extension in metropolitan Los Angeles. Also, Sanchez (2004) analysed the land use change for land located up to 3 km from different projects of increasing highway capacity in fifteen cities in Oregon, USA. Siethoff and Kockelman (2002) studied the effect of expanding road capacity on land values, using commercial property prices in Austin, TX, USA. They used the property located within 0.8 km of the road section used in their study.

In the current study and based on the average of the three mentioned studies, a distance of up to 3 km from the access point of an inter-urban road development, with a series of 0.5 km was used to produce the model of CLVs as an impact of such a road development.

4.4.3 Time

Due to the impact of road investments that change the values of the adjacent land with time, it is important to study this impact over a long term period (Chernobai et al., 2011; Mikelbank, 2004; Mikelbank, 2005; Yiu and Wong, 2005; Smersh and Smith, 2000; Siethoff and Kockelman, 2002; Neelawala et al., 2015). Chernobai et al. (2011) studied a time horizon of 11 years centred around the completion of the roadwork project. They found that the effect of road investment on the prices of adjacent houses is non-linear with time and is often changed gradually over time.

Siethoff and Kockelman (2002) analysed the impact of road expansion on the price of land, considering property prices over an 18-year period. Also, Sanchez (2004) examined aerial photography to analyse the relationship between changes in land use and proximity to different highway projects. His analysis covered 20 years, from 1970 to 1990. Despite the positive effect of road investment on the adjacent land values, especially after road works' completion, Siethoff and Kockelman (2002); Mikelbank (2004); Neelawala et al. (2015) confirmed the negative and significant effects of an announcement about road investment and they stated that these negative effects cause a short-term loss (i.e. temporary decrease) in the values of the adjacent property. They also stated that these values increase with the completion of such an investment, due to the disappearance of the negative effects and with an increase in accessibility (Mikelbank, 2004; Siethoff and Kockelman, 2002). As a result, and to assess the impacts of road development on the adjacent lands, an analysis period extending from 3 years before the road works' completion date to 30 years after it was opened for use, was considered in this study, as a series of 1-year intervals.

4.4.4 Land Use

Forkenbrock et al. (2001), Chomitz and Gray (1996) and Siethoff and Kockelman (2002) have reported the significance of studying different land use types, as each type has its associated value. In the UK, average estimations of per-hectare prices for different land uses have been published (Department for Communities and Local Government (DCLG), 2015). These prices are established by the Valuation Office Agency, and provided to the department for communities and local government. The prices from 326 local authorities in (£)/hectare in England were identified. Three different land types have been considered in this study-agricultural, industrial and residential- and their average values are listed in Table 4-2.

Table 4- 2: Average Prices (£) for Each Type of Land Use (DCLG, 2015)

Type	Average price (£/hectare)	Averaged price (£/m^2)
Residential -land use	2,000,000	200
Industrial -land use	482,000	50
Agricultural- land use	21,000	2

The commercial land use was merged with the industrial land use. The same classification was used by Harrison (2006), as can see in Figure C.1 in appendix C. Wightman (2013) gave land values for different land uses across England and he also merged commercial with industrial land use, as shown in Table 4-3. In the current study and on the basis of (DCLG, 2015) price estimations, the three different types of land use shown above have been used to give the produced model the ability to calculate the PCLV for different land uses.

Table 4- 3: Land Values for Different Land Uses across England (after Wightman, 2013)

	Hectares	£ per ha land value	Total land value £
Business Property	86,895	3,280,453	£285,055,000,000
Residential	715,284	2,047,760	£1,464,729,766,246
Agricultural	8,925,000	10,000	£89,250,000,000
Woodland	1,295,000	1,000	£89,250,000,000
Inland water	343,620	0	£0
Urban greenspace	106,550	0	£0
Other greenspace	1,247,612	1,000	£1,247,612,000
Infrastructure	327,237	0	£0
Other	185,173	1,000	£185,172,921
England	13,232,271		£1,841,762,551,167

4.4.5 Land Area

Different studies have noted the importance of including land area in the studies dealing with land value, such as Chernobai et al. (2011), Sanchez (1993), Sanchez (2004) and Siethoff and Kockelman (2002). The models developed in their studies were used to determine the impacts of road investment on the values of properties of residential or commercial use. They did not provide a range for the land area, they used the actual property areas in the models they developed. As a result, a range of 10-80 hectares was assumed as reasonable to be used in this study to cover the range of land areas that are adjacent to an inter-urban road (Bittner and Sofer, 2013).

The chosen variables and their maximum and minimum values are shown in Figure 4-1.

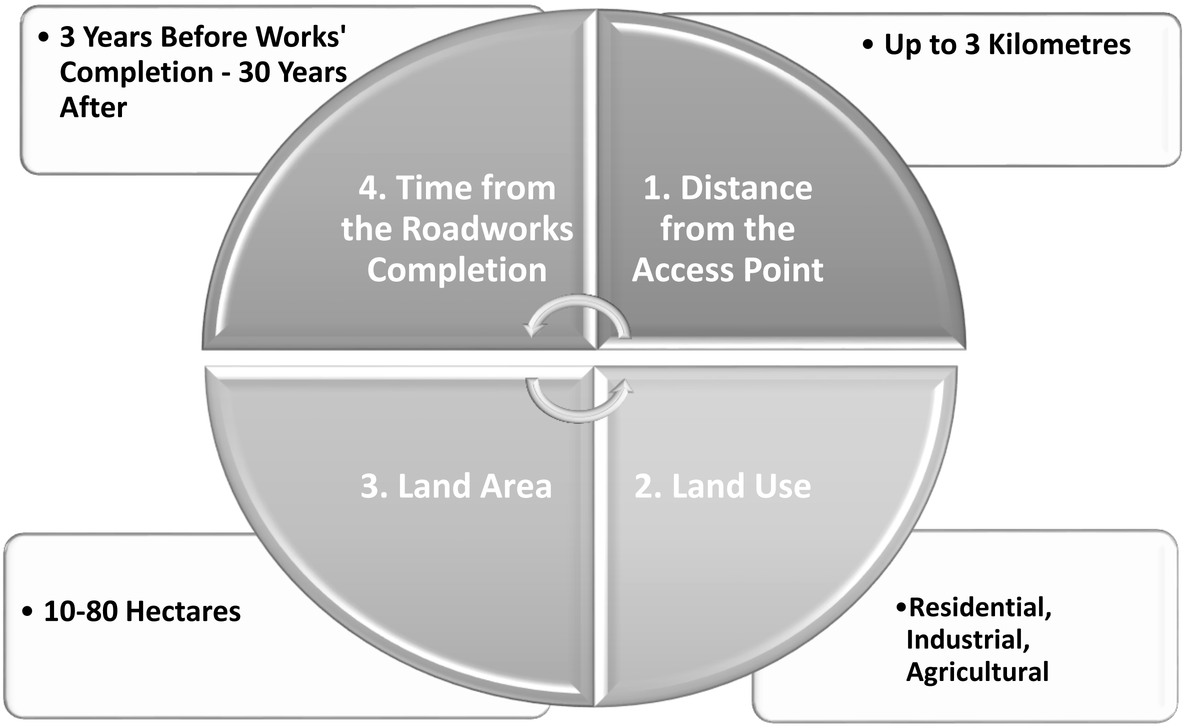


Figure 4- 1: The Independent Variables Chosen as Common Variables in the Literature Models and their Chosen Maximum and Minimum Values

4.5 Data Used

To build the model of change in land value in the absence of real data, a set of artificial data was established for the parameters chosen, based on their expected minimum and maximum number. The artificial data were obtained using a random number generator (RNG) method, which has been used in various scientific applications such as computer science, statistical work, psychological research and computational methods (Park and Miller, 1988; Wagenaar, 1972). The RNG method provided by MS Excel was used in the current study to generate representative data for the proposed model. The chosen distribution of the data was normal distribution (Gaussian distribution), which is a continuous probability distribution (Casella and Berger, 2001). Despite the popularity of normal distribution to characterize the variation of the data in question, Limpert and Stahel (2011) reviewed the literature and

highlighted the poor description of the data that resulted from using such a distribution in some examples; which in turn resulted in wrong conclusions due to the skewness of the data. To solve this problem, it is important to test the generated data for skewness (Razali and Wah, 2011), the allowable limit for skewness should be less than 0.98 (Noor et al., 2014); analyse the error for the produced model; and assess the goodness of fit for the developed model, as shown in Chapter 5. However, before generating the data, it is important to determine the sample size needed for data to generate, which may be achieved using the statistical test of sample size selection.

4.5.1 Sample Size Selection

Sample size selection is the process of choosing the number of samples needed to produce the model. In general, the selection of sample size depends on the degree of precision needed to produce the model i.e. percentage of error of the mean. This percentage should be less than 5%, which means the size of the sample is sufficiently large to produce the model. The percentage error can be calculated using Equation (4.1) (Kennedy and Neville, 1986):

$$Error = CoV \times t / n^{0.5} \quad \text{.................................} (4.1)$$

Where:

CoV	=	*Coefficient of variation (= standard deviation/mean)*
t	=	*t-statistics*
n	=	*Sample size*

As stated in Equation 4.1, it is important to determine the mean, the standard deviation, t-statistics and the sample size. Many trials were developed to get the optimum set of data that represent the minimum and maximum values of the variables in question as given by the literature. The percent of error was checked after each iteration as shown in Figure 4-2.

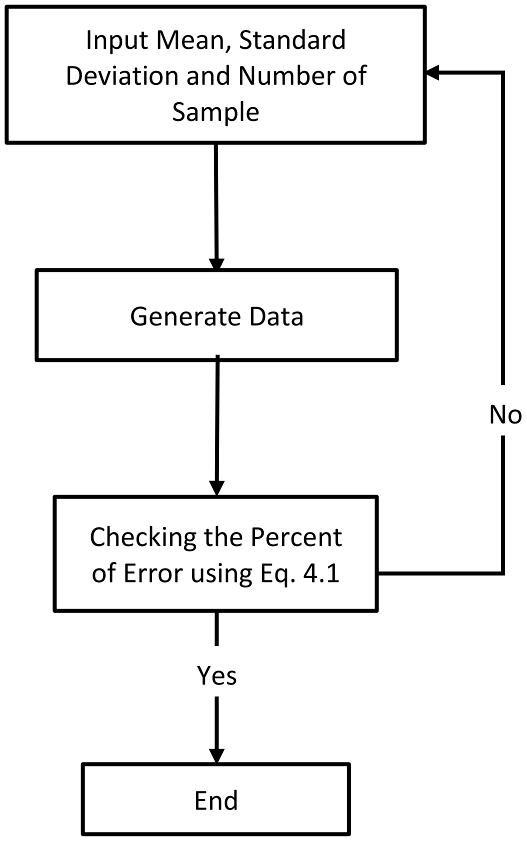


Figure 4- 2: Flow Chart of the Determination for Sample Size

To calculate the percentage of error of the mean (equation 4.1) the value of t-statistics should be obtained. This value can be determined from Table C.1 in Appendix C. To choose this value, the confidence level chosen was 0.95% (Limpert and Stahel, 2011; Cowles and Davis, 1982; Zar, 1984; Allison, 1999). To this end, 500 case numbers were generated in this study. These numbers were sufficient as the percentage error was less than 5%, as can be seen in Table 4-4.

Table 4- 4: Sample Size Calculation

Standard Deviation	6.59
Mean	18.8
CoV	0.35
t-statistics	1.9764
Sample size	500
Error %	3.1

Table 4-4 shows the standard deviation, mean, CoV, t-statistics, sample size and the corresponding percent of error for the data intended for generation using MS Excel. The 500 case numbers of the dependent variable and its corresponding independent variables are shown in Table C.2 in Appendix C. The generated data was tested for skewness and it was equal to 0.043, which is acceptable as it should be less than 0.98 (maximum allowable limit) (Noor et al., 2014).

4.6 Summary

In this chapter, the statistical modelling development process for the changes in land values' model was presented. Step-wise multiple regression models were chosen to be used in this study to model the impacts of inter-urban road development on the adjacent land values. Four independent variables were chosen due to them being common variables in recent studies. These variables are distance from the access point of the new road, time that has elapsed since the completion of the road works, land use and land area. The minimum and maximum value for each independent variable was chosen after reviewing the literature references. For distance from the access point of the road; a range of up to 3 km was chosen;

while for the time variable, the range started from 3 years before the road works' completion to 30 years afterwards. Different land uses such as residential, industrial and agricultural were selected to complete the requirements of this study. In addition, a range of 10-80 hectares was chosen for the land area variable.

The RNG method provided by MS Excel was used in the current study to generate representative data for the changes in land values' model. A statistical test of sample size selection was carried out to choose the number of cases that could be used to produce the model. The selection was dependent on the percentage of error for the mean, which should be less than 5%. As a result from the statistical test of sample size selection (equation 4.1), 500 cases were chosen as the percentage error was equal to 3.1%. The maximum and minimum limits of the dependent and independent variables were obtained from the literature models.

CHAPTER FIVE
STATISTICAL MODEL PREDICTING

5.1 Introduction

This chapter lists the prediction steps of the CLV model. Such a model tends to determine one of the secondary impacts of an inter-urban road development, which is the change in the value of the adjacent land. Two different model forms have been produced in this study: the linear model and the non-linear model.

This chapter is organised in three main sections. The first section outlines the model building form, which in turn is divided into the linear model and the non-linear model. For each model form and to choose the best form to model the CLV, three different analyses have been conducted that include the analysis of error for the produced model, the goodness of fit and the sensitivity analysis. The last section deals with the conclusions obtained from this chapter.

5.2 Model Form

The IBM SPSS V23 package (Rasbash, 2004) was used to build the change in land value model. The linear form was presented firstly due to the general rule in science, which outlines the use of a simpler form when it is unknown which form should be used to produce the model (Allison, 1999). The linear model was in turn followed by a non-linear model.

Sensitivity analysis can be used to test if the model form can represent well the CLVs as an impact of road development, by checking the uncertainty in the model result. In addition, it can be used to determine the separate effect of each independent variable on the dependent variable (i.e. model outcome) (Vu, 2016). Furthermore, it is useful to: test the robustness of the model's outputs; and understand the relationship between the dependent variable, model output and each independent variable, including investigating any unanticipated relationships between them. Reducing the uncertainty in the model output through discovering which input leads to such uncertainty (Pannell, 1997) would be also useful.

To this end, sensitivity analysis is used in this study to choose the best model form by examining: the relationship between the PCLV with each of the independent variables, the distance from the access point, the time from road works' completion, the land use and land area. There are different approaches to achieve sensitivity analysis for models of multiple parameters (Saltelli et al., 2008) that include: linear models, one-at-a-time sampling, limits on the number of influential parameters, fractional factorial sampling, Latin hypercube sampling, multivariate stratified sampling and quasi-random sampling with low-discrepancy. The one variable at a time approach was used in this study due to its simplicity and popularity. The chosen approach involved checking the difference in the PCLV with changing only one variable at a time (Campbell et al., 2008) and then comparing the results with the relationship obtained from the literature. As mentioned in Chapter Two, all the recent studies of the change in land value chiefly concerned urban roads and focused on one type of land use such as residential or industrial; only the relationship between the land values with each distance from the road and the time from the road works' completion have been obtained from the literature as follows:

For the relationship between the distance from the road and the land values, considered in terms of real estate prices, Hushak (1975), Holway and Burby (1990), and Mcmillen and Mcdonald (1991) concluded that such a relationship is negatively linear; but Chernobai et al. (2011) and Sanchez (1993) confirmed a non-linear relationship between the distance from the road project and the land values. In addition, they reported that as the distance from the road project decreases, the values of lands may rise as a result of increasing accessibility and decreasing the travel time and traffic accidents, leading to a decrease in the travel costs for road users. However, close proximity to transportation infrastructure is not always preferred due to the effects of the negative externalities of a road project, such as congestion, noise, vibration and air quality degradation (Nelson, 1982; Hanley et al., 2013; Siethoff and Kockelman, 2002; Levkovich et al., 2015); which may lead to a decline in the values of land (Sanchez, 1993; Boarnet and Chalermpong, 2001; Neelawala et al., 2010). However, increasing the distance from the road project may mean decreasing the value of the land due to inaccessibility.

The preferred trend for the relationship between the time from the road works' completion and the land values, considered in terms of real estate prices was reported by Chernobai et al. (2011). They presented a non-linear relationship between the time from the road works' completion and the land values. When the project is announced and the road construction time period both have significant negative effects and may cause a temporary decline in adjacent land values. Such a decline may disappear as the negative effects disappear (Mikelbank, 2004; Siethoff and Kockelman, 2002). Moreover, Chernobai et al. (2011) reported that after the completion of the road works, the value of lands increases as a result of increasing accessibility and decreasing RUCs.

Thus, the non-linear relationship between the dependent variable, PCLV, with the distance from the road and the time from the road works' completion can be used as a basis for selecting the best model for change in land value as an impact of inter-urban road development.

5.2.1 Linear Model

A linear model was established using step-wise regression analysis, which is an approach that removes the insignificant variables (Nazif et al., 2016) and allows only for the important variables to be included in the regression model. There are two types of step-wise regression analysis, forward selection and backward selection. Both selections may be achieved using a step by step approach (Nazif et al., 2016). In this study, forward selection was used, which includes the addition of one variable in a step and checks the result of including such a variable; it keeps on with this process until the best improvement can be achieved (Thompson, 2001). The linear model is shown in Equation (5.2) (Al-Mumaiz and Evdorides, 2016):

$$\boldsymbol{PCLV} = 11.487 - 2.035\boldsymbol{D} + 3.356\,\boldsymbol{log\,LU} + 0.124\boldsymbol{A} + 0.403\boldsymbol{T} \qquad \text{.................(5.2)}$$

Where:

PCLV	*is the percentage change in land value*
D	*is the distance from the road (0-3 km)*
LU	*is the average land value (£2/m² for agricultural land use; £50/m² for industrial land use; £200/m² for residential land use)*
A	*is the land area (10-80 ha)*
T	*is the time from road works' completion (from 3 years before completion of works (announcement of project) to 30 years after works' completion)*

The output from the linear model is illustrated below. The adjusted R^2 (coefficient of determination) for the produced linear model is equal to 0.841, which means the produced model can predict successfully the actual dependent variable to a degree of 84% (Nagelkerke, 1991; Allison, 1999). Figures 5-1, 5-2, 5-3 and 5-4 illustrate the relationship between the predicted PCLV with regard to each distance from the access point of the road, time from the road works' completion, land area and land use respectively, and the actual PCLV.

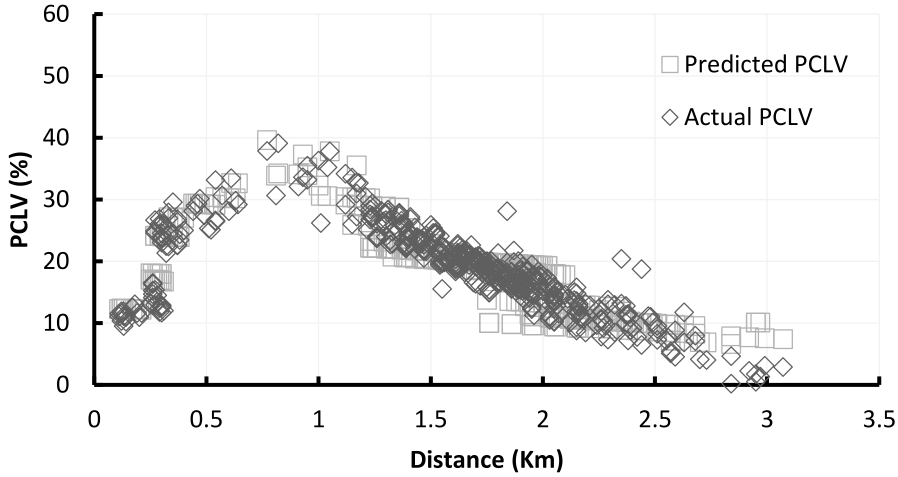


Figure 5- 1: Relationship between PCLV and Distance from the Access Point of the Road (km)

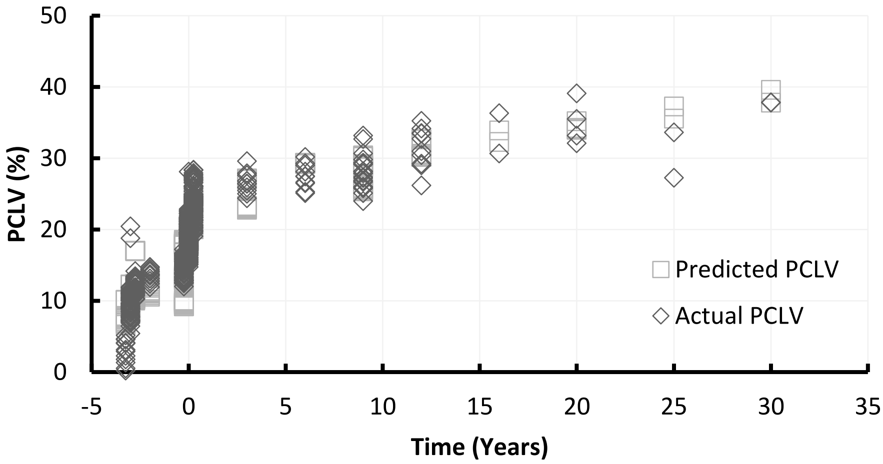


Figure 5- 2: Relationship between PCLV (%) and Time after Road Works' Completion (years)

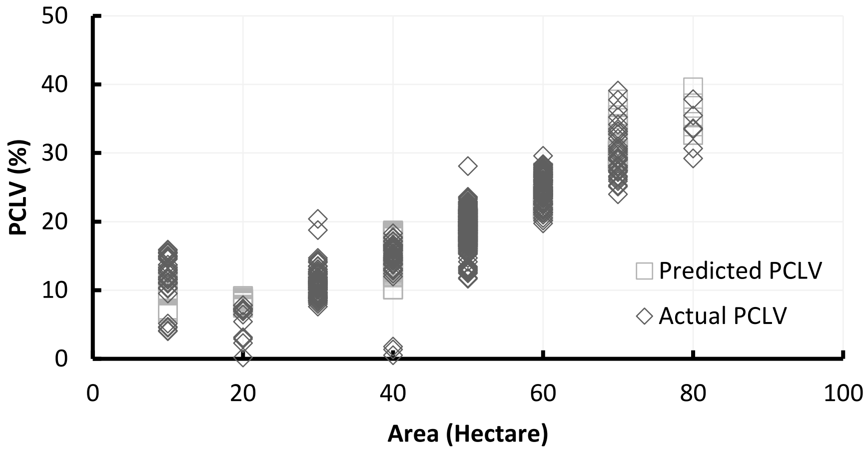


Figure 5- 3: Relationship between PCLV (%) and Land Area (hectare)

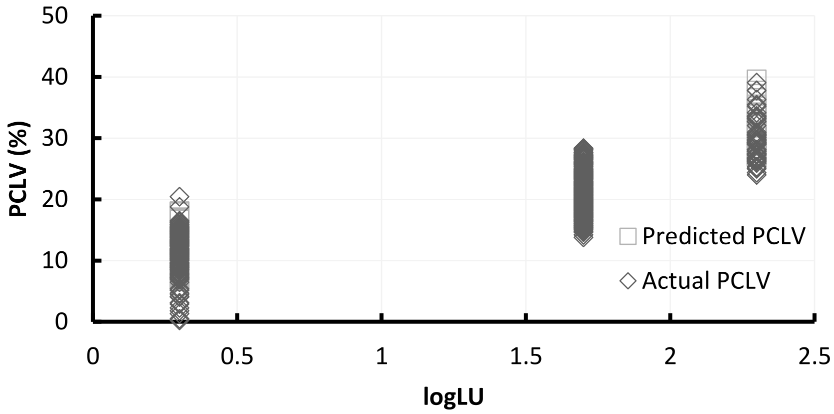


Figure 5- 4: Relationship between PCLV (%) and Land Use

- **Analysis of Error for the Linear Model Produced**

To check the normality assumption, the residuals (ei) from the regression, the result of subtracting the model output value (y_i') from the model input value (y_i) as can be seen in Equation (5.3), should be calculated and their distribution has to be checked if they follow a normal distribution (Allison, 1999). Figure 5-5 shows the frequency distribution of the standardised residual, from the SPSS output.

$$e_i = y_i - y'_i \qquad \text{...} (5.3)$$

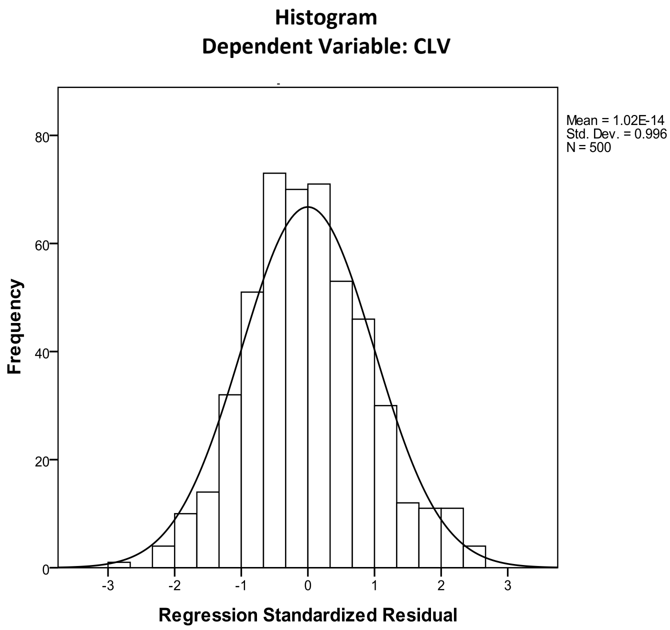


Figure 5- 5: The Histogram for the Residual of the Linear Model, from the SPSS Output.

According to Figure 5-5, the residual from the linear model is normally distributed with the mean equal to zero.

The normal probability plot (P-P) of the regression standardised residual of the predicted model is a kind of representation of the residual which is drawn by the SPSS software. Standardising the residual means that the residual values are scaled to be between (0-1) and then the relation between the (x: observed cum probability) and (y: expected cum probability) is drawn. As much of the residual standardised values are closer to the (45º) line, so the developed model fits the data. The normal probability plot (P-P) of the regression standardised residual of the linear model is shown in Figure 5-6, which reveals that the developed model, in the linear regression form, fits the data used in model building.

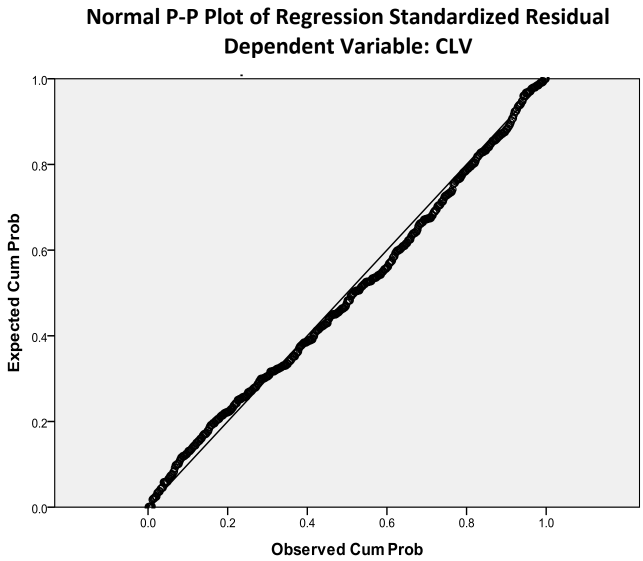


Figure 5- 6: The P-P Plot of the Linear Model, from the SPSS Output

- Assessing the Goodness-of-Fit for the Developed Model

The measurement of the goodness of fit for the developed model is aimed to quantify whether the outcome of such a regression model follows the same probability distribution for the input data (Schermelleh-Engel and Moosbrugger, 2003; Vu, 2016; Hosmer and Lemesshow, 1989; Scheaffer and Mcclave, 1995). The distribution chosen for generating such input data was the normal distribution (Casella and Berger, 2001; Razali and Wah, 2011) as shown in Chapter Four. As a result, the measurement of the goodness of fit is aimed to check the normal distribution for the outcome of the linear model, which is the PCLV.

The widest applicable and most popularity techniques used for assessing the goodness of fit are (Scheaffer and Mcclave, 1995): (1) Chi-square test, which is used for discrete distribution; and (2) the Kolmogorov-Smirnov (K-S) technique that is used for continuous distribution. The Scheaffer and Mcclave (1995) study was used to choose whether the outcome from the linear model (the PCLV) was a continuous distribution or a discrete distribution. The PCLV has been chosen as a continuous distribution due to the range used

for the PCLV being from 0 to 40% and also for the capability to choose any value between such a maximum and minimum limit. To this end, the Kolmogorov-Smirnov (K-S) technique was used in this study to test the goodness of fit for the linear model, as shown in Table 5-1. It is important to mention that all the outcomes of the linear model were used in the Kolmogorov-Smirnov (K-S) test.

Table 5- 1: Kolmogorov-Smirnov (K-S) Test Results for the Linear Model

N		**500**
Normal Parameters[a,b]	Mean	**18.377**
	Std. Deviation	**5.9989**
Most Extreme Differences	Absolute	**.187**
	Positive	**.131**
	Negative	**-.187**
Test Statistic		**.187**
Asymp. Sig. (2-tailed)		**.000[c]**

a. **Test distribution is Normal**.

b. Calculated from data.

c. Lilliefors Significance Correction.

The results shown in Table 5-1 were obtained from SPSS software, which proved that the outcome of the linear model followed a normal distribution.

- Sensitivity Analysis for the Linear Model

The uncertainty in the model result (outcome) is related to the uncertainty in the inputs of the produced model, i.e. the independent variable(s) (Saltelli et al., 2004). Such model uncertainty can be checked using sensitivity analysis. The one at-a-time approach was used in this study; it depended on changing only one independent variable at a time, keeping the other independent variables constant and determining what the effect of this change was on the model output (Campbell et al., 2008). The linear model form was used to obtain the change in the PCLV with the separate change of each of the four independent variables used in this study, which were:

a- Distance from the access point of the road

b- Time from the roadworks' completion

c- Land use

d- Land area

The changes of the independent variables were within the required ranges (maximum and minimum values) that were used for producing the model. The statistics of the input variables used to estimate the changes in the land values' model are summarized in Table 5-2.

Table 5- 2: Summary of the Data Set for Sensitivity Analysis

Variables	Mean	Standard Deviation	Minimum	Maximum
Distance from the access point (km)	1.556	0.648	0.11	3
Time from the roadworks' completion (years)	0.6265	4.315	-3	30
Land use	50.131	53.828	2	200,000
Land area (hectare)	46.62	15.852	10	80

To investigate the influence of the distance variable on the change in land values, different values for distance variables that range from 0.11 km to 3.07 km were used as model inputs to obtain the model outputs. The model results represent the change in land value derived from the change of distance variable as shown in Table 5-3. The relationship between the changes in land value with the change of distance variable is shown in Figure 5-7.

Table 5- 3: The Effect of Distance Variable on the Change in Land Value

Distance (km)	0.2	0.4	0.8	1	1.2	1.4	1.8	2	2.4	2.6	2.8	3
% PCLV	30.73	30.32	29.51	29.1	28.7	28.29	27.48	27.07	26.25	25.85	25.44	25.03

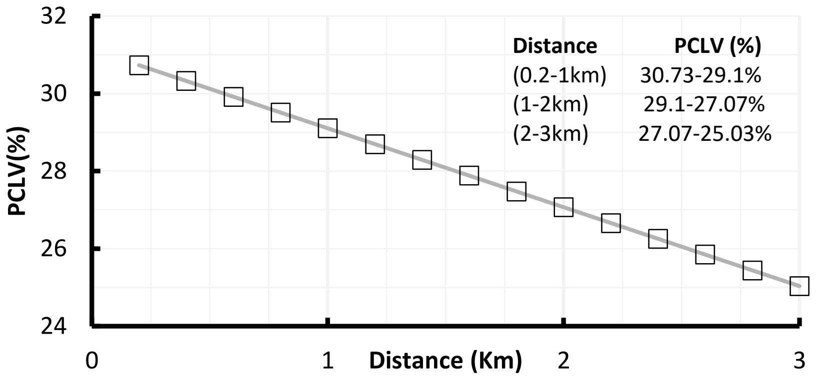


Figure 5- 7: Linear Model Sensitivity Based on Distance Change

It can be seen from Figure 5-7 that the PCLV decreases as the distance from the road increases. Increasing the distance from 0.2 to 1 km resulted in decreasing the PCLV from 30.73 to 29.1%; while increasing the distance from 1 to 2 km resulted in decreasing the PCLV from 29.1 to 27.07% and so on until reaching the maximum distance from the road used in this study, which is equal to 3 km with its associated PCLV equal to 25.03. The problem with this relationship is that Chernobai et al. (2011) and Sanchez (1993) confirmed the non-linear relationship between the distance from the road project and the changes in land values. To this end, it appears that the linear model cannot achieve this non-linear relationship and there is a need to predict another model form that serves to obtain such a relationship.

The effect of the variation in the time variable on the change in the land values is shown in Table 5-4, which gives the results estimated for different time values ranging from -3 years (3 years before road works' completion) to 30 years after works' completion. The relationship between PCLV with the change of time variable is illustrated in Figure 5-8.

Table 5- 4: The Effect of Time Variable on the Change in Land Value

Time (Years)	-3	-2	-1	0	1	2	4	6	8	10	14	20	30
%PCLV	22.85	23.25	23.65	24.06	24.46	24.86	25.67	26.47	27.28	28.09	29.7	32.12	36.15

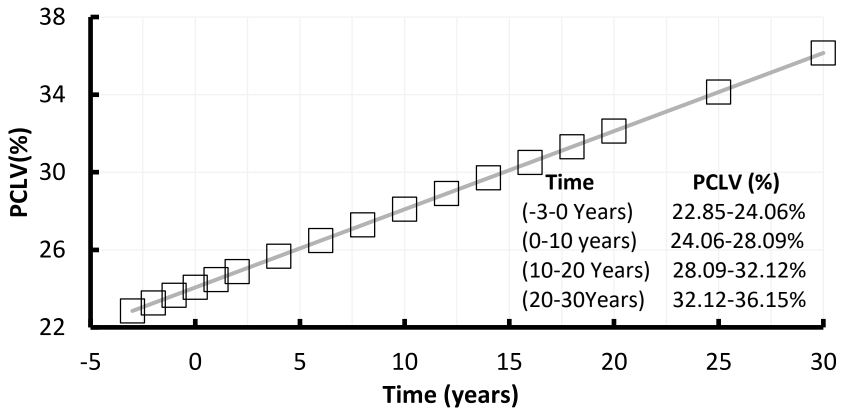


Figure 5- 8: Linear Model sensitivity based on time change

As shown in the results, the PCLV increases as the time from the roadworks' completion increases; which may be explained by the changes in the economy of the affected area, due to the road development, that take time to develop. Increasing the time from 3 years before works' completion to the year of the road opening resulted in decreasing the PCLV from 22.85 to 24.06%; while increasing the time after the road works' completion from 10 to 20 years resulted in decreasing the PCLV from 28.09 to 32.12%. The problem with the relationship between the PCLV and the time variable is that the preferred trend for such a relationship, as reported by Chernobai et al. (2011), was described as non-linear. To this end, it appears that a linear model is incapable of achieving this non-linear relationship and there is a need to predict another model form.

The influence of land area on the change in land value is examined by estimating the change in land value for different values of this variable ranging from 10 hectares to 80 hectares. The estimate results are described in Table 5-5 and Figure 5-9.

Table 5- 5: The Effect of Area Variable on the Change in Land Value

Area (Hectare)	10	20	30	40	50	60	70	80
%PCLV	19.41	20.65	21.89	23.13	24.37	25.61	26.85	28.09

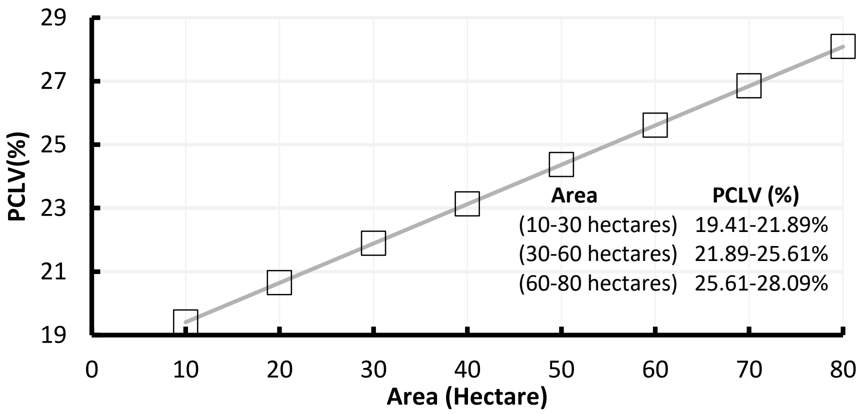


Figure 5- 9: Linear Model Sensitivity Based on Land Area Change

Table 5-5 and Figure 5-9 reveal that increasing the land area from 10 to 30 hectares resulted in increasing the PCLV from 19.41 to 21.89%; while increasing the area from 60 to 80 hectares resulted in increasing the PCLV from 25.61 to 28.09%. Thus, the PCLV increases as the land area also increases.

Table 5-6 and Figure 5-10 reveal the outputs of the PCLV estimated for different values of land use type, ranging from £2/m^2 for agricultural use to £200/m^2 for residential use.

Table 5- 6: The Effect of Land Use Variable on the Change in Land Value

Land use value (£/m^2)	2	50	200
%PCLV	23.39	28.09	30.11

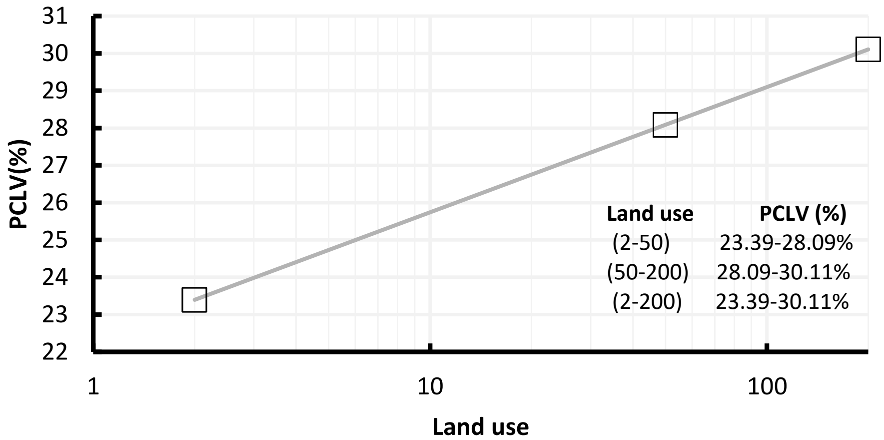


Figure 5- 10: Model Sensitivity Based on Land Use Change

The results illustrate that the change in land value increases with an increase in the value of the land.

As a result from the sensitivity analysis, the preferred relationships between the changes in land values with each distance from the road and time after the roadworks' completion have not been achieved using the linear model. To that end, it is important to predict another model that can achieve these preferred relationships.

- **Conclusion from the Produced Linear Model**

Step-wise regression analysis was used to predict the linear model form. The coefficient of determination, the adjusted R^2, for the linear model was good as it was equal to 0.841. The analysis of error was achieved to test the normality assumption and the results confirmed the normal distribution for the residual of the produced model with the mean equal to zero. In addition, the goodness of fit was achieved to quantify whether the outcome of the linear regression model follows the same probability distribution for the input data; and the result obtained from the Kolmogorov-Smirnov (K-S) test confirmed the normal distribution for the outcome of the linear model.

The sensitivity analysis of the relationship between the dependent variable with each of independent variable, especially time and distance variables, using the linear model, confirmed the need for another model form that can achieve the preferred non-linear relationship between each distance and time variable and the PCLV mentioned in the literature.

5.2.2 Non-linear Model

A non-linear model was established using a step-wise regression approach. The non-linear model is shown in Equation (5.4) (Al-Mumaiz and Evdorides, 2017):

$$\boldsymbol{PCLV} = \frac{\boldsymbol{e}^{2.491} * \boldsymbol{LU}^{0.037} * \boldsymbol{A}^{0.07} * (\boldsymbol{T} + \boldsymbol{\alpha_2})^{0.247}}{(\boldsymbol{D} + \boldsymbol{\alpha_1})^{0.189}} - \boldsymbol{\alpha_1} \qquad \text{……………}(5.4)$$

Where:

α_1=1

α_2=3.3

The other variables are as defined in the linear model.

The output from the non-linear model is illustrated below. The adjusted R^2 (coefficient of determination) was equal to 0.821, which means the produced model can explain 82% successfully from the actual dependent variable (Nagelkerke, 1991). Figures 5-11, 5-12, 5-13 and 5-14 illustrate the relationship between the actual PCLV and the predicted PCLV and each of the distances from the access point of the road, the time from the road works' completion, the land area and the land use, respectively.

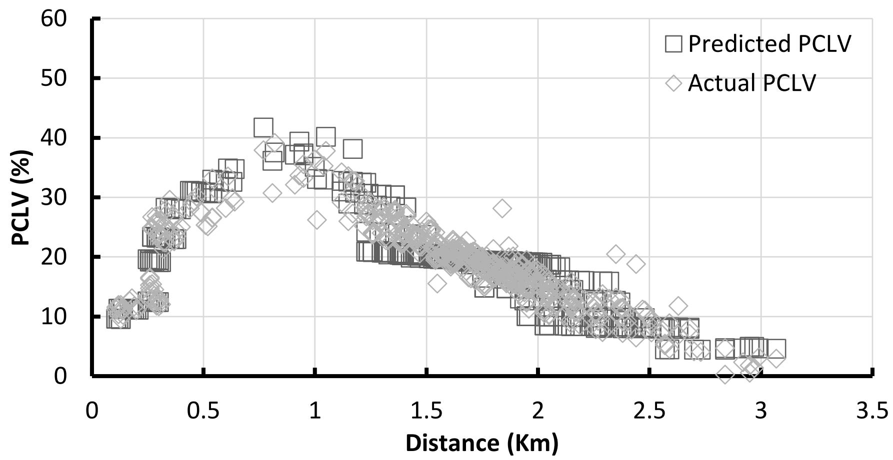


Figure 5- 11: Relationship between PCLV and Distance (km)

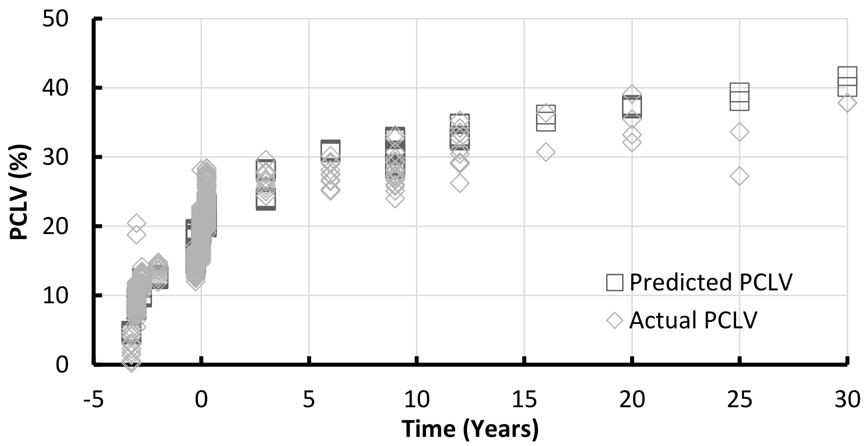


Figure 5- 12: Relationship between PCLV and Time (years)

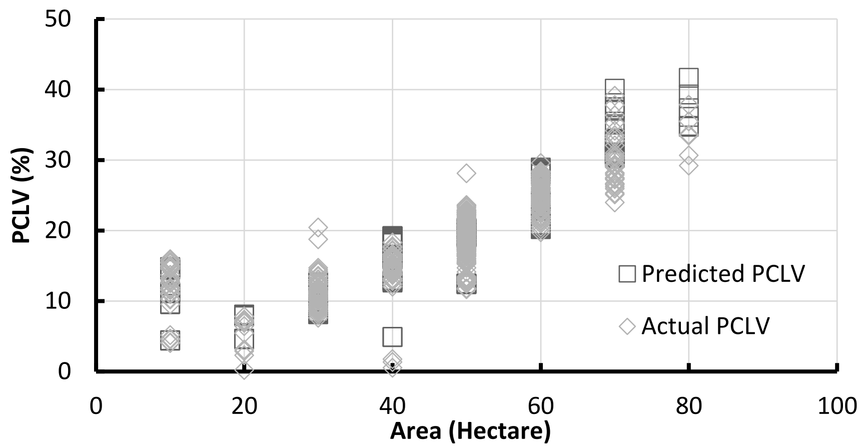


Figure 5- 13: Relationship between PCLV and Land Area (hectare)

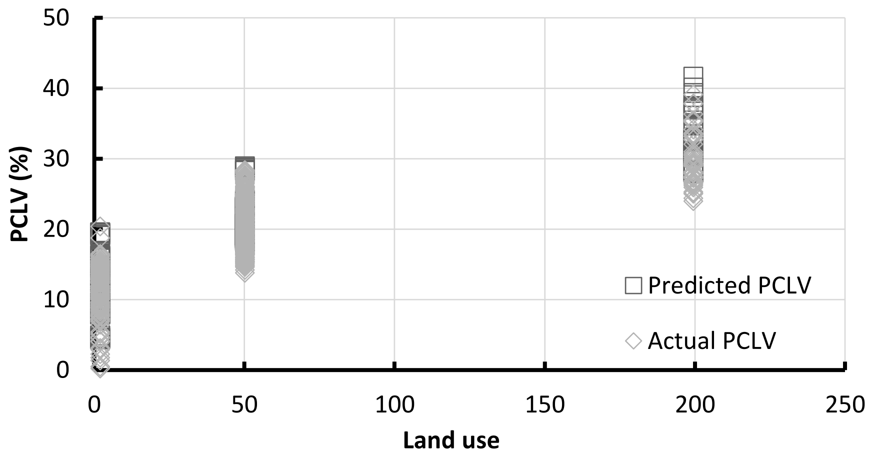


Figure 5- 14: Relationship between PCLV and Land Use

- **Analysis of Error for the Nonlinear Model Produced**

For the non-linear model, the frequency distribution and the normal probability plot (P-P) of the regression standardised residual are shown in Figures 5-15 and 5-16 respectively. The two figures were drawn by the SPSS software.

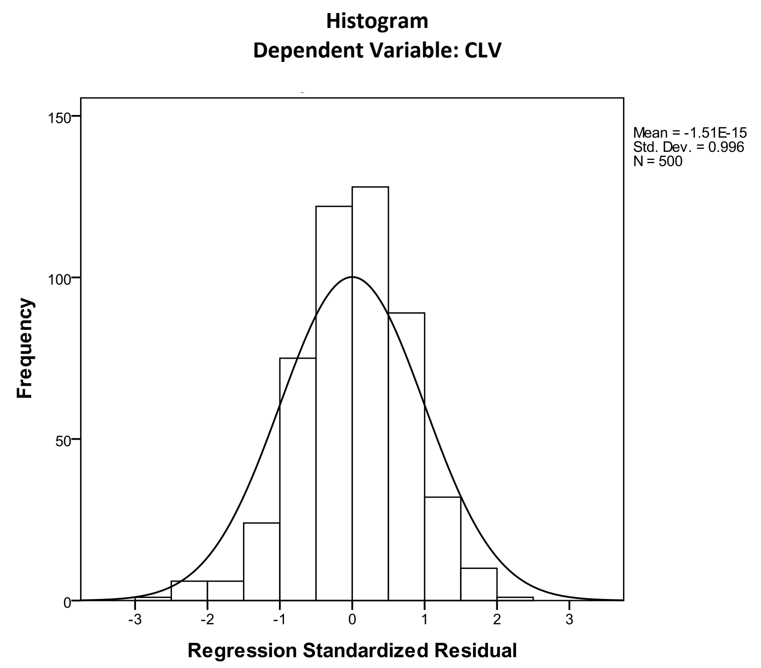


Figure 5- 15: The Histogram for the Residual of the Non-linear Model

According to Figure 5-15, the residual from the non-linear model is normally distributed with the mean equal to zero. The normal probability plot (P-P) of the regression standardised residual for the non-linear model is shown in Figure 5-16, which reveals that the developed model, in a non-linear regression form, fits the data used for model building.

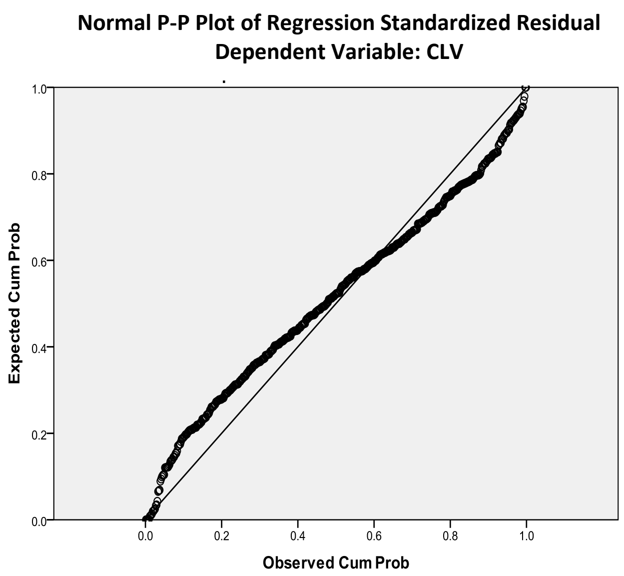


Figure 5- 16: The P-P Plot of the Non-linear Model

- **Assessing the Goodness-of-Fit for the Developed Model**

The measurement of the goodness of fit for the developed non-linear model is aimed to quantify whether the outcome of such a regression model follows the same probability distribution for the input data (Schermelleh-Engel and Moosbrugger, 2003; Vu, 2016); (Hosmer and Lemesshow, 1989; Scheaffer and Mcclave, 1995). In the non-linear model, the same data which was used to produce the linear model was also used to produce the non-linear model, which generated using a normal distribution assumption. As a result, the measurement of the goodness of fit is aimed to check the normal distribution for the outcome of the non-linear model, which is the PCLV.

To this end, the Kolmogorov-Smirnov (K-S) technique was also used in this study to test the goodness of fit for the non-linear model as shown in Table 5-7. It is important to mention that all the outcomes of the non-linear model were used in the Kolmogorov-Smirnov (K-S) test.

Table 5- 7: Kolmogorov-Smirnov (K-S) Test Results for the Non-linear Model

N		**500**
Normal Parameters[a,b]	Mean	**7.2433**
	Std. Deviation	**2.44120**
Most Extreme Differences	Absolute	**.209**
	Positive	**.209**
	Negative	**-.204**
Test Statistic		**.209**
Asymp. Sig. (2-tailed)		**.000[c]**

a. **Test distribution is Normal**.

b. Calculated from data.

c. Lilliefors Significance Correction.

The results shown in Table 5-7 were obtained from SPSS software, which proved that the outcome of the non-linear model followed a normal distribution.

- **Sensitivity Analysis for the Models Produced**

The one at-a-time approach was also used for the non-linear model to obtain the change in the PCLV with the change of each independent variable (Campbell et al., 2008). The change of these independent variables was within the same ranges (upper and lower limits) that were used for producing the model and for the sensitivity analysis of the linear model. The results of the sensitivity analysis for the non-linear model are shown in Figures 5-17, 5-18, 5-19 and 5-20, which display the relationship between the PCLV with the change of each distance from the access point of the road, the time from the road works' completion, the land area and the land use, respectively. To compare the results of the sensitivity analysis achieved by the non-linear model with those obtained using the linear model, Figure 5-17, 5-18, 5-19 and 5-20 also include the results of the sensitivity analysis achieved by the linear model.

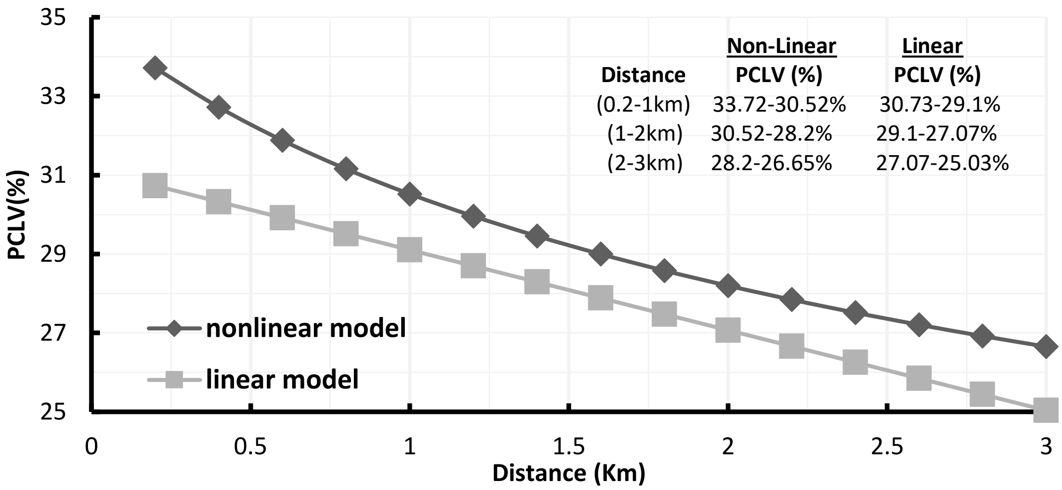


Figure 5- 17: Model Sensitivity Based on Distance Change

Figure 5-17 shows the comparison between the change of PCLV with the change of the distance variable. Changing the distance from the road from 0.2 km to 1 km results in changing the PCLV from 33.72% to 30.52% in the case of the non-linear model; while the

PCLV changed from 30.73% to 29.1% in the case of using the linear model. Changing the distance from the road from 2 km to 3 km resulted in changing PCLV from 28.2% to 26.65% when using the non-linear model; while the PCLV changed from 27.07% to 25.03% when using the linear model. As a result, there are differences in the results obtained from the linear model compared to those obtained from the non-linear model.

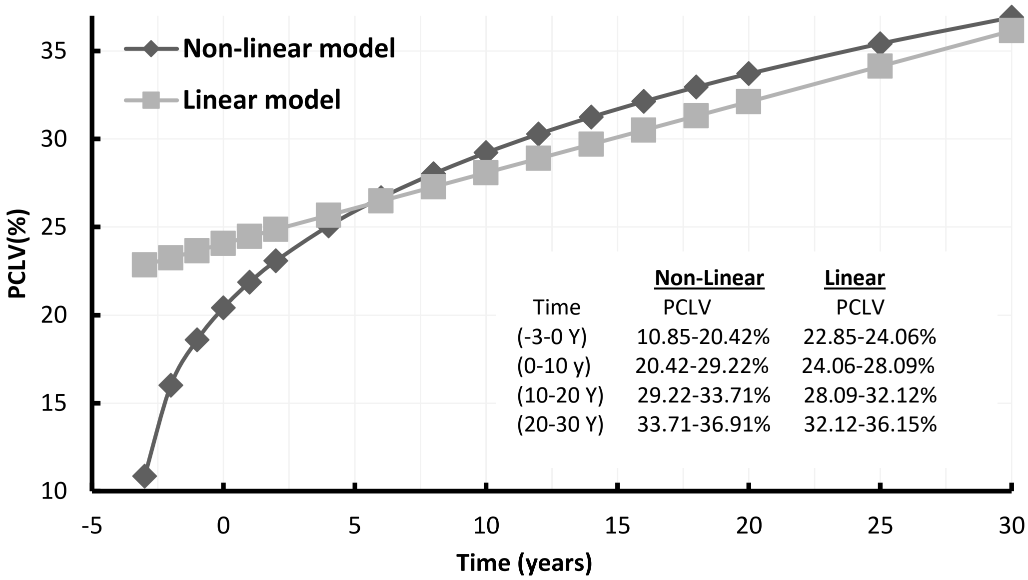


Figure 5- 18: Model Sensitivity Based on Time Change

Figure 5-18 shows the comparison between the change of the PCLV with the change of time variable from 3 years before the road works' completion to 30 years after by using both the linear and the non-linear model. It is clear from this figure that the linear model gave a higher PCLV up to 5 years after the works' completion and then the PCLV obtained by the two model forms became closer to each other; but the PCLV obtained from the non-linear model was higher than that obtained by the linear by about 2% for each year.

Changing the time variable from 3 years before the works' completion (the time of announcement about the project) to year zero (the time of the works' completion) resulted in changing the PCLV from 10.85% to 20.42% in the case of the non-linear model; while the PCLV changed from 22.85% to 24.06% in the case of the linear model. Changing the time variable from 10 years after the roadworks' completion to 20 years after the works' completion resulted in changing the PCLV from 29.22% to 33.71% in the case of the non-linear model; while the PCLV changed from 28.09% to 32.12% in the case of the linear model.

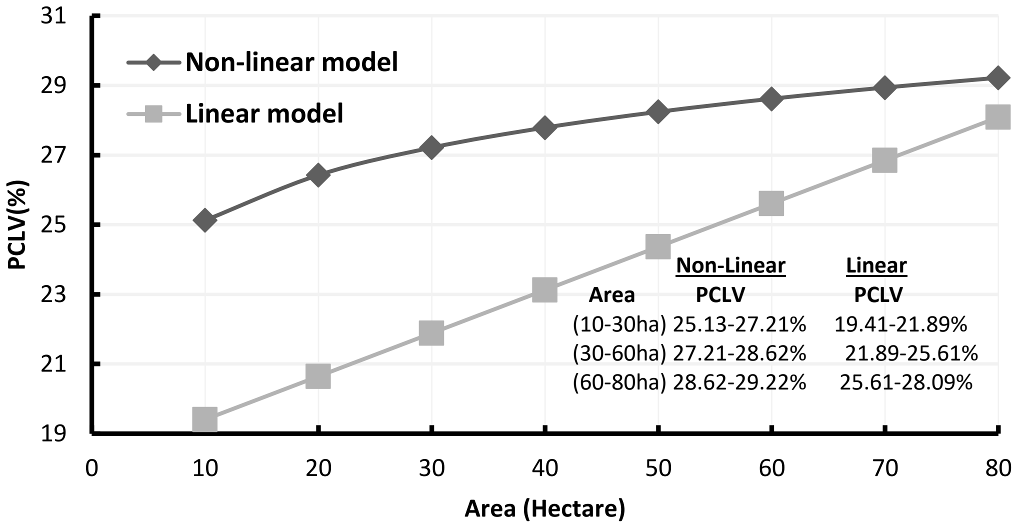


Figure 5- 19: Model Sensitivity Based on Land Area Change

Figure 5-19 shows the comparison between the change of the PCLV with the change of the land area variable by using the linear and non-linear models. Changing the land area from 10 hectares to 30 hectares resulted in changing the PCLV from 25.13% to 27.21% in the case of the non-linear model; while the PCLV changed from 19.41% to 21.89% in the case of the linear model. Changing the land area value from 60 to 80 hectares resulted in changing the PCLV from 28.62% to 29.22% in the case of the non-linear model; while the PCLV changed from 25.61% to 28.09% in the case of the linear model.

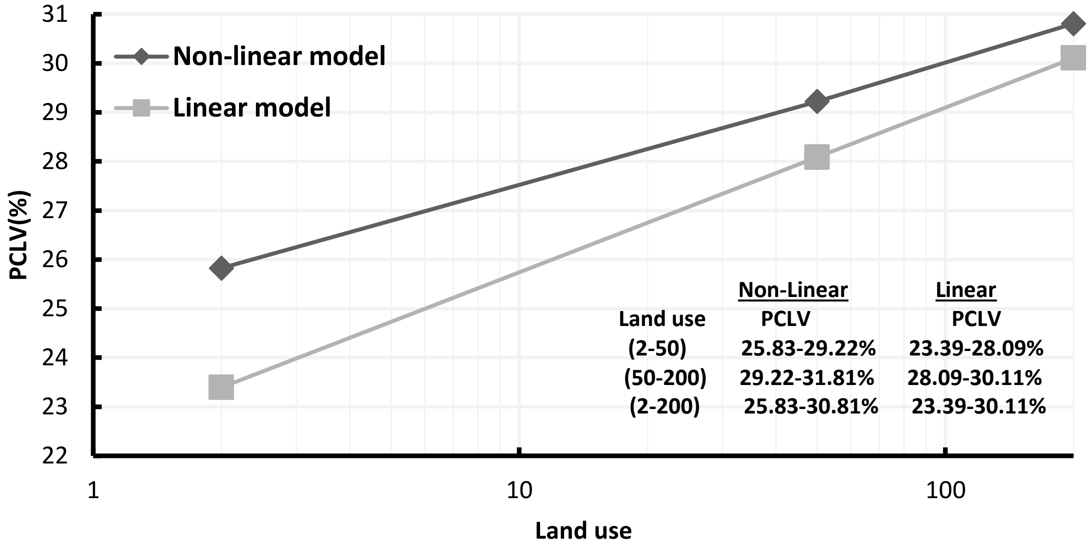


Figure 5- 20: Model Sensitivity Based on Land Use Change

Figure 5-20 shows the comparison between the change of the PCLV with the change of the land use variable by using the linear and non-linear models. Changing the value of land use from £2/m^2 to £50/m^2 resulted in changing the PCLV from 25.83% to 29.22% in the case of the non-linear model; while the PCLV changed from 23.39% to 28.09% in the case of the linear model. In addition, changing the value of land use from £50/m^2 to £200/m^2 hectares resulted in changing the PCLV from 29.22% to 31.81% in the case of the non-linear model; while the PCLV changed from 28.09% to 30.11% in the case of the linear model.

5.3 Conclusion

A linear model was predicted from using the representative data for the change in land value to relate the PCLV with the four independent variables. The R^2 for the linear model was equal to 84%, which means the produced model can predict 84% successfully from the actual dependent variable (Nagelkerke, 1991).

The independent variables of the produced model were used in a sensitivity analysis to investigate the effect of these variables on the output of changes in the land values' model. The obtained results confirmed the need for another model, as the relationship between the changes in land values and these variables did not give the trends reported in the literature. Another model form was predicted, which was the non-linear model related to the PCLV with the same independent variables used in the linear model. The R^2 for the non-linear model was equal to 82%. The results from using the non-linear model in the sensitivity analysis showed more reasonable trends than those obtained from using the linear model. Analyses of error were carried out for both linear and non-linear models and good results were obtained from the two analyses.

To this end, a comparison between the linear and non-linear models concluded that: (a) the results of R^2 for the linear and non-linear models were close to each other; (b) the same result of the goodness of fit for the two models was obtained; and (c) the same result of the analysis of error was obtained for the two models.

The non-linear model was chosen to model the changes in the values of land affected by the inter-urban road project due to the results of the sensitivity analyses for the non-linear model were consistent with the results mentioned in the literature than those obtained from the linear model.

CHAPTER SIX
MODEL VERIFICATION

6.1 Introduction

This chapter outlines the process of verifying the developed non-linear model. The purpose of the model verification is to evaluate the prediction ability of the developed model using real data.

To this end, this chapter is organized into two sections. The first section presents the verification task for the proposed model; while the second section outlines the conclusion obtained from the model verification.

6.2 Verification Test for the Developed Model

The purpose of this test is to evaluate the accuracy of the produced model to estimate the changes in land values as secondary impacts of an inter-urban road development. Land in the United Kingdom adjacent to the M65 motorway (between junctions 1 and 2) was used to complete this task; the choice of this location was based on the following requirements:

1- Construction of a new road.
2- Prices for lands adjacent to the motorway could be found on the internet (Zoopla, 2017).
3- Adjacent land was accessible.

The Chris's British Road Directory (CBRD) website (Cbrd, 2016) was used to help select this section of the M65 as this website provides a chronology map for motorways constructed in England and gives the user the ability to search for road sections that were built in a specific year. Such a motorway has been defined by the SABRE website as a "motorway link from Preston and M6 to Blackburn and Burnley, ending at Colne" (Sabre,

2017). The chosen section of motorway M65 is located in the North West of England near Preston city, to the south of Walton Summit Centre and to the north of Clayton Green. Figure 6-1 shows the part of the M65 motorway (between J1 and J2) that was used to verify the non-linear model.

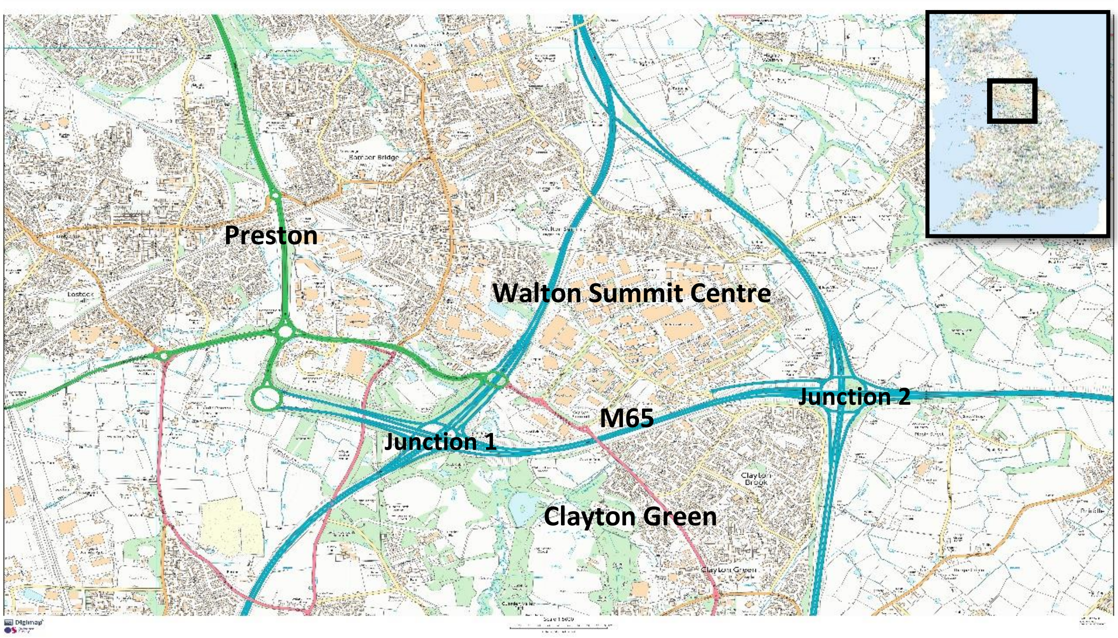
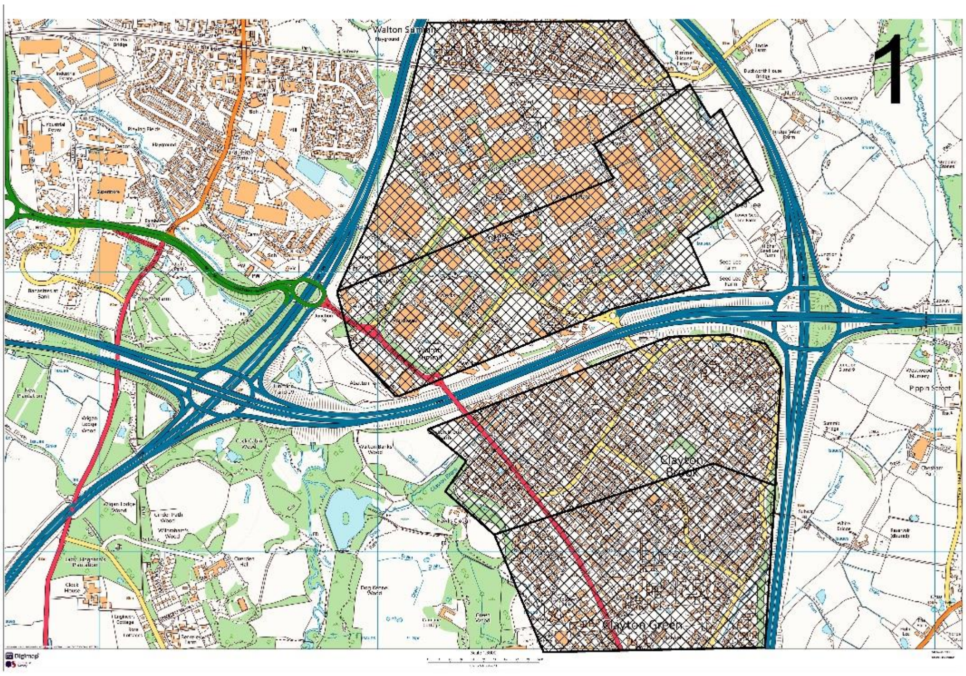


Figure 6- 1: M65 Motorway (between junction 1 and 2) According to UK Map (© Crown copyright and database rights [2017] OS (Digimap Licence))

6.2.1 Methodology

The study area, land adjacent to the M65 motorway (between J1 and 2) contains two different land uses: industrial (Walton Summit Centre, which is land to the north of the chosen motorway section); and residential (Clayton Green, located to the south of the chosen motorway section). Prices for up to 20 years for land adjacent to the M65 motorway obtained from the Zoopla website (Zoopla, 2017) were used to compare with the estimations of changes in land prices obtained from the application of the developed non-linear model. Due to the effect of the distance and area variables on the model application outcomes, the study

area was subdivided into three different ways to identify the effect of area subdivision and its corresponding distance on the results of the model. Figure 6-2 shows the three subdivisions for the case study.



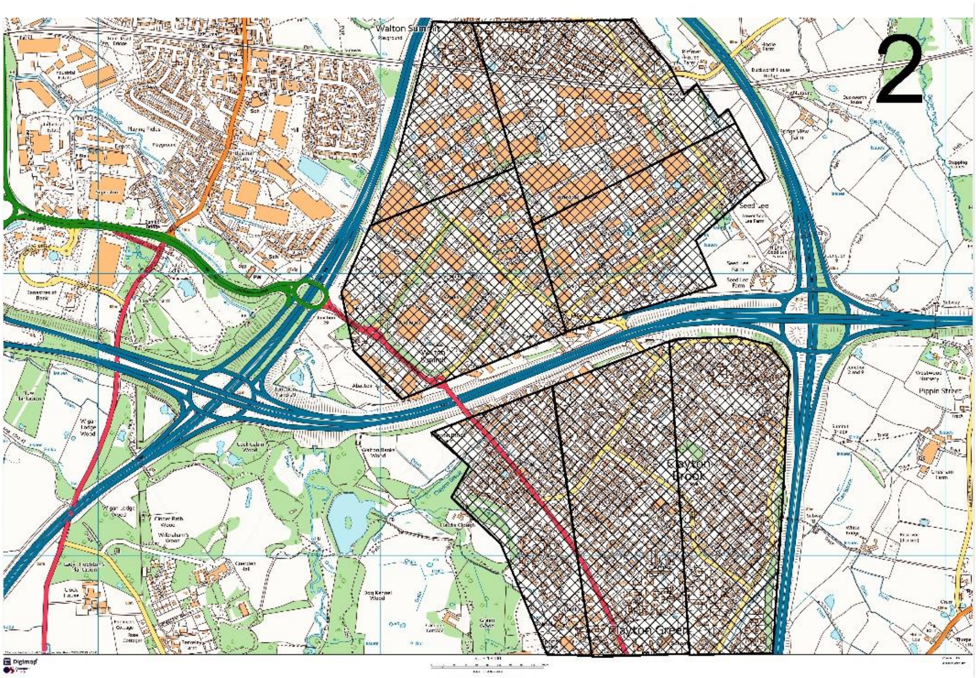


Figure 6- 2: Subdivisions for Area Adjacent to M65 (© Crown copyright and database rights [2017] OS (Digimap Licence)) (continued on next page)

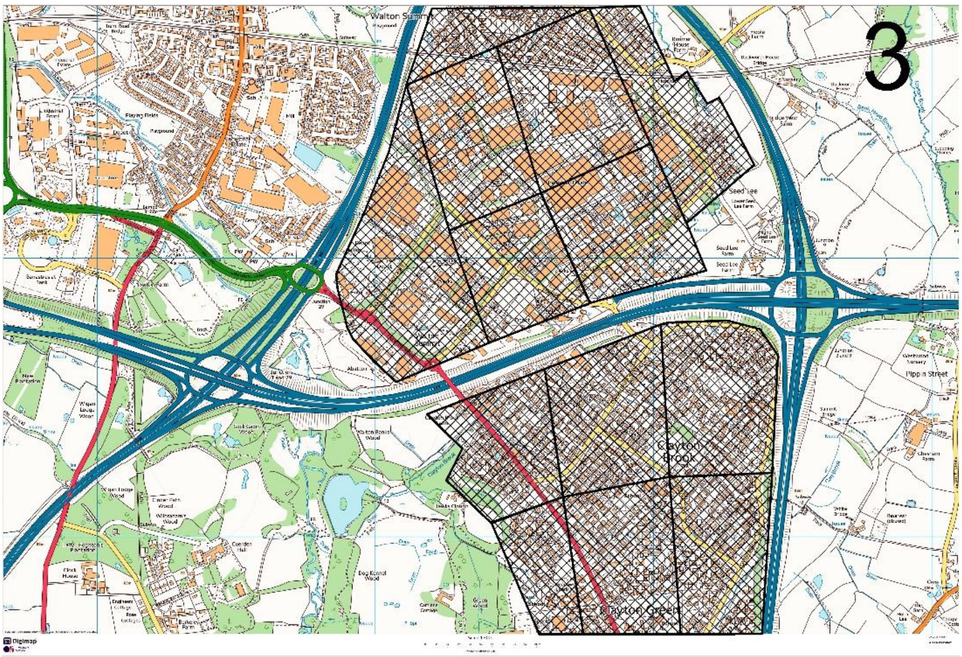


Figure 6-2: continued

The areas for each subdivision were calculated using GIS and the centroid of each area was specified in the same way. Their distances from the new road were obtained by using either the straight-line distance or the network distance (i.e. the distance from the actual horizontal alignment) (Dziauddin, 2009). In the current study, the straight-line distance was used and was measured from the centroid of the selected area to the nearest access point (Kockelman et al., 2002; Sanchez, 1993). The non-linear model was applied to each subdivision and so three PCLV results were produced for each year. The average of the three results was calculated and then compared with the historical PCLV for that year.

6.2.2 Data Description

Data pertinent to land adjacent to the M65 motorway (between Junctions 1 and 2) were used to verify the non-linear model. Historical real estate prices were gathered for the area under study (Zoopla, 2017). The GIS Arc Map version 10.2 was used to measure distances, calculate areas and other spatial data needed for the model application. Maps for the case study were obtained from Bing maps and Digimap.

6.2.3 Results and Discussion

- **PCLVs calculated from the historical land values**

The historical land values for the Walton Summit Centre, land located to the north of the chosen motorway section, were obtained from the Zoopla website (Zoopla, 2017). These historical land prices may be seen in Table 6-1, which shows the PCLVs after the road project was completed.

Table 6- 1: Historical Values and PCLVs for the Walton Summit Centre

Year	Average price paid (£)	PCLV: %
1997 (road works were completed)	114218	
2007	148866	30.34
2012	149091	30.53
2016	157648	38.00
2017	160911	40.88

Table 6-1 shows the outputs of the PCLV obtained for different years after road works' completion. The PCLV are equal to 30.34, 30.53, 38.00 and 40.88% for the years 2007, 2012, 2016 and 2017, respectively.

The historical land values for Clayton Green, residential land use located to the south of the chosen motorway section, may be seen in Table 6-2. These land values and PCLVs were obtained from the Zoopla website (Zoopla, 2017) for the same range of years obtained for the Walton Summit Centre.

Table 6- 2: Historical Land Values and PCLVs for Clayton Green

Year	Average price paid (£)	PCLV: %
1997 (road project was completed)	129734	
2007	174477	34.49
2012	179029	37.997
2016	189824	46.318
2017	182467	40.647

The average PCLV of the two sites (i.e. Walton Summit Centre and Clayton Green) are shown in Table 6-3. The results reveal that the PCLV is equal to 32.42% for 2007 (i.e. 10 years after road opening) and equal to 34.26% for 2012 (i.e. 15 years after road opening). The PCLV are equal to 42.16% and 40.76% for 2016 and 2017, respectively.

Table 6- 3: Average PCLV of Walton Summit Centre and Clayton Green

Year	PCLV: %
2007 (10 years after road opening)	32.42
2012 (15 years after road opening)	34.26
2016 (19 years after road opening)	42.16
2017 (20 years after road opening)	40.76

- PCLVs calculated from the non-linear model

The non-linear model was applied to each sub-area, three PCLV values were produced for each year. The average of the three results was calculated and shown in Tables 6-4, 6-5 and 6-6 for the Walton Summit Centre, Clayton Green and the overall average for both areas, respectively.

Table 6- 4: PCLVs for the Walton Summit Centre from the Model Application

Year (after road opening)	PCLV of Area Subdivision 1	PCLV of Area Subdivision 2	PCLV of Area Subdivision 3	Average PCLV:%
2007	31.24	28.72	29.96	29.97
2012	33.9	31.17	32.52	32.53
2016	35.66	32.8	34.2	34.22
2017	36.1	33.17	34.6	34.62

Table 6-4 reveals the outputs of PCLVs obtained from the model application for different years ranging from 2007 to 2017. For each year, three PCLVs were obtained; one for each area subdivision. The overall average of the three PCLVs was calculated and the results illustrate that the PCLV increases with time after the completion of road works. After 10 years of works' completion in; 2007, the average PCLV for lands in the Walton Summit Centre was 29.97%. In 2012, 15 years after works' completion, the average PCLV was 32.53%; while the PCLVs for 2016 and 2017 were equal to 34.22 and 34.62%, respectively.

Table 6-5 shows the PCLVs of Clayton Green, calculated by the non-linear model. The results reveal that the PCLV is equal to 31.43% in 2007 and equal to 33.7% in 2012; while the PCLVs are equal to 35.2% and 35.55% for 2016 and 2017, respectively.

Table 6- 5: PCLVs for Clayton Green from the Model Application

Year (after road opening)	PCLV of Area Subdivision 1	PCLV of Area Subdivision 2	PCLV of Area Subdivision 3	Average PCLV:%
2007	31.99	30.57	31.72	31.43
2012	33.48	33.19	34.42	33.7
2016	34.48	34.91	36.21	35.2
2017	34.72	35.3	36.62	35.55

The average PCLVs of the two sites are shown in Table 6-6. The results reveal that the PCLV is equal to 30.7% in 2007 and increased to 33.11, 34.71 and 35.09% in the years 2012, 2016 and 2017, respectively.

Table 6- 6: Average PCLV of the Walton Summit Centre and Clayton Green

Year (after road opening)	PCLV of Area Subdivision 1	PCLV of Area Subdivision 2	PCLV of Area Subdivision 3	Average PCLV: %
2007	31.62	29.65	30.84	30.7
2012	33.69	32.18	33.47	33.11
2016	35.07	33.86	35.21	34.71
2017	35.41	34.24	35.61	35.09

- Comparison between historical PCLVs and PCLVs calculated from the developed model

A comparison between the historical PCLVs and the PCLVs calculated from the nonlinear model for Walton Summit Centre may be seen in Figure 6-3. Good results were obtained as the correlation coefficient between the historical PCLVs and computed PCLVs for the Walton Summit Centre was found to be 0·87.

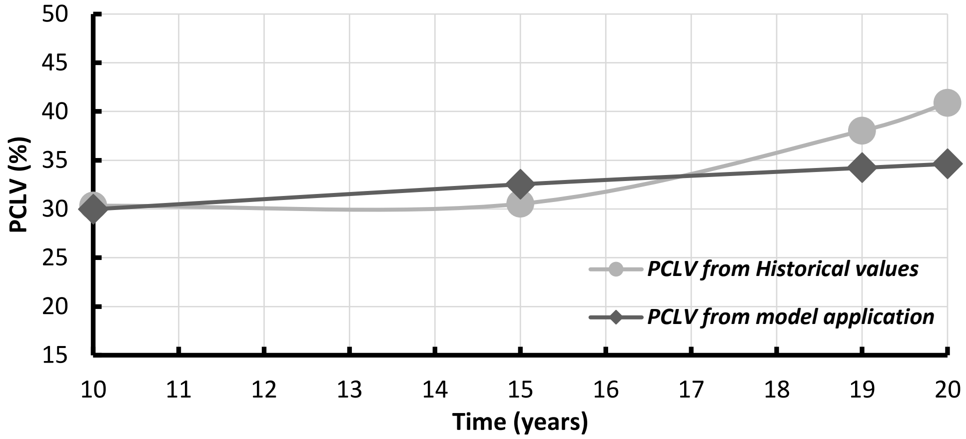


Figure 6- 3: Comparison between the PCLV Obtained from Historical Value and the PCLV Obtained from the Model for the Walton Summit Centre

Figure 6-4 shows the comparison between the historical PCLVs and the PCLVs calculated from the non-linear model for the Clayton Green. Good results were also obtained as the correlation coefficient between the historical PCLVs and computed PCLVs was found to be 0·83.

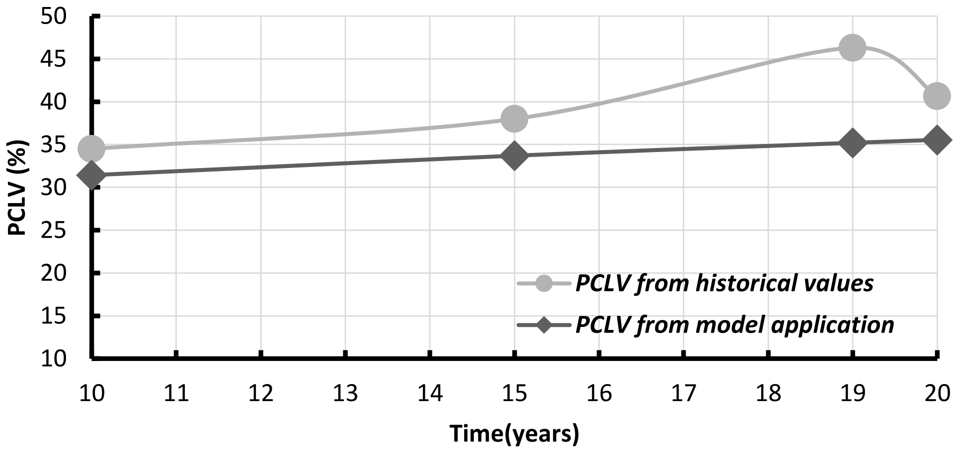


Figure 6- 4: Comparison between the PCLV Obtained from Historical Value and the PCLV Obtained from the Model for Clayton Green.

The comparison between historical PCLVs and the PCLVs obtained from the model application can be seen in Figure 6-5. The correlation coefficient between the historical PCLVs and computed PCLVs was found to be 0·92.

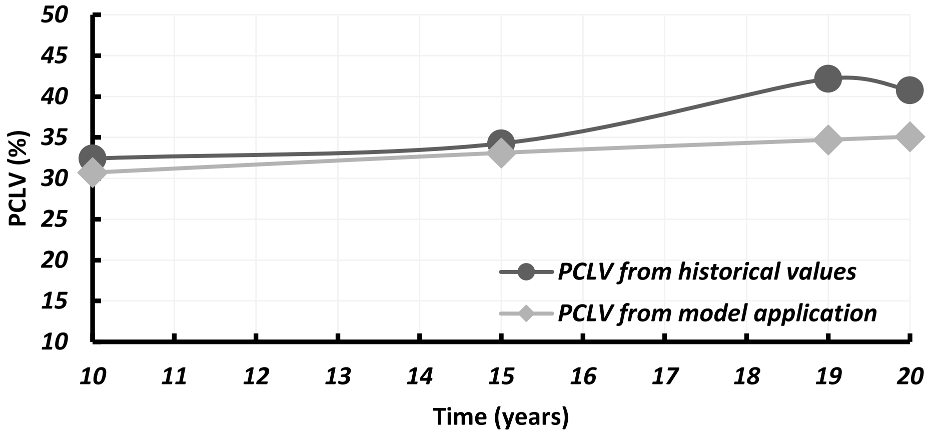


Figure 6- 5: The PCLV over Time, Averaged for the Two Sites, Obtained from Both Historical Values and Model Estimation Values

The correlation coefficient for the Walton Summit Centre is greater than that obtained for Clayton Green. The reason may be due to external effects that caused a temporary increase in real estate prices, especially for year 19, as shown in Figure 6-4. It is important to mention that this model has the ability to estimate the change in land prices that occurs as an impact from road projects, but the historical land prices provided by Zoopla (2017) may be affected by many external factors, such as increasing the demand and strong markets (Olejnik, 2017), including the impact of the road project; this may be the reason behind the difference between the two PCLV values in year 19 for Clayton Green.

6.3 Conclusion

The verification results achieved in this chapter showed good estimations of land value changes were obtained using the model developed in this study. In addition, the verification test showed a strong correlation coefficient between the PCLVs obtained from the historical land values and the PCLVs obtained from the non-linear model application. This indicated that the methodology followed in this study to choose the independent variables, their limits (maximum and minimum values) and trends was more than reasonable to estimate the changes in land values as an impact of inter-urban road development.

CHAPTER SEVEN

MODEL APPLICATION: OBTAINING CHANGES IN LAND VALUES

7.1 Introduction

This chapter presents the process of applying the proposed model of changes in land values using the case study chosen for this purpose. The application of the proposed model has been used to obtain the CLVs and to use them in a comparison with the primary impact of the same development over a defined analysis period. This chapter consists of five main sections. The first section presents the chosen case study. The second section outlines the characteristics of this case study and the criteria used to facilitate this choice. The third section describes the methodology used to apply the proposed model of changes in land values; while the results obtained from the model's application are presented in the fourth section. The fifth section summarises this chapter.

7.2 The Case Study

The case study chosen concerns a project located to the north west of England: particularly, in the county of Lancashire, to the south east of the city of Preston, to the south of Walton Summit Centre and to the north of Clayton Green, as shown in Figure 7-1. This case study includes the same motorway chosen for the verification of the proposed model of changes in land values, but using two sections instead of the one section used for the model verification.

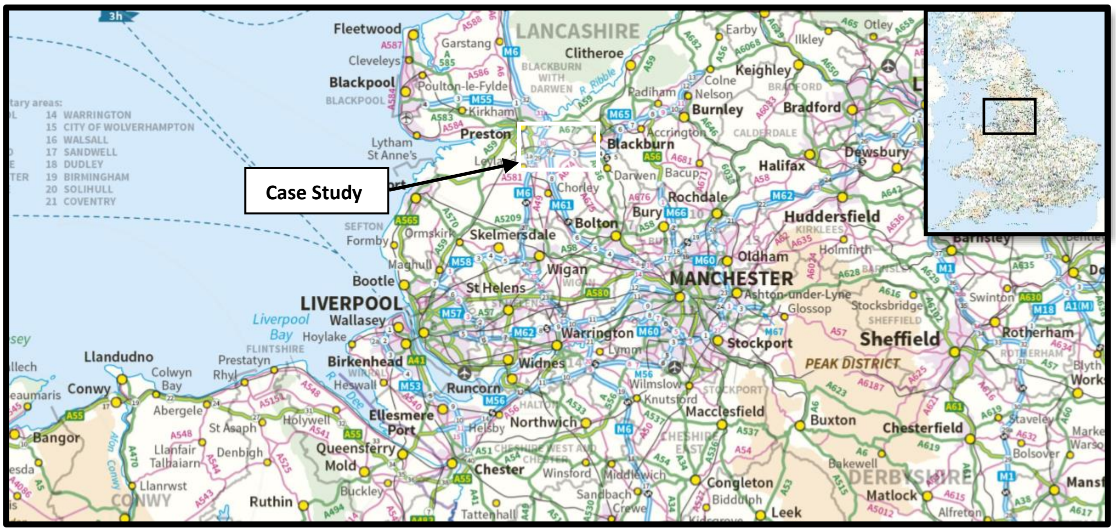


Figure 7- 1: The Chosen Case Study according to England Map (© Crown copyright and database rights [2017] OS (Digimap Licence))

The road network of this case study consisted of three sections of the M6 motorway, two sections of the M61 motorway and three sections of the A6 trunk road. This is the base case (do-nothing case) of the road network. The do-something case for this network focused on adding two sections of the M65 motorway (sections between junctions 1a and 2). Figure 7-2 shows all road sections of the do-something case of the road network used in this study. The two sections of the M65 motorway were constructed in 1997 (Cbrd, 2016). The whole length of these two sections is 3.1 km; which is made up of 0.9 km for the first section from junction 1a to 1 and 2.2 km for the second section from junction 1 to 2. The typical cross section of all motorways used in this study has three lanes in each direction; while the typical cross section of all trunk roads (A roads) of the Lancashire case study has two lanes in each direction.

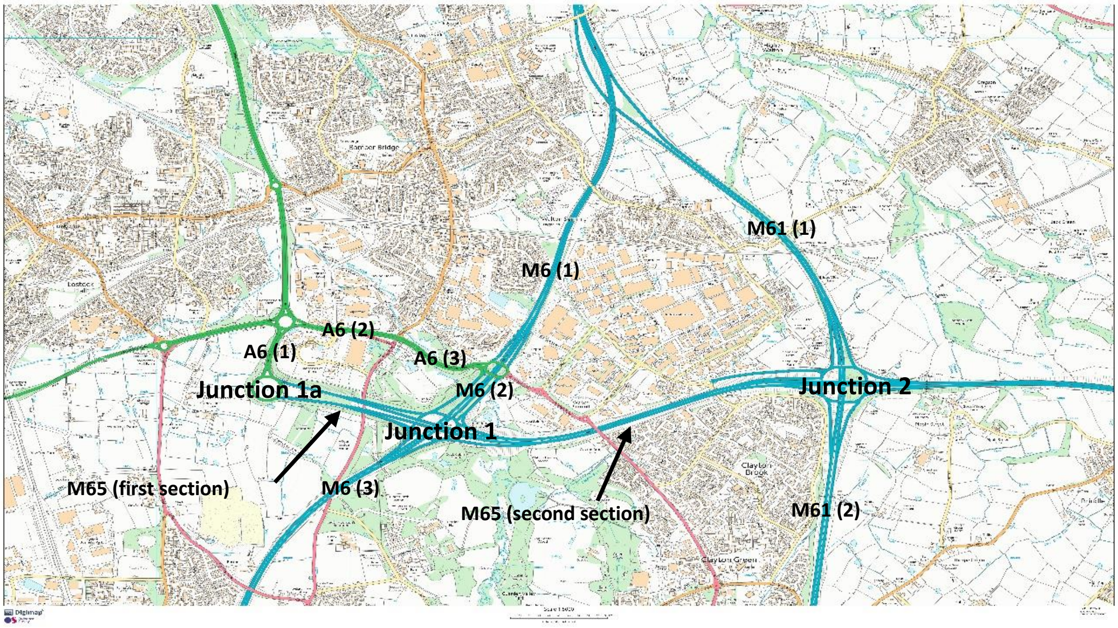


Figure 7- 2: All Road Sections of Do-Something Case of the Road Network Used in this Study (© Crown copyright and database rights [2017] OS (Digimap Licence))

The Motorway Database (Cbrd, 2016) was used to facilitate the selection of the M65 motorway as an inter-urban road development based on the following criteria:

1- Accessibility to adjacent lands

2- Proximity to urban fringe

3- Access to traffic data from Dft (2016a)

Accessibility has been always linked to the availability of transportation facilities, which determine the ease of movement for people and goods to the destination point (Litman, 2017b). Lands served by a transportation project tend to be more attractive than lands without; their values increase as a consequence of the resulting facilities (Mikelbank, 2004). This research focuses on the development of an inter-urban road, which may decrease the travel time and travel costs for road users and leads to increasing the accessibility of the adjacent land as a result. Increasing the accessibility may increase the economic activities in

the affected area and so lead to a change in the type of land use or the values of these lands. Inter-urban roads have full control of access to them (see Chapter Two for more details). As a consequence, these two sections of the M65 motorway have been chosen due to the existence of some access points to the adjacent land; which gives the ability to examine the change in the values of these lands as a result of the development of these two motorway sections.

It has been reported that road development leads to a change in land values. The rate of change increases with the proximity of land to an urban area (Litman, 2017a). As a consequence, the two sections of the M65 motorway between junctions 1a and 2 have been chosen owing to the proximity of their affected area to the city of Preston, to test the change in the values of these lands due to the development of these two motorway sections, as shown in Figure 7-3.

Figure 7- 3: The Chosen Case Study and its Proximity to Preston (© Crown copyright and database rights [2017] OS (Digimap Licence))

It has been demonstrated that traffic data is a critical parameter in the accuracy of the models used in this study (Williams and Yamashita, 1992; Johnston and Ceerla, 1996). It was therefore felt necessary to identify a project with reliable traffic data obtained from a reputable source such as the Department for Transport. Consequently, the case study has been chosen due to the availability of its real traffic data; which may have been collected over a 20 year road life span and is available to use for calculating the RUCSs of generated traffic using the HDM-4.

7.3 Characteristics of the Chosen Case Study

The characteristics of each road section in the network of Lancashire in terms of their geometric design, traffic data, traffic flow pattern, and climate conditions are illustrated in the following sections.

7.3.1 Geometric Design of Road Sections

The geometric design characteristics of each road section in the Lancashire network such as section length, carriageway width, rise and fall, horizontal curvature, super-elevation, altitude and speed limit, have been determined for use in the application task of this study.

The length of each road section was measured using ArcGIS version 10.4.1, which is a tool that has the capability to draw above the scaled map to extract the required information. A map for the study area has been downloaded with scale of 1:5000 from the Digimap webpage. This webpage has been provided by the University of Edinburgh and has been used here to complete the application requirements of this study. As a result, the obtained length of each road section is shown in Table 7-1

It was observed that the actual width of the carriageway had changed over the length of any road section due to the presence of the interchange. As a consequence, representative sections obtained from (DMRB, 2005) for both the motorway and the trunk road have been used, as shown in Figure D.1 and D.2 in Appendix D, respectively.

The rise and fall (m/km) for any road section in the Lancashire network was determined using the UK grid reference finder by positioning the required points on the road section and then finding the difference between the elevations of these points. The result was in turn divided by the distance between these points.

The horizontal curvature (deg/km) for each road section was measured using the ArcGIS software to find the degrees to the left or to the right that the road bent from its horizontal projection and then dividing the accumulated angles by the length of the section in question.

The super-elevation for each road section used in this study was calculated using Equation 7.1 (Bennett and Greenwood, 2004).

$$e = a_0 . C \qquad (7.1)$$

Where:

e =	*Super-elevation (m/m)*
C =	*Curvature (degree/km)*
a_0 =	*constant, this is equal to (0.012 for paved roads, 0.017 for unpaved roads)*

The altitude, the elevation above sea level (m), for each road section was obtained using the UK grid reference finder.

The speed limit (km/hr) for each section used in this study was determined using the data published by the Highways England webpage (Highways Englands, 2016). As a result, the obtained characteristics for all sections of the road network in Lancashire are shown in Table 7-1.

Table 7- 1: Characteristics of the Main Sections of the Road Network in Lancashire

Road section	Length (km)	Carriageway Width (m)	Shoulder Width (m)	Rise +Fall (m/km)	Super-Elevation (%)	Horizontal Curvature (deg/km)	Altitude (m)	Speed Limit (km/hr)
M6 (1) 6030	1.7	11	3.3	7.2	4	30	47	110
M6 (2) 99555	1.2	11	3.3	7.2	4	30	51	110
M6 (3) 26030	2.6	11	3.3	9.3	4	30	66	110
M61 (1)	2.7	11	3.3	19.6	4	50	64	110
M61 (2)	5.4	11	3.3	19.6	4	50	64	110
A6 (1) 99554	0.5	7.3		16.67	2	56	40	95
A6 (2) 38613	0.6	7.3		13.3	4	60	46	95
A6 (3) 28555	1.2	7.3		25	2	293	49	95
M65 (1)	0.9	11	3.3	15.5	6	19	67	110
M65 (2)	2.2	11	3.3	15.5	6	19	67	110

7.3.2 Traffic Data of the Road Sections

Real traffic data obtained from the Dft (2016a) has been used for each section in the road network of Lancashire. The average traffic volumes of the three sections of the M6 motorway were used as a traffic volume for this motorway. The traffic volumes of the M61 motorway, M65 motorway and A6 trunk road were also obtained using the same method as shown in Figure 7-4.

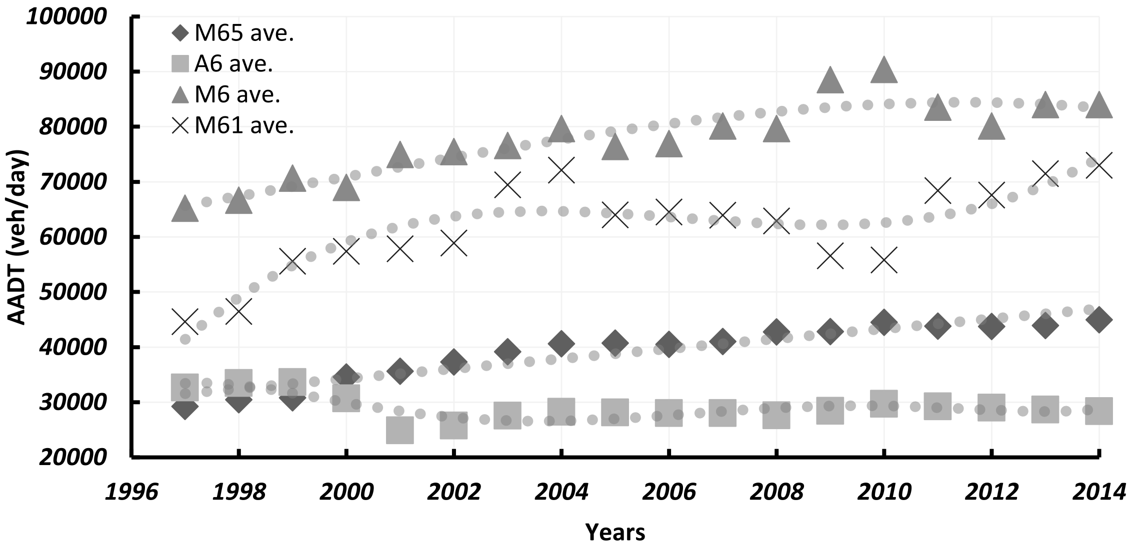


Figure 7- 4: Real Traffic Data of the Road Network in Lancashire

7.3.3 Traffic Flow Pattern

Traffic flow patterns represent the difference in traffic intensities throughout the day, which are defined as flow periods. Each period represents the number of hours of the day (over a year) with the same intensity of traffic flow (Stannard et al., 2006). In this study, the traffic flow pattern for each road section was calculated. The data obtained from the Highways England webpage (Highways Englands, 2016) was used to calculate the number of hours per year, hourly volume and the percentage of annual average daily traffic (AADT) for each

period type. Tables 7-2, 7-3, 7-4 and 7-5 show all the information necessary for traffic flow patterns of the A6 trunk road, M6 motorway, M61 motorway and for the M65 motorway, respectively.

Table 7- 2: Traffic Flow Pattern for A6 Trunk Road

Period		**Hrs per year (HRYRp)**	**Hourly Volume (HVp)**	**% of AADT (PCNADTp)**
1	Peak	1186	0.098	31.85
2	Medium Flow	3559	0.057	55.57
3	Overnight	4015	0.011	12.10

Table 7- 3: Traffic Flow Pattern for M6 Motorway

Period		**Hrs per year (HRYRp)**	**Hourly Volume (HVp)**	**% of AADT (PCNADTp)**
1	Peak	1004	0.077	21.17
2	Medium Flow	5019	0.052	71.50
3	Overnight	2737	0.010	7.50

Table 7- 4: Traffic Flow Pattern for M61 Motorway

Period		**Hrs per year (HRYRp)**	**Hourly Volume (HVp)**	**% of AADT (PCNADTp)**
1	Peak	1004	0.08	22.00
2	Medium Flow	3924	0.062	66.65
3	Overnight	3832	0.011	11.55

Table 7- 5: Traffic Flow Pattern for M65 Motorway

Period		Hrs per year (HRYRp)	Hourly Volume (HVp)	% of AADT (PCNADTp)
1	Peak	821	0.102	22.95
2	Medium Flow	4198	0.059	67.85
3	Next to flow	1551	0.016	6.80
4	Overnight	2190	0.005	3.00

7.3.4 Climate Condition for the Chosen Case Study

The climate condition has been obtained to use in the application task of this study. Thus, humid moisture and a cool temperature classification were specified from the AccuWeather webpage for Lancashire weather (Accuweather, 2016). The details of the climate condition of Lancashire is shown in Table 7-6.

Table 7- 6: Details of the Climate Condition of Lancashire

Moisture Classification	Humid
Moisture Index	60
Duration of Dry Season	3 months
Mean Monthly Precipitation	175 mm
Temperature Classification	Temperate-cool
Mean Temperature	12 ºC
Avg. Temperature Range	15 ºC
Days T>32 ºC	15 days

7.4 Methodology Used to Apply the Proposed Model

To apply the proposed model of changes in land values, a methodology was proposed to obtain the four variables of the developed model (more details are found in Chapter Four). These variables are distance from the new road, land use, land area and time that has elapsed since the completion of the road works. The proposed methodology consists of eight steps of measurements and calculations as shown in Figure 7-5, to calculate the CLVs as a secondary impact of an inter-urban road development with the aid of ArcGIS.

The ArcGIS system was used to obtain the characteristics of land affected by the new road development due to its popularity, easy use and its ability to create shape files. The latter gives the ability to draw above the scaled map to extract the required information, such as the distance between any two points, areas of different shapes of land and the centroid for any shape of land cell.

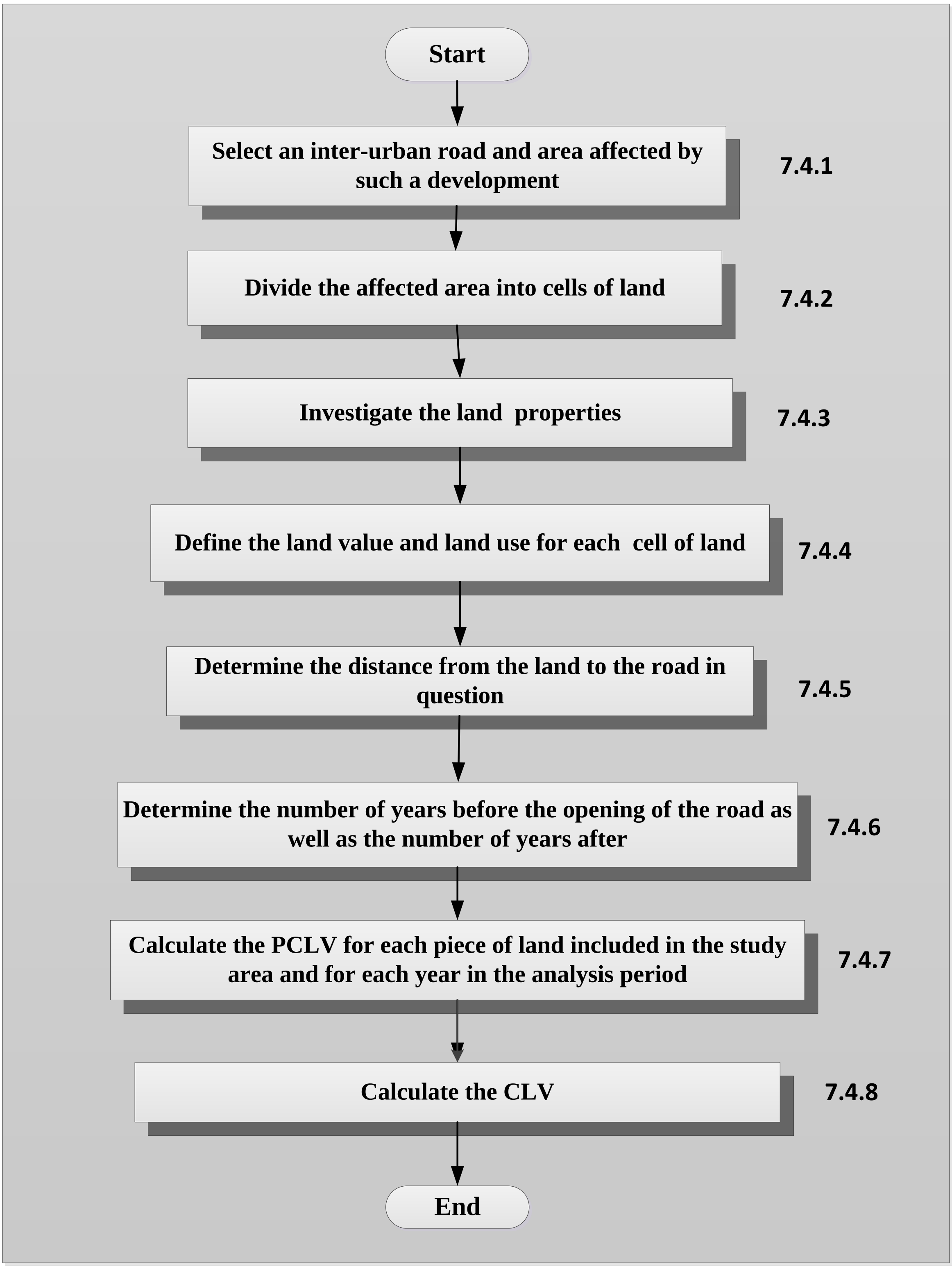


Figure 7- 5: Flow Chart of the Methodology Used to Apply the Proposed Model of Changes in Land Values

7.4.1 Selection of an Inter-urban Road and Area Affected by such a Development

The two sections of the M65 motorway (sections between junctions 1a to 2) were chosen as a new development of an inter-urban road to apply the proposed model of changes in land values. To highlight the land affected by the development of these two sections, the distance of 1.5 km from the alignment of the M65 motorway sections was used after taking into account the model's limitation for the distance variable and the access points available in this case study; these play an important role for an inter-urban road (see Chapter Two for more details). Thus, ArcGIS was used to measure a distance of 1.5 km around the two motorway sections to use later. This land for the model's application is highlighted in Figure 7-6. The total area of the highlighted land is equal to about 16,238,468.9 m^2, which was calculated using the ArcGIS.

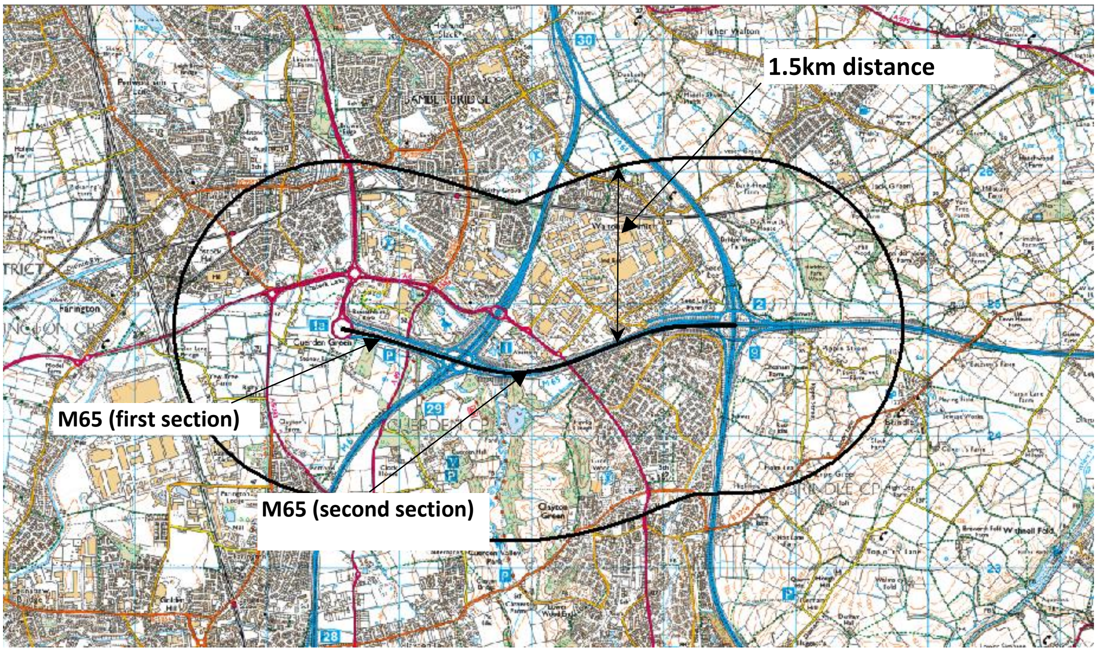


Figure 7- 6: The Highlighted Area around the Two Sections of the M65 Motorway (sections between junctions 1a and 2) (© Crown copyright and database rights [2017] OS (Digimap Licence))

The distance of 1.5 km from the alignment of the M65 motorway sections was divided into distances of 0.5 and 1 km as shown in Figure 7-7. These distances were used to facilitate the division of the highlighted land into cells for later model application. The reason for dividing the highlighted area is due to the limitation of the developed model regarding the variable of the land area (more information is available in Section 4.4.5).

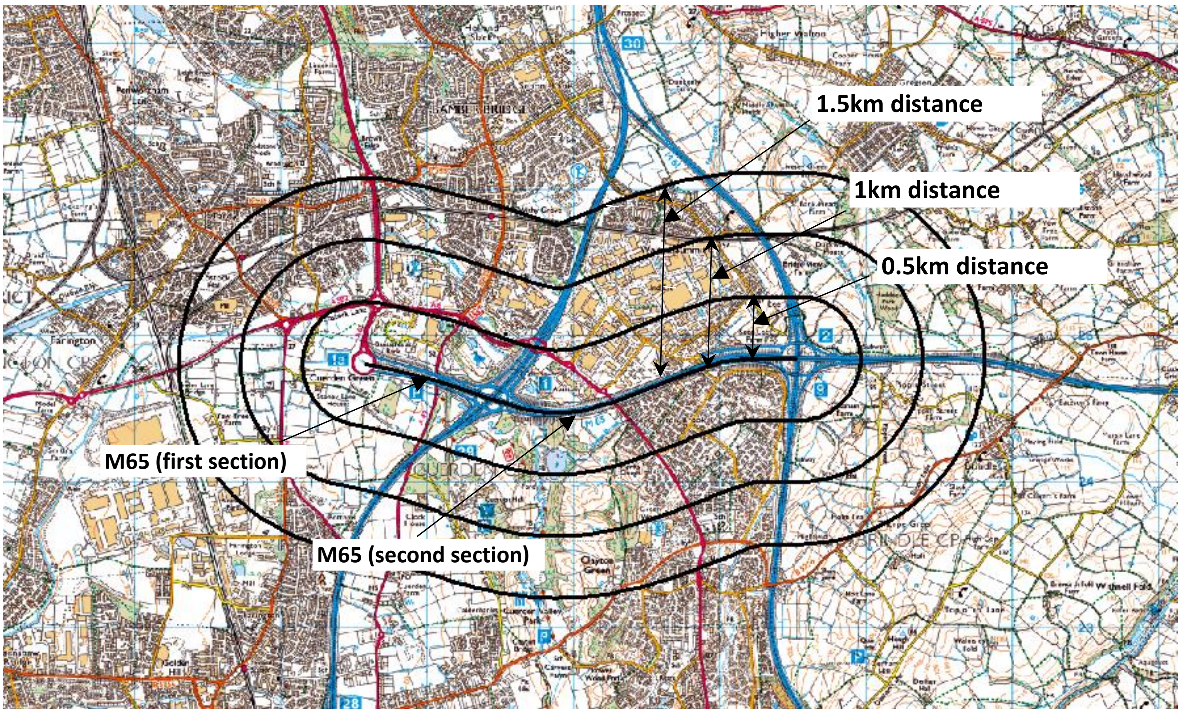


Figure 7- 7: The Division of the Highlighted Area around the M65 Motorway (sections between junctions 1a and 2) (© Crown copyright and database rights [2017] OS (Digimap Licence))

7.4.2 Dividing the Affected Land into Cells of Land

Lands affected by the development of the two sections of M65 motorway, i.e. lands located between 0.5, 1 and 1.5 km distances were delimited into 75 cells of land, as shown in Figure 7-8. Such a division has been used due to the limitation of the proposed model regarding the

land area variable, which should be within the required range of 10-80 hectares. As a consequence, these cells of land have been used later for obtaining the independent variables of the proposed model, to calculate the CLVs as a secondary impact of an inter-urban road development. These independent variables are distance from the new road, time that has elapsed since the completion of the road works, land use and land area.

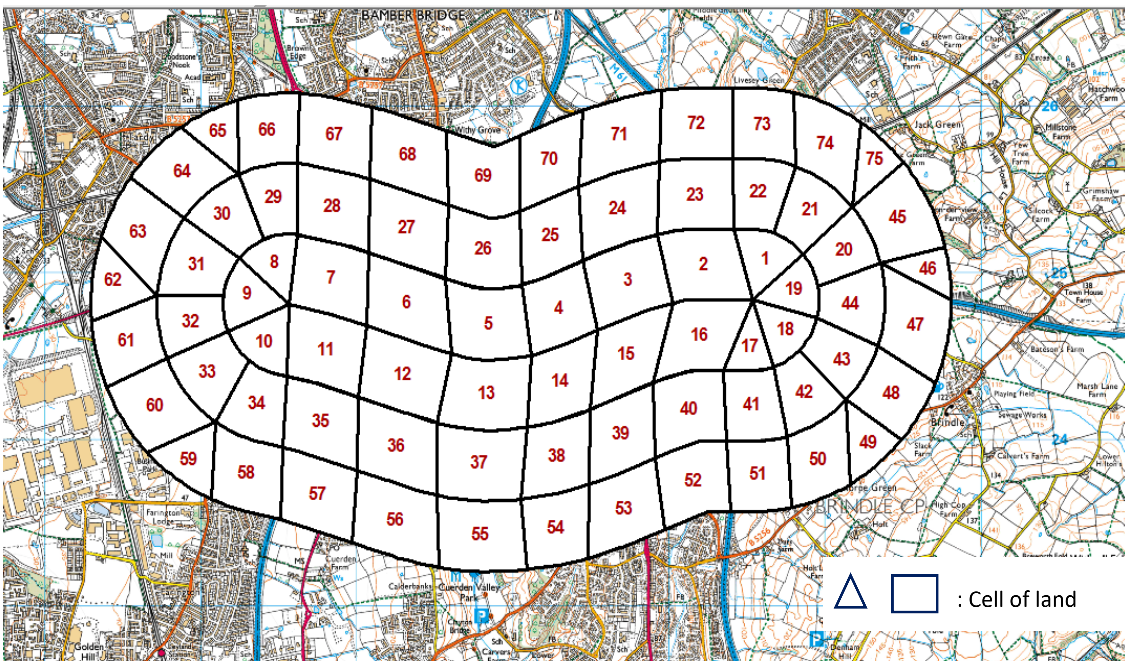


Figure 7- 8: Cells of Land Affected by the M65 Motorway Road Development (© Crown copyright and database rights [2017] OS (Digimap Licence))

7.4.3 Investigating the Land's Properties

Properties of land cells such as the area of the cell and its centroid are important to achieve for the application of the proposed model, due to the effect of these properties on the resulting changes in land values. These properties were determined using the different tools provided in the ArcGIS system, i.e. the area of each cell of land was determined using the calculation tool provided; while the centroid of each cell was calculated using the management tool of the same system. The obtained centroid of each cell of land is

represented by a green dot as shown in Figure 7-9. The calculated areas for the 75 cells of land (hectare) are shown in Table D.1 in Appendix D.

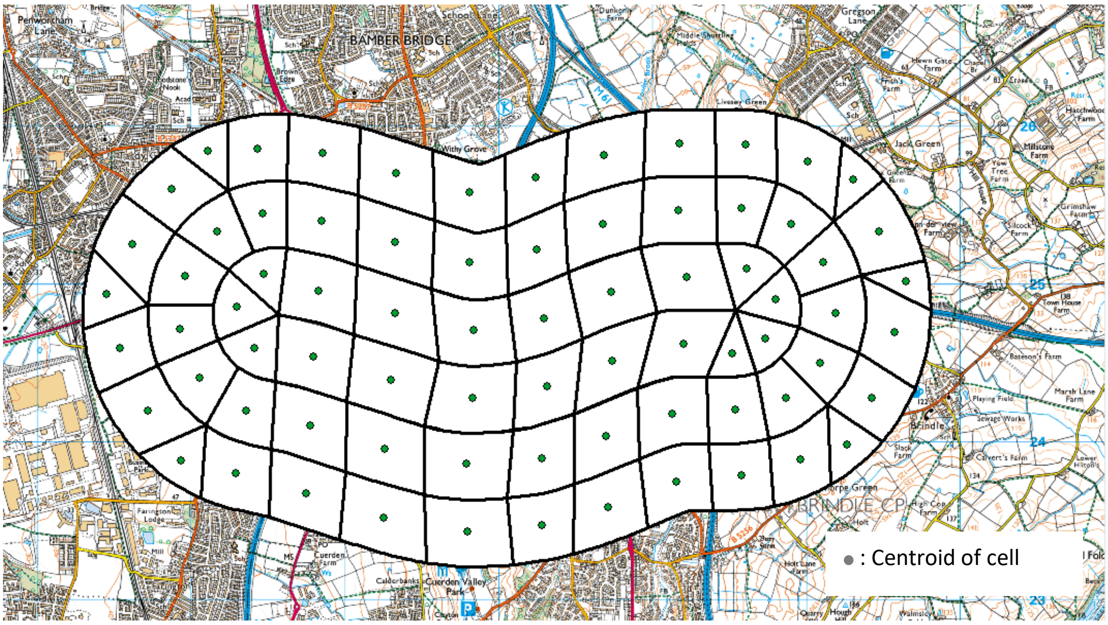


Figure 7- 9: Centroid of Cells of Land Affected by the M65 Motorway Road Development

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7.4.4 Definition of Land Use and Land Value for Each Cell of Land

Land value according to its usage has been calculated for each cell of land in order to express the land use in the proposed model and then achieve its effect on the resulting CLV. The case study chosen to apply the proposed model consists of different types of land use; such as residential, agricultural and industrial, as shown in Figures 7-10. Consequently, a Google Earth map with the aid of the ArcGIS technique was used to identify the percentage of each type of land use in each cell of land, which in turn has been used to calculate the average land value (LU) (£/m^2) for each cell.

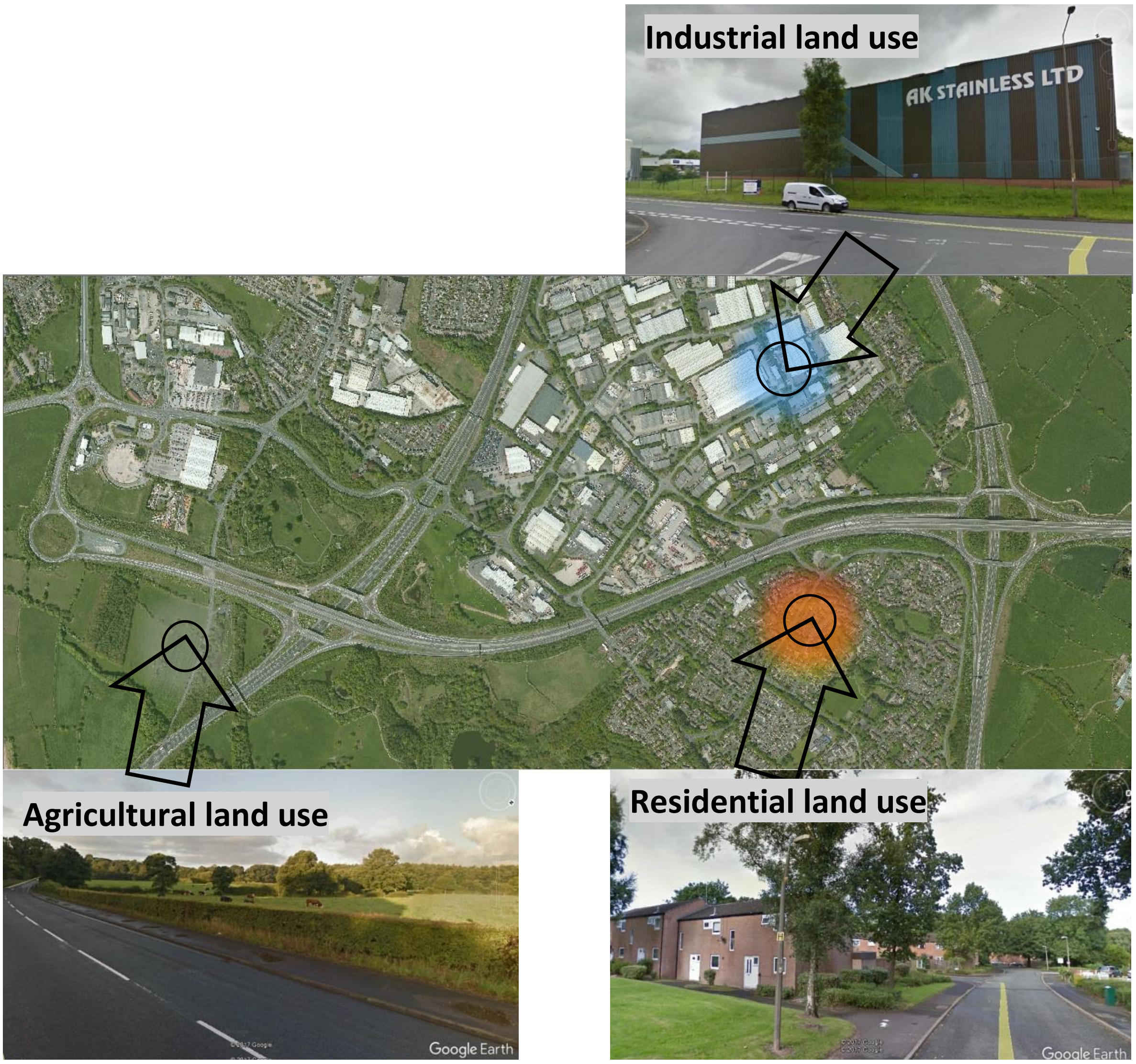

Figure 7- 10: Main Types of Land Use in the Study Area (Google Earth)

The proposed model of change in land values has the ability to deal with only three types of land use: residential, agricultural and industrial (see Chapter Four). As a consequence, it was felt necessary to exclude land dedicated for road development from the calculations of LU as shown in Figure 7-11.

Cell number two has been taken as an example to identify the percentages of industrial, residential and agricultural land use as shown in Figure 7-11. This figure shows that cell number two includes three types of land use. For the agricultural use, three parts have been observed in cell number two as shown in Table 7-7. The area of each part has been measured

using the GIS software. The area of the three parts has been summed together to obtain the total area of agricultural use in cell number two. The same procedure was repeated for the residential and industrial land uses of cell number two. Consequently, the percentage of land for agricultural, industrial and residential uses has been calculated, which is equal to 65%, 25% and 10% respectively, as shown in Table 7-7.

Figure 7- 11: The Classification of Land Use Types for Cell Two (Google Earth)

Table 7- 7: The Procedure for the Calculation Used to Obtain the Percentage for Each Type of Land Use and the Resulting Land Value

Type of Land Use	Agricultural	Industrial	Residential
Area 1 (m^2)	87587	18648	8677
Area 2 (m^2)	17107	35370	11003
Area 3 (m^2)	35747		1936
Total Area of Land Use Type (m^2)	140441	54018	21610
Summation of Areas (m^2)	216061		
Percentage (%)	65	25	10
Value of Each Land Use	0.65*2=1.3	0.25*50=12.5	0.1*200=20
Land Value LU (£/m2)	33.8		

Each percentage of land has been multiplied by its land use value (£/m^2), obtained from the UK's DCLG (2015) (see Chapter Four). The three results have been added together to obtain the land value LU (£/m^2) for cell number two, as shown in the same table. The same procedure used for cell number two has been repeated for the 75 cells of land to calculate the percentage of agricultural, residential and industrial use for each cell, as shown in Table D.2 in Appendix D.

7.4.5 Determination of the Distance from the Land to the Road in Question

Measuring the distance variable from each cell of land to the new road can be achieved using either the straight-line distance or the network distance (i.e. the distance from the actual horizontal alignment) (Dziauddin, 2009). In the current study, the straight-line distance was used and it was measured from the centroid of each cell of land (Brocker et al., 2001) to the nearest access point of an inter-urban road (Banerjee et al., 2012; Kockelman et al., 2002;

Sanchez, 1993) (see Chapter Two). The centroid of each cell of land was used to get the average distance for each cell of land. Thus, seven access points for the two sections of the M65 motorway had been noted and the straight distances were measured from the centroid of each cell of land to its nearest access point, as shown in Figure 7-12. A distance variable (m) for each cell of land was measured and shown in Table D.3 in Appendix D.

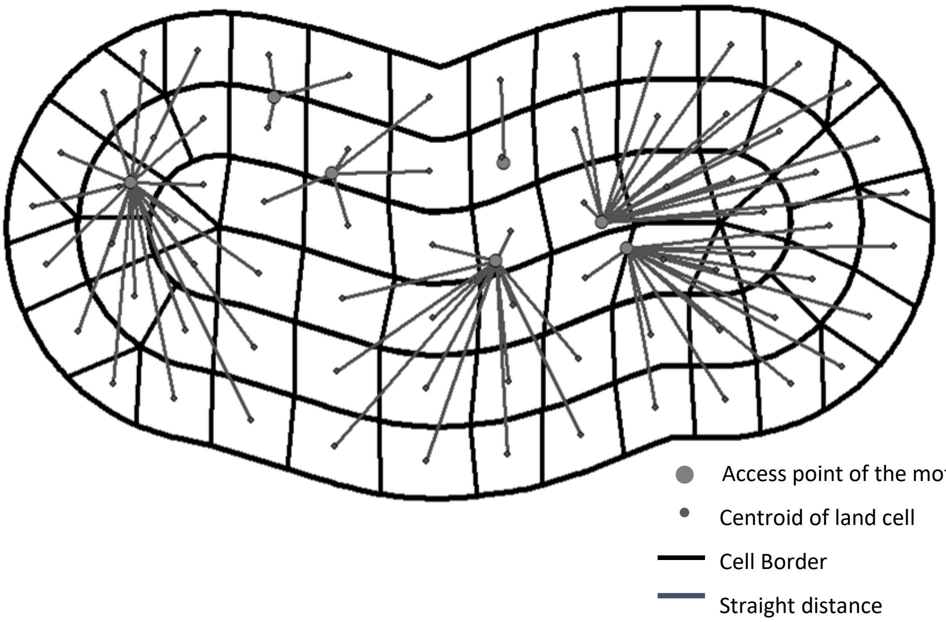

Figure 7- 12: Straight Distances from Centroids of Cells to the Nearest Access Points

7.4.6 Determination of the Number of Years Before and After the Opening of the New Road

Although the proposed model has the ability to estimate the changes in land values from three years before the road works' completion (more details are found in Chapter Four), these years were not considered in the model's application due to the goal of this study, which is the comparison between the CLVs as a secondary impact of road development and the RUCSs of the generated traffic as a primary impact of road development. These RUCSs

are obtained from the year of the road's opening onwards. As a consequence, a time period selected to apply the proposed model of changes in land values started from the road works' completion, i.e. from the road's opening in 1997 up to 30 years later with a period of one year intervals.

7.4.7 Calculation of the PCLV for Each Piece of Land Included in the Study Area and for Each Year in the Analysis Period

For each cell of land, the cell area (A), the land value (LU) and the distance from the centroid of the cell to the nearest access point (D) were used to calculate the PCLV of each cell in each year (T) in the time period, starting from the year of the road's opening in 1997 and up to 30 years afterwards. The obtained PCLVs for 1997, considered as year zero in the proposed model, for the 75 cells of land are shown in Table D.3 in Appendix D.

7.4.8 Calculation of the CLV

For each cell of land, the PCLV calculated in the previous step has been multiplied by its cell price to obtain the CLV, as shown in Table D.4 in Appendix D. The cell price was calculated by multiplying its LU (£/m^2) by the cell area.

The resulting CLVs (£) for each cell of land from the road's opening (year zero) to 10 years later are shown in Table D.5 in Appendix D; while the resulting CLVs (£) from 11 years after the road's opening to 20 years later for the same cells are shown in Table D.6 in Appendix D. Moreover, the CLVs (£) calculated from year 21 to year 30 are shown in Table D.7 in Appendix D. By adding the CLVs for the 75 cells of land for each year of analysis, the total CLV may be calculated.

7.5 The Results Obtained from the Model's Application

The resulting CLVs (£) from using the methodology proposed for applying the developed model of changes in land values are shown in Figure 7-13. These CLVs have been obtained as a secondary impact from the development of the two sections of the M65 motorway in Lancashire. These CLVs (£) were expressed in prices from 2015 as this was the base year for the analysis reported herein.

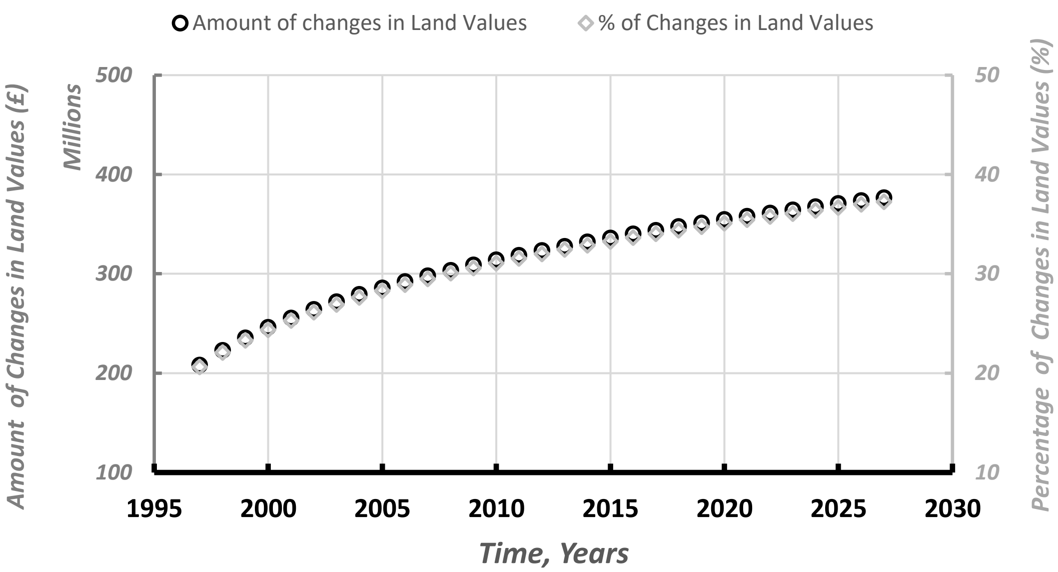

Figure 7- 13: The resulting CLVs (£) in 2015 prices

Figure 7-13 reveals that the amount of CLV increased from about £200 m in 1997, which is equal to about a 20% land value increase, to about £300 m in 2007 that is equal to about a 30% land value increase. In 2017, the CLV is equal to about £350 m; while the CLV in the last year of analysis is about £368 m. This means that the rate of increase of the CLV (£) decreased from £100 m for the first ten years to about £50 m in the second ten years of the time period; which in turn was followed by an increase of about £18 m in the last seven years. The obtained trend of the CLVs with time is consistent with the result obtained by Chernobai et al. (2011), who reported on the non-linear relationship between the time after the road works' completion and the values of the adjacent land, in terms of real estate prices used in their study.

7.6 Summary

The Motorway Database (Cbrd, 2016) was used to facilitate the selection of this case study for different reasons related to the availability of some access points to the adjacent land, the proximity to the urban fringe and the access to real traffic data. This case study was chosen to achieve the goal of this research, which includes comparing the primary impact of an inter-urban road development with its secondary impact. Two sections of the M65 motorway located in Lancashire, England were chosen to complete the application tasks of this study. The proposed methodology was used to obtain the total CLV for each year in the analysis period that started from the road's opening in 1997 (year of road works' completion) up to 30 years later. The proposed methodology needed some calculations and measurements using ArcGIS, which proved its capability to serve this kind of study. This software has been considered as a revolution in computer software since the 1980s (Audet and Abegg, 1996). It is used to integrate geographical databases with maps and it provides an easy approach for software users with different functions, such as those used for creating, analysing, acquiring, modelling, visualizing and archiving information (Goodchild, 2009). This method gives the GIS the capability to serve different kinds of studies, especially those dealing with land development and geographical data.

There are some alternatives to the ArcGIS software (Redhat, 2018) to work with geospatial data analysis, such as the Geographical Resources Analysis Support System (GRASS)

(Neteler et al., 2012), QGIS, GeoNode and uDig but ArcGIS was used in this study due to its simplicity and popularity.

Informative results were obtained for the CLV over the analysis period used, as the obtained results are consistent with the results obtained by Chernobai et al. (2011), who also focused on the effect of road investment.

More accurate results might be obtained using the network distance (Dziauddin, 2009) instead of the straight distance used in this study for distance measurement. The approach of using the network distance (the distance from the actual horizontal alignment of the road concerned) will be more complicated to obtain.

CHAPTER EIGHT
HDM-4 APPLICATION

8.1 Introduction

This chapter reviews the use of HDM-4 to aid obtaining the primary effects of the M65 motorway road development. This chapter is organised in seven sections. The first section gives an overview of the HDM-4. The second section deals with the concepts of CBA. The third section presents the modelling of the RUC in the HDM-4; while the key input data used in HDM-4 and its impacts on the calculations are presented in the fourth section of this chapter. The fifth section outlines the results obtained from the HDM-4. The sixth section presents the accuracy of the results; while the last section summarizes the conclusions obtained from this chapter.

8.2 HDM-4 Software

HDM-4 is software used worldwide for road management works (Kerali et al., 1998; Aswathy et al., 2013; Ko et al., 2016). It is the new version of "The Highway Design and Maintenance Standards Model (HDM-III)" which was developed by the World Bank (Harral et al., 1979; Kerali et al., 1998) and has been used for more than 20 years (Kerali et al., 1998b) for analysis purposes of strategies and standards and for road projects' appraisal. Moreover, HDM-III was used in more than 100 countries (Ndli, 1995; Aswathy et al., 2013), but there were some limitations in its working ability as recognized by some applicants. Thus, the HDM-4 was developed after conducting an international study to extend the scope of the previous version and to provide software having a capability beyond the traditional elements to work with projects' appraisal (Kerali et al., 1998). The conceptual structure of the HDM-4 is as shown in Figure 8-1.

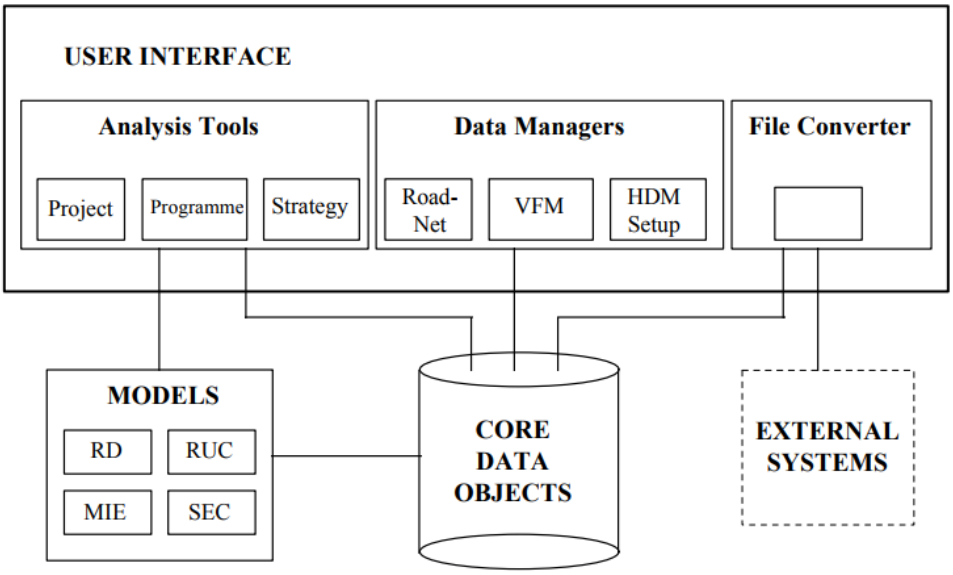

Figure 8- 1: Conceptual Structure of HDM-4 (Kerali et al., 1998)

Three types of analysis can be conducted using this software, which are project analysis, program analysis and strategy analysis (Kerali et al., 1998b). All the data used in HDM-4 are defined under three data managers: (1) road network manager; (2) vehicle fleet manager; and (3) HDM-4 set-up.

Any details relating to the road network including the road length, the road width, the geometric design of the roads and others are defined in the road network manager; while information relating to the characteristics of the vehicle fleet that used the specified network is defined in the vehicle fleet manager (VFM). The HDM-4 default data is defined in the HDM set-up; these data can be used directly or after being modified by a software user to reflect the user's prevailing circumstances. Four types of models are within the HDM-4: road deterioration (RD), maintenance and improvement effects (MIE), RUC and socio-economic costs (SEC). The HDM-4 includes a series of sub-models; each sub-model has its own involvement in the calculations and as a result needs its special inputs and produces its specific output (Bennett and Paterson, 2000).

It is important to mention that representative vehicles have been used in this software to signify the various types of vehicles in the traffic stream (Bennett, 1996a; Bennett and Greenwood, 2004).

8.3 Concepts of CBA

The CBA is an assessment method adopted to quantify the monetary values of all consequences of a road project to all members in a society (Boardman et al., 2006; Mackie, 2010), i.e. for road users and non-users (despite their living place or working place) (TRB, 2010; Laird and Venables, 2017). The CBA is used to help the decision maker rank the project's options (Litman, 2017c; Snell, 1997; Aswathy et al., 2013) and choose the best option for investing in road infrastructure (Boardman et al., 2006). Such an evaluation is based on the economic viability of each option, i.e. net social benefits (Archondo-Callao, 2008; Boardman et al., 2006; Joseph et al., 2014; Aswathy et al., 2013; Mackie, 2010), which are the result of subtracting the total transport costs required for the development of the road project (expenditures) from the total benefits aggregated from such a project (revenues) (Hanley and Spash, 1993). The total transport costs include the RUCs, construction cost and the maintenance costs (Boardman et al., 2006). There is an inter-relationship between all these mentioned costs (Bennett and Greenwood, 2004), as shown in Figure E.1 in Appendix E.

The RUC constitutes the main part of the total transport costs (Bennett and Greenwood, 2004) and includes vehicle operating cost (VOC), travel time cost (TTC) and accidents' cost (AC) (Aswathy et al., 2013; Gillespie, 1998; Bennett and Greenwood, 2004; Garber and

Hoel, 2009; Bennett, 1996b). The VOC is in turn considered as an important item in the RUC (Garber and Hoel, 2009), which reflects the components related to vehicle operation (Bennett and Greenwood, 2004; Robinson, 2008) in terms of fuel, engine oil, tyres, maintenance and depreciation (Gillespie, 1998; Garber and Hoel, 2009), as shown in Figure 8-2.

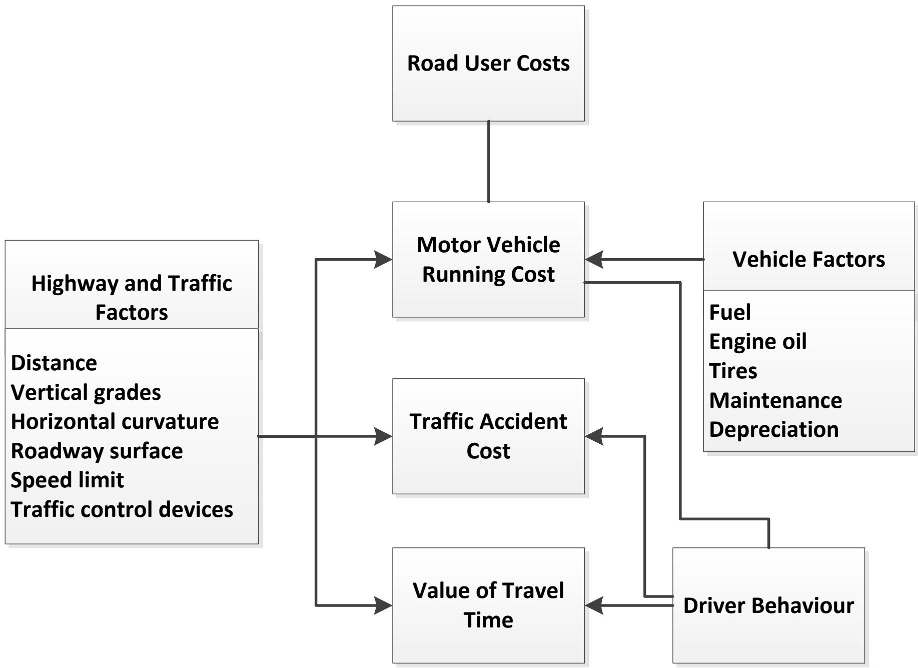

Figure 8- 2: Road User Cost Factors (adopted from Garber and Hoel, 2009)

The VOC consists of variable costs and fixed costs (Mackie et al., 2005; Litman, 2016c). The variable costs are affected by the distance travelled in miles that include fuel, engine oil, tyres, parts, user time and stress, and user crash risk (Bennett and Greenwood, 2004); while the fixed costs are not affected by the distance travelled and include the price of a new vehicle, vehicle registration, insurance payments and part of the maintenance price (Litman and Doherty, 2009).

The fuel consumption in turn constitutes the major part of the VOC (Ko et al., 2016); which represents about (20-40) % from the total VOC (HTC, 1999b cited in Bennett and

Greenwood, 2004). In addition, Mackie et al. (2005) and Litman (2016c) reported that the VOC varies according to several factors, such as: vehicle type and its speed; the geometric design of the road; and the road surface type (bitumen, concrete or gravel surface) (Bennett and Greenwood, 2004; Robinson, 2008; Zaabar and Chatti, 2010).

On the other hand, the anticipated benefits from the road project save travel time, reducing the number of accidents and the vehicle operating costs for drivers using the new road; and reducing the congestion on the existing old roads (Boardman et al., 2006; Archondo-Callao, 2008; Weisbrod, 2008; Botham, 1980).

The costs and benefits of the road project are extended with the project's life over a long analysis period (Kerali et al., 1998; Boardman et al., 2006; Mackie, 2010). Thus, to aggregate these costs and benefits, they should be discounted to the present value of money (PVM) (Boardman et al., 2006; Layard and Glaister, 2012; Robinson, 2008; Litman, 2006; Litman and Doherty, 2009; Mackie, 2010). There are three reasons for discounting money: inflation, interest rate and risk of the project (Litman, 2006; Garber and Hoel, 2009). The equation used to discount money is as shown below (Robinson, 2008):

$$\boldsymbol{PVM} = \frac{c_i}{(1+\frac{r}{100})^i} \qquad \text{.............................} \quad (8.1)$$

Where:

PVM =	*is the present value of money*
c_i =	*is the costs or benefits incurred in year i*
r =	*is the discount rate expressed as a percentage*
i =	*is the year of analysis where, for the base year, i=0.*

The discount rate (r) can be considered as the reflection of the time value of money ((Robinson, 2008; Litman and Doherty, 2009; WMO, 2007; Boardman et al., 2006). Selection of an appropriate discount rate has a special importance especially in the case of evaluating the future impacts, such as benefits resulting from the road development.

In this study, different references were used to choose the appropriate discount rate for the HDM-4 software and are as follows: Trading Economics (TE) (2017) was used to obtain the discount rate, which was equal to 6% in 1997; while the Green Book long-term discount rate provided by (Lowe, 2008) is equal to 3.5% as shown in Table 8-1. In addition, the typical discount rates are between (4-12) % (Litman, 2006) and between (6-10)% (Litman and Doherty, 2009). Thus, a 6% discount rate was used in this study for the HDM-4 software.

Table 8- 1: Green Book Long Term Discount Rate (Lowe, 2008)

Period of years	**0-30**	**31-75**	**76-125**	**126-200**	**201-300**	**301+**
Standard rate as published in the Green Book	3.5%	3%	2.5%	2%	1.5%	1%
Reduced rate where "Pure STP" = 01	3%	2.57%	2.14%	1.71%	1.29%	0.86%

8.4 Modelling the RUC in the HDM-4 Software

The HDM-4 RUC model is the improved version of the HDM-III model after taking the following points into account (Bennett and Greenwood, 2004): (1) improving the fuel consumption model to achieve the technologies occurring in a motor vehicle; (2) focusing on the impacts of traffic congestion (Kerali et al., 1998) as well as on depreciation and interest rate; (3) considering the effects of traffic safety; (4) incorporating the impacts of road works on the VOC and resulting delay in time; (5) modelling the vehicle speed; (6) using 16 types of representative vehicles instead of 10 types used in HDM-III; (7) modelling a variety of road pavement types, such as bituminous, concrete and unsealed pavement (Kerali et al., 1998b); and (8) modelling the emissions due to the noise effect (Kerali et al., 1998b).

The HDM-4 RUC model consists of different sub-models including the fuel consumption model, the tyre consumption model, the maintenance and repair costs model, the utilisation and service life model, the capital costs model, the engine oil consumption model, the travel time model, the traffic safety model, the non-motorised transport model, the work zone effects model, the emission model and the vehicle noise model (Bennett and Greenwood, 2004). Thus, Litman (2017c) reported on the complexity of the HDM-4's calculations to obtain the economic viability of road development. The model forms and their variables may be found elsewhere (Bennett and Greenwood, 2004).

Although the components of the RUC are the VOC, TTC and AC, each one has in turn its different components (Bennett and Greenwood, 2004); but Anderson et al. (1992) stated that not all these components have the same impact on the resulting RUC, as shown in Table E.1 in Appendix E. Thus, the HDM-4 RUC model has focused mainly on modelling the components that have greater impacts on the RUC, such as the model of fuel consumption which has had more attention than other RUC components. On the other hand, modelling the oil and tyre costs has been given the least attention among the RUC components (Bennett and Greenwood, 2004). The maintenance and depreciation costs have medium impacts on the obtained RUC (Bennett and Greenwood, 2004).

The VOC model of HDM-4 was improved with time as the first version of the model was adopted in 1966, but the improvement continued until the last version of the model which superseded all the recent models, as shown in Figure E.2 in Appendix E (Bennett and Greenwood, 2001; Kerali et al., 1998b). The HDM-4 VOC model is recommended by the

World Bank (Mackie et al., 2005) because all the important components of the VOC and their inter-relationships have been included in this model (Bennett and Greenwood, 2004), as shown in Figure E.3 in Appendix E. A detailed presentation of the HDM-4 VOC model and the comparison of HDM-4 and HDM-III may be found elsewhere (Kerali et al., 1998b).

8.4.1 Strength and Weakness of the HDM-4 Model

The two important issues which arise in modelling the HDM-4 RUC are: (1) the effect of improving vehicle technology on fuel economy (Ko et al., 2016; Naudé et al., 2015), which in turn decreases the cost needed for vehicle operation (Glaeser and Kohlhase, 2004); and (2) the model's transferability from one region to another due to the differences in driver behaviour and the surrounding environment. Thus, the model needs frequent updating to take into account the changes in vehicle technology; such as hybrid vehicles that contribute to air quality and fuel saving (Bonilla, 2009), or any change resulting in minimizing the cost of vehicle operation (Glaeser and Kohlhase, 2004), such as the changes in tyre technology that offer a longer life and lower rolling resistance (Bennett and Greenwood, 2004). Cox (1996) cited in Bennett and Greenwood (2004) that the VOC showed a cost reduction equal to 66% over 22 years from 1970 to 1992 due to improving the vehicle technologies that resulted in decreasing the consumption of fuel, tyres, lubricant oil, maintenance costs and other capital costs.

Bennett and Greenwood (2004) reported that this shortcoming can be overcome through using different types of representative vehicles and using a negative growth percentage for some types of vehicle fleets. Over time, these types can be replaced with other vehicle types, while the problem of transferability can be overcome with calibrating the HDM-4 model.

Odoki et al. (2012) reported that HDM-4 should be calibrated to use the local conditions. There are three levels for calibrating the HDM-4 (Bennett and Paterson, 2000): low level (basic application), medium level (verification) and major level (adaptation). In this study, the calibration of the HDM-4 to the prevailing conditions in Lancashire was achieved to the medium level, which involves good field surveys and measures the parameters of the inputs.

To calculate the costs and benefits of the M65 motorway road development, it is important to provide the key input data.

8.5 The Key Input Data Used in HDM-4 and its Impacts on the Calculation

A wide range of data is required to run the HDM-4 software (Aswathy et al., 2013; Kerali et al., 1998b; Odoki et al., 2012) that includes: (1) primary data; (2) secondary data; and (3) other data. These data are classified according to their importance to the results.

8.5.1 Primary Data

The primary data includes the traffic volume data survey and the pavement condition survey (Aswathy et al., 2013), which have the main impact on the HDM-4's results.

8.5.1.1 Traffic Volume Data Survey

Traffic volume forecasting is considered as a key factor in the calculation of the RUCs and road user benefits resulting from road development (Mackie et al., 2005; Litman, 2017a), which provides an estimation of the number of vehicles using the road and how it will increase in the future. The estimation depends on current circumstances and any error in this forecast may result in over or underestimating the RUCs; thereby undermining the reliability of the appraisal (Williams and Yamashita, 1992; Mackie et al., 2005).

Any improvement in network serviceability that reduces journey time and cost generates new traffic (Goodwin, 1996); which is dependent on the characteristics of the road, such as the road location and its capacity and the amount of saving in transport costs (Goodwin, 1996; Robinson, 2008; Wood, 1994). Different percentages of generated traffic, diverted traffic and induced traffic, have been adopted in recent studies and ranged from 10-50% for diverted traffic and 50-100% for induced traffic, as mentioned in Chapter Three. Zhao and Kockelman (2002) reported that the future prediction of a transportation model involves a lot of uncertainty, due to two reasons: uncertainty in the input used and uncertainty in the model building (Zhao and Kockelman, 2002; De Jong et al., 2007).

Thus, real data of traffic volume obtained from the Dft (2016a) was used in this study to ensure the benefitting of exact traffic volume as mentioned in Chapter Seven.

The crash map website was used in this study to obtain the number of accidents in the Lancashire network (Map, 2017); while the accident costs and casualties in Great Britain (prices of 2015) were obtained using Dft (2016b) as shown in Table 8-2.

Table 8- 2: Average Value of Prevention of Reported Road Accidents by Road Type (adopted from DfT (2016b)) (prices of 2015)

Accident Type	**Road Type**			**All roads**
	Built-up roads	**Non-built-up roads**	**Motorways**	
Fatal	1,922,917	2,066,360	2,121,965	2,005,664
Serious	221,054	248,472	258,769	229,757
Slight	22,880	27,598	32,964	24,194
All injury accidents	61,966	125,975	94,161	76,466
Damage only	2,027	2,964	2,848	2,142
All accidents	5,233	16,942	13,465	6,715

8.5.1.2 Pavement Condition

All the characteristics of the main sections used in the proposed network were determined in Chapter Seven: the section length, the carriageway width, the rise and fall, the horizontal curvature and the super-elevation.

Pavement roughness has a significant impact on the VOC (Gillespie, 1998). It is the main measure of the pavement performance related to the economics and the serviceability for road users (Odoki et al., 2012). The components affecting the pavement roughness include: structural deformation; rutting; cracking; potholes and environmental effects. All these components were represented in the HDM-4 roughness model (Odoki et al., 2012; Morosiuk et al., 2004; World Bank, 2008b), as shown in Figure 8-3.

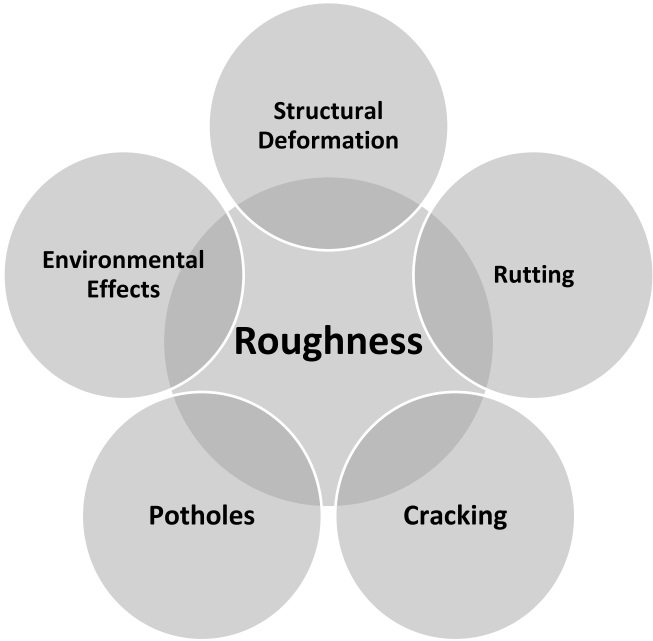

Figure 8- 3: Components Represented in HDM-4 Roughness Model

The work of Dreyer and Steyn (2015) and Pavia (2012) was used to obtain the value of pavement roughness (m/km) to input in HDM-4 as shown in Table 8-3 and Figure 8-4, respectively.

Table 8- 3: Road Roughness Categories (adopted from Dreyer and Steyn, 2015)

	Sayers (1986) (m/Km)	**Cantisani and Loprencipe (2010) (m/Km)**	**Combined categories (m/Km)**	
Very good	≤ 2.0	< 1.42	} ≤ 2.24	Very good to good
Good	1.5-3.5	1.42-2.84		
Fair	2.5-6.0		} 2.25-4.05	Fair to mediocre
Mediocre	3.8-11.0	2.84-4.06		
Poor	> 8.0	> 4.06	> 4.05	Poor

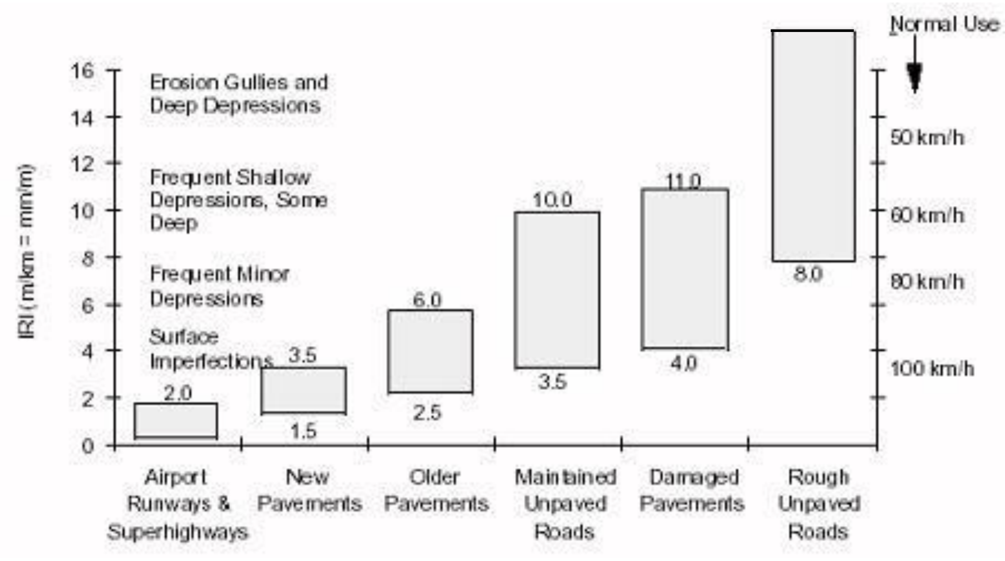

Figure 8- 4: IRI Roughness Scale (Pavia, 2012)

Thus, pavement roughness values used in this study were between 1.5-4 (m/km) for the M6, M61 and M65 motorways and between 2.5-5 (m/km) for the A6 trunk road.

It is important to preserve the road surface with routine and periodic maintenance. The latter includes: surface dressing, spot rehabilitation, overlay and reconstruction; while the routine maintenance includes: crack sealing, patching and edge repair. The description and price of each type of work can be found in (Burningham and Stankevich, 2005), which was used to preserve the surface of the proposed road network in this study.

8.5.2 Secondary Data

Secondary data is huge data necessary for each vehicle used in the economic analysis; it includes the basic characteristics and economic unit costs. The basic characteristics of vehicles are in turn include the physical characteristics, utilization and loading; while the economic unit costs include the vehicle resources and time value (Aswathy et al., 2013).

Seven categories of motorised vehicles were utilized in this study to represent the fleet of vehicles that use the proposed network, as shown in Table 8-4. All the required secondary data were collected using various sources such as the World Bank (2008a); Dft (2013); Bennett and Greenwood (2004); (Road Sector Development Team (RSDT) 2014).

Table 8- 4: Representative Vehicles for Motorized Vehicle Categories

No.	Name as used in HDM-4	Class	Type
1	Motor Cycle	Motor Cycle	Motor Cycle
2	Car/Taxis	Passenger Cars	Medium Car
3	Light Goods Vehicle	Utilities	Light Goods Vehicle
4	2-Axle Rigid HGV	Trucks	Light Truck
5	3 or more-Axle Rigid HGV	Trucks	Heavy Truck
6	Buses Coaches	Buses	Coaches
7	Articulated Truck	Trucks	Articulated Truck

8.5.2.1 Basic Characteristics

- **Physical Characteristics**

Representative vehicle classes and characteristics such as number of axles and number of wheels were obtained from Bennett and Greenwood (2004) as shown in Table E.2 in Appendix E. For passenger car space equivalence (PCSE), the HDM-4 provided default values as can be seen in Table E.3 in Appendix E.

- **Utilization**

The average number of kilometres driven annually, working hours and average life of each type of motorised vehicle were obtained from Bennett and Greenwood (2004) as shown in Table E.4 in Appendix E.

- **Loading**

The equivalent standard axle load factor (ESALF) was calculated using Equation 8.2 (Boamah, 2002). The resulting values of the ESALF for representative vehicles used in this study are shown in Table 8-5.

$$\boldsymbol{ESALF} = \left(\frac{\left(\frac{\boldsymbol{Vehicle\ weight}}{\boldsymbol{Number\ of\ axles}}\right)}{\boldsymbol{8.2}}\right) \quad \text{...} \quad (8.2)$$

Table 8- 5: ESALF for Representative Vehicles

Vehicle Type	Number of Axles	Operating Weight	ESALF
Motor Cycle	2	0.2	0.01
Car Taxis	2	1.2	0.07
Light Goods Vehicle	2	1.5	0.09
2-Axle Rigid HGV	2	2	0.12
3 or more-Axle Rigid HGV	3	13	0.53
Buses Coaches	3	15	0.61
Articulated Truck	5	28	0.68

As a result, the basic characteristics of the fleet motorised vehicles used in this study are shown in Table 8-6.

Table 8- 6: Basic Characteristics of Motorised Vehicle Fleet

Vehicle Name	Physical			Tyres			Utilisation						Loading	
	P.C. Space Equivalence*	Number of Wheels	Number of Axles	Tyre Type	Base Number of Recaps	Retread Costs (%)	Annual Number of Kilometres Travelled as an Average	Working Hours (average) per Year	Average Life (Years)	Vehicle Usage for Private Trips (%)	Passengers Number	Work Related Passenger Trips (%)	Operating Weight (tonnes)	ESALF
Motor cycle	0.5	2	2	Bias-ply	1.3	15	10000	400	10	50	1	50	0.2	0.01
Car/Taxis	1	4	2	Radial-ply	1.3	15	23000	550	10	50	1.5	50	1.2	0.07
Light Goods Vehicle	1	4	2	Radial-ply	1.3	15	30000	1300	8	0	0	0	1.5	0.09
2-Axle Rigid HGV	1.3	4	2	Bias-ply	1.3	15	30000	1300	8	0	0	0	2	0.12
3 or more-Axle Rigid HGV	1.6	10	3	Bias-ply	1.3	15	86000	2050	14	0	0	0	13	0.53
Buses Coaches	1.6	10	3	Bias-ply	1.3	15	70000	1750	12	0	30	75	15	0.61
Articulated Truck	1.8	18	5	Bias-ply	1.3	15	86000	2050	14	0	0	0	28	0.68

*P.C.: Passenger Car

8.5.2.2 Economic Unit Costs

The input data required to calculate the economic unit costs are represented in the following sections. These unit costs can be divided into two main classifications: vehicle resources and the time value.

-Vehicle Resources

UK fuel price, lubricant oil price, new vehicle price, tyre price, crew wage, annual overhead, car maintenance labour and cost of passenger travel time are included in the classification of vehicle resources. All these prices were obtained from various online sources as follows:

- **Price of new vehicle**

The Dft (2014) was used to obtain the percentage of vehicles by type that use petrol, diesel or mains electricity due to the effect of fuel type on vehicle price. Table E.5 in Appendix E reveals that the percentage of cars in 2004 that used petrol, diesel and electricity are equal to 73.28%, 26.72% and 0%, respectively. The percentage of light goods vehicles (LGVs) in the same year that used petrol and diesel are equal to 11% and 88.93%, respectively.

Thus, different websites were used to obtain the average price of the most popular vehicles driven in the UK, as shown in Table E.6 in Appendix E.

- **Fuel Price**

A website of petrol prices was used to obtain the prices of fuel in the UK Petrol Prices (2016). The results are as shown in Table 8.7.

Table 8- 7: UK Petrol Prices (petrol prices, 2016) (accessed 15/12/2016)

	Average	Minimum	Maximum
Unleaded	113.99	108.7	133.9
Diesel	116.37	110.7	134.9
Super Unleaded	128.00	114.9	148.9
Premium Diesel	130.46	118.9	149.9
LPG	58.57	49.7	61.9

- **Lubricating Oil Price**

Halfords website was used to obtain the price of lubricating oil in the UK (Halfords, 2017).

- **Replacement Tyre**

Different websites were used to obtain the average tyre price of different types of vehicles driven in the UK, as shown in Table E.7 in Appendix E.

- **Crew Wage**

Different websites were used to obtain the average crew wages of different types of vehicles used in the UK, as shown in Table E.8 in Appendix E.

- **Annual Overheads**

The Automobile Association's website was used to obtain an estimated cost for owning and operating all the categories of cars in this study (AA, 2014). In addition, DFF International Ltd (2014) was used to obtain the annual overheads of trucks in the UK.

- **Price of Maintenance Labour**

The average rate of maintaining the car by licenced dealers was equal to about £92.11 per hour using the This is Money website (This is Money, 2016); while the price of servicing the car in an independent garage was about £64 using the same website. Thus, the average price of £75 was used in this study for cars and taxis, motor cycles, and light goods vehicle. For trucks and buses, a price of £90 was taken using the same website (This is Money, 2016).

- **Time Value**

There are two types of travel: travel for work and travel for leisure (Bennett and Greenwood, 2004). Passengers are in turn divided into three types: employed people travelling during work hours, employed people travelling outside of working hours and unemployed people. Any savings in working travel time would be used for productive purposes. Therefore, saving in work travel time has the equivalent value of an hourly wage. It is important to mention that saving travel time in any circumstances, including during leisure time, has a value because people generally prefer fast journeys with no congestion and they are always willing to pay more to that end. The willingness to pay is related to income. Thus, a range of 20–25 percent is commonly used in studies, as reported by Bennett and Greenwood (2004). The Dft (2014) was used to obtain the values of working time per person as shown in Table E.9 in Appendix E.

For the cost of cargo time, Rsdt (2014) reported that cost of cargo time is equal to approximately twice the value of working time. Thus, the unit costs used in this study for all types of motorised vehicle are shown in Table 8-8.

Table 8- 8: Economic Unit Costs (£), price for 1997

Vehicle Name	Vehicle Resources								Time Value		
	New Vehicle	Replacement Tyre	Fuel per Litre	Lubricating Oil per Litre	Maintenance Labour per Hour	Crew Wages per Hour	Annual Overheads	Annual Interest (%)	Cost of Passenger Working Time (£/hr)	Cost of Passenger Non-working Time (£/hr)	Cargo per Hour
Motor cycle	1600	18	0.69	3	45	0	1000	6	14	2.8	0
Car/Taxis	13650	36	0.69	3	45	0	4550	6	12.34	2.5	0
Light Goods Vehicle	14232	68	0.69	3	45	4	4550	6	7.3	1.5	14.6
2-Axle Rigid HGV	17800	150	0.69	3	54	6	4460	6	8.62	1.724	17.24
3 or more-Axle Rigid HGV	32600	180	0.69	3	54	6	5800	6	8.62	1.724	17.24
Buses Coaches	130500	210	0.69	3	54	6	8120	6	10	2	0
Articulated Truck	39733	237	0.69	3	54	6	8120	6	8.62	1.724	17.24

8.5.3 Other Data Required by HDM-4

8.5.3.1 Cost of Motorway Construction

Five studies were used to estimate the construction cost of the M65 motorway (sections between junctions 1a to 2) as shown in Table 8-9.

Table 8- 9: Different Estimations for the Price of Road Development

Study number	**1**	**2**	**3**	**4**	**5**
Author	Starkie (2002) cited by Archer and Glaister (2006)	Bayliss and Wood (2002)	Highway Agency cited by Bayliss and Wood (2002)	Affuso et al. (2003)	Transport Watch UK (2008)
Road work type	New motorway (3-lanes)	New open motorway	Widening motorway dual 3 lanes to 4 lanes	Motorway widening from two to three lanes	Motorway dual 3 lanes with shoulder
Price	£ 6.46 m/km (price of 2003)	£20 m/km (price of 2002)	£7.86 m/km (price of 2002)	£8.86 m/km (price of 1999)	£16 m/km (2007 price)
(1997 price)	£5.6 m/km	£17.67 m/km	£6.95 m/km	£8.34 m/km	£12.4 m/km

Thus, a price of £17 m/km (price of 1997) was used in this study as a construction cost of the M65 motorway.

8.5.3.2 Financial cost

In this study and depending on HDM-4's requirements, economic costs were converted to market prices (financial costs) using an indirect tax correction factor as shown in Equation 8.3 (Dft, 2014).

$$\textbf{\textit{Financial Cost}} = \textbf{\textit{Economic Cost}} * (1 + 19\%) \qquad \text{.................} (8.3)$$

8.6 Results of the Project Analysis of HDM-4 Software

To conduct the project analysis of HDM-4, the road network was considered as a group of links and nodes (Kerali et al., 1996). The road sections are represented by links; while the intersections are represented by nodes. Each link has its own physical characteristics and as a result has been analysed individually (Kerali et al., 1998b). The case study chosen to apply the proposed model of changes in land values has also been used for the application of HDM-4. The road network of this case study consisted of three sections of the M6 motorway, two sections of the M61 motorway and three sections of the A6 trunk road, which is the base case (do-nothing case) of the road network. The do-something case for this network focused on adding two sections of the M65 motorway (sections between junctions 1a to 2); which were chosen as an inter-urban road to complete the application tasks of this study, as shown in Figure 8-5. The two sections of the chosen motorway were constructed in 1997 (Cbrd, 2016). The length of the first section is 0.9 km from junction 1a to 1; while the length of the second section is 2.2 km from junction 1 to 2.

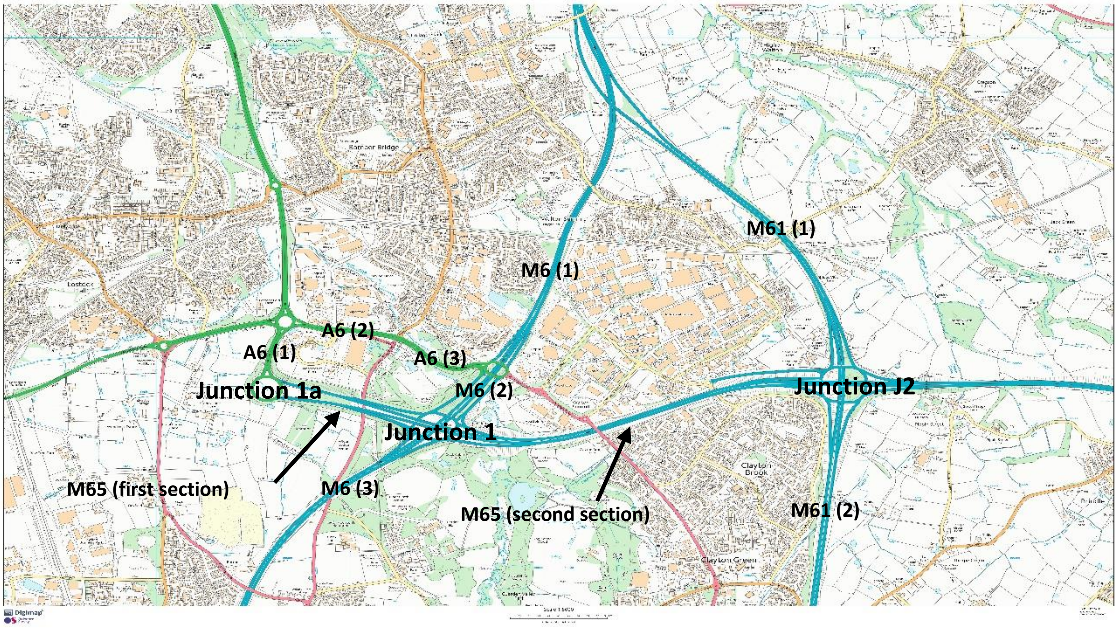

Figure 8- 5: The Sections of the Road Network Used in This Study (© Crown copyright and database rights [2017] OS (Digimap Licence))

Different reports have been obtained from the project analysis of HDM-4 (Archondo-Callao, 2008). One of these reports is the Road Agency and User Cost Streams that calculated two different costs (Aswathy et al., 2013): RACs and RUCs. The RACs result from adding the capital cost and the total maintenance costs; while the RUCs result from adding the VOC, TTC and AC (Aswathy et al., 2013; Gillespie, 1998; Garber and Hoel, 2009). Both the RAC and RUC have been calculated for each year in the analysis period, which was chosen to be for 30 years in this study and within the allowable limit reported by Odoki et al. (2012).

The RUCS includes the savings in the VOC, TTC and the AC (Aswathy et al., 2013; Dft, 2016c; Parkinson, 1981) that has been obtained from another report from the HDM-4, the Comparison of Cost Stream; where the RUC of the do-something case is subtracted from the RUC of the do-nothing case. The RUCSs of the M6 motorway that resulted due to the

M65 motorway road development (sections between junctions 1a and 2) are as shown in Figure 8-6.

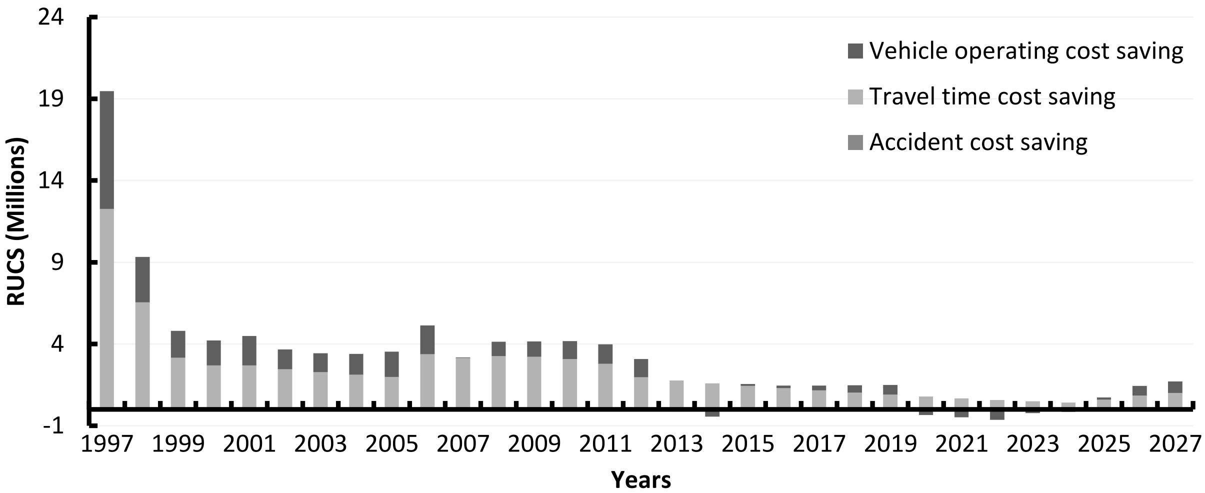

Figure 8- 6: RUCSs (m£) of the M6 Motorway

Figure 8-6 reveals that the RUCS of the M6 motorway decreases with time. The RUCS is about £19 m in 1997 and decreases to nearly half in 1998 to be about £9 m. In 1999, the RUCS is about £5 m and continues to decrease until it reaches to about £0.261 m in 2024. Although the general trend of the RUCS with time is a decreasing trend, there is an increase in the value of the RUCS, especially in 2006. The reason may be due to the maintenance schedule that results in increasing the saving of the vehicle operating cost for that year. It is important to mention that the accident cost saving is invisible in Figure 8-6 due to the small values compared with the savings of both vehicle operating costs and travel time costs.

The RUCSs of the A6 trunk road that were calculated using the HDM-4 are as shown in Figure 8-7.

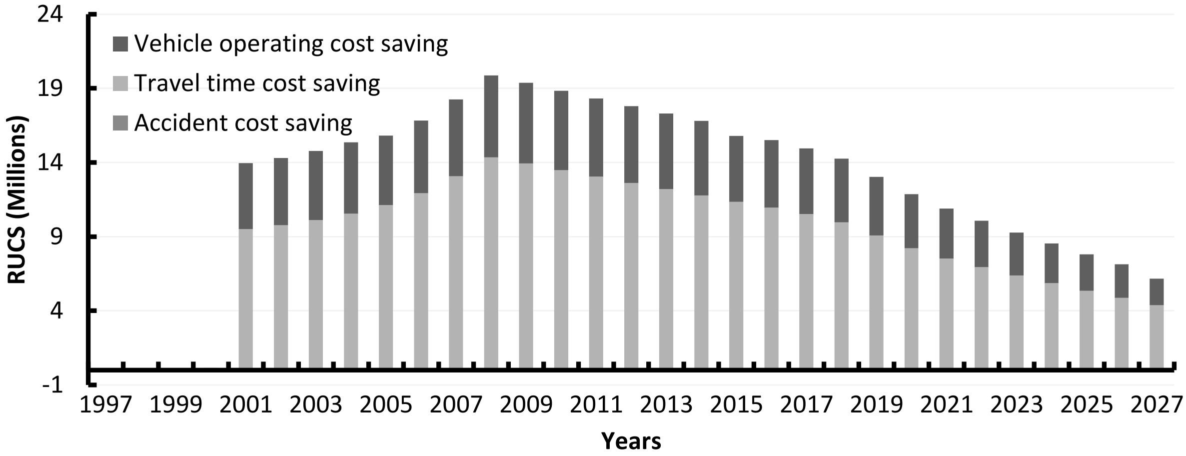

Figure 8- 7: RUCSs (m£) of the A6 Trunk Road

Figure 8-7 reveals that no savings have been obtained in the first years of analysis from 1997-2000 due to the traffic volumes that are equal in both cases of analysis. The RUCS is equal to about £14 m in 2001, which continues to increase until 2008, to reach about £20 m and then decreases to about £7 m by 2027.

The RUCSs of the M61 motorway for each year in the analysis period are shown in Figure 8-8.

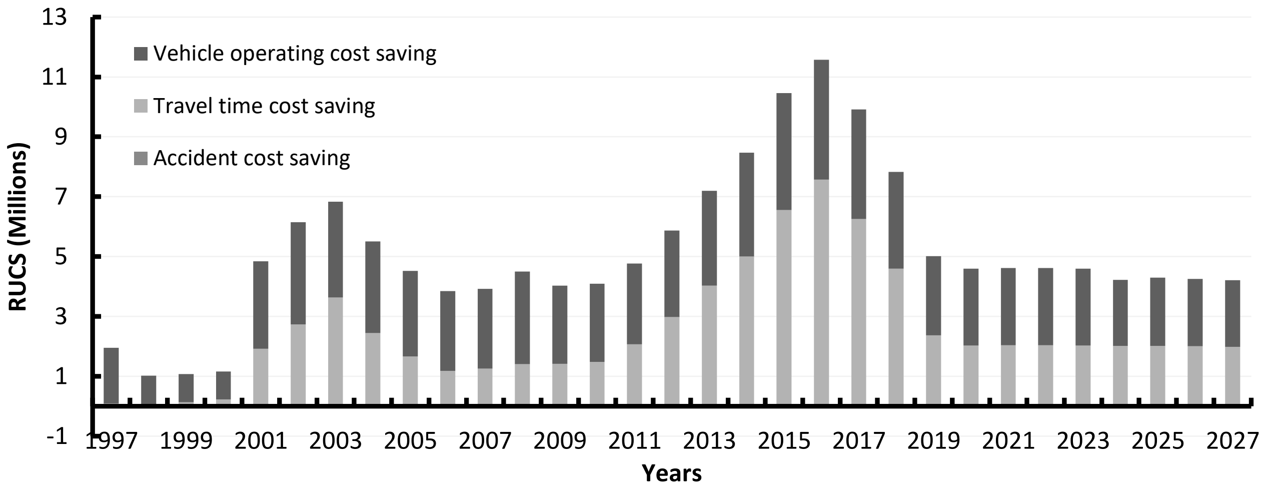

Figure 8- 8: RUCSs (m£) of the M61 Motorway

Figure 8-8 reveals that the calculated values of the RUCSs have changed over the analysis period. There are two peaks: the first peak is about £7 m in year 2003 while the second peak is about £11.5 m in 2016.

The RUCSs of the M65 motorway over the time period are shown in figure 8-9.

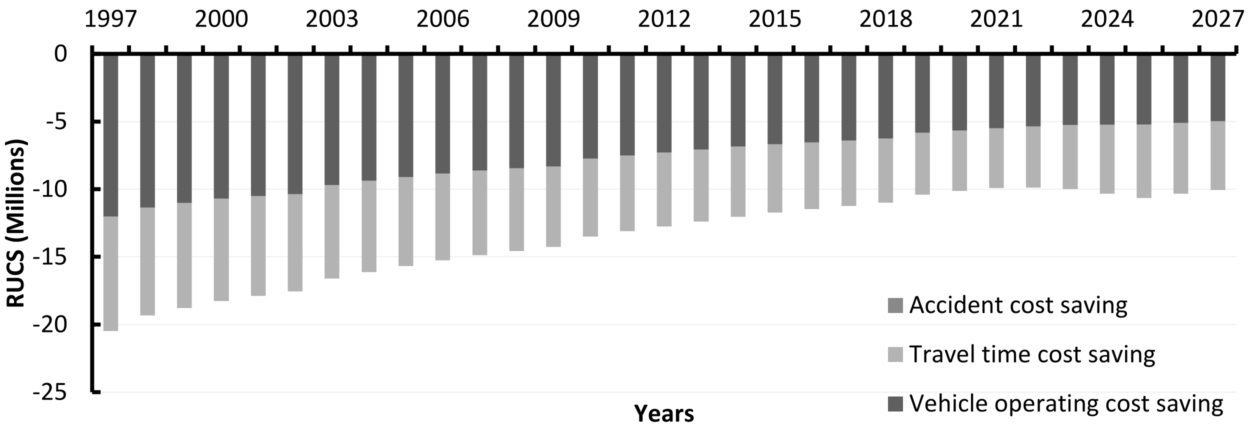

Figure 8- 9: RUCSs (m£) calculated for motorway M65

Figure 8-9 reveals that the RUCSs calculated for the M65 motorway are negative over the analysis period, which means that there is no saving for the users of this motorway.

Thus, the distribution of the RUCSs over the analysis period is different for each road due to many factors that are related to the response of the network users to the new road (Robinson, 2008); this in turn is dependent on the amount of cost saving (Dft, 2016c) and accessibility obtained from the new road (Weisbrod, 2008), and furthermore on the road's characteristics, such as road geometry and road surface roughness (Robinson, 2008). The summation of the RUCSs for all roads used in the network are shown Figure 8-10.

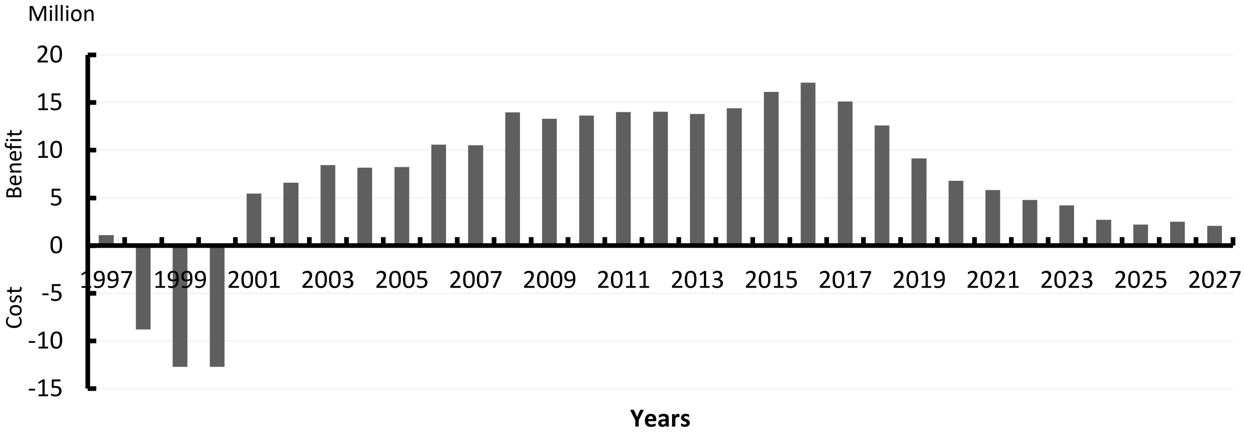

Figure 8- 10: The Summation of RUCSs (m£) for all roads

Figure 8-10 reveals that RUCSs are equal to £1.13 m in 1997. Three years later, only the costs reached to about £12.5 m in 1999 and 2000. From 2001 onwards, the benefits increased until the maximum benefit in 2016 of about £17 m. From 2016 to the end year of the analysis, there is a decrease in the trend of benefits that reaches to about £4 m in 2024.

For a similar project, (Litman, 2006; 2017a) estimated the costs and benefits of a road section over the analysis period as shown in Figure 8-11. This figure reveals that in the first year of analysis, there is only the construction cost of the new road. In the later years, there are benefits that decreased over the analysis period. Litman's estimation includes detailed costs and benefits relating to the diverted and induced traffic over the analysis period.

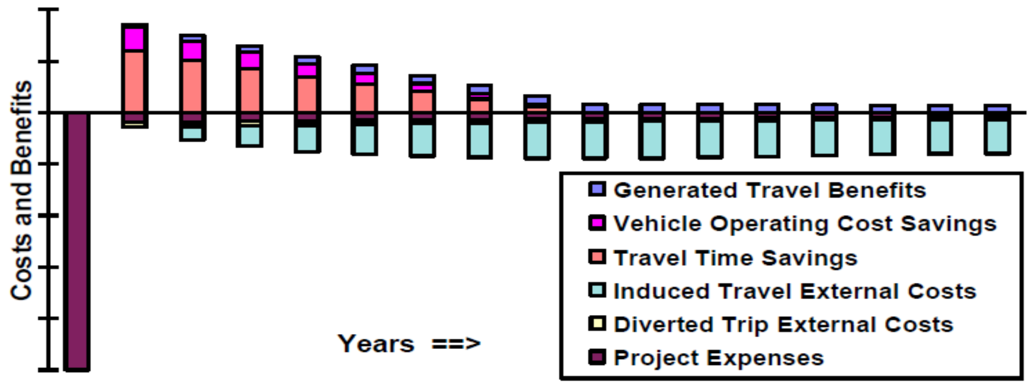

Figure 8- 11: The Estimated Costs and Benefits (Litman, 2001; 2017a)

8.7 The Accuracy of the Results

It is important to test the accuracy of the results obtained from the HDM-4. Thus, the VOC which is considered as an important item in the RUC (Garber and Hoel, 2009) was used to check the accuracy of these results. The VOCs of the A6 trunk road, M6 and M61 motorways that were calculated using HDM-4 were compared with the VOCs provided by Mackie et al. (2003), as the latter provided information about VOCs under similar conditions in the UK. As a result, a range of VOCs equal to (12-14) (pence/min.) was chosen to compare with the VOC of the A6 trunk road obtained in this study.

The VOCs of Mackie's study are in prices of 1994, which were changed to the prices of the required years by adding the rate of inflation using Morley (2017).

The total VOCs (£m) of the A6 trunk road calculated using the HDM-4 were changed to VOC (£/km) and then compared with the range of VOCs of Mackie's study, as shown in Figure 8-12. There are some differences that are due to Mackie's study using only petrol cars, as the results obtained in this study used a combination of petrol and diesel cars. The

VOC obtained using HDM-4 during the analysis period ranged from 0.13-0.18 (£/km); while the VOC of Mackie's study ranged from 0.12-0.18 (£/km), which gives a good indication about the accuracy of the HDM-4 results.

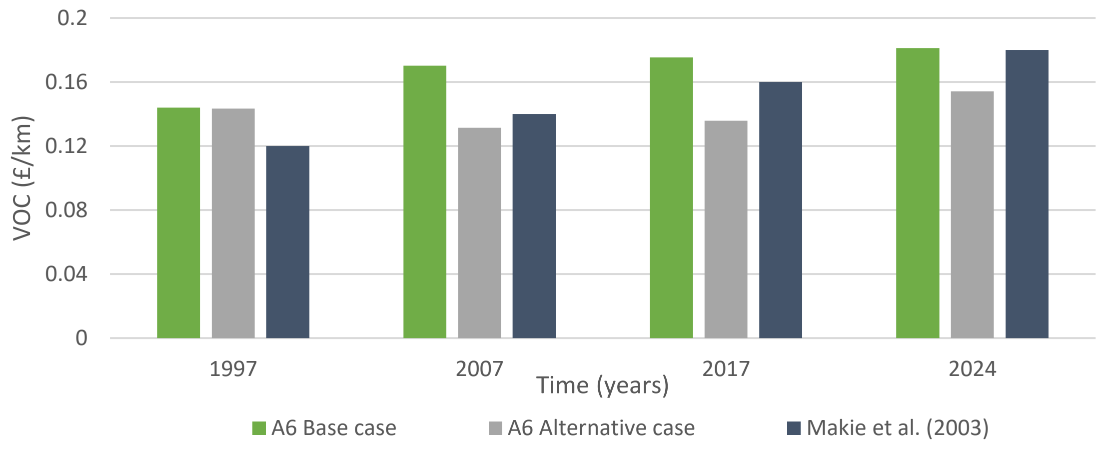

Figure 8- 12: VOC of the A6 Trunk Road and the VOC of Mackie's Study

Figure 8-12 also reveals that VOCs in 1997 for both base and do-something cases are equal and there is no effect from the development of the M65 motorway; while there are reasonable effects in 2007, 2017 and 2024 due to the development of the M65 motorway that result in decreasing the VOCs for the do-something cases compared to the base cases.

The information about the VOC obtained from Mackie's study (Mackie et al., 2003) was also used to compare with the VOCs of the M6 and M61 motorways that were calculated using HDM-4. As a result, a range of VOCs equal to (13-15) (pence/min.) was used to compare with the VOCs of the M6 and M61 motorways. The VOCs of Mackie's study are in prices of 1994, which were changed to the prices of the required years using Morley (2017). The comparison of the VOCs (£/km) of the M6 and M61 motorways and the VOCs of Mackie's study are as shown in Figure 8-13.

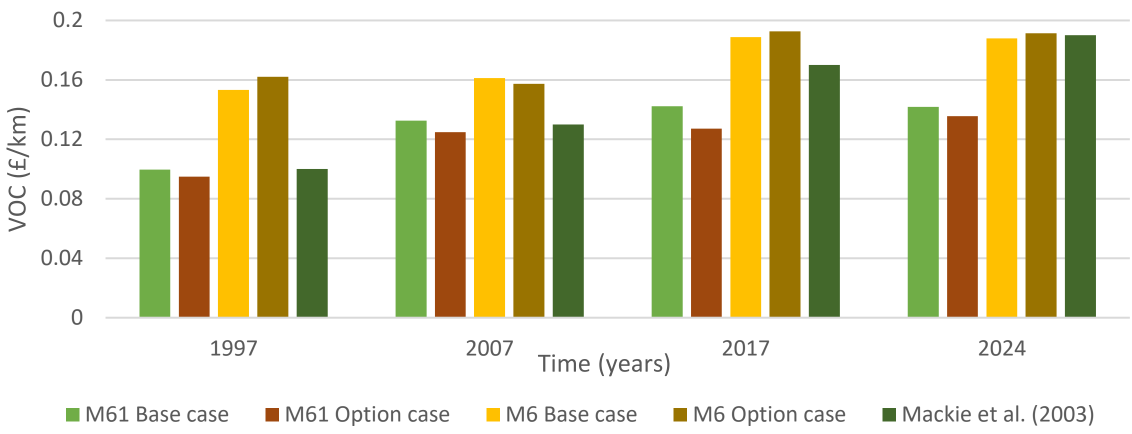

Figure 8- 13: The VOC of the M6 and M61 Motorways and the VOC of Mackie's Study

Good results were obtained from the comparison shown in Figure 8-13, which confirms that the range of VOCs for the M6 and M61 motorways is equal to the range of VOCs in the Mackie study, which is equal to 0.1-0.19 (£/km).

Figure 8-13 also reveals that VOCs for the do-something case of the M61 are less than that for the base cases in 1997, 2007, 2017 and 2024, due to the development of M65 motorway; but there is no relation between the option and base cases for the M6 motorway for the same years, due to the development of the M65 motorway. This means that the M6 and M61 motorways obtained a little effect compared to that obtained by the A6 trunk road from the development of the two sections of the M65 motorway.

The accuracy of the results obtained from HDM-4 is dependent upon (Aswathy et al., 2013; Bennett and Paterson, 2000): (1) the input data and its representing the reality of the prevailing conditions; (2) the predictability of the HDM-4's models to fit the actual behaviour of the various factors and the interactions between them (Bennett and Paterson, 2000).

The accuracy of travel time savings achieved in this study using HDM-4 was checked by comparing the travel time savings obtained in this study with travel time savings reported by Mackie's study (Mackie et al., 2003), which is shown in Table 8-10.

Table 8- 10: Car Users' Values of Travel Time Savings by Mode (Mackie et al., 2003)

Trip purpose and distance		**Car Users**		
		VTTS $_{car}$	**VTTS $_{rail}$**	**VTTS $_{bus}$**
		Pence per minute	**as % of VTTS $_{car}$**	**as % of VTTS $_{car}$**
Commute	**2 miles**	3.6	94	131
	10 miles	5.4	85	119
	25 miles	6.9	78	109
Leisure	**2 miles**	3.2	97	134
	10 miles	4.9	84	118
	50 miles	9.6	75	104
	200 miles	13.8	67	93

To calculate the travel time saving using the above table for the A6 trunk road, many attempts have been made to find the ideal percentages of trips based on trip distance. It was found that the most reasonable percentages were as follows: 60% of trips were for commuting purposes and 40% of trips were for leisure purposes. Trips for commuting purposes consisted of 2% (2% cars+0% buses), 28% (24% cars+4% buses) and 70% (55% cars+15% buses) for 2, 10 and 25 miles, respectively. Trips for leisure purposes consisted of 2% (2% cars+0% buses), 8% (6% cars+2% buses), 20% (15% cars+5% buses) and 70% (50% cars+20% buses) for 2, 10, 50 and 200 miles, respectively. The obtained result has been multiplied by the average time needed by a car to pass along the road using the effective speed of the trunk road (DMRB, 2002), which is equal to 2 minutes. The result has then been divided by the road length to obtain the travel time saving per km, which is around 8 pence; while the average travel time saving obtained using HDM-4 is 10 (pence/km). This reliable result confirms the accuracy of the calculation of travel time saving obtained using HDM-4.

Smaller values of travel time savings have been obtained for the M6 and M61 motorways compared with that obtained for the A6 trunk road. Thus, the accuracy test has only been done for the results of the A6 trunk road.

8.8 Conclusions

The project analysis of HDM-4 was used to calculate the RUCS as a primary impact from the development of the M65 motorway. The distribution of the resulting RUCSs over the analysis period is different for each road due to many factors that are related to the response of the network users to the new road (Robinson, 2008). This is dependent on the amount of saving in the travel cost (Dft, 2016c; Botham, 1980) that in turn affects the accessibility obtained from such a project (Weisbrod, 2008; Linneker and Spence, 1996). The decreasing in the travel cost is dependent on the status of the network, i.e. traffic density (Combes and Lafourcade, 2005), and on the type and quality of the new road development (Robinson, 2008). Valuable results regarding the accuracy of the HDM-4's results were obtained using Mackie's study (Mackie et al., 2003).

CHAPTER NINE
PRIMARY VERSUS SECONDARY IMPACTS OF ROAD DEVELOPMENT

9.1 Introduction

This chapter presents a comparison of the primary and the secondary impacts for a road development for up to 30 years from the road's opening. It is organized in five sections: the concepts of CBA and EIA are presented in the first section. The second section reviews the data issues; while the third section outlines the comparison between the primary and the secondary impacts of road development, which is followed by a CBA-EIA comparison. A brief summary of the results obtained from this chapter is presented in the fifth section.

9.2 The Concepts of CBA and EIA

The economic evaluation tool CBA (Arrow et al., 1996) is focused on calculating the monetary equivalents that are related to the primary impacts of road development. The RUCSs are calculated using the HDM-4 for each year in the 30 years of the analysis period that starts from the roadworks' completion (see section 8.6 for more details).

The EIA is the determination of the impacts of the project on the economy of a well-defined area (Gkritza et al., 2008); it was measured in this study in terms of increasing the values of land affected by the road development using the developed model (more information about the resulted CLVs is available in Chapter 7).

Both CBA and EIA have been used in this study to complement each other to help the decision maker, (i.e. economist, road planner and politician) to obtain a broader view of all the impacts resulting from road development. Using the two analyses is important to overcome the shortcomings of the traditional way that is widely used to evaluate the viability of the project's options, i.e. CBA; which is the subject of some debate due to its sensitivity and uncertainty, as reported by Börjesson et al. (2014a) and De Jong et al. (2007). In addition, it was reported that the impact of generated traffic due to changes in land use is not explicitly addressed in the conventional CBA (Börjesson et al., 2014b) (more details are found in section 2.4.2). All these issues confirm the need for another analysis, such as the EIA model (the developed model of change in land values), which can work with the CBA to have a complete view of all the impacts, primary and secondary, obtained from the road development.

9.3 Data Issues

To compare the primary and the secondary impacts of road development, there are two data issues needed to create a common base for price comparison: cost and prices' conversions and traffic data.

9.3.1 Cost and Prices' Conversions

The application of the developed model was focused on calculating the CLVs for land affected by the road development (see Chapter 7 for more information). The obtained CLVs for the prices of 2015 were converted to the prices of 1997, the year of the road works' completion and the road's opening in order to be compatible with the RUCSs calculated using the HDM-4. The price conversion was achieved using Morley's calculator (Morley, 2017) to convert historical prices into their equivalent current prices or vice versa, i.e. between any two years from 1949 to 2017. Morley (2017) used data of the recent inflation rates in the UK, which were obtained from the Office for National Statistics. In addition, there are other rules for economic evaluation, which were conducted to complete the requirement of this research, such as the adjustment for the time value of money and discounting both costs and benefits to the present values of money, as reported by recent studies such as Boardman et al. (2006), Layard and Glaister (2012), Alder and Posner (2000), Garber and Hoel (2009) and Robinson (2008) (see Chapter 2 for more details).

9.3.2 Traffic Data

The RUCSs were obtained with the aid of HDM-4 as primary impacts of road development (more details about the resulting RUCSs are available in section 8.6). Different percentages of generated traffic have been adopted in recent studies (Rodier et al., 2001; Litman, 2017a), as mentioned in Chapter 3. The differences are due to the decreasing value of transport costs resulting from road development (Dft, 2016c), which changed the land use in the affected area and then generated traffic as a result; and the consumers' ability to exploit the travel cost reduction (Robinson, 2008). In other words, a large decrease in travel costs results in a higher percentage of generated traffic and vice versa (Goodwin, 1996). The decrease in the travel costs is dependent on the traffic density and the congestion in the road network (Combes and Lafourcade, 2005).

Generated traffic may be considered in terms of diverted traffic (DT) and induced traffic (IT). Traffic generated in the short term, i.e. up to halfway through year two from the start of the project's life is represented by DT; while IT is the term used for traffic that is generated in the long term, i.e. from the second half of year two onwards (Litman, 2017a). There are significant impacts from generated traffic: (1) increased external costs due to the resulting traffic congestion, parking demand, pollution, environmental effects and vehicle crash damages. The average external cost of IT has been assumed to be about £0.23 per vehicle-kilometre (Litman, 2017a) that includes parking cost, external crash damages, congestion, environmental damages, medical expenses and crash pain; (2) benefits derived from generated traffic tend to be uncertain and are subject to change with any increase in the RUCs (Litman and Colman, 2001).

The benefits derived from generated traffic can be calculated using the rule of half (Small, 1998), which is approximately half the benefit per trip of that obtained by the original road user (Small, 1998).

Real traffic data from the road network of the county of Lancashire was used as an input in HDM-4 to determine the RUCSs for all road users over the 30 years of the analysis period (see Chapter 8 for more details). The average percentages of generated traffic for both diverted traffic and induced traffic shown in Table 3-2 were used to obtain the RUCS of the generated traffic. The benefits of the generated traffic were calculated in this study using the rule of half.

9.4 Comparison of the Primary and Secondary Impacts of Road Development over a Long Analysis Period

The primary impacts of road development were compared with the secondary impacts of changes in land values, with a view to examine whether they may follow similar trends and as a result, provide a more comprehensive appraisal tool for road investments. Thus, the RUCSs of the generated traffic were compared with the CLVs over a long analysis period, from the year of the road's opening up to 30 years later. Three main periods were found through this comparison, as shown in Figure 9-1, which were denoted by the change in the trend of the RUCS' distribution over the analysis period. The first period is from year 0 (year of the road's opening) to year 3; the second period is from year 4 after the road's opening to year 19. The last period starts from year 20 and finishes at the end of the analysis (year 30).

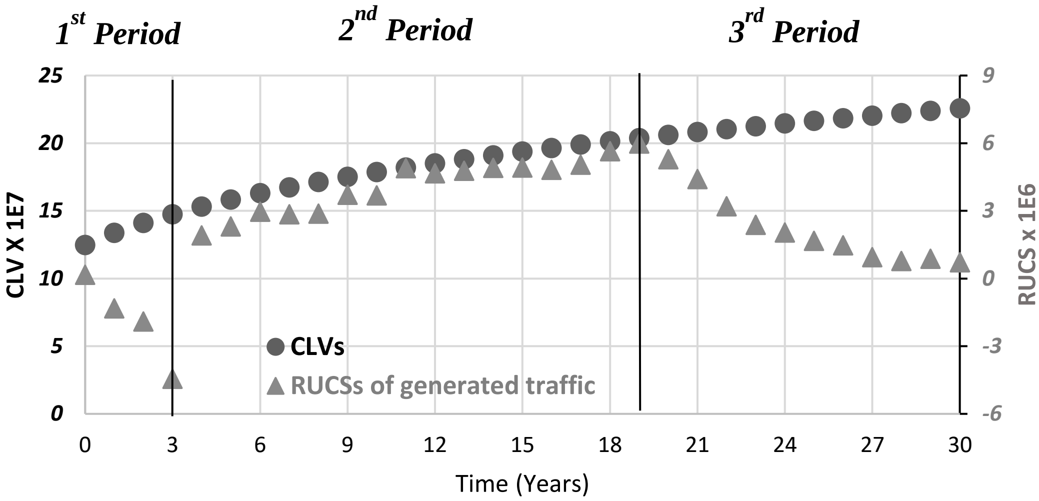

Figure 9- 1: Comparison between RUCSs of Generated Traffic and CLVs over the Analysis Period

It may be seen that the CLVs, shown in Figure 9-1 increased over the three periods of analysis, but the rate of their changes decreases with time. This result is consistent with the result obtained by Chernobai et al. (2011). The Lancashire population increased about 3% through these 30 years (Office for National Statistics, 2011).

The first period of analysis (year 0-3) shows an inverse behaviour of primary and secondary impacts of road development. It shows a decrease in the RUCS of generated traffic from 0.2 to -4.5 (£m) due to the growth in network capacity resulting from the development of the new road. Such growth in network capacity leads to an increase in the average running speed, which in turn increases the fuel consumption, the main element of the VOC (Zaabar and Chatti, 2010); and decreases the savings of the road user cost as a result. The same period also shows an increase in the changes of land values from £125 m to £147 m as a secondary impact of road development.

The second period of analysis reveals the same behaviour of primary and secondary impacts. The change in land values increases from 147 to 203 (£m) that resulted in a rate of change less than that shown in the first period of analysis. Moreover, the second period shows an increase in the RUCS from 4.5 to 6 (£m) due to traffic volume generated in this period that decreases the average running speed, which in turn increases the RUCS as a result.

The third period of analysis is from 19 years after the road's opening up to 30 years later. This period shows an inverse behaviour of primary and secondary impacts of road development. The RUCS decreases from 6 to 0.96 (£m) due to normal traffic growth that reaches to about the capacity of the road; this decreased the road serviceability and then the RUCS as a result. The change in land values for this period of analysis increases from 203 to 220 (£m). The rate of change in this period is smaller than that shown in the first and second periods due to the minimizing of the change in land values with time.

As a result, the primary and secondary impacts in the first and the third period of analysis behaved inversely. These two mentioned periods represent about half the whole period of analysis; while the rest of the analysis period showed similar behaviour for the CLV and the RUCS, i.e. both of them increased in spite of the difference in their magnitudes, from £ 4.5 m to £6 m for the RUCS and from £147 m to £203 m for the CLV, as shown in Figure 9.1. This proves that the benefits obtained from CLVs, the secondary impact of an inter-urban road development, are much more than those obtained from the RUCSs, the primary impact of the same development. Despite these high secondary benefits, i.e. CLVs obtained from the road development, the government financial revenues derived from such benefits are only equal to the change in the tax applied. The range of the tax applied chosen for this study was 4 to 8 percent from the land value; which was chosen due to the variety in the characteristics of the land used to apply the developed model, such as the land use, the land area and the distance from the road. To this end, applying the case study in Lancashire with an area equal to 16,238,468.9 m^2 demonstrated that the government revenue for the case of 5% tax was increased from £ 6 m in 1997 (year of the road's opening) to about £8 m in 2007 (10 years after the year of the road's opening) and increased to about £10 m in 2017 (20 years after the year of the road's opening).

The factors affecting the degree of similarity in terms of the trend of both the primary and the secondary impacts of road development are the traffic prediction and the response of the network users to the new inter-urban road. The users' response is associated with the increased accessibility that was obtained from the new road. This is in an agreement with Weisbrod (2008) and Linneker and Spence (1996) who reported that the amount of saving in the travel cost affects the accessibility obtained from the new road. The decreases in the travel cost may be attributed to the status of the network, i.e. traffic density, and also the type and quality of the new road development. Moreover, the limitation of the proposed model of changes in land values in terms of the variables used and particularly in their maximum and minimum values also affects the degree of similarity.

The result obtained in this study was based on using real traffic volumes and the conditions associated with the chosen case study, such as the geometric design of all road sections used in the HDM-4 application in terms of their lengths, carriageway widths, rises and falls, horizontal curvatures and their speed limit.

9.5 CBA-EIA Comparison

A CBA-EIA comparison was used to test the similarities in the trends of both RUCSs and CLVs over the long term. Some rules of transportation economics that were reported in recent studies (WMO, 2007) were taken into account in this comparison. These rules were related to the individual presentation of the results for both CBA and EIA, not adding their results together, to avoid double counting of the costs or benefits and adjusting the time value of money for both the CLVs and the RUCSs results, i.e. predicting at present values.

A comparison of the results obtained from HDM-4 and the CLV model in terms of their geographic scope, ability to obtain their direct benefits and follow-on benefits, input data used, the time value of money used in the two approaches, analysis period and the quantitative values resulting from the two models are shown in Table 9-1.

Table 9- 1: Comparison of the Results Obtained from HDM-4 and CLV models

	Results Obtained	
Criteria	**CBA Model of HDM-4 Software**	**CLV Model**
Geographic Scope	CBA analysed the road sections of the Lancashire case study and determined the benefits for all road users and non-users (despite their living or working location). The benefits for road users have been obtained from the decreasing of their travel time, VOC and the number of accidents; while the benefits for non-users have been obtained from the decreasing of the environmental effects, in terms of emissions by vehicle type and energy usage.	EIA model determined the CLV benefits in a well-defined area of about 16,238,469m^2 in Lancashire, which was chosen after taking into account the model's limitation in terms of the distance variable and the access points available in the case study used for the application of the proposed model. The access points of inter-urban roads play an important role for these roads due to their full control of access.

Direct Benefits	CBA analysed the direct impacts of road development in terms of the economic, safety and the environmental impacts. The economic impacts were represented in the HDM-4 by decreasing the VOCs and travel time costs for road users; while the safety impacts were calculated in terms of the decreasing number of accidents for road users. The environmental impacts were represented in the HDM-4 by the decreasing emissions and the energy usage, which in turn affected road users and non-users.		EIA did not deal with the direct impacts of road development.
Follows-on Benefits	CBA did not deal with the follow-on benefits such as the indirect benefits and the induced benefits.		EIA analysed the changes in land values as a consequent economic impact (indirect impact) of the road development that resulted from increasing the economic activities due to the road development. The induced impacts have not been calculated in this study due to the unavailability of the real data needed to calculate such an impact.
Input Data	CBA model of HDM-4 needed considerably huge input data. The primary data includes the traffic volume data survey and the pavement condition for all road sections used in the project analysis of HDM-4; while the secondary data includes the basic characteristics and economic unit costs for each vehicle used in the same analysis of HDM-4.		EIA model needed data regarding the characterisation of each cell of the land affected by the road development. These characteristics are the distance from the cell centroid to the nearest access point of the road in question, area of land cell and type of land use for each cell.
Time Value of Money	Adjusted for the time value of money		Adjusted for the time value of money
Quantitative Values	**1st Period**	0.2-4.5 (£m)	125-147 (£m)
	2nd Period	4.5-6 (£m)	147-203 (£m)

	3rd Period	6-0.96 (£m)	203-220 (£m)
Analysis Period	CBA model of HDM-4 has the ability to conduct the project analysis for up to 50 years including the years of roadworks and construction.		CLV model calculated these changes from 3 years before roadworks' completion to 30 years after. These 3 years were included in the model to take into account the negative effects of an announcement about the road investment in the developed model.
Double Counting	Presents the result of CBA individually to avoid double counting of costs and benefits		Presents the result of CLV model individually to avoid double counting of costs and benefits

9.6 Summary

To sum up, the result obtained from the comparison of the CLVs and the RUCSs proved that the two impacts behaved differently in the three periods found in this comparison. The differences were due to their geographic scale used in the two analyses, types of benefits used in the two models' calculations, input data used and specifically, in the outcomes obtained. These differences prove the importance of the model developed in this study to achieve the CLVs resulting as a secondary impact of the M65 motorway development, which cannot be obtained using conventional CBA. Thus, the CLVs which resulted from applying the developed model can be used with the CBA to help the decision maker to attain all the impacts stemming from the road development over the long term, to rank the project's options and choose the best option for investing in road infrastructure.

CHAPTER TEN
DISCUSSION

10.1 Introduction

A discussion of the results obtained from this study regarding the proposed model of change in land values and the comparison between the primary and the secondary impacts of an inter-urban road development are presented in this chapter. It is arranged as follows: a discussion of the developed model of change in land values is carried out in the first section; while the use of the developed model is presented in the second section. The value of the developed model is illustrated in the third section. The fourth section reviews the model's limitations, which are related to the variables used in the developed model and the use of artificial data for land values. The fifth section presents the model's improvement; while the novelty of this study is illustrated in the sixth section. The traffic issues are presented in the seventh section and the double counting of the costs and benefits is reviewed in the eighth section. The ninth section presents the project analysis of HDM-4. Finally, the tenth section illustrates the benefits obtained from the GIS system.

10.2 Model of Change in Land Values

The model of change in land values developed in this study helps to obtain one of the secondary impacts of road development considered by the CLVs, which were captured for each year in the 30 years of the analysis period starting from the road's opening. Kelly (1994) stated the difficulty of estimating the precise impact of a transportation project on the values of the adjacent land, especially the long-term impact, but the developed model proved its capability to predict the change in land values due to road development. The prediction ability of the developed model was evaluated with a verification test, which used historical data from the Zoopla website (Zoopla, 2017) and compared it with the CLVs estimated by using the developed model. A strong correlation coefficient equal to 0.92 was obtained between the historical land values and the computed land values, which proved a good estimation of the change in land values had been computed using the developed model.

The CLVs obtained from applying the developed model resulted due to three existing sets of important conditions necessary for promoting these CLVs: the road investment conditions, the economic conditions and the government guidelines and institutional conditions. These three types of conditions were reported by Banister and Berechman (2001) as important and their existence is essential to achieve the development of the affected land. As a result, the road project plays a supporting role for the change in land values and particularly when the other conditions mentioned above are presented. The existence of only one or two of these conditions limited the change in land values. More information about these three sets of conditions may be found elsewhere (Banister and Berechman, 2001). In addition, the CLVs that resulted from increasing the economic activities due to road development are specific to a geographic area and are affected by the response of the network users to the new road and the availability of the access points for the road in question. These access points play an essential role in the economic development of the adjacent land, especially for inter-urban roads (more information is available in Chapter Two). As a result, only land near access points of the inter-urban road is affected by the development of the new road, due to decreasing transport costs; in turn this leads to an increase in the economic activities of the land and an increase in the land values. The most benefits are seen for the land which is located near the access point of the new road and has a close proximity to an urban area.

10.3 Use of the Model of Change in Land Value

The model developed in this study is one of the EIA models. This model was proposed to obtain more knowledge about the yearly increase in the values of land affected by road development for up to 30 years of road life. The developed model as a result offers a complementary method to be used with the CBA to help the road appraisal to have a more realistic view through obtaining all the long-term impacts from the road development and also to aid the choice of the best option for investing in road infrastructure. In addition, the proposed model was developed to facilitate the comparison of the CBA-EIA that showed six differences between these two analyses. These differences are related to: the geographic scope included in the two analyses and the input data used; the road benefits that have been analysed; the length of the analysis period and the obtained results (more details are found in section 9.5). These differences prove that the developed model focused on issues completely different from that of the CBA, which in turn confirm the importance of using the developed model in the appraisal process of the road investment.

10.4 Value of the Model

The developed model of change in land values could be used macroscopically to assess the wider impacts of a one-transport project. This model can make a difference in the evaluation process of the road investment, change the ranking of the project's options and aid the selection of the option that will bring the highest benefits for the affected area. It may ultimately benefit all parties working to evaluate the project's options such as the economists, land-owners, politicians, engineers and the decision makers. Moreover, this model can help with both road economy and road management of developed countries, especially in the United Kingdom.

The model developed in this study facilitated the comparison of its results with the primary impacts of road development over the analysis period. This comparison would enable the appraiser by including all the long-term impacts in the evaluation process and in choosing the best option for the road investment. In addition, this comparison could make a significant contribution towards saving a large amount of money that may be lost each year during the road's life, due to the use of a CBA appraisal tool that does not deal with the secondary impact of the road development, which in turn leads to the choice of an unwise option for the road investment.

During the second period of analysis that extended between year 4 after the road's opening and year 19, the CLVs obtained using the proposed model showed the same increase as the RUCSs. These RUCSs obtained using the HDM-4 were about 1-3% from the calculated CLVs. Accordingly, the produced model can be used to estimate the RUCSs instead of using the traditional methods.

10.5 Model Limitations

10.5.1 Limitations Related to the Variables Used in the Developed Model of the Change in Land Values

The methodology used to choose the variables for the proposed model reviewed different models, chose their common variables and then used these chosen variables to develop the model of change in land values. Thus, the model proposed in this study was dependent completely on these models and their variables. All these recent models concerned essentially urban roads and only one type of land use, but the model proposed in this study focuses on inter-urban roads. Using models that consider the inter-urban roads may improve the developed model through employing different independent variables, but it seems that it would have an insignificant influence on the model developed in this study due to the result obtained from the step-wise regression analysis of the SPSS software. This analysis was applied in the building process of the developed model due to its ability to remove the unnecessary variables from the proposed model. In this study, this analysis used the four independent variables in the developed model due to their importance in estimating the CLVs as an impact of an inter-urban road. In addition, the step-wise regression analysis has the ability to calculate the coefficient of determination (R^2) for different cases of the proposed model, i.e. a case of including only one independent variable, a case of including two independent variables and so on and then choosing the case that gives the highest R^2. In this study, the highest R^2 was equal to 0.821 and it was obtained in the case of using the four independent variables altogether. The capability of the regression analysis to remove the insignificant variables and allow only for the important variables to be included in the regression model was reported by Nazif et al. (2016), who mentioned the importance of the step-wise regression analysis in model building to remove the unnecessary variables from the proposed model.

The limits (maximum and the minimum values) for each independent variable of the developed model were obtained from the same models that focused on urban roads (see Chapter Five for more details). Changing the limits of the independent variables may improve the developed model, but it appears that it would have an unimportant influence on the model developed in this study due to the result of the verification test. This test was used to evaluate the capabilities of the proposed model to estimate the change in land values. The verification test showed an informative result for the estimation of the developed model due to the strong correlation coefficient between the PCLVs obtained from the historical values and the PCLVs obtained from the application of the developed model (see section 6.2.3 for more detail).

10.5.2 Limitations Due to the Use of Artificial Data of Land Values

A random number generator method provided by MS Excel was used in this study to generate artificial data of land values due to the unavailability of real data for public use in the UK. The random number generator method has been used in many scientific applications ((Park and Miller, 1988; Wagenaar, 1972) due to its capability to provide artificial data as a representative of real data. The use of the real data may improve the developed model but it seems it would have an insignificant influence on the developed model due to the result of the verification test. This test was used to evaluate the capabilities of the developed model and its result showed that the computed land values using the developed model were similar to the actual data of land value.

10.6 Model Improvement

Modelling the impacts of road development on land values is a challenging issue; it may be difficult to determine the impact of the road development on land values, especially the long-term impact. It may be affected by many factors; such as the characteristics of the population in the affected region, the extent of decreasing the travel cost due to the new development (Garber and Hoel, 2009; DETR, 1999) and the amount of traffic generated due to the change in land use because of the two-way relationship between them (Mackett, 1993; Kockelman et al., 2002; Chang, 2006).

The proposed model of change in land values could be improved if real prices of land were used instead of the average estimations of per-hectare prices for only three types of land use (DCLG, 2015). In addition, the change in land use can help in predicting the traffic generated due to such a change, as opposed to the change in land values which cannot give any estimation about the generated traffic (see section 2.2 for more detail).

A more complex method to obtain the distance variable for the application of the developed model could be used. This method would consider more detailed traffic characteristics such as the length of the road section and the speed of vehicle that uses the section in question. In other words, using the network distance instead of the straight distance to apply the proposed model (more details are found in section 7.4.5). The importance of using the network distance in the application of the developed model was reported in Dziauddin's study (Dziauddin, 2009). The network distance was not included in this study due to the infinite options the road user has to travel from the centre of a specific cell to the nearest access point of the inter-urban road. To this end, it was decided to use straight distances to connect the centre of each cell to the nearest access point to estimate the CLVs for each year in the 30 years of analysis of this study. However, good estimations of the CLVs were obtained from the application of the developed model and these estimations may be modified to consider the network distance; this approach will be more difficult to obtain but it may provide a more accurate result.

10.7 Novelty

The impacts of changes in the transportation infrastructure on the value of adjacent property have been a significant issue for urban economists; however, their developed models have focused mainly on the impacts of urban roads on the adjacent property values, especially those of residential or commercial use. These models were regression models which give the price of a property depending on its attractiveness, i.e. the number of rooms, the number of bathrooms, the distance to the CBD, the distance to the nearest road.

For the models that have been developed by transportation planners, these models have attempted to describe the relationship between transportation investments and changes in land use in urban regions (Iacono et al., 2008). As a result, all the models developed by the two approaches mainly have concerned urban roads.

To address this gap, this study integrated the above two approaches by producing a model capable of calculating the changes in land values as an impact of inter-urban road development and linked it with the output of conventional road project appraisal models.

As a result, this study achieved two main invaluable innovations that would give the ability for the road appraiser to obtain the yearly long-term impacts of the road investment: (a) a model calculating PCLV as a secondary impact of an inter-urban road development; and (b) a comparison of up to 30 years between the obtained CLVs and the RUCSs of the generated traffic starting from the completion of the roadworks. Thus, this study achieved a methodology capable of obtaining the primary and the secondary impacts of the road development, over a 30 year analysis period.

This study provided a simpler and a better approach compared to the two approaches available in this field of study. These two approaches are the road economists' approach and the road planners' approach. The impact of the urban road investment, road expansion or road extension, on the values of the adjacent land considered by property values has been studied since the late 1970s (Chernobai et al., 2011) by the road economists, who concentrated on the impact of the road development on the monthly rental price or the selling price as a result of increasing road accessibility. Although efforts have been made to evaluate the ultimate impact of a road project decision on the affected land, this impact still needs more studies to be well understood, as reported by Siethoff and Kockelman (2002); especially the impacts of the inter-urban roads, as the lack in the relevant studies affects the level of understanding of these changes in land values.

The road planners' approach produced the LUTI models that have been widely used by the road appraisers for more than forty years to evaluate road projects, as stated by Martínez and Araya (2000). The road planners are still producing enhanced new models, which have increased capabilities to closely predict the two-way relationship of the road investment and the land use. These models take into account the combined effect of transport on land use and vice versa. Although these models are well represented regarding the two-way relationship between the road project and land use, these models focus mainly on how land use affects travel demand, in terms of the four steps of the travel forecasting model (Giannopoulos and Curdes, 1992). However, the impacts the road project has on the adjacent land use are poorly represented (Mackett, 1993). In the United States, many studies have been conducted to study the impact of transport on land use patterns and also on the travel demand. These planning studies have been performed due to the government requirements to evaluate the air quality in the affected area, which should not decrease due to the impact of transportation investments (Still et al., 1999). To this end, the model proposed in this study looks at the impact the road development has on the change in the values of the adjacent land with regard to their land use; and it considers in a comprehensive manner, the way to overcome the shortcomings of the recent models mentioned above in a particular project.

10.8 Traffic Issues

To obtain the RUCS (the primary impact of road development) via the project analysis of the HDM-4, this study adopted the use of real traffic data which was obtained from the UK's Department for Transport (Dft, 2016a). The adoption of this real data was chosen based on the importance of the traffic data on the calculation of both RUCs and benefits as stated in section 8.5.1.1. In addition, the real traffic data was also chosen to be used in this study to overcome the problem of FTM assumption that is used in the HDM-4; this means depending on the same matrix for origin and destination in both a do-nothing case and a do-something case (see section 3.2.1 for more information). Moreover, the usage of real traffic data could overcome the four types of errors that are widely observed in estimating the traffic volume: omission, forecasting, measurement and valuation errors (more details are found in section 2.4.2).

10.9 Double Counting of Costs and Benefits

It was demonstrated by Mohring (1993) and TRB (2010) that there are three stages of the economic impacts of road development: direct impact, indirect impacts and induced impacts (see section 2.4.3 for more details). This study focused on estimating the direct and one of the indirect impacts of an inter-urban road development, which were obtained using the CBA model and the EIA model, respectively. These two impacts were used to complement each and aid the reviewing of all the impacts resulting from the road development. The importance of determining the direct impacts of the road development, plus its wider economic impacts that resulted over the long term was reported in Mackie's study, who stated that the appraiser has to use all these impacts resulting from the road development in its appraisal process (Mackie, 2010).

The direct impact of an inter-urban road development has been calculated in this study using the CBA of the HDM-4; while the indirect impact of the same development has been calculated using the EIA model proposed in this study to focus on the changes in land values in a well-defined area and over the long period of analysis covering 30 years of road life. The induced impact from the same road development has not been calculated in this study, due to unavailability of the real data needed to calculate such an impact.

It was demonstrated in different studies, such as TRB (2010), Dft (2016c), Banister and Berechman (2001) and Lee (2000), where adding the results of the two analyses together is a double counting of benefits that resulted from the same development. As a consequence, a comparison between the results obtained from the CBA and the EIA was used in this study to focus on all the impacts caused by the road development (more details are available in Chapter Nine).

10.10 Project Analysis of HDM-4

The project analysis of the HDM-4 was used in this study to calculate the RUCSs (the direct impact of the road development) due to its ability to monetize all the impacts that resulted from the development of the two sections of the M65 motorway, including the non-market impacts such as travel time and the environmental effect. In addition, HDM-4 has the ability to calculate the operating cost for each vehicle used the road network. Seven categories of motorized vehicles were utilized in this study and for each road section in the road network, in spite of the differences between them in terms of their geometric design considered by the rise and fall, the horizontal curvature, the super-elevation and the speed limit. All these reasons are behind the popularity of HDM-4, as this system has been used in different studies conducted by consultants, agencies and researchers for both developed and developing countries, as reported by Kerali et al. (2006).

10.11 Benefits Obtained from ArcGIS application

ArcGIS version 10.4.1 was used in this study as assisting software to facilitate the verification and the application of the developed model. This software proved its ability to serve this kind of study that deals with land development and geographic data. This software has the ability to save working time due to: (1) its capability to work with large spatial data and different land use types; and (2) its capability to specify the spatial characteristics of any land as this software gives its user the ability to draw above a scaled map to extract the required information. The choice of this software was based on these criteria, to complete the requirements of this study. Although the exact estimation of land characteristics was achieved using the GIS, this software needs a reliable map obtained from a reputable source to get these precise results. In this study, a map for the study area has been downloaded from the Digimap webpage.

The work done using the GIS can be achieved manually with the aid of the same map quality, but the result would be approximate estimations, especially in the case of calculating the area of irregular land shapes and specifying the centre of such land. In addition, a large amount of time is consumed to achieve these approximation results.

CHAPTER ELEVEN
CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

11.1 Introduction

In this study, a new model of change in land values was developed to increase the understanding of the impact of an inter-urban road development on the affected land and to facilitate the comparison of its predictions with the road benefits calculated by conventional CBA. The obtained changes in land values were then compared with the road user cost savings calculated by the HDM-4 for the same period of analysis, to aid the acquirement of a broader view of all the impacts, primary and secondary, resulting from the road development. Two main innovations resulted from this study: (1) a model calculating the PCLV as a secondary impact of an inter-urban road development; and (2) a comparison between the CLVs and RUCSs of generated traffic over a long analysis period. The proposed model was fitted and validated using UK historical data. Moreover, a case study located in the County of Lancashire, England, was chosen to demonstrate the goal of this research.

To this end, this chapter summarizes the key findings from this research and provides suggestions for future studies. This chapter has been divided into five sections as follows:

11.2 Modelling the Change in Land Values (Secondary Impact)

1. The RNG method provided by MS Excel was used to generate representative data for the changes in land values' model. The chosen distribution of the data was normal distribution.

2. A statistical test of a sample size selection was carried out to choose the number of samples needed to produce the model; which was equal to 500 cases.

3. To model the change in land values, two models were produced as follows:

a- Linear model

b- Non-linear model

4. The linear model could predict successfully the actual change in land values and its model outcome followed a normal distribution with $R^2 = 84\%$; but this model did not describe satisfactorily the changes in land values as a function of the distance from the road and the time after the roadworks' completion.

5. A logarithmic model was shown to be more realistic in describing the change in land values with $R^2 = 82\%$.

6. A new model was developed that provides good estimates of changes in land values, especially near city boundaries, as an impact of an inter-urban road development.

7. The model is innovative, in terms of its variables, its purpose and the results achieved. It describes the change in land values in terms of four variables:

A. The distance from the road for up to 3 km,

B. The time from 3 years before the roadworks' completion to 30 years after,

C. The area of land from 10-80 hectares,

D. The type of land use.

8. Unlike other models, this model deals with three types of land use: residential, industrial and agricultural.

9. Sensitivity analysis, the one variable at a time approach, was used to choose the best model form; it examined the relationship between the changes in land values with each distance from the road and the time that has elapsed since the completion of the roadworks.

10. The step-wise forward regression analysis demonstrated the importance of the four independent variables to produce the change in land values' model.

11. There was a strong correlation equal to 0.92 between the PCLVs obtained from the historical land values and those obtained from the application of the proposed model.

11.3 Model Application

1. The CLVs model was used to predict data over a period of 30 years. The predictions were consistent with the results of other models found in the literature.

2. GIS software was used in this study to facilitate the application of the proposed model. It provided the land's characteristics in terms of calculating the area of land, specifying its centre and measuring all the distances needed for the model's application.

3. GIS can offer a saving in working time due to its ability to facilitate working with large spatial data (geographical data) and land use categories.

4. Access points can be considered as the main difference in the application of a model of an urban road than that of an inter-urban road. To apply the model of an urban road, the distance has to be measured from the road in question to the centroid of a land cell; while for inter-urban roads, the distance has to be measured from an access point of the road in question to the centroid of a land cell.

11.4 Using HDM-4 to Obtain the Primary Impacts of Road Development

1. Traffic volume forecasting is a key factor in the calculation of RUCs and benefits.

2. Erroneous estimation of generated traffic would lead to miscalculation of benefits resulting from road development, leading to errors in the ranking of a project's options and an erroneous decision as a result.

3. A wide range of data was required to run the HDM-4 software that includes:

   3.1 Primary data that comprised of a traffic volume data survey and a pavement condition survey,

   3.2 Secondary data, which consisted of basic characteristics and economic unit costs,

   3.3 Other data that included the cost of motorway construction and the financial cost.

4. For the case study considered:

4.1 Road users' benefits were achieved when the new road project saved some travel time and VOCs of the network users; and decreased their number of accidents.

4.2 The accumulated RUCS over the analysis period for the A6 trunk road (£384 m) was about double of that obtained from the M61 motorway (£160 m) and it was equal to about four times of that obtained from the M6 motorway (£99.5 m).

4.3 The total construction cost of the M65 motorway sections (£43 m) was less than the accumulated RUCS over the 30 years of the analysis period for each of the A6 trunk road (£384 m), the M61 motorway (£160 m) and the M6 motorway (£99 m).

4.4 The accumulated maintenance cost that was needed to maintain all the road sections over the 30 years of the analysis was equal to (£5 m). This cost was less than the construction cost of the two sections of the M65 motorway and was less than the accumulated RUCS over the same period for each of the A6 trunk road (£384 m), the M61 motorway (£160 m) and the M6 motorway (£99 m).

4.5 The net present value (NPV) obtained from the analysis of the HDM-4 for the development of the M65 motorway sections was equal to £181.58 m using a discount rate of 6%.

4.6 The yearly government revenue from the change in land values was equal to the increase in the obtained tax. Applying a particular case study of an area equal to 16,238,468.9 m^2 demonstrated that the government revenue of 4% tax was applied in years 1997 (road opening), 2000, 2016 and 2027 and was about £5 m, £6 m, £8 m and £9 m, respectively.

11.5 The Comparison of Primary and Secondary Impacts of Inter-urban Road Development

The RUCSs of the generated traffic were compared with the CLVs over a long analysis period, from the year of the road's opening up to 30 years later. The analysis period was divided into three periods. The first period was from year 0 (year of the road's opening) to year 3; the second period was from year 4 after the road's opening to year 19. The last period started from year 20 and finished at the end of the analysis (year 30). Different results were obtained from over the three periods studied.

1. In the first and last years of the analysis period, the CLV and RUCS behaved inversely; while in the years in the middle of the analysis period, similar behaviour was shown for the CLV and RUCS of the generated traffic, i.e. both of them were increased in spite of the difference in their magnitudes, from £147 m to £203 m for the CLV and from £4.5 m to £6 m for the RUCS.

2. The factors affecting the degree of similarity in terms of the trend of both the RUCSs and the CLVs were the traffic volume and the response of the network users to the new inter-urban road.

3. Some rules of transportation economics that were reported in the literature were taken into account in this comparison. These rules were related to the individual presentation of the results for both the CBA and EIA and adjusting the time value of money for both the CLVs and the RUCSs' results.

4. The results obtained from this study demonstrated the differences, qualitatively and quantitatively, between the primary and the secondary impacts that were calculated by the CBA and EIA models. These differences were related to:

4.1 The geographic scope that was included in the two analyses - the CBA determined the RUCS' benefits for all road users and non-users, despite their living or working location; while the EIA determined the CLV's benefits in a well-defined area, which was chosen after taking into account the model's limitation in terms of the distance variable from the new road and the access points available.

4.2 The input data used - the CBA model needed more data than that needed by the EIA's model. The primary data includes the traffic volume data survey and the pavement condition survey for all road sections used in the project analysis of HDM-4; while the secondary data included the basic characteristics and economic unit costs for each vehicle used in the analysis. On the other side, the EIA model needs data that describes the characteristics of each cell of land affected by the road development, such as land area, centre of land and the distance from the new road.

4.3 The road's benefits that were analysed - the CBA analysed the RUCS as a direct impact of the road's development; while the EIA analysed the CLVs as a secondary economic impact from the same development.

4.4 The obtained results over the three periods - the first period showed a decrease from £0.2 m to £-4.5 m for the RUCS of generated traffic and an increase from £125 m to £147 m for the CLV. The second period showed an increase from £4.5 m to £6 m for the RUCS of the generated traffic and from £147 m to £203 m for the CLV. The third period showed reverse behaviour: a decrease from £6 m to £0.96 m for the RUCS and an increase from £203 m to £220 m for the CLV.

5. The proposed model was important in the determination of the CLVs due to the development of the M65 motorway. These CLVs can be used with the CBA to help the decision maker, economist, engineer and road planner to predict all the impacts (primary and secondary) caused due to road development over the long term. To evaluate the viability of the Project's options, the shortcomings of using the CBA alone, which is traditionally widely used, can be overcome by the combination of the proposed EIA model and the CBA.

11.6 Suggestions for Future Research

Although this study has provided an insight into the primary and the secondary impacts of an inter-urban road development, there are still essential areas that require further investigation as follows:

1. Focusing on modelling another secondary impact of road development such as variation in the number of jobs, increasing personal income or changing the use of land.

2. Trying to obtain the network distance, i.e. the distance of the horizontal alignment for the application of the developed model of change in land values. This approach will provide more precise results for the CLVs but it is difficult to obtain.

3. A comparison between the primary impacts of road development calculated using different CBA models such as COBA, TUBA and URECA.

4. The inclusion of more types of land use apart from the three types used, i.e. residential, industrial and agricultural.

5. Development of a more accurate traffic prediction model jointly with HDM-4.

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Appendix A: Uncertainty of Traffic Forecasts

Table A.1: Summary of the Literature on Uncertainty of Traffic Forecasts (adopted from De Jong et al., 2007)

Publication	Type of Uncertainty studied	Variables for which uncertainty is studied	Methods to Quantify Uncertainty	How is Uncertainty Expressed	Order Magnitude of Uncertainty
Ashley, 1980	Model and Input uncertainty	Traffic flow on specific (old and new) road links	Random draws from distributions for inputs and model coefficients	Graph of probability distribution of traffic flows	Probability of 5% that flow on new by-pass will be less than 18,000 vehicles/16 hours and 5% that it will be more than 36,000
Lowe, et al., 1982	Input uncertainty (focus) and model uncertainty	Link flows	Random draws from distributions for inputs and model coefficients	Percentiles	Probability of 5% that flow will be less than 14,000 vehicles/day and 5% that it will be more than 20,000
Ben-Akiva and Lerman, 1985	Model uncertainty	Transport cost and time coefficients (as an example)	Analytic formula for model uncertainty in multi-coefficients model	95% confidence interval	Not reported
De Jong, 1989	Model uncertainty (sampling, coefficients)	Number of households with a car; number of car km/year	Analytic formula for sampling and Estimation variance	Variation and Standard error	Estimation standard error between 3% and 6% of predicted values
Fowkes, 1995	Model uncertainty (coefficients)	Coefficients of modal split model, Including costs, wait time and in vehicle time; Willingness to pay	Repeated estimation on simulated datasets	Standard deviation of estimated coefficients; Confidence interval around mode benefit	95% confidence interval for mode benefit ranges from 0 to twice the average value.
Kroes, 1996	Input uncertainty and model uncertainty (incl. model application)	Link flows and revenues	Repeated model runs for simulated inputs and coefficients	Standard error and other statistics	Not reported
Leurent, 1996	Input uncertainty	Travel time; daily number of cars on a link	Repeated model runs for simulated inputs	Standard error	Standard deviation is about 10% of predicted flow

Publication	Type of Uncertainty studied	Variables for which uncertainty is studied	Methods to Quantify Uncertainty	How is Uncertainty Expressed	Order Magnitude of Uncertainty
Brundell-Freij, 1997	Model uncertainty	Coefficients of modal split model, including costs, time and constants	Repeated estimation on simulated datasets for Different sample sizes	t-ratios and confidence intervals for estimated coefficients	Even with 850 observations 5 out of 11 parameters are not significant.
De Jong et al, 1998	Model uncertainty (specification, coefficients)	Value of time	Jack-knife method and draws from multivariate normal distribution	Standard error	Standard deviation between 6% and 24% of average values of time
Boyce, 1999	Model and input uncertainty (focus on inputs)	vkm	Repeated model simulation, drawing from distributions for input variables	Standard errors and ratio of forecasts	Not reported
Grue, 1999	Model uncertainty	Number of cars, number of trips by mode, elasticities	Repeated model simulation, drawing from distributions for model coefficients	95% confidence interval	95% confidence interval ±1% for set of income coefficients on the total number of short trips and ±8% for long trips
Brundell-Freij, 2000	Model uncertainty (specification, sampling, estimation)	Value of time	As Brundell-Freij, 1997; Bootstrap analysis	Standard error of the value of time	Standard error between 3% and 20% of in-vehicle value of time
Zhao and Kockelman, 2002	Model and input uncertainty	Link flows	Random draws for inputs and parameters in 4-stage model	Standard error	Uncertainty propagates when going from trip generation to distribution and modal split, but is reduced in assignment.
Rodier and Johnston, 2002	Input uncertainty	Trips, vmt, vehicle hours delay, (emissions)	Sensitivity analysis on number of input factors	Percentage over- and Under-prediction	0-70% under- or over-prediction
Armoogum, 2003	Model and input uncertainty	Number of trips and pkm	Jack-knife and scenario analysis	Variance and percentage deviation from reference	Model uncertainty: for trips in 2030 variance is 27% of the mean (pkm: 6%).

Publication	Type of Uncertainty studied	Variables for which uncertainty is studied	Methods to Quantify Uncertainty	How is Uncertainty Expressed	Order Magnitude of Uncertainty
Boyce and Bright, 2003	Model and input uncertainty (focus on inputs)	Revenue from privately-financed project	Repeated model simulation, drawing from distributions for input variables; Scenario analysis	Percentiles; private funders want to see 95-99% probability of no loss.	Only the worst scenario fell below the first percentile
Ecorys, 2003	Input uncertainty	Revenues	Sensitivity analysis	Different revenue amounts	Revenues 1.2 or 3.9 mln depending on traffic growth
Ministerie van Financiën and CPB, 2003	No distinction made between model and Input uncertainty	Financial outcomes of projects	Add a risk paragraph in project assessment	Not reported	Not reported
Research Results Digest, 2003	Model uncertainty (coefficients)	Number of pavement sections	Jack-knife method	Correlation coefficient, Standard error	Not reported
Schrijver et al., 2003	Input uncertainty	Travel time	Random draws from inputs distributions	Interval around mean travel time	Not reported
Beser Hugosson, 2004, 2005	Model uncertainty (coefficients)	Total and OD demand by mode, link flows, train lines and value of time	Bootstrap sampling, repeated Estimation and model application	95% confidence interval	95% confidence interval between ±7% and ±14%

Traffic Forecasts (pkm: passenger kilometres; vkm: vehicle kilometres; vmt: vehicle miles travelled).

Appendix B: Types of CBA

CBA can be achieved using one of a range of techniques, which including: NPV, IRR and NPV/cost (Robinson, 2008). The same choice between project's options may be obtained by using any of these techniques, but the results are presented differently (Garber and Hoel, 2009). It is important to mention that the same discount rate should be used for all a project's options (Robinson, 2008).

Discount Rate can be considered as the reflection of the time value of money (Robinson, 2008). There are three reasons for discounting money: inflation, interest rate and risk of the project (Litman, 2001a; (Garber and Hoel, 2009). In addition, Garber and Hoel (2009) reported that, it is important to use interest rate in the economic evaluation of transportation investment because the money used in the transportation project cannot be used in another investment and unfortunately cannot earn a dividend. The rate of interest depends on the risk of the project ((Garber and Hoel, 2009; Robinson, 2008; Litman, 2006). As a result, money used in CBA should be discounted to present value of money.

Net Present Value (NPV)

The NPV decision rule is the subtraction of costs from benefits over the time horizon, and it is used to choose the alternative with the maximum return (Robinson, 2008). The calculation of NPV is performed using Eq. (B.1) (Robinson, 2008):

$$NPV = \sum_{i=0}^{n-1} \frac{b_i - c_i}{(1 + \frac{r}{100})^i} \quad \text{................ } (B.1)$$

Where:

n	=	*Analysis period in years*
i	=	*Current year, with i=0 in the base year*
b_i	=	*Sum of all benefits in year i*
c_i	=	*Sum of all costs in year i*
r	=	*Planning discount rate expressed as a percentage*

The project's options can then be ranked by their NPV results; the alternative with the highest NPV is the most economical.

Internal Rate of Return (IRR)

Although the economic assessment of a project's alternatives mainly depends on the NPV, in some cases it may be impractical to use it, due to the risk of using the wrong value for discount rate, or when appraising lots of different projects worldwide (Robinson, 2008). In these instances, another method should be used: IRR (Robinson, 2008). This may be obtained by equating eq. (3.1) to zero and solving it to get the discount rate value, as shown in eq. (B.2):

$$\sum_{i=1}^{n-1} \frac{b_i - c_i}{(1+\frac{r}{100})^i} = 0 \qquad \text{............ (B.2)}$$

Where:

n	=	*Analysis period per year*
i	=	*Current year, with i=0 in the base year*
b_i	=	*Sum of all benefits in year i*
c_i	=	*Sum of all costs in year i*
r	=	*Planning discount rate expressed as a percentage*

This method can be used as a guide to ascertain the viability/profitability of the investment. The standard procedure is to choose the highest IIR when comparing different projects, and if it is bigger than the discount rate, then the project is economically viable (Robinson, 2008).

NPV/cost ratio

As the NPV result depends on the size of the investment, i.e. the bigger the investment, the larger the benefit, the project with the biggest NPV would always be selected. However, this method is different, because it offers the ability to divide the NPV obtained for each investment by its cost, which gives the ability to take into consideration the size of the investment (Robinson, 2008). With a limited budget, the investment with the highest ratio should be chosen first, followed by the investment with the next highest ratio, and so on (Robinson, 2008).

Appendix C: Model Prediction

Figure C.1: National Land Use Database (Harrison, 2006)

Figure 1 NLUD Classification (Version 3.2)

NLUD Classification (Version 3.2)

1 Agricultural
- 1.1 Field crops
- 1.2 Ploughed fields
- 1.3 Fallow land
- 1.4 Horticulture and orchards
- 1.5 Improved pasture
- 1.6 Field margin

2 Woodland
- 2.1 Conifer woodland
- 2.2 Mixed woodland
- 2.3 Broadleaved woodland
- 2.4 Undifferentiated young woodland
- 2.5 Scrub
- 2.6 Felled woodland
- 2.7 Land cultivated for afforestation

3 Unimproved Grassland and Heathland
- 3.1 Unimproved grassland
- 3.2 Heathland
- 3.3 Bracken
- 3.4 Upland mosaic

4 Water and Wetland
- 4.1 Sea/Estuary
- 4.2 Standing water
- 4.3 Running water
- 4.4 Freshwater marsh
- 4.5 Salt marsh
- 4.6 Bog

5 Rock and Coastal Land
- 5.1 Inland rock
- 5.2 Coastal rocks and cliffs
- 5.3 Inter-tidal sand and mud
- 5.4 Dunes

6 Minerals and Landfill
- 6.1 Mineral workings and quarries
- 6.2 Landfill waste disposal

7 Recreation
- 7.1 Indoor recreation
- 7.2 Outdoor recreation
- 7.3 Allotments

8 Transport
- 8.1 Roads
- 8.2 Car parks
- 8.3 Railways
- 8.4 Airports
- 8.5 Docks

9 Residential
- 9.1 Residential
- 9.2 Institutional and communal accommodation

10 Community Buildings
- 10.1 Institutional buildings
- 10.2 Educational buildings
- 10.3 Religious buildings

11 Industrial and Commercial
- 11.1 Industry
- 11.2 Offices
- 11.3 Retailing
- 11.4 Storage and warehousing
- 11.5 Utilities
- 11.6 Agricultural buildings

12 Vacant Land and Buildings
- 12.1 Previously developed land which is now vacant
- 12.2 Vacant buildings
- 12.3 Derelict land and buildings

13 Defence Land and Buildings

Table C.1: t-statistics

t Table

cum. prob	$t_{.50}$	$t_{.75}$	$t_{.80}$	$t_{.85}$	$t_{.90}$	$t_{.95}$	$t_{.975}$	$t_{.99}$	$t_{.995}$	$t_{.999}$	$t_{.9995}$
one-tail	0.50	0.25	0.20	0.15	0.10	0.05	0.025	0.01	0.005	0.001	0.0005
two-tails	1.00	0.50	0.40	0.30	0.20	0.10	0.05	0.02	0.01	0.002	0.001
df											
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71	31.82	63.66	318.31	636.62
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	22.327	31.599
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.000	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0.000	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	0.000	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0.000	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	0.000	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	0.000	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	0.000	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0.000	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	0.000	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	0.000	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	0.000	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	0.000	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	0.000	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	0.000	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	0.000	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	0.000	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	0.000	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	0.000	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0.000	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807	3.485	3.768
24	0.000	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	0.000	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	0.000	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0.000	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	0.000	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0.000	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	0.000	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750	3.385	3.646
40	0.000	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	0.000	0.679	0.848	1.045	1.296	1.671	2.000	2.390	2.660	3.232	3.460
80	0.000	0.678	0.846	1.043	1.292	1.664	1.990	2.374	2.639	3.195	3.416
100	0.000	0.677	0.845	1.042	1.290	1.660	1.984	2.364	2.626	3.174	3.390
1000	0.000	0.675	0.842	1.037	1.282	1.646	1.962	2.330	2.581	3.098	3.300
z	0.000	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576	3.090	3.291
	0%	50%	60%	70%	80%	90%	95%	98%	99%	99.8%	99.9%
	Confidence Level										

Table C.2: Data used for model producing

Number	CLV	D	A	T	LU
1	0.2155	2.84	20	-3.25	2
2	25.01628	0.4	60	3	200
3	28.37815	1.31	60	0.25	50
4	19.99896	1.58	50	0	50
5	21.10315	1.67	50	0	50
6	17.22788	2.02	50	0	50
7	26.66114	1.3	70	9	200
8	18.43051	1.78	50	0	50
9	27.16693	1.24	60	0.25	50
10	23.47207	0.38	60	0.25	50
11	10.35862	0.12	10	-3	2
12	27.0045	1.24	60	0.25	50
13	19.34946	1.74	50	0	50
14	20.59617	1.69	50	0.25	50
15	11.65441	0.19	10	-2.75	2
16	18.67346	1.82	50	0	50
17	12.932	0.27	50	-2.75	2
18	16.58348	1.89	50	0	50
19	7.191255	2.55	20	-3	2
20	21.66756	1.65	50	0	50
21	20.06948	1.89	50	0	50
22	1.354449	2.97	40	-3.25	2
23	18.15486	1.8	50	0	50
24	17.79653	1.79	50	0	50
25	11.63199	0.21	10	-2.75	2
26	24.19762	1.48	60	0.25	50
27	29.36326	1.24	70	9	200
28	21.00514	1.62	60	0.25	50
29	18.67814	1.74	50	0	50
30	20.04052	1.58	50	0	50
31	21.28454	1.54	50	0.25	50
32	33.53706	1.15	70	12	200
33	14.47873	0.28	40	-0.25	2
34	28.12996	0.44	70	6	200
35	22.84906	1.62	50	0	50
36	30.98661	1.17	70	12	200
37	24.41558	1.52	60	0.25	50
38	18.70783	1.72	50	0	50
39	23.7099	1.44	60	0.25	50

Number	CLV	D	A	T	LU
40	22.75722	1.32	60	0.25	50
41	18.50564	1.9	50	0	50
42	36.33311	1	70	16	200
43	18.47904	1.79	50	0	50
44	0.525965	2.95	40	-3.25	2
45	23.38974	1.45	60	0.25	50
46	16.72261	1.98	50	0	50
47	27.43318	0.49	70	6	200
48	24.95802	1.4	60	0.25	50
49	30.68617	0.81	80	16	200
50	13.97898	2.11	40	-0.25	2
51	19.49175	1.75	50	0	50
52	33.63565	0.93	80	25	200
53	30.15763	0.47	70	6	200
54	17.27466	1.83	50	0	50
55	18.77862	1.8	50	0	50
56	33.46631	0.61	80	12	200
57	19.0991	1.72	50	0	50
58	19.85562	1.56	50	0	50
59	11.76805	2.63	30	-3	2
60	37.85649	0.77	80	30	200
61	20.56892	1.69	50	0	50
62	22.03106	1.47	60	0.25	50
63	16.62941	1.86	40	0	50
64	17.58242	1.83	50	0	50
65	20.32361	1.58	50	0	50
66	19.26407	1.74	50	0	50
67	24.88961	1.4	60	0.25	50
68	6.901076	2.63	20	-3	2
69	14.64288	1.95	10	-0.25	2
70	21.69454	1.53	50	0.25	50
71	16.48181	1.86	40	0	50
72	27.64373	1.36	60	3	50
73	30.68388	0.57	70	9	200
74	16.10393	1.86	40	0	50
75	13.08918	2.16	30	-2.75	2
76	12.75885	2.16	30	-2.75	2
77	18.03993	1.83	50	0	50
78	23.98624	0.3	60	0.25	50
79	19.99213	1.75	50	0	50
80	7.796137	2.42	20	-3	2

Number	CLV	D	A	T	LU
81	7.281828	2.51	20	-3	2
82	3.12843	2.99	20	-3.25	2
83	23.04049	0.3	60	0.25	50
84	26.83638	0.37	60	3	200
85	20.96281	1.59	50	0	50
86	10.23949	0.14	10	-2.75	2
87	13.45631	0.28	50	-0.25	2
88	22.5201	1.4	60	0.25	50
89	23.61121	0.3	60	0.25	50
90	20.75974	1.72	50	0	50
91	23.89952	0.3	60	0.25	50
92	16.98453	1.91	50	0	50
93	30.45177	1.21	70	12	200
94	13.81352	2.01	40	-0.25	50
95	12.92115	0.3	40	-0.25	2
96	16.50742	1.88	50	0	50
97	8.28045	2.51	30	-3	2
98	21.26694	1.54	50	0.25	50
99	17.86885	1.78	50	0	50
100	15.75833	1.89	40	-0.25	50
101	22.7034	0.37	60	0.25	50
102	12.45123	0.29	50	-0.25	2
103	11.90487	0.13	10	-3	2
104	25.92521	1.3	70	9	200
105	12.01423	0.31	40	-0.25	2
106	20.54169	1.47	60	0.25	50
107	7.820318	2.26	20	-3	2
108	15.82055	2.15	10	-0.25	2
109	11.82912	0.29	50	-2.75	2
110	18.89049	1.8	50	0	50
111	15.02141	1.95	10	-0.25	2
112	5.425068	2.57	20	-3	2
113	13.91728	2.04	40	-0.25	2
114	20.61704	1.7	50	0	50
115	13.14967	2.19	40	-0.25	2
116	26.66311	0.27	60	0.25	50
117	12.56447	2.16	10	-0.25	2
118	18.99038	1.8	50	0	50
119	21.96971	1.47	60	0.25	50
120	21.66026	1.48	50	0.25	50
121	27.24126	1.17	70	25	200

Number	CLV	D	A	T	LU
122	11.88961	2.16	30	-2.75	2
123	17.37761	1.84	50	0	50
124	13.31809	2.05	10	-0.25	2
125	19.65202	1.71	50	0	50
126	19.95849	1.74	50	0	50
127	15.79035	1.92	50	0	50
128	17.09353	1.87	50	0	50
129	12.84082	2.21	40	-0.25	2
130	7.096106	2.68	20	-3	2
131	18.87281	1.76	50	0	50
132	16.53188	1.87	50	0	50
133	22.48981	0.32	60	0.25	50
134	20.06896	1.64	50	0	50
135	24.00396	1.3	70	9	200
136	27.61579	1.23	60	0.25	50
137	14.85914	1.94	40	-0.25	2
138	16.6167	1.81	50	0	50
139	18.63335	1.8	50	0	50
140	16.7061	1.8	50	0	50
141	14.80705	2.15	10	-0.25	2
142	19.48288	1.75	50	0	50
143	16.47735	1.87	50	0	50
144	9.537648	0.13	10	-3	2
145	22.63841	1.68	50	0	50
146	21.76107	1.47	60	0.25	50
147	12.42222	2.25	40	-2	2
148	19.74771	1.54	60	0.25	50
149	11.90666	2.26	30	-2	2
150	15.04854	1.96	40	0	50
151	9.635302	2.28	30	-3	2
152	18.27426	1.78	50	0	50
153	16.05088	1.88	50	0	50
154	12.84631	2.06	10	-0.25	2
155	16.04001	1.93	50	0	50
156	28.12613	1.84	50	0	50
157	13.73384	2.05	10	-0.25	2
158	15.35499	1.92	50	0	50
159	11.62917	0.12	10	-2.75	2
160	21.32255	1.8	50	0	50
161	25.96289	1.38	60	0.25	50
162	15.61835	1.92	50	0	50

Number	CLV	D	A	T	LU
163	19.60604	1.72	50	0	50
164	23.6578	1.45	60	0.25	50
165	22.66304	1.47	60	0.25	50
166	21.76107	1.47	60	0.25	50
167	2.914691	3.07	20	-3.25	2
168	29.00409	1.23	70	12	200
169	29.34337	1.24	70	9	200
170	7.179474	2.38	20	-3	2
171	20.19184	1.54	60	0.25	50
172	15.37299	1.9	50	0	50
173	11.68324	0.3	50	-2.75	2
174	11.57181	2.07	30	-2.75	2
175	14.23241	1.99	40	-0.25	50
176	10.69441	2.18	30	-2.75	2
177	8.924727	2.39	30	-3	2
178	21.75204	1.47	60	0.25	50
179	19.35102	1.73	50	0	50
180	19.05384	1.62	50	0.25	50
181	32.09816	0.91	70	20	200
182	17.32135	1.89	50	0	50
183	25.30405	0.51	70	6	200
184	14.52986	1.96	10	-0.25	2
185	28.14793	0.6	70	9	200
186	18.71616	1.8	50	0	50
187	18.35844	1.86	50	0	50
188	39.1033	0.82	70	20	200
189	24.22344	0.33	60	0.25	50
190	16.34648	1.8	50	0	50
191	12.81098	0.3	50	-0.25	2
192	23.34945	1.45	60	0.25	50
193	16.41875	1.87	50	0	50
194	24.38777	0.38	60	3	200
195	24.07241	1.54	60	0.25	50
196	11.1454	0.13	10	-2.75	2
197	10.89267	2.39	30	-2.75	2
198	19.92593	1.55	50	0.25	50
199	25.11305	0.52	70	6	200
200	16.36331	1.84	50	0	50
201	12.60263	0.3	50	-0.25	2
202	24.51113	1.52	60	0.25	50
203	9.043254	2.51	30	-3	2

Number	CLV	D	A	T	LU
204	10.73374	2.26	30	-2.75	2
205	37.7845	1.05	70	30	200
206	26.56091	1.37	60	0.25	50
207	19.84828	1.58	50	0	50
208	19.42762	1.67	50	0	50
209	15.97354	2.05	40	0	50
210	25.48864	1.43	60	3	50
211	24.57421	0.3	60	0.25	50
212	17.03231	1.89	50	0	50
213	33.20242	0.95	70	20	200
214	10.53642	2.26	30	-3	2
215	17.46899	1.84	50	0	50
216	22.94654	1.45	60	0.25	50
217	26.14645	1.38	60	0.25	50
218	20.85566	1.71	50	0	50
219	16.82196	1.91	50	0	50
220	34.17544	1.12	70	12	200
221	27.88604	1.36	70	9	200
222	27.69296	1.3	60	0.25	50
223	11.49004	2.38	30	-2.75	2
224	27.19699	1.41	60	9	50
225	17.36476	1.96	50	0	50
226	20.67757	1.62	50	0.25	50
227	8.854037	2.59	30	-3	2
228	11.14743	0.14	10	-2.75	2
229	13.75697	2.29	40	-0.25	2
230	21.33027	0.32	60	0.25	50
231	15.29116	1.91	40	-0.25	50
232	10.10049	2.49	30	-3	2
233	17.58933	1.82	50	0	50
234	20.05632	1.77	50	0	50
235	17.08541	1.97	50	0	50
236	26.04423	1.37	60	0.25	50
237	32.70722	1.18	70	9	200
238	19.75714	1.69	50	0.25	50
239	7.626958	2.56	30	-3	2
240	14.84976	2.08	40	-0.25	50
241	27.37068	1.36	70	9	200
242	13.15568	2.35	40	-2	2
243	12.77468	2.37	30	-2	2
244	26.40744	0.37	60	3	200

Number	CLV	D	A	T	LU
245	17.57285	1.99	50	0	50
246	28.36201	1.23	60	0.25	50
247	19.5074	1.62	50	0.25	50
248	8.003134	2.68	30	-3	2
249	24.65246	1.52	60	0.25	50
250	27.50207	0.49	70	6	200
251	15.43819	1.89	50	0	50
252	17.77274	1.96	50	0	50
253	13.02899	2.29	30	-2.75	2
254	17.58721	1.82	50	0	50
255	25.90602	1.5	60	3	50
256	24.41987	1.52	60	0.25	50
257	10.98092	0.14	10	-2.75	2
258	21.68498	1.54	60	0.25	50
259	29.83276	0.63	70	9	200
260	17.94421	1.91	50	0	50
261	13.55867	2.15	30	-2	2
262	20.03947	1.75	50	0	50
263	22.57196	0.37	60	0.25	50
264	21.40157	1.62	60	0.25	50
265	19.15633	1.91	50	0	50
266	9.55815	2.51	30	-3	2
267	20.42502	2.35	30	-3	2
268	20.3358	1.61	50	0.25	50
269	11.36921	2.37	30	-2.75	2
270	15.00163	1.76	10	-0.25	2
271	21.77633	1.87	50	0	50
272	25.38361	1.51	60	0.25	50
273	20.26799	1.69	50	0.25	50
274	19.89444	1.87	50	0	50
275	19.49331	1.95	50	0	50
276	21.27573	1.54	60	0.25	50
277	17.75635	1.96	50	0	50
278	21.322	1.54	60	0.25	50
279	4.680261	2.84	10	-3.25	2
280	35.49794	0.95	80	20	200
281	24.36998	0.35	60	0.25	50
282	18.39082	1.98	50	0	50
283	11.30343	2.38	30	-2.75	2
284	27.92776	1.31	60	0.25	50
285	11.52727	0.11	10	-3	2

Number	CLV	D	A	T	LU
286	21.6625	1.47	50	0	50
287	15.71923	2.05	40	0	50
288	22.29831	1.56	50	0	50
289	4.140348	2.7	10	-3.25	2
290	21.52488	1.55	50	0	50
291	20.36923	1.56	50	0	50
292	24.31333	1.52	60	0.25	50
293	13.09827	0.25	50	-2.75	2
294	15.01153	2.14	40	-0.25	2
295	18.22454	1.81	50	0	50
296	32.75113	1.17	70	12	200
297	22.44537	0.33	60	0.25	50
298	26.48416	0.54	70	6	200
299	16.74736	1.97	50	0	50
300	17.18856	1.91	50	0	50
301	17.43642	1.93	50	0	50
302	18.29361	1.93	50	0	50
303	18.37986	1.61	50	0	50
304	13.27223	0.25	50	-0.25	2
305	20.72964	1.7	50	0	50
306	18.71147	1.93	50	0	50
307	16.32007	2.02	50	0	50
308	17.7156	1.98	50	0	50
309	8.87457	2.39	30	-3	2
310	16.29926	0.26	40	-0.25	2
311	26.6269	0.54	70	6	200
312	24.82853	1.33	60	0.25	50
313	14.76987	1.97	40	0	50
314	13.7233	1.92	40	-2	2
315	17.37333	1.96	50	0	50
316	6.463858	2.44	20	-3	2
317	11.91292	0.12	10	-2.75	2
318	21.32366	1.58	50	0	50
319	22.60783	1.39	50	0.25	50
320	16.51353	0.26	40	-0.25	2
321	4.55861	2.59	10	-3.25	2
322	7.338819	2.29	20	-3	2
323	24.9245	0.27	60	0.25	50
324	27.89705	0.33	60	3	200
325	12.54409	0.17	10	-2.75	2
326	4.036695	2.73	10	-3.25	2

Number	CLV	D	A	T	LU
327	11.28069	1.96	30	-2.75	2
328	21.60083	1.53	50	0	50
329	21.15396	1.67	50	0	50
330	13.27371	0.25	50	-2.75	2
331	11.14641	2.03	30	-2.75	2
332	17.82294	1.89	50	0	50
333	22.03106	1.43	50	0	50
334	23.72777	1.26	60	0.25	50
335	22.55405	1.39	50	0.25	50
336	29.15546	1.12	70	9	200
337	20.71138	1.64	50	0	50
338	16.37845	1.7	40	-0.25	50
339	24.62313	1.51	60	0.25	50
340	2.297224	2.92	20	-3.25	2
341	15.44296	1.76	10	-0.25	2
342	17.59571	1.68	40	0	50
343	14.07346	1.94	30	-2	2
344	15.17472	1.88	40	-0.25	2
345	10.21798	2.05	30	-3	2
346	25.79113	1.34	60	9	50
347	16.03544	1.72	40	-0.25	50
348	18.24653	1.65	50	0	50
349	19.69958	1.69	50	0	50
350	22.06154	1.39	50	0.25	50
351	15.85591	1.75	40	-0.25	2
352	10.53531	2.03	30	-3	2
353	18.29466	1.84	50	0	50
354	10.35978	2.05	30	-3	2
355	11.0142	2.48	30	-2.75	2
356	20.41811	1.56	50	0	50
357	8.512062	2.19	30	-3	2
358	14.89977	1.76	10	-0.25	2
359	18.14018	1.82	50	0	50
360	22.83015	1.33	50	0.25	50
361	16.55243	1.69	40	0	50
362	12.29906	1.95	30	-2.75	2
363	26.79309	1.23	60	3	50
364	25.99637	1.15	60	9	50
365	22.29364	1.39	50	0.25	50
366	11.15756	2.47	30	-3	2
367	23.76959	1.26	60	0.25	50

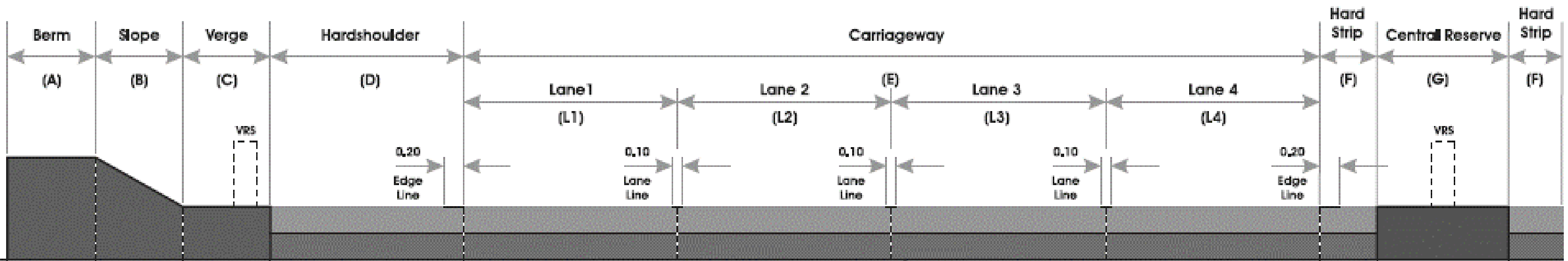
Number	CLV	D	A	T	LU
368	10.09435	2.12	30	-3	2
369	20.83139	1.57	50	0	50
370	15.36819	1.76	10	-0.25	2
371	22.4649	1.55	50	0	50
372	12.53919	1.95	30	-2.75	2
373	35.24326	1.04	70	12	200
374	18.98257	1.63	50	0	50
375	17.64138	2	50	0	50
376	24.01078	1.26	60	0.25	50
377	19.70168	1.55	50	0	50
378	24.5968	1.52	60	0.25	50
379	23.90155	1.44	60	0.25	50
380	26.11039	1.26	60	0.25	50
381	19.54287	1.62	50	0	50
382	16.65924	1.8	40	-0.25	50
383	21.5299	1.59	50	0	50
384	24.05113	1.26	60	0.25	50
385	9.371871	2.15	30	-3	2
386	26.20727	1.01	70	12	200
387	21.84773	1.64	50	0	50
388	21.19338	1.65	50	0	50
389	22.26092	1.55	50	0	50
390	25.91038	0.31	60	0.25	50
391	15.51732	1.55	50	0	50
392	23.94889	1.44	60	0.25	50
393	16.64268	1.81	40	-0.25	50
394	20.83246	1.66	50	0	50
395	15.55226	1.86	10	-0.25	2
396	25.71787	0.29	60	0.25	50
397	11.09859	0.11	10	-3	2
398	24.62313	0.27	60	0.25	50
399	13.02975	0.18	10	-2.75	2
400	15.25853	0.26	50	-0.25	2
401	8.568094	2.32	30	-3	2
402	14.37634	1.9	40	-0.25	2
403	19.31509	1.62	50	0	50
404	23.42826	1.46	50	0.25	50
405	28.33526	1.31	60	0.25	50
406	19.28958	1.75	50	0	50
407	27.38958	1.24	60	0.25	50
408	10.74681	2.17	30	-3	2

Number	CLV	D	A	T	LU
409	14.69958	0.26	50	-0.25	2
410	15.92406	1.86	10	-0.25	2
411	13.71345	2.14	40	-2	2
412	29.01947	0.45	70	6	200
413	14.3376	2.08	40	-0.25	2
414	20.42236	1.73	50	0	50
415	15.41012	0.27	40	-0.25	2
416	22.95269	1.38	50	0.25	50
417	5.15103	2.57	10	-3.25	2
418	10.98405	0.2	10	-2.75	2
419	14.1469	0.26	50	-2.75	2
420	26.89937	0.29	60	0.25	50
421	23.93871	1.44	60	0.25	50
422	24.70628	1.4	60	0.25	50
423	23.23139	1.46	50	0.25	50
424	29.29402	0.46	70	6	200
425	19.1787	1.7	50	0	50
426	12.45372	2.05	30	-2.75	2
427	23.84908	1.4	60	0.25	50
428	21.17859	1.63	50	0	50
429	20.03684	1.65	50	0	50
430	15.15277	2	40	-0.25	2
431	22.55167	1.62	50	0	50
432	21.69679	1.66	50	0	50
433	25.12944	1.22	60	9	50
434	28.16469	1.28	60	9	50
435	17.24079	1.82	50	0	50
436	20.3427	1.69	50	0	50
437	23.61056	1.46	50	0.25	50
438	22.22536	1.63	50	0	50
439	14.737	2.03	40	-2	2
440	22.72212	1.51	50	0	50
441	16.19821	1.85	40	-0.25	2
442	18.31453	1.77	40	0	50
443	26.45657	1.29	60	3	50
444	17.76534	1.77	40	0	50
445	22.89127	1.46	50	0.25	50
446	18.68856	1.74	50	0	50
447	8.783842	2.15	30	-3	2
448	26.0808	1.3	60	0.25	50
449	25.68069	1.38	60	0.25	50

Number	CLV	D	A	T	LU
450	18.83742	1.61	50	0	50
451	15.54279	1.86	10	-0.25	2
452	13.45486	2.05	30	-2.75	2
453	29.59168	0.35	60	3	200
454	18.76717	1.62	50	0	50
455	29.22905	0.64	80	12	200
456	26.85055	1.41	60	9	50
457	9.225049	2.27	30	-3	2
458	14.71673	2.05	30	-2	2
459	14.20576	2.05	30	-2	2
460	18.40492	1.74	50	0	50
461	18.7349	1.79	50	0	50
462	17.1065	1.78	40	0	50
463	11.88961	2.15	30	-2.75	2
464	26.03712	0.29	60	0.25	50
465	11.06683	2.17	30	-3	2
466	24.08547	1.4	60	0.25	50
467	11.02868	2.17	30	-3	2
468	20.13273	1.71	50	0	50
469	9.703302	2.24	30	-3	2
470	18.77133	2.44	30	-3	2
471	15.79151	1.88	40	0	50
472	18.6396	1.93	50	0	50
473	14.44753	2.05	30	-2	2
474	1.784895	2.95	40	-3.25	2
475	19.4469	1.54	50	0	50
476	10.93276	2.03	30	-3	2
477	26.97028	0.33	60	0.25	50
478	18.97998	1.63	50	0	50
479	27.26734	1.33	60	0.25	50
480	20.67113	1.63	50	0	50
481	18.73073	1.61	50	0	50
482	16.32794	1.98	40	-0.25	2
483	33.16574	0.54	70	9	200
484	19.34685	1.61	50	0	50
485	23.50312	1.4	50	0.25	50
486	19.65672	1.72	50	0	50
487	14.62306	2.1	40	-0.25	50
488	24.20459	1.4	60	0.25	50
489	23.43019	1.32	60	0.25	50
490	10.05867	2.37	30	-3	2

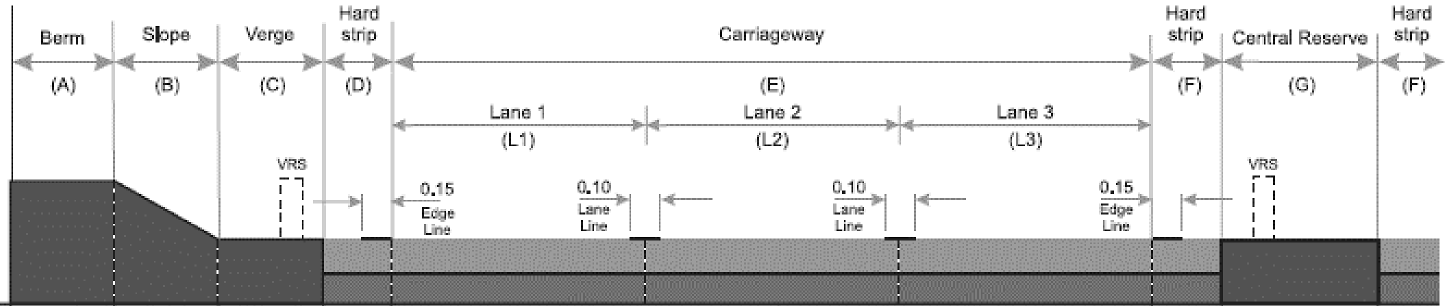
Number	CLV	D	A	T	LU
491	17.19881	1.81	40	-0.25	50
492	21.49648	1.65	50	0	50
493	15.13811	2.06	40	0	50
494	12.95289	2.32	40	-0.25	2
495	19.917	1.71	50	0	50
496	9.16475	2.4	30	-3	2
497	21.41985	1.53	50	0	50
498	10.35744	2.27	30	-2.75	2
499	11.33985	2.15	30	-3	2
500	21.17312	1.62	50	0	50

Appendix D: Model Application



Road Type	A	B	C[2, 6]	D[3]	E[3]				F[5]	G[2]	
					L1	L2	L3	L4			
Dual 2 Lane (D2M)	Varies	Varies	1.50	3.30	7.30		N/A		0.70	3.1	
					3.65	3.65[9]					
Dual 3 Lane (D3M)	Varies	Varies	1.50	3.30	11.00			N/A	0.70	3.1	
					3.65	3.70	3.65[9]				
Dual 4 Lane (D4M)	Varies	Varies	1.50	3.30	14.70				0.70	3.1	
					3.65	3.70	3.70	3.65			

Figure D.1: Dimensions of Cross-Section Components for Rural Motorway Mainline (adopted from DMRB, 2005)



Road Type	A	B	C[2]	D[3, 11]	E[3] L1	E[3] L2	E[3] L3	F[5]	G[2]	
Dual 2 Lane (D2AP)	Varies	Varies	2.50	1.00	7.30 (L1 + L2): 3.65	3.65[9]	N/A	1.00	2.50	
Dual 3 Lane (D3AP)	Varies	Varies	2.50	1.00	11.00 (L1 + L2 + L3): 3.65	3.70	3.65	1.00	2.50	

Figure D.2: Dimensions of Cross-Section Components of the Dual Carriageway for Rural All-Purpose Roads Mainline (adopted from DMRB, 2005)

Table D.1: Calculated Area for each Cells of Land (Hectare)

Cell Number	**Area (Hectare)**
1	13.44
2	23.53
3	23.51
4	23.49
5	23.46
6	23.52
7	23.52
8	12.17
9	12.18
10	12.18
11	23.50
12	23.31
13	23.70
14	23.52
15	23.69
16	23.34
17	10.38
18	12.23
19	12.46
20	21.62
21	16.66
22	21.70
23	24.65
24	24.66
25	24.68
26	24.61
27	24.66
28	24.69
29	18.62
30	18.45
31	19.02
32	17.99
33	19.33
34	17.68
35	24.66
36	24.44

Table D.1: continued

Cell Number	Area (Hectare)
37	24.65
38	24.69
39	24.67
40	24.61
41	22.97
42	18.15
43	18.97
44	15.83
45	25.01
46	12.69
47	24.82
48	24.98
49	12.70
50	24.81
51	24.98
52	25.05
53	24.96
54	24.98
55	24.94
56	24.96
57	24.95
58	24.93
59	12.57
60	24.94
61	24.94
62	12.64
63	24.96
64	24.96
65	12.61
66	24.94
67	24.94
68	24.97
69	25.04
70	24.99
71	24.96
72	25.00
73	24.97
74	24.77
75	12.75

Table D.2: Percentage of Land for each Type of Usage and the Resulted LU (£/m^2)

Cell Number	Percentage of Agricultural	Percentage of Residential	Percentage of Industrial	LU (£/m^2)
1	1	0	0	2
2	0.65	0.1	0.25	33.8
3	0	0	1	50
4	0	0	1	50
5	0.75	0.1	0.15	29
6	0.95	0	0.05	4.4
7	0.2	0	0.8	40.4
8	1	0	0	2
9	0.9	0.1	0	21.8
10	0.95	0.05	0	11.9
11	1	0	0	2
12	1	0	0	2
13	1	0	0	2
14	0.8	0.2	0	41.6
15	0	1	0	200
16	0.1	0.9	0	180.2
17	0.9	0.1	0	21.8
18	1	0	0	2
19	1	0	0	2
20	1	0	0	2
21	1	0	0	2
22	1	0	0	2
23	0.5	0.25	0.25	63.5
24	0.1	0.15	0.75	67.7
25	0	0	1	50
26	0.2	0.3	0.5	85.4
27	0.2	0.6	0.2	130.4
28	0.3	0.1	0.6	50.6
29	0.05	0.95	0	190.1
30	0.3	0.6	0.1	125.6
31	0.75	0.05	0.2	21.5
32	1	0	0	2
33	0.8	0.2	0	41.6
34	1	0	0	2
35	1	0	0	2

Table D.2: continued

Cell Number	Percentage of Agricultural	Percentage of Residential	Percentage of Industrial	LU (£/m^2)
36	0.6	0.4	0	81.2
37	0.9	0.1	0	21.8
38	0.9	0	0.1	6.8
39	0.2	0.7	0.1	145.4
40	0	1	0	200
41	0.85	0.15	0	31.7
42	0.9	0	0.1	6.8
43	0.85	0.15	0	31.7
44	1	0	0	2
45	1	0	0	2
46	1	0	0	2
47	0.9	0.1	0	21.8
48	0.9	0.1	0	21.8
49	1	0	0	2
50	0.8	0.2	0	41.6
51	1	0	0	2
52	0.15	0.85	0	170.3
53	0.05	0.8	0.15	167.6
54	0.7	0.3	0	61.4
55	0.95	0.05	0	11.9
56	0.75	0.25	0	51.5
57	0.75	0.25	0	51.5
58	0.15	0.85	0	170.3
59	0.5	0	0.5	26
60	0.15	0	0.85	42.8
61	0.6	0.1	0.3	36.2
62	0.8	0.2	0	41.6
63	0.3	0.6	0.1	125.6
64	0.2	0.7	0.1	145.4
65	0	0.9	0.1	185
66	0.1	0.8	0.1	165.2
67	0.2	0.6	0.2	130.4
68	0.05	0.95	0	190.1
69	0.1	0.8	0.1	165.2
70	0.5	0.35	0.15	78.5
71	0.5	0.5	0	101
72	0.95	0.05	0	11.9
73	0.9	0.1	0	21.8
74	0.75	0.2	0.05	44
75	0.7	0.1	0.2	31.4

Table D.3: Percent change in Land Value

No.	Distance (km)	LU	Area (Hectare)	Time (years)	PCLV (%)
1	0.812	2	13.44	0	16.83
2	0.431	33.8	23.53	0	20.53
3	0.206	50	23.51	0	21.56
4	0.209	50	23.49	0	21.55
5	0.472	29	23.46	0	20.29
6	0.230	4.4	23.52	0	19.55
7	0.451	40.4	23.52	0	20.62
8	0.351	2	12.17	0	17.72
9	0.314	21.8	12.18	0	19.56
10	0.612	11.9	12.18	0	18.34
11	0.921	2	23.50	0	17.34
12	0.997	2	23.31	0	17.20
13	0.618	2	23.70	0	17.96
14	0.351	41.6	23.52	0	20.93
15	0.397	200	23.69	0	22.11
16	0.220	180.2	23.34	0	22.59
17	0.565	21.8	10.38	0	18.67
18	0.792	2	12.23	0	16.75
19	0.993	2	12.46	0	16.42
20	1.394	2	21.62	0	16.49
21	1.295	2	16.66	0	16.31
22	1.056	2	21.70	0	17.01
23	0.792	63.5	24.65	0	20.19
24	0.677	67.7	24.66	0	20.51
25	0.145	50	24.68	0	21.86
26	0.501	85.4	24.61	0	21.15
27	0.294	130.4	24.66	0	22.14
28	0.127	50.6	24.69	0	21.94
29	0.551	190.1	18.62	0	21.24
30	0.277	125.6	18.45	0	21.70
31	0.229	21.5	19.02	0	20.47
32	0.494	2	17.99	0	17.88
33	0.769	41.6	19.33	0	19.56
34	1.020	2	17.68	0	16.81
35	1.255	2	24.66	0	16.85
36	1.273	81.2	24.44	0	19.43

Table D.3: continued

No.	Distance (km)	LU	Area (Hectare)	Time (years)	PCLV (%)
37	1.028	21.8	24.65	0	18.90
38	0.867	6.8	24.69	0	18.36
39	0.846	145.4	24.67	0	20.73
40	0.651	200	24.61	0	21.45
41	0.824	31.7	22.97	0	19.48
42	1.083	6.8	18.15	0	17.56
43	1.234	31.7	18.97	0	18.45
44	1.336	2	15.83	0	16.19
45	1.874	2	25.01	0	16.07
46	2.006	2	12.69	0	15.14
47	1.772	21.8	24.82	0	17.77
48	1.685	21.8	24.98	0	17.89
49	1.659	2	12.70	0	15.52
50	1.450	41.6	24.81	0	18.67
51	1.250	2	24.98	0	16.88
52	1.170	170.3	25.05	0	20.22
53	1.332	167.6	24.96	0	19.92
54	1.371	61.4	24.98	0	19.09
55	1.480	11.9	24.94	0	17.75
56	1.644	51.5	24.96	0	18.55
57	1.706	51.5	24.95	0	18.47
58	1.462	170.3	24.93	0	19.71
59	1.387	26	12.57	0	17.53
60	1.137	42.8	24.94	0	19.22
61	0.910	36.2	24.94	0	19.52
62	0.848	41.6	12.64	0	18.79
63	0.674	125.6	24.96	0	21.03
64	0.693	145.4	24.96	0	21.11
65	0.885	185	12.61	0	19.84
66	0.960	165.2	24.94	0	20.60
67	0.500	130.4	24.94	0	21.52
68	0.513	190.1	24.97	0	21.81
69	0.824	165.2	25.04	0	20.90
70	0.666	78.5	24.99	0	20.67
71	1.184	101	24.96	0	19.78
72	1.276	11.9	25.00	0	18.06
73	1.467	21.8	24.97	0	18.19
74	1.670	44	24.77	0	18.39
75	1.868	31.4	12.75	0	17.04

Table D.4: Change in Land Value (£)

No.	Area (m2)	LV (£/m^2)	Price	Change in land value (£)
1	134407.14	2	268,814	45,251
2	235318.25	33.8	7,953,757	1,633,010
3	235127.47	50	11,756,374	2,534,918
4	234939.88	50	11,746,994	2,531,503
5	234607.34	29	6,803,613	1,380,529
6	235207.3	4.4	1,034,912	202,279
7	235155.17	40.4	9,500,269	1,958,580
8	121743.97	2	243,488	43,148
9	121760.58	21.8	2,654,381	519,161
10	121752.1	11.9	1,448,850	265,739
11	235000.46	2	470,001	81,504
12	233134.76	2	466,270	80,184
13	236996.38	2	473,993	85,116
14	235198.11	41.6	9,784,241	2,048,211
15	236933.43	200	47,386,686	10,477,710
16	233403.25	180.2	42,059,266	9,503,038
17	103782.85	21.8	2,262,466	422,387
18	122285.15	2	244,570	40,973
19	124627.06	2	249,254	40,935
20	216167.82	2	432,336	71,297
21	166618.9	2	333,238	54,361
22	216961.18	2	433,922	73,794
23	246486.38	63.5	15,651,885	3,160,244
24	246591.18	67.7	16,694,223	3,423,932
25	246779.78	50	12,338,989	2,697,521
26	246092.61	85.4	21,016,309	4,445,289
27	246620.21	130.4	32,159,275	7,121,586
28	246886.57	50.6	12,492,460	2,740,990
29	186244.27	190.1	35,405,036	7,519,454
30	184450.15	125.6	23,166,939	5,028,179
31	190242	21.5	4,090,203	837,254
32	179852.78	2	359,706	64,304
33	193306.78	41.6	8,041,562	1,572,932
34	176813.86	2	353,628	59,443
35	246563.07	2	493,126	83,110
36	244419.42	81.2	19,846,857	3,856,785
37	246505.19	21.8	5,373,813	1,015,558

Table D.4: continued

No.	Area (m2)	LV (£/m^2)	Price	Change in land value (£)
38	246882.6	6.8	1,678,802	308,247
39	246699.56	145.4	35,870,116	7,435,689
40	246055.32	200	49,211,064	10,556,800
41	229692.02	31.7	7,281,237	1,418,578
42	181506.6	6.8	1,234,245	216,742
43	189682.49	31.7	6,012,935	1,109,401
44	158328.36	2	316,657	51,278
45	250063.91	2	500,128	80,373
46	126921.26	2	253,843	38,436
47	248227.83	21.8	5,411,367	961,391
48	249844.44	21.8	5,446,609	974,298
49	127008.93	2	254,018	39,426
50	248103.34	41.6	10,321,099	1,927,297
51	249751.69	2	499,503	84,303
52	250477.54	170.3	42,656,325	8,625,796
53	249601.05	167.6	41,833,136	8,332,022
54	249837.31	61.4	15,340,011	2,928,811
55	249421.44	11.9	2,968,115	526,749
56	249595.01	51.5	12,854,143	2,384,963
57	249494.36	51.5	12,848,960	2,372,948
58	249333.74	170.3	42,461,536	8,371,124
59	125717.89	26	3,268,665	572,889
60	249401.04	42.8	10,674,365	2,051,278
61	249356.9	36.2	9,026,720	1,762,261
62	126362.2	41.6	5,256,668	987,890
63	249581.54	125.6	31,347,441	6,593,380
64	249641.12	145.4	36,297,819	7,661,039
65	126095.88	185	23,327,738	4,627,141
66	249432.03	165.2	41,206,171	8,489,770
67	249351.74	130.4	32,515,467	6,998,897
68	249670.01	190.1	47,462,269	10,349,617
69	250415.62	165.2	41,368,660	8,648,040
70	249908.39	78.5	19,617,809	4,055,979
71	249596.07	101	25,209,203	4,987,620
72	249991.12	11.9	2,974,894	537,164
73	249681.41	21.8	5,443,055	990,201
74	247685.11	44	10,898,145	2,004,620
75	127493.02	31.4	4,003,281	682,079

Table D.5: Changes in Land Value (£) from Year Zero to 10 Years Later

No.	0 years	1 years	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years
1	45,251	48,490	51,202	53,553	55,637	57,516	59,232	60,814	62,284	63,659	64,952
2	1,633,010	1,748,716	1,845,618	1,929,587	2,004,044	2,071,174	2,132,462	2,188,972	2,241,489	2,290,615	2,336,820
3	2,534,918	2,714,129	2,864,216	2,994,271	3,109,594	3,213,567	3,308,494	3,396,019	3,477,361	3,553,450	3,625,013
4	2,531,503	2,710,477	2,860,366	2,990,249	3,105,419	3,209,255	3,304,056	3,391,466	3,472,700	3,548,688	3,620,157
5	1,380,529	1,478,400	1,560,365	1,631,390	1,694,370	1,751,152	1,802,993	1,850,792	1,895,214	1,936,767	1,975,849
6	202,279	216,645	228,676	239,102	248,346	256,681	264,291	271,307	277,827	283,927	289,664
7	1,958,580	2,097,327	2,213,527	2,314,217	2,403,501	2,483,998	2,557,492	2,625,255	2,688,231	2,747,139	2,802,545
8	43,148	46,228	48,807	51,042	53,024	54,811	56,442	57,946	59,344	60,652	61,882
9	519,161	556,030	586,908	613,665	637,391	658,782	678,311	696,318	713,053	728,707	743,430
10	265,739	284,672	300,528	314,268	326,452	337,436	347,465	356,712	365,305	373,344	380,904
11	81,504	87,328	92,206	96,432	100,180	103,559	106,644	109,489	112,132	114,605	116,931
12	80,184	85,917	90,718	94,878	98,567	101,893	104,929	107,729	110,331	112,765	115,054
13	85,116	91,187	96,271	100,677	104,583	108,106	111,321	114,286	117,042	119,620	122,044
14	2,048,211	2,193,207	2,314,638	2,419,862	2,513,167	2,597,289	2,674,092	2,744,906	2,810,718	2,872,279	2,930,180
15	10,477,710	11,217,639	11,837,318	12,374,290	12,850,435	13,279,721	13,671,656	14,033,030	14,368,874	14,683,030	14,978,502
16	9,503,038	10,173,514	10,735,029	11,221,599	11,653,052	12,042,044	12,397,191	12,724,645	13,028,966	13,313,634	13,581,373
17	422,387	452,453	477,634	499,453	518,801	536,245	552,171	566,855	580,502	593,267	605,274
18	40,973	43,907	46,363	48,492	50,380	52,082	53,636	55,069	56,400	57,646	58,817
19	40,935	43,869	46,327	48,456	50,344	52,046	53,601	55,034	56,365	57,611	58,783
20	71,297	76,407	80,685	84,393	87,681	90,645	93,352	95,847	98,166	100,335	102,375
21	54,361	58,259	61,523	64,352	66,861	69,122	71,187	73,091	74,860	76,515	78,071
22	73,794	79,073	83,494	87,325	90,722	93,785	96,581	99,159	101,555	103,797	105,905
23	3,160,244	3,384,336	3,572,011	3,734,637	3,878,840	4,008,853	4,127,553	4,236,998	4,338,710	4,433,855	4,523,341
24	3,423,932	3,666,544	3,869,729	4,045,795	4,201,916	4,342,673	4,471,183	4,589,673	4,699,792	4,802,799	4,899,681

Table D.5: continued

No.	0 years	1 years	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years
25	2,697,521	2,888,112	3,047,730	3,186,043	3,308,689	3,419,264	3,520,219	3,613,302	3,699,808	3,780,729	3,856,837
26	4,445,289	4,759,828	5,023,250	5,251,514	5,453,920	5,636,407	5,803,017	5,956,634	6,099,400	6,232,945	6,358,549
27	7,121,586	7,624,474	8,045,636	8,410,586	8,734,195	9,025,957	9,292,334	9,537,939	9,766,194	9,979,708	10,180,525
28	2,740,990	2,934,622	3,096,785	3,237,305	3,361,908	3,474,247	3,576,813	3,671,380	3,759,267	3,841,479	3,918,801
29	7,519,454	8,051,416	8,496,927	8,882,977	9,225,295	9,533,925	9,815,702	10,075,508	10,316,958	10,542,817	10,755,244
30	5,028,179	5,383,553	5,681,175	5,939,073	6,167,757	6,373,935	6,562,174	6,735,736	6,897,036	7,047,919	7,189,830
31	837,254	896,585	946,275	989,332	1,027,512	1,061,934	1,093,362	1,122,339	1,149,268	1,174,459	1,198,152
32	64,304	68,892	72,734	76,063	79,015	81,677	84,107	86,348	88,430	90,378	92,210
33	1,572,932	1,684,638	1,778,190	1,859,256	1,931,139	1,995,948	2,055,118	2,109,674	2,160,376	2,207,804	2,252,411
34	59,443	63,698	67,262	70,350	73,088	75,557	77,811	79,889	81,820	83,627	85,326
35	83,110	89,059	94,040	98,357	102,185	105,636	108,787	111,692	114,392	116,917	119,293
36	3,856,785	4,130,773	4,360,234	4,559,069	4,735,380	4,894,340	5,039,470	5,173,282	5,297,642	5,413,970	5,523,381
37	1,015,558	1,087,803	1,148,308	1,200,737	1,247,227	1,289,142	1,327,410	1,362,694	1,395,485	1,426,159	1,455,009
38	308,247	330,208	348,600	364,537	378,668	391,409	403,042	413,767	423,735	433,059	441,828
39	7,435,689	7,962,307	8,403,341	8,785,512	9,124,391	9,429,920	9,708,865	9,966,060	10,205,085	10,428,674	10,638,966
40	10,556,800	11,303,304	11,928,492	12,470,236	12,950,613	13,383,714	13,779,132	14,143,718	14,482,547	14,799,495	15,097,593
41	1,418,578	1,519,342	1,603,730	1,676,855	1,741,697	1,800,157	1,853,531	1,902,743	1,948,478	1,991,260	2,031,498
42	216,742	232,219	245,182	256,414	266,374	275,354	283,552	291,111	298,137	304,708	310,889
43	1,109,401	1,188,418	1,254,595	1,311,938	1,362,786	1,408,630	1,450,485	1,489,077	1,524,942	1,558,491	1,590,045
44	51,278	54,957	58,037	60,707	63,074	65,208	67,156	68,953	70,623	72,184	73,653
45	80,373	86,142	90,972	95,159	98,870	102,217	105,272	108,089	110,708	113,157	115,460
46	38,436	41,204	43,523	45,532	47,313	48,919	50,386	51,738	52,994	54,170	55,275
47	961,391	1,030,002	1,087,463	1,137,255	1,181,406	1,221,213	1,257,556	1,291,065	1,322,206	1,351,337	1,378,735
48	974,298	1,043,805	1,102,017	1,152,459	1,197,186	1,237,513	1,274,330	1,308,277	1,339,825	1,369,336	1,397,092
49	39,426	42,261	44,636	46,694	48,518	50,163	51,665	53,050	54,337	55,541	56,673
50	1,927,297	2,064,486	2,179,379	2,278,938	2,367,219	2,446,812	2,519,480	2,586,482	2,648,750	2,706,997	2,761,780

Table D.5: continued

No.	0 years	1 years	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years
51	84,303	90,336	95,389	99,767	103,650	107,150	110,346	113,292	116,031	118,592	121,001
52	8,625,796	9,237,407	9,749,622	10,193,472	10,587,045	10,941,884	11,265,850	11,564,554	11,842,156	12,101,831	12,346,063
53	8,332,022	8,923,228	9,418,355	9,847,397	10,227,839	10,570,840	10,883,998	11,172,737	11,441,078	11,692,089	11,928,173
54	2,928,811	3,137,056	3,311,459	3,462,584	3,596,590	3,717,408	3,827,715	3,929,420	4,023,939	4,112,355	4,195,513
55	526,749	564,343	595,828	623,111	647,303	669,114	689,027	707,388	724,452	740,413	755,426
56	2,384,963	2,554,784	2,697,007	2,820,248	2,929,528	3,028,054	3,118,007	3,200,946	3,278,026	3,350,128	3,417,943
57	2,372,948	2,541,954	2,683,494	2,806,143	2,914,899	3,012,952	3,102,473	3,185,014	3,261,724	3,333,480	3,400,969
58	8,371,124	8,965,396	9,463,091	9,894,359	10,276,774	10,621,554	10,936,336	11,226,573	11,496,305	11,748,619	11,985,928
59	572,889	613,804	648,070	677,762	704,091	727,829	749,501	769,483	788,054	805,426	821,764
60	2,051,278	2,197,082	2,319,190	2,425,001	2,518,826	2,603,418	2,680,649	2,751,858	2,818,036	2,879,941	2,938,164
61	1,762,261	1,887,425	1,992,247	2,083,080	2,163,623	2,236,239	2,302,537	2,363,666	2,420,476	2,473,617	2,523,599
62	987,890	1,058,187	1,117,060	1,168,075	1,213,311	1,254,096	1,291,331	1,325,664	1,357,571	1,387,417	1,415,489
63	6,593,380	7,060,032	7,450,847	7,789,500	8,089,792	8,360,530	8,607,713	8,835,621	9,047,428	9,245,558	9,431,904
64	7,661,039	8,203,171	8,657,199	9,050,628	9,399,491	9,714,021	10,001,184	10,265,956	10,512,023	10,742,199	10,958,686
65	4,627,141	4,955,529	5,230,549	5,468,862	5,680,180	5,870,702	6,044,646	6,205,028	6,354,078	6,493,504	6,624,638
66	8,489,770	9,091,210	9,594,908	10,031,378	10,418,406	10,767,345	11,085,923	11,379,661	11,652,647	11,908,004	12,148,174
67	6,998,897	7,493,736	7,908,157	8,267,266	8,585,696	8,872,789	9,134,902	9,376,576	9,601,178	9,811,275	10,008,877
68	10,349,617	11,080,942	11,693,417	12,224,145	12,694,754	13,119,049	13,506,427	13,863,598	14,195,537	14,506,041	14,798,078
69	8,648,040	9,260,283	9,773,028	10,217,338	10,611,317	10,966,523	11,290,824	11,589,838	11,867,727	12,127,671	12,372,156
70	4,055,979	4,343,270	4,583,872	4,792,362	4,977,234	5,143,912	5,296,088	5,436,398	5,566,796	5,688,773	5,803,496
71	4,987,620	5,341,634	5,638,115	5,895,026	6,122,835	6,328,224	6,515,743	6,688,640	6,849,322	6,999,628	7,140,995
72	537,164	575,467	607,545	635,341	659,989	682,211	702,500	721,207	738,592	754,854	770,150
73	990,201	1,060,780	1,119,889	1,171,109	1,216,527	1,257,475	1,294,860	1,329,330	1,361,365	1,391,331	1,419,515
74	2,004,620	2,147,423	2,267,018	2,370,651	2,462,545	2,545,395	2,621,037	2,690,780	2,755,596	2,816,227	2,873,252
75	682,079	730,868	771,727	807,134	838,529	866,835	892,678	916,506	938,650	959,364	978,847
Sum	208,464,748	223,232,209	235,599,757	246,316,624	255,819,508	264,387,183	272,209,408	279,421,689	286,124,451	292,394,363	298,291,398

Table D.6: Changes in Land Value (£) from 11 years after road opening to 20 years

No.	11 years	12 years	13 years	14 years	15 years	16 years	17 years	18 years	19 years	20 years
1	66,174	67,334	68,437	69,491	70,500	71,468	72,399	73,296	74,162	75,000
2	2,380,478	2,421,894	2,461,319	2,498,963	2,535,002	2,569,587	2,602,849	2,634,898	2,665,834	2,695,742
3	3,692,633	3,756,780	3,817,844	3,876,149	3,931,968	3,985,536	4,037,053	4,086,692	4,134,607	4,180,930
4	3,687,687	3,751,750	3,812,733	3,870,960	3,926,706	3,980,203	4,031,651	4,081,225	4,129,077	4,175,338
5	2,012,778	2,047,810	2,081,158	2,112,999	2,143,483	2,172,737	2,200,871	2,227,980	2,254,147	2,279,445
6	295,084	300,226	305,121	309,795	314,270	318,564	322,693	326,673	330,514	334,227
7	2,854,897	2,904,561	2,951,837	2,996,977	3,040,193	3,081,666	3,121,551	3,159,982	3,197,079	3,232,942
8	63,044	64,146	65,195	66,197	67,157	68,077	68,962	69,816	70,639	71,435
9	757,342	770,539	783,102	795,097	806,581	817,602	828,200	838,413	848,271	857,801
10	388,048	394,825	401,276	407,436	413,333	418,993	424,435	429,680	434,742	439,636
11	119,128	121,213	123,198	125,093	126,907	128,648	130,322	131,935	133,492	134,998
12	117,217	119,269	121,222	123,087	124,873	126,586	128,234	129,822	131,355	132,837
13	124,335	126,508	128,576	130,551	132,442	134,257	136,002	137,684	139,307	140,876
14	2,984,889	3,036,789	3,086,194	3,133,367	3,178,529	3,221,869	3,263,550	3,303,712	3,342,479	3,379,957
15	15,257,691	15,522,542	15,774,663	16,015,391	16,245,859	16,467,029	16,679,732	16,884,685	17,082,515	17,273,774
16	13,834,356	14,074,347	14,302,803	14,520,936	14,729,771	14,930,182	15,122,920	15,308,635	15,487,897	15,661,204
17	616,619	627,381	637,625	647,407	656,772	665,759	674,402	682,731	690,769	698,541
18	59,924	60,974	61,973	62,928	63,842	64,718	65,562	66,374	67,159	67,917
19	59,890	60,940	61,940	62,894	63,808	64,685	65,529	66,342	67,126	67,884
20	104,303	106,132	107,873	109,535	111,126	112,654	114,122	115,537	116,904	118,224
21	79,542	80,937	82,266	83,534	84,748	85,913	87,033	88,113	89,155	90,163
22	107,896	109,786	111,585	113,302	114,947	116,524	118,042	119,504	120,916	122,280
23	4,607,895	4,688,107	4,764,463	4,837,370	4,907,168	4,974,151	5,038,570	5,100,641	5,160,556	5,218,480
24	4,991,223	5,078,064	5,160,731	5,239,662	5,315,230	5,387,748	5,457,491	5,524,692	5,589,558	5,652,269
25	3,928,750	3,996,971	4,061,912	4,123,919	4,183,283	4,240,252	4,295,040	4,347,832	4,398,789	4,448,054
26	6,477,231	6,589,817	6,696,992	6,799,325	6,897,295	6,991,313	7,081,732	7,168,856	7,252,953	7,334,256

Table D.6: continued

No.	11 years	12 years	13 years	14 years	15 years	16 years	17 years	18 years	19 years	20 years
27	10,370,273	10,550,278	10,721,630	10,885,240	11,041,876	11,192,194	11,336,756	11,476,051	11,610,505	11,740,493
28	3,991,862	4,061,171	4,127,148	4,190,144	4,250,455	4,308,333	4,363,995	4,417,629	4,469,399	4,519,450
29	10,955,963	11,146,375	11,327,633	11,500,702	11,666,394	11,825,402	11,978,322	12,125,670	12,267,898	12,405,401
30	7,323,919	7,451,122	7,572,211	7,687,829	7,798,518	7,904,743	8,006,900	8,105,335	8,200,350	8,292,208
31	1,220,539	1,241,776	1,261,992	1,281,295	1,299,775	1,317,510	1,334,565	1,351,000	1,366,863	1,382,199
32	93,941	95,583	97,146	98,639	100,067	101,439	102,758	104,028	105,255	106,441
33	2,294,560	2,334,544	2,372,607	2,408,949	2,443,743	2,477,133	2,509,244	2,540,186	2,570,052	2,598,926
34	86,932	88,455	89,905	91,289	92,614	93,886	95,109	96,288	97,426	98,526
35	121,537	123,666	125,693	127,628	129,481	131,259	132,969	134,617	136,207	137,745
36	5,626,761	5,724,833	5,818,191	5,907,330	5,992,670	6,074,567	6,153,328	6,229,220	6,302,475	6,373,296
37	1,482,268	1,508,128	1,532,745	1,556,249	1,578,751	1,600,346	1,621,114	1,641,125	1,660,441	1,679,116
38	450,114	457,975	465,457	472,602	479,442	486,006	492,319	498,402	504,274	509,950
39	10,837,668	11,026,167	11,205,604	11,376,934	11,540,961	11,698,371	11,849,755	11,995,623	12,136,421	12,272,543
40	15,379,263	15,646,469	15,900,830	16,143,698	16,376,213	16,599,350	16,813,943	17,020,717	17,220,306	17,413,265
41	2,069,518	2,105,586	2,139,919	2,172,702	2,204,087	2,234,206	2,263,172	2,291,083	2,318,023	2,344,069
42	316,729	322,269	327,543	332,578	337,399	342,026	346,475	350,762	354,900	358,901
43	1,619,860	1,648,143	1,675,068	1,700,775	1,725,387	1,749,006	1,771,721	1,793,608	1,814,735	1,835,159
44	75,041	76,358	77,611	78,808	79,954	81,053	82,111	83,130	84,113	85,064
45	117,636	119,701	121,667	123,543	125,340	127,064	128,722	130,320	131,862	133,353
46	56,320	57,310	58,254	59,154	60,017	60,844	61,640	62,407	63,147	63,863
47	1,404,623	1,429,182	1,452,561	1,474,883	1,496,253	1,516,762	1,536,485	1,555,489	1,573,834	1,591,568
48	1,423,318	1,448,198	1,471,881	1,494,495	1,516,144	1,536,920	1,556,901	1,576,154	1,594,738	1,612,704
49	57,743	58,758	59,724	60,646	61,529	62,377	63,192	63,977	64,735	65,468
50	2,813,543	2,862,649	2,909,394	2,954,027	2,996,757	3,037,764	3,077,201	3,115,201	3,151,880	3,187,341
51	123,278	125,438	127,493	129,456	131,335	133,139	134,873	136,544	138,157	139,717
52	12,576,835	12,795,756	13,004,154	13,203,135	13,393,635	13,576,450	13,752,266	13,921,676	14,085,199	14,243,290

Table D.6: continued

No.	11 years	12 years	13 years	14 years	15 years	16 years	17 years	18 years	19 years	20 years
53	12,151,246	12,362,863	12,564,308	12,756,651	12,940,796	13,117,512	13,287,462	13,451,221	13,609,288	13,762,105
54	4,274,088	4,348,628	4,419,584	4,487,335	4,552,198	4,614,444	4,674,307	4,731,989	4,787,666	4,841,494
55	769,611	783,068	795,877	808,108	819,818	831,055	841,862	852,276	862,327	872,045
56	3,482,019	3,542,806	3,600,670	3,655,920	3,708,814	3,759,575	3,808,393	3,855,432	3,900,836	3,944,732
57	3,464,738	3,525,232	3,582,819	3,637,803	3,690,444	3,740,961	3,789,544	3,836,358	3,881,544	3,925,229
58	12,210,157	12,422,872	12,625,362	12,818,703	13,003,803	13,181,435	13,352,267	13,516,875	13,675,762	13,829,371
59	837,202	851,847	865,788	879,100	891,844	904,073	915,835	927,168	938,107	948,683
60	2,993,179	3,045,368	3,095,049	3,142,485	3,187,898	3,231,480	3,273,394	3,313,780	3,352,763	3,390,450
61	2,570,825	2,615,626	2,658,274	2,698,995	2,737,980	2,775,392	2,811,372	2,846,041	2,879,506	2,911,858
62	1,442,013	1,467,175	1,491,128	1,513,998	1,535,894	1,556,906	1,577,114	1,596,586	1,615,381	1,633,551
63	9,607,981	9,775,015	9,934,020	10,085,841	10,231,190	10,370,677	10,504,822	10,634,080	10,758,846	10,879,468
64	11,163,243	11,357,294	11,542,018	11,718,395	11,887,255	12,049,302	12,205,146	12,355,311	12,500,258	12,640,389
65	6,748,544	6,866,088	6,977,982	7,084,819	7,187,103	7,285,261	7,379,660	7,470,620	7,558,420	7,643,302
66	12,375,109	12,590,389	12,795,322	12,990,994	13,178,327	13,358,102	13,530,994	13,697,587	13,858,391	14,013,853
67	10,195,589	10,372,713	10,541,323	10,702,314	10,856,443	11,004,355	11,146,603	11,283,669	11,415,971	11,543,879
68	15,074,020	15,335,792	15,584,981	15,822,910	16,050,698	16,269,297	16,479,526	16,682,096	16,877,627	17,066,662
69	12,603,166	12,822,314	13,030,927	13,230,114	13,420,812	13,603,816	13,779,814	13,949,399	14,113,091	14,271,346
70	5,911,896	6,014,730	6,112,620	6,206,088	6,295,571	6,381,445	6,464,030	6,543,607	6,620,419	6,694,679
71	7,274,571	7,401,287	7,521,913	7,637,088	7,747,353	7,853,171	7,954,937	8,052,996	8,147,646	8,239,153
72	784,602	798,312	811,363	823,824	835,755	847,204	858,214	868,824	879,065	888,965
73	1,446,146	1,471,409	1,495,458	1,518,421	1,540,404	1,561,501	1,581,790	1,601,339	1,620,210	1,638,453
74	2,927,134	2,978,249	3,026,907	3,073,366	3,117,845	3,160,530	3,201,581	3,241,136	3,279,316	3,316,228
75	997,256	1,014,719	1,031,343	1,047,216	1,062,412	1,076,996	1,091,021	1,104,535	1,117,579	1,130,190
Sum	303,863,428	309,149,329	314,181,134	318,985,584	323,585,248	327,999,363	332,244,474	336,334,918	340,283,211	344,100,350

Table D.7: Changes in Land Value (£) from 21 years after road opening to 30 years

No.	21 years	22 years	23 years	24 years	25 years	26 years	27 years	28 years	29 years	30 years
1	75810	76596	77359	78100	78821	79523	80208	80875	81527	82163
2	2724698	2752771	2780020	2806500	2832259	2857342	2881788	2905634	2928912	2951655
3	4225780	4269260	4311465	4352478	4392375	4431224	4469088	4506021	4542077	4577302
4	4220128	4263551	4305700	4346659	4386504	4425302	4463115	4500000	4536008	4571185
5	2303938	2327683	2350732	2373130	2394919	2416135	2436813	2456983	2476673	2495910
6	337822	341308	344691	347979	351177	354291	357326	360287	363177	366001
7	3267665	3301328	3334004	3365757	3396646	3426723	3456037	3484632	3512546	3539818
8	72206	72953	73678	74383	75069	75736	76387	77022	77641	78247
9	867028	875973	884656	893094	901302	909295	917084	924683	932101	939348
10	444374	448967	453426	457759	461974	466078	470079	473981	477790	481511
11	136455	137868	139240	140573	141870	143132	144363	145563	146735	147880
12	134271	135662	137012	138324	139600	140843	142054	143236	144389	145516
13	142395	143868	145298	146687	148039	149355	150638	151889	153110	154304
14	3416244	3451423	3485570	3518752	3551032	3582464	3613098	3642980	3672152	3700651
15	17458948	17638470	17812726	17982062	18146789	18307190	18463520	18616012	18764879	18910314
16	15828997	15991668	16149568	16303009	16452275	16597620	16739276	16877455	17012349	17144133
17	706065	713360	720441	727322	734015	740533	746886	753082	759131	765041
18	68651	69363	70054	70725	71378	72014	72634	73238	73829	74405
19	68619	69331	70022	70693	71346	71982	72602	73207	73797	74374
20	119503	120742	121946	123115	124252	125360	126439	127492	128520	129524
21	91138	92084	93002	93894	94762	95607	96431	97234	98018	98784
22	123601	124882	126125	127333	128509	129653	130768	131856	132918	133956
23	5274561	5328931	5381705	5432990	5482879	5531457	5578803	5624986	5670071	5714118
24	5712985	5771848	5828984	5884507	5938519	5991112	6042371	6092371	6141182	6188868
25	4495751	4541992	4586877	4630495	4672925	4714241	4754509	4793788	4832133	4869594
26	7412972	7489286	7563361	7635345	7705369	7773555	7840010	7904833	7968116	8029939

Table D.7: continued

No.	21 years	22 years	23 years	24 years	25 years	26 years	27 years	28 years	29 years	30 years
27	11866346	11988357	12106789	12221877	12333833	12442849	12549097	12652738	12753914	12852758
28	4567908	4614887	4660488	4704801	4747909	4789884	4830794	4870700	4909656	4947715
29	12538530	12667595	12792874	12914616	13033045	13148363	13260755	13370387	13477413	13581972
30	8381144	8467365	8551057	8632386	8711501	8788539	8863622	8936861	9008359	9078209
31	1397047	1411442	1425415	1438993	1452202	1465064	1477599	1489827	1501764	1513425
32	107589	108702	109782	110832	111853	112848	113817	114763	115686	116587
33	2626881	2653984	2680291	2705855	2730724	2754940	2778540	2801562	2824036	2845992
34	99591	100623	101625	102599	103546	104469	105368	106244	107101	107937
35	139233	140677	142077	143439	144763	146053	147309	148535	149732	150901
36	6441864	6508339	6572864	6635567	6696564	6755959	6813846	6870312	6925436	6979289
37	1697196	1714724	1731738	1748272	1764355	1780017	1795281	1810170	1824705	1838905
38	515446	520774	525946	530972	535861	540621	545261	549787	554205	558522
39	12404334	12532102	12656122	12776641	12893880	13008039	13119302	13227832	13333783	13437291
40	17600085	17781202	17957006	18127847	18294038	18455865	18613585	18767432	18917621	19064349
41	2369286	2393734	2417464	2440524	2462957	2484800	2506089	2526856	2547128	2566934
42	362774	366530	370175	373717	377163	380518	383788	386978	390092	393134
43	1854934	1874106	1892714	1910798	1928389	1945519	1962213	1978498	1994396	2009927
44	85985	86877	87743	88585	89404	90202	90979	91737	92477	93200
45	134797	136196	137555	138875	140159	141409	142628	143817	144977	146111
46	64555	65227	65879	66513	67129	67729	68314	68884	69441	69985
47	1608739	1625385	1641544	1657246	1672520	1687394	1701890	1716030	1729834	1743319
48	1630099	1646963	1663332	1679239	1694713	1709781	1724466	1738791	1752775	1766437
49	66178	66866	67534	68183	68814	69428	70027	70612	71182	71740
50	3221674	3254958	3287267	3318663	3349205	3378944	3407929	3436202	3463803	3490768
51	141227	142691	144111	145492	146835	148143	149418	150661	151875	153061
52	14396351	14544741	14688777	14828747	14964907	15097491	15226711	15352758	15475808	15596022

Table D.7: continued

No.	21 years	22 years	23 years	24 years	25 years	26 years	27 years	28 years	29 years	30 years
53	13910059	14053498	14192729	14328029	14459647	14587808	14712716	14834558	14953503	15069706
54	4893610	4944134	4993177	5040835	5087195	5132339	5176336	5219254	5261151	5302082
55	881453	890574	899428	908031	916401	924551	932493	940241	947805	955194
56	3987231	4028434	4068427	4107291	4145098	4181912	4217791	4252790	4286956	4320335
57	3967524	4008529	4048330	4087008	4124633	4161270	4196977	4231808	4265810	4299029
58	13978093	14122276	14262229	14398231	14530531	14659357	14784913	14907387	15026949	15143755
59	958922	968849	978485	987848	996957	1005826	1014471	1022903	1031135	1039177
60	3426939	3462314	3496652	3530019	3562479	3594086	3624891	3654940	3684274	3712933
61	2943182	2973549	3003025	3031670	3059534	3086667	3113111	3138906	3164088	3188689
62	1651144	1668199	1684755	1700842	1716492	1731731	1746583	1761071	1775214	1789031
63	10996252	11109472	11219370	11326165	11430054	11531215	11629808	11725980	11819866	11911588
64	12776063	12907596	13035269	13159339	13280031	13397554	13512094	13623822	13732894	13839452
65	7725484	7805158	7882494	7957647	8030755	8101942	8171323	8239001	8305069	8369615
66	14164369	14310291	14451932	14589574	14723471	14853850	14980921	15104872	15225876	15344091
67	11667717	11787775	11904312	12017558	12127722	12234993	12339541	12441523	12541080	12638342
68	17249683	17427117	17599347	17766714	17929526	18088062	18242574	18393293	18540429	18684173
69	14424565	14573108	14717293	14857408	14993709	15126431	15255784	15381961	15505139	15625477
70	6766576	6836279	6903937	6969685	7033643	7095922	7156620	7215828	7273628	7330096
71	8327748	8413639	8497011	8578028	8656841	8733584	8808379	8881338	8952562	9022145
72	898551	907844	916864	925630	934157	942460	950553	958447	966153	973681
73	1656116	1673240	1689862	1706014	1721727	1737027	1751939	1766484	1780684	1794557
74	3351966	3386613	3420243	3452924	3484716	3515672	3545843	3575274	3604004	3632072
75	1142400	1154237	1165727	1176892	1187754	1198330	1208638	1218693	1228509	1238098
Sum	347,796,049	351,378,941	354,856,729	358,236,325	361,523,948	364,725,225	367,845,256	370,888,687	373,859,757	376,762,350

Appendix E: HDM-4

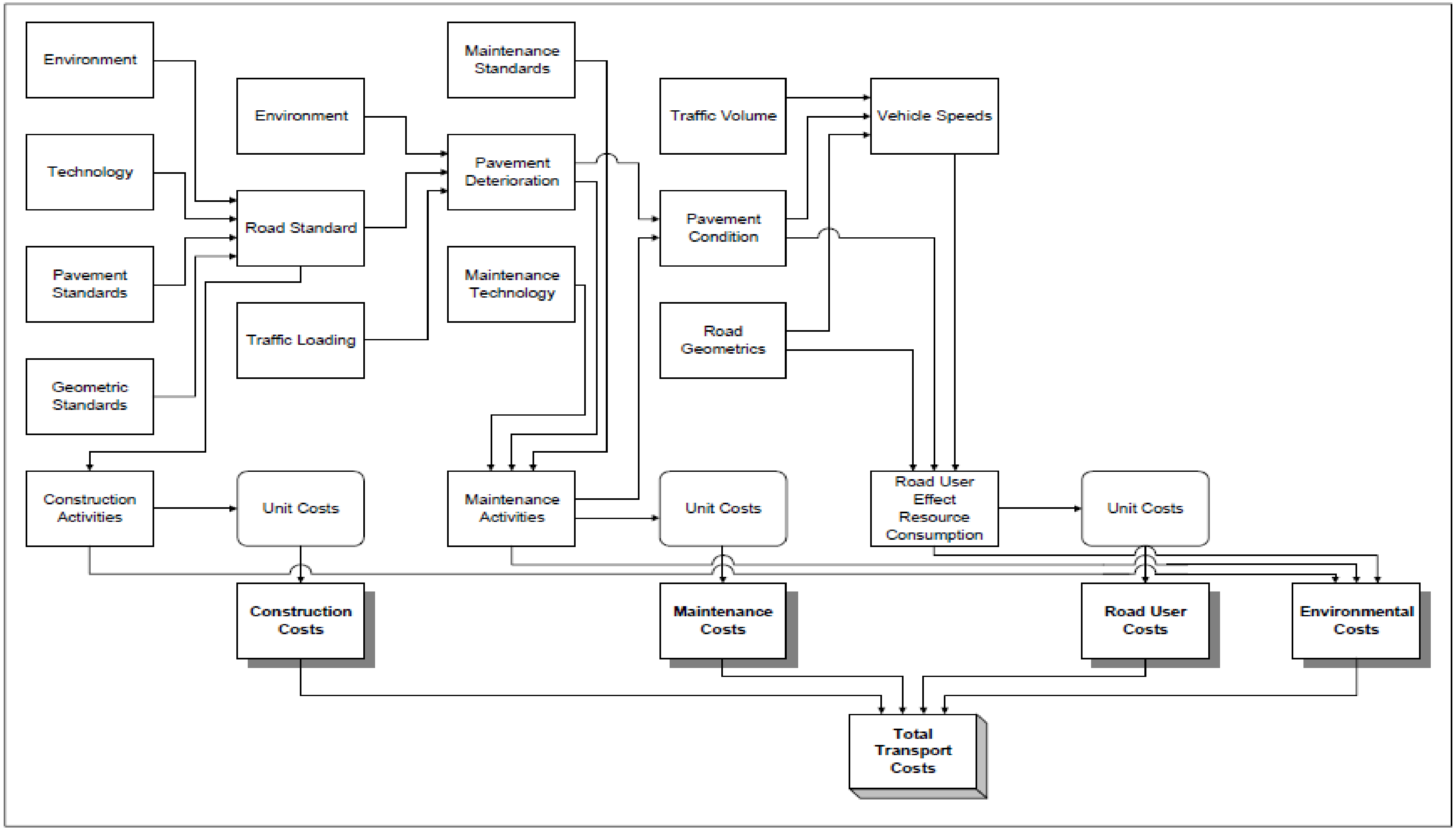


Figure E.1: Inter-relationship between Total Transport Cost Components (Bennett and Greenwood, 2004)

Table E.1: Road User Component Impact Matrix (Bennett and Greenwood, 2004)

		Road User Effect Component										
		Vehicle Operating Costs					Delay Costs			Accident Costs		
	Cost Impact	Fuel	Oil	Tyres	Maintenance and Repairs	Depreciation and Interest	Delay at Work Zone	Delay Due to Congestion	Delay at Intersections	Direct Costs	Indirect Costs	Cost Incurred Due to Deferral of Maintenance
Impact on User Costs	High	■						■				■
	Medium				■	■	■		■		■	
	Low		■	■						■		
Sensitivity of Pavement Type[1]	High			■			■					
	Medium	■	■									■
	Low	■			■	■			■	■	■	
Sensitivity to Pavement Condition[2]	High			■			■	■				■
	Medium	■	■		■			■		■	■	
	Low					■			■			
Extent of Research[3]	Major	■							■	■		
	Fair			■	■	■	■	■			■	
	Limited		■									■

Source: Adapted from Anderson, et al. (1992)

Notes: 1/ Sensitivity of the user cost to pavement type considers portland cement concrete and asphaltic concrete pavements.
2/ Pavement condition in terms of the Pavement Serviceability Index (PSI).
3/ Amount of research to date pertains to the user cost component of interest, not the subject as a whole.
4/ ■ Indicates that cost component has been assigned that cost impact.

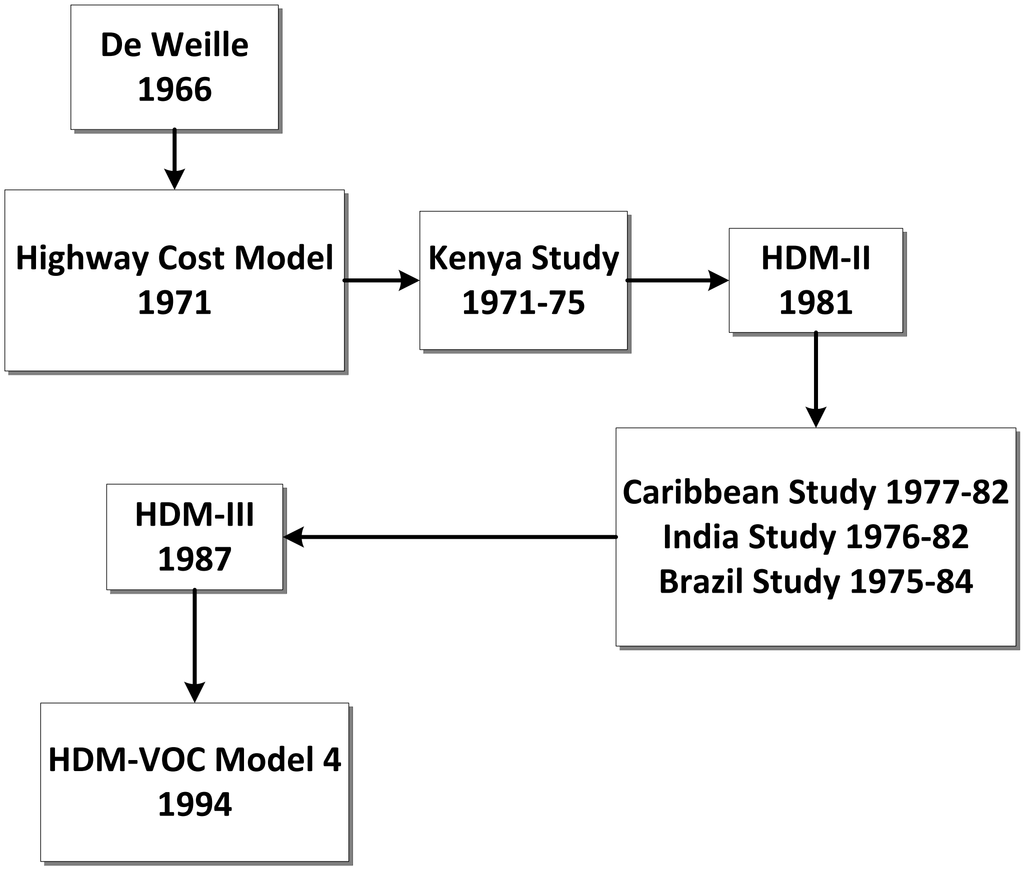


Figure E.2: Development of VOC model of HDM-4 software (Bennett and Greenwood, 2001)

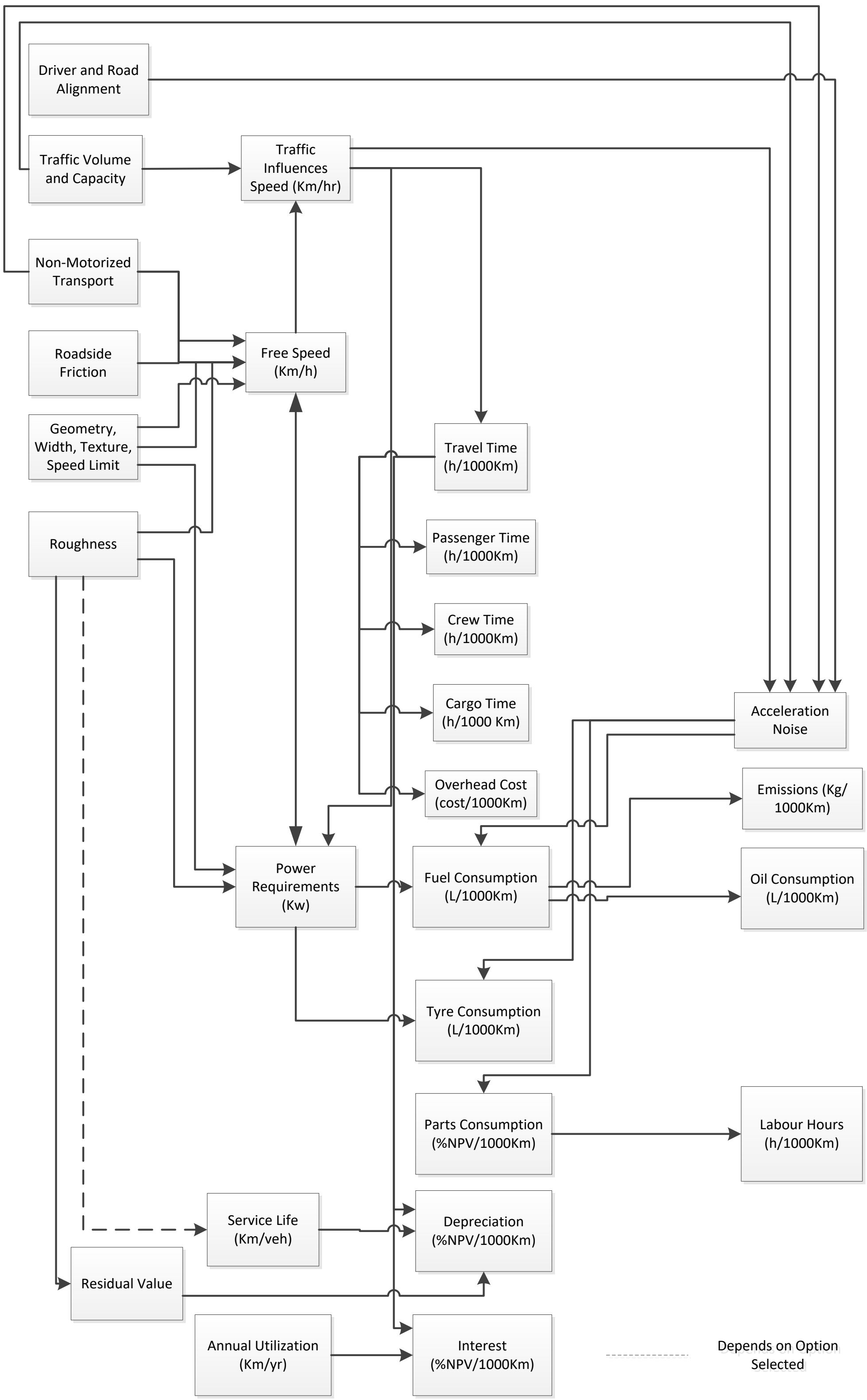


Figure E.3: HDM-4' VOC model and Their components' Interactions (Bennett and Greenwood, 2004)

Table E.2: HDM-4 Default Representative Vehicle Classes and Characteristics (Bennett and Greenwood, 2004)

Vehicle Number	Type	Description	Abbrev-iation	Fuel Type	Number of Axles	Number of Wheels	Aero-dynamic Drag Coeff.	Projected Frontal Area (m^2)	Tare Weight (t)	Operating Weight (t)
1	Motorcycle	Motorcycle or scooter	MC	P	2	2	0.70	0.8	0.1	0.2
2	Small Car	Small passenger cars	PC-S	P	2	4	0.40	1.8	0.8	1.0
3	Medium Car	Medium passenger cars	PC-M	P	2	4	0.42	1.9	1.0	1.2
4	Large Car	Large passenger cars	PC-L	P	2	4	0.45	2.0	1.2	1.4
5	Light Delivery Vehicle	Panel van, utility or pickup truck	LDV	P	2	4	0.50	2.0	1.3	1.5
6	Light Goods Vehicle	Very light truck for carrying goods (4 tyres)	LGV	P	2	4	0.50	2.8	0.9	1.5
7	Four Wheel Drive	Landrover/Jeep type vehicle	4WD	P/D	2	4	0.50	2.8	1.5	1.8
8	Light Truck	Small two-axle rigid truck (approx. < 3.5 t)	LT	D	2	4	0.55	4.0	1.8	2.0
9	Medium Truck	Medium two-axle rigid truck (> 3.5 t)	MT	D	2	6	0.60	5.0	4.5	7.5
10	Heavy Truck	Multi-axle rigid truck	HT	D	3	10	0.70	8.5	9.0	13.0
11	Articulated Truck	Articulated truck or truck with drawbar trailer	AT	D	5	18	0.80	9.0	11.0	28.0
12	Mini-bus	Small bus based on panel van chassis (usually 4 tyres)	MNB	P	2	4	0.50	2.9	1.1	1.5
13	Light Bus	Light bus (approx. < 3.5 t)	LB	D	2	4	0.50	4.0	1.75	2.5
14	Medium Bus	Medium bus (3.5 - 8.0 t)	MB	D	2	6	0.55	5.0	4.5	6.0
15	Heavy Bus	Multi-axle or large two-axle bus	HB	D	3	10	0.65	6.5	8.0	10.0
16	Coach	Large bus designed for long distance travel	COACH	D	3	10	0.65	6.5	10.0	15.0

Source: NDLI (1995)

Table E.3: HDM-4 Default PCSE Values (Bennett and Greenwood, 2004)

Vehicle Class	Average Length (m)	Time Headway (s)	Space Headway (m)	Total Space (m)	Basic PCSE	Recommended Values (Includes "Basic" plus adjacent lane effects)		
						Two-Lane Four-Lane	Narrow Two-Lane	One-Lane
Car	4.0	1.6	32	36.0	1.0	1.0	1.0	1.0
Pickup	4.5	1.8	36	40.5	1.1	1.0	1.0	1.0
Heavy Bus	14.0	2.2	44	58.0	1.6	1.8	2.0	2.2
Light Truck	5.0	2.0	40	45.0	1.3	1.3	1.4	1.5
Medium Truck	7.0	2.2	44	51.0	1.4	1.5	1.6	1.8
Heavy Truck	9.0	2.4	48	57.0	1.6	1.8	2.0	2.4
Truck and Trailer	15.0	2.5	50	65.0	1.8	2.2	2.6	3.0

Table E.4: Default Vehicle Utilization Model Values (Bennett and Greenwood, 2004)

Vehicle Number	Vehicle Type	AKM0 (Km/yr)	LIFE0 (years)	HRWK0 (hrs/yr)
1	Motorcycle	10000	10	400
2	Small Car	23000	10	550
3	Medium Car	23000	10	550
4	Large Car	23000	10	550
5	Light Delivery Vehicle	30000	8	1300
6	Light Goods Vehicle	30000	8	1300
7	Four Wheel Drive	30000	8	1300
8	Light Truck	30000	8	1300
9	Medium Truck	40000	12	1200
10	Heavy Truck	86000	14	2050
11	Articulated Truck	86000	14	2050
12	Mini-Bus	30000	8	750
13	Light Bus	34000	8	850
14	Medium Bus	70000	7	1750
15	Heavy Bus	70000	12	1750
16	Coach	70000	12	1750

Table E.5: Proportion of cars and light good vehicles using petrol, diesel or mains electricity (%) (DfT, 2014).

Year	Cars			LGVs	
	Petrol	Diesel	Electric	Petrol	Diesel
2004	73.28%	26.72%	0.00%	11.07%	88.93%
2010	59.27%	40.73%	0.00%	5.86%	94.14%
2015	47.97%	51.87%	0.16%	3.64%	96.36%
2020	43.7%	55.33%	0.96%	1.89%	98.11%
2025	44.41%	53.05%	2.54%	1.04%	98.96%
2030	44.46%	50.23%	5.31%	0.79%	99.21%

Table E.6: Websites Used to obtain the Average Price of Vehicles Used in the UK

Vehicle Type	Website
Motor cycle	British Motorcyclists Federation (2017)
Car Taxis	Automobile Association Development (AA) (2017)
Light Good Vehicle	Parker (2018)
2-Axle Rigid HGV	Truck Locator (2018)
3 or more Axle Rigid HGV	Truck Locator (2018)
Buses Coaches	Arrive bus and coach (2018)

Table E.7: Websites Used to obtain the Average Price of Tyres in the UK

Vehicle Type	Website
Motor cycle	Tyre Tec (2018)
Car Taxis	Gold Garages (2018)
Light Good Vehicle	My tyres (2018)
2, 3 or more-Axle Rigid HGV	Tyre Leader (2018)
Buses Coaches	Big Tyres (2018)
Articulated Truck	Tyre Leader (2018)

Table E.8: Websites Used to obtain the Average Crew Wages in the UK

Vehicle Type	Website
Car Taxis	Pay Scale (2018)
Light Good Vehicle	
2, 3 or more-Axle Rigid HGV	Pay Scale (2018) and National Careers Service (2018)
Articulated Truck	
Buses Coaches	Pay Scale (2018)

Table E.9: Values of Working Time per Person (£/hr) (2010 prices) DfT/TAG (2014)

Vehicle Occupant	Resource Cost	Perceived Cost	Market Price
Car driver	22.74	22.74	27.06
Car passenger	17.25	17.25	20.52
LGV (driver or passenger)	10.24	10.24	12.18
OGV (driver or passenger)	12.06	12.06	14.35
PSV driver	12.32	12.32	14.66
PSV passenger	13.97	13.97	16.63
Taxi driver	10.89	10.89	12.96
Taxi/Minicab passenger	21.96	21.96	26.13
Rail passenger	26.86	26.86	31.96
Underground passenger	22.08	22.08	26.28
Walker	17.54	17.54	20.88
Cyclist	17.47	17.47	20.78
Motorcyclist	19.42	19.42	23.11
Average of all working Persons	22.75	22.75	27.07

Table 2- 2: Land Values for Different Land Uses across England (after Wightman, 2013)

	Hectares	£ per ha land value	Total land value £
Business property	86,895	328,0453	£285,055,000,000
Residential	715,284	2,047,760	£1,464,729,766,246
Agricultural	8,925,000	£10,000	£89,250,000,000
Woodland	1,295,000	£1,000	£89,250,000,000
Inland water	343,620	£0	£0
Urban greenspace	106,550	£0	£0
Other greenspace	1,247,612	£1,000	£1,247,612,000
Infrastructure	327,237	£0	£0
Other	185,173	£1,000	£185,172,921
ENGLAND	13,232,271		£1,841,762,551,167

Road transport projects have many impacts on land use. In general, these impacts can be divided broadly into: direct impacts and indirect impacts (Litman, 2016a), as illustrated in Figure 2-2.

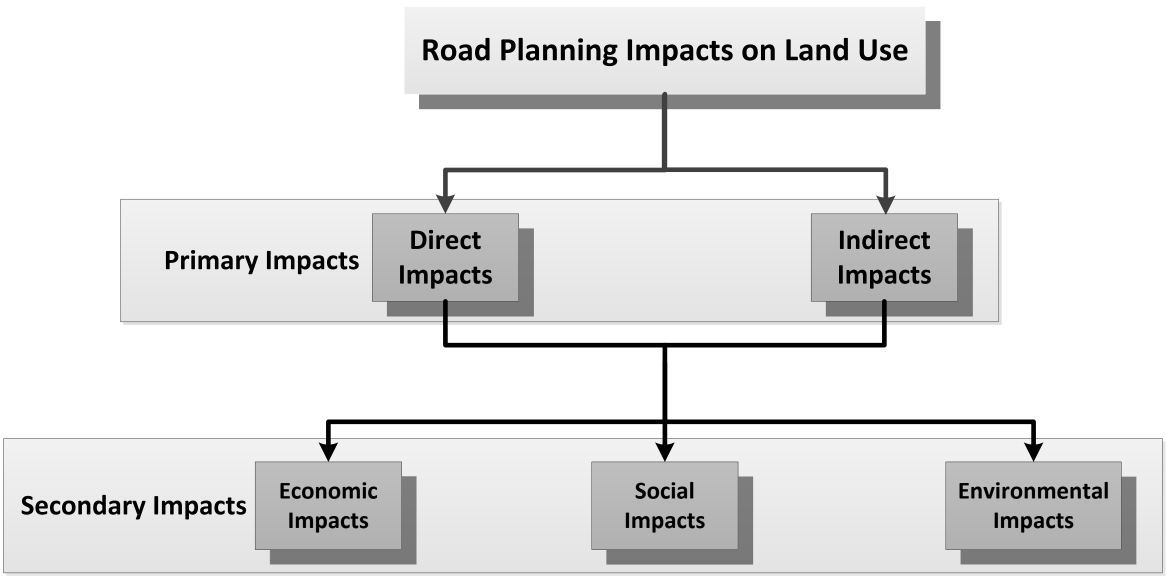


Figure 2- 2: Road Project Impacts on Land Use

EIA may be seen as a determination of how a transportation project would affect the economy of a well-defined area, which can be measured in terms of the variation in number of jobs, increasing personal income, increasing the land value and changing the use of land (TRB, 2010; Kockelman et al., 2002; Lavee, 2015; Chang, 2006).

On the other hand, CBA is an analysis that may be used to compare between a project's options and subsequently rank them in terms of their costs and associated benefits (Robinson, 2008). These two types of analysis seem to complement each other to make the project more convincing for investment in road infrastructure (Melo et al., 2013). However, the main differences between CBA and EIA may be considered in terms of their geographic scope, their direct benefits and their follow-on benefits (TRB, 2010), as shown in Figure 2-3:

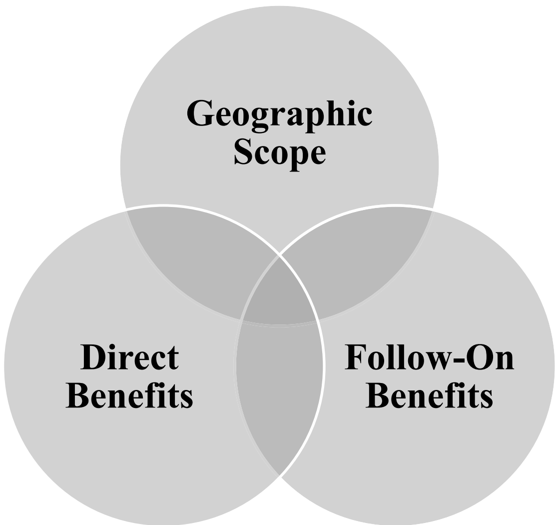


Figure 2- 3: Main Differences between CBA and EIA

- Geographic scope: EIA analyses the changes in economic activity in a defined area, while CBA takes in its analysis a broader view than EIA (TRB, 2010). A CBA is used to determine the project option's social welfare effects by measuring the benefits derived from such an

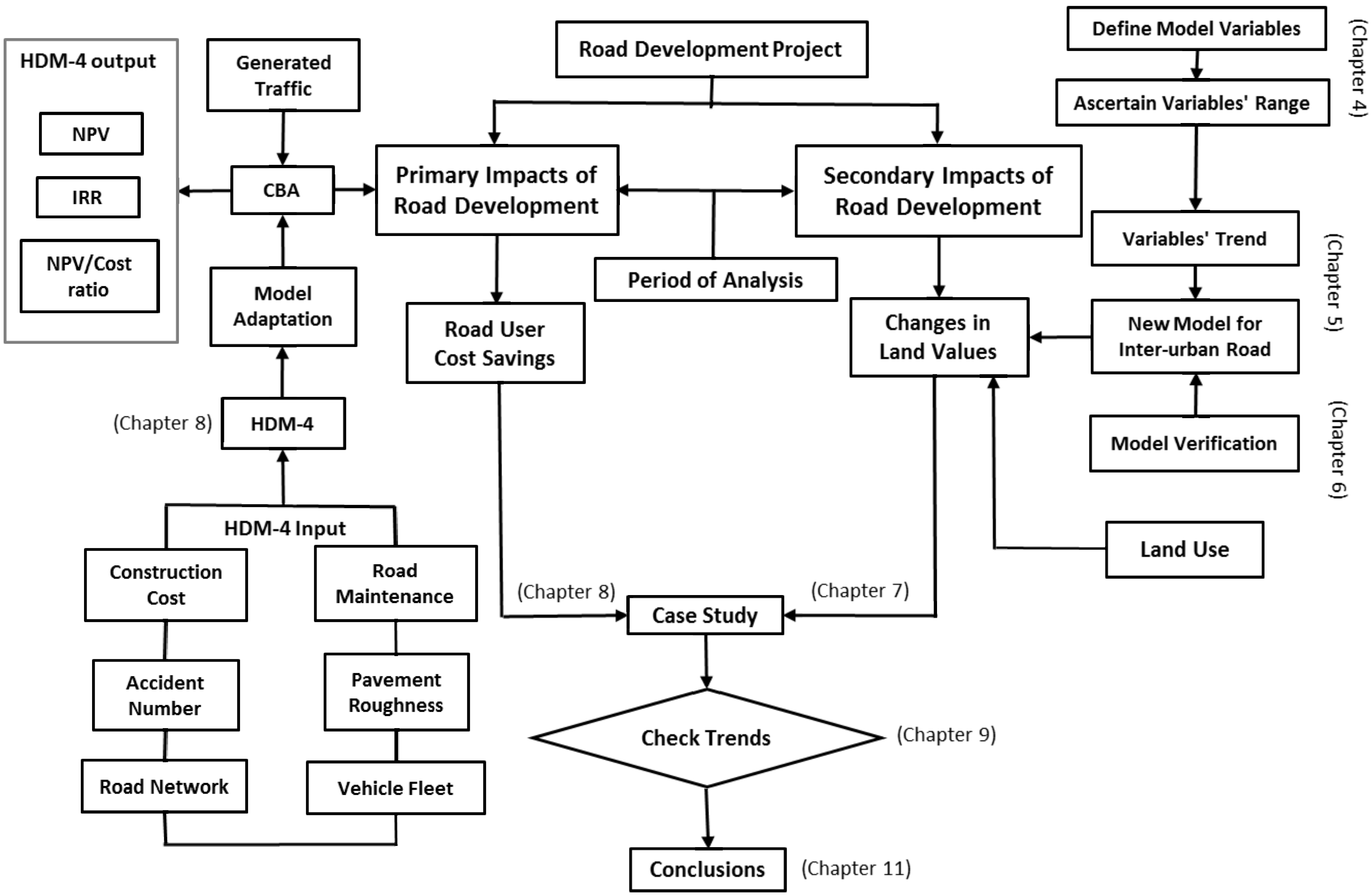


Figure 3- 1: Proposed Outline of the Methodology for this Study

in land use is considered to be a two-way relationship (Kockelman et al., 2002; Chang, 2006; Mackett, 1993) and has received much attention in recent years (Banister and Thurstain-Goodwin, 2005; Huang, 1994; Landis et al., 1995; Levkovich et al., 2016), as shown in Figure 3-2.

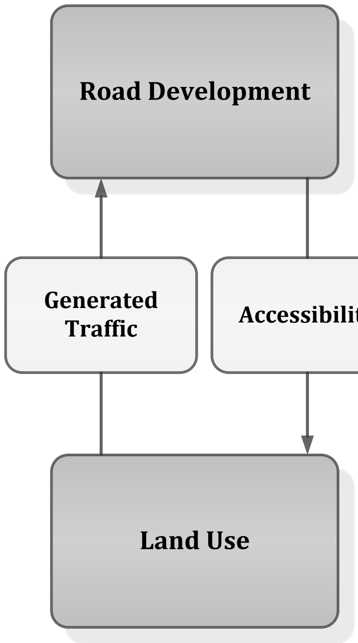


Figure 3- 2: Simplification of the Road Development-Land Use Relationship

A two-way relationship means that the road development project would increase the accessibility to the adjacent land, which would decrease travel times and costs for road users; this in turn would increase the economic activities in these regions, causing a change in the land use and then a change in the value of such land. This could generate more traffic, leading to an increase in the traffic volume on the transport system (Iacono et al., 2008).

It may be seen from reviewing the literature that there is no model that can explicitly address the impacts from inter-urban roads. In addition, there is a need to choose suitable parameters for the model that could reflect better the road transport characteristics of inter-urban roads

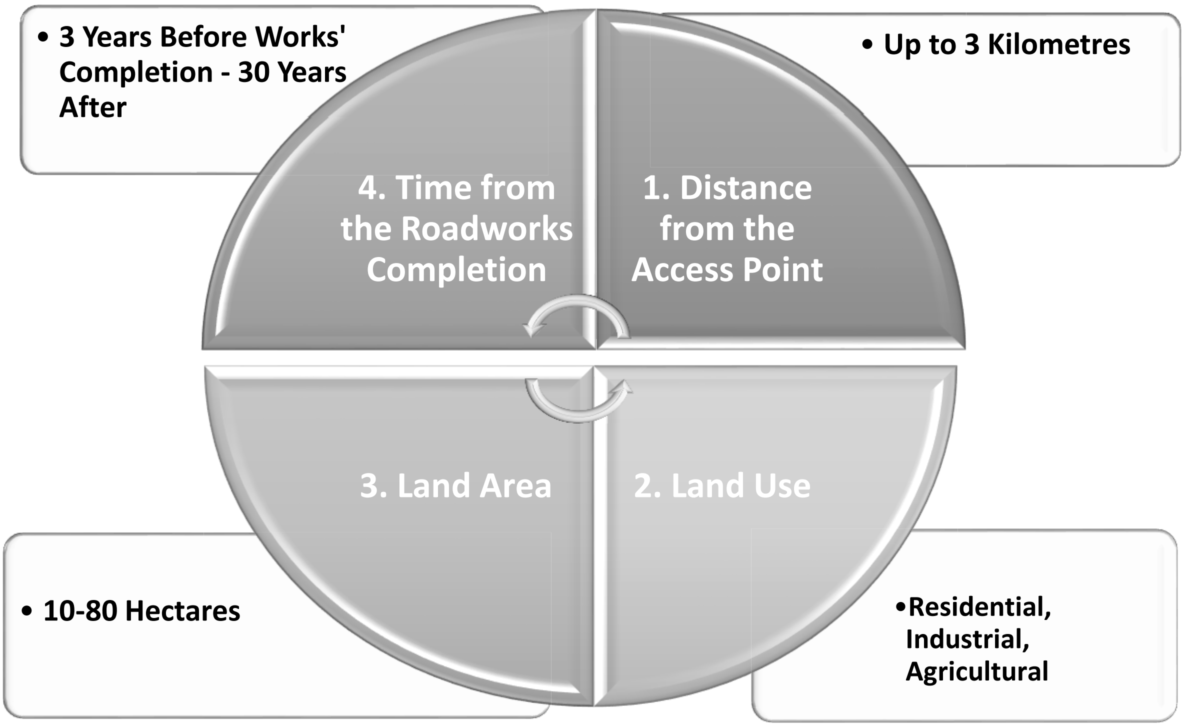


Figure 4- 1: The Independent Variables Chosen as Common Variables in the Literature Models and their Chosen Maximum and Minimum Values

4.5 Data Used

To build the model of change in land value in the absence of real data, a set of artificial data was established for the parameters chosen, based on their expected minimum and maximum number. The artificial data were obtained using a random number generator (RNG) method, which has been used in various scientific applications such as computer science, statistical work, psychological research and computational methods (Park and Miller, 1988; Wagenaar, 1972). The RNG method provided by MS Excel was used in the current study to generate representative data for the proposed model. The chosen distribution of the data was normal distribution (Gaussian distribution), which is a continuous probability distribution (Casella and Berger, 2001). Despite the popularity of normal distribution to characterize the variation of the data in question, Limpert and Stahel (2011) reviewed the literature and

$e_i = y_i - y_i'$ ……………………………………………

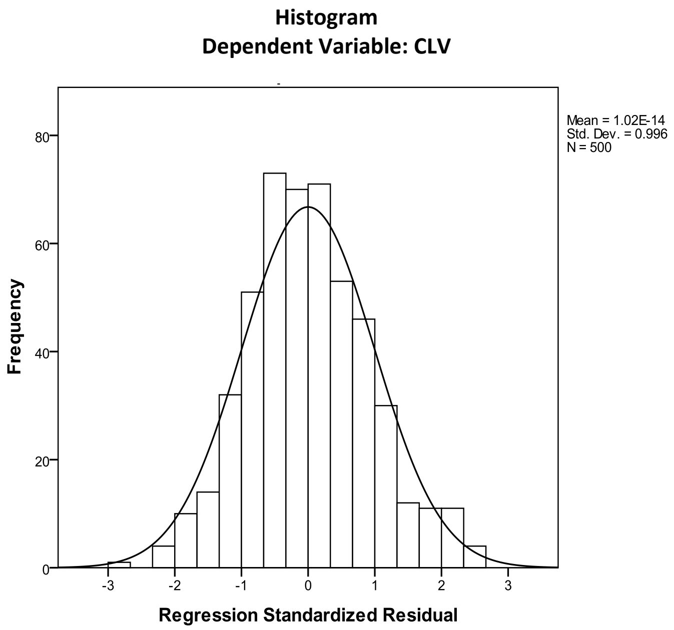


Figure 5- 5: The Histogram for the Residual of the Linear Model, from the SPSS Output.

According to Figure 5-5, the residual from the linear model is normally distributed with the mean equal to zero.

The normal probability plot (P-P) of the regression standardised residual of the predicted model is a kind of representation of the residual which is drawn by the SPSS software. Standardising the residual means that the residual values are scaled to be between (0-1) and then the relation between the (x: observed cum probability) and (y: expected cum probability) is drawn. As much of the residual standardised values are closer to the (45º) line, so the developed model fits the data. The normal probability plot (P-P) of the regression standardised residual of the linear model is shown in Figure 5-6, which reveals that the developed model, in the linear regression form, fits the data used in model building.

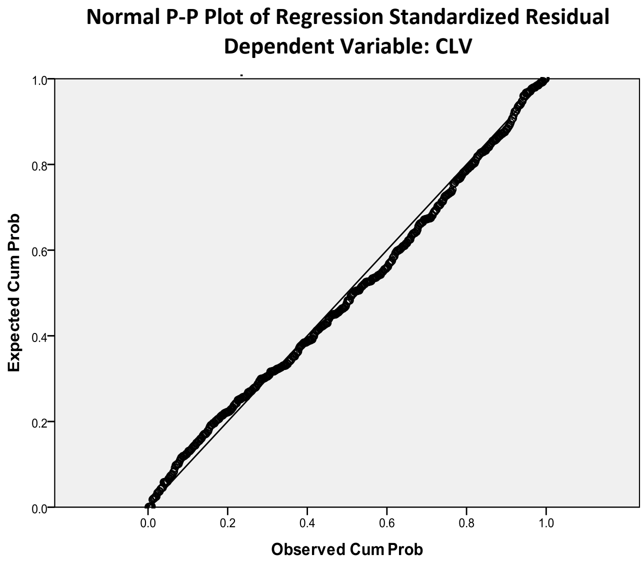


Figure 5- 6: The P-P Plot of the Linear Model, from the SPSS Output

- Assessing the Goodness-of-Fit for the Developed Model

The measurement of the goodness of fit for the developed model is aimed to quantify whether the outcome of such a regression model follows the same probability distribution for the input data (Schermelleh-Engel and Moosbrugger, 2003; Vu, 2016; Hosmer and Lemesshow, 1989; Scheaffer and Mcclave, 1995). The distribution chosen for generating such input data was the normal distribution (Casella and Berger, 2001; Razali and Wah, 2011) as shown in Chapter Four. As a result, the measurement of the goodness of fit is aimed to check the normal distribution for the outcome of the linear model, which is the PCLV.

The widest applicable and most popularity techniques used for assessing the goodness of fit are (Scheaffer and Mcclave, 1995): (1) Chi-square test, which is used for discrete distribution; and (2) the Kolmogorov-Smirnov (K-S) technique that is used for continuous distribution. The Scheaffer and Mcclave (1995) study was used to choose whether the outcome from the linear model (the PCLV) was a continuous distribution or a discrete distribution. The PCLV has been chosen as a continuous distribution due to the range used

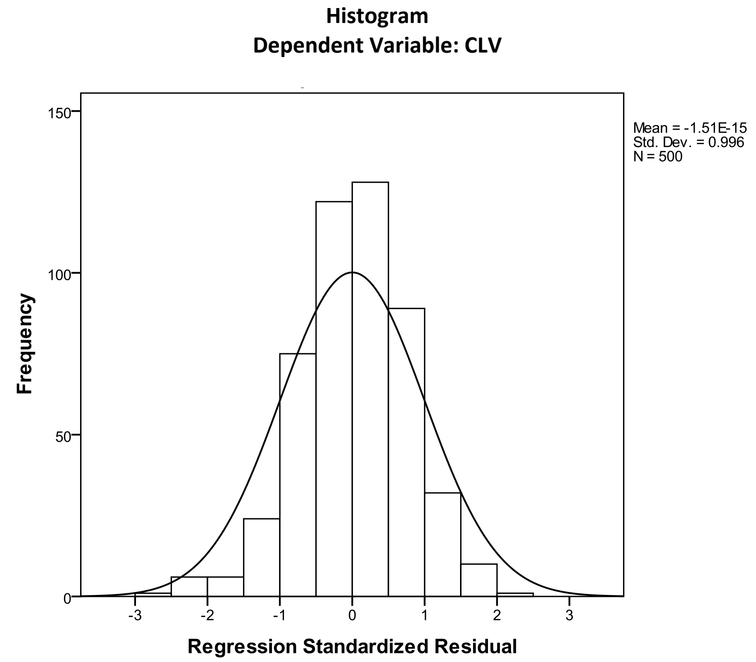


Figure 5- 15: The Histogram for the Residual of the Non-linear Model

According to Figure 5-15, the residual from the non-linear model is normally distributed with the mean equal to zero. The normal probability plot (P-P) of the regression standardised residual for the non-linear model is shown in Figure 5-16, which reveals that the developed model, in a non-linear regression form, fits the data used for model building.

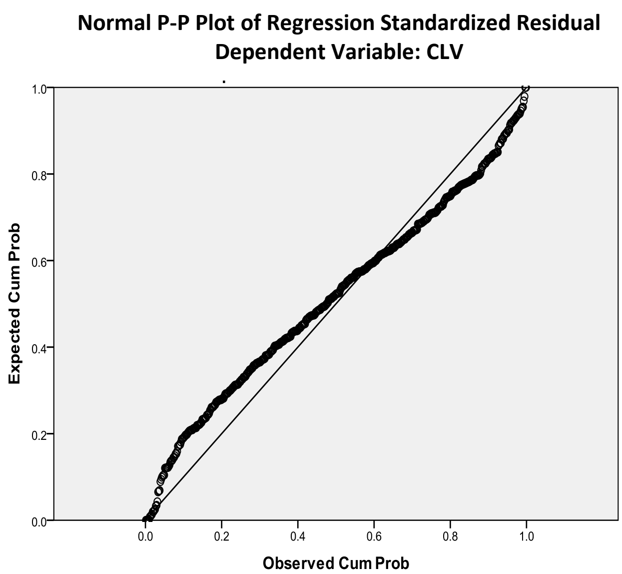


Figure 5- 16: The P-P Plot of the Non-linear Model

2017). The chosen section of motorway M65 is located in the North West of England near Preston city, to the south of Walton Summit Centre and to the north of Clayton Green. Figure 6-1 shows the part of the M65 motorway (between J1 and J2) that was used to verify the non-linear model.

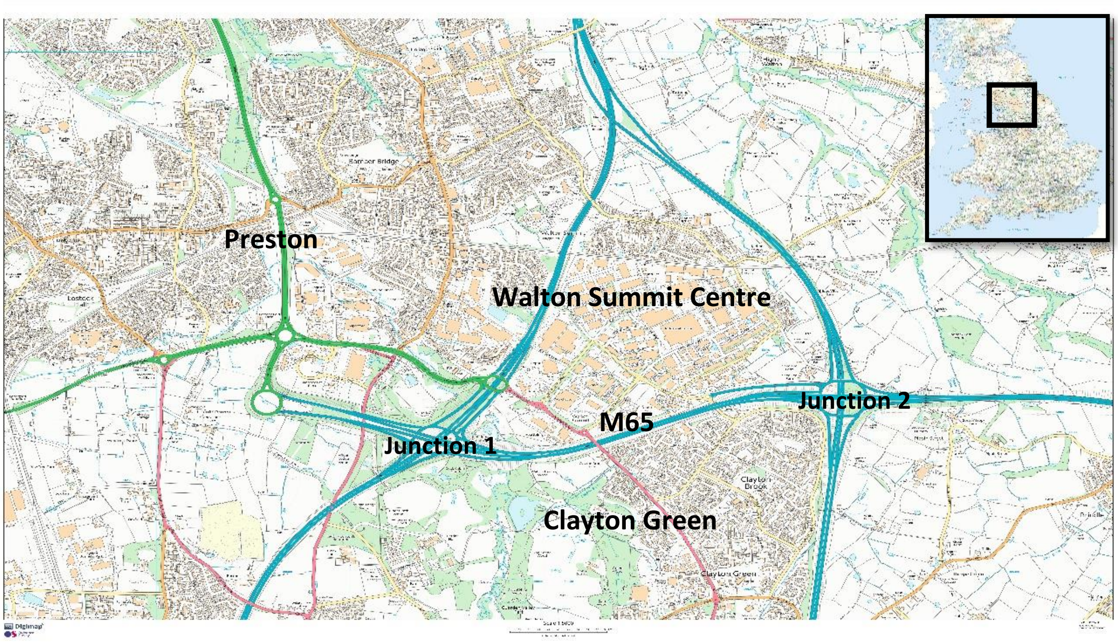


Figure 6- 1: M65 Motorway (between junction 1 and 2) According to UK Map (© Crown copyright and database rights [2017] OS (Digimap Licence))

6.2.1 Methodology

The study area, land adjacent to the M65 motorway (between J1 and 2) contains two different land uses: industrial (Walton Summit Centre, which is land to the north of the chosen motorway section); and residential (Clayton Green, located to the south of the chosen motorway section). Prices for up to 20 years for land adjacent to the M65 motorway obtained from the Zoopla website (Zoopla, 2017) were used to compare with the estimations of changes in land prices obtained from the application of the developed non-linear model. Due to the effect of the distance and area variables on the model application outcomes, the study

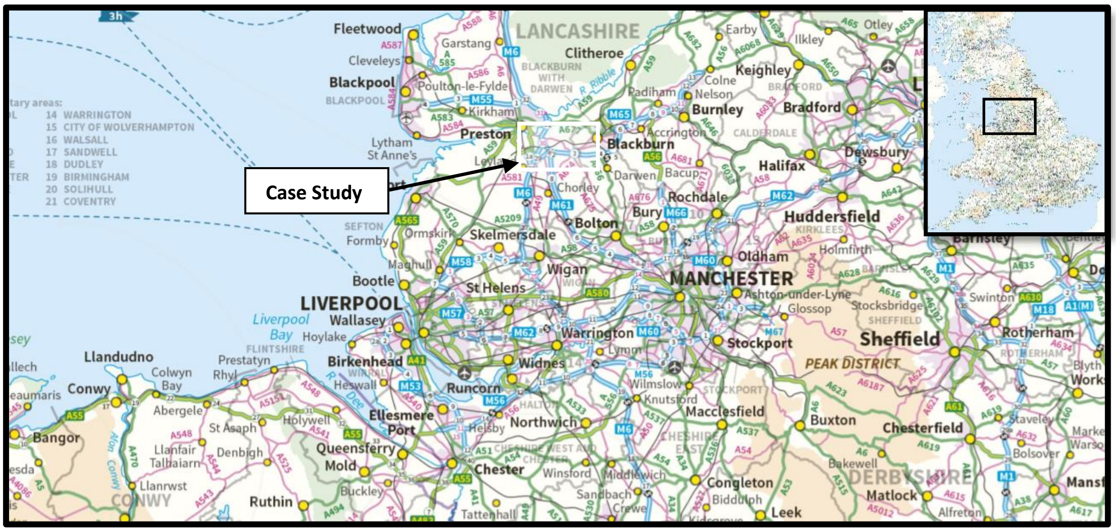


Figure 7- 1: The Chosen Case Study according to England Map (© Crown copyright and database rights [2017] OS (Digimap Licence))

The road network of this case study consisted of three sections of the M6 motorway, two sections of the M61 motorway and three sections of the A6 trunk road. This is the base case (do-nothing case) of the road network. The do-something case for this network focused on adding two sections of the M65 motorway (sections between junctions 1a and 2). Figure 7-2 shows all road sections of the do-something case of the road network used in this study. The two sections of the M65 motorway were constructed in 1997 (Cbrd, 2016). The whole length of these two sections is 3.1 km; which is made up of 0.9 km for the first section from junction 1a to 1 and 2.2 km for the second section from junction 1 to 2. The typical cross section of all motorways used in this study has three lanes in each direction; while the typical cross section of all trunk roads (A roads) of the Lancashire case study has two lanes in each direction.

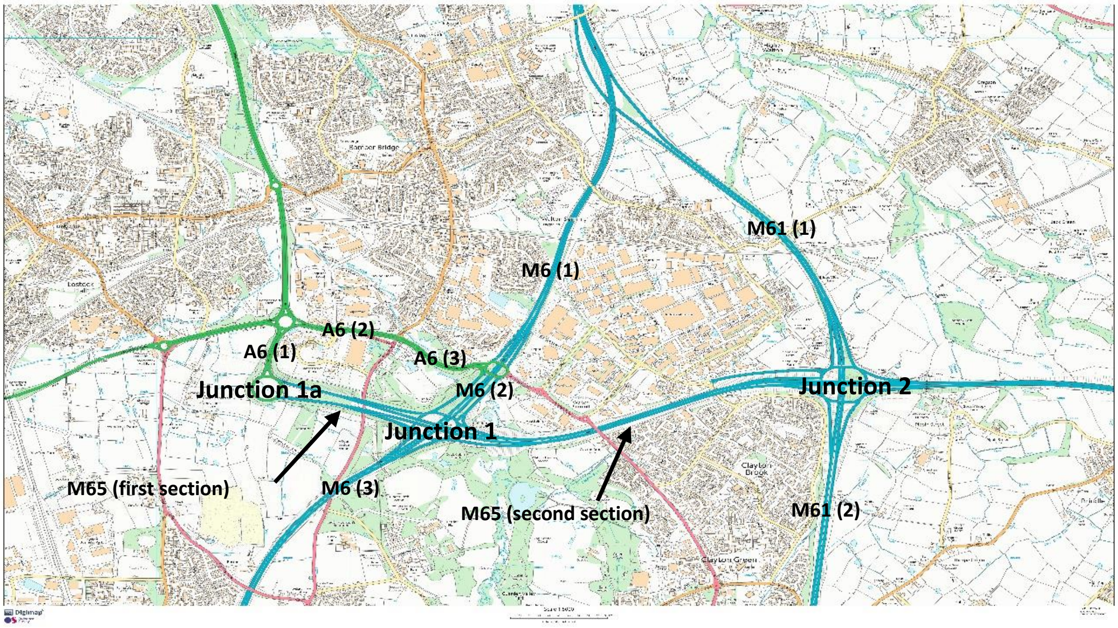


Figure 7- 2: All Road Sections of Do-Something Case of the Road Network Used in this Study (© Crown copyright and database rights [2017] OS (Digimap Licence))

The Motorway Database (Cbrd, 2016) was used to facilitate the selection of the M65 motorway as an inter-urban road development based on the following criteria:

1- Accessibility to adjacent lands

2- Proximity to urban fringe

3- Access to traffic data from Dft (2016a)

Accessibility has been always linked to the availability of transportation facilities, which determine the ease of movement for people and goods to the destination point (Litman, 2017b). Lands served by a transportation project tend to be more attractive than lands without; their values increase as a consequence of the resulting facilities (Mikelbank, 2004). This research focuses on the development of an inter-urban road, which may decrease the travel time and travel costs for road users and leads to increasing the accessibility of the adjacent land as a result. Increasing the accessibility may increase the economic activities in

the affected area and so lead to a change in the type of land use or the values of these lands. Inter-urban roads have full control of access to them (see Chapter Two for more details). As a consequence, these two sections of the M65 motorway have been chosen due to the existence of some access points to the adjacent land; which gives the ability to examine the change in the values of these lands as a result of the development of these two motorway sections.

It has been reported that road development leads to a change in land values. The rate of change increases with the proximity of land to an urban area (Litman, 2017a). As a consequence, the two sections of the M65 motorway between junctions 1a and 2 have been chosen owing to the proximity of their affected area to the city of Preston, to test the change in the values of these lands due to the development of these two motorway sections, as shown in Figure 7-3.

Figure 7- 3: The Chosen Case Study and its Proximity to Preston (© Crown copyright and database rights [2017] OS (Digimap Licence))

7.3.2 Traffic Data of the Road Sections

Real traffic data obtained from the Dft (2016a) has been used for each section in the road network of Lancashire. The average traffic volumes of the three sections of the M6 motorway were used as a traffic volume for this motorway. The traffic volumes of the M61 motorway, M65 motorway and A6 trunk road were also obtained using the same method as shown in Figure 7-4.

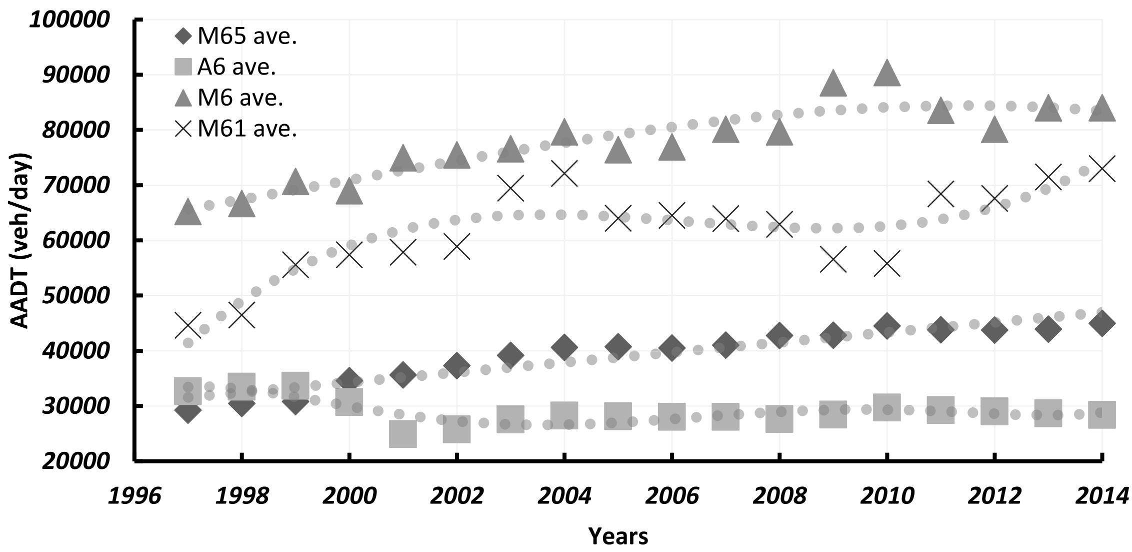


Figure 7- 4: Real Traffic Data of the Road Network in Lancashire

7.3.3 Traffic Flow Pattern

Traffic flow patterns represent the difference in traffic intensities throughout the day, which are defined as flow periods. Each period represents the number of hours of the day (over a year) with the same intensity of traffic flow (Stannard et al., 2006). In this study, the traffic flow pattern for each road section was calculated. The data obtained from the Highways England webpage (Highways Englands, 2016) was used to calculate the number of hours per year, hourly volume and the percentage of annual average daily traffic (AADT) for each

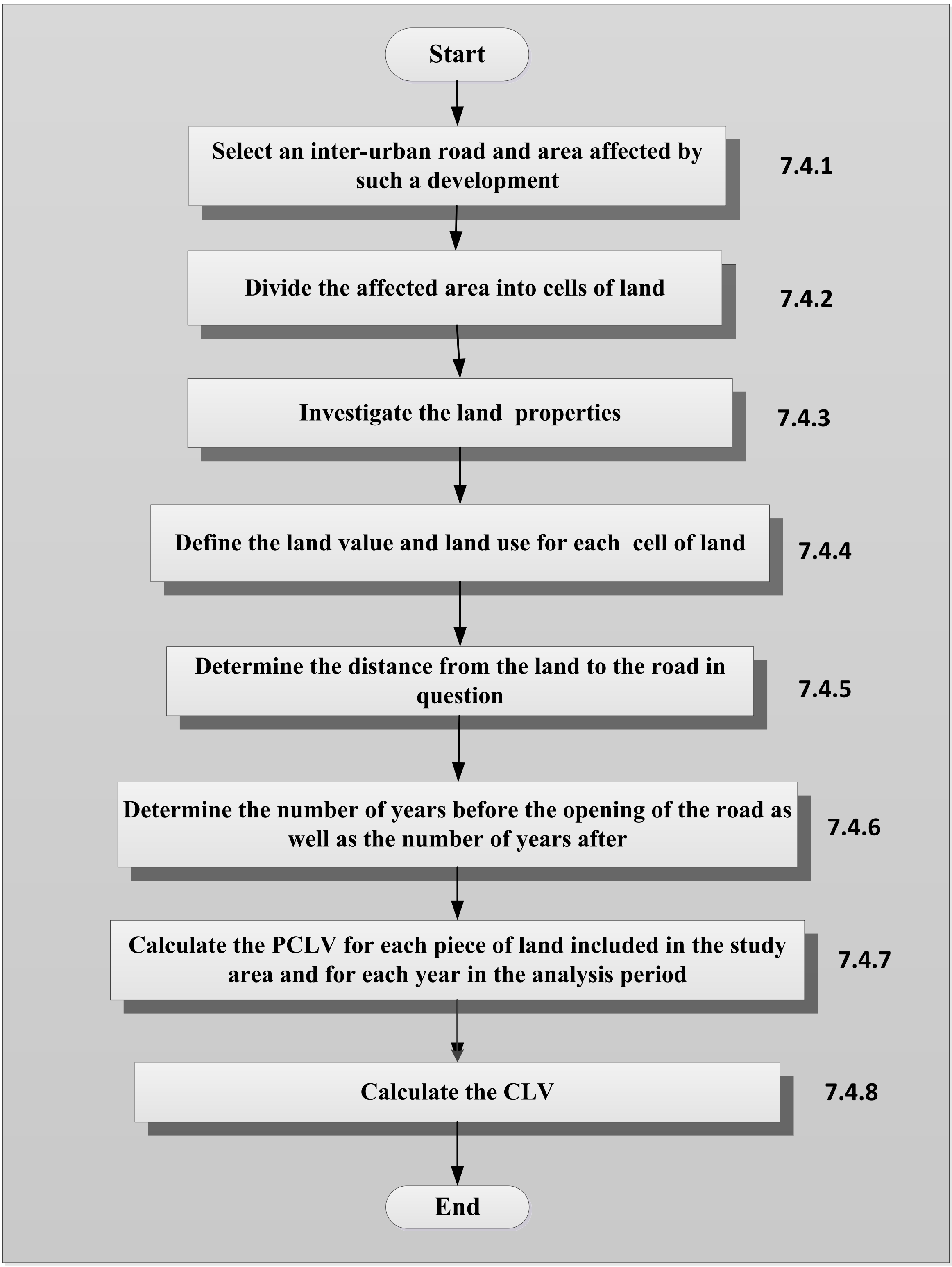


Figure 7- 5: Flow Chart of the Methodology Used to Apply the Proposed Model of Changes in Land Values

7.4.1 Selection of an Inter-urban Road and Area Affected by such a Development

The two sections of the M65 motorway (sections between junctions 1a to 2) were chosen as a new development of an inter-urban road to apply the proposed model of changes in land values. To highlight the land affected by the development of these two sections, the distance of 1.5 km from the alignment of the M65 motorway sections was used after taking into account the model's limitation for the distance variable and the access points available in this case study; these play an important role for an inter-urban road (see Chapter Two for more details). Thus, ArcGIS was used to measure a distance of 1.5 km around the two motorway sections to use later. This land for the model's application is highlighted in Figure 7-6. The total area of the highlighted land is equal to about 16,238,468.9 m^2, which was calculated using the ArcGIS.

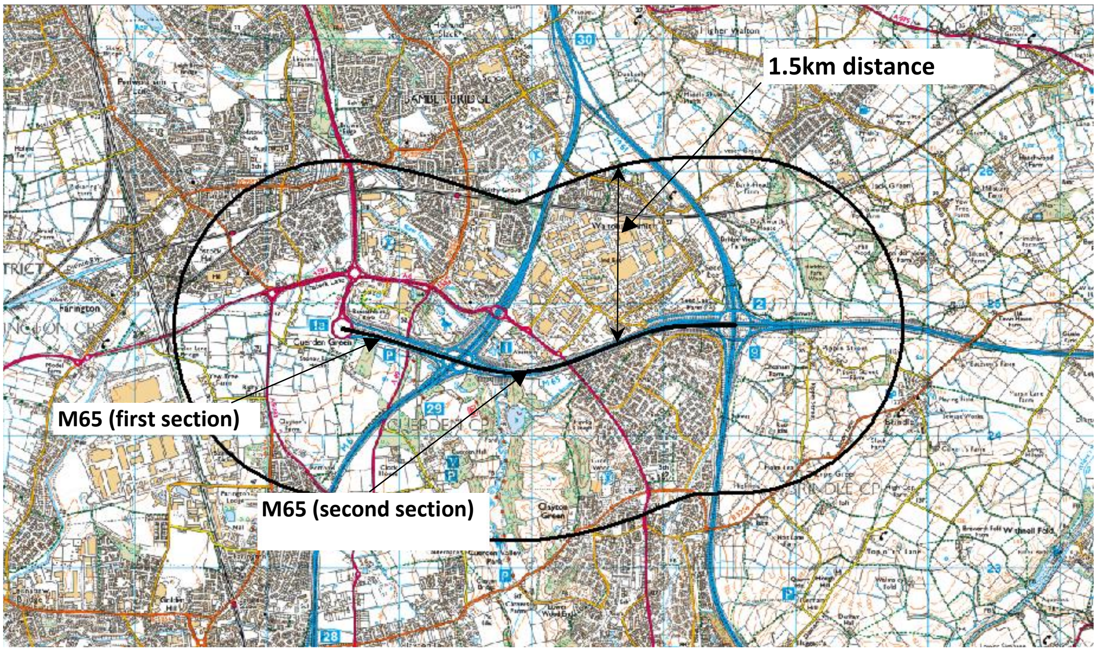


Figure 7- 6: The Highlighted Area around the Two Sections of the M65 Motorway (sections between junctions 1a and 2) (© Crown copyright and database rights [2017] OS (Digimap Licence))

The distance of 1.5 km from the alignment of the M65 motorway sections was divided into distances of 0.5 and 1 km as shown in Figure 7-7. These distances were used to facilitate the division of the highlighted land into cells for later model application. The reason for dividing the highlighted area is due to the limitation of the developed model regarding the variable of the land area (more information is available in Section 4.4.5).

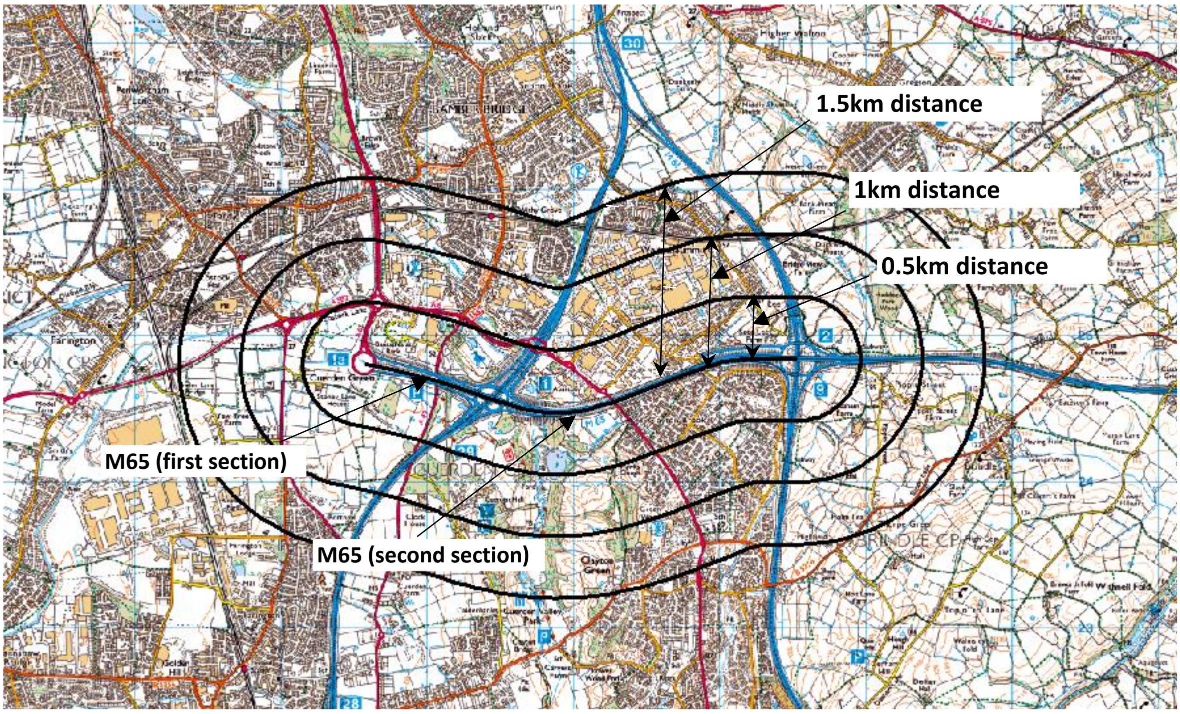


Figure 7- 7: The Division of the Highlighted Area around the M65 Motorway (sections between junctions 1a and 2) (© Crown copyright and database rights [2017] OS (Digimap Licence))

7.4.2 Dividing the Affected Land into Cells of Land

Lands affected by the development of the two sections of M65 motorway, i.e. lands located between 0.5, 1 and 1.5 km distances were delimited into 75 cells of land, as shown in Figure 7-8. Such a division has been used due to the limitation of the proposed model regarding the

land area variable, which should be within the required range of 10-80 hectares. As a consequence, these cells of land have been used later for obtaining the independent variables of the proposed model, to calculate the CLVs as a secondary impact of an inter-urban road development. These independent variables are distance from the new road, time that has elapsed since the completion of the road works, land use and land area.

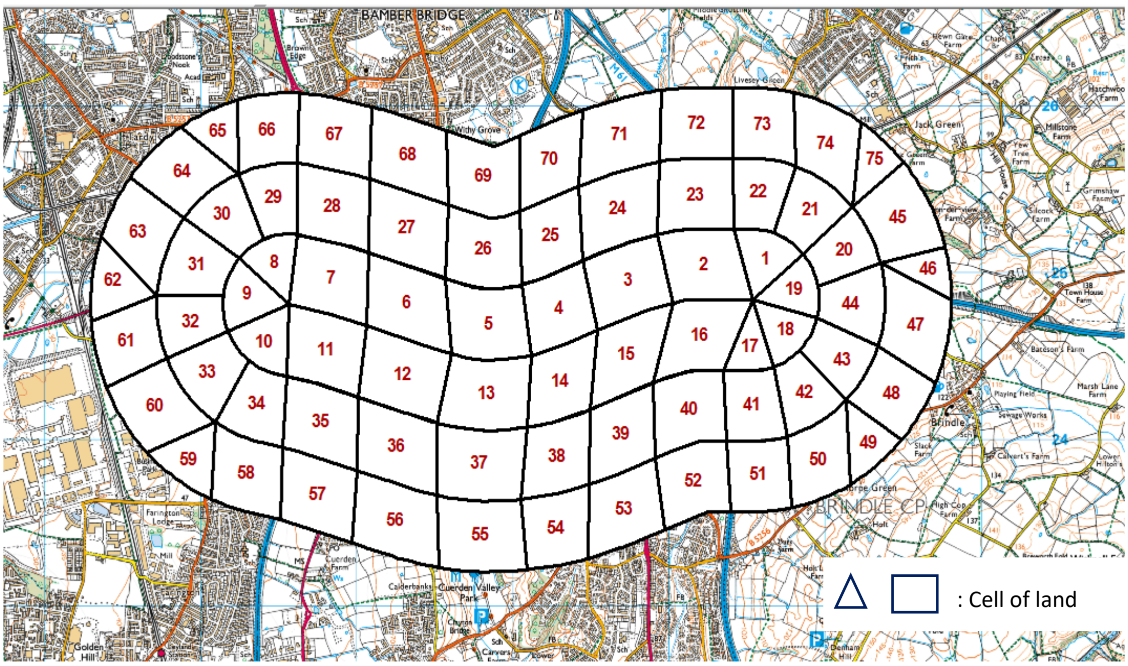


Figure 7- 8: Cells of Land Affected by the M65 Motorway Road Development (© Crown copyright and database rights [2017] OS (Digimap Licence))

7.4.3 Investigating the Land's Properties

Properties of land cells such as the area of the cell and its centroid are important to achieve for the application of the proposed model, due to the effect of these properties on the resulting changes in land values. These properties were determined using the different tools provided in the ArcGIS system, i.e. the area of each cell of land was determined using the calculation tool provided; while the centroid of each cell was calculated using the management tool of the same system. The obtained centroid of each cell of land is

represented by a green dot as shown in Figure 7-9. The calculated areas for the 75 cells of land (hectare) are shown in Table D.1 in Appendix D.

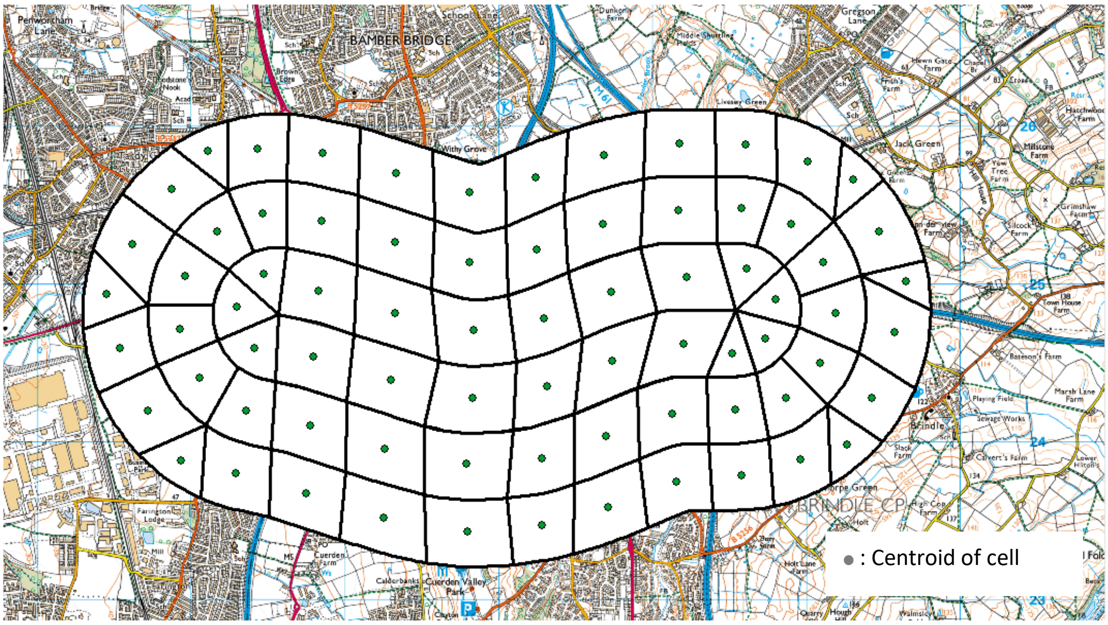


Figure 7- 9: Centroid of Cells of Land Affected by the M65 Motorway Road Development

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7.4.4 Definition of Land Use and Land Value for Each Cell of Land

Land value according to its usage has been calculated for each cell of land in order to express the land use in the proposed model and then achieve its effect on the resulting CLV. The case study chosen to apply the proposed model consists of different types of land use; such as residential, agricultural and industrial, as shown in Figures 7-10. Consequently, a Google Earth map with the aid of the ArcGIS technique was used to identify the percentage of each type of land use in each cell of land, which in turn has been used to calculate the average land value (LU) (£/m^2) for each cell.

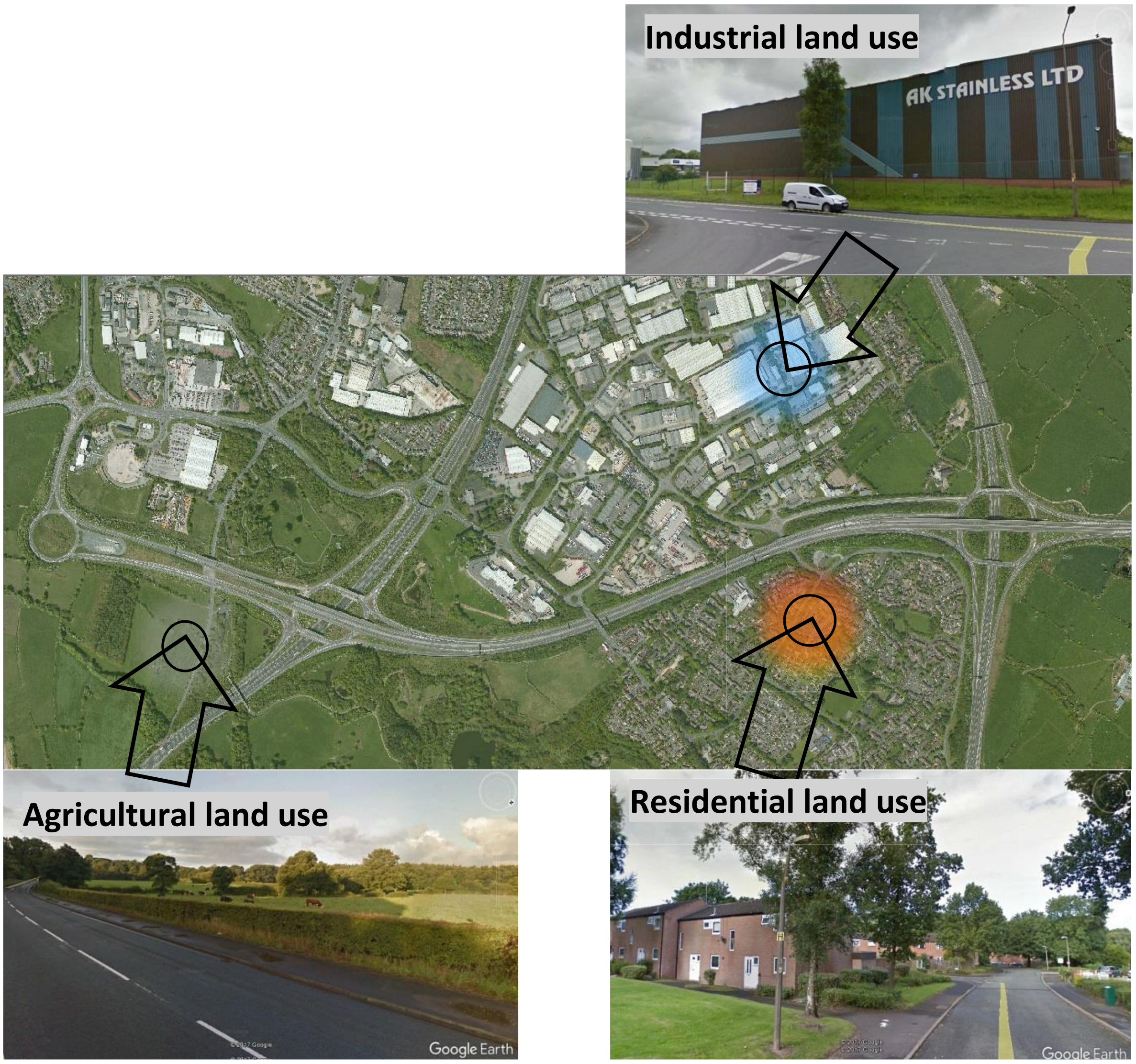

Figure 7- 10: Main Types of Land Use in the Study Area (Google Earth)

The proposed model of change in land values has the ability to deal with only three types of land use: residential, agricultural and industrial (see Chapter Four). As a consequence, it was felt necessary to exclude land dedicated for road development from the calculations of LU as shown in Figure 7-11.

Cell number two has been taken as an example to identify the percentages of industrial, residential and agricultural land use as shown in Figure 7-11. This figure shows that cell number two includes three types of land use. For the agricultural use, three parts have been observed in cell number two as shown in Table 7-7. The area of each part has been measured

using the GIS software. The area of the three parts has been summed together to obtain the total area of agricultural use in cell number two. The same procedure was repeated for the residential and industrial land uses of cell number two. Consequently, the percentage of land for agricultural, industrial and residential uses has been calculated, which is equal to 65%, 25% and 10% respectively, as shown in Table 7-7.

Figure 7- 11: The Classification of Land Use Types for Cell Two (Google Earth)

Sanchez, 1993) (see Chapter Two). The centroid of each cell of land was used to get the average distance for each cell of land. Thus, seven access points for the two sections of the M65 motorway had been noted and the straight distances were measured from the centroid of each cell of land to its nearest access point, as shown in Figure 7-12. A distance variable (m) for each cell of land was measured and shown in Table D.3 in Appendix D.

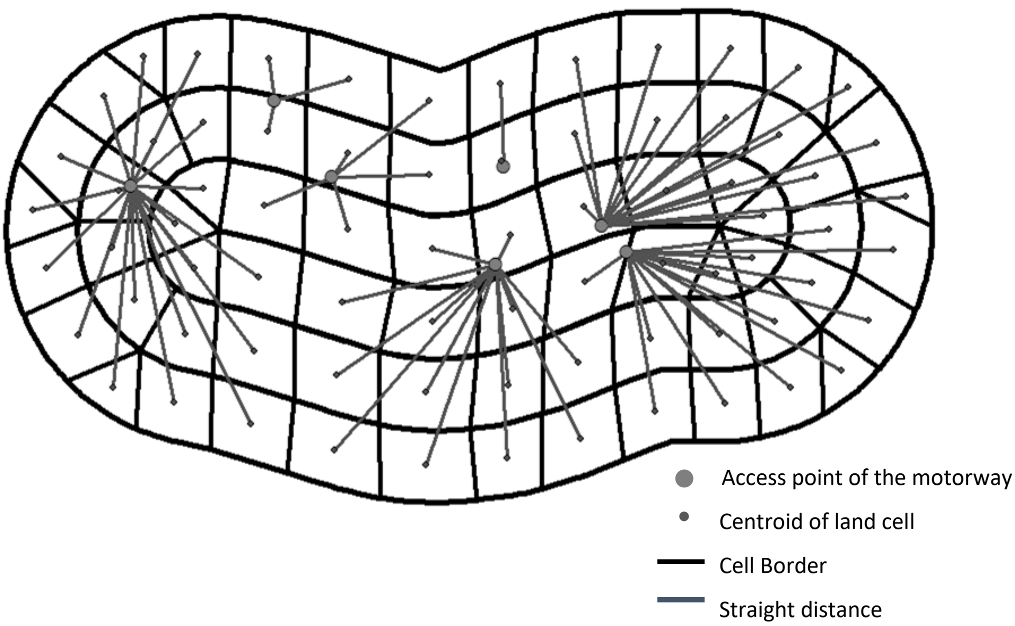

Figure 7- 12: Straight Distances from Centroids of Cells to the Nearest Access Points

7.4.6 Determination of the Number of Years Before and After the Opening of the New Road

Although the proposed model has the ability to estimate the changes in land values from three years before the road works' completion (more details are found in Chapter Four), these years were not considered in the model's application due to the goal of this study, which is the comparison between the CLVs as a secondary impact of road development and the RUCSs of the generated traffic as a primary impact of road development. These RUCSs

Hoel, 2009; Bennett, 1996b). The VOC is in turn considered as an important item in the RUC (Garber and Hoel, 2009), which reflects the components related to vehicle operation (Bennett and Greenwood, 2004; Robinson, 2008) in terms of fuel, engine oil, tyres, maintenance and depreciation (Gillespie, 1998; Garber and Hoel, 2009), as shown in Figure 8-2.

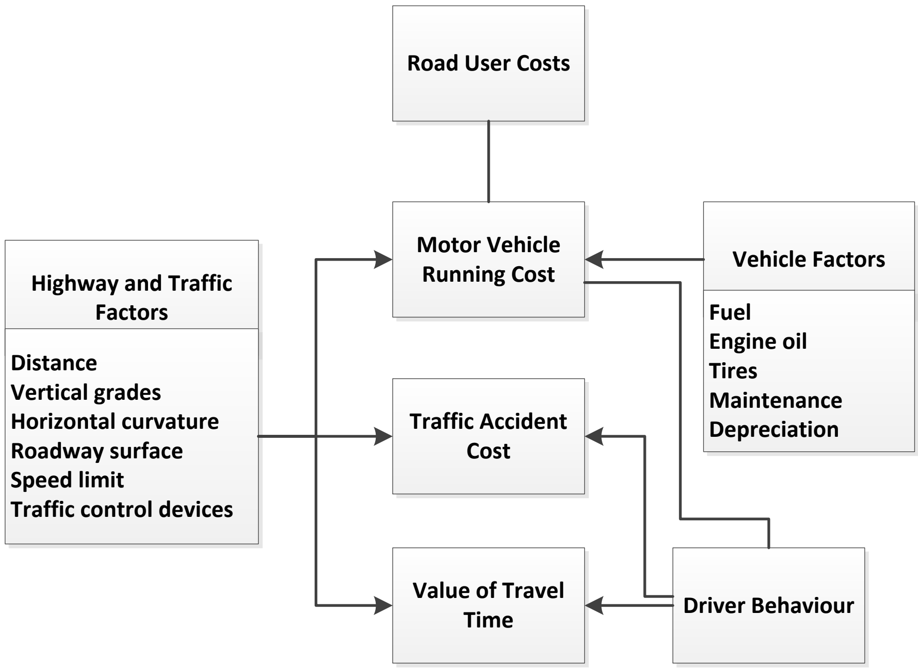

Figure 8- 2: Road User Cost Factors (adopted from Garber and Hoel, 2009)

The VOC consists of variable costs and fixed costs (Mackie et al., 2005; Litman, 2016c). The variable costs are affected by the distance travelled in miles that include fuel, engine oil, tyres, parts, user time and stress, and user crash risk (Bennett and Greenwood, 2004); while the fixed costs are not affected by the distance travelled and include the price of a new vehicle, vehicle registration, insurance payments and part of the maintenance price (Litman and Doherty, 2009).

The fuel consumption in turn constitutes the major part of the VOC (Ko et al., 2016); which represents about (20-40) % from the total VOC (HTC, 1999b cited in Bennett and

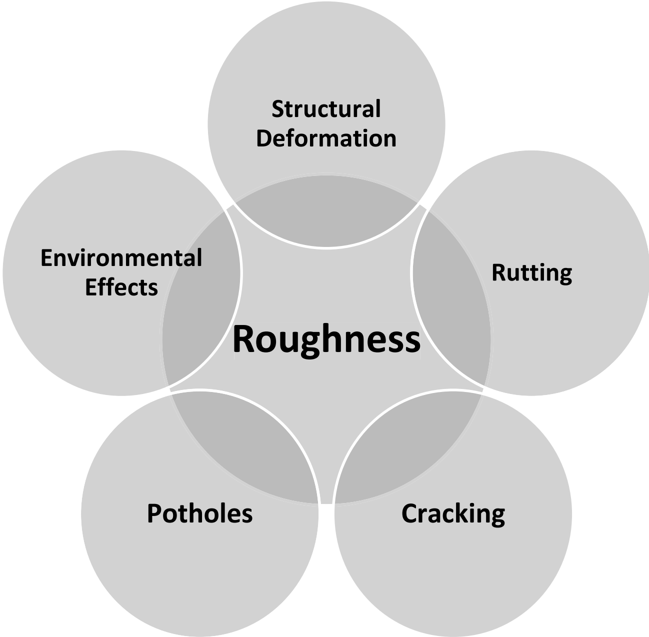

Figure 8- 3: Components Represented in HDM-4 Roughness Model

The work of Dreyer and Steyn (2015) and Pavia (2012) was used to obtain the value of pavement roughness (m/km) to input in HDM-4 as shown in Table 8-3 and Figure 8-4, respectively.

Table 8- 3: Road Roughness Categories (adopted from Dreyer and Steyn, 2015)

	Sayers (1986) (m/Km)	**Cantisani and Loprencipe (2010) (m/Km)**	**Combined categories (m/Km)**	
Very good	≤ 2.0	< 1.42	} ≤ 2.24	Very good to good
Good	1.5-3.5	1.42-2.84		
Fair	2.5-6.0		} 2.25-4.05	Fair to mediocre
Mediocre	3.8-11.0	2.84-4.06		
Poor	> 8.0	> 4.06	> 4.05	Poor

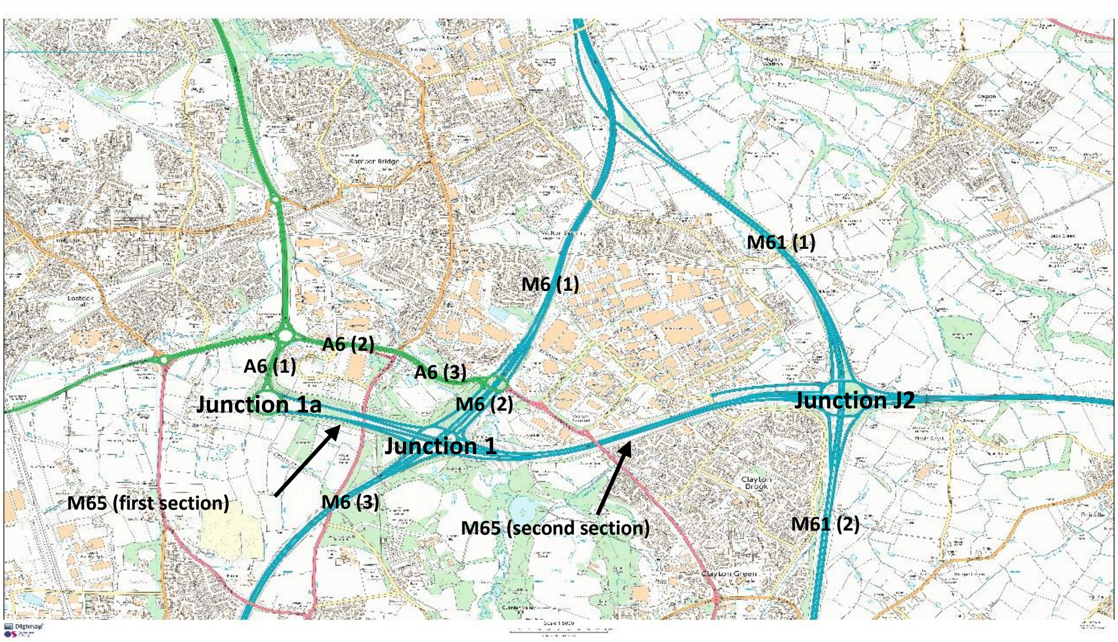

Figure 8- 5: The Sections of the Road Network Used in This Study (© Crown copyright and database rights [2017] OS (Digimap Licence))

Different reports have been obtained from the project analysis of HDM-4 (Archondo-Callao, 2008). One of these reports is the Road Agency and User Cost Streams that calculated two different costs (Aswathy et al., 2013): RACs and RUCs. The RACs result from adding the capital cost and the total maintenance costs; while the RUCs result from adding the VOC, TTC and AC (Aswathy et al., 2013; Gillespie, 1998; Garber and Hoel, 2009). Both the RAC and RUC have been calculated for each year in the analysis period, which was chosen to be for 30 years in this study and within the allowable limit reported by Odoki et al. (2012).

The RUCS includes the savings in the VOC, TTC and the AC (Aswathy et al., 2013; Dft, 2016c; Parkinson, 1981) that has been obtained from another report from the HDM-4, the Comparison of Cost Stream; where the RUC of the do-something case is subtracted from the RUC of the do-nothing case. The RUCSs of the M6 motorway that resulted due to the

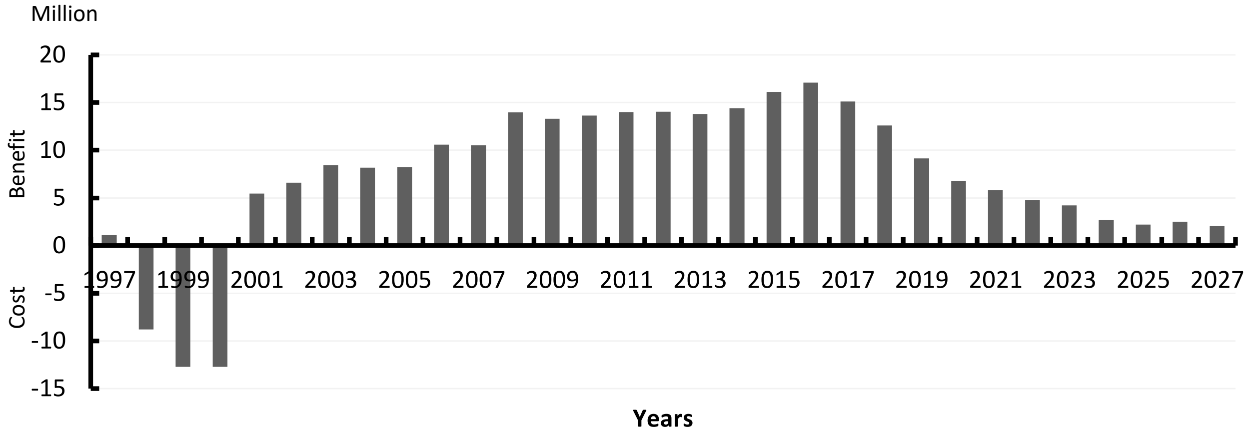

Figure 8- 10: The Summation of RUCSs (m£) for all roads

Figure 8-10 reveals that RUCSs are equal to £1.13 m in 1997. Three years later, only the costs reached to about £12.5 m in 1999 and 2000. From 2001 onwards, the benefits increased until the maximum benefit in 2016 of about £17 m. From 2016 to the end year of the analysis, there is a decrease in the trend of benefits that reaches to about £4 m in 2024.

For a similar project, (Litman, 2006; 2017a) estimated the costs and benefits of a road section over the analysis period as shown in Figure 8-11. This figure reveals that in the first year of analysis, there is only the construction cost of the new road. In the later years, there are benefits that decreased over the analysis period. Litman's estimation includes detailed costs and benefits relating to the diverted and induced traffic over the analysis period.

Table C.1: t-statistics

t Table

cum. prob	$t_{.50}$	$t_{.75}$	$t_{.80}$	$t_{.85}$	$t_{.90}$	$t_{.95}$	$t_{.975}$	$t_{.99}$	$t_{.995}$	$t_{.999}$	$t_{.9995}$
one-tail	0.50	0.25	0.20	0.15	0.10	0.05	0.025	0.01	0.005	0.001	0.0005
two-tails	1.00	0.50	0.40	0.30	0.20	0.10	0.05	0.02	0.01	0.002	0.001
df											
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71	31.82	63.66	318.31	636.62
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	22.327	31.599
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.000	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0.000	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	0.000	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0.000	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	0.000	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	0.000	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	0.000	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0.000	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	0.000	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	0.000	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	0.000	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	0.000	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	0.000	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	0.000	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	0.000	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	0.000	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	0.000	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	0.000	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0.000	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807	3.485	3.768
24	0.000	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	0.000	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	0.000	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0.000	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	0.000	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0.000	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	0.000	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750	3.385	3.646
40	0.000	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	0.000	0.679	0.848	1.045	1.296	1.671	2.000	2.390	2.660	3.232	3.460
80	0.000	0.678	0.846	1.043	1.292	1.664	1.990	2.374	2.639	3.195	3.416
100	0.000	0.677	0.845	1.042	1.290	1.660	1.984	2.364	2.626	3.174	3.390
1000	0.000	0.675	0.842	1.037	1.282	1.646	1.962	2.330	2.581	3.098	3.300
z	0.000	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576	3.090	3.291
	0%	50%	60%	70%	80%	90%	95%	98%	99%	99.8%	99.9%
	Confidence Level										

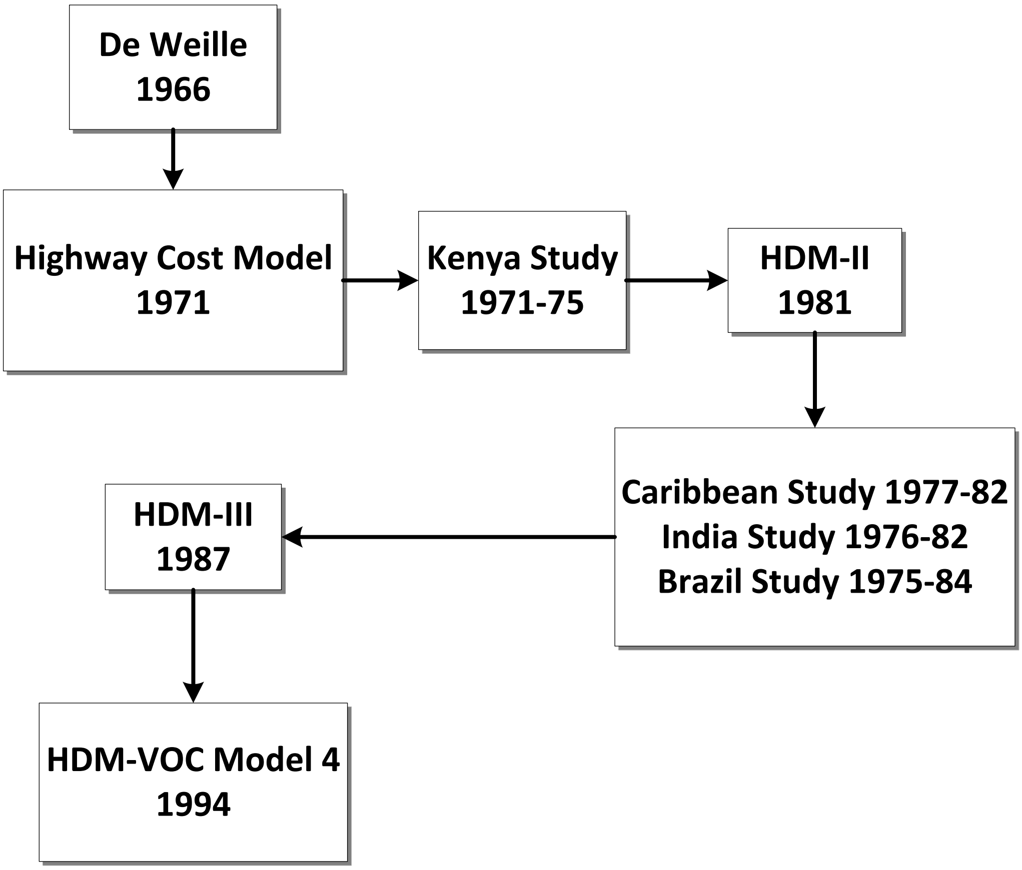

Figure E.2: Development of VOC model of HDM-4 software (Bennett and Greenwood, 2001)

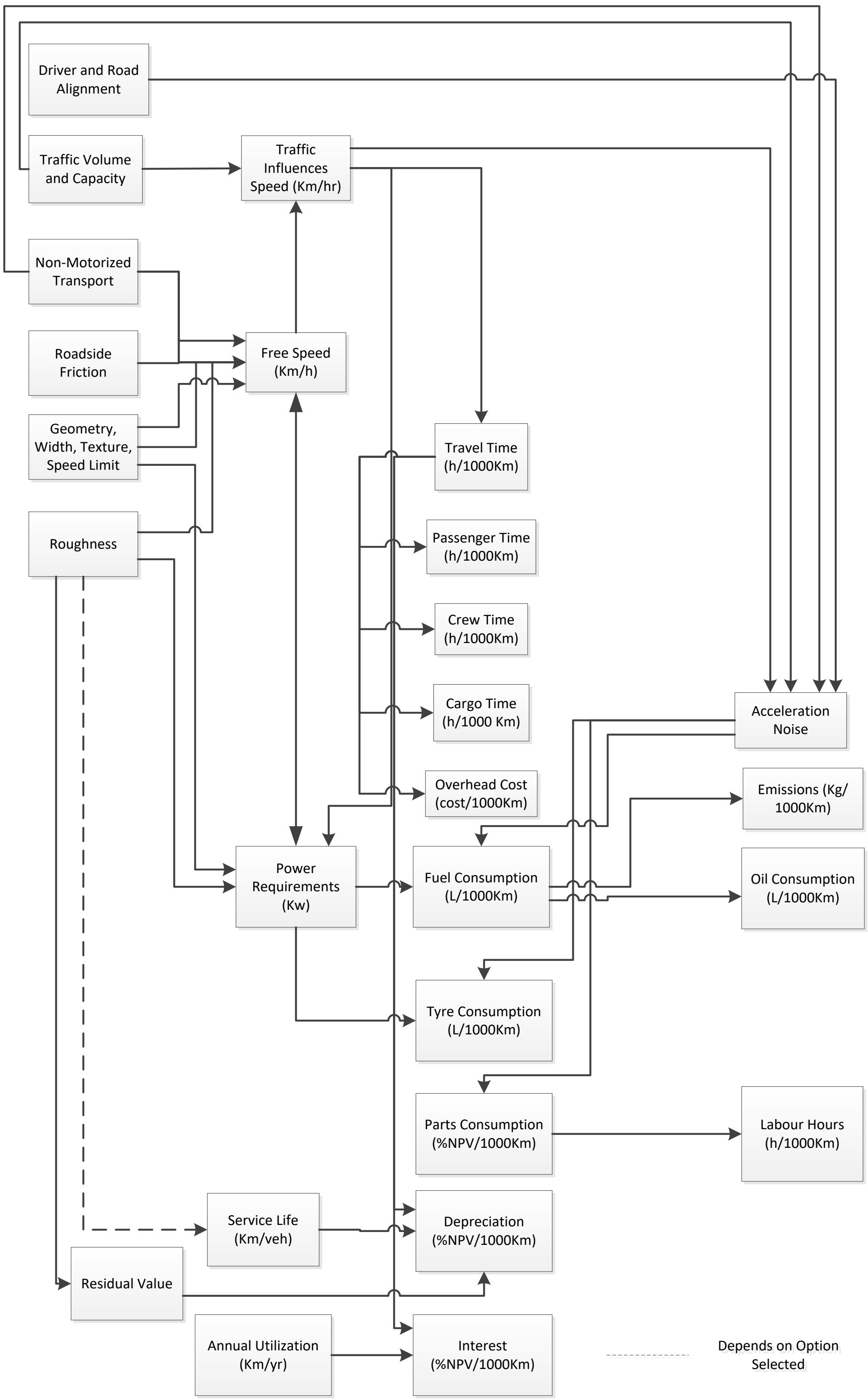

Figure E.3: HDM-4' VOC model and Their components' Interactions (Bennett and Greenwood, 2004)

Table 2- 2: Land Values for Different Land Uses across England (after Wightman, 2013)

	Hectares	£ per ha land value	Total land value £
Business property	86,895	328,0453	£285,055,000,000
Residential	715,284	2,047,760	£1,464,729,766,246
Agricultural	8,925,000	£10,000	£89,250,000,000
Woodland	1,295,000	£1,000	£89,250,000,000
Inland water	343,620	£0	£0
Urban greenspace	106,550	£0	£0
Other greenspace	1,247,612	£1,000	£1,247,612,000
Infrastructure	327,237	£0	£0
Other	185,173	£1,000	£185,172,921
ENGLAND	13,232,271		£1,841,762,551,167

Road transport projects have many impacts on land use. In general, these impacts can be divided broadly into: direct impacts and indirect impacts (Litman, 2016a), as illustrated in Figure 2-2.

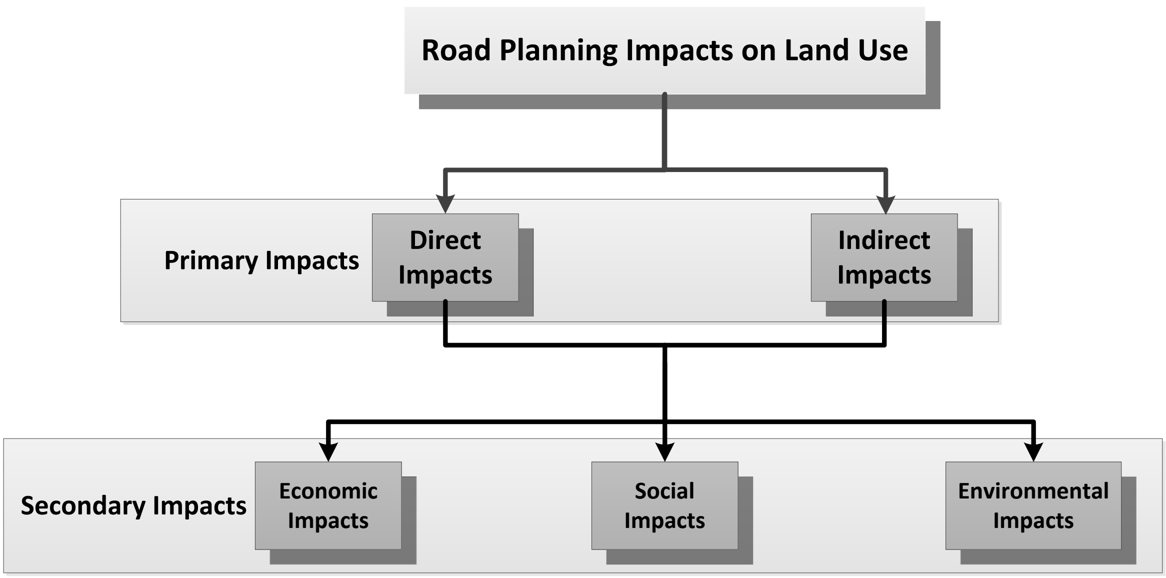

Figure 2- 2: Road Project Impacts on Land Use

EIA may be seen as a determination of how a transportation project would affect the economy of a well-defined area, which can be measured in terms of the variation in number of jobs, increasing personal income, increasing the land value and changing the use of land (TRB, 2010; Kockelman et al., 2002; Lavee, 2015; Chang, 2006).

On the other hand, CBA is an analysis that may be used to compare between a project's options and subsequently rank them in terms of their costs and associated benefits (Robinson, 2008). These two types of analysis seem to complement each other to make the project more convincing for investment in road infrastructure (Melo et al., 2013). However, the main differences between CBA and EIA may be considered in terms of their geographic scope, their direct benefits and their follow-on benefits (TRB, 2010), as shown in Figure 2-3:

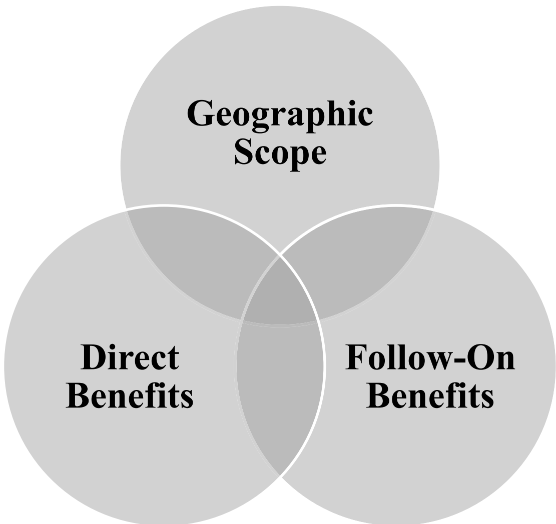

Figure 2- 3: Main Differences between CBA and EIA

- Geographic scope: EIA analyses the changes in economic activity in a defined area, while CBA takes in its analysis a broader view than EIA (TRB, 2010). A CBA is used to determine the project option's social welfare effects by measuring the benefits derived from such an

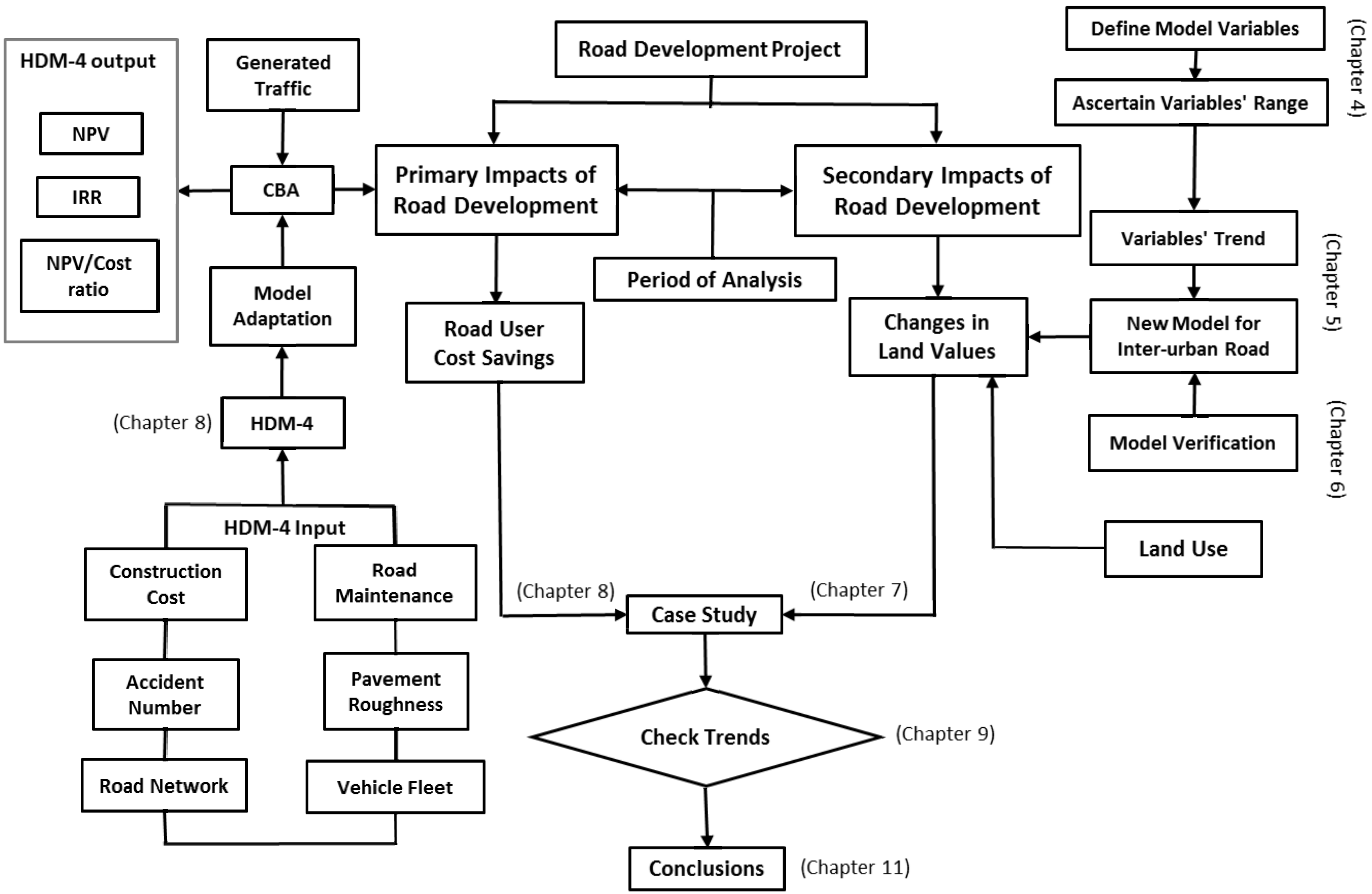

Figure 3- 1: Proposed Outline of the Methodology for this Study

in land use is considered to be a two-way relationship (Kockelman et al., 2002; Chang, 2006; Mackett, 1993) and has received much attention in recent years (Banister and Thurstain-Goodwin, 2005; Huang, 1994; Landis et al., 1995; Levkovich et al., 2016), as shown in Figure 3-2.

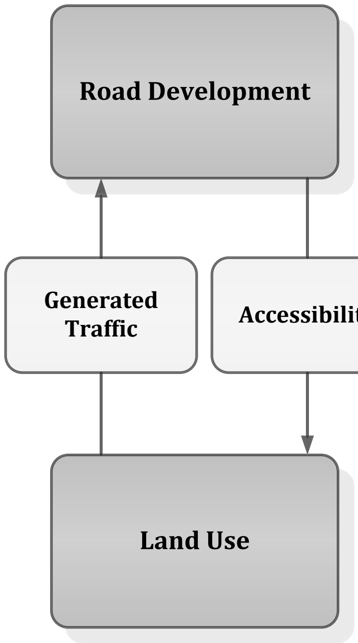

Figure 3- 2: Simplification of the Road Development-Land Use Relationship

A two-way relationship means that the road development project would increase the accessibility to the adjacent land, which would decrease travel times and costs for road users; this in turn would increase the economic activities in these regions, causing a change in the land use and then a change in the value of such land. This could generate more traffic, leading to an increase in the traffic volume on the transport system (Iacono et al., 2008).

It may be seen from reviewing the literature that there is no model that can explicitly address the impacts from inter-urban roads. In addition, there is a need to choose suitable parameters for the model that could reflect better the road transport characteristics of inter-urban roads

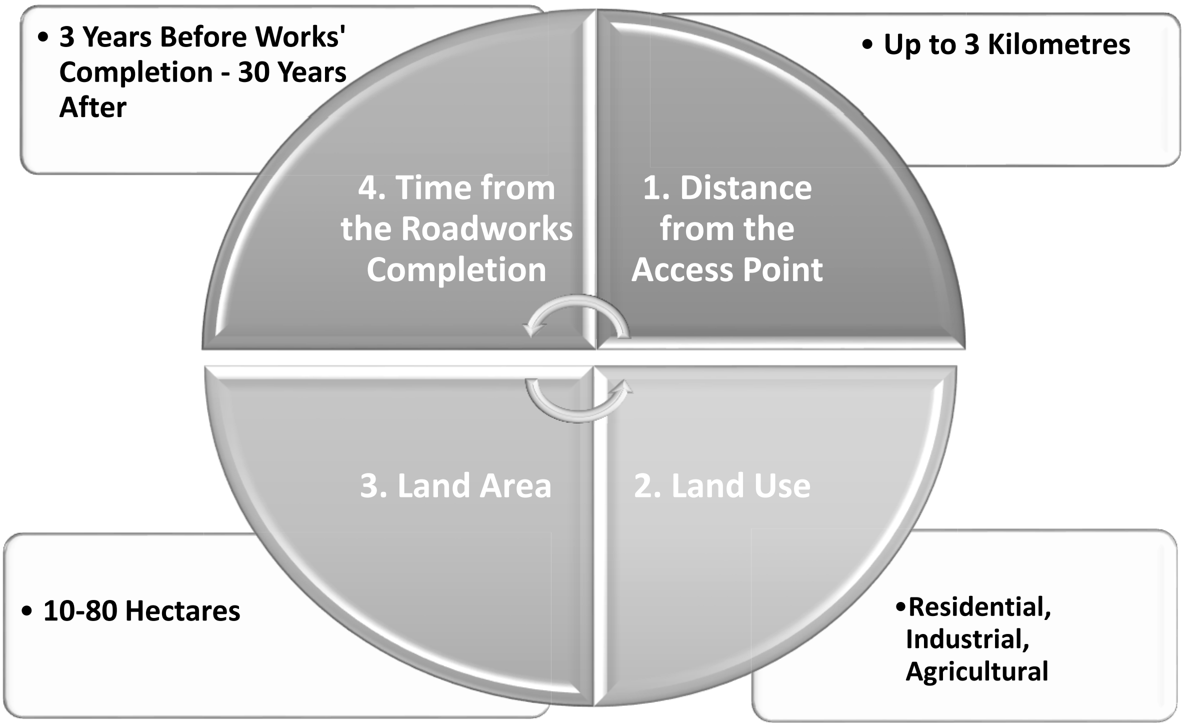

Figure 4- 1: The Independent Variables Chosen as Common Variables in the Literature Models and their Chosen Maximum and Minimum Values

4.5 Data Used

To build the model of change in land value in the absence of real data, a set of artificial data was established for the parameters chosen, based on their expected minimum and maximum number. The artificial data were obtained using a random number generator (RNG) method, which has been used in various scientific applications such as computer science, statistical work, psychological research and computational methods (Park and Miller, 1988; Wagenaar, 1972). The RNG method provided by MS Excel was used in the current study to generate representative data for the proposed model. The chosen distribution of the data was normal distribution (Gaussian distribution), which is a continuous probability distribution (Casella and Berger, 2001). Despite the popularity of normal distribution to characterize the variation of the data in question, Limpert and Stahel (2011) reviewed the literature and

$e_i = y_i - y'_i$ ……………………………………………

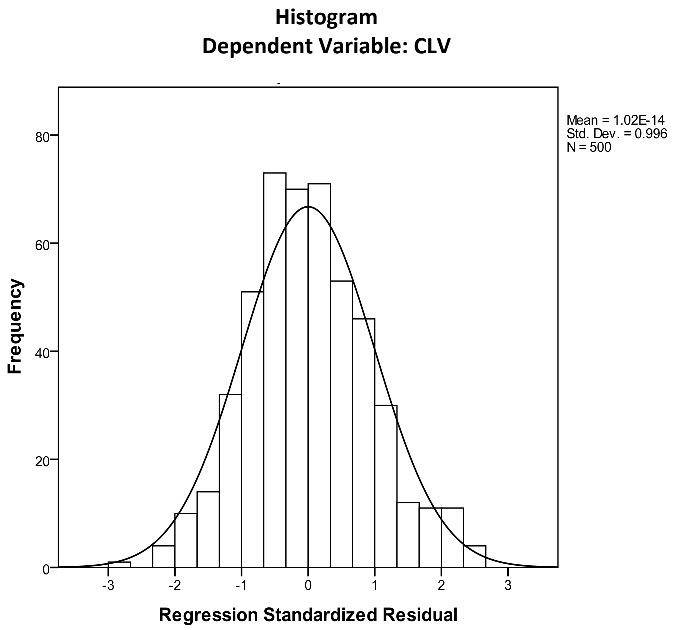

Figure 5- 5: The Histogram for the Residual of the Linear Model, from the SPSS Output.

According to Figure 5-5, the residual from the linear model is normally distributed with the mean equal to zero.

The normal probability plot (P-P) of the regression standardised residual of the predicted model is a kind of representation of the residual which is drawn by the SPSS software. Standardising the residual means that the residual values are scaled to be between (0-1) and then the relation between the (x: observed cum probability) and (y: expected cum probability) is drawn. As much of the residual standardised values are closer to the (45º) line, so the developed model fits the data. The normal probability plot (P-P) of the regression standardised residual of the linear model is shown in Figure 5-6, which reveals that the developed model, in the linear regression form, fits the data used in model building.

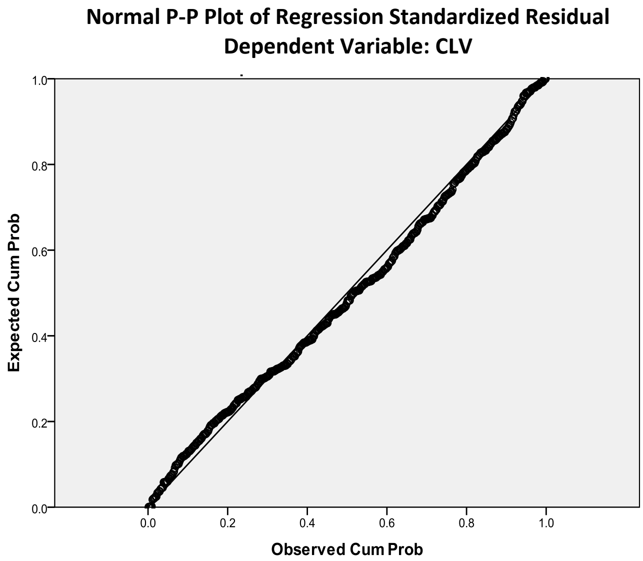

Figure 5- 6: The P-P Plot of the Linear Model, from the SPSS Output

- **Assessing the Goodness-of-Fit for the Developed Model**

The measurement of the goodness of fit for the developed model is aimed to quantify whether the outcome of such a regression model follows the same probability distribution for the input data (Schermelleh-Engel and Moosbrugger, 2003; Vu, 2016; Hosmer and Lemesshow, 1989; Scheaffer and Mcclave, 1995). The distribution chosen for generating such input data was the normal distribution (Casella and Berger, 2001; Razali and Wah, 2011) as shown in Chapter Four. As a result, the measurement of the goodness of fit is aimed to check the normal distribution for the outcome of the linear model, which is the PCLV.

The widest applicable and most popularity techniques used for assessing the goodness of fit are (Scheaffer and Mcclave, 1995): (1) Chi-square test, which is used for discrete distribution; and (2) the Kolmogorov-Smirnov (K-S) technique that is used for continuous distribution. The Scheaffer and Mcclave (1995) study was used to choose whether the outcome from the linear model (the PCLV) was a continuous distribution or a discrete distribution. The PCLV has been chosen as a continuous distribution due to the range used

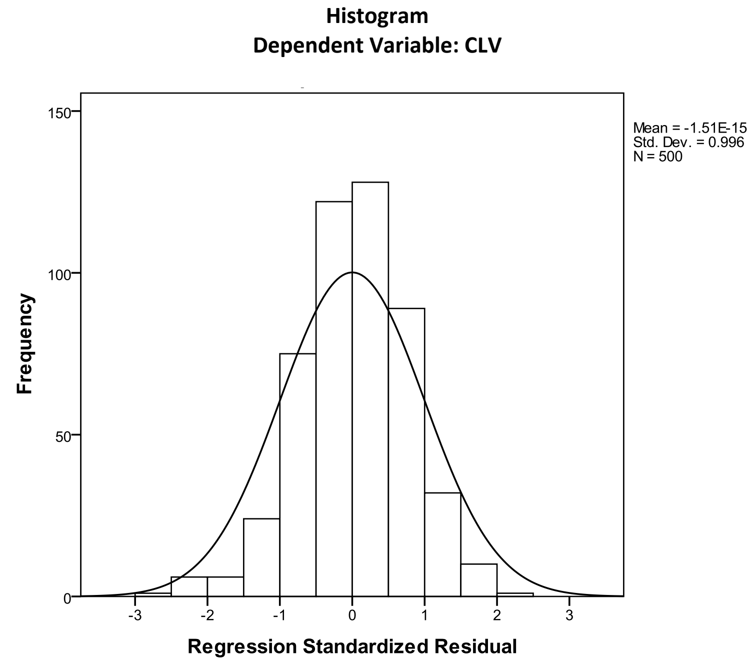

Figure 5- 15: The Histogram for the Residual of the Non-linear Model

According to Figure 5-15, the residual from the non-linear model is normally distributed with the mean equal to zero. The normal probability plot (P-P) of the regression standardised residual for the non-linear model is shown in Figure 5-16, which reveals that the developed model, in a non-linear regression form, fits the data used for model building.

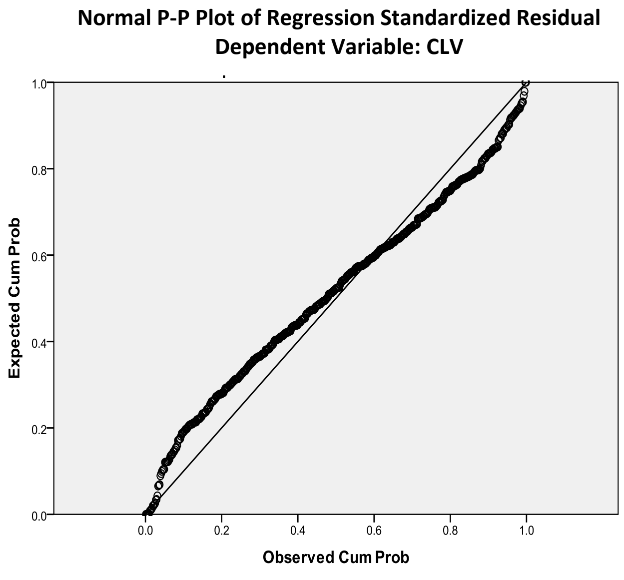

Figure 5- 16: The P-P Plot of the Non-linear Model

2017). The chosen section of motorway M65 is located in the North West of England near Preston city, to the south of Walton Summit Centre and to the north of Clayton Green. Figure 6-1 shows the part of the M65 motorway (between J1 and J2) that was used to verify the non-linear model.

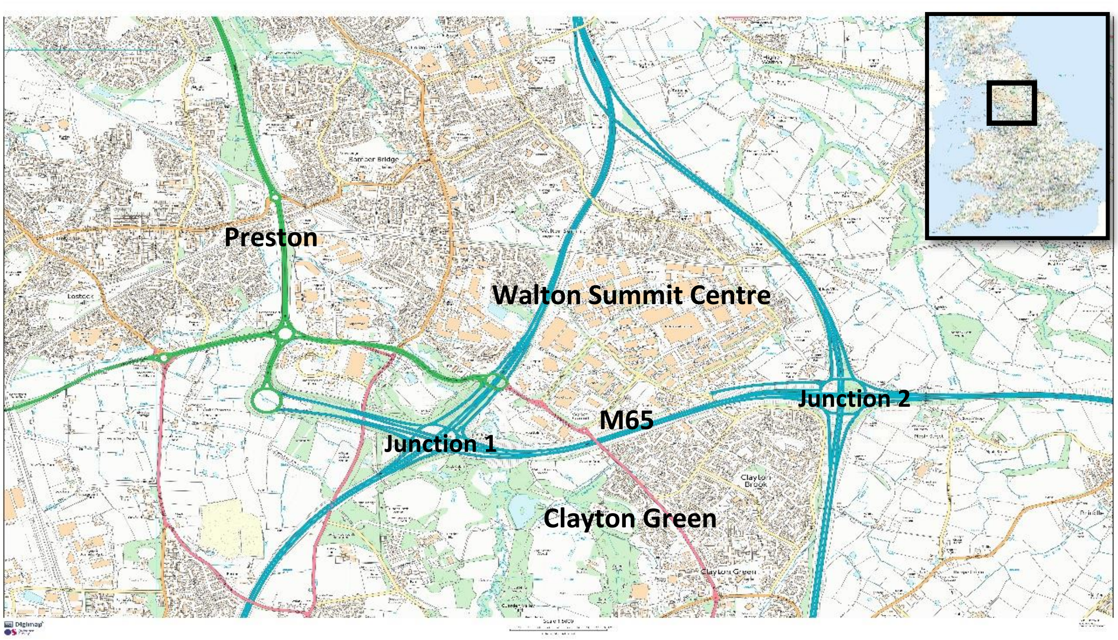

Figure 6- 1: M65 Motorway (between junction 1 and 2) According to UK Map (© Crown copyright and database rights [2017] OS (Digimap Licence))

6.2.1 Methodology

The study area, land adjacent to the M65 motorway (between J1 and 2) contains two different land uses: industrial (Walton Summit Centre, which is land to the north of the chosen motorway section); and residential (Clayton Green, located to the south of the chosen motorway section). Prices for up to 20 years for land adjacent to the M65 motorway obtained from the Zoopla website (Zoopla, 2017) were used to compare with the estimations of changes in land prices obtained from the application of the developed non-linear model. Due to the effect of the distance and area variables on the model application outcomes, the study

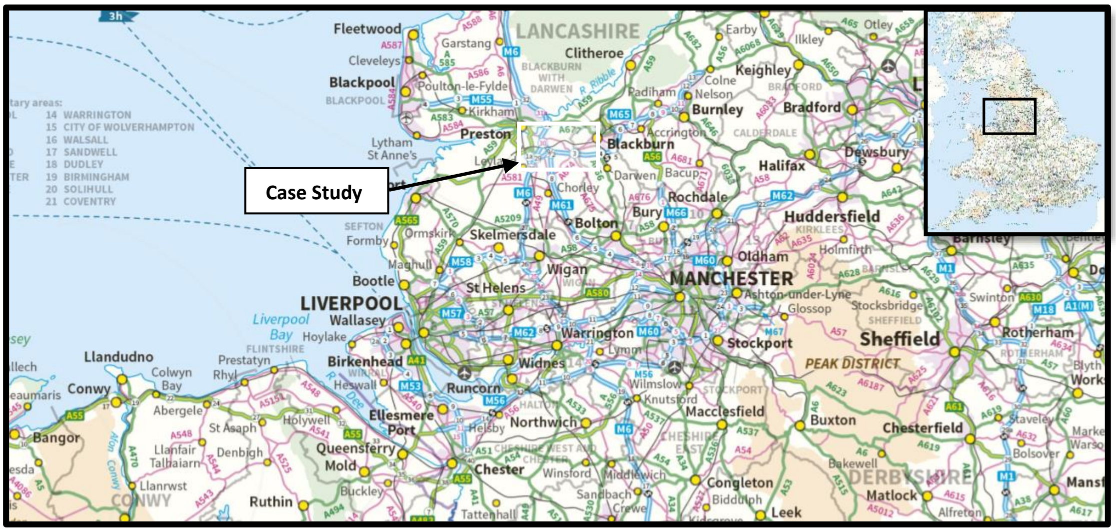

Figure 7- 1: The Chosen Case Study according to England Map (© Crown copyright and database rights [2017] OS (Digimap Licence))

The road network of this case study consisted of three sections of the M6 motorway, two sections of the M61 motorway and three sections of the A6 trunk road. This is the base case (do-nothing case) of the road network. The do-something case for this network focused on adding two sections of the M65 motorway (sections between junctions 1a and 2). Figure 7-2 shows all road sections of the do-something case of the road network used in this study. The two sections of the M65 motorway were constructed in 1997 (Cbrd, 2016). The whole length of these two sections is 3.1 km; which is made up of 0.9 km for the first section from junction 1a to 1 and 2.2 km for the second section from junction 1 to 2. The typical cross section of all motorways used in this study has three lanes in each direction; while the typical cross section of all trunk roads (A roads) of the Lancashire case study has two lanes in each direction.

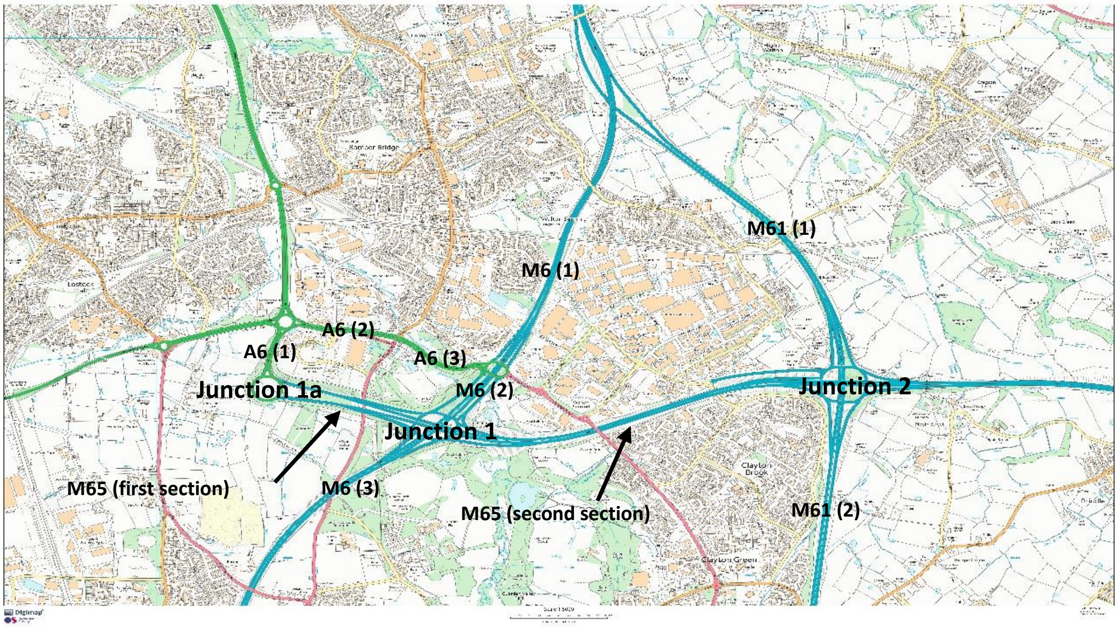

Figure 7- 2: All Road Sections of Do-Something Case of the Road Network Used in this Study (© Crown copyright and database rights [2017] OS (Digimap Licence))

The Motorway Database (Cbrd, 2016) was used to facilitate the selection of the M65 motorway as an inter-urban road development based on the following criteria:

1- Accessibility to adjacent lands

2- Proximity to urban fringe

3- Access to traffic data from Dft (2016a)

Accessibility has been always linked to the availability of transportation facilities, which determine the ease of movement for people and goods to the destination point (Litman, 2017b). Lands served by a transportation project tend to be more attractive than lands without; their values increase as a consequence of the resulting facilities (Mikelbank, 2004). This research focuses on the development of an inter-urban road, which may decrease the travel time and travel costs for road users and leads to increasing the accessibility of the adjacent land as a result. Increasing the accessibility may increase the economic activities in

the affected area and so lead to a change in the type of land use or the values of these lands. Inter-urban roads have full control of access to them (see Chapter Two for more details). As a consequence, these two sections of the M65 motorway have been chosen due to the existence of some access points to the adjacent land; which gives the ability to examine the change in the values of these lands as a result of the development of these two motorway sections.

It has been reported that road development leads to a change in land values. The rate of change increases with the proximity of land to an urban area (Litman, 2017a). As a consequence, the two sections of the M65 motorway between junctions 1a and 2 have been chosen owing to the proximity of their affected area to the city of Preston, to test the change in the values of these lands due to the development of these two motorway sections, as shown in Figure 7-3.

Figure 7- 3: The Chosen Case Study and its Proximity to Preston (© Crown copyright and database rights [2017] OS (Digimap Licence))

7.3.2 Traffic Data of the Road Sections

Real traffic data obtained from the Dft (2016a) has been used for each section in the road network of Lancashire. The average traffic volumes of the three sections of the M6 motorway were used as a traffic volume for this motorway. The traffic volumes of the M61 motorway, M65 motorway and A6 trunk road were also obtained using the same method as shown in Figure 7-4.

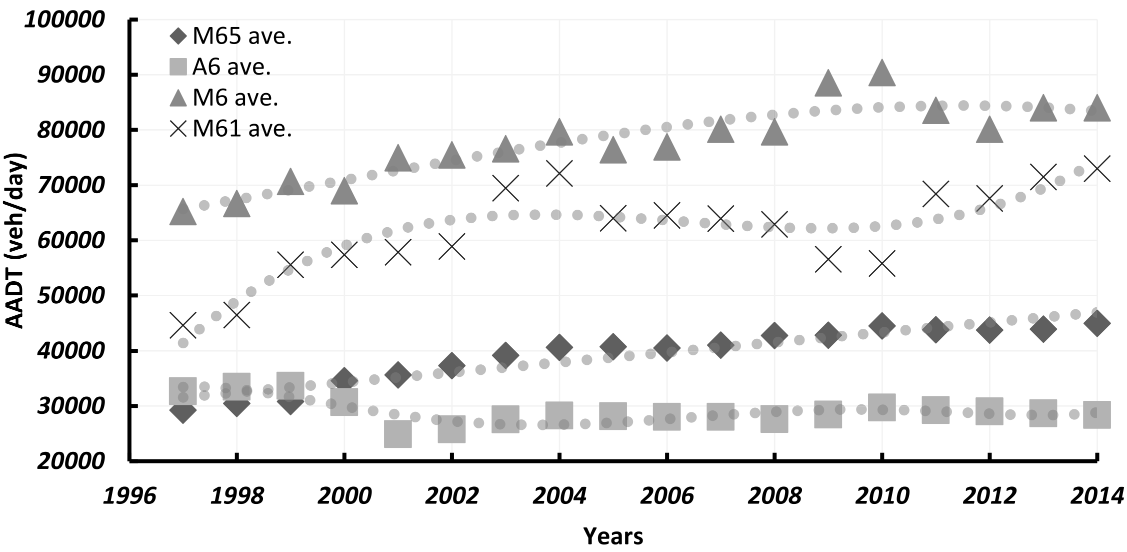

Figure 7- 4: Real Traffic Data of the Road Network in Lancashire

7.3.3 Traffic Flow Pattern

Traffic flow patterns represent the difference in traffic intensities throughout the day, which are defined as flow periods. Each period represents the number of hours of the day (over a year) with the same intensity of traffic flow (Stannard et al., 2006). In this study, the traffic flow pattern for each road section was calculated. The data obtained from the Highways England webpage (Highways Englands, 2016) was used to calculate the number of hours per year, hourly volume and the percentage of annual average daily traffic (AADT) for each

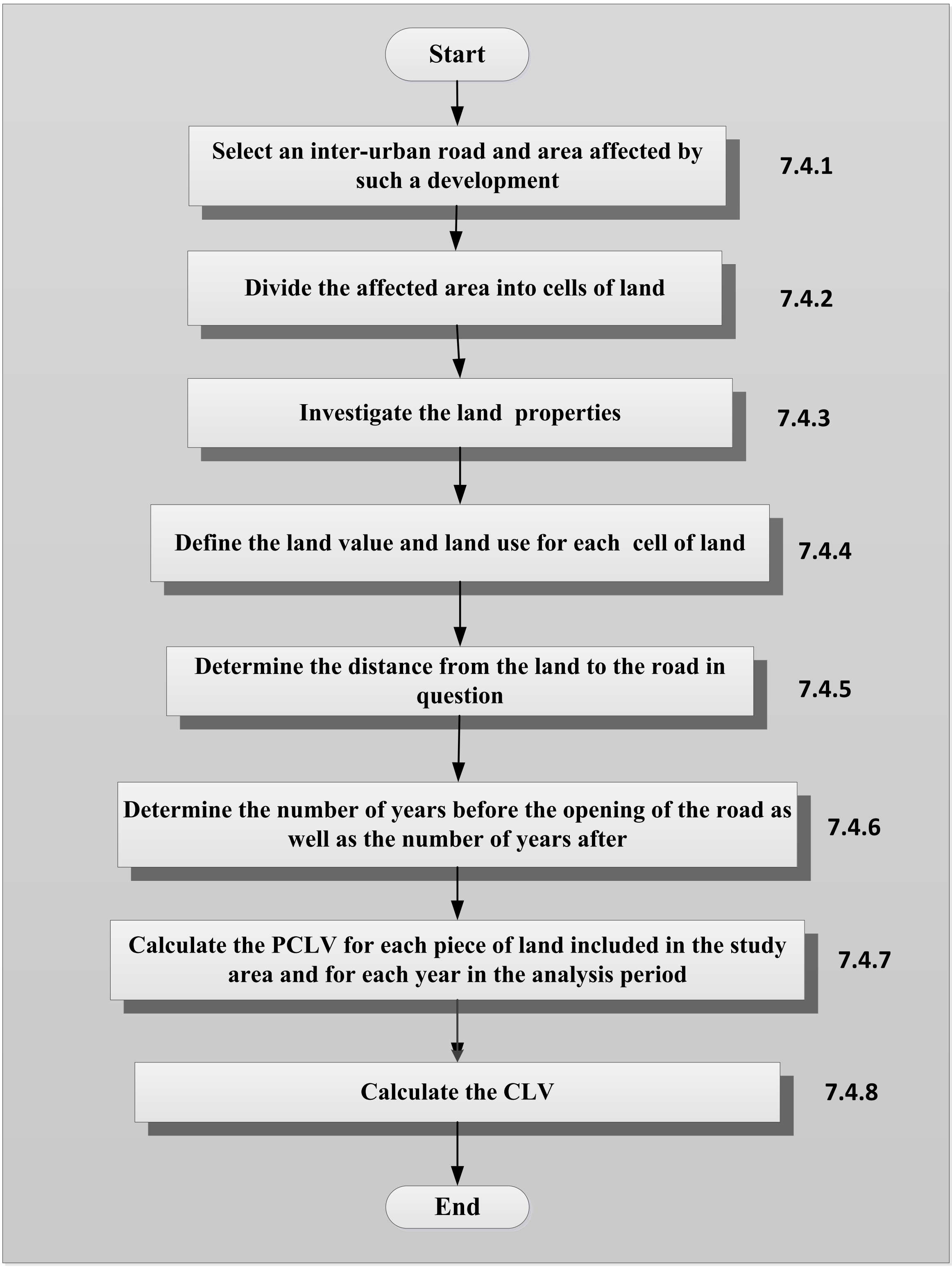

Figure 7- 5: Flow Chart of the Methodology Used to Apply the Proposed Model of Changes in Land Values

7.4.1 Selection of an Inter-urban Road and Area Affected by such a Development

The two sections of the M65 motorway (sections between junctions 1a to 2) were chosen as a new development of an inter-urban road to apply the proposed model of changes in land values. To highlight the land affected by the development of these two sections, the distance of 1.5 km from the alignment of the M65 motorway sections was used after taking into account the model's limitation for the distance variable and the access points available in this case study; these play an important role for an inter-urban road (see Chapter Two for more details). Thus, ArcGIS was used to measure a distance of 1.5 km around the two motorway sections to use later. This land for the model's application is highlighted in Figure 7-6. The total area of the highlighted land is equal to about 16,238,468.9 m^2, which was calculated using the ArcGIS.

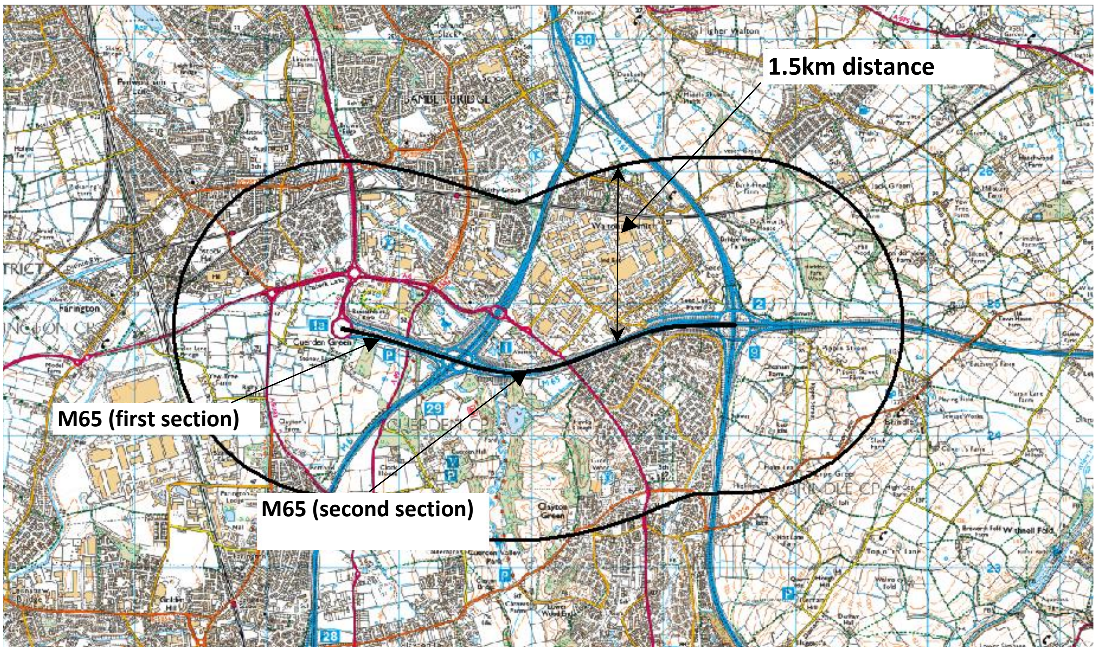

Figure 7- 6: The Highlighted Area around the Two Sections of the M65 Motorway (sections between junctions 1a and 2) (© Crown copyright and database rights [2017] OS (Digimap Licence))

The distance of 1.5 km from the alignment of the M65 motorway sections was divided into distances of 0.5 and 1 km as shown in Figure 7-7. These distances were used to facilitate the division of the highlighted land into cells for later model application. The reason for dividing the highlighted area is due to the limitation of the developed model regarding the variable of the land area (more information is available in Section 4.4.5).

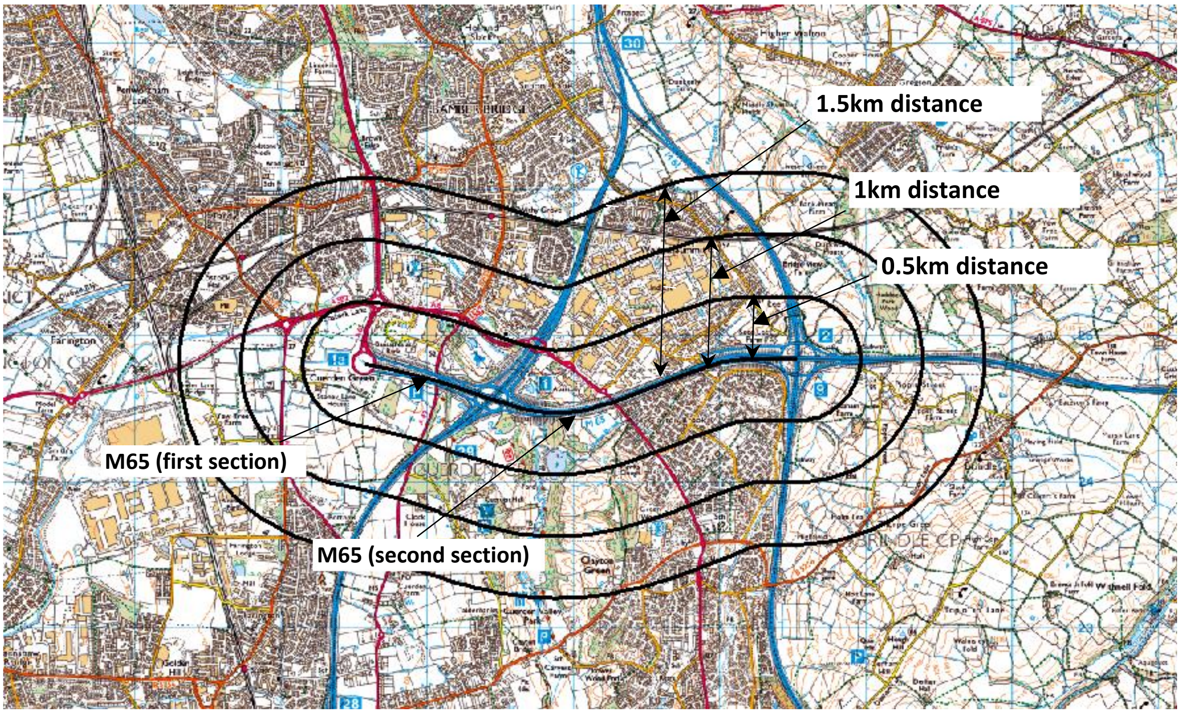

Figure 7- 7: The Division of the Highlighted Area around the M65 Motorway (sections between junctions 1a and 2) (© Crown copyright and database rights [2017] OS (Digimap Licence))

7.4.2 Dividing the Affected Land into Cells of Land

Lands affected by the development of the two sections of M65 motorway, i.e. lands located between 0.5, 1 and 1.5 km distances were delimited into 75 cells of land, as shown in Figure 7-8. Such a division has been used due to the limitation of the proposed model regarding the

land area variable, which should be within the required range of 10-80 hectares. As a consequence, these cells of land have been used later for obtaining the independent variables of the proposed model, to calculate the CLVs as a secondary impact of an inter-urban road development. These independent variables are distance from the new road, time that has elapsed since the completion of the road works, land use and land area.

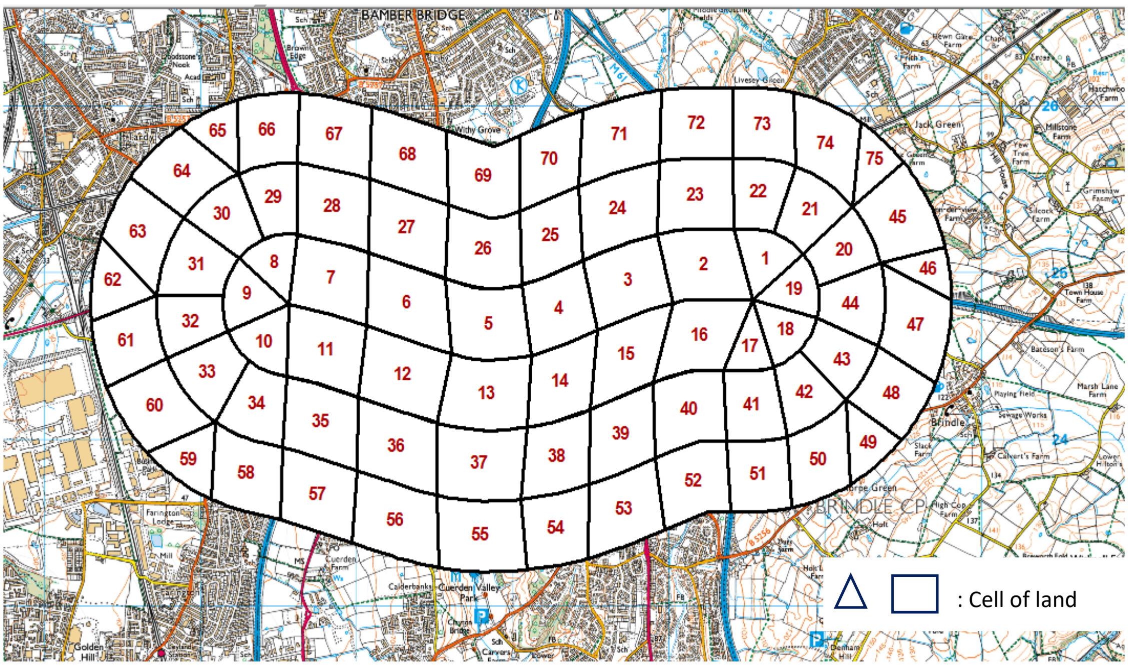

Figure 7- 8: Cells of Land Affected by the M65 Motorway Road Development (© Crown copyright and database rights [2017] OS (Digimap Licence))

7.4.3 Investigating the Land's Properties

Properties of land cells such as the area of the cell and its centroid are important to achieve for the application of the proposed model, due to the effect of these properties on the resulting changes in land values. These properties were determined using the different tools provided in the ArcGIS system, i.e. the area of each cell of land was determined using the calculation tool provided; while the centroid of each cell was calculated using the management tool of the same system. The obtained centroid of each cell of land is

represented by a green dot as shown in Figure 7-9. The calculated areas for the 75 cells of land (hectare) are shown in Table D.1 in Appendix D.

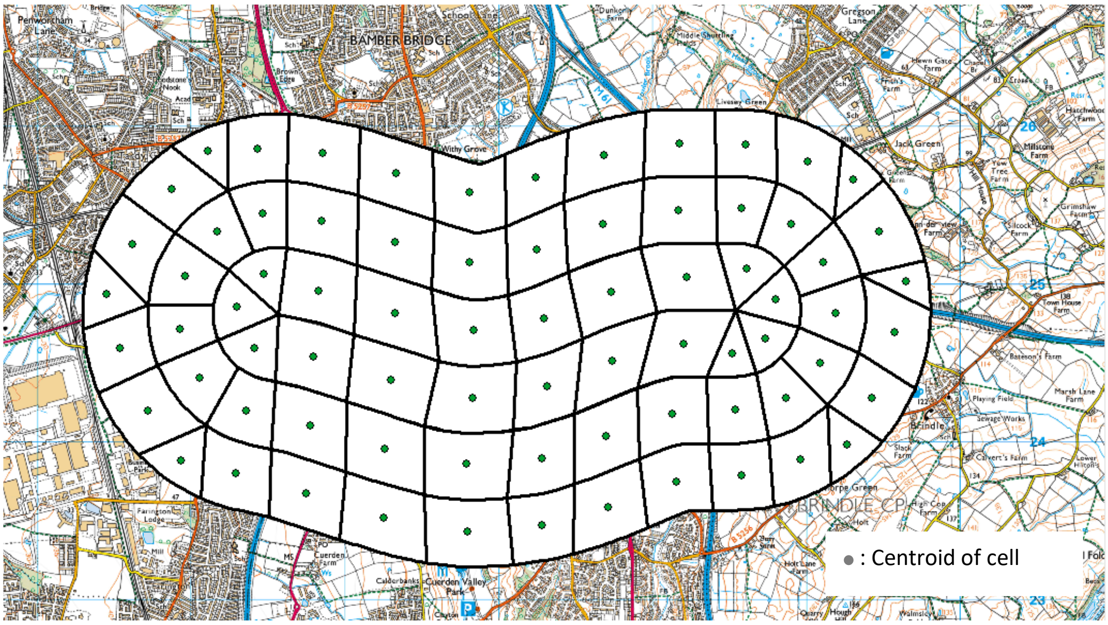

Figure 7- 9: Centroid of Cells of Land Affected by the M65 Motorway Road Development

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7.4.4 Definition of Land Use and Land Value for Each Cell of Land

Land value according to its usage has been calculated for each cell of land in order to express the land use in the proposed model and then achieve its effect on the resulting CLV. The case study chosen to apply the proposed model consists of different types of land use; such as residential, agricultural and industrial, as shown in Figures 7-10. Consequently, a Google Earth map with the aid of the ArcGIS technique was used to identify the percentage of each type of land use in each cell of land, which in turn has been used to calculate the average land value (LU) (£/m^2) for each cell.

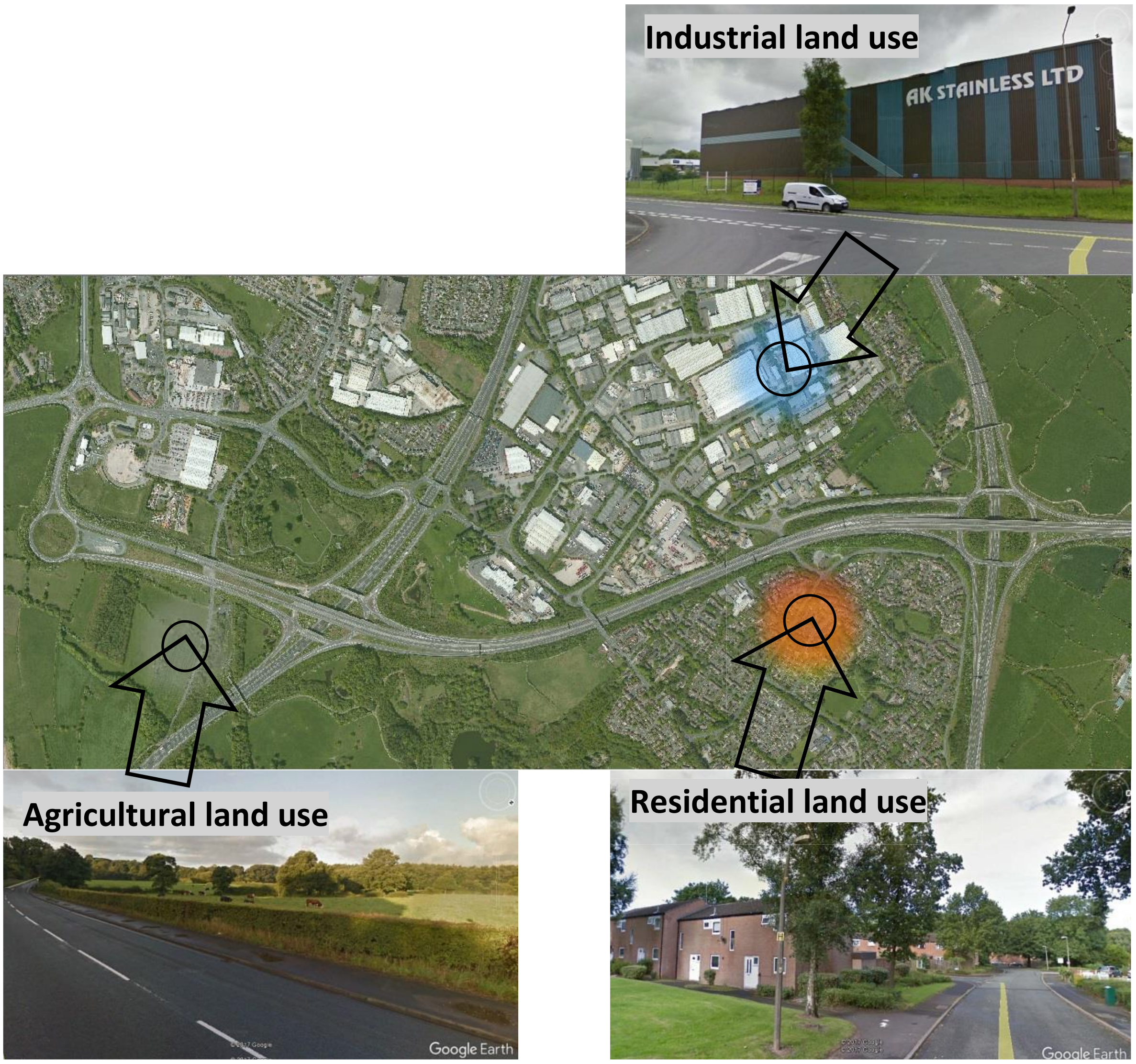

Figure 7- 10: Main Types of Land Use in the Study Area (Google Earth)

The proposed model of change in land values has the ability to deal with only three types of land use: residential, agricultural and industrial (see Chapter Four). As a consequence, it was felt necessary to exclude land dedicated for road development from the calculations of LU as shown in Figure 7-11.

Cell number two has been taken as an example to identify the percentages of industrial, residential and agricultural land use as shown in Figure 7-11. This figure shows that cell number two includes three types of land use. For the agricultural use, three parts have been observed in cell number two as shown in Table 7-7. The area of each part has been measured

using the GIS software. The area of the three parts has been summed together to obtain the total area of agricultural use in cell number two. The same procedure was repeated for the residential and industrial land uses of cell number two. Consequently, the percentage of land for agricultural, industrial and residential uses has been calculated, which is equal to 65%, 25% and 10% respectively, as shown in Table 7-7.

Figure 7- 11: The Classification of Land Use Types for Cell Two (Google Earth)

Sanchez, 1993) (see Chapter Two). The centroid of each cell of land was used to get the average distance for each cell of land. Thus, seven access points for the two sections of the M65 motorway had been noted and the straight distances were measured from the centroid of each cell of land to its nearest access point, as shown in Figure 7-12. A distance variable (m) for each cell of land was measured and shown in Table D.3 in Appendix D.

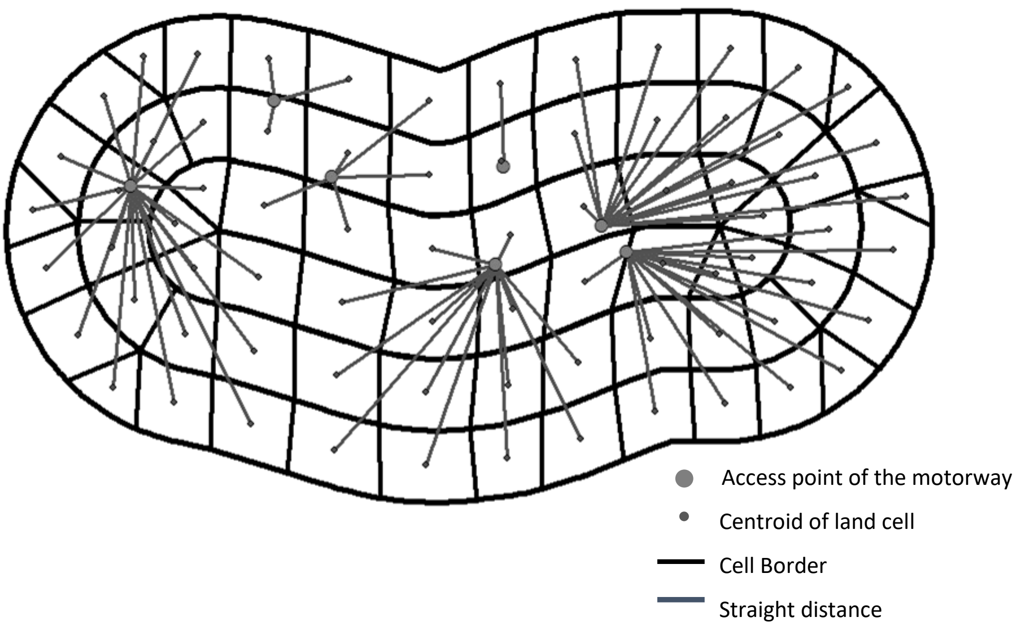

Figure 7- 12: Straight Distances from Centroids of Cells to the Nearest Access Points

7.4.6 Determination of the Number of Years Before and After the Opening of the New Road

Although the proposed model has the ability to estimate the changes in land values from three years before the road works' completion (more details are found in Chapter Four), these years were not considered in the model's application due to the goal of this study, which is the comparison between the CLVs as a secondary impact of road development and the RUCSs of the generated traffic as a primary impact of road development. These RUCSs

Hoel, 2009; Bennett, 1996b). The VOC is in turn considered as an important item in the RUC (Garber and Hoel, 2009), which reflects the components related to vehicle operation (Bennett and Greenwood, 2004; Robinson, 2008) in terms of fuel, engine oil, tyres, maintenance and depreciation (Gillespie, 1998; Garber and Hoel, 2009), as shown in Figure 8-2.

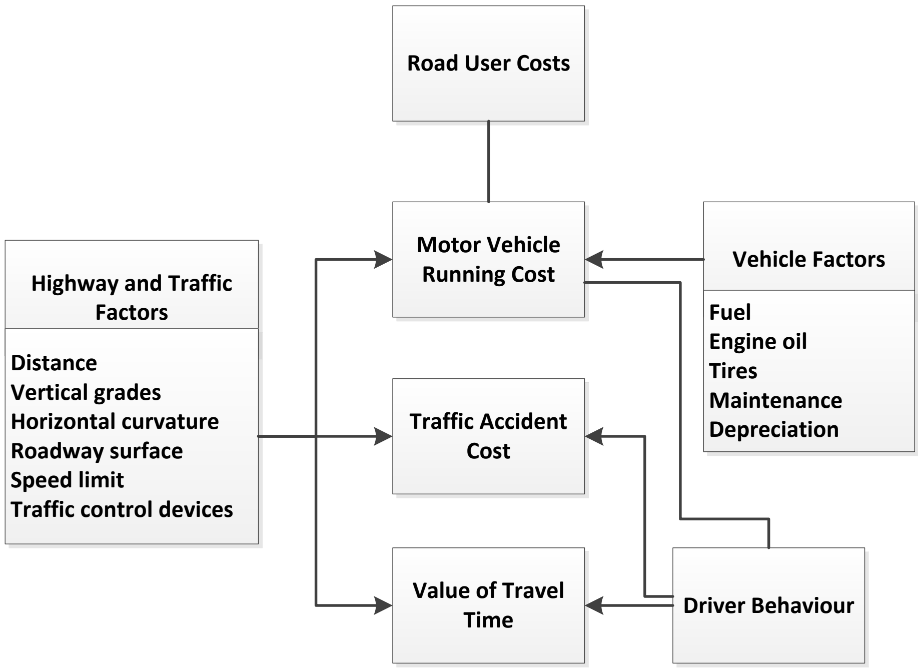

Figure 8- 2: Road User Cost Factors (adopted from Garber and Hoel, 2009)

The VOC consists of variable costs and fixed costs (Mackie et al., 2005; Litman, 2016c). The variable costs are affected by the distance travelled in miles that include fuel, engine oil, tyres, parts, user time and stress, and user crash risk (Bennett and Greenwood, 2004); while the fixed costs are not affected by the distance travelled and include the price of a new vehicle, vehicle registration, insurance payments and part of the maintenance price (Litman and Doherty, 2009).

The fuel consumption in turn constitutes the major part of the VOC (Ko et al., 2016); which represents about (20-40) % from the total VOC (HTC, 1999b cited in Bennett and

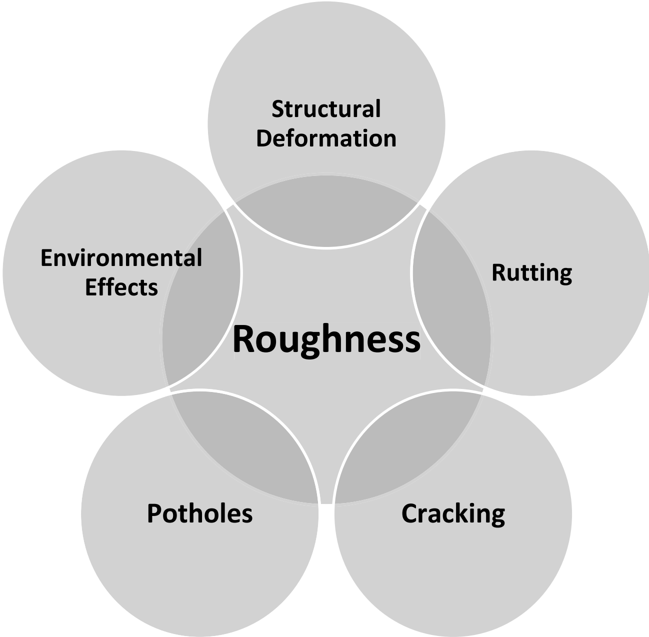

Figure 8- 3: Components Represented in HDM-4 Roughness Model

The work of Dreyer and Steyn (2015) and Pavia (2012) was used to obtain the value of pavement roughness (m/km) to input in HDM-4 as shown in Table 8-3 and Figure 8-4, respectively.

Table 8- 3: Road Roughness Categories (adopted from Dreyer and Steyn, 2015)

	Sayers (1986) (m/Km)	**Cantisani and Loprencipe (2010) (m/Km)**	**Combined categories (m/Km)**	
Very good	≤ 2.0	< 1.42	≤ 2.24	Very good to good
Good	1.5-3.5	1.42-2.84		
Fair	2.5-6.0		2.25-4.05	Fair to mediocre
Mediocre	3.8-11.0	2.84-4.06		
Poor	> 8.0	> 4.06	> 4.05	Poor

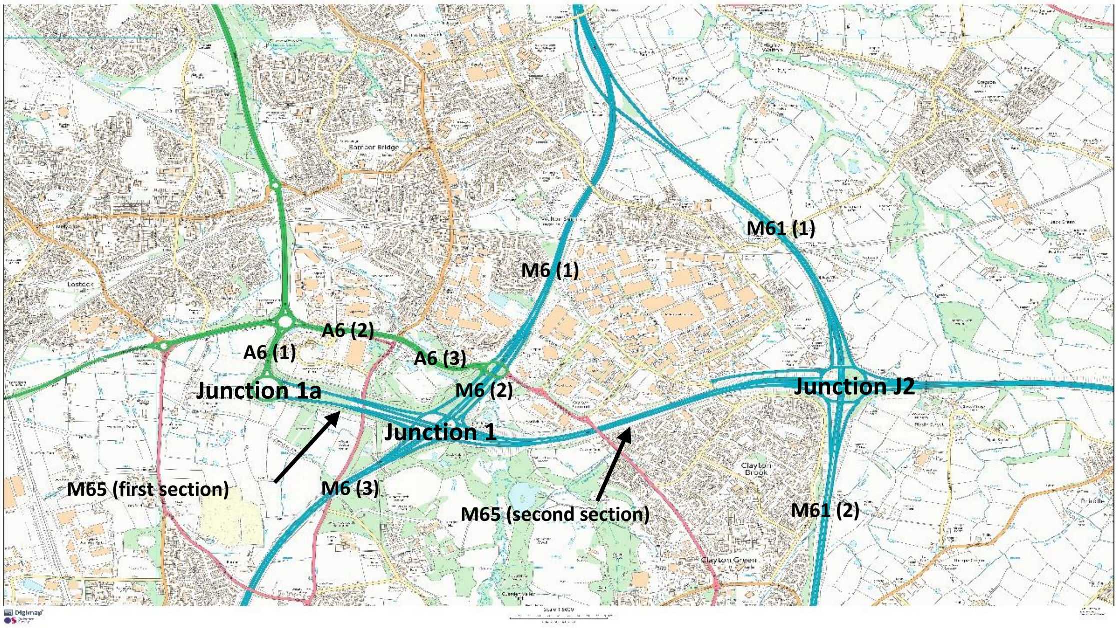

Figure 8- 5: The Sections of the Road Network Used in This Study (© Crown copyright and database rights [2017] OS (Digimap Licence))

Different reports have been obtained from the project analysis of HDM-4 (Archondo-Callao, 2008). One of these reports is the Road Agency and User Cost Streams that calculated two different costs (Aswathy et al., 2013): RACs and RUCs. The RACs result from adding the capital cost and the total maintenance costs; while the RUCs result from adding the VOC, TTC and AC (Aswathy et al., 2013; Gillespie, 1998; Garber and Hoel, 2009). Both the RAC and RUC have been calculated for each year in the analysis period, which was chosen to be for 30 years in this study and within the allowable limit reported by Odoki et al. (2012).

The RUCS includes the savings in the VOC, TTC and the AC (Aswathy et al., 2013; Dft, 2016c; Parkinson, 1981) that has been obtained from another report from the HDM-4, the Comparison of Cost Stream; where the RUC of the do-something case is subtracted from the RUC of the do-nothing case. The RUCSs of the M6 motorway that resulted due to the

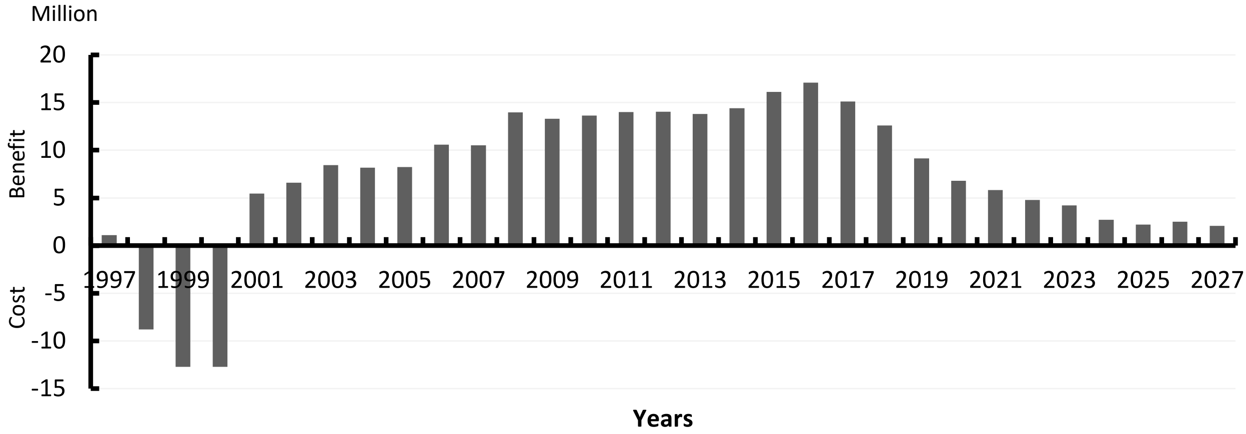

Figure 8- 10: The Summation of RUCSs (m£) for all roads

Figure 8-10 reveals that RUCSs are equal to £1.13 m in 1997. Three years later, only the costs reached to about £12.5 m in 1999 and 2000. From 2001 onwards, the benefits increased until the maximum benefit in 2016 of about £17 m. From 2016 to the end year of the analysis, there is a decrease in the trend of benefits that reaches to about £4 m in 2024.

For a similar project, (Litman, 2006; 2017a) estimated the costs and benefits of a road section over the analysis period as shown in Figure 8-11. This figure reveals that in the first year of analysis, there is only the construction cost of the new road. In the later years, there are benefits that decreased over the analysis period. Litman's estimation includes detailed costs and benefits relating to the diverted and induced traffic over the analysis period.

Table C.1: t-statistics

t Table

cum. prob	$t_{.50}$	$t_{.75}$	$t_{.80}$	$t_{.85}$	$t_{.90}$	$t_{.95}$	$t_{.975}$	$t_{.99}$	$t_{.995}$	$t_{.999}$	$t_{.9995}$
one-tail	0.50	0.25	0.20	0.15	0.10	0.05	0.025	0.01	0.005	0.001	0.0005
two-tails	1.00	0.50	0.40	0.30	0.20	0.10	0.05	0.02	0.01	0.002	0.001
df											
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71	31.82	63.66	318.31	636.62
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	22.327	31.599
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.000	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0.000	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	0.000	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0.000	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	0.000	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	0.000	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	0.000	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0.000	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	0.000	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	0.000	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	0.000	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	0.000	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	0.000	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	0.000	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	0.000	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	0.000	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	0.000	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	0.000	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0.000	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807	3.485	3.768
24	0.000	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	0.000	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	0.000	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0.000	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	0.000	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0.000	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	0.000	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750	3.385	3.646
40	0.000	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	0.000	0.679	0.848	1.045	1.296	1.671	2.000	2.390	2.660	3.232	3.460
80	0.000	0.678	0.846	1.043	1.292	1.664	1.990	2.374	2.639	3.195	3.416
100	0.000	0.677	0.845	1.042	1.290	1.660	1.984	2.364	2.626	3.174	3.390
1000	0.000	0.675	0.842	1.037	1.282	1.646	1.962	2.330	2.581	3.098	3.300
z	0.000	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576	3.090	3.291
	0%	50%	60%	70%	80%	90%	95%	98%	99%	99.8%	99.9%
	Confidence Level										

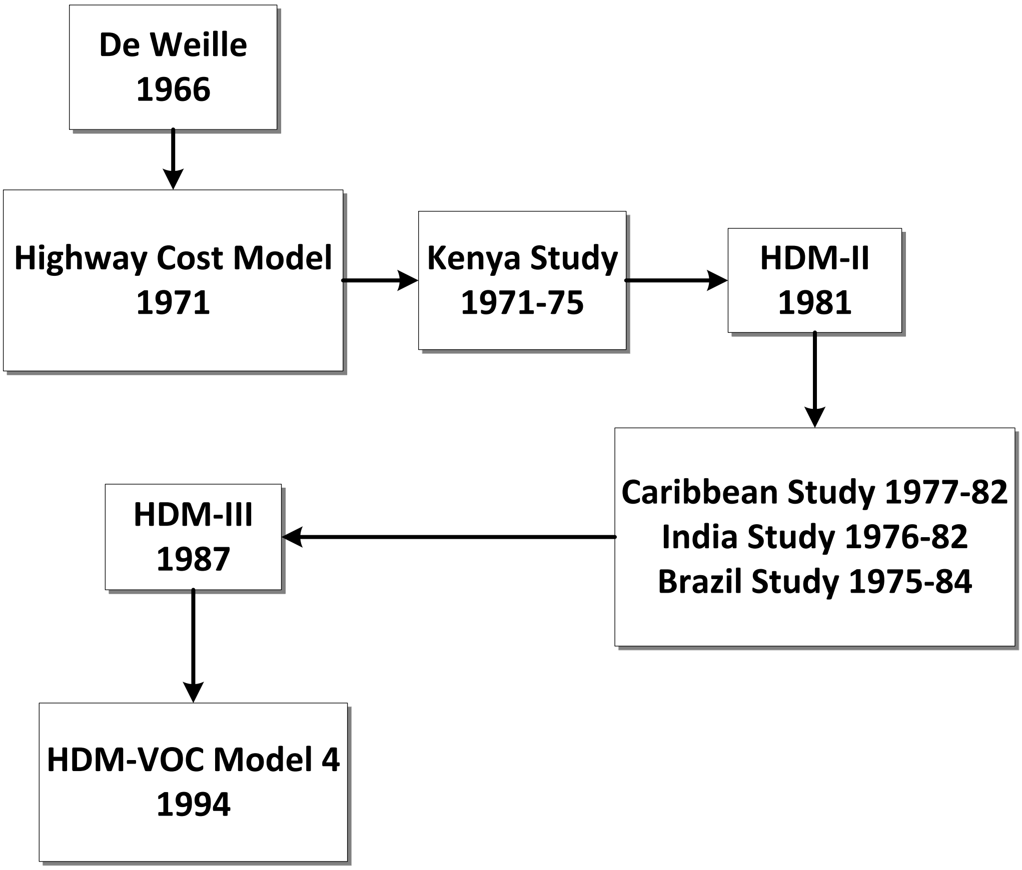

Figure E.2: Development of VOC model of HDM-4 software (Bennett and Greenwood, 2001)

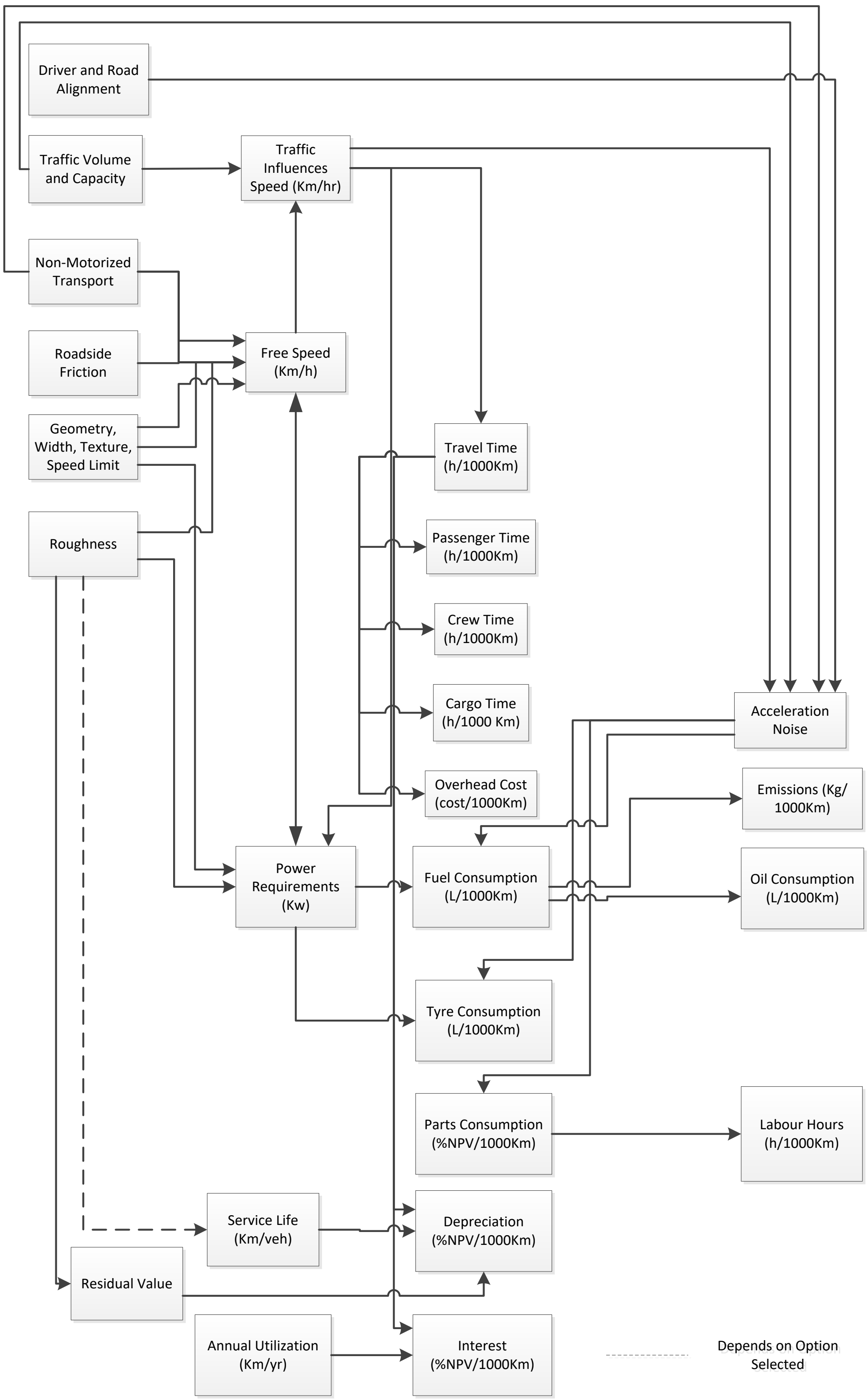

Figure E.3: HDM-4' VOC model and Their components' Interactions (Bennett and Greenwood, 2004)