LAND USE, TRAFFIC GENERATION AND EMISSIONS IN FORMULATING A SIMPLIFIED APPROACH IN ASSESSING DEVELOPMENT IMPACTS IN RESIDENTIAL AREAS

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ABSTRACT

The relationship between land use planning and traffic generation is internationally recognised. At the same time, the spatial impacts of unlocking land for development in terms of transit orientated development through corridor and nodal development; densification in integrating spatial development in urban context, urban development and regeneration are also evident. It represents implications for spatial systems and the environment in terms of factors such as traffic flows, traffic congestion, noise, emissions and traffic accidents. International research on theory and practical case studies revealed that planning activities are mostly undertaken by professions such as urban and regional planners; transportation engineers and environmental practitioners. Limited multi-disciplinary practices related to integrated land use, transportation, traffic and environmental management plans for residential areas are undertaken with exception of isolated thematically consultation. However, specialisation in integrated research (theory) in focuses such as land use management; transportation and emissions impacts are evident. Development approaches in modelling of such focusses necessitates integration as illustrated in various urban system studies undertaken. Development of applicable decision support systems for residential areas through multi-disciplinary planning will enhance accountability in land use densification and development of new township extensions. Application of improved technology in terms of vehicles will affect levels of emissions/pollution while land use planning is guided by accessibility, density and spatial form and especially in residential areas. In planning and research, the application of key performance indicators through estimated passenger car units per land use category, road classes, densities and estimated pollution impacts are fundamental for resilience and sustainability in spatial planning and quality of living in residential neighbourhoods. The objective of the paper will be to address this interface in residential areas through development of a simplified practical assessment and development approach for initial impact overview informing detailed planning and decision making. It will assist in selecting the best and preferred development scenarios and to guide actions and input by stakeholders affected by planning proposals. It thus precedes formal modelling exercises related to planning (land use), transportation and environmental planning through normal project life cycle integration.
Keywords: development impact overview, environmental management, land use, project life cycle integration, spatial impacts and traffic generation.

1 INTRODUCTION

Waddell [1] states that "*Academic research in integrated land use and transportation modelling is on the rise, in no small part due to growing interest from public agencies that need to improve their capacity to respond to complex policy questions arising in the context of transportation, land use and environmental planning. But the process of taking models developed in an academic research setting, where theoretical validity and the advancement of methodology receive high priority, and moving them into public agency settings in which priorities such as reliability, ease of use and staff capacity to explain to stakeholders what the models are doing, and why, create predictable gaps in understanding and can undermine a project*".

This statement depicts that there is a need to develop a simplified decision support system informing perceived impacts to development in residential areas. Therefore, the current paper will enhance spatial, transportation and environmental planning prior to detailed land use

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and transportation modelling, traffic impact assessments (TIA's) and environmental impact assessments (EIA's) be undertaken for such development. It is not implied that such a tool is to replace detailed land use and transportation modelling and/or detailed spatial analysis.

The paper thus deals with some core components of applicable theoretical founding; land uses; traffic generation and distribution (road network attributes) principles and environmental considerations in developing a simplified approach towards guiding final planning proposals and decision making affecting residential areas.

2 SPATIAL AND URBAN FORM

The city provides access for people, goods, services and information and forms the framework for economic development [2]. The better and more efficient this access, the greater the economic benefits through economies of scale, agglomeration effects and networking advantages. Cities with higher levels of agglomeration tend to have higher gross domestic product per capita and higher levels of productivity. This depends on spatial location, economic potential, market realities and accessibility. Urban form and transportation systems impacts directly on levels of human development and well-being. In this residential areas are fulfilling a meaningful role.

Spatial and urban form reported on in spatial planning theory includes classical location theory; spatial organization theory and regional growth theory [3]. The supportive theories are well assessed and reported on by Schoeman [4] and Dawkins [5]. The theory by Friedman in 1972 represents a multifunctional approach to changes within regional and urban space specifically applicable to developing spatial systems as experienced in developing countries.

Although these theories describe location of urban places and transformation within the spatial systems, urban form is spatially defined in terms of quality of access to and movement between land uses. It includes theoretical urban forms as depicted in the concentric zone model; sector model and/or the multiple nuclei-model as the founding base for resulting urban form. The different urban forms/zones represent different levels of land uses linked and integrated by a road system of different classes and modes of mass transport. The movement systems and spatial adjustments is based on establishment and locational factors underpinned by spatial considerations described and interpreted in the locational, organizational and regional growth theories [3–5].

3 TRANSPORTATION AND MOVEMENT SYTEMS

The following road forms/patterns of streets or road networks commonly serves the broadly defined urban forms (land uses) [6]:

- Rectangular, grid or street block pattern.
- Rectangular street network combined with radial/diagonal streets.
- Concentric and radial street system.
- Rectangular combined with a radial road patterns/system.
- Irregular medieval street system developed based on historic urban form.
- Combination of rectangular and irregular street system depending on urban form.
- Hexagonal street patterns.

Williams [7] points out that urban form consists of the physical characteristics that make up built-up areas, including the shape, size, density and configuration of settlements. It should be considered at different scales: regional, urban, neighbourhood, ‘block’ and street. Urban form within the UK has been shaped since the beginning of human settlement, and is evolving continually in response to social, environmental, economic and technological developments, mediated by policies in numerous sectors. During post-war periods, it reconstruction predominantly included planning, housing and urban policy, as well as health, transport and economic related focuses.

There have been different relationships between the development of urban form and infrastructure over specific timeframes and between sectors. For example, Williams [7] points out that at times, urban form and transport infrastructure has been closely planned (new settlements located near train stations and motorways), while at other times, road building has led to speculative and unplanned developments.

For some infrastructure systems, there has been little influence on urban form or morphology, other than providing services to new developments. For example, water and energy infrastructure is usually planned to service new developments once master plans have been drawn up rather than the infrastructure playing a part in shaping the layout. This observation refers specifically to the spatial dynamics underlying urban land use and transportation integration and especially in promoting resilience and sustainability.

Snellen et al. [8] state that one of the most common goals of current transportation policies in the Western World is to reduce the growth of car use and stimulate the use of public transport. They point out that a variety of economic, transportation and spatial policies have been formulated and implemented in order to achieve this goal. The planning and design of neighbourhoods should, according to them, also play a role. This statement thus relates well to the theme of this paper.

4 RESIDENTIAL NEIGBOURHOOD CONCEPT AND LAYOUT DESIGN

Biddulph [9] states that housing environments take up the majority of developed land in which communities spend long periods of their lives. As such the way that they are designed can enhance the quality of life of its inhabitants. Some spatial layout and designs can make it hard to live our lives the way that we would like. How a neighbourhood is designed and developed, effects the quality of the built environment.

Berk [10] points out that several definitions may be used to describe the physical layout of the residential neighbourhood. He argues that the physical space of the neighbourhood should be viewed in relation to the space within which the residential environment consists of: the private space of the dwelling, collective space of the residential buildings and the public space of the surrounding land.

This should include the movement patterns of goods, services and people serving the residential neighbourhood. According to Burton [11], the following traffic movements affects the quality and functioning of a residential neighbourhood:

- External to external through traffic.
- External to internal traffic (inbound).
- Internal to external (outbound).
- Internal movements of traffic.

In assessing traffic movements, the volumes of traffic per modal split is important. This is applicable to both existing spatial structures and its future or planned development. Various planning instruments exists to articulate and address traffic problems: Spatial Development Frameworks (SDP's); Precinct Plans (PP's); Integrated Transportation Plans (ITP's); Land Use Schemes (LUS); Environmental Impact Assessments (EIA's), etc.

Litman [12] summarises the factors affecting accessibility within urban spatial systems (inclusive of residential areas) as follows:

- Motor vehicle travel conditions: Vehicle travel speeds, affordability and safety.
- Quality of other modes: Walking, cycling, public transit, telecommunication networks, delivery services speeds, convenience, comfort, affordability and safety.
- Transport network connectivity: Density of paths and roadway connections, and therefore the directness of travel between destinations, plus the quality of connections between modes, such as the ease of walking and cycling to public transport stations.
- Land use proximity: Development density and mix, and therefore distances between activities.

Thus in terms of the theme of this paper the following planning components are important (refer to [13]): layout of the neighbourhood; land-use categories; densities; numbers of floors; socio-economic profile; internal and external road layout and standards (classes); private car ownership; access to work places and amenities and availability and affordability of the passenger transportation systems.

Figures 1 and 2 show typical layout of a modern residential neighbourhood. Within a neighbourhood cell, most residential erven are zoned for Residential 1 (single dwellings) and Residential 2 (flats) purposes. The erf sizes are approximately 800 m² with maximum 50% coverage. Flats are approximately 150 m²/unit. Vehicles ownership is assumed at 1.5–2 vehicle units per erf [14,15].

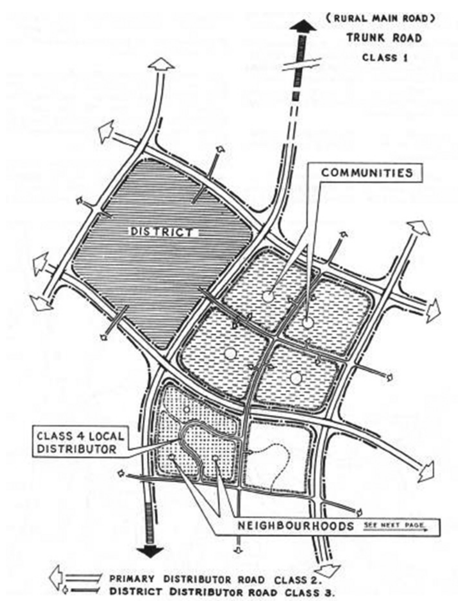

Figure 1: Residential layout with road classes [14].

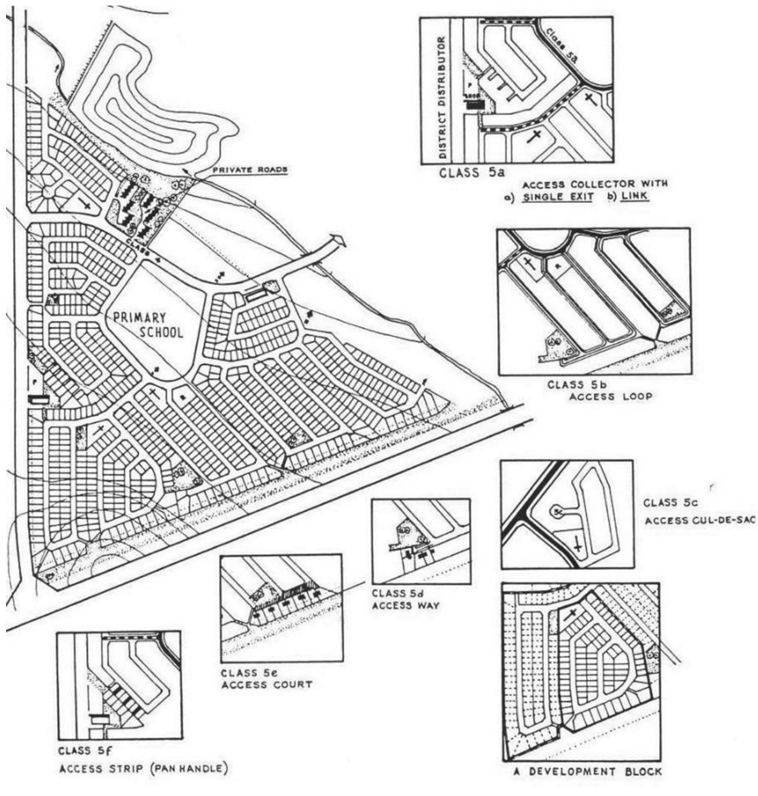

Figure 2: Typical residential neighbourhood components [14].

5 TRANSPORTATION PLANNING PRINCIPLES

Burton [11] states that 'trip making' (traffic generation) is a function of three basic factors:

- The land use characteristics (land zoning) within and adjacent to the study area.
- The socio-economic characteristics of the trip making population.
- The nature, extent and the capacity of the road network.

5.1 Land use and traffic generation principles based on existing knowledge

Tables 1 and 2 show the criteria used in assessing the estimated land use and traffic generation criteria for existing and planned spatial development within residential areas (neighbourhood) developments and planned development adjacent or within the urban structure that will affect the quality of such residential areas. Table 3 depicts the road capacities standards for passenger car units/hour for two-lane roads in residential areas.

Table 1: Peak hour vehicle movements related to residential neighbourhood catchments for the various classes of roadways.

	Function	Local distributor (local bus route)	Residential access road		
			Access collector	Access street	
	From	2-lane single carriageway	2-lane single carriageway	Loop 2-lane or single track way	Other closed street forms
Desirable maximum environmental capacity p.c.u./h (peak h)*		1,500	400	120	60
Number of dwellings at various peak hour generation rates	1 veh/d.u./hr high income	1,500	400	120	60
	0.5 veh/d.u./hr design value	3,000	800	240	120
	0.1 veh/d.u./hr low income	15,000	4,000	1,200	600
Recommended catchments		[1,500 m; 3,000 m]	[400 m; 600 m]	[60 m; 200 m]	≤100 m
Direction		2-way movements	2-way or tidal movements	Tidal movements	Tidal movements
Vehicle composition		All vehicles including buses	All vehicles but buses	Light passenger vehicles and occasional small to medium size service trucks	

* For capacity of higher order roads (primary and district distributors) and mini-bus routes see the Transportation Research Board (TAB) Highway Capacity Manual, 1985, [16]. Refer also to [14,15].

Table 2: Land allocation in residential neighbourhoods Source: [14].

Land use allocation	Area (ha)		% of total	
Residential sites (each 450–500 m²) + 10% for larger corner sites)		90.0		56.3%
Streets (incl. primary roads)		39.0		24.4%
3 crèches (0.17 ha each)	0.5	30.9	0.3%	19.3%
1 secondary school (5.0 ha)	5.0		3.1%	
Religious sites (1 for every 200 d.u.)	1.4		0.9%	
Business sites	3.0		1.8%	
Public open spaces (5,800–6,000 m²/1,000 persons)	6.5		4.1%	
3 lower primary schools (2.5 ha each)	7.5		4.7%	
3 upper primary schools (3.5 ha each)	7.0		4.4%	
		160		100%

Table 3: Road capacities for residential neighbourhoods Source: [14] and [15]. Also refer to [16].

Road conditions: Road capacities of 2-lane roadways with 2-way traffic for Residential Neighbourhoods	Capacity p.c.u.*/h (both direction of flow)		
	Width of roadway between kerb faces		
	6.1 m	6.7 m	7.4 m
All-purpose road, no frontage access, no standing vehicles and little cross traffic	1,200	1,350	1,500
All-purpose road with large capacity junctions and 'no stopping' restrictions. Local distributor falls within this range because of restrictions on fronting access.	800	1,000	1,200
All-purpose road with capacity restricted by junctions, cross-traffic and stationary vehicle	[300;500]	[450;600]	[600;750]

*p.c.u.: passenger car units (Bus: 3 p.c.u.).

5.2 Traffic estimates for various land use classes and trip generation in urban areas (middle income areas)

Table 4 shows the estimated traffic generation per land use classes based on deductions from various TIA and existing knowledge on land use and trip generation rates [13–18]. The interpretation of Table 4 should be assessed with the principles as contained above read in combination with Litman [12,13]. It includes the calculated traffic generation rates for various land uses for three different scenarios of passenger car ownership. All trip generation rates calculations should be expressed in terms of equivalent passenger car units (e.p.c.u.'s). It distinguishes between intra-traffic impacts and inter-traffic movements for land uses based on trip data. It thus covers all traffic movements that are generated from outside and through the residential neighbourhood in terms of origin and destination purposes for all modes of traffic. Intra traffic movements relates to traffic movements within the residential neighbourhood.

6 LAND USE, TRAFFIC GENERATION AND ENVIRONMENTAL IMPACT

Rodriques, Comtois and Slack [19] conclude that the impacts of transportation on the environment are threefold:

- Direct impacts: The immediate consequence of transport activities on the environment where the cause and effect relationship relates to aspects such as noise and carbon monoxide emissions.
- Indirect impacts: This relates to the effects of transport activities on environmental systems.
- Cumulative impacts: Consists of multiplicative or synergetic consequences of transportation activities. It includes the effects of direct and indirect impacts on an ecosystem. Climate change, with complex causes and consequences, forms part of this cumulative impact of several natural and anthropogenic factors, in which transportation is responsible for 15% of global CO_2 emissions through the transport sector.

Condurat et al. [20] state that the continuous increase in the vehicle fleet along with the development of transportation networks (all modes) is associated with a wide range of externalities

Table 4: Calculated trip rates for core land uses in residential neighbourhoods (middle and high income areas) Source: Own construction from selected case studies, 2019.

Land use zoning	Preferred access road classes	Estimated trip rates		
		Private motor-vehicle ownership		
		Low scenario	Medium scenario	High scenario
Intra-traffic movements				
Residential 1 (House)/unit	5	0.50	1.56	2.50
Residential 2 (Flats/unit)	4	0.40	1.21	2.00
Residential 3 (Flats)/unit	4	0.30	0.85	1.50
Residential 4 (Flats)/unit	4	0.40	0.75	1.25
Business 1 (Shops)/100 m² GLA	5	1.00	1.59	2.28
Business 2 (Shops)/100 m² GLA		0.80	1.03	2.50
Churches/seat	5	0.60	0.80	1.50
Schools/student	4	0.40	0.85	1.20
Library/clinics/100 m² GLA	5	0.50	0.97	1.45
Offices/100 m²GLA	4	1.50	2.15	2.85
Service station (fuel)/100 m²GLA	4	2.60	5.75	7.50
Recreational/open spaces/10 ha	5	15.00	40.15	51.80
Inter traffic movements				
Shopping centres/100 m²GLA	4	1.50	2.57	3.45
Shopping malls/100 m²GLA	4	2.50	4.49	5.80
Office parks/100 m² GLA	4	1.75	2.45	3.78
Hospitals/bed	4	1.00	1.78	2.50
Municipal offices/100 m²GLA	4	1.75	2.43	2.40
Restaurant/100 m²GLA	4	2.87	9.41	12.10
Hotel/room		0.45	0.95	1.10
Industrial/100m²GLA	3	0.59	1.11	1.97
Higher education/student	4	0.25	0.85	1.28
Medical doctors/100 m²GLA	4	3.75	7.78	9.1
Central sport facilities/1000 seats	4	85.00	179.19	200.54

*Equivalent passenger car units.

related to greenhouse gas (GHG) emissions. They state that as transportation is considered as a system, it consists of several subsystems that are independent but also interdependent from/on each other, consisting of air, road transport, water transport and underground transport. For the purposes of this paper, the focus will be on road transport only.

The form and shape of a city and distribution pattern of land use affect air quality and includes health impacts [21]. Urban form determines locations of emission sources; where people spend their time; as well as the emission levels by influencing the amount of polluting activities.

Four primary objectives for urban planning are identified:

- To promote efficient provision of urban infrastructure and allocation of land use, thereby contributing to economic growth.
- To manage spatial extension while minimizing infrastructure costs.
- To maintain or improve the quality of the urban environment (including the quality of the housing stock).
- To preserve the natural environment immediately outside the urban area.

Condurat et al. [20] further state that pollution effects from road traffic are extensive due to factors such as atmospheric conditions, topographical conditions, traffic congestion, types of fuel used and the age and poor maintenance of motor vehicles. They indicate that the consequences are reflected in exhaust emissions, fuel leakage on roads, dust and noise pollution. It also includes accidental spillage of toxic chemicals. Such externalities which are expressed in CO_2 emissions lead to ecosystem fragmentation and release into the atmosphere of particular matter. Land use, traffic generation and air quality considerations (consequences) thus needs to be taken into account in the simplified model developed in this paper.

For the estimation of GHG emissions (for the transport sector), the IPCC (2006) use the Tier 1 and Tier 2 approach. The Tier 2 approach uses for CH_4 and N_2O emissions fuel-based emission factors specific to vehicle subcategories [22]. In the 2007 IPCC report [23] the GHG emissions were converted to CO_2 eq. (carbon dioxide equivalent) emissions. Emissions are reported in gigagrams (Gg) (1 Gg = 1,000 tonnes). Scheutz et al. [24] calculated the CO_2 equivalents for methane CH_4 and nitrous oxide N_2O as 25 CH_4 = 1 CO_2 and 298 N_4O = 1 CO_2. Tongwane et al. [25] used data (obtained from RTMC [26]) on the number of vehicles by vehicle type, distance travelled, Tier 2 approach and equation (1) to determine South African's [2002–2009] emissions from road transport (in terms of Carbon dioxide equivalents).

$$CO_2 = \sum S_{a,b} * D_{a,b} * FE_{a,b} * NCV_{a,b} * CEF_{a,b} * 10-3\left(1-CS_{a,b}\right) * FCO_{a,b} * \frac{44}{12} \quad (1)$$

where S = # of vehicles, a = fuel type and b = vehicle type; distance (km); FE = fuel efficiency rates (L/km); NCV = net calorific value of the fuel (MJ/L); CEF = carbon emission factor (kg/MJ); CS = carbon stored; FCO = fraction of carbon oxidized. The authors [25] calculate that in South Africa (developing country) the road transport emissions increased by approximately 2.6% per annum between 2000 and 2009. Table 5 shows the estimated emissions (CO_2-eq (Gg)) from the traffic volumes (e.p.c.u.'s). (Note that the combined contribution to road emissions in South Africa (SA) by motor cars and HDVs were approximately 70% in 2009).

Example: To determine a new (middle income) high scenario neighbourhood, the emission impact (of intra traffic movements) under the following land use assumptions:

- Residential 1 units and access road class 5: 150 units (375 e.p.c.u.'s ⇒ Road emissions = 1.26 CO_2 eq. Gg)
- Residential 2 units and access road class 4: 30 units (60 e.p.c.u.'s ⇒ Road emissions = 0.2 CO_2 eq. Gg)
- Business 1 shop of 1,800 m² (182 e.p.c.u.'s => Road emissions = 0.61 CO_2 eq. Gg).

Table 5: Estimated emissions per passenger car units Source: Own construction from RTMC [25] and Tongwane et al. [26].

	Equivalents	EPCU's	Road transport CO_2-eq (Gg) emissions in 2009 (source: [23])	Emissions (CO_2-eq gigagrams) per e.p.c.u.'s
Motor cars	1	5,411,093	18,135.2	3.35E-03
Mini-busses	1	282,941	2,408.6	8.51E-03
Busses	3	135,651	1,826.5	1.35E-02
Motor cycles	0.75	271,800	227.3	8.36E-04
LDV	1	1,946,292	8,353	4.29E-03
HDV	3	964,812	12,838.1	1.33E-02
Other	2.5	576,210	100.9	1.75E-04
Total	12.25	9,588,799	43,890	4.39E-02

The content of Tables 4 and 5 may be used to calculate the emissions from land uses.

For the estimation of road transport emissions in terms of carbon dioxide grams per kilometre (CO_2 g/km), the 1996 IPCC Guidelines [27] are considered for the following values:

- US light- and heavy-duty methanol vehicles: 183 g/km;
- Motor cars/mini-busses ε [178 g/km; 213 g/km];
- Motor cycles ε [51.17 g/km; 78.61 g/km].

The calculated South African (developing country) national emissions in terms of carbon dioxide equivalents (CO_2-eq g/km) from the 2009 RTMC [26] data and emissions [28] are as follows:

- LDV and HDV = 423.88 g/km,
- Motor cars and mini-busses = 682.44 g/km, (high usage of mode figure due to lack of public transport)
- Motor cycles = 42 g/km.

7 DEVELOPMENT OF A SIMPLIFIED PRE-ASSESSMENT OVERVIEW BEFORE SUBMISSION OF STATUTORY PLANNING APPLICATION.

From the content and the line of reasoning of the paper, the conclusion may be drawn that due to the interface between land use, traffic generation and emission impacts, statutory planning legislation should make provision for a Pre-Submission Overview for land development impacts in residential neighbourhoods inclusive of the following minimum requirements:

7.1 Assessment of spatial status quo:

The status quo traffic generation and distribution impact within residential neighbourhoods is the product of the total sum of the following core spatial development considerations [5,11,14] as represented by the original layout and design considerations:

- Urban spatial structure layout and design (Figs. 1 and 2) [14,15];
- Land uses and its distribution within the spatial system (Tables 1 and 2);
- Road network classes serving the spatial system and the geometric and structural road network design (Table 3);
- Estimated trip rates for land uses (Table 4)*.

(* = Refer to [28]. Road capacity data as used is based on calculated numbers as included in the different tables and not on annual average daily traffic values (AADTs) surveyed).

7.2 Assessment of the new (add-on) development impact (inclusive of densification; redevelopment, rezoning, etc.)

The impact of new development proposals should consist of an elementary assessment (quantitatively and qualitatively) of the following factors:

- Trip origin and destination factors.
- New land uses and areas (ha or m^2).
- Traffic generation characteristics and road network distribution impacts.
- Modal split in terms of morning, midday and afternoon peak hour traffic (motorised and non-motorised traffic) for trip types within traffic cordon demarcated.
- Heavy goods transport and impact on traffic flow and residential quality.
- Daily trip generation types and trip length.
- Estimation of equivalent passenger car units.
- Impact on vehicle ownership characteristics.
- Modal choice and alternative transit accessibility.
- Reduction and related impact factors.
- Environmental impact through emissions generated (Table 5).

Abovementioned factors as calculated, analysed and motivated in terms of the existing and approved planning instruments such as the Spatial Development Framework (SDF); Precinct Planning (PP); Integrated Transport Plan (ITP); Environmental Management Plan (EMP); Land Use Scheme (LUS) should be included in a Pre-Submission Reviews before formal submission of any formal Statutory Development Application (SDA).

8 CONCLUSIONS

The quality of residential neighbourhoods within developing countries are negatively being impacted upon due to the fact that the dynamics and specific sensitivities of residential areas are not always attended to effectively due to the fact that that the rules applicable for other land use zones also applies to the areas where families need to be protected from inter traffic volumes; traffic accidents; noise pollution and health impacts due to emissions from motor vehicles. The paper represents and endeavour to address such issues by rethinking and assessing the existing statutory planning processes and thus motivating the need for introduction of Pre-Submissions Reviews to be formulated as to broaden public participation by all stakeholders before the formal submission of Statutory Development Planning Applications that is dominated by speculative focuses city wide to the detriment of inhabitants in residential neighbourhoods.

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