Ministry of Finance and Economic Planning

Republic of Ghana

Integrated Transport Plan for Ghana

Volume 6: Transport Model Calibration

Final Version

June 2010

Financed by the 9th European Development Fund

Service Contract N°9 ACP GH019

In association with

egis bceom International

ASSOCIATED CONSULTANTS

Executive Summary

This report presents the process of model calibration for the Integrated Transport Plan of Ghana. Model calibration is the estimation of the type of model and its parameters that replicate the reality.

The model is developed using CUBE software, of which a licence has been acquired by the Ministry of Transportation. CUBE is a very flexible and complete suite of modules dedicated to transport modelling.

For **passengers**, the model applied consists of a slightly modified version of the classic four-step model. The **four-step model** consists of:

- **Trip generation** determines the frequency of origins or destinations of trips in each zone by trip purpose, as a function of land uses and household demographics, and other socio-economic factors. This model applies Ordinary Least Squares (OLS) on per capita trips per region, and then splits them to zones.
- **Trip distribution** matches origins with destinations, to develop a trip table; a matrix that displays the number of trips going from each origin to each destination, using the Fratar model.
- **Passenger modal choice** computes the proportion of trips between each origin and destination that use a particular transportation mode, using a logit choice model.
- **Network assignment** allocates trips between an origin and destination by a particular mode to a route. Wardrop's principle of user equilibrium is applied (equivalent to a Nash equilibrium), wherein each traveller chooses the cheaper path, subject to every other driver doing the same.

In addition to the classic model, an **Induction Model** is developed. This induction model takes into account the fact that more infrastructure tends to generate more traffic, as it reduces the cost of travelling.

For freight, two alternative modules are developed. A **fixed-structure matrix** model assumes that the global freight transport increases proportionally to the GDP growth by an elasticity factor. This model considers that the structure of the freight transport (in terms of zones producing and attracting traffic) remains constant.

An alternative method consists of integrating an **exogenous matrix** which will be developed through a series of workshops with different bodies. **Freight modal split** is based on a qualitative assessment of the potential demand for rail.

The models aim to replicate the reality of Ghana. The calibration carried out provides a good representation of Ghana’s transport system.

Contents

List of Tables

List of Figures

Acronyms and Abbreviations

AADT	Annual Average Daily Traffic
GHA	Ghana Highway Authority
GLSS	Ghana Living Standards Surveys
IRI	International Roughness Index
ITPG	Integrated Transport Plan of Ghana
OD	Origin-Destination (usually refers to an OD pair or an OD matrix)
OLS	Ordinary Least Square
VOC	Vehicle Operation Cost
VoT	Value of Time

Chapter 1 Transport Demand Modelling

1. Transport Models

In order to plan transportation infrastructure, it is necessary to forecast how much they will be used. In order to evaluate whether specific projects are worthwhile at all, it is necessary to have a measure of the benefits they produce. All these requirements are in the province of travel demand analysis[1].

Both the economic and the transport system are subject to constant changes. These changes either occur autonomously, or they are planned. By autonomous developments we mean societal changes outside of the transport sector sphere of influence. Examples include technological developments, changes in incomes structures, changing attitudes towards work and leisure time, etc. Developments can also result from deliberately planned intervention. Examples here include the construction of new infrastructure, measures to stimulate alternative means of transport, the pursuit of particular planning goals, etc.

[1] Small and Voerhof (2007) The economics of urban transportation. Routledge.

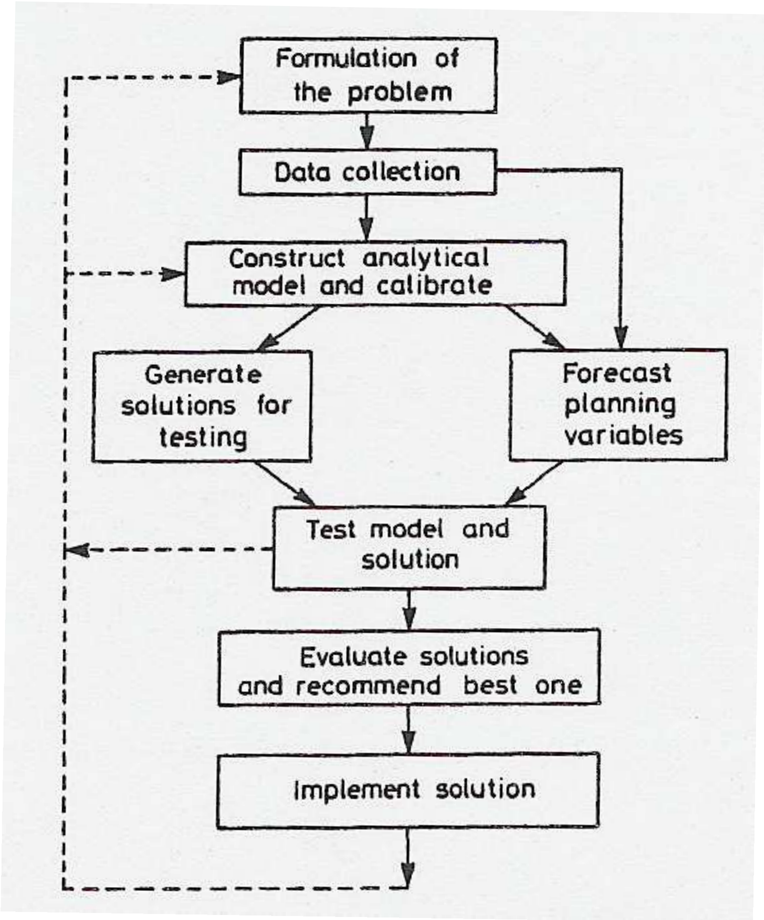


Figure 1: The planning process[2]

The function of the traffic demand model is to calculate the equilibrium that results from a given situation in the economic and the transport system. The calculated traffic flows can be used to design traffic facilities and evaluate their effectiveness in solving transport-related problems and producing benefits to the economy.

Transport models seek the following objectives:

- *Relevance.* The model must be able to calculate the impact of every single measure of intervention that one wants to investigate. The objective of the ITP model is to assess the impact on transport patterns of new infrastructure and improved service level on existing infrastructure.

[2] From Ortuzar and Willumsen (2001) Modelling Transport.

- *Accuracy*. The results of the model and the observations must agree to a reasonable extent. Note that it is unrealistic to expect great accuracy in traffic models, when compared to models in the exact sciences. Traffic engineering is not an exact science, but a field of knowledge that lies between the exact and the social sciences. The accuracy of our model will be discussed later in this report.

- *Theoretical foundation*. The formulation of the model should, ideally, be based on a solid theoretical foundation. Those models that depend on a simple extrapolation of observed behaviour have only a limited field of application, both in place and time. ITP model tries to extract the most of existing data using reliable methods.

- *Simplicity*. The simplicity of a model should be seen as its mark of quality. Generally, simple models are also more robust, i.e. they are more resistant to input errors than complex models. This is even truer when data is not very accurate of insufficient as in our case.

- *Practical applicability*. One must be able to apply the model in the framework drawn up in regard to available time, funds, and personnel. This relates particularly to the gathering of input data required for the model. ITP model applies the latest available data.

2. Structure of the model

The history of transport demand modelling has been dominated by the modelling approach which has come to be referred to as the four step (or four stage) model. The steps are: trip generation, trip distribution, modal split and network assignment.

Trip generation determines the frequency of origins or destinations of trips in each zone by trip purpose, as a function of land uses and household demographics, and other socio-economic factors.

Trip distribution matches origins with destinations, to develop a trip table; a matrix that displays the number of trips going from each origin to each destination.

Mode choice computes the proportion of trips between each origin and destination that use a particular transportation mode. They are estimated by either aggregated of disaggregated choice models.

Network assignment allocates trips between an origin and destination by a particular mode to a route. Often (for road assignment) Wardrop's principle of user equilibrium is applied (equivalent to a Nash equilibrium), wherein each traveller chooses the cheaper path, subject to every other driver doing the same.

Table 1 shows the question that need to be answered with each step in the model.

Table 1 : Questions to be answered by each model step

Model step	Answer the question
Trip Generation	*How many trip does the user in some location wants to take in a day?*
Trip Distribution	*Where is the user going with each trip among all possible destinations?*
Modal Split	*Which transport mode the user adopts for each trip? What are the factors affecting that decision and to what extend?*
Network Assignment	*Which route between the origin and the destination does the user choose?*

The model is developed using the Cube software. Cube[3] is a comprehensive set of modules that support transportation planning, including transportation forecasting and system analysis. Cube is a very flexible tool which allows virtually any type of treatment and any model development, from the analysis of a single roundabout to a national-wide master plan.

Cube has been applied by Egis Bceom International in several countries, including the transport master plan of Kumasi and Tamale, in Ghana.

The Figure 2 shows an example of model structure in Cube.

[3] Developed by ESRI.

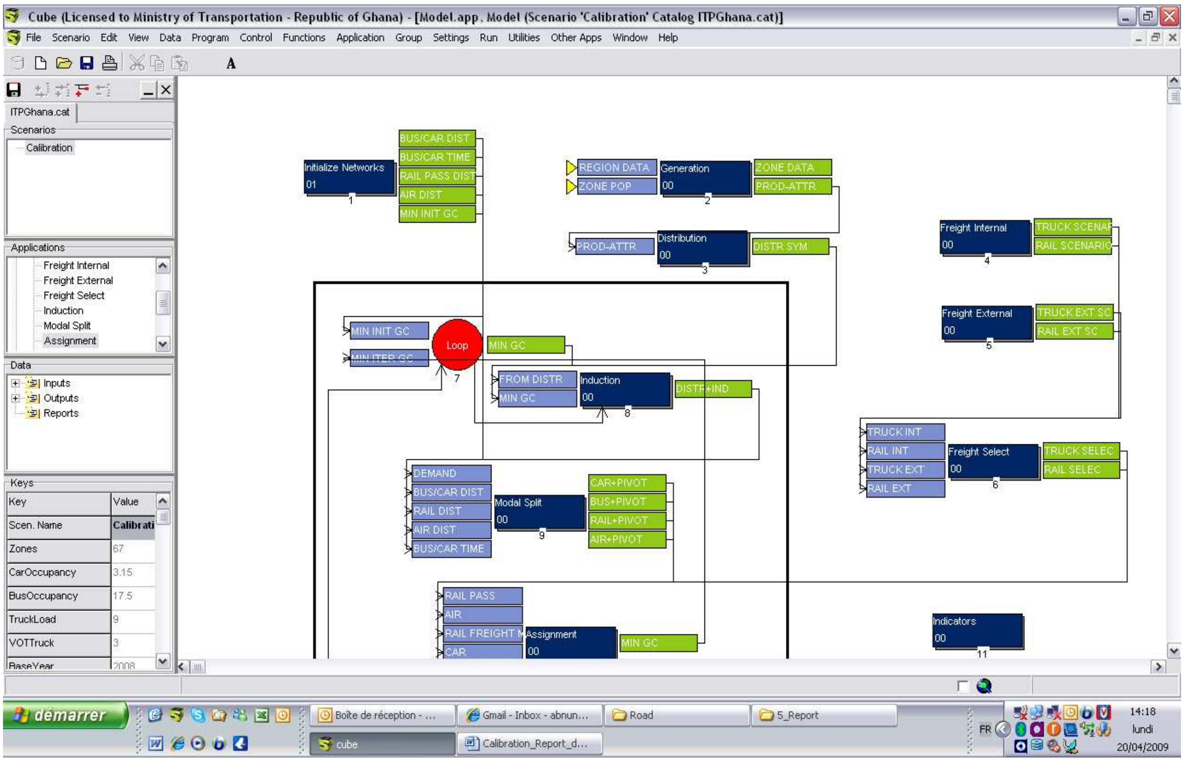
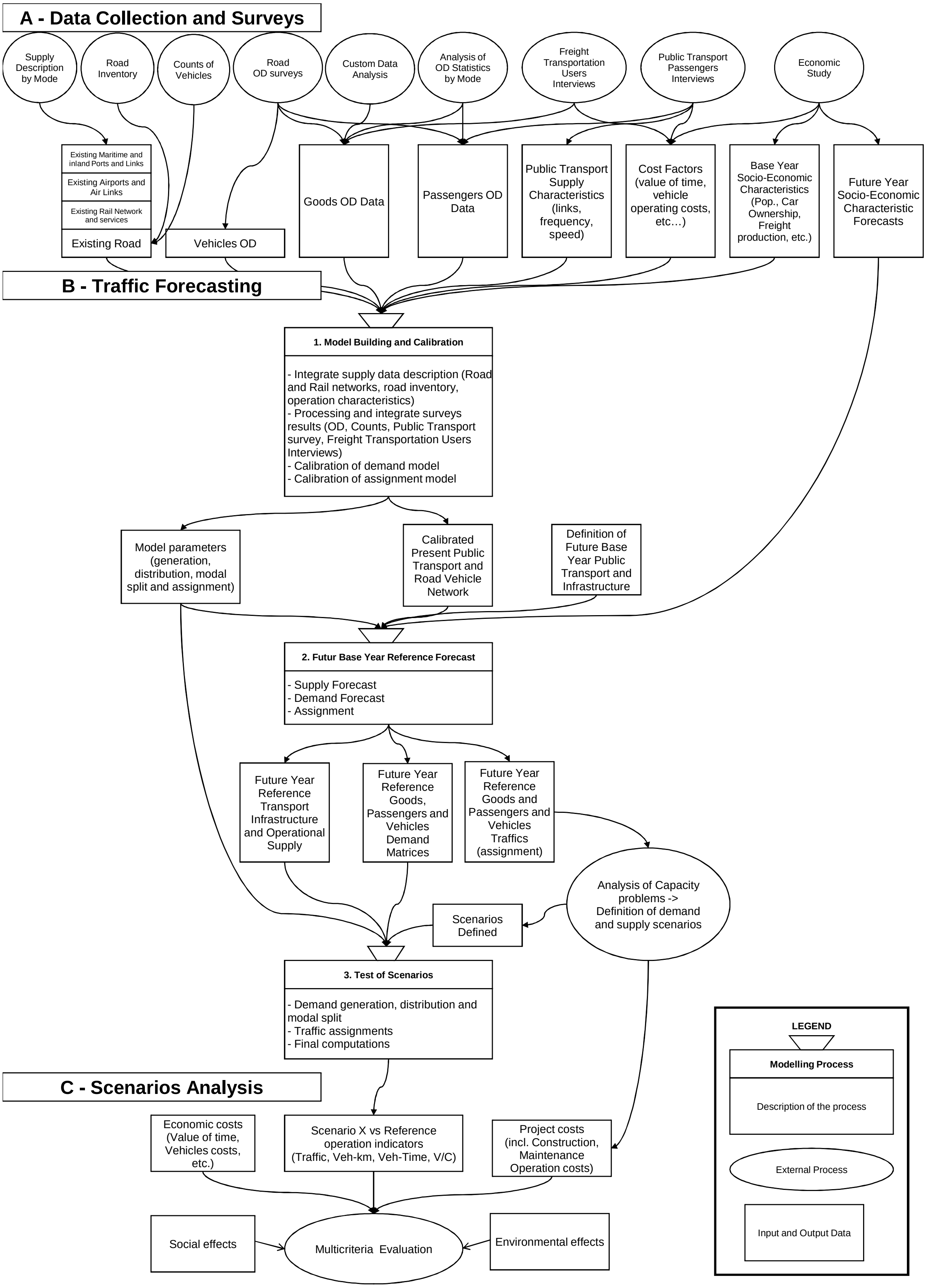


Figure 2 : Cube window

3. Integrated Approach

The chart below represents the different inputs, processes and outputs for the integrated planning process.



A - Data Collection and Surveys
Supply Description by Mode
Road Inventory
Counts of Vehicles
Road OD surveys
Custom Data Analysis
Analysis of OD Statistics by Mode
Freight Transportation Users Interviews
Public Transport Passengers Interviews
Economic Study
Existing Maritime and inland Ports and Links
Existing Airports and Air Links
Existing Rail Network and services
Existing Road
Vehicles OD
Goods OD Data
Passengers OD Data
Public Transport Supply Characteristics (links, frequency, speed)
Cost Factors (value of time, vehicle operating costs, etc…)
Base Year Socio-Economic Characteristics (Pop., Car Ownership, Freight production, etc.)
Future Year Socio-Economic Characteristic Forecasts
B - Traffic Forecasting
1. Model Building and Calibration
- Integrate supply data description (Road and Rail networks, road inventory, operation characteristics)
- Processing and integrate surveys results (OD, Counts, Public Transport survey, Freight Transportation Users Interviews)
- Calibration of demand model
- Calibration of assignment model
Model parameters (generation, distribution, modal split and assignment)
Calibrated Present Public Transport and Road Vehicle Network
Definition of Future Base Year Public Transport and Infrastructure
2. Futur Base Year Reference Forecast
- Supply Forecast
- Demand Forecast
- Assignment
Future Year Reference Transport Infrastructure and Operational Supply
Future Year Reference Goods, Passengers and Vehicles Demand Matrices
Future Year Reference Goods and Passengers and Vehicles Traffics (assignment)
Analysis of Capacity problems -> Definition of demand and supply scenarios
Scenarios Defined
3. Test of Scenarios
- Demand generation, distribution and modal split
- Traffic assignments
- Final computations
C - Scenarios Analysis
Economic costs (Value of time, Vehicles costs, etc.)
Scenario X vs Reference operation indicators (Traffic, Veh-km, Veh-Time, V/C)
Project costs (incl. Construction, Maintenance Operation costs)
Social effects
Multicriteria Evaluation
Environmental effects
LEGEND
Modelling Process
Description of the process
External Process
Input and Output Data

The integrated approach combines the data collection, the analysis of mobility and the economic activity as the input for model calibration, transport forecasting and analysis of the different scenarios. Under this approach the model can be viewed as the link between the forecast of the economic activity which drives the demand for transport and the socio-economic evaluation of the different alternatives (or scenarios) available.

4. Model building and calibration

Calibrating the model means that we determine the values for the parameters in order to ensure maximum agreement between the values calculated through the model and the original observations. The observations for a traffic model apply to a specific point in time that we use as a point of reference. One usually says that the model is calibrated for a specific baseline year. Other terms used for calibration are: the ‘estimation’ of a model and the ‘fitting’ of a model.

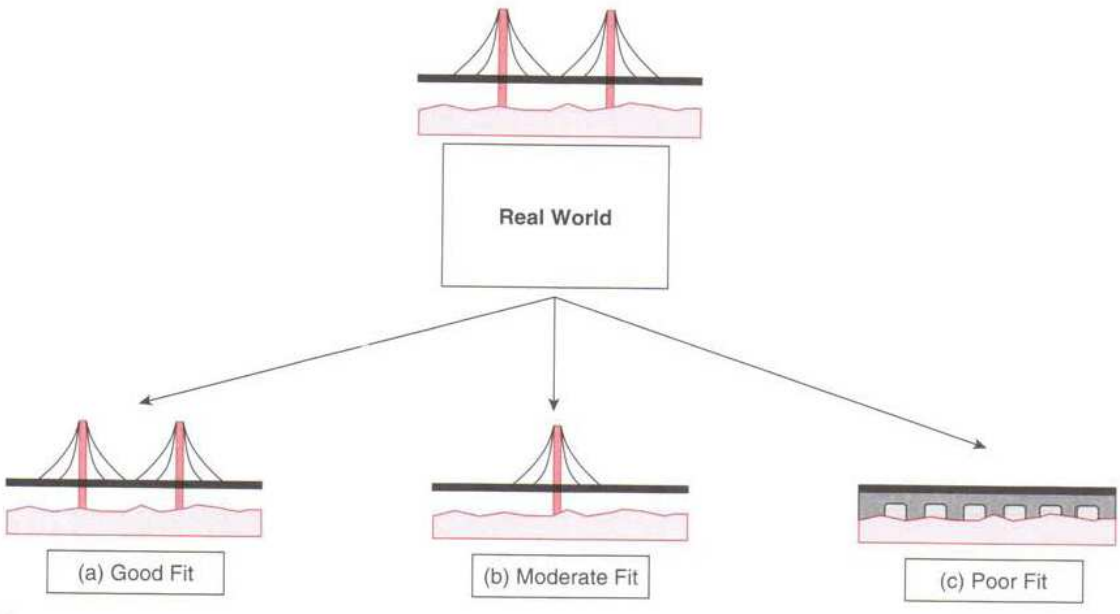


Figure 3 : Illustrative notion of fit quality.

An iterative process of parameters calibration was implemented until results of the model tallied with the observation reflecting the present transport situation in Ghana.

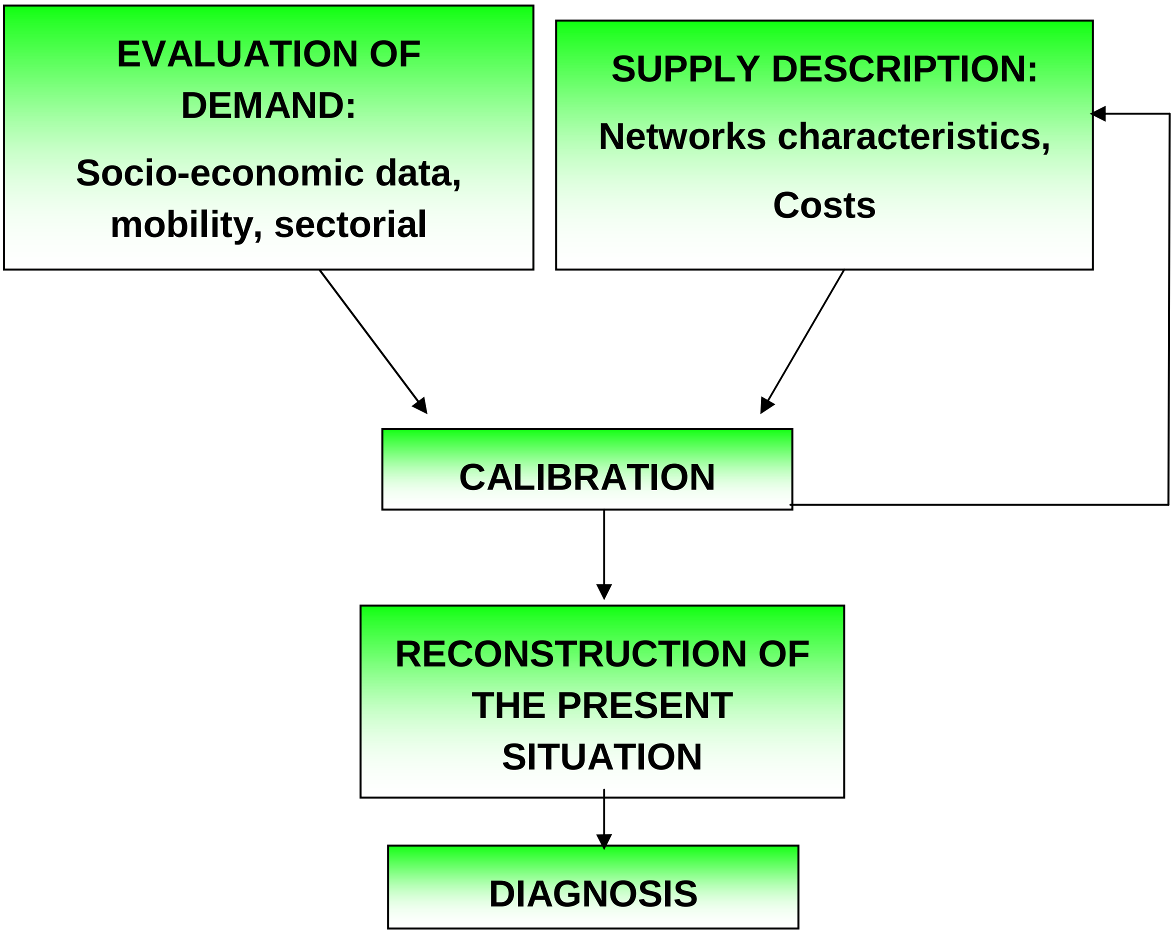


Figure 4 : Model building and calibration Diagram

At the end of the model building and calibration process, the model is used to construct the present situation.

Chapter 2 Zoning System

A traffic demand model applies to a particular geographical study area. In principle, trips in this area can begin and end at any address, and travellers can choose from all roads, streets and other transport options. Because of the sheer volume of data, however, it is not practical to gather and analyse data based on individual information. We construct a simplified model of reality by dividing the area to be studied into a number of *zones*. We study the trips from and to these zones. We assume that all trips begin and end at an imaginary point inside this zone, which is called the centroïd of that zone.

Networks: the transport system consists of a number of networks that represent the available transport modalities. The network is an abstraction of reality. The detailed level of representation depends on the problem to be solved. We are concerned here with long distance trips.

We distinguish the *study area* and a surrounding *area of influence*. Both areas are divided into zones, called respectively the internal and the external zones. In the study area we investigate the traffic flows from and to each zone. As for the area of influence we only examine traffic flows that start or end inside the study area. When traffic moves between two external zones, we only look at the traffic that crosses the study area.

Important parameters are the number of zones to be used and their size. Each zone has a fictitious point, usually situated in the point of gravity of the area, from which all trips from and to the zone are supposed to depart and arrive. This point, called the *centroid* is linked to the network by *connectors.* Trips between two zones, the *interzonal* traffic, occur on the network. Traffic that does not leave the zone, the *intrazonal* traffic, has its departure and arrival point in the same centroid and is not analysed.

This means that zones must not be too large. If they are too large, a sizeable part of the traffic does not appear on the network and will, therefore, fall outside the analysis. Nor can zones be too small. Small zones require numerous input data. This increases the costs of studies, hampers interpretation of the results and increases the chances of mistakes.

The main criteria used to divide the area of study – Ghana – into zones were:

- Each zone must be within one, and only one, region;
- Zones are compatible with 169 and 138 districts; this means that the districts created in the 169 system are in the same zone of the “parent” district.
- Zones should be as homogeneous as possible in terms of socio-economic characteristics.
- They must permit the analysis of the main corridors and facilities (train stations, ports) in the network
- Each main cross-border link is associated to an external zone.

The following zoning system was adopted in the study.

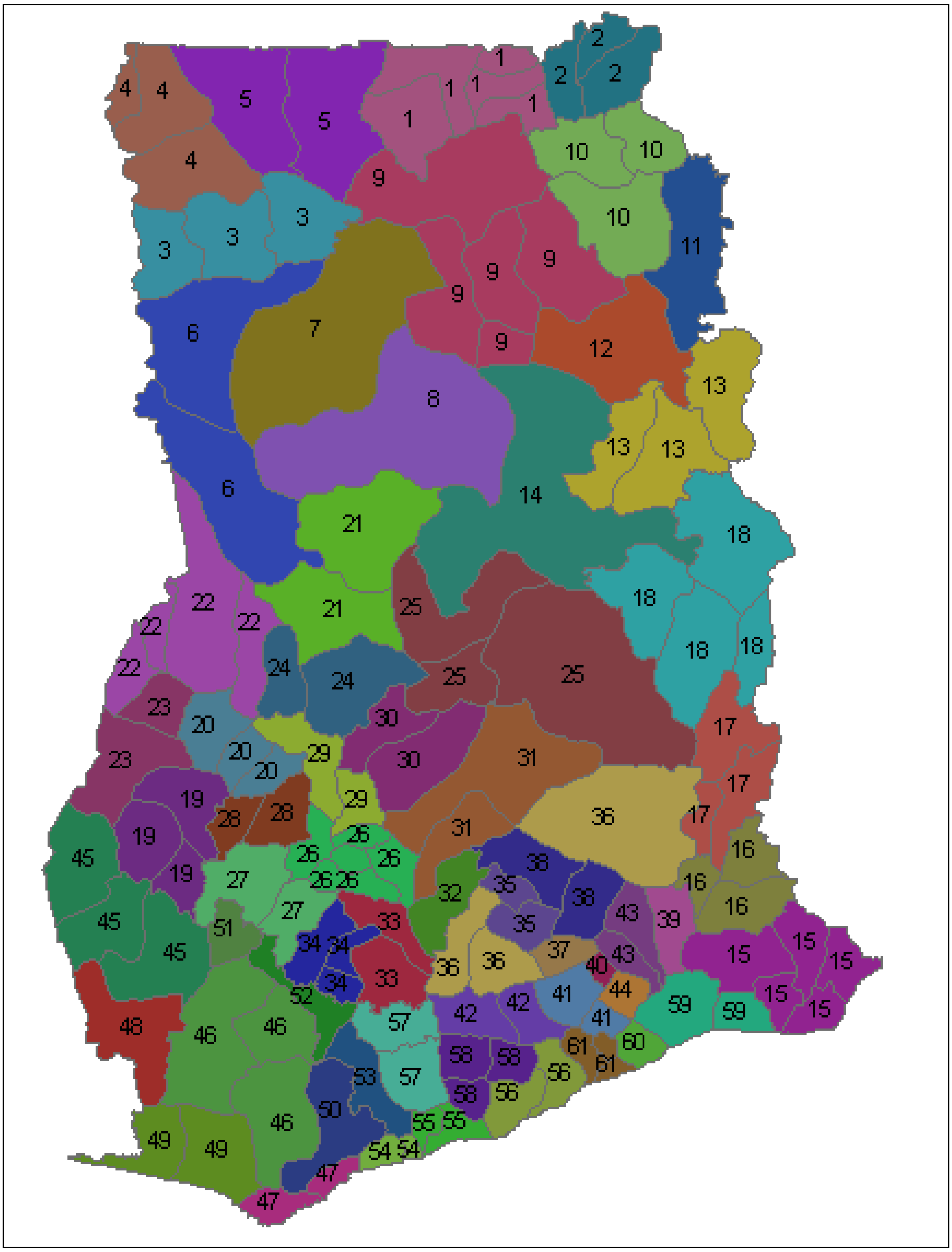


Figure 5 : Zoning system for the ITP model

The table below presents the zone corresponding to each district according to both 138 and 169 district division.

Table 2 : Internal zones

District Code	District 169	District 138	Region	Zone
1	Adansi North	Adansi North	Ashanti	33
2	Adansi South	Adansi South	Ashanti	34
3	Afigya Kwabre	Afigya Sekyere	Ashanti	29
4	Afigya Sekyere	Afigya Sekyere	Ashanti	29
5	Ahafo Ano North	Ahafo Ano North	Ashanti	28
6	Ahafo Ano south	Ahafo Ano South	Ashanti	28
7	Amansie Central	Amansie Central	Ashanti	34
8	Amansie East	Amansie East	Ashanti	33
9	Amansie West	Amansie West	Ashanti	27
10	Asante Akim North	Asante Akim North	Ashanti	31
11	Asante Akim South	Asante Akim South	Ashanti	32
12	Atwima Nwabiagya	Atwima Nwabiagya	Ashanti	26
13	Atwima Nponua	Atwima Nponua	Ashanti	27
14	Atwima Kwanwoma	Bosomtwe Kwanwoma	Ashanti	26
15	Bosome Freho	Bosomtwe Kwanwoma	Ashanti	26
16	Bosomtwe Kwanwoma	Bosomtwe Kwanwoma	Ashanti	26
17	Ejisu/Juabeng	Ejisu/Juabeng	Ashanti	26
18	Ejura-Sekyedumase	Ejura-Sekyedumase	Ashanti	30
19	Kwabre	Kwabre	Ashanti	26
20	New Juabeng Municipality	New Juabeng Municipality	Eastern	40
21	Obuasi Municipality	Obuasi Municipality	Ashanti	34
22	Offinso	Offinso	Ashanti	29
23	Sekyere East	Sekyere East	Ashanti	31
24	Sekyere West	Sekyere West	Ashanti	30
25	KMA	KMA	Ashanti	26
26	Sekyere Central	Amansie East	Ashanti	33
27	Sekyere Afram Plains	Sekyere East	Ashanti	31
28	Atebubu-Amantin	Atebubu-Amantin	Brong Ahafo	25

29	Asunafo North	Asunafo North	Brong Ahafo	19
30	Asunafo South	Asunafo South	Brong Ahafo	19
31	Asutifi	Asutifi	Brong Ahafo	19
32	Berekum	Berekum	Brong Ahafo	23
33	Dormaa	Dormaa	Brong Ahafo	23
34	Dormaa East	Dormaa	Brong Ahafo	23
35	Jaman North	Jaman North	Brong Ahafo	22
36	Jaman South	Jaman South	Brong Ahafo	22
37	Kintampo North	Kintampo North	Brong Ahafo	21
38	Kintampo South	Kintampo South	Brong Ahafo	21
39	Nkoranza	Nkoranza	Brong Ahafo	24
40	Nkoranza North	Nkoranza	Brong Ahafo	24
41	Pru	Pru	Brong Ahafo	25
42	Sene	Sene	Brong Ahafo	25
43	Sunyani	Sunyani	Brong Ahafo	20
44	Sunyani West	Sunyani	Brong Ahafo	20
45	Tain	Tain	Brong Ahafo	22
46	Tano South	Tano South	Brong Ahafo	20
47	Tano North	Tano North	Brong Ahafo	20
48	Techiman	Techiman	Brong Ahafo	24
49	Wenchi East	Wenchi East	Brong Ahafo	22
50	Abura/Asebu/Kwamankese	Abura/Asebu/Kwamankese	Central	55
51	Agona	Agona	Central	58
52	Agona East	Agona	Central	58
53	Ajumako/Enyan/Essian	Ajumako/Enyan/Essian	Central	58
54	Asikuma/Odoben/Brakwa	Asikuma/Odoben/Brakwa	Central	58
55	Assin North	Assin North	Central	57
56	Assin South	Assin South	Central	57
57	Awutu/Efutu/Senya	Awutu/Efutu/Senya	Central	56
58	Awutu Senya	Awutu/Efutu/Senya	Central	56
59	Cape Coast	Cape Coast	Central	54
60	Gomoa	Gomoa	Central	56
61	Komenda/Edina Eguafo/Abirem	Komenda/Edina Eguafo/Abirem	Central	54

62	Mfantsiman	Mfantsiman	Central	55
63	Twifo-Hemang/Lower Denkyira	Twifo-Hemang/Lower Denkyira	Central	53
64	Upper Denkyira	Upper Denkyira	Central	52
65	Upper Denkyira West	Upper Denkyira	Central	52
66	Afram Plains	Afram Plains	Eastern	36
67	Akwapim North	Akwapim North	Eastern	44
68	Akwapim South	Akwapim South	Eastern	41
69	Akyemansa	Asante Akim South	Ashanti	32
70	Asuogyaman	Asuogyaman	Eastern	39
71	Atiwa	Atiwa	Eastern	35
72	Birim Central	Birim South	Eastern	42
73	Birim South	Birim South	Eastern	42
74	Birim North	Birim North	Eastern	36
75	East Akim	East Akim	Eastern	37
76	Fanteakwa	Fanteakwa	Eastern	38
77	Kwaebibirem	Kwaebibirem	Eastern	36
78	Kwahu East	Kwahu South	Eastern	38
79	Kwahu South	Kwahu South	Eastern	38
80	Kwahu West	Kwahu West	Eastern	35
81	Manya Krobo	Manya Krobo	Eastern	43
82	New Juabeng Municipality	New Juabeng Municipality	Eastern	40
83	Suhum/Kraboa/Coaltar	Suhum/Kraboa/Coaltar	Eastern	41
84	Upper Manya Krobo	Manya Krobo	Eastern	43
85	West Akim	West Akim	Eastern	42
86	Yilo Krobo	Yilo Krobo	Eastern	43
87	Accra Metropolitan Assembly	Accra Metropolitan Assembly	Greater Acc	61
88	Adenta	Ga East	Greater Acc	61
89	Ashaiman	Tema Municipality	Greater Acc	60
90	Dangme East	Dangme East	Greater Acc	59
91	Dangme West	Dangme West	Greater Acc	59
92	Ga West	Ga West	Greater Acc	61
93	Ga East	Ga East	Greater Acc	61
94	Ledzekuku-Krowor	Accra Metropolitan Assembly	Greater Acc	61

95	Tema Municipality	Tema Municipality	Greater Acc	60
96	Weija	Ga West	Greater Acc	61
97	Bole	Bole	Northern	6
98	Bunkprugu Yunyoo	Bunkprugu Yunyoo	Northern	10
99	Chereponi	Saboba/Chereponi	Northern	11
100	East Gonja	East Gonja	Northern	14
101	East Mamprusi	East Mamprusi	Northern	10
102	Central Gonja	Central Gonja	Northern	8
103	Gushiegu	Gushiegu	Northern	10
104	Karaga	Karaga	Northern	9
105	Kpandai	East Gonja	Northern	14
106	Nanumba South	Nanumba South	Northern	13
107	Nanumba North	Nanumba North	Northern	13
108	Saboba/Chereponi	Saboba/Chereponi	Northern	11
109	Savelugu Nanton	Savelugu Nanton	Northern	9
110	Sawla Tuna-Kalba	Sawla Tuna-Kalba	Northern	6
111	Tamale Municipality	Tamale Municipality	Northern	9
112	Tolon Kumbungu	Tolon Kumbungu	Northern	9
113	West Gonja	West Gonja	Northern	7
114	West Mamprusi	West Mamprusi	Northern	9
115	Yendi	Yendi	Northern	12
116	Zabzugu Tatale	Zabzugu Tatale	Northern	13
117	Bawku East	Bawku East	Upper East	2
118	Bawku West	Bawku West	Upper East	2
119	Bolgatanga Municipality	Bolgatanga Municipality	Upper East	1
120	Bongo	Bongo	Upper East	1
121	Builsa	Builsa	Upper East	1
122	Garu Tempane	Garu Tempane	Upper East	2
123	Kassena Nankana	Kassena Nankana	Upper East	1
124	Kassena Nankana West	Kassena Nankana	Upper East	1
125	Talensi Nabdam	Talensi Nabdam	Upper East	1
126	Jirapa	Jirapa Lambussie	Upper West	4
127	Lambussie	Jirapa Lambussie	Upper West	4

128	Lawra	Lawra	Upper West	4
129	Nadowli	Nadowli	Upper West	4
130	Sissala West	Sissala West	Upper West	5
131	Sissala East	Sissala East	Upper West	5
132	Wa East	Wa East	Upper West	3
133	Wa West	Wa West	Upper West	3
134	Wa Municipality	Wa Municipality	Upper West	3
135	Adaklu-Anyigbe	Adaklu-Anyigbe	Volta	16
136	Akatsi	Akatsi	Volta	15
137	Biakoye	Jasikan	Volta	17
138	Ho	Ho	Volta	16
139	Hohoe	Hohoe	Volta	17
140	Jasikan	Jasikan	Volta	17
141	Kadjebi	Kadjebi	Volta	18
142	Keta	Keta	Volta	15
143	North Dayi	North Dayi	Volta	17
144	Krachi East	Krachi East	Volta	18
145	Ketu	Ketu	Volta	15
146	Ketu North	Ketu	Volta	15
147	Krachi West	Krachi West	Volta	18
148	Nkwanta South	Nkwanta South	Volta	18
149	Nkwanta North	Nkwanta South	Volta	18
150	North Tongu	North Tongu	Volta	15
151	South Dayi	South Dayi	Volta	16
152	South Tongu	South Tongu	Volta	15
153	Ahanta West	Ahanta West	Western	47
154	Aowin/Suaman	Aowin/Suaman	Western	48
155	Bia	Bia	Western	45
156	Bibiani/Anhwiaso/Bekwai	Bibiani/Anhwiaso/Bekwai	Western	51
157	Ellembele	Nzema East	Western	49
158	Jomoro	Jomoro	Western	49
159	Juabeso	Juabeso	Western	45
160	Mpohor Wassa East	Mpohor Wassa East	Western	50

161	Nzema East	Nzema East	Western	49
162	Prestea Huni Valley	Wassa West	Western	46
163	Sefwi Akontombra	Sefwi Wiawso	Western	45
164	Sefwi Wiawso	Sefwi Wiawso	Western	45
165	Shama	Shama Ahanta East	Western	47
166	Shama Ahanta East	Shama Ahanta East	Western	47
167	Wassa Amenfi East	Wassa Amenfi East	Western	46
168	Wassa Amenfi West	Wassa Amenfi West	Western	46
169	Wassa West	Wassa West	Western	46

In addition to these zones, 6 external zones were created, corresponding to the main borders crossings in the country, they are:

Table 3 : External zones

Border	Zone
Hamile Border	65
Paga Border	66
Kulungugu Border	67
Dormaa Ahenkro Border	64
Elubo Border	63
Aflao Border	62

Chapter 3 Collecting Demand Data

In order to calibrate the model it is necessary to assess the current demand for transport. Some Aggregated demand data can be found in the Transport Indicators Database produced by the Ministry of Transportation.

However, more detailed data is necessary for model calibration. We need a good picture of the long distance displacements in terms of origin, destination and the flow between each origin and destination. This information is compiled in a so-called O-D matrix, which usually has the following structure:

Destination

Origin

	1	**2**	**3**	**4**	**5**	**6**	**7**	**…**	**J**
1	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	…	T_{1j}
2	T_{21}	T_{22}	T_{23}	T_{24}	T_{25}	T_{26}	T_{27}	…	T_{2j}
3	T_{31}	T_{32}	T_{33}	T_{34}	T_{35}	T_{36}	T_{37}	…	T_{3j}
4	T_{41}	T_{42}	T_{43}	T_{44}	T_{45}	T_{46}	T_{47}	…	T_{4j}
5	T_{51}	T_{52}	T_{53}	T_{54}	T_{55}	T_{56}	T_{57}	…	T_{5j}
6	T_{61}	T_{62}	T_{63}	T_{64}	T_{65}	T_{66}	T_{67}	…	T_{6j}
7	T_{71}	T_{72}	T_{73}	T_{74}	T_{75}	T_{76}	T_{77}	…	T_{7j}
…	…	…	…	…	…	…	…		…
I	T_{I1}	T_{I2}	T_{I3}	T_{I4}	T_{I5}	T_{I6}	T_{I7}	…	T_{IJ}

Figure 6 : Structure of the O-D matrix

Where i ($1 \leq i \leq I$) indexes the origins and j ($1 \leq j \leq J$) indexes the destinations.

To collect this data a road Origin-Destination survey was carried out by the consultants. Annex 1 presents details of the survey.

Regarding railways and aviation, since they represent very few ODs, we used the aggregated data and added the traffic they represent to the respective cells in the OD matrix.

Chapter 4 Supply Data

Physical and economic characteristics of transport supply are necessary inputs for the transport model.

1. Physical Characteristics

The road network GIS used by the consultant consists of an update of the GIS provided by GHA. It includes up to date data on:

- Number of lanes
- Lane width
- IRI
- Free flow speed
- Capacity
- Slope
- Type of surface

2. Economic Characteristics

The most important economic data related to the network for the modelling process are prices and costs. Transport prices are necessary for all modes; they drive the modal choice (where it exists). Vehicle operation costs (VOC) are used to compute the route chosen between two zones.

Generalized costs and generalized prices are the sum of monetary and time costs. Monetary costs represent all financial costs, including tolls when they exist. Time cost is the product of the time (travel time, waiting time or access time) to the value of this time, which represents the marginal rate of substitution between time and money.

The estimation of VOC is described in Volume 5, Transport Cost Analysis. Transport prices are presented in the section dedicated to the modal split.

Chapter 5 Passenger Trip Generation

Trip generation is the process of estimating the total number of trips produced and attracted by each zone.

A production model describes the number of journeys that are generated in a zone as a function of a number of personal characteristics and characteristic features of the environment. The total number of journeys produced per zone is calculated, without reference as yet, to the destinations of these trips. A zone can both generate trips and attract them.

An attraction model describes the total number of trips that a zone attracts independent of the origin, as a function of characteristics such as employment rate and retail area. The productions and attractions that have been calculated are also called trip-ends.

At the end of this process, an OD matrix with only the totals for each line and column is produced.

Destination

Origin

	1	**2**	**3**	**4**	**5**	**6**	**…**	**J**	**∑Origin**
1									$\sum T_{1j}$
2									$\sum T_{2j}$
3									$\sum T_{3j}$
4									$\sum T_{4j}$
5									$\sum T_{5j}$
6									$\sum T_{6j}$
…								…	…
I									$\sum T_{Ij}$
∑Dest	$\sum T_{i1}$	$\sum T_{i2}$	$\sum T_{i3}$	$\sum T_{i4}$	$\sum T_{i5}$	$\sum T_{i6}$		$\sum T_{iJ}$	$\sum\sum T_{IJ}$

Figure 7 : Result of the trip generation

The main assumption behind the trip generation model is that the demand for transport is derived. That is, transport is not an end in itself; people move to satisfy other needs, like work and leisure; goods are moved to link production and consumption centres[4].

[4] There are a few examples where the transport is in itself an end ; driving a car just for the pleasure of driving is the most common. This kind of behaviour represents an insignificant part of the trips and is not included in the analysis.

If the demand for transport is related to the users' activities, it can be explained by a function of users' socio-economic characteristics. The traditional approach to trip generation modelling consists of estimating the total number of trips produced and attracted by each zone as a function of the socio-economic characteristics of the zone.

Typical functions would be:

$$A_i = f(POP_i, EMP_i, INC_i, TUR_i, ...)$$

and

$$P_i = g(POP_i, INC_i, ...)$$

Where:

A_i	is the total number of trips attracted by zone *i*
P_i	is the total number of trips produced by zone *i*
$f(\bullet)$ and $g(\bullet)$	are functions, usually they are linear in parameters
POP_i	in the population in zone *i*
EMP_i	is the employment in zone *i*
INC_i	is the per capita income in zone *i*
TUR_i	is the touristic attractivity of zone *i*

This traditional approach implies the existence of data on the zonal level (or in a more disaggregated level that can be aggregated in zones). This is not the situation in Ghana, where the statistical data available is on the regional level.

1. Data for generation

The data used for the calibration of the generation model comes mainly from the GLSS 5, the Ghana Living Standards Survey, carried out in 2005/2006, whose results just become available in late March 2009[5].

A database including the most representative variables for trips production and attraction was compiled for the generation model.

[5] A CD including data and reports is available in the bookstore of the Ministry of Finance.

2. Estimation method

The challenge here is to estimate zonal trips when only data for the regions are available, and, as shown earlier, each region contains on average six zones.

Therefore, due to the lack of data for zones, an innovative approach has been taken, consisting of estimating the per capita number of trip production and attraction by region, based on the socio-economic data.

The number of trips per capita by zone in the calibration year (2008) is then estimated dividing the total number of trips by the population of the zone. The population is the sum of the estimate of the population of the districts in the zone. This estimate was provided by the GSS (Table 5).

For each zone two factors are computed:

KPi is the ratio between the number of trips per capita produced by zone *i* and the number of trips per capita produced by the region it belongs.

KAi is the ratio between the number of trips per capita attracted by zone *i* and the number of trips per capita attracted by the region it belongs.

We suppose that these factors will remain constant over time.

The number of trips produced by zone *i* will then be estimated by:

$$P_i = KP_i . RP_{R, i \in R} . POP_i$$

Where:

P_i	is the total number of trips produced by zone *i*
KP_i	is the “production factor” of zone *i*, as defined above
$RP_{R, i \in R}$	is the per capita production of the region to which *i* belongs
POP_i	is the population of zone *i*

and similarly for the trip attraction.

The next step consists in estimating the per capita productions and attractions per region, as functions of their socio-economic variables.

3. Model and results

The model proposed is:

$$\ln(TPC_r) = \beta_0 + \sum_k \beta_k \ln(SEV_k) \text{ for trip production}$$

Where:

$\ln(\bullet)$	is the natural logarithm function
TPC_r	is the number of trips per capita in region *r*
β_k	are the coefficients to be estimated in the calibration (k=0 for the intercept)
SEV_k	are the socio-economic variables

The socio-economic variables must include any relevant available variable which is believed to drive the generation of trips. Usual variables include variables describing the individuals (income or expenditure for example) and variables describing the zones (industries and tourism for example).

This model form is usually called log-log or double log model. Using variables in logarithms instead of in levels – which is the traditional approach – has two main advantages: it reduced heteroskedasticity (unequal variances), and the coefficients (β_k) can be read directly as elasticities.

Models are estimated using OLS (ordinary least squares). The resultant models for trip generation are:

For trip production

$$\ln(TPPC_r) = -36.76 + 2.2\ln(\mathrm{EXPENDTOT}) + 0.06\ln(NBCARS) + 0.79\ln(TURISM) - 3.92\ln(\mathrm{URBSHARE}) + 2.68 D_{Accra}$$

(-4.04) (2.72) (0.12) (3.18) (-2.6) (3.02)

R^2= 0.87

For trip attraction

$$\ln(TAPC_r) = -36.69 + 2.12\ln(\mathrm{EXPENDTOT}) + 0.34\ln(NBCARS) + 0.85\ln(TURISM) - 4.51\ln(\mathrm{URBSHARE}) + 2.48D_{Accra}$$

(-3.18) (2.04) (0.52) (2.69) (-2.36) (2.21)

R^2= 0.82

The values in brackets are the *t-test* for the coefficient above. We can see that the only variable not statistically significant is the number of cars. However, as this variable can be judged as an important determinant of mobility, we decide to keep it in the model.

The other variables have high *t* values, which mean that they are significant in the model. The overall fit (represented by the R^2) is very good, especially given the limitation of data.

D_{Accra} is a dummy variable, valuing 1 for Greater Accra and 0 otherwise. The other variables can be found in Table 4.This dummy is used to include the particular mobility pattern of Accra.

Among the variables available from the different sources, those not used in the model are either not statistically significant or present collinearity problems with other variables in the model. These variables include the price index, the welfare index and employment by region. The income is also available; however, since the GSS affirms that the expenditure is a more reliable variable for wealth than the income, the expenditure is used.

For the external zones, since they concern other countries, we do not estimate their traffic in terms of socio-economic variables, but just apply an annual growth rate of 5%.

Table 4 : Socio-economic data by region.

	POP2008	URBSHARE	TOURISM	NBCARS	EXPENDTOT
Western	2424139	36.3	1517536	15881	6482076
Central	1801520	37.5	3042523	8046	6763269
Greater Accra	4057434	87.7	2087141	89005	1.05E+07
Volta	1822054	27.0	2385286	7527	4907515
Eastern	2267772	34.6	6373393	13625	6125471
Ashanti	4589377	51.3	5533511	38872	6817916
Brong-Ahafo	2164589	37.4	1707132	10740	5144491
Northern	2165606	26.6	582158.9	5277	3616290
Upper East	983575	15.7	254779.2	2238	2289306
Upper West	624861	17.5	863414.7	1589	1658085

Where:

variable	**source**	**comments**
POP2008	GSS (estimate)	
URBSHARE	GSS 2000 census	Share of urban population in %
TOURISM	GLSS 05/06	weighted number of visits made outside usual environment (computed as s5bq2*weight)
NBCARS	GLSS 05/06	number of cars working - weighted sum of s12bq1a, s12bq1b and s12bq1c when they value 1 (1= yes, working)
EXPENDTOT	GLSS 05/06	weighted average per capita total expediture (ratio expendc/hhsize)

The population in 2008 by zone as well as *KP* and *KA* are presented in the table below.

Table 5 : Coefficients for trip generation

ZONE	REGION	Population2008	KA	KP
1	Upper East	572458.8	2.0985	1.6634
2	Upper East	411116.2	0.8524	0.8640
3	Upper West	243849.6	1.2224	1.4196
4	Upper West	288004.5	0.6129	0.4626
5	Upper West	93007.0	0.5903	0.5106
6	Northern	151510.4	1.4794	1.3978
7	Northern	75702.4	0.1617	0.0225
8	Northern	90065.5	0.0997	0.0567
9	Northern	818881.1	0.8581	1.3324
10	Northern	289279.9	0.0095	0.0350
11	Northern	112258.1	0.0676	0.0014
12	Northern	154641.2	0.1341	0.0575
13	Northern	266428.9	0.2492	0.2267
14	Northern	206838.4	0.5149	0.4434
15	Volta	730977.5	1.8567	2.0612
16	Volta	307130.8	1.3295	1.3492
17	Volta	379338.0	0.8440	0.8725
18	Volta	404607.7	0.0532	0.0552
19	Brong Ahafo	306300.2	0.0792	0.0110
20	Brong Ahafo	364434.4	2.6310	3.2693
21	Brong Ahafo	170284.1	2.1618	2.4317
22	Brong Ahafo	374778.6	0.0546	0.0936
23	Brong Ahafo	291582.3	2.2878	2.3548
24	Brong Ahafo	365275.6	4.0900	3.2736
25	Brong Ahafo	291933.8	0.0015	0.0522
26	Ashanti	2224871.8	1.5136	1.1767
27	Ashanti	263719.0	0.0215	0.0262
28	Ashanti	251348.3	0.0031	0.0779
29	Ashanti	331201.1	0.0072	0.0096
30	Ashanti	283884.6	0.0337	0.0197

31	Ashanti	353564.2	1.4357	0.7647
32	Ashanti	121688.0	1.8303	4.3138
33	Ashanti	301339.6	0.2415	0.6449
34	Ashanti	457760.5	3.2778	3.1949
35	Eastern	187803.6	0.7723	0.7214
36	Eastern	469883.9	0.1216	0.0303
37	Eastern	109737.9	0.6566	0.8365
38	Eastern	229403.6	0.1678	0.1333
39	Eastern	83131.3	2.6886	4.0310
40	Eastern	152965.1	1.6747	2.1230
41	Eastern	305627.6	1.1753	0.7805
42	Eastern	359951.7	0.2036	0.2611
43	Eastern	257401.7	0.2237	0.3637
44	Eastern	111865.4	3.8011	4.6689
45	Western	497554.5	0.0139	0.0245
46	Western	585850.6	0.2985	0.2551
47	Western	594111.5	1.7262	1.7117
48	Western	150308.5	0.1586	0.0415
49	Western	316917.6	0.7552	0.8614
50	Western	149188.9	1.0243	1.1061
51	Western	130207.3	0.0088	0.0646
52	Central	122637.0	0.6051	0.6679
53	Central	125100.2	0.0168	0.0347
54	Central	262613.8	2.6200	2.0389
55	Central	271462.9	0.5275	0.7140
56	Central	416038.3	1.5059	1.0503
57	Central	221010.1	2.2018	1.8641
58	Central	382657.6	0.3225	0.4975
59	Greater Acc	251685.5	0.0434	0.1957
60	Greater Acc	709729.3	0.5934	0.3919
61	Greater Acc	3096019.1	1.1709	1.2049

Chapter 6 Passenger Trip Distribution

In the distribution model the trips originating in a certain zone *i*, that have been calculated in the production model, are distributed over possible destinations *j*. The trips that have been calculated in the attraction model with zone *j* as their destination, are distributed over the possible points of origin *i*. The distribution process produces an origin-destination matrix in which the rows of the table represent the origins and the columns represent the destinations and the entries in the table represent the trips between a certain origin and destination.

Destination

Origin

	1	**2**	**3**	**4**	**5**	**6**	**…**	**J**	**∑Origin**
1	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	…	T_{1j}	$\sum T_{1j}$
2	T_{21}	T_{22}	T_{23}	T_{24}	T_{25}	T_{26}	…	T_{2j}	$\sum T_{2j}$
3	T_{31}	T_{32}	T_{33}	T_{34}	T_{35}	T_{36}	…	T_{3j}	$\sum T_{3j}$
4	T_{41}	T_{42}	T_{43}	T_{44}	T_{45}	T_{46}	…	T_{4j}	$\sum T_{4j}$
5	T_{51}	T_{52}	T_{53}	T_{54}	T_{55}	T_{56}	…	T_{5j}	$\sum T_{5j}$
6	T_{61}	T_{62}	T_{63}	T_{64}	T_{65}	T_{66}	…	T_{6j}	$\sum T_{6j}$
…	…	…	…	…	…	…	…	…	…
I	T_{I1}	T_{I2}	T_{I3}	T_{I4}	T_{I5}	T_{I6}	…		$\sum T_{Ij}$
∑Dest	$\sum T_{i1}$	$\sum T_{i2}$	$\sum T_{i3}$	$\sum T_{i4}$	$\sum T_{i5}$	$\sum T_{i6}$	…	$\sum T_{iJ}$	$\sum\sum T_{IJ}$

Figure 8 : Result of the trip distribution

When an O-D matrix is available for the calibration year (from the OD survey), as is the case here, the distribution problem consists in updating this matrix given the productions and attractions issued from the generation model using future data.

This implies different growth rates for trips in and out of each zone and consequently having two sets of growth factors for each zone, say *fp* and *fa*. The application of an average growth factor, say $f = 0.5(fp + fa)$ is only a poor compromise as none of the two targets of trip-end constraints will be satisfied.

We therefore prefer to apply an iterative method involving the calculation of intermediate coefficients which are then applied to cell entries in each row or column as appropriate. After applying these corrections to say, each row, the totals for each column are calculated and compared with target values. If the differences are significant, new correction coefficients are calculated and applied as necessary. This method is usually called “fratar” or “double constrained growth factors”.

If the traffic for a cell (OD) is:

$$T_{ij} = t_{ij} f_a f_p A_j P_i$$

Where:

T_{ij}	is the future traffic
t_{ij}	is the base-year traffic
f_a and f_p	are the growth factors
A_j and P_i	are the balancing factors

We can incorporate the growth rates into new variables a_j and p_i, with $a_j = f_a A_j$ and $p_i = f_p P_j$.

The factors a_j and p_i must be calculated so that the constraints (production and attraction) are satisfied. This is achieved in an iterative process which in outline is as follows:

1. set all a_j=1.0 and solve for p_i; in this context, solve for p_i means find the correction factors p_i that satisfy the trip production constraints;
2. with the latest p_i, solve for a_j, e.g. satisfy the trip attraction constraints;
3. keeping the a_j's fixed, solve for p_i;
4. repeat steps 2 and 3 until the changes are sufficiently small (the convergence is achieved)

This method produces solutions within 1% of target values in a very small computer time.

Chapter 7 Induced Demand

Induced (also called generated) demand, is the increase of demand due to an increase or improvement of the supply[6].

A journey on a road can be considered as having an associated cost or price (the generalised cost) which includes the out-of-pocket cost (e.g. fuel costs and tolls) and the opportunity cost of the time spent travelling, which is usually calculated as the product of travel time and the value of travellers' time.

When road capacity is increased, initially there is more road space per vehicle travelling than there was before, so congestion is reduced, and therefore the time spent travelling is reduced - reducing the generalised cost of every journey (by affecting the opportunity cost of the time). In fact, this is one of the key justifications for construction of new road capacity (the reduction in journey times).

A change in the cost (or price) of travel results in a change in the quantity consumed. This can be explained using the simple supply and demand theory, illustrated below. When supply shifts from S1 to S2, the price (explained below) drops from P1 to P2, and quantity consumed increases from Q1 to Q2.

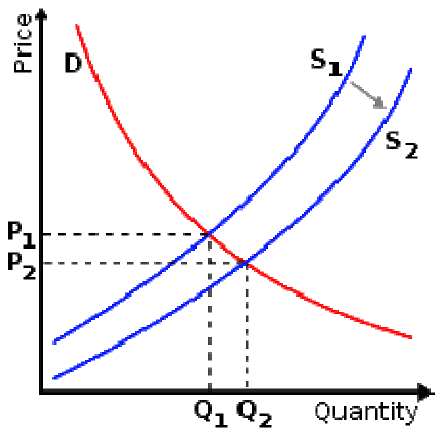


Figure 9 : Impact on demand of a change in supply.

For roads or highways, the supply relates to capacity and the quantity consumed refers to vehicle-kilometres travelled. The size of the increase in quantity consumed depends on the elasticity of demand.

[6] 6 This section is based on the article 'Induced Demand' on Wikipedia and VTPI (2009) Induced Travel and Generated Traffic. For more information about induced traffic, see the works of Professor Phil Goodwin on this topic.

Although planners take into account future traffic growth when planning new roads (this often being an apparently reasonable justification for new roads in itself - that traffic growth will mean more road capacity is required), this traffic growth is calculated from increases in car ownership and economic activity, and does not take into account traffic induced by the presence of the new road (i.e. it is assumed that traffic will grow, regardless of whether a road is built or not).

In the UK, the idea of induced traffic was used as a grounds for protests against government policy of road construction in the 1970s, 1980s and early 1990s, until it became accepted as a given by the government as a result of their own SACTRA (Standing Advisory Committee on Trunk Road Assessment) study of 1994. However, despite the concept of induced traffic now being accepted, it is not always taken notice of.

A classic example of induced demand was the construction of an orbital motorway around London, the M25, in the late 1980s and early 1990s. In the short term (almost from opening), the motorway became extremely busy and often congested (as planners underestimated the level of demand, because some was induced, and thus the road did not have high enough levels of capacity to accommodate it). In the long term (over a few years), new development occurred around the new motorway and people adjusted their home and work locations to depend upon it, further increasing demand.

In this study we apply elasticity of traffic between two zones with respect to the minimum generalized cost between them(among the modal options available) which is equal to -0.2.

It means that a reduction in the generalized cost of 10% generates, per se, an increase of the traffic of 2%. This is the induced demand.

For each OD pair, the traffic will be:

$$T_S^{OD} = T_B^{OD}\left[1 + e.\left(\frac{GC_S^{OD} - GC_B^{OD}}{GC_B^{OD}}\right)\right]$$

Where:

T_S^{OD}	is the traffic in the scenario situation
T_B^{OD}	is the traffic in the base-case (without project) situation
e	is the elasticity of traffic with respect to the generalized cost
GC_S^{OD}	is the minimum generalized cost in the scenario situation
GC_B^{OD}	is the minimum generalized cost in the base-case (without project) situation

Chapter 8 Passenger Modal Split

The modal split model estimates the distribution of trips over the transport modes available. At the end of this process, several OD matrices, one by mode, will be generated.

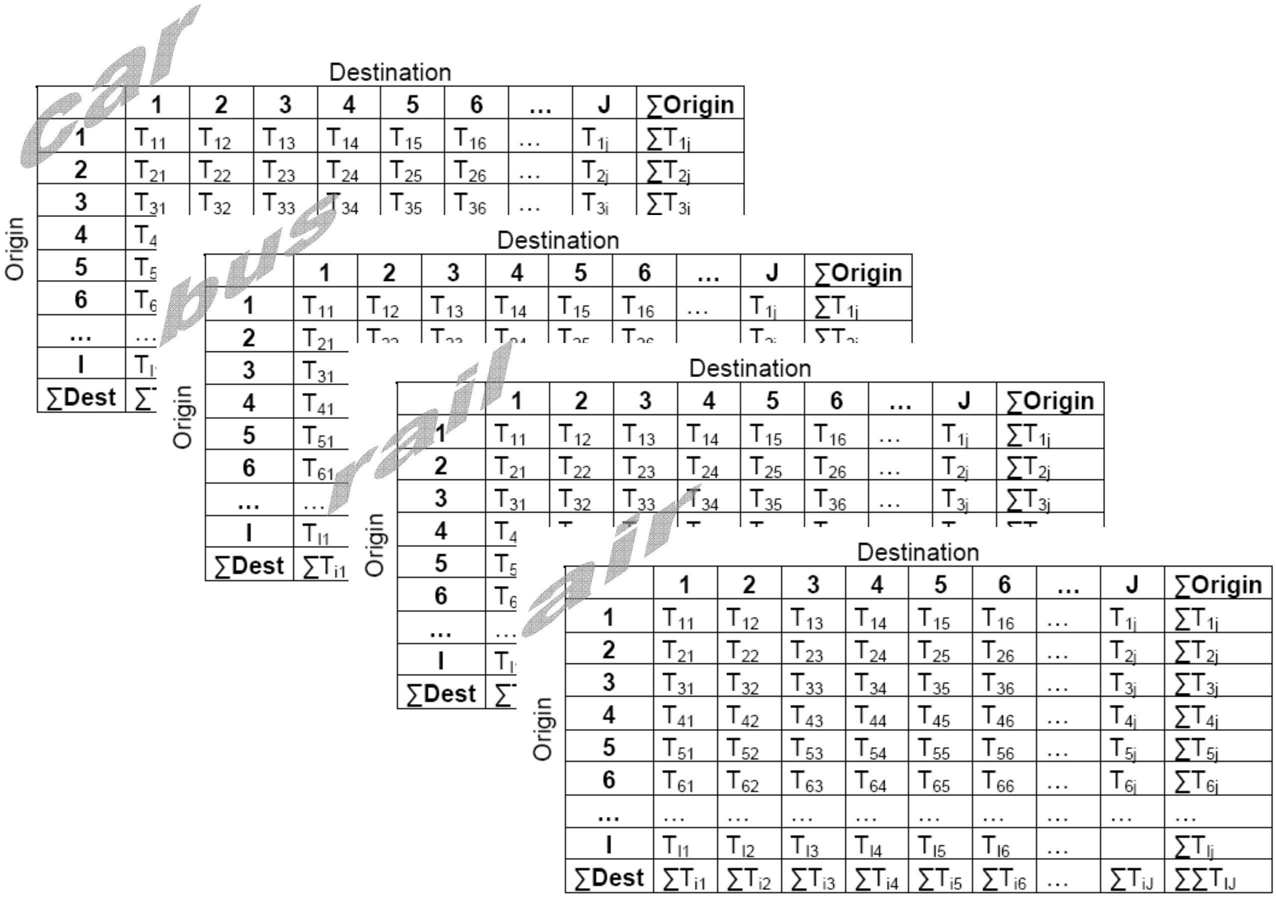


Figure 10 : Output from the modal split model.

The modal choice modelling is the field of transport economics which has probably known most progress in the last few years. Advances in disaggregated choice theory and in computers, now allow the application of increasingly complex and sophisticated models.

Three main factors prevent the application of such models in Ghana, first, the unavailability of disaggregated data on choice behaviour, the unavailability of detailed data on transport supply and, most importantly, the fact that there is no real modal choice, since almost all transport is made by road and only a few ODs are served by either rail or air transport.

The model used here is the aggregated logit model. It is called aggregated since it is estimated based on average values instead of individual values.

The first step is the estimation of generalized costs for each model. For this, we need to apply the value of time. Since no standard value is applied in Ghana, we start by the estimation of the value of time.

1. Value of time in Ghana

In economics, the value of time represents the marginal rate of substitution between time and money, or in other words, how much a person is willing to pay to save one hour of his time.

We approximate the value of time by the value of a working hour. This calculation is summarized in the table below.

Table 6 : Value of time estimation

VARIABLE	VALUE	COMMENTS
GDP	1.68E+10	2008 current dollars; estimated, source IMF
employed	8.76E+06	extrapolated from 2000 census
GDP/employed	1.92E+03	dollars/employed person
hours/year	1830.4	4.4 days/week*8 hours/day*52 weeks/year
value time employed	1.05	dollars/hour

We will consider a value of time of 1$/hour for working trips. For non working trips, we will consider 1/3 of this value, or 0.35 dollars/hour. Since, from the OD survey, 17.5% of trips are for working purposes, the average value of time is 0.46 dollars/hour.

2. Generalized costs

Generalized costs are the sum of monetary and time costs. There may also be a constant to approximate those elements of the cost that cannot be readily quantified, like quality or any subjective valuation. These constants are usually called *bonus* or *malus.*

The travel time and the travel distance can be estimated from the network in the model.

Given the strategic objective of the model and the level of data available, we apply average km costs for each mode.

Car

Since we consider that only the marginal costs affect the modal choice, the fuel costs are representative of these marginal costs. An average of 0.6 $/litre and an average consumption of 10km/litre, which means a price of 0.06 dollars/km.

Private cars and taxis are not modelled as different modes, since the use of taxis is related to the unavailability of private cars. There is therefore no competition between them. The use of fuel costs for taxis could be criticized. However, the idea behind this is that whatever additional cost for taxi we could add, the cost for car ranges between the cost for public transportation (bus and train) and the cost for air.

Therefore, using private car costs provides the same results in terms of modal split and there is no need to introduce another variable in the model; such as the evolution of the taxis in the country, which is hard to forecast.

Bus

Based on data from Intercity STC Coaches and Metromass, the average tariff per km is 0.02 dollars. The access time for bus is considered as 0.5 hour at each trip-end, i.e. 1 hours/trip.

Train

The average train fare is also 0.02 dollars/km, according to data from Ghana Railways Company. The access time for train is considered as 1 hour at each trip-end, i.e. 2 hours/trip.

Air

Average air tariffs are 0.4 dollars/passenger km. Access time are estimated as 3 hours/trip.

3. Logit Model

The logit model estimated the modal share of one mode, given the generalized costs of all the modes available. For example, the modal share for car will be:

$$P(car) = \frac{e^{\lambda GC_{car}}}{e^{\lambda GC_{car}} + e^{\lambda GC_{bus}} + e^{\lambda GC_{train}} + e^{\lambda GC_{air}}}$$

Where λ is a negative scale parameter, which measures the impact of variation of generalized costs on the modal shares. The higher is λ in absolute values, the higher is the preference for low cost modes. Figure 11 shows an example of the impact of λ.

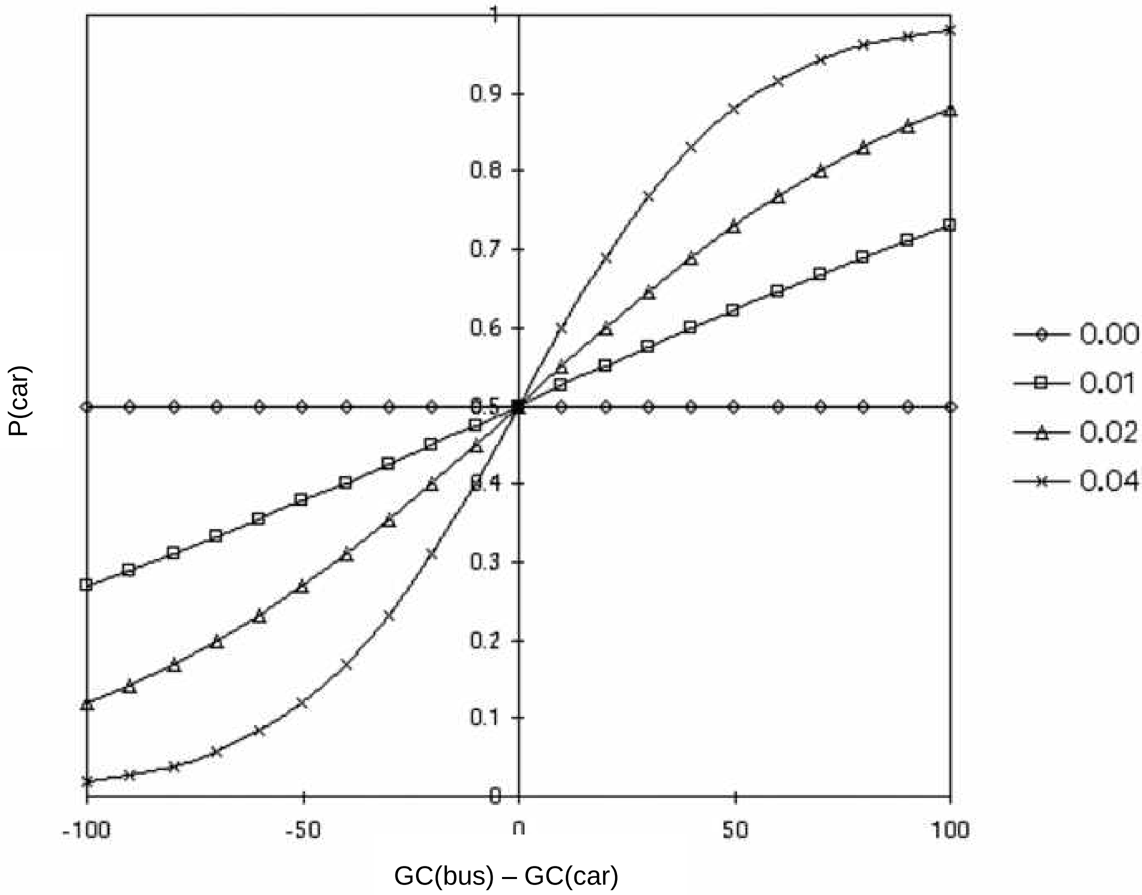


Figure 11 : Example of Logit model

In addition, we can add a *bonus/malus* factor. These factors take into account any “non cost” variables affecting the choices. The final cost represents the perceived or psychological cost for the user.

Using the actual modal shares and the generalized costs, we can now estimate the values of λ and the *bonus/malus.*

We find λ = 0.02 and an additive *malus* for buses of 70 and 33 for rail and 25 for air. Finally, pivot matrices are used to ensure that the actual situation is reproduced and to correct for the modal shares in the future. The use of pivot matrices is illustrated below.

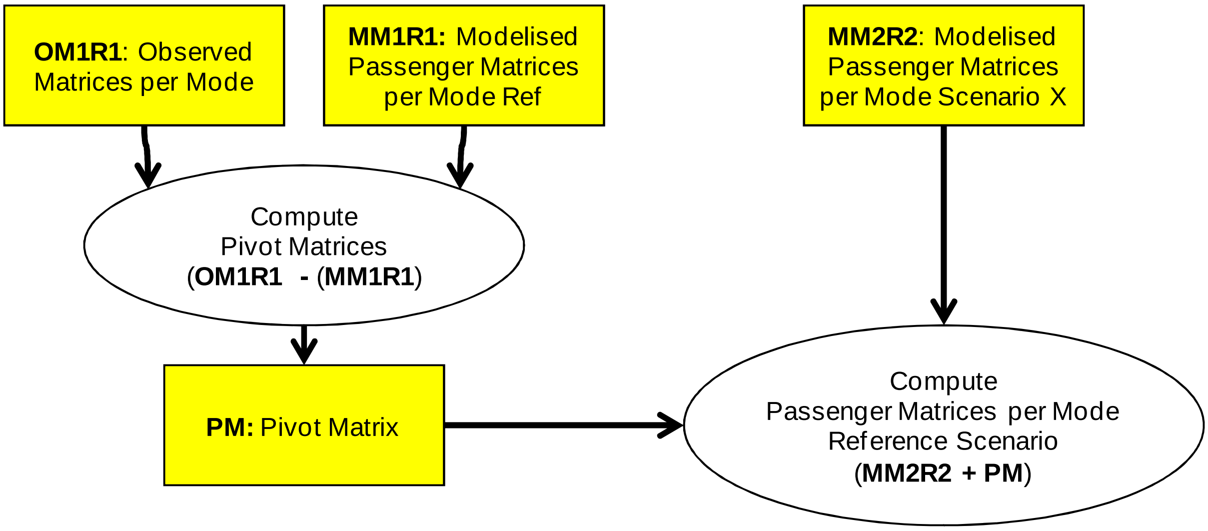


Figure 12 : Using pivot matrices to correct modal split

Chapter 9 Freight Modelling

Due to the complexity of the freight system and the little data available we decided not to apply a sequential model for freight.

Freight transport models are based on complex relationships between producers and consumers, national and global economy. Carrying out this kind of exercise in absence of reliable data would produce a naïve model.

We propose, instead, to apply two different, alternative analysis.

1. Fixed structure matrix

In this analysis we consider that the structure of the OD matrix in terms of distribution of freight between origins and destinations as well as the composition of the traffic in terms of goods being transported remain the same. The only variable increasing over time with the economic growth is the total volume transported.

The World Bank[7] suggests that the lower bond elasticity of freight transport with respect to GDP (in PPP) in developing countries should be higher than 1.25. We could use a slightly higher value.

However, as the GDP forecasts have been done in market prices, and the elasticity to market prices tend to be lower than to international (PPP) prices, an elasticity of 1.25 appears to be reasonable for Ghana.

It means that for each year *y* the volume of freight transported is estimated as:

$$FT_y = FT_{2008} \cdot \left[1 + 1.25 \left(\frac{GDP_y - GDP_{2008}}{GDP_{2008}} \right) \right]$$

Where:

FT_y is the total freight transport in Ton.km in year *y*

GDP_y is national GDP (in constant prices) in year *y*

[7] The World Bank (1992) What Determines Demand for Freight Transport. Policy Research Working Papers. Available at http://go.worldbank.org/CJOK2UFS10

Or equivalently:

$$FT_y = FT_{2008}.\left[1 + 1.25.\left[(1 + AAG_{GDP})^{y-2008} - 1\right]\right]$$

Where AAG_{GDP} is the annual average GDP growth between 2008 and *y*, computed as a geometric (and not arithmetic) mean.

This approach is presented as an option in the model but has not been applied in the ITP project evaluations.

2. Exogenous matrix

The freight transport is highly dependent of the economic activity of the country. New industrial developments, mining exploitations, investments, technological change, etc, can dramatically change the structure of freight transport[8].

Under this perspective, the use of a fixed structure matrix can be an over simplistic approach. In order to get the best possible picture about the planned and expected developments on the different industries, the Ministry of Roads and Highways and the Ministry of Transport organized workshops with the following bodies:

- Ministry of Finance
- Ministry of Trade and Industry
- Ministry of Energy
- Ministry of Food and Agriculture
- Ministry of Lands and Natural Resources
- Forestry Commission
- Minerals Commission
- Energy Commission
- Timber Export Development Board
- Cocoa Board
- Bulk Oil Storage and Transportation

The outputs of these workshops are presented in the reports:

[8] For a review on transport models applied to freight transport see : Recent Developments in Transport Modelling – Lessons from the Freight Sector. Ben-Akiva, Meersman and Van de Voorde. Emerald Publications. 2008.

- Socio-Economic Variables and Commodities Forecasts for Ghana 2008-2015-2025
- Commodities Generation and Transport in Ghana

Using this information an updated forecast freight matrix could be generated, which is then applied as the most likely demand scenario for freight transport.

3. Freight Modal Split

Due to the lack of data on price structure and in particular to the lack of real modal competition for freight transport in Ghana, the use of a mathematical model is not viable. In addition, the real market for rail will heavily depend on the quality of service offered.

Instead we adopt a qualitative assessment of the potential freight market for rail for those origin-destination pairs linked by rail in the infrastructure project scenarios.

We suppose that if the rail is available, all the cement, timber, bauxite, manganese, cocoa and 70% of general cargo are transported by rail. The rest, 30% of general cargo and all agriculture products, are still transported by road. Of course, this market share concerns only the long distance trips (interzonal).

This simplified approach gives only an idea of the potential traffic and can be used as a strategic approach but a detailed analysis is required if a feasibility study is carried out.

Chapter 10 Network Assignment

Network assignment is the process of determining which route, among all available, will be used by each user between his origin and destination.

Figure 13 : Assignment process

1. Assignment for roads

Assuming that the number of road users who want to move from a given origin to a given destination is known and assuming that origin and destination are connected by a number of routes: how will the road users distribute themselves over these routes?

If all of them were to take the shortest route (calculated over the unloaded network) then this route could become congested. This would lead to an increase in travel impedance along that route to the point where this route would no longer be the shortest one. Some road users would choose an alternative route. Congestion could also develop on the alternative route, etc. Eventually an equilibrium will be reached, as formulated for the first time in 1952 by *Wardrop*. (Wardrop's first principle):

Traffic distributes itself across the links of a network in such a way that an equilibrium occurs in which no individual road user can lower his travel resistance by unilaterally (independently of the other road users) choosing another route.

If all road users are fully aware of the travel impedances on all links (even if they do not use these links themselves), and if they also judge these travel resistances in the same way, Wardrop's first principle implies the following:

In the equilibrium situation all routes used between a given origin and destination have the same travel impedance, while routes not used have a higher level of travel impedance.

Wardrop's first principle describes the traffic flows that occur when each individual user strives to minimise his own travel impedance. It is a *descriptive* principle. The distribution of traffic flows that occurs is called a deterministic user-equilibrium or a deterministic *user optimal equilibrium assignment.*

An increase in the traffic volume on a link leads to an increase in travel time and thus to an increase in the travel impedance on a link. The connection between traffic load and travel time is represented by a timeloss function. One of the most widely-used functions is the BPR-function (Bureau of Public Roads):

$$TC = T0(1 + a(V / C)^b$$

In this formula:

TC is the travel time including congestion effects

T0 is the travel time at free flow speed

V is the volume in the link (in PCU equivalent)

C is the capacity of the link(in PCU equivalent)

a and *b* are empirically determined coefficients

Common values for the coefficients are *a* = 0.15 and *b* = 4. These values are used in this study (Bureau of Public Roads).

The graphic below compares the traffic estimated in the model with the traffic counts in each count station; the results show that except for one station, the model was able to replicate the traffic counted with a high level of precision.

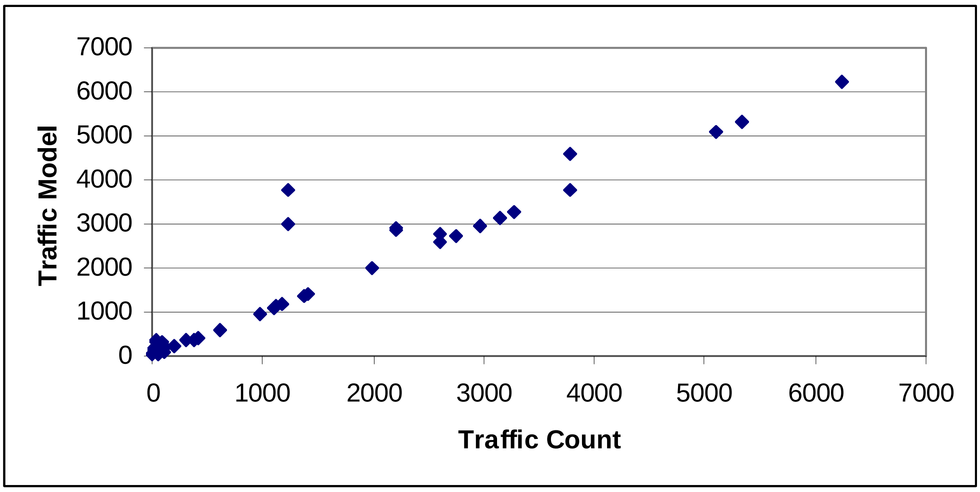


Figure 14 : Trafic model versus counts

2. Assignment for rail and air

The assignment for rail and air consists simply in finding the lowest cost path (which usually coincides with the shortest path) for each OD. Given the very small rail and air networks in Ghana, the assignment is straightforward, namely; identifying if there is any link available between the origin and the destination and assigning the traffic for that OD on this link.

Chapter 11 Transport Indicators

A number of indicators can be drawn from the model. These indicators can provide a better understanding of the current situation of the transport sector in Ghana.

The total number of interzonal trips observed was 524,600 trips/day, which means that, in average, one out of 44 people are making a long distance trip every day.

These trips are divided into the different modes as follows:

- Car: 21%
- Bus: 78%
- Rail: 0.7%
- Air: 0.05%

The road sector (cars and buses) accounts for 99.2% of all passenger trips.

The total number of passenger kilometres is 94 million, which represents an average distance of 179 km.

The freight transport represents 71,300 tons/day. The road transport accounts for 93% of these movements. The traffic generated by freight transport represents 23.6 million ton.km; the average distance for freight is 330 km.

Chapter 12 Issues about recalibration

A frequent question about model calibration is: When should the model be recalibrated? There are two different issues about ensuring the validity of the model. The first one is the recalibration and the second is keeping the model up to date. We should think about model recalibration when:

- the economic reality has dramatically changed from the situation in the model; while most changes, including macro-economic and population growth and other socio economic characteristics can be easily included in the model, some structural changes can not; a high increase in the service sector for example will affect the global economy and also the mobility patterns.
- the infrastructure has dramatically changed; the development of some projects can obviously be included in the model – this is actually the main purpose of the model. However, when a significantly large number of infrastructure projects have been completed, the mobility patterns can change as a function of these developments; for example, the developments of new industries along these new roads.
- any external factor affecting the mobility patterns in a significant way. These factors can be psychological (some countries invest in campaigns to improve perceptions about public transport), technological (affecting costs and way of travel), etc.
- when more reliable information becomes available. This is the main issue in Ghana, since data: is often not available; requires disaggregation; and not always reliable. We would in particular seek to improve the quality of data on a district-by-district level.

However, a model can only be applied if it is up to date. Updating the model does not mean recalibrating it, but ensuring that each new project is included in the base network and that each new actual socio-economic data replaces a forecast data.

It is fundamental that the model must be frequently updated to remain valid. Otherwise the model becomes obsolete in a very short time.

The process of updating should be continuous and a single version of the model must be used (different versions of updates must be avoided). We recommend at least an annual complete update. The recalibration must be driven by external factors affecting the validity of the model. We can, however, expect that a new calibration will be needed in about 5 years.

Chapter 13 Improving the quality of data for transport modelling

In the transport modelling process, we need to simulate the demand for transport and supply and the interaction between them. All these simulations require a large amount of reliable data. Some fundamental data include:

1. Data on demand

- A matrix of daily traffic by mode (car, taxi, tro-tro, bus, train, air) by origin and destination. This matrix can be based on a large survey for the first time and then updated using small samples (based for example on Bayesian procedures);
- Time series on traffic counts;
- Socio-economic characteristics on a district base for national models and more refined for local (urban) models; this data includes population, employment by sector, income, expenditure, etc.
- Agricultural, industrial and service production by district; type of goods/ commodities, volumes, prices;

2. Data on supply

- A detailed description of the network in terms of physical characteristics: capacity, free-flow speeds, speed-flow diagrams, IRI , slope, average travel times for train and aviation, access and waiting times;
- Economic characteristics of the networks: vehicle operating costs for roads, cost of production and market prices for each mode (by passenger.km and ton.km, differentiated by purpose, type of commodity, seasonality…)
- Economic data on transport providers; cost and prices, capacity, infrastructure available (warehouses), load per trucks (overloading)…

3. Standard Economic variables

Although not fundamental, the availability of standard values ensures homogeneity and comparability for the various transport studies. They are composed mainly by:

- Recommended growth rates for economic variables: GDP, Population, Income ...
- Values of time, differentiated by purpose
- Growth for the different sectors of the economy
- Discount rates,
- Etc.

4. Data availability and reliability

Regarding socio-economic data, the availability and the reliability of data is very limited. Data, including production and consumption, should be available by districts and updated on a regular basis.

The transport indicators database compiles several statistics on the transport sector. These are, in most of cases, highly aggregated, which make them unsuitable for modelling.

However, many ratios and averages can be drawn, which, in some cases is enough, or at least is a solid base to compare the input variables, from different sources.

The database should be enlarged, be detailed and aim to serve as a common reference for all the transport studies being (and to be) carried out in the country.

Annexe 1 OD Surveys

The main purposes of the traffic surveys are to:

- Estimate person-trips and cargo-trips between Zones (Traffic Analysis Zones) for Demand Forecasting
- Calibrate the Traffic Model to be employed for the development of the demand forecast and subsequent Transport Plans

Type of Traffic Surveys

Traffic surveys conducted to meet the objectives of the Project comprise:

- Origin-Destination and Vehicle occupancy surveys
- Manual Classified traffic volume counts

The surveys were limited to the National trunk roads. The Route Corridors, road sections, locations and study periods are shown in Table 2.0.1.The choice of locations was based on the following key considerations:

- Transport operators' routes
- Major destination nodes
- Travel pattern
- Road network configuration
- GHA Highway Network Master Plan studies conducted in 2001.

The studies on a particular Route corridor were undertaken at the same time/period on all the locations so as to facilitate the synchronization of results. Four teams were formed with each team headed by an Engineer for the field data collection, which spanned from September 29th to October 25, 2008. The work programme for the studies is presented in the table below.

Table 7 : Traffic Survey Locations and Study Periods

Road No.	Road Corridor	Road Section	Survey Location	*Study Period*	Team Responsible
N1	Aflao-Tema-Cape Coast-Takoradi-Elubo	Aflao-Abor	About 5 km West of Aflao Border	***30/9-1/10***	Team 1
		Accra-Cape Coast	About 500 m East Winneba Jct.	***30/9-1/10***	Team 2
		Cape Coast-Takoradi	About 24 km East of Takoradi (Around Daboasi	***30/9-1/10***	Team 3
		Takoradi-Mpataba-Elubo	About 10 km East of Elubo	***30/9-1/10***	Team 4
N2	Tema-Asikuma-Nkwanta-Yendi-Kulungugu	Tema-Asikuma	Around Kpong	***21-22/10***	Team 4
		Asikuma-Nkwanta	Around Hohoe	***21-22/10***	Team 1
		Nkwanta-Yendi	Around Bimbilla	***21-22/10***	Team 2
		Yendi-Kulungugu	Around Missiga	***21-22/10***	Team 3
N3	Kpong-Nkurakan-Koforidua	Kpong-Nkurakan-Koforidua	Around Nkurakan	***3-4/10***	Team 1
N4	Accra-Aburi-Koforidua-Bunso	Accra-Aburi	Around Ayi Mensah	***3-4/10***	Team 4
		Aburi-Koforidua	Around Mamfe	***3-4/10***	Team 3
		Koforidua-Bunso	Around Bunso	***3-4/10***	Team 2
N5	Asikuma-Ho	Asikuma-Ho	Around Asikuma	***24-25/10***	Team 1
N6	Accra-Nsawam-Nkawkaw-Kumasi-Sunyani-Dormaa Ahenkro-Gonokrom	Accra-Nsawam-Nkawkaw	Around Amansaman	***7-8/10***	Team 4
		Nkawkaw-Kumasi	Around Juaso	***7-8/10***	Team 3
		Kumasi-Sunyani	Around Bechem	***7-8/10***	Team 1
		Sunyani-Dormaa Ahenkro-Gonokrom	Around Dormaa Ahenkro	***7-8/10***	Team 2
N7	Fufulso-Damango-Sawla	Fufulso-Damango-Sawla	Around Damango	***17-18/10***	Team 4
N8	Yamoransa-Assin Foso-Anwiankwanta	Yamoransa-Assin Foso-Anwiankwanta	Around Assin Foso	***24-25/10***	Team 4
N9	Pusuga-Tamale	Pusuga-Tamale	Around Jerigu	***24-25/10***	Team 2
N10	Daboasi Jn.-Obuasi-Anwiankwanta-Kumasi-Tamale-Bolgatanga-Paga	Daboasi Jnct-Kumasi	Around Obuasi	***10-11/10***	Team 4
		Kumasi-Tamale	Around Techiman	***10-11/10***	Team 3
		Tamale-Bolgatanga	Around Winkonko	***10-11/10***	Team 2
		Bolgatanga-Paga	Around Navrongo	***10-11/10***	Team 1
N11	Polmakon-Bawku-Bolgatanga	Polmakon-Bawku-Bolgatanga	Around Zebilla	***17-18/10***	Team 1
N12	Elubo-Goaso-Sunyani-Wenchi-Bamboi-Sawla-Wa-Hamille	Elubo-Sunyani	Around Sayerenso	***14-15/10***	Team 4
		Sunyani-Wenchi-Bamboi	Around New Longoro	***14-15/10***	Team 3
		Bamboi-Sawla	Around Bole	***14-15/10***	Team 2
		Sawla-Wa-Hamille	Around Nandom	***14-15/10***	Team 1
N13	Navrongo-Chuchuliga-Tumu-Han-Lawra	Navrongo-Chuchuliga-Tumu	Around Chana	***17-18/10***	Team 2
		Tumu-Han-Lawra	Around Han	***17-18/10***	Team 3

Origin-Destination and Vehicle Occupancy (O-D) Surveys

O-D Data Collection

The roadside-interview method was employed for the O-D surveys. The studies were conducted for two days in each direction at each location, excluding Sundays. The surveys were conducted for 10 hours each day at 15-minute intervals. The studies took place simultaneously with the classified traffic volume counts. Due to the nature of the ITPG project, only the types of vehicles that normally traverses significantly long distances were involved in the surveys. These comprise the following:

1. Cars
2. Taxis
3. Vans, Pick-Ups
4. Mini/Small Buses
5. Medium Buses
6. Large Buses
7. All Trucks

Only bicycle and motor bike traffic were not considered in this regard. Sampling of vehicles was done where necessary. The data that were recorded include the following for each vehicle:

- Origin and Destination
- Number of persons carried
- Trip purpose at the origin and destination
- Number of persons permitted
- Commodity carried

For each type of vehicle, the number of passengers interviewed is as follows:

- Private cars, pick ups, vans: driver only;
- Taxis: 1 passenger;
- Minibuses/Small buses: 2 passengers;
- Medium/Large Buses: 4 passengers;
- Trucks: driver only

The following personnel conducted the field interviews for each direction at each location:

- Two enumerators, with the assistance of the Police
- An Engineer supervised the operations for each location.

Sample of the field data collection form used for the O-D surveys is shown below.

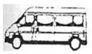
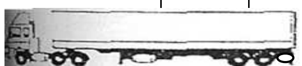
ORIGIN-DESTINATION SURVEY FORM																
Station n°	From (city name):								To (city name):							
Date:	Day of Week:		Time Start:	Time Finish:	Recorder:											
All vehicles						*Passenger vehicles*							*Freight vehicles*			
Vehicle Code	Origin City+Origin OR Border+Country	Origin Zone	Destination City+Destination OR Border+Country	Destination Zone	No. of Persons carried + driver	No. of Persons Permitted	Trip Purpose Origin Code	Trip Purpose Destination Code	No. of cars in the household	Transport price (Gh. Cedis)	Would you take train? (Y/N)	Maximum price for train	Maximum Gross weight (tons)	Commodity Code	Weight of commodity (tons)	Remark
VEHICLE TYPE CODE							TRIP PURPOSE CODE							COMMODITY CODE		
3. Cars		11. Medium Trucks					1 - home		8 - Other (State)					1. Agric Products, eg. Cocoa, Coffee, Tea, spices and manufactures thereof	8. Feeding stuff for animals (not including unmilled cereals)	15. Empty
4. Taxis		12. Heavy Trucks					2 - usual working place							2. Livestock, eg. Cattle	9. Miscellaneous edible products and preparations	
5. Pick Ups/Vans/ Jeeps		13. 3-Axle S/Trailers					3 - business place							3. Sugars, sugar preparations and honey	10.Construction Materials, eg. Sand, Cement, etc.	
6. Mini/Small Buses		14. 4-Axle S/Trailers					4 - school, education							4. Meat and meat preparations	11. Petroleum Products	
7. Medium Buses	 (6 wheels)	15. 5-Axle Trucks					5 - personal business (administration, bank, medical, etc)							5. Dairy products and birds' eggs	12. Timber, Logs	
8. Large Buses		16. 6-Axle Trucks					6 - visit family/social							6. Cereals and cereal preparations	13.Machinery and Transport Equipment	
10. Light Trucks							7 - recreation / tourism							7. Vegetables and fruits	14. Other (State)	

Figure 15 : Field Data Collection for the OD Survey

O-D Data Processing and Analysis

The O-D survey data was processed electronically using the Excel spreadsheet into a database structured format as required by the Cube modeling software. The Access database software was employed in the final processing of data, (ref. Section 4).

The detailed analysis of data and results thereof are provided under the results and interpretation of the traffic modeling.

Manual Classified Traffic Volume Counts

Traffic Volume Data Collection

Manual classified traffic volume counts were undertaken for two days for a period of 24 hours each day at 15-minute intervals. The studies were conducted simultaneously with the O-D surveys so as to generate the daily adjustment factors to be applied to the O-D survey results.

The categories of traffic that were counted comprise the following GHA vehicle classes, which are presented in Table 8. Two enumerators were engaged for each direction per shift at each location. The 24-hour counts consisted of three shifts at each location.

Sample of the field data collection form used for the traffic volume counts is shown in

Table 8 : Summary of Category of Vehicles (GHA Vehicle Classes)

Item	Vehicle Category	Description
1	Bicycles	
2	Motorbikes	
3	Taxis	This category includes all taxis
4	Cars	This category includes private, hired and saloon or estate cars.
5	Vans, Pick-Ups	This category includes pick-ups, land- rovers, vans, jeeps, etc.
6	Small buses	Small buses include up to 19-seater buses, etc., with four (4) wheels
7	Medium Buses	Medium buses include 33-seater buses, etc., with six (6) wheels

8	Large Buses	Large buses include 54-seater buses and upwards.
9	Mammy Wagons	Mammy Wagons are special trucks having wooden bodies for conveying both passengers and goods.
10	Light Trucks	This category comprises 2-axle trucks with single rear wheels or 2-axle trucks with twin rear wheels less than 10 tons.
11	Medium Trucks	This category comprises 2-axle trucks with twin rear wheels of at least 10 tons.
12	Heavy Trucks	Heavy trucks comprise 3-axle rigid trucks, including tankers.
13	3-Axle S/Trailers - Semi-Trailers (Light)	These are semi-trailers with any configuration of 3 axles.
14	4-Axle S/Trailers - Semi-Trailers (Heavy)	These are semi-trailers with any configuration of 4 axles.
15	5-Axle Trucks –Truck Trailers	These are large trucks with any configuration of 5 axles.
16	6-Axle Trucks -Large Trucks	These are extra-large trucks with any configuration of 6 axles.
17	Others	This category also includes tractors, bull-dozers, graders, or other heavy agricultural or constructional machinery.

MANUAL CLASSIFIED TRAFFIC VOLUME COUNT FORM								Sheet of
Road Link:		Road Section:				Count Location:		Direction:
Weather:		Date:				Day of Week:		Enumerator:
VEHICLE TYPE	15 MINUTES INTERVAL		15 MINUTES INTERVAL		15 MINUTES INTERVAL		15 MINUTES INTERVAL	
	From	To	From	To	From	To	From	To
1. Bicycles								
2. Motor Bikes								
3. Cars								
4. Taxis								
5. Pick Ups/Vans/Jeeps								
6. Mini/Small Buses								
7. Medium Buses (6 wheels)								
8. Large Buses								
9. Mammy Wagons								
10. Light Trucks								
11. Medium Trucks								
12. Heavy Trucks								
13. 3-Axle S/Trailers								
14. 4-Axle S/Trailers								
15. 5-Axle Trucks								
16. 6-Axle Trucks								
17. Others								

Note: Light Truck - 2-axle truck with Single or Twin Rear Wheel (<10 TONS); Medium Truck - 2-axle truck with Twin Rear Wheel (>=10 TONS); Heavy Truck - 3-axle Rigid Truck

Figure 16 : Field Data Collection Form for the Traffic Volume Counts

The traffic volume data was processed and analysed electronically using the Excel spreadsheet application software.

The following have been computed for each location:

- Average Daily Traffic (ADT) volumes for each vehicle type /group and the total ADT
- Seasonal (Monthly) variation factors for the estimation of Annual Average Daily Traffic (AADT)
- Annual Average Daily Traffic (AADT) volumes
- Peak hour volumes and relation of Peak hour traffic to ADT

Computation of Average Daily Traffic (ADT) Volumes

ADT volumes have been computed for each location by direction as well as the total volume. The two-day 24-hour counts were averaged over the period to obtain the ADT volumes.

Summary of results of the ADT volumes are presented in Table 9 together with some comments/interpretations. Table 10 shows the summary of composition for the traffic groups: light, medium and heavy and the total ADT.

Computation of Seasonal (Monthly) Variation (AADT) Factors

Monthly variation factors were computed for each road section/location, using available historic traffic data obtained from the GHA. The computation of these factors was accomplished by dividing the computed historic Annual Average Daily Traffic (AADT) by the Average Daily Traffic (ADT) for each month.

Thus,

$$\mathbf{MVF = AADT/ADT_M}$$

where,

MVF = Monthly Variation Factor,

AADT = Historic Annual Average Daily Traffic (2000 to 2006), where available

ADT_M = Average Daily Traffic for the month in which traffic was counted, (October).

A factor of unity was assumed for sections with no available historic traffic data. For sections with data for other months except October, average of the various MVFs was employed.

Computation of Annual Average Daily Traffic (AADT)

AADT was computed as:

AADT = MVF x ADT

Summary of results are presented in Table 11.

Computation of Peak Hour Traffic Volumes

Peak hour traffic volumes have been computed as well as the proportion of the ADT occurring during the peak hour. The peak hour volumes were computed from the maximum of the hourly volume totals. Summaries of results are presented in Table 12.

Observations on Average Daily Traffic (ADT) Volumes

The following can be observed from Table 9:

- Routes N1, N2, N4, N6 and N10 as expected recorded heavy average daily volumes in excess of 4,000 vehicles per day for some sections as highlighted. The ADT volumes range from 4,171 to 11,986 vehicles per day.
- Some road sections recorded low ADT volumes mainly due to the poor state of the roads. These include:
  - Fufulso-Damango-Sawla road, which recorded 33 vehicles per day, and
  - Elubo-Sunyani road with only 14 vehicles per day
- The overall ADT volumes range from 14 to 11,986 vehicles per day.

Observations on the Composition of Traffic by Vehicle Group

The following can be observed from Table 10:

- Routes N1, N2, N6, N9, N10, N11, N12 and N13 recorded significant percentages of heavy group traffic of at least 12 percent of total ADT. The affected road sections are highlighted. The heavy group traffic ranges from about 13 to 47 percent.
- The overall proportion of heavy group traffic ranges from 0 to 47 percent. The medium group traffic ranges from 4 to 34 percent with the light group traffic ranging from 40 to 96 percent.

Observations on Annual Average Daily Traffic (AADT) Volumes

The results of the AADT volumes naturally follow as much as possible the same pattern as that of the ADT volumes.

The following can be observed from Table 11:

- The AADT/Monthly variation factors (MVF), range from 0.7 to 1.54.

Observations on the Peak Hour Traffic Volumes

The following can be observed from Table 12:

- Routes N1, N4 and N6 recorded high peak hour volumes in excess of 400 vehicles per hour for some sections as highlighted. The volumes range from 451 to 957 vehicles per hour.

- The overall peak hour volumes range from 4 to 957 vehicles per hour.

- The overall proportion of ADT occurring during the peak hour ranges from 0.06 to 0.29, (i.e. 6 to 29 percent of the ADT volumes occur during the Peak hour).

Table 9 : Summary of results of the Average Daily Traffic (ADT) Volumes

Road No.	Road Corridor	Road Section	Survey Location	Section Code	Direction	ADT (vpd)	Direction	ADT (vpd)	TOTAL ADT (vpd)	Comment/Interpretation
N1	Aflao-Tema-Cape Coast-Takoradi-Elubo	Aflao-Abor	About 5 km West of Aflao Border	N1-01	To Aflao	*6,569*	From Aflao	*5,417*	***11,986***	*Local traffic constituted about 63% of the total ADT*
		Accra-Cape Coast	About 500 m East Winneba Jct.	N1-02	To Cape Coast	*3,489*	From Cape Coast	*3,001*	***6,490***	
		Cape Coast-Takoradi	About 24 km East of Takoradi (Around Daboasi Jn)	N1-03	ToTakoradi	*2,762*	From Takoradi	*2,233*	***4,995***	
		Takoradi-Mpataba-Elubo	About 10 km East of Elubo	N1-04	To Elubo	*615*	From Elubo	*599*	***1,214***	
N2	Tema-Asikuma-Nkwanta-Yendi-Kulungugu	Tema-Asikuma	Around Kpong	N2-01	To Tema	*2,078*	From Tema	*2,093*	***4,171***	
		Asikuma-Nkwanta	Around Hohoe	N2-02	To Nkwanta	*1,138*	From Nkwanta	*1,011*	***2,149***	
		Nkwanta-Yendi	Around Bimbilla	N2-03	To Yendi	*64*	From Yendi	*51*	***115***	
		Yendi-Kulungugu	Around Missiga	N2-04	To Kulungugu	*99*	From Kulungugu	*101*	***200***	*Because of the curfew count was done for only 10hrs. Adjusted to ADT using GHA average factor of 1.36.*
N3	Kpong-Nkurakan-Koforidua	Kpong-Nkurakan-Koforidua	Around Nkurakan	N3-01	To Kpong	*1,224*	From Kpong	*1,046*	***2,270***	
N4	Accra-Aburi-Koforidua-Bunso	Accra-Aburi	Around Ayi Mensah	N4-01	To Aburi	*2,475*	From Aburi	*2,483*	***4,958***	
		Aburi-Koforidua	Around Mamfe	N4-02	To Koforidua	*4,187*	From Koforidua	*3,855*	***8,042***	
		Koforidua-Bunso	Around Bunso	N4-03	To Bunso	*1,265*	From Bunso	*1,212*	***2,477***	
N5	Asikuma-Ho	Asikuma-Ho	Around Asikuma	N5-01	To Ho	*1,360*	From Ho	*1,286*	***2,646***	
N6	Accra-Nsawam-Nkawkaw-Kumasi-Sunyani-Dormaa Ahenkro-Gonokrom	Accra-Nsawam-Nkawkaw	Around Amansaman	N6-01	To Accra	*4,652*	From Accra	*4,962*	***9,614***	
		Nkawkaw-Kumasi	Around Juaso	N6-02	To Kumasi	*3,392*	From Kumasi	*3,314*	***6,706***	
		Kumasi-Sunyani	Around Bechem	N6-03	To Sunyani	*1,061*	From Sunyani	*1,080*	***2,141***	
		Sunyani-Dormaa Ahenkro-Gonokrom	Around Dormaa Ahenkro	N6-04	To Gonokrom	*624*	From Gonokrom	*640*	***1,264***	

Road No.	Road Corridor	Road Section	Survey Location	Section Code	Direction	ADT (vpd)	Direction	ADT (vpd)	TOTAL ADT (vpd)	Comment/Interpretation
N7	Fufulso-Damango-Sawla	Fufulso-Damango-Sawla	Around Damango	N7-01	To Fufulso	*14*	From Fufulso	*19*	***33***	*Road was in a very bad state*
N8	Yamoransa-Assin Foso-Anwiankwanta	Yamoransa-Assin Foso-Anwiankwanta	Around Assin Foso	N8-01	To Anwiankwanta	*2,084*	From Anwiankwanta	*1,805*	***3,889***	
N9	Pusuga-Tamale	Pusuga-Tamale	Around Jerigu	N9-01	To Pusuga	*85*	From Pusuga	*86*	***171***	
N10	Daboasi Jn.-Obuasi-Anwiankwanta-Kumasi-Tamale-Bolgatanga-Paga	Daboasi Jnct-Kumasi	Around Obuasi	N10-01	To Kumasi	*2,545*	From Kumasi	*2,318*	***4,863***	
		Kumasi-Tamale	Around Techiman	N10-02	To Tamale	*2,804*	From Tamale	*2,890*	***5,694***	
		Tamale-Bolgatanga	Around Winkonko	N10-03	To Bolgatanga	*1,117*	From Bolgatanga	*966*	***2,083***	
		Bolgatanga-Paga	Around Navrongo	N10-04	To Paga	*345*	From Paga	*293*	***638***	
N11	Polmakon-Bawku-Bolgatanga	Polmakon-Bawku-Bolgatanga	Around Zebilla	N11-01	To Bawku	*264*	From Bawku	*264*	***528***	
N12	Elubo-Goaso-Sunyani-Wenchi-Bamboi-Sawla-Wa-Hamille	Elubo-Sunyani	Around Sayerenso	N12-01	To Sunyani	*8*	From Sunyani	*6*	***14***	*The road section was very deplorable and as such Motorists used alternative routes to their destinations*
		Sunyani-Wenchi-Bamboi	Around New Longoro	N12-02	To Bamboi	*341*	From Bamboi	*486*	***827***	
		Bamboi-Sawla	Around Bole	N12-03	To Sawla	*166*	From Sawla	*207*	***373***	
		Sawla-Wa-Hamille	Around Nandom	N12-04	To Wa	*76*	From Wa	*89*	***165***	
N13	Navrongo-Chuchuliga-Tumu-Han-Lawra	Navrongo-Chuchuliga-Tumu	Around Chana	N13-01	To Navrongo	*48*	From Navrongo	*45*	***93***	
		Tumu-Han-Lawra	Around Han	N13-02	To Tumu	*95*	From Tumu	*80*	***175***	*The road section was very bad and commercial vehicles traversed some sections once a day. During the day major transport mode was motor bikes and bicycles*
Note: Results exclude Motor bikes and Bicycles.										

Table 10 : Composition of Traffic by Vehicle Group and Total ADT Volumes

					Vehicle Group				
Road No.	Road Corridor	Road Section	Survey Location	Section Code	Light (%)	Medium (%)	Heavy (%)	*TOTAL ADT (vpd)*	Comment/Interpretation
N1	Aflao-Tema-Cape Coast-Takoradi-Elubo	Aflao-Abor	About 5 km West of Aflao Border	N1-01	92.8	3.9	3.3	***11,986***	
N1	Aflao-Tema-Cape Coast-Takoradi-Elubo	Accra-Cape Coast	About 500 m East Winneba Jct.	N1-02	78.2	14.7	7.1	***6,490***	
N1	Aflao-Tema-Cape Coast-Takoradi-Elubo	Cape Coast-Takoradi	About 24 km East of Takoradi (Around Daboasi Jn)	N1-03	65.3	13.1	21.6	***4,995***	*Significant amount of trucks as expected due to the Takoradi harbour/port*
N1	Aflao-Tema-Cape Coast-Takoradi-Elubo	Takoradi-Mpataba-Elubo	About 10 km East of Elubo	N1-04	89.7	6.6	3.7	***1,214***	
N2	Tema-Asikuma-Nkwanta-Yendi-Kulungugu	Tema-Asikuma	Around Kpong	N2-01	83.0	11.0	6.0	***4,171***	
N2	Tema-Asikuma-Nkwanta-Yendi-Kulungugu	Asikuma-Nkwanta	Around Hohoe	N2-02	80.5	12.6	6.9	***2,149***	
N2	Tema-Asikuma-Nkwanta-Yendi-Kulungugu	Nkwanta-Yendi	Around Bimbilla	N2-03	47.0	34.3	18.7	***115***	*Significant amount of trucks. Traffic uses this route to/from Yendi and Burkina Faso*
N2	Tema-Asikuma-Nkwanta-Yendi-Kulungugu	Yendi-Kulungugu	Around Missiga	N2-04	40.1	12.9	47.0	***200***	
N3	Kpong-Nkurakan-Koforidua	Kpong-Nkurakan-Koforidua	Around Nkurakan	N3-01	88.3	6.6	5.1	***2,270***	
N4	Accra-Aburi-Koforidua-Bunso	Accra-Aburi	Around Ayi Mensah	N4-01	92.9	6.1	1.0	***4,958***	
N4	Accra-Aburi-Koforidua-Bunso	Aburi-Koforidua	Around Mamfe	N4-02	95.8	3.6	0.6	***8,042***	
N4	Accra-Aburi-Koforidua-Bunso	Koforidua-Bunso	Around Bunso	N4-03	90.9	6.8	2.3	***2,477***	
N5	Asikuma-Ho	Asikuma-Ho	Around Asikuma	N5-01	76.6	14.2	9.2	***2,646***	
N6	Accra-Nsawam-Nkawkaw-Kumasi-Sunyani-Dormaa Ahenkro-Gonokrom	Accra-Nsawam-Nkawkaw	Around Amansaman	N6-01	67.5	14.8	17.7	***9,614***	*Significant amount of trucks as expected. Traffic to/from the North through Techiman to Paga/Burkina Faso*
N6	Accra-Nsawam-Nkawkaw-Kumasi-Sunyani-Dormaa Ahenkro-Gonokrom	Nkawkaw-Kumasi	Around Juaso	N6-02	66.1	11.6	22.3	***6,706***	
N6	Accra-Nsawam-Nkawkaw-Kumasi-Sunyani-Dormaa Ahenkro-Gonokrom	Kumasi-Sunyani	Around Bechem	N6-03	79.4	12.9	7.7	***2,141***	
N6	Accra-Nsawam-Nkawkaw-Kumasi-Sunyani-Dormaa Ahenkro-Gonokrom	Sunyani-Dormaa Ahenkro-Gonokrom	Around Dormaa Ahenkro	N6-04	89.9	7.5	2.6	***1,264***	

					Vehicle Group				
Road No.	Road Corridor	Road Section	Survey Location	Section Code	Light (%)	Medium (%)	Heavy (%)	*TOTAL ADT (vpd)*	Comment/Interpretation
N7	Fufulso-Damango-Sawla	Fufulso-Damango-Sawla	Around Damango	N7-01	57.8	32.8	9.4	***33***	
N8	Yamoransa-Assin Foso-Anwiankwanta	Yamoransa-Assin Foso-Anwiankwanta	Around Assin Foso	N8-01	76.7	11.7	11.6	***3,889***	
N9	Pusuga-Tamale	Pusuga-Tamale	Around Jerigu	N9-01	71.6	15.5	12.9	***171***	*Significant amount of trucks. Traffic uses this route to/from Tamale/Bolgatanga and Paga/Burkina Faso*
N10	Daboasi Jn.-Obuasi-Anwiankwanta-Kumasi-Tamale-Bolgatanga-Paga	Daboasi Jnct-Kumasi	Around Obuasi	N10-01	71.0	15.2	13.8	***4,863***	*Significant amount of trucks as expected. Traffic to/from the North through Tamale to Paga/Burkina Faso*
		Kumasi-Tamale	Around Techiman	N10-02	69.7	11.3	19.0	***5,694***	
		Tamale-Bolgatanga	Around Winkonko	N10-03	75.4	11.3	13.3	***2,083***	
		Bolgatanga-Paga	Around Navrongo	N10-04	72.0	6.9	21.1	***638***	
N11	Polmakon-Bawku-Bolgatanga	Polmakon-Bawku-Bolgatanga	Around Zebilla	N11-01	65.4	18.3	16.3	***528***	*Significant amount of trucks. Traffic uses this route to/from Bolgatanga and Paga/Burkina Faso*
N12	Elubo-Goaso-Sunyani-Wenchi-Bamboi-Sawla-Wa-Hamille	Elubo-Sunyani	Around Sayerenso	N12-01	74.1	25.9		***14***	
		Sunyani-Wenchi-Bamboi	Around New Longoro	N12-02	47.2	22.9	29.9	***827***	*Significant amount of trucks as expected due to the border with Burkina Faso*
		Bamboi-Sawla	Around Bole	N12-03	60.2	24.1	15.7	***373***	
		Sawla-Wa-Hamille	Around Nandom	N12-04	74.1	12.5	13.4	***165***	
N13	Navrongo-Chuchuliga-Tumu-Han-Lawra	Navrongo-Chuchuliga-Tumu	Around Chana	N13-01	76.1	14.1	9.8	***93***	
		Tumu-Han-Lawra	Around Han	N13-02	57.4	28.6	14.0	***175***	*Trucks use this route to/from Lawra/Wa/Hamille and Paga/Burkina Faso for both goods and passenger transport due to the poor state of the road*

Note: Results exclude Motor bikes and Bicycles.

Table 11 : Summary of results of the AADT Volumes

Road No.	Road Corridor	Road Section	Survey Location	Section Code	Direction	AADT (vpd)	Direction	AADT (vpd)	TOTAL AADT (vpd)	AADT FACTOR (MVF)
N1	Aflao-Tema-Cape Coast-Takoradi-Elubo	Aflao-Abor	About 5 km West of Aflao Border	N1-01	To Aflao	*6,832*	From Aflao	*5,634*	***12,465***	1.04
		Accra-Cape Coast	About 500 m East Winneba Jct.	N1-02	To Cape Coast	*3,524*	From Cape Coast	*3,031*	***6,555***	1.01
		Cape Coast-Takoradi	About 24 km East of Takoradi (Around Daboasi Jn)	N1-03	ToTakoradi	*2,872*	From Takoradi	*2,322*	***5,195***	1.04
		Takoradi-Mpataba-Elubo	About 10 km East of Elubo	N1-04	To Elubo	*615*	From Elubo	*599*	***1,214***	1.00
N2	Tema-Asikuma-Nkwanta-Yendi-Kulungugu	Tema-Asikuma	Around Kpong	N2-01	To Tema	*2,203*	From Tema	*2,219*	***4,421***	1.06
		Asikuma-Nkwanta	Around Hohoe	N2-02	To Nkwanta	*1,172*	From Nkwanta	*1,041*	***2,213***	1.03
		Nkwanta-Yendi	Around Bimbilla	N2-03	To Yendi	*45*	From Yendi	*35*	***80***	0.70
		Yendi-Kulungugu	Around Missiga	N2-04	To Kulungugu	*106*	From Kulungugu	*108*	***214***	1.07
N3	Kpong-Nkurakan-Koforidua	Kpong-Nkurakan-Koforidua	Around Nkurakan	N3-01	To Kpong	*1,261*	From Kpong	*1,077*	***2,338***	1.03
N4	Accra-Aburi-Koforidua-Bunso	Accra-Aburi	Around Ayi Mensah	N4-01	To Aburi	*3,143*	From Aburi	*3,153*	***6,297***	1.27
		Aburi-Koforidua	Around Mamfe	N4-02	To Koforidua	*5,317*	From Koforidua	*4,896*	***10,213***	1.27
		Koforidua-Bunso	Around Bunso	N4-03	To Bunso	*1,265*	From Bunso	*1,212*	***2,477***	1.00
N5	Asikuma-Ho	Asikuma-Ho	Around Asikuma	N5-01	To Ho	*1,442*	From Ho	*1,363*	***2,805***	1.06
N6	Accra-Nsawam-Nkawkaw-Kumasi-Sunyani-Dormaa Ahenkro-Gonokrom	Accra-Nsawam-Nkawkaw	Around Amansaman	N6-01	To Accra	*5,164*	From Accra	*5,508*	***10,672***	1.11
		Nkawkaw-Kumasi	Around Juaso	N6-02	To Kumasi	*3,833*	From Kumasi	*3,745*	***7,578***	1.13
		Kumasi-Sunyani	Around Bechem	N6-03	To Sunyani	*1,114*	From Sunyani	*1,134*	***2,248***	1.05
		Sunyani-Dormaa Ahenkro-Gonokrom	Around Dormaa Ahenkro	N6-04	To Gonokrom	*961*	From Gonokrom	*986*	***1,947***	1.54

Road No.	Road Corridor	Road Section	Survey Location	Section Code	Direction	AADT (vpd)	Direction	AADT (vpd)	TOTAL AADT (vpd)	AADT FACTOR (MVF)
N7	Fufulso-Damango-Sawla	Fufulso-Damango-Sawla	Around Damango	N7-01	To Fufulso	*11*	From Fufulso	*15*	***26***	0.78
N8	Yamoransa-Assin Foso-Anwiankwanta	Yamoransa-Assin Foso-Anwiankwanta	Around Assin Foso	N8-01	To Anwiankwanta	*2,126*	From Anwiankwanta	*1,841*	***3,967***	1.02
N9	Pusuga-Tamale	Pusuga-Tamale	Around Jerigu	N9-01	To Pusuga	*94*	From Pusuga	*95*	***190***	1.11
N10	Daboasi Jn.-Obuasi-Anwiankwanta-Kumasi-Tamale-Bolgatanga-Paga	Daboasi Jnct-Kumasi	Around Obuasi	N10-01	To Kumasi	*2,876*	From Kumasi	*2,619*	***5,495***	1.13
		Kumasi-Tamale	Around Techiman	N10-02	To Tamale	*2,916*	From Tamale	*3,006*	***5,922***	1.04
		Tamale-Bolgatanga	Around Winkonko	N10-03	To Bolgatanga	*1,474*	From Bolgatanga	*1,275*	***2,750***	1.32
		Bolgatanga-Paga	Around Navrongo	N10-04	To Paga	*414*	From Paga	*352*	***766***	1.20
N11	Polmakon-Bawku-Bolgatanga	Polmakon-Bawku-Bolgatanga	Around Zebilla	N11-01	To Bawku	*304*	From Bawku	*304*	***607***	1.15
N12	Elubo-Goaso-Sunyani-Wenchi-Bamboi-Sawla-Wa-Hamille	Elubo-Sunyani	Around Sayerenso	N12-01	To Sunyani	*8*	From Sunyani	*6*	***14***	1.00
		Sunyani-Wenchi-Bamboi	Around New Longoro	N12-02	To Bamboi	*348*	From Bamboi	*496*	***844***	1.02
		Bamboi-Sawla	Around Bole	N12-03	To Sawla	*184*	From Sawla	*230*	***414***	1.11
		Sawla-Wa-Hamille	Around Nandom	N12-04	To Wa	*74*	From Wa	*87*	***162***	0.98
N13	Navrongo-Chuchuliga-Tumu-Han-Lawra	Navrongo-Chuchuliga-Tumu	Around Chana	N13-01	To Navrongo	*54*	From Navrongo	*51*	***105***	1.13
		Tumu-Han-Lawra	Around Han	N13-02	To Tumu	*121*	From Tumu	*102*	***222***	1.27

Note: Results exclude Motor bikes and Bicycles.

Table 12 : Summary of results of the Peak Hour Volumes and relation to the ADT

Road No.	Road Corridor	Road Section	Survey Location	Section Code	TOTAL ADT (vpd)	PEAK HOUR VOLUME (veh/h)	PEAK HR. VOL. / TOTAL ADT
N1	Aflao-Tema-Cape Coast-Takoradi-Elubo	Aflao-Abor	About 5 km West of Aflao Border	N1-01	*11,986*	957	*0.08*
		Accra-Cape Coast	About 500 m East Winneba Jct.	N1-02	*6,490*	488	*0.08*
		Cape Coast-Takoradi	About 24 km East of Takoradi (Around Daboasi Jn)	N1-03	*4,995*	322	*0.06*
		Takoradi-Mpataba-Elubo	About 10 km East of Elubo	N1-04	*1,214*	94	*0.08*
N2	Tema-Asikuma-Nkwanta-Yendi-Kulungugu	Tema-Asikuma	Around Kpong	N2-01	*4,171*	276	*0.07*
		Asikuma-Nkwanta	Around Hohoe	N2-02	*2,149*	254	*0.12*
		Nkwanta-Yendi	Around Bimbilla	N2-03	*115*	14	*0.12*
		Yendi-Kulungugu	Around Missiga	N2-04	*200*	21	*0.11*
N3	Kpong-Nkurakan-Koforidua	Kpong-Nkurakan-Koforidua	Around Nkurakan	N3-01	*2,270*	197	*0.09*
N4	Accra-Aburi-Koforidua-Bunso	Accra-Aburi	Around Ayi Mensah	N4-01	*4,958*	377	*0.08*
		Aburi-Koforidua	Around Mamfe	N4-02	*8,042*	704	*0.09*
		Koforidua-Bunso	Around Bunso	N4-03	*2,477*	216	*0.09*
N5	Asikuma-Ho	Asikuma-Ho	Around Asikuma	N5-01	*2,646*	254	*0.10*
N6	Accra-Nsawam-Nkawkaw-Kumasi-Sunyani-Dormaa Ahenkro-Gonokrom	Accra-Nsawam-Nkawkaw	Around Amansaman	N6-01	*9,614*	633	*0.07*
		Nkawkaw-Kumasi	Around Juaso	N6-02	*6,706*	451	*0.07*
		Kumasi-Sunyani	Around Bechem	N6-03	*2,141*	166	*0.08*
		Sunyani-Dormaa Ahenkro-Gonokrom	Around Dormaa Ahenkro	N6-04	*1,264*	102	*0.08*

Road No.	Road Corridor	Road Section	Survey Location	Section Code	*TOTAL ADT (vpd)*	PEAK HOUR VOLUME (veh/h)	*PEAK HR. VOL. / TOTAL ADT*
N7	Fufulso-Damango-Sawla	Fufulso-Damango-Sawla	Around Damango	N7-01	*33*	7	*0.21*
N8	Yamoransa-Assin Foso-Anwiankwanta	Yamoransa-Assin Foso-Anwiankwanta	Around Assin Foso	N8-01	*3,889*	311	*0.08*
N9	Pusuga-Tamale	Pusuga-Tamale	Around Jerigu	N9-01	*171*	20	*0.12*
N10	Daboasi Jn.-Obuasi-Anwiankwanta-Kumasi-Tamale-Bolgatanga-Paga	Daboasi Jnct-Kumasi	Around Obuasi	N10-01	*4,863*	326	*0.07*
		Kumasi-Tamale	Around Techiman	N10-02	*5,694*	320	*0.06*
		Tamale-Bolgatanga	Around Winkonko	N10-03	*2,083*	188	*0.09*
		Bolgatanga-Paga	Around Navrongo	N10-04	*638*	55	*0.09*
N11	Polmakon-Bawku-Bolgatanga	Polmakon-Bawku-Bolgatanga	Around Zebilla	N11-01	*528*	48	*0.09*
N12	Elubo-Goaso-Sunyani-Wenchi-Bamboi-Sawla-Wa-Hamille	Elubo-Sunyani	Around Sayerenso	N12-01	*14*	4	*0.29*
		Sunyani-Wenchi-Bamboi	Around New Longoro	N12-02	*827*	49	*0.06*
		Bamboi-Sawla	Around Bole	N12-03	*373*	29	*0.08*
		Sawla-Wa-Hamille	Around Nandom	N12-04	*165*	20	*0.12*
N13	Navrongo-Chuchuliga-Tumu-Han-Lawra	Navrongo-Chuchuliga-Tumu	Around Chana	N13-01	*93*	10	*0.11*
		Tumu-Han-Lawra	Around Han	N13-02	*175*	15	*0.09*

Note: Results exclude Motor bikes and Bicycles.

Overall Observations on the Traffic Volumes

From the fore-going analysis, results and observations, it can be said that the following road corridors and sections constitute the major heavily trafficked National routes:

- Route N1, from Aflao to Takoradi
- Route N2, from Tema to Nkwanta
- Route N4, from Accra to Koforidua
- Route N6, from Accra to Kumasi, and
- Route N10, from Daboasi Junction to Bolgatanga.

Problems Encountered and Recommended Measures for Improving Future Surveys

This section highlights the major problems encountered during the traffic surveys and measures proposed to improve future studies. The following constitute the major problems faced during the surveys:

- Some drivers refused to stop and some of those who stopped were impatient to answer all the items in the questionnaire

- Some passengers were also impatient and some even demanded to see the identity cards of the enumerators before being interviewed.

- It was quite difficult to solicit for Police assistance at some locations due to the inadequate personnel at the affected areas. Some of those available did not also give out their maximum cooperation. It should be mentioned that the Police in the influence areas were formally informed before the surveys.

- Police patrol teams disrupted the surveys in some areas because of the spate of armed robberies in the affected areas.

- Inclement weather hampered the surveys at some locations.

The following are suggestions to improve future surveys:

- Advertisements should be made through both electronic and the print media as well as in both English and major local dialects before the commencement of the surveys so as to adequately inform the general public, especially the road users and the Police.

- In addition, the various transport associations should be informed so as to educate their members to fully cooperate

- Surveys should be undertaken during the dry season, if possible, so as to minimize disruptions by rain.

Annexe 2 Construction of the Database

The construction of the database for the modeling involved processing and assigning unique IDs in Microsoft Excel and the final importation of the data into Access.

The processing stage aided in the restructuring and correction of inconsistencies in the data where necessary. This was to ensure that the final data used for the modeling would be as reliable as possible for data analysis.

The importation of the data into access added a layer of reliability to the resultant data for the modeling as the in-built mechanisms in Microsoft Access ® were employed to check the data before importation.

Four main groups of data were processed and imported:

i. Existing road network
ii. Existing railway network
iii. Flight Links
iv. Origin-Destination (OD) survey data

This section outlines all the various stages in the construction of the database for the transport modeling

Existing Road Network Data

The existing road network data, comprising the 2008 annual road condition survey from the Ghana Highway Authority and a GIS map of the trunk road network, provided data to model the existing infrastructure. It provided information such as road characteristics and road condition.

The road characteristics include the following:

- Lane width
- Number of lanes
- Length
- Surface type

The road condition includes information on:

- The condition of the road
- The roughness index of the road (IRI value)

The GIS map provided data to aid in the replication of the network in the modeling software.

It must be mentioned that the main corridors of interest were the National routes, per GHA standards. The national routes are the main road corridors numbering about 13 referenced as N1 to N13.

Processing and Structuring the Road Network Data

Road Condition Survey Data

The processing of road condition survey data included the restructuring of the originally flat database into a relational one as required by the modeling software.

Thus, the data was split into roads, links, sections and sub-sections. The diagram shows the relationship between the various components of the road network data.

The roads list contained a unique list of all the roads in the network. The links list contained the unique list of all links for each road. These are considered the segments between major intersections or administrative boundaries.

The sections list contained all the sections for each link. These are usually homogenous segments of road sharing the same characteristics.

The sub-sections, were created because road characteristics can changed along the section. To ensure that the relational system was maintained, all road sections were considered to have sub-sections. The road conditions were thus disaggregated to this level.

Road Characteristics

Some of the road characteristics were not originally available in the GHA database. These had to be, therefore, generate in consultations with GHA.

The road characteristics include:

- Width/lane: the width of each lane
- Number of lanes/direction: the number of lanes per direction
- Capacity: the capacity of the roads
- Free flow speed: the maximum speed by vehicles plying the road under free flow conditions
- Slope: the average slope of the road section

GIS Map

As mentioned above, the GIS map provided a means to replicate the road network in the modeling software.

The problem encountered with the GIS map was the fact that the segments in the road condition survey database were not the same as the segments in the map. As a result, the map segments had to be related to the road network at the road section level, where both the map and the road database shared similar characteristics. This was done by the assignment of section IDs to the map segments, based on the sections they belonged to. The means for generating these IDs are discussed in the next section.

The diagram below shows this situation

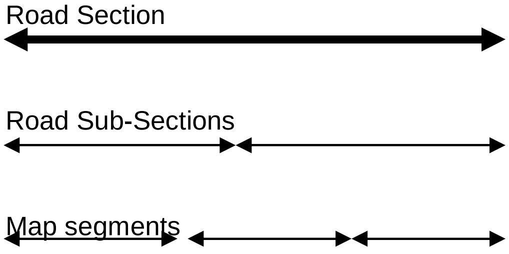


Figure 17 : Relationship between sections, sub-sections and map segments

Generation of Unique IDs for Various Components

To ensure that the data for the various components of the road network data created could be related to each other unique IDs (numeric) were created for the roads , links, sections and sub-sections.

Roads: The unique IDs for roads were generated based on the road class and the road number. This is based on the referencing used by the GHA for roads. The format is a letter representing the road class and the road number. This combination is unique for each road.

The ID system was formatted as R###.

Where

R represents a numeric value for the road class – 1 for National (N); 2 for Inter-Regional (IR) and 3 for Regional (R).

- A three digit number representing the road's number

For example route N1 would be formatted as 1001 and N12 would be 1012, etc.

Links: The unique IDs for links were generated in the format (R###)(LL).

Where

(R###) - is the road ID for the link.

LL – The link number (a unique number based on GHA referencing)

For example the fourth link of route N12 would have an ID of 101204, etc.

Sections: The IDs for road sections were generated based on the link IDs and a unique number assigned to each road section in the road condition database. The format was

(R###LL)(SS)

Where

(R###LL) – is the link ID for the section

SS – The section number, reformatted as a two digit number

For example the first section of the link with ID 101204 would be 10120401, etc.

Sub-Sections: The road sub-section IDs were formatted as (R###LLSS)(SB).

Where

(R###LLSS) – The section ID for a given sub-section

(SB) – The sub-section number

For example if a given section with ID (10120401) has no sub-sections, then the sub-section ID generated for it would be 1012040101 and for the case where it has three sub-sections it may have SB values of 01 (1012040101), 02 (1012040102) and 03 (1012040103) respectively.

Primary and Foreign Keys

The unique IDs described above were assigned as the primary keys for their respective tables. These are the main IDs used to identify each record.

Foreign keys were created to relate the tables in the database where applicable. These are IDs in a table which helps setup a relationship with records in another table.

For the road links, a road ID key was created. The road IDs generated were then assigned to their related links as the foreign keys.

Road sections had link ID foreign keys and the sub-sections had section ID foreign keys.

The road characteristics also had section IDs as foreign keys.

In the case of the GIS, an attribute was created to assign the section IDs as foreign keys. In the final processing however, FIDs which are unique IDs assigned to each map feature where assigned as foreign keys in the road characteristics table as well as for the road conditions table.

Existing Railway Network

The existing railway network is made up of three main corridors:

- The Western Line (Takoradi-Kumasi),
- The Central line (Huni Valley-Kotoku)
- The Eastern Line (Kumasi-Kotoku).

The data processed here were all in a GIS map. Two main sets of data were processed: the network and the railway stations.

Railway Network

The processing done here included the assignment of extra attributes to the railway network and the merging and splitting of railway segments to account of the locations of the railway stations within the network.

Some of the additional attributes include:

- FNode: the start point – this is the unique ID (FID) of the railway station at the start point
- TNode: the end point – this is also the FID of the railway station at the end point
- SegCondn: this is the condition of the segment (good, fair, poor)
- Status: the status of a given segment (active, inactive)
- SectName: the name of a given segment. This is normally the origin and destination of the segment (e.g. Takoradi-Kojokrom)
- Length: the length of the segment in kilometres

Railway Stations

The railway stations were created based on the list of stations provided. The processing done involved locating the stations and assigning some attributes to them.

The attributes of importance included in this map feature were:

- TownName: The name of the town in which the station is located
- Stat_X: The geographical x-coordinate of the station
- Stat_Y: The geographical y-coordinate of the station

As mentioned in the previous sub-section, the FIDs generated in this feature were assigned to the FNode and TNode attributes of the railway network to reflect the start and end points of the segments respectively. They also showed the connectivity between the various segments in the network.

Flight Links

This was mainly the generation of links to show the flight paths between:

- Accra to Kumasi,
- Accra to Sunyani
- Accra to Tamale

In addition, the location of all the airports and airstrips were setup.

All the above processing was done in the GIS map.

OD Survey Data

The OD survey was conducted by the consultant. It was conducted on the main National trunk roads (N1-N13).

The following is a description of the processes employed in getting the data into the database.

OD Data

The OD data had thirty-one (31) stations. For each station, the survey was conducted in both directions. The survey was conducted for two days for each station and the whole exercise started from 30th September, 2008 to 30th October, 2008.

The data was collected for forty periods of 15 minutes.

Data Entry and Processing

For both zones and districts, unique IDs were assigned. The relationship between districts and zones were also established, as were towns and districts. This aided in the assignment of the right zones and districts to the towns mentioned by the respondents as their respective origins and destinations.

The data entry was done in pre-formatted Microsoft Excel and for a given station, forty sheet tabs bearing the period names were created. The data was entered into these sheet tabs.

In all, one hundred and twenty-four (124) workbooks were processed

The processing exercise required the following steps

Compilation of Lookups

The lookups in this case were the list of survey stations, survey station directions, the OD date list and the period list.

The survey stations were 31 and each station was assigned a station ID. This aided in the assignment of station direction IDs after creating the list of station directions. For each station, there were two directions and each direction had a unique ID.

The OD date list was also compiled and each date had a unique ID assigned to it.

The period list was also compiled. Each period had a unique ID.

These lookups were created to aid in the assignment of IDs to the OD data and also in setting up the relationship between the various data tables in the database.

Merging of Data

For each Excel workbook, the data from all the sheet tabs had to be copied to a single sheet tab. Thus, a new sheet tab was created and the data copied to this sheet.

To keep track of which contained what data, blank rows were left between consecutive sets of data. This is particularly important since unique IDs had to be assigned later.

Generation of OD Sheet List

This data was stored in the ODSheet database table. For each workbook a list of all the sheets was generated. The most important feature of the sheet list is the unique ID generated for every sheet.

The unique ID, a numeric value, was generated in the format (SD) (D) (SN).

SD is the station direction ID obtained from the station directions list.

D is the date ID from the OD Date list. This was formatted as a two digit number.

SN is a serial number for each sheet formatted as a 2 digit number. Thus for the forty sheets, sheet 1 would have an SN of 01 and so on.

For example, for a station direction ID of 28 and a Date ID of 9 and a sheet number of 1 then sheet ID would be 280901.

The unique ID was used to setup a relationship with the other parts of the OD data. It ensured that the data related to a specific station can easily be retrieved during the modeling process.

Other items in this list include:

- StatDirID – the station direction ID
- DateID – the date ID
- PeriodID – the period ID

Generation of Vehicles List

The next stage was the generation of a list containing all the vehicles stopped for the interview in a given direction.

Unique IDs were generated for each given vehicle for a given sheet tab. The ID was in the format (SID)(V).

SID is the sheet ID generated in the stage above

V is a serial number assigned to each vehicle found on a given sheet formatted as a two digit number. Thus, if there are three vehicles on the sheet they will have V values of 01, 02, 03 respectively.

For instance, if the sheet ID is 280901 and the vehicle is the second one on the sheet, then the vehicle record ID would be 28090102.

The process also involved the assignment of the sheet ID to every vehicle on a given sheet.

The vehicles list included the following additional information:

- Vehicle Type ID: An ID assigned to all the vehicle types. The vehicle types were based on the official vehicle types used by the Ghana Highway Authority (GHA).
- Origin: an ID for the origin of the vehicle. This ID was obtained from the list of Districts in Ghana
- Destination: an ID for the destination of the vehicle. This ID was also obtained from the list of Districts in Ghana
- persNum: The number of passengers on board the vehicle
- seatNum: the number of passengers allowed on the vehicle

Generation of Passenger List

This list contained the responses from the various passengers on board each vehicle.

As in the other cases, the most important feature in the processing was the assignment of a unique ID to each passenger as well as the assignment of the vehicle ID for the vehicle on which these passengers were found.

In most cases, the interviewers interviewed a maximum of three passengers per vehicle.

The unique ID generated for each passenger is in the format (VID)(P).

VID is the vehicle ID from the previous process

P is the passenger's serial number.

For the situation where there are two passengers one would have a P of 1 and the following would have a P of 2 and so on.

For instance, the passengers on vehicle with ID 28090102 would have IDs 280901021 and 280901022 respectively.

Other items in this list include:

- vehicleID: The ID for the vehicle on which this passenger was found
- purpOrigin: This is the trip purpose from the Origin, a numeric value obtained from the list of trip purposes
- purpDest: This is the trip purpose from the Destination, a numeric value obtained from the list of trip purposes
- carsHsld: The number of cars in the household
- transpPrice: The cost of transport
- takeTrain: Whether the passenger would take a train
- maxPriceTrain: The maximum price expected for train

Generation of Freight List

This list contained the details on freight carried by the vehicles.

The first stage was the assignment of the unique IDs to the freight records. The unique ID is formatted as (VID)(F), where

VID is the vehicle ID generated for the vehicles list

F is a serial number for the freight record. On most occasions the vehicles carried only one type of commodity and hence the serial numbers were mostly 1.

The formatting for the freight record was similar to that of the passengers.

Other features in the list are:

- vehRecID: the vehicle record ID
- maxGrossWeight: the maximum gross weight of the vehicle
- comNum: the commodity type ID obtained from the list of commodities
- freightWeight: the weight of the freight
- remarks: for situations where further remarks on the freight was necessary

Building the Access Database

This was done based on a class diagram developed at the outset of the project. Some modifications had to be done as a result of the available data and how best the consultant considered the data could be structured.

As this was the final stage of data processing for the model, stringent measures were employed to ensure that the data would be accurate and also reliable for the analysis.

With built-in checks and data indices, the uniqueness of the IDs generated was checked.

Relationships between tables also helped in the identification of orphaned data in child tables. This ensured that relationships would behave as expected.

Tables were created either directly in Access or via the process of importation of data from Excel.

Most of the tables were created via the importation process.

To ensure data integrity, the lookup tables:

Districts, Zones, CommodityType, TripPurpose, ODDate, Period, VehicleType were created first. These were tested for uniqueness of their respective IDs (primary keys).

The road network data and other related data were then imported, with corrections as and when necessary.

The last set of data imported was the OD Data. The process involved the importation of the sheets, vehicle records, passenger records and freight records respectively.

The OD Data was then linked to the road network database via the section ID in the sections tables.

A diagram below shows the relationship between the various tables in the database.

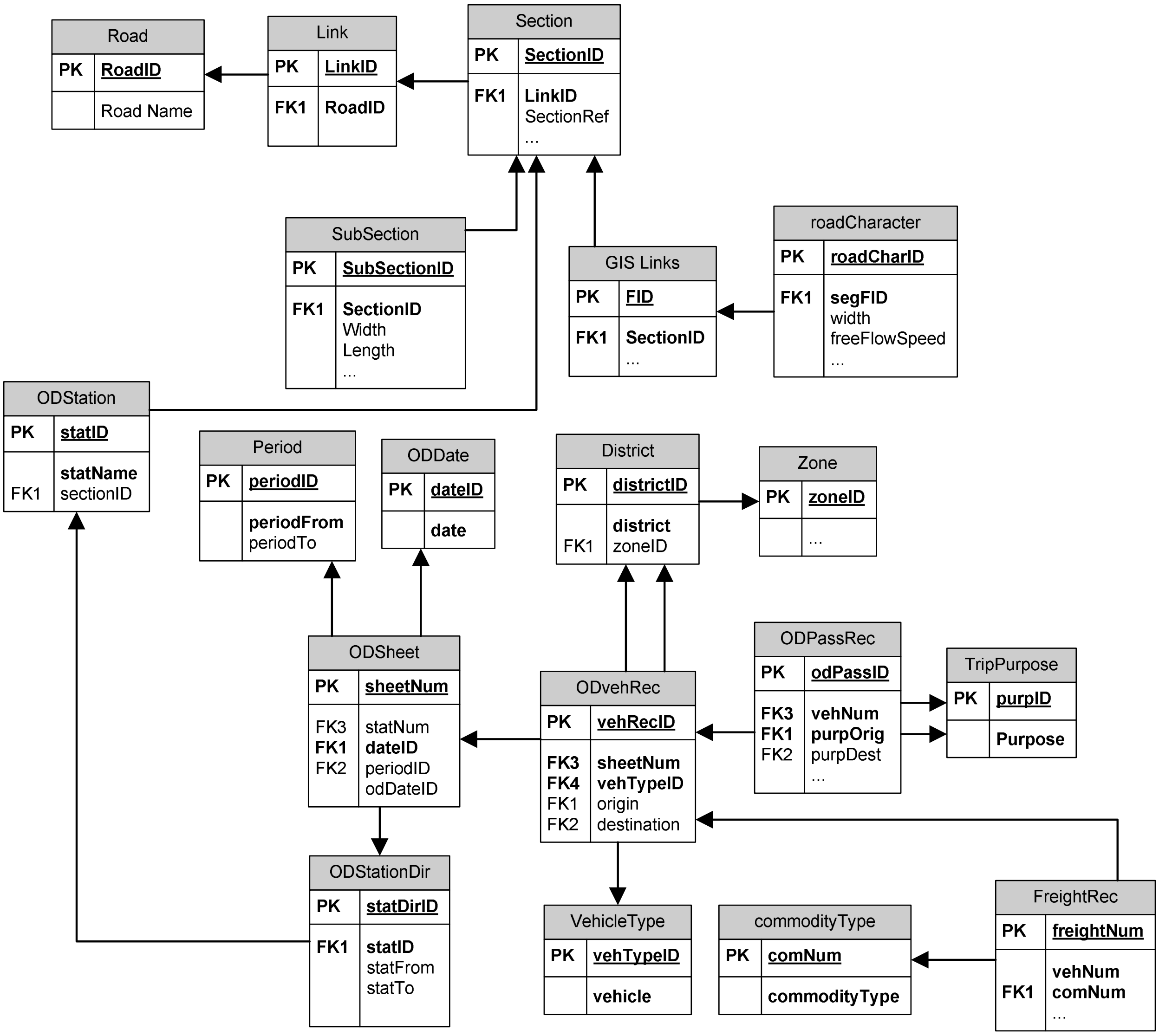


Figure 18 : Database diagram showing the relationship between the variables