Rik Arends

RAPID ASSESSMENT OF TRANSPORT EMISSIONS IN DEVELOPING ASIAN CITIES

Requirements of a sketch-planning tool and evaluation of the model RACE

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CLEAN AIR ASIA

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“Slow and steady wins the RACE”

(Associated with Aesop's fable of “The Tortoise and the Hare.”)

PREFACE

Travelling is something amazing, you can explore something new every day; in particular in urban areas as they combine all kind of activities and transport modes. You can go by foot, car, train, jeepney, bus, metro, or by bike. Each has its own advantages and disadvantages. Each is amazing to use, over and over again.

Human settlements exist already for thousands of years. Currently more people are living within an urban area than in rural areas. The need for transportation is also of all times. And due to the development of the combustion engine we are able to move a lot faster between and within the cities with all economic and social advantages. But this has an environmental down side, currently we emit way more greenhouse gases than the Earths system can manage.

I am fascinated by this constant movement of people, but I'm also most concerned with the impact transport has. This thesis is providing a starting point on how cities can develop more environmental sustainable. Therefore I hope that it will be used to improve the model RACE and it will encourage others to improve urban land use planning to reduce transport emissions.

I was able to study my fascination for mobility and environment with pleasure at the University of Twente and Lund University. I would not have written this thesis without the support by numerous friends.

I would like to thank my supervisors of the University of Twente. Mark Zuidgeest, you guided me throughout this thesis with a constant positivism, which made it more enjoyable to work on this thesis. Your valuable and positive comments were of great help. Karst Geurs, thank you for providing every time the critical note to ensure that I was motivated to improve this thesis. Your comments have provided significant improvements to this thesis.

Bert and Alvin, you have welcomed me at Clean Air Asia. The trips to all different cities showed me a little bit of the world of advocating sustainable urban development. Thank you for taking me along, I will remember all of them, in particular the travelling to Bangkok. Together with Sudhir, the three of you provided valuable insights and critical side notes on the assessment of RACE, thank you for this support.

Besides the work I conducted at Clean Air Asia we tried to visit all restaurant in Robinsons Galeria in Ortigas. Chee-Anne, Kaye, May, Gaile, Cathy, Jerey, Jaja, Glynda, Art, Iris, and Sophie. I have enjoyed every lunch and every trip. I am still looking for a good Filipino restaurant in the Netherlands.

The numerous dinners, drinks and beaches of the Philippines I would never have explored alone, Flavje, Roy, Evelien, Anita, Roxi, Nellie, Yumi, Florence, you guys showed me the Philippines from a different side and made my time in the Philippines very memorable.

At ITC, in the explorative research group as we called ourselves, we discussed the problems of our thesis many times, but we also provided good reasons for procrastinating by playing pictionary or learning how to juggle. Thank you Peter, Judith and Priya!

Back in the Netherlands I was welcomed back (again) in 't Koetshuys. As they say: there is no place like home. Every roommate of the past years, thank you. It was amazing and I guess I will hope to come back each time in Enschede. In particular I would like to thank Judith for the numerous talks at the Koetshuys table, at ITC, or for a drink in 't Bolwerk. You supported me throughout this thesis and made my time in 't Koetshuys much more fun. Thank you for your friendship,

Special thanks goes to my parents and Mirjam, you supported me always and unconditional to which I am deeply grateful.

Finally I would like to thank Kivi Niria and the EFL Stichting for financially supporting this thesis.

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SUMMARY

Asian cities are growing rapidly with approximately 120,000 people a day and the earth's climate system is changing due to the copious amounts of emitted greenhouse gases. To mitigate climate change it is important to reduce the impact of the city on the natural environment. In particular reducing transport emissions is essential in mitigating climate change. Sustainable urban development can reduce transport emissions. Models can provide insights in these developments and show how policies can reduce emissions.

The first objective of this research is to determine what the requirements are for a sketch-planning tool that models from land-use transport emissions. This results in a descriptive evaluation framework. The second objective is to assess the model RACE (Rapid Assessment of City Emissions) and provide an overview of the strengths and weaknesses of this model, by using the evaluation framework.

The RACE model is developed by *Clean Air Asia* to provide insights in transport emissions caused by urban development. It creates 'what-if' scenarios to show how transport emissions could develop over a 20-year period. RACE uses GIS mapping for scenario development and a spreadsheet to calculate transport volume and emissions.

To determine the requirements of a sketch-planning tool the conceptual framework of Kolkman (2005) is used. The framework distinguishes two cycles in model development: 1. The problem solving cycle, which looks into the context in which a model has to operate; this is applied to the problems of land use planning in developing Asian cities. 2. The model development cycle, which interprets the knowledge of real world phenomena in a model; this is applied to modeling land-use transport emissions in developing Asian cities. The problem solving cycle is researched by conducting interviews and literature review regarding the policy process of land use planning in developing Asian cities. The model development cycle is researched by a literature review of land use transport emissions modeling. In addition to these two modelling cycles, Kolkman acknowledges the importance of the end-user. This concept is used to determine the role of and requirements from end-users in land use planning.

The determined requirements of a sketch-planning tool resulted in an evaluation framework of ten criteria and identified two important end-users: local policymakers and development agencies. The ten criteria describe on the one hand how the model can be useful in the context of land use planning in developing Asian cities, according to the limitations and requirements of the different end-users. On the other hand describes how the model can be theoretically sound by showing how a model can be advanced. A model is useful if it is (1) cognizant of the drivers of urban planning, (2) used at a strategic planning level, (3) easy to use and understandable, (4) adaptable and flexible to the local situation, (5) the cost of implementation are minimal, and (6) complete and comprehensive. A model is theoretical sound if it (7) correctly models the relationship between land use and transport, (8) correctly models the relationship between transport and emissions, (9) is empirically and behaviorally valid and (10) is consistent.

RACE is assessed by applying the ten criteria of the evaluation framework. Insights in RACE are gained by conducting the analytical tests of Forrester and Senger (1980) and complemented by interviews with its developers, end-users, and stakeholders.

It is concluded that RACE is a tool that is potentially useful for many developing Asian cities. It is cognizant of the drivers of urban planning in the cities in which it is currently implemented and is providing long-term strategic policy options. It is, however, heavily reliant on costly and slow-to-develop GIS maps which also severely limits it as a sketch-planning tool. RACE has incorporated both important end-users. From the perspective of local policymakers, RACE shows how their city will develop in 20-years time, but it falls short to identify local projects or problems. For the development agencies, RACE can provide an indicative citywide assessment of transport emissions. The feedback link between land use and transport is not complete. The transport calculations are very aggregate, it omits the transport network and the modal split is an input variable. The emissions calculations are aggregate but correct. In addition, the direction of policy implications is not always correct. Comparison to other cities is difficult due to the large variation in local circumstances and limited options for validation.

Regarding the evaluation framework and RACE several recommendations are made. It is recommended to determine which criteria of the evaluation framework are more important and whether or not they are generalizable. The land use policy process in developing Asian cities should be researched in greater detail to understand the policy process better and to improve the usefulness of a model. Regarding RACE the main recommendations are to: validate the results; improve the connections between the GIS maps and the spreadsheet; improve the flexibility and adaptability to different input variables; improve the transport calculations; and model the directions and magnitude of change due to different policies correctly.

SAMENVATTING

Aziatische steden groeien met ongeveer 120.000 personen per dag en het klimaat verandert door de uitstoot van grote hoeveelheden broeikasgassen. Om klimaatverandering te verminderen is het van belang om de invloed van steden op de natuurlijke omgeving te beperken. Voornamelijk het verminderen van transportemissies is essentieel om klimaatverandering tegen te gaan. Duurzame stadsontwikkeling kan transportemissies verminderen. Modellen kunnen inzicht geven in deze ontwikkelingen en laten zien hoe beleid de uitstoot kan verminderen.

Het eerste doel van dit onderzoek is het bepalen van de eisen aan een sketch-planning tool die op basis van landgebruik transportemissies modelleert. Dit resulteert in een beschrijvend evaluatiekader. Daarnaast is het doel het model RACE (Rapid Assessment of City Emissions) te beoordelen en een overzicht te geven van de sterke en zwakke punten van dit model door gebruik te maken van het evaluatiekader.

Het RACE-model is ontwikkeld door *Clean Air Asia* om inzicht te bieden in transportemissies veroorzaakt door stadsontwikkeling. Het model laat door middel van 'wat als' scenario's zien hoe emissies van transport zich in twintig jaar kunnen ontwikkelen. RACE gebruikt GIS-kaarten voor scenario-ontwikkeling en een spreadsheet om transportvolume en transportemissie te berekenen.

Om de eisen van een sketch-planning tool te bepalen is het conceptuele kader van Kolkman (2005) gebruikt. Het kader onderscheidt twee cycli in modelontwikkeling: 1. De probleemoplossingscyclus, die kijkt naar de context waarbinnen het model dient te werken; dit is toegepast op de problemen van het plannen van gebiedsontwikkeling in Aziatische ontwikkelingssteden. 2. De modelontwikkelingscyclus, die vertaalt de werkelijkheid naar een model; dit is toegepast op het modelleren van transportemissies in Aziatische ontwikkelingssteden op basis van landgebruik. De probleemoplossingscyclus is onderzocht door middel van interviews en literatuuronderzoek naar het ruimtelijke inrichtingsbeleid in Aziatische ontwikkelingssteden. De modelontwikkelingscyclus is onderzocht door middel van literatuuronderzoek naar landgebruik-transport-emissie-modellering. Naast de twee ontwikkelingscycli,

beschrijft Kolkman het belang van de gebruiker in model ontwikkeling. Dit is gebruikt om de rol en de behoeften van de gebruikers in ruimtelijke inrichting te bepalen.

De vastgestelde eisen van een sketch-planning tool hebben geleid tot een evaluatiekader van tien criteria en de identificatie van twee gebruikers: de lokale beleidsmaker en de ontwikkelingsorganisaties. De tien criteria beschrijven enerzijds hoe een model bruikbaar kan zijn in de context van ruimtelijke inrichting in Aziatische ontwikkelingssteden, rekening houdend met de beperkingen en behoeften van de verschillende gebruikers. Anderzijds beschrijven dezen wanneer een model theoretisch correct is door te laten zien hoe een model kan worden doorontwikkeld. Een model is bruikbaar als het (1) bewust is van de drijfveren van stadsonwikkeling, (2) gebruikt wordt op een strategisch planningsniveau, (3) hanteerbaar en begrijpelijk is, (4) toepasbaar is op en flexibel is voor de lokale situatie, (5) de kosten van implementatie minimaal zijn en (6) compleet en volledig is. Een model is theoretisch correct als het (7) correct de relatie tussen landgebruik en transport modelleert, (8) correct de relatie tussen transport en emissies modelleert, (9) empirisch en conceptueel valide is en (10) consistent is.

RACE is beoordeeld door het toepassen van de tien criteria van het evaluatiekader. Inzichten in RACE zijn verkregen door het uitvoeren van de analytische testen van Forrester en Senger (1980) en aangevuld met interviews met de ontwikkelaars, gebruikers en stakeholders.

Het is geconcludeerd dat RACE een tool is die potentieel bruikbaar is voor vele Aziatische ontwikkelingssteden. RACE is bewust van de drijfveren van stadsontwikkeling in de steden waarin het is geïmplementeerd en het geeft strategische lange-termijnbeleidsmaatregelen. Het leunt daarentegen sterk op de dure en trage ontwikkeling van GIS kaarten waardoor het sterk beperkt is als sketch-planning tool. RACE omvat beide belangrijke gebruikers; vanuit het perspectief van de lokale beleidsmaker kan RACE laten zien hoe de stad zou kunnen ontwikkelen in de komende 20 jaar. Het schiet echter tekort in het identificeren van lokale projecten en problemen. Vanuit het perspectief van de ontwikkelingsorganisaties kan RACE een indicatieve beoordeling geven van de totale uitstoot van transportemissies voor de gehele stad. De feedbackloop tussen landgebruik en transport is niet volledig. De transportberekeningen zijn sterk geaggregeerd, het verkeersnet ontbreekt en de verdeling over de modaliteiten is exogeen van het model. De emissieberekeningen zijn ook sterk geaggregeerd maar correct. Daarnaast reageert het model niet altijd zoals te verwachten is bij verschillende beleidsmaatregelen. Een vergelijking met andere steden is moeilijk vanwege de grote veranderingen in lokale omstandigheden en de beperkte mogelijkheden voor validatie.

Met betrekking tot het evaluatiekader en het model RACE zijn verschillende aanbevelingen gedaan. Het wordt aangeraden om te bepalen welke criteria van het evaluatiekader belangrijker zijn en of ze te generaliseren zijn. Het beleidsproces van ruimtelijke inrichting van Aziatische ontwikkelingssteden moet verder worden onderzocht om het beleidsproces beter te begrijpen en het model bruikbaarder te maken. De hoofdaanbevelingen voor het RACE model zijn: het valideren van de resultaten, het verbeteren van de link tussen de GIS kaarten en de spreadsheet, het verbeteren van de flexibiliteit en toepasbaarheid van het model voor verschillende inputparameters, het verbeteren van de transportberekeningen in het model en het correct modelleren van de richting en grootte als gevolg van beleidsveranderingen

TABLE OF CONTENTS

PREFACE I

SUMMARY III

SAMENVATTING V

1 INTRODUCTION 1

1.1 Research question 2
1.2 Methodology 2
1.3 Scope 3
1.4 Reading guide 5

2 SKETCH-PLANNING FOR LAND USE TRANSPORT EMISSIONS 7

2.1 Asian cities and emissions 8
2.2 Transport emissions 8
2.3 Strategic land-use planning & Planning Support Systems 10
2.3.1 Land-use planning 10
2.3.2 Planning Support Systems 11
2.3.3 Requirements of PSS 12

2.4 Model development and evaluation 13
2.5 General requirements from model development 13
2.6 Modeling Transport Emissions 15
2.6.1 Conceptualization 15
2.6.2 Modeling transport emissions 15
2.6.3 Critique and requirements 17

2.7 Modeling Land use and Transport 17

2.7.1 Conceptualization 17
2.7.2 Theoretical and empirical relationships 19
2.7.3 Land-use transport models 21
2.7.4 Critique and requirements 22

3 EVALUATION FRAMEWORK 25

3.1 Land-use planning in developing Asian cities 25
3.1.1 Problems 25
3.1.2 Stakeholders 26
3.1.3 Conclusions 27

3.2 Modeling land-use transport emissions 28
3.3 Requirements for a Sketch-planning Land-use transport emissions model 30

4 ASSESSMENT: RAPID ASSESSMENT OF CITY EMISSIONS TOOL 33

4.1 Description of RACE 34
4.1.1 Objective of RACE 34
4.1.2 Methodology of RACE 34

4.2 Usable 35
4.2.1 Cognizant of the drivers of urban planning 35
4.2.2 Strategic planning level 37
4.2.3 Easy to use and understandable 40
4.2.4 Adaptable and flexible 41
4.2.5 Cost of implementation 42
4.2.6 Complete and comprehensive 43

4.3 Theoretically sound 44
4.3.1 Modeling land use and transport 44
4.3.2 Modeling transport emissions 46
4.3.3 Empirically and behaviorally valid 47
4.3.4 Consistent 47

4.4 Overview of results 49

5 DISCUSSION 51

5.1 The evaluation framework 51
5.2 The criteria of the evaluation framework 52
5.3 Discussion of RACE 53

6 CONCLUSIONS AND RECOMMENDATIONS 55

6.1 Requirements for Sketch-Planning 55
6.2 Assessment of RACE 56

6.3 **Recommendations** ... 57

7 REFERENCES ... 61

APPENDICES ... 67

Appendix A. Evaluation framework ... 67

A.1 Usable ... 67

A.2 Theoretically sound ... 68

Appendix B. Detailed description of RACE ... 71

B.1 RACE in formula ... 71

B.2 Outcomes ... 73

B.3 Calculation flow ... 74

B.4 Sensitivity tests ... 75

B.5 Calculation errors ... 75

LIST OF FIGURES

Figure 1. The gap between scientists, stakeholders and decision makers and how a model can help (Kolkman, 2005) ... 2

Figure 2. Conceptual model of the relationship between context, model, and knowledge (adapted from Kolkman, Kok, and van der Veen (2005)) ... 3

Figure 3. Research design ... 3

Figure 4. Research scope ... 4

Figure 5. ASIF2 framework with the PREIT instruments (Dalkmann & Brannigan, 2007) ... 9

Figure 6. Four realms of change in land-use planning (Couclelis, 2005) ... 11

Figure 7. The dilemma of model development and the knowledge gained by the model (Lee, 1973). 12

Figure 8. Levels of conceptualization and implementation of the natural system (Dee, 1995) ... 13

Figure 9. Interactions of pollutants in atmosphere (Ho, Golay, & Clappier, 2010) ... 15

Figure 10. Example of a bus in India, showing the difficulty of determining the emissions per passenger per kilometer (photo: Singh, 2010) ... 17

Figure 11. Supply demand relationship (Hensher & Button, 2000) ... 18

Figure 12. Land-use transport interaction (Wegener & Fürst, 1999) ... 18

Figure 13. Chronological development of Land use and Transportation models (Iacono et al., 2008) 21

Figure 14. Classification of possible model directions, from simple to advanced models in the categories Land Use, Transport, and Emissions ... 29

Figure 15. Outline of RACE process (Clean Air Asia & Chreod Ltd., 2012) ... 34

Figure 16. Calculation steps of the transport volume and respective emissions ... 36

Figure 17. Sensitivity of the outcome variables of RACE, considering a 10% increase of the input variable ... 37

Figure 18. Factors explaining the difference between the BAU and the LCR scenario ... 38

Figure 19. Draft results of Colombo, left: comparison between the three scenarios, right: the number of motorized trips per day per cell in the baseline scenario (Clean Air Asia & Chreod Ltd., 2012).... 39
Figure 20. Digitized land use maps converted to the 500x500m grid cell..43
Figure 21. Land-use transport feedback cycle as implemented by RACE 44
Figure 22. Flow of calculation of RACE 74

LIST OF TABLES

Table 1. Relationship between land use/urban form and transport (adapted from Wegener and Fürst (1999) 19
Table 2. Elasticities from VMT, Walking and Transit use with respect to the built-environment variables (Ewing & Cervero, 2010).. 19
Table 3. Potential impacts of compact city policy (OECD, 2012) 20
Table 4. Overview of requirements for a transport model and a land-use transport interaction model according to Supernak (1983), Miller et al. (1998), and Waddell (2011) respectively........................23
Table 5. Comparison of local policymakers and development agencies.. 28
Table 6. Comparison of modeling requirements to existing model types....................................... 30
Table 7. Descriptive evaluation framework, with satisfactory defined as the 'core' of a sketch-planning tool, weak if it has major deficiencies and excellent if it adds aspects to the model which are not necessarily required but improve the quality of the tool.. 31
Table 8. Output variables of RACE..40
Table 9. Comparison of the possibilities of local policymakers, development agencies to RACE....41
Table 10. Input requirements for RACE 42
Table 11. Comparison of direction of results between theoretical expected influence and RACE....48
Table 12. Overview of the results of the evaluation of RACE...49
Table 13. Outcomes of RACE 73

1 INTRODUCTION

Greenhouse gas emissions need to be reduced to avoid a 4°C warming of the earth's climate by 2100. The impacts of the climate change will hit harder in developing countries as they have less ability to adapt and cope with the impacts due to lesser economic, institutional, scientific, and technical capacity (World Bank, 2012). Transport is currently contributing already 25% of the world greenhouse gases and this is expected to rise in future years (IEA, 2012). To achieve a maximum of 2°C warming of the earth's climate – the goal of the UNFCCC (2011) – the transport sector needs to contribute 19% of all emission reduction (IEA, 2012). Therefore reducing transport emissions is essential.

It is expected that more than half of the population in Asia will live in urban areas by 2020 (United Nations, 2012). The urban population growth poses a huge challenge on urban planning. It requires the (re)development of large areas of land use to accommodate new housing, employment, and commercial activities. The increase in urban population, in combination with economic growth, will have a big impact on the transport volume and transport size, hence on greenhouse gas emissions.

The urban system is highly complex and encompasses many facets (Te Brömmelstroet, 2010b). Urban planning is trying to intervene and plan the urban system. However, this is a daunting task and requires knowledge of nearly every discipline (Couclelis, 2005). Planning support systems could help and assist planners in spatial strategy making (i.e. urban planning) by integrating knowledge from different disciplines and different types of knowledge (e.g. beliefs, expert judgment, model outcomes, etc.). The question remains *how* to integrate the different knowledge from different fields into the strategy-planning process of developers. Most instruments developed earlier focused on providing technical solutions by developing advanced models which provide systematized, scientific, results and forgot about the context in which the instrument is used (Te Brömmelstroet, 2010b).

A common effort in modeling the urban system is the integration of transport and land use as is widely assumed that integration of these two pillars could lead to a more sustainable urban form (Banister, 2005). Land use and transport are mutually influencing each other (Crane, 2000; Wegener & Fürst, 1999) and a better planning of land use and transport could reduce the need for motorized travel, pollution, risk, etc. (Banister, 2005; Dalkmann & Brannigan, 2007; Grazi & van den Bergh, 2008; Tiwari, Cervero, & Schipper, 2011).

Modeling of land use-transport interaction has resulted in some highly complex models with many dependencies and requiring large amount of data, the so called Large Scale Urban Models (LSUM) (Iacono, Levinson, & El-Geneidy, 2008). These models, however, failed to live up to its expectations and being used in policy planning context (Lee, 1973, 1994)

Clean Air Asia has developed a strategic land-use transport emissions planning tool, called RACE: Rapid Assessment of City Emissions. RACE can calculate the volume of travel from land use at a disaggregated level and can estimate the total amount of emissions from transport. It is developed to be a quick-scan model for developing Asian cities to show the impact of urban land use on transport emissions. The tool is applied in three cities: Ahmedabad, India; Colombo, Sri Lanka; and Ho Chi Minh City, Vietnam (Clean Air Asia & Chreod Ltd., 2012).

1.1 RESEARCH QUESTION

The urban growth of developing Asian cities requires complex urban planning, while the earth's climate system is requiring a significant reduction in greenhouse gas emissions. Sustainable urban planning is therefore a daunting task. RACE epitomize these developments, it is however unclear how RACE performs in this. Investigating this is synthesized by the following central research questions:

> *What are the requirements of a sketch-planning tool for land use – transport – emissions in the context of developing Asian cities?*
>
> *What is the quality and usefulness of RACE as a sketch-planning tool for transport emissions for developing Asian cities?*

Defining the **requirements** of a sketch-planning tool is the first objective and will result in an evaluation framework. It consists of the theoretical requirements from sketch-planning, exemplified by e.g. planning support systems, but also by defining the context in which the model has to operate. Secondly, it will describe the requirements of land-use transport emissions tool, by reviewing the current system knowledge of land-use transport emissions modeling. There is a trade-off between these two aspects. This will also be discussed.

RACE is the tool under review. RACE is a sketch-planning tool to estimate transport emissions based on current and future land use. **Usefulness** reflects the needs and requirements of a sketch-planning tool in urban strategy making in Asian cities. It is defined as the degree to which the tool meets the requirements of the end-users. **Quality** reflects the need for a scientific valid model. Many scientific studies are conducted to the empirical and theoretical relationship between land use, transport, and emissions. These relationships are also modeled in various models. Quality is defined as the extent to which RACE models the empirically known relationships between land use, transport and emissions correctly and the extent to which it is applicable in the context of developing Asian cities. This will result in a comprehensive analysis of RACE, including the current range of application suitable for RACE for different end-users, and suggestions for improvement.

1.2 METHODOLOGY

Models can transfer knowledge between decision makers and experts (Kolkman, 2005). The transfer in knowledge creates an area of tension due to the different frames and perceptions of the expert and non-expert (Wynne, 1991). A model can reduce the gap between the different stakeholders, decision makers, and scientists. This is schematically shown in figure 1.

Many attempts have been taken to develop planning support models, however many models fail to be used as the model developers are not able to 'sell' there model results to the decision makers. The results are not believed or not providing the required knowledge for the problem at hand (Kolkman, 2005; Rogers & Fiering, 1986). The contribution of a model should be to provide insights, not predictions (Brunner, 1996).

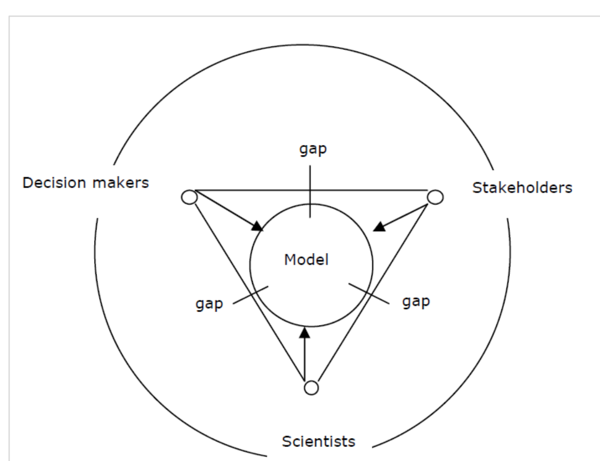


Figure 1. The gap between scientists, stakeholders and decision makers and how a model can help (Kolkman, 2005)

This research is assessing the development of a model from two sides. On the one hand the scientific modeling approach, which has developed very advanced and detailed models with the most detailed knowledge about land use, transport, emissions, and air quality. On the other hand, the gap between stakeholders and decision makers is evaluated by analyzing the policy process of land-use planning and what role models can play; this incorporates the analysis of the stakeholders that are involved in land-use planning.

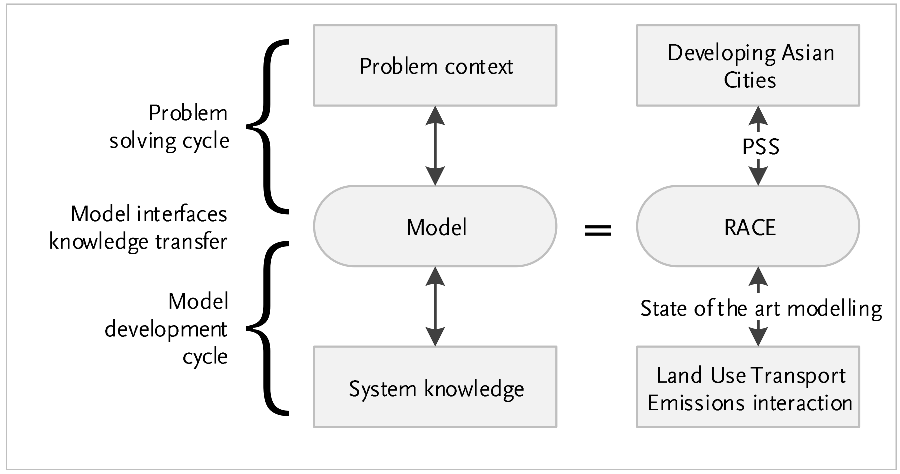


Figure 2. Conceptual model of the relationship between context, model, and knowledge (adapted from Kolkman, Kok, and van der Veen (2005))

This is also shown in the framework of Kolkman (2005), which explains the relationship between the problem context, the model, and system knowledge (Figure 2). Two cycles are taking place: The problem solving cycle is assessed with the question whether and how a model is solving the problems at hand. The model development cycle is interpreting the knowledge of real world phenomena in a model (Kolkman, 2005). Both cycles will be evaluated.

These two perspectives on a sketch-planning for land-use transport emissions will result in a detailed evaluation framework with requirements for a model that wants to assist developing Asian cities in planning there cities by modeling transport emissions. To develop the evaluation framework a literature review is conducted to understand the system knowledge about land-use transport emissions. This is complemented by two city workshops, a seminar about long-term action plan for low emission transport in ASEAN, and various interviews with stakeholders (e.g. ADB, CDIA, Clean Air Asia, and cities). These are also used to understand the local policy situations and problem context of urban planning in developing Asian cities.

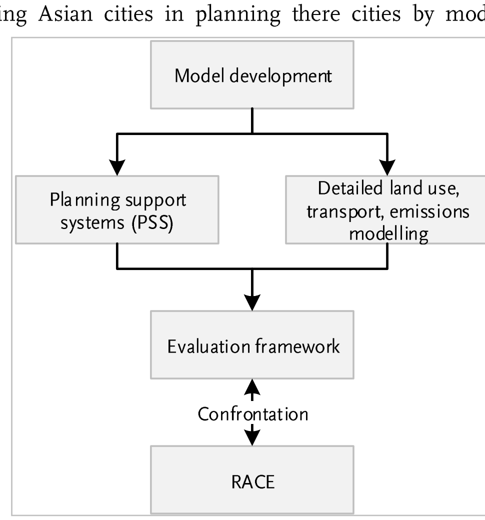


Figure 3. Research design

The evaluation framework provides criteria and requirements for a sketch-planning tool, and enables answering the second research question: the assessment of RACE. The assessment of RACE is conducted by an in-depth analysis of RACE, using the tests described by Forrester and Senger (1980), complemented by interviews with the end-users and developers.

1.3 SCOPE

Setting requirements for a model can be very detailed, up to the most detailed level prescribing certain methodologies and quantifying the required uncertainty and precision. This research provides rather guidelines and a preliminary framework with requirements for a sketch-planning tool, but does not specify the maximum uncertainty allowed or the need to quantify. It shows model directions and options for development, while any developer can strike the balance differently.

In model development various steps are undertaken, see Figure 4. This research will review the steps 1 to 5, from problem analysis to verification. Therefore, the evaluation framework will provide guidelines up to the level of conceptual model, model structure, and the implementation process so verification is possible. Calibration and validation is not part of this research, this would involve the detailed comparison and fitting of a model outcomes to observed real world data. This would be part of the recommendations of this study.

RACE as a sketch-planning land-use transport emissions tool is the essence in the second research question. It refers on the one hand to the concept of a sketch-planning tool, which implies that a planning tool for developing Asian cities and as such can be seen as a planning support system with the use of RACE, other conceptual PSS are not considered. On the other hand, RACE refers to the requirements from land-use transport emissions modeling. There are many scientific valid models developed and empirical relationships found between land use, transport and the respective emissions. These relationships are considered and other common modeling techniques are considered, it is however not a comparison of models.

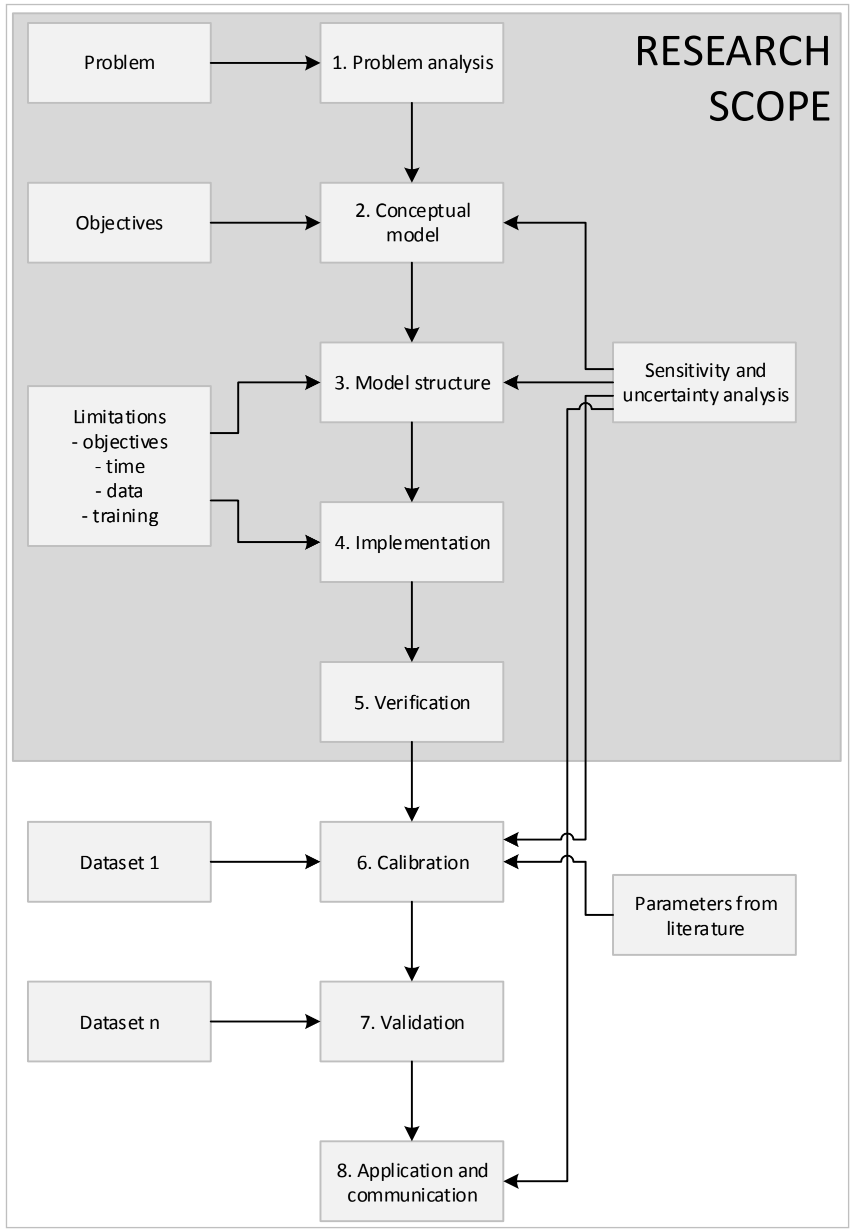


Figure 4. Research scope

The focus is on the criteria and needs for a planning support system and the conceptual requirements of such a model, as shown in Figure 4. Therefore, the focus within RACE is on the methodology, concept, and implementation of RACE. Hence, only the way the calculations are done, scenarios are constructed, and data is acquired are reviewed. The three applications are used to determine the methodology. The calibration and the validation of the three applications are not researched. Only the reports available to the three applied cities are used. Interviews with the organizations that assisted in applying RACE complement the reports of RACE.

RACE is an ongoing project of Clean Air Asia and the version of RACE under review is of June 2012. Improvements after June 2012 are not considered. More recently, RACE is developing guidelines and manuals for implementation. These are also not considered. RACE can calculate besides transport emissions, building energy use and the respective emissions. Assessment of building energy use is excluded from this research.

1.4 READING GUIDE

The two model development cycles of Kolkman (2005) are applied in chapter 2 by describing the problems of land-use planning and transport emissions in developing Asian cities and how models can assist in land use planning. Secondly, it provides insights in the current knowledge of the relationship between and modeling techniques of respectively land use, transport, and emissions. These two perspectives describe the requirements for a planning tool for land-use transport emissions and result in an evaluation framework. This is described in chapter 3. Chapter 4 will provide the results regarding the assessment of RACE. It will start with a brief description of RACE and secondly a description of how RACE is performing on each of the criteria described in chapter 3. In chapter 5 the evaluation framework and the assessment of RACE will be discussed. Chapter 6 provides conclusions and recommendations regarding the evaluation framework and the model RACE.

2 SKETCH-PLANNING FOR LAND USE TRANSPORT EMISSIONS

Central in this research is the problem solving cycle and the model development cycle as set out by Kolkman (2005). These two cycles are applied to the concepts of land-use planning in developing Asian cities to reduce transport emissions (the problem solving cycle), and the current knowledge, including the modeling efforts, of the relationships between land use, transport, and emissions (the model development cycle).

The problem solving cycle is describing the relationship between the problem context and the model (Kolkman, 2005). It is part of the problem solving, decision making or policy analysis cycle. In any of these steps a model plays a role, but more essential is the stakeholders and the policymakers involved (Walker, 2000). They have to actively participate in the process to solve the right problem, instead of finding the right solution for the wrong problem (Ackoff, 1974). The problem solving cycle can be assisted by process oriented models that assist in planning, so called planning support systems (or sometimes decision support systems (DSS) or even spatial decision support systems (SDSS) (Vonk, Geertman, & Schot, 2005)). Essential in the problem solving cycle is to understand the frames of the different actors in the development cycle (Kolkman, 2005).

Paragraph one to three of this chapter describe the problem solving cycle in which first the context and problems of land-use planning and emissions in Asian cities (§1), and the relation to transport emissions (§2) are described. A solution could be to improve the land-use planning of these cities, this is explored and the possible role of Planning Support Systems (§3).

A model is useful as it can integrate different disciplines. In this study the integration of the disciplines of land use (planning), transport, and emissions are of importance. The model developer constructs a conceptual model, incorporating various aspects of the natural system. The conceptual model can be translated into algorithms and in the end to a software tool (Dee, 1995; Kolkman et al., 2005). The

Paragraph four describes the function of models and the stages of model development as described in Dee (1995). Paragraph five and six describe the model development cycle, in which the three steps of translation of Dee (1995) from natural system to software are applied to respectively transport emissions (§5), and land use and transport (§6).

2.1 ASIAN CITIES AND EMISSIONS

Without further action to reduce greenhouse gas emissions, ‘dangerous’ climate change will occur. Mitigating and adapting to climate change is considered one of the biggest challenges in future decades (World Bank, 2012).

Emissions from transport contribute about 25% of the total amount of CO_2 emitted global. In nearly every city in Asia pollutant emissions are above the health standards set by the WHO (Clean Air Initiative for Asian Cities, 2010; Yuen & Kong, 2009), while by 2020 more than half of the population in Asia lives in urban areas (United Nations, 2012). This substantial increase in population, in combination with expected economic growth will probably result in an increase in transport demand and rising private motor vehicle ownership (Dimitriou, 2006). Currently many Asian cities are already facing problems with transport congestion and urban planning (Ansari, 2009; Roberts & Kanaley, 2006; United Nations Human Settlements Programme, 2009; Yuen, 2009). A key element to consider in overcoming the environmental degradation is the coordination of land use, transport and housing in space (Douglass & Ling, 2000).

Dimitriou (2006) outlines the transport planning challenges for medium sized Asian cities:

- A fast-rising transport demand
- Rising motor-vehicle ownership and use
- Fragmented road hierarchies
- Increased marginalization of the urban poor who are growing in number
- Weakness of land use development control, particularly in areas outside the urban core
- Poor coordination and duplicity of government agencies concerned with urban transport
- A combined absence of sustained funding for the improvement of the transport sector

The problems mentioned by Dimitriou (2006) can be placed in the broader context of urban planning by policymakers. In the global study of United Nations Human Settlements Programme (2009), the detailed regional studies for South Asia (Ansari, 2009) and South-East Asia and the Pacific (Yuen, 2009) they conclude that the problems arising are not only because of the natural and economic drivers, but also because of the governance. There is limited coordination between departments and levels, most cities are struggling with the structure and power (not) given by the decentralization of government in many countries. Secondly, most local governments lack the capacity, skills, and expertise to effectively develop and implement strategic plans. Thirdly, the problem is that most local authorities cannot collect their own revenue and are therefore dependent on higher levels of government. Last problem mentioned is the lack of awareness and understanding of participation by stakeholders. These problems hinder the effective implementation of projects and development of plans.

City authorities design and develop their city, while development agencies such as ADB and World Bank fund various projects and have in that case a strong influence to the requirements of the development of a project or a city plan. The problem is, however, that development agencies are used to work with decision makers on a national level instead of local level and that urban planning requires a cross-sectorial approach, while the institutes are structured according to different sectors. An important role of the development agencies is to assist in developing analytical frameworks and improve the information base on which cities can decide; hence that they should “focus on their catalytic role as facilitator and enablers rather than as providers of infrastructure and services” (Roberts & Kanaley, 2006; Yuen, 2009). The Cities Development Initiative for Asia (CDIA) is an example of an organization that tries to connect city authorities to funding from development agencies (Cities Development Initiative for Asia, 2009)

2.2 TRANSPORT EMISSIONS

The Avoid-Shift-Improve (ASIF2)[1] framework is developed to find and develop strategies to reduce transport emissions. The goal in this framework is three folded: first to avoid transport, secondly to shift to cleaner modes (non-motorized or public

[1] Finance is included in some papers but often omitted as part of the strategy.

transport), thirdly by improving the quality of vehicles by reducing the energy consumption and finally to use financial measures to reduce traffic as well (Dalkmann & Brannigan, 2007; Tiwari et al., 2011).

In line with the ASIF2 framework several instruments are found to propose measures : Planning, Regulation, Economic, Information, and Technological instruments (PREIT), see figure 5 (Dalkmann & Brannigan, 2007):

- Planning: the development of a more sustainable urban form with higher densities, mixed land use, and pedestrian and cyclist friendly streets could avoid the need for transportation and reduce the total amount of vehicle kilometers and therefore emissions. The planning of more public transport could reduce the need for private transport. The design of streets could improve the energy efficiency of streets, for instance by introducing a 'green wave' in succeeding traffic lights.
- Regulation: restricting the use of certain motorized vehicles or banning traffic from certain areas could reduce traffic; setting emission standards to vehicles could improve the air quality.
- Economic: discouragement of private transport, and encouraging public transport and non-motorized by financial means, for instance increasing parking place prices or subsidizing public transport and investing in pedestrian facilities.
- Information: the provision of information about alternative transport modes could improve the awareness and could lead to shift towards non-motorized or public transport modes of transport.
- Technological: the introduction of more fuel-efficient vehicles or introduction of end-of-pipe control devices can reduce the emission of pollutants.

Schwela et al. (2006) are describing the measures from the perspective of the type of implementation: command and control

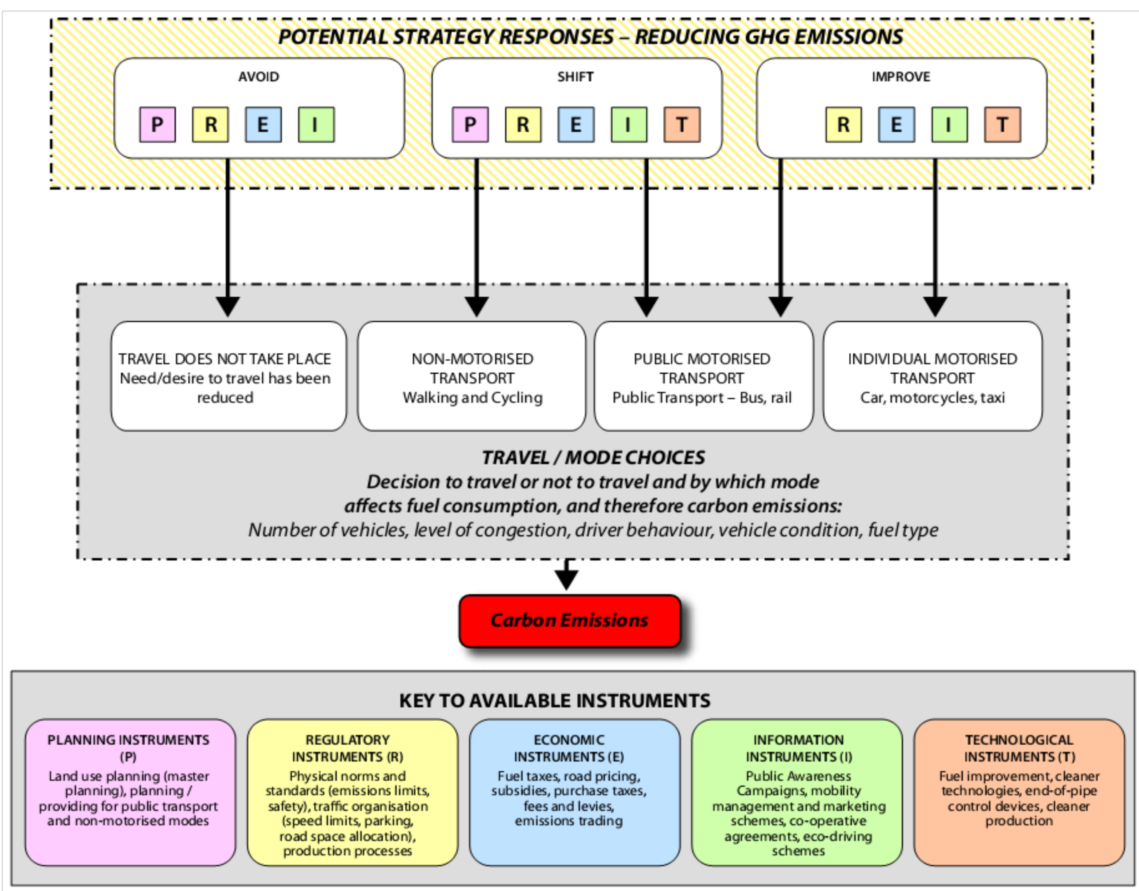


Figure 5. ASIF2 framework with the PREIT instruments (Dalkmann & Brannigan, 2007)

measures, economic instruments, co-regulation and voluntary initiatives, self-regulation, and education & information. For an overview of sustainable transport policies the reader is referred to Santos, Behrendt, and Teytelboym (2010).

Grazi and van den Bergh (2008) conclude that planning instruments (physical planning) are the most effective to reduce greenhouse gas emissions on the long run by affecting the transport volume and mode shares. Pricing and command & control measures (in the line of regulatory instruments from Dalkmann and Brannigan (2007)) are more effective on the short run. Their effects are mainly regarding the mode shares and shifts to different vehicle fleets.

In planning for a more sustainable urban form several names are coined (e.g. smart growth, transit-oriented development, compact city), they share the same goal in that there are less motorized trips, increase the share of non-motorized transport, reduce trip lengths and increase vehicle occupancies. This can be achieved by changing the urban form of a city along three dimensions: density, diversity and design (Cervero & Kockelman, 1997). In later years the distance to transit and the accessibility of the destination are added (Cervero & Murakami, 2008). An increase in density results in an increase of public transport shares; mixed developments result in more non-motorized transport; and a pedestrian and cyclist friendly design also increase the share of non-motorized transport. Distance to transit and accessibility of the destination can increase public transport share (Ewing & Cervero, 2010; Milder, 2011; Tiwari et al., 2011).

There is however still a debate how a 'sustainable city' should look like, in this debate not only the volume of travel, but also social, economic, and environmental issues are considered (e.g. Breheny, 1997; Gordon & Richardson, 1997; Milder, 2011; Schwanen, Dieleman, & Dijst, 2001; Williams, 2004).

2.3 STRATEGIC LAND-USE PLANNING & PLANNING SUPPORT SYSTEMS

2.3.1 LAND-USE PLANNING

Planning is a future-oriented activity that links "scientific and technical knowledge to actions in the public domain" (Friedmann, 1987). Urban land-use planning is a specific form of planning and is the attempt to regulate and structure the physical space. The goal of urban planning is *"to devise mechanisms for directing or controlling the timing, rate and location of [urban] growth"* (United Nations Human Settlements Programme, 2009). Harris (1989 cited in Couclelis, 1991) identified four different planning functions: Operational, managerial, strategic, and communicative. Operational and managerial planning functions are dealing with implementation and tactical decisions respectively (Couclelis, 1991; Lee, 1994). Strategic land-use planning functions are always at the long-term (Healey, 2007) and are trying to *"affect the course of socioeconomic and environmental processes in an area towards desired ends through sequences of interdependent decisions and actions"* (Couclelis, 2005). Planning of future developments is also more effective than regularization in affecting these processes (United Nations Human Settlements Programme, 2009). Communication is essential in planning; not only because of the need for informing all stakeholders involved, also because of the political need to inform and communicate to the public. It is the political legitimization and credibility on which planning depends (Couclelis, 1991).

Land-use planning is highly complex; the urban dynamics are too complex and too dynamic to fully understand, let alone predict and plan (Healey, 2007). Planning requires not alone the analysis of the spatial temporal component, but also the interplay of economic, socio-cultural, environmental and political/administrative dynamics (Couclelis, 2005; Healey, 2007). The solution of one problem in a community (e.g. transport congestion) cannot be seen without the direct implications for other fields and communities (Calthorpe & Fulton, 2001). Hence, land-use planning is highly dependent on the institutional framework (United Nations Human Settlements Programme, 2009).

Land-use planning is following the process of policy analysis and policymaking. It is a constant political process. It can be considered as a process in which the stakes are high and the systems processes are highly uncertain; requiring therefore a post-normal science approach in which *"[o]nly a dialogue between all sides, in which scientific expertise takes its place at the table with* *local and environmental concerns, can achieve creative solutions to such problems, which can then be implemented and enforced"* (Funtowicz & Ravetz, 1993, 1994).

Another problem is the multitude of stakeholders involved in land-use planning; public and private actors have a stake in the development and try to alter the strategy. The challenge of effective governance is to integrate these stakes into a land use strategy (Healey, 2007; Salet & Thornley, 2007). It should be noted that policymaking is however different from rational policy analysis, policymaking is the process of bargaining, negotiating, and intermediation to find political acceptable solutions (Rondinelli, 1973), while policy analysis is *"a rational, systematic approach ... to **assist** policymakers in choosing a course of action from among complex alternatives under uncertain conditions"* (Walker, 2000; emphasis added). It helps to determine what alternatives there are to solve the problem and how they score relative to each other. The emphasis is also on the participation of the policymaker within the process, as they have to finally understand and use the results (Walker, 2000). Policy analysis can help the policymaker on deciding future land use plans, but has to accept the political interaction of policymaking (Rondinelli, 1973).

2.3.2 PLANNING SUPPORT SYSTEMS

A way to overcome the knowledge gap between different stakeholders, researchers and decision makers is using a model (Kolkman, 2005). A model can integrate the different knowledge and make it understandable to all stakeholders involved. In land-use planning these are often called Planning Support Systems (PSS) which "*should lead to an environment in which research and practice are brought much closer together and in which many more people in various walks of life, professions, and disciplinary fields become more deeply involved"* (B. Harris & Batty, 1993) and are designed to provide *"easy-to-digest, scientifically based insights on the possible implications of alternative planning strategies."* (Couclelis, 2005). This shows immediately the two functions of PSS's: strategy planning and communication of this planning; both are essential to change and improve the land-use planning (Couclelis, 2005; Healey, 2007; Te Brömmelstroet, 2010b).

In a conceptual framework of Vonk, Geertman, and Schot (2007) they describe the successive planning tasks, from problem definition to exploration of alternatives, consultation to decisions and implementation. A PSS can cater this function by gathering the information, visualize and communicate it, but also analyze and model the alternatives. These are presented to different users. They identified the following users of PSS: professional planner, executive, geo-info specialist, citizen, and professional stakeholder.

Couclelis (2005) places PSS in four interrelated domains (Figure 6): (1) the land use system itself, which is the system of interest, and changes according to the internal processes and decisions but also the outer world. (2) The wider system, capturing events outside of the scope of the land use model; for instance changes in the world environment or global technological breakthroughs. (3) The planning system with the stakeholders involved acting upon the current situation. (4) The land use model that tries to capture the behavior of the land use system and explaining, interpreting and give forecasts for the future with the respective implications of decisions.

Each of the four domains have inherent uncertainty that needs to be addressed in planning (Couclelis, 2005), a possibility therefore is to develop several internally consistent scenarios to understand the fragile parts of the system and where the uncertainty come about (Wack, 1985).

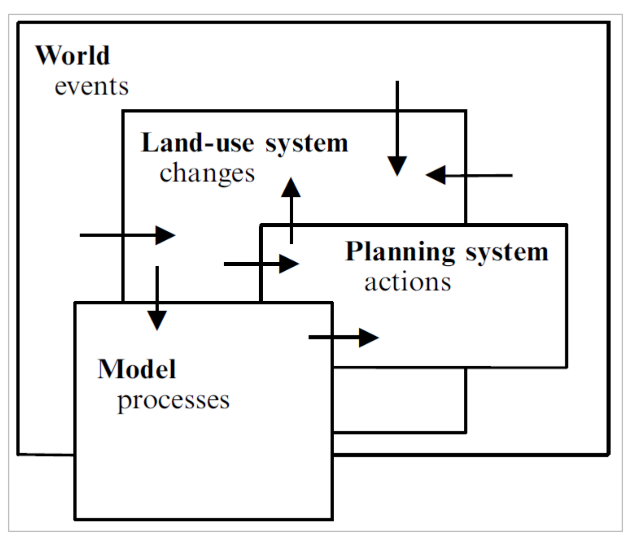


Figure 6. Four realms of change in land-use planning (Couclelis, 2005)

Planning is concerning future situations. The future is inherently uncertain. Therefore planning is more than just fact-finding, it is also about visions and ideals, where creativity, analysis and judgment techniques go together (Myers & Kitsuse, 2000). Three ways of examining future situations are identified in urban planning: visioning, scenarios, and storytelling (Myers & Kitsuse, 2000). Visioning is the process of encouraging citizens to think of how their city should look like and has the advantage of looking beyond the current boundaries. Essential is however the back casting in which the vision is translated to concrete actions. Scenarios are telling possible futures based on current and future (external) events; it can show the implications of current policies and how different events can alter the situation. Storytelling is the part where models can be translated into *"socially meaningful stories that will shake people out of their complacency and into action"* (Couclelis, 2005). It is without saying that all three are backed up by each other, so that a vision is also a realistic scenario; and storytelling could provide the communicative function of planning.

2.3.3 REQUIREMENTS OF PSS

While PSS is already known for several decades, it is still unclear what the structure of a PSS should be and what should be included (Vonk & Geertman, 2008). In the same research of Vonk and Geertman (2008) they argue that there is a mismatch between the demand and supply of PSS's. Several requirements and problems of a PSS have been identified in theoretical and empirical studies (e.g. B. Harris & Batty, 1993; Te Brömmelstroet, 2010b; Vonk, 2006). The most important ones are described in the next section.

The first requirements are regarding the possibilities and way of usage of PSS. B. Harris and Batty (1993) describe two requirements for planning support systems in relationship to GIS. They acknowledge the fact that a perfect system optimization is impossible, therefore planning is an informed process of trial and error; often referred to as sketch planning. The second requirement they set out is that it should be extensive for consequences of alternatives; otherwise, improvement and comparison is not possible. This continues on the line found by Te Brömmelstroet (2010a), they conclude that a PSS should be used to create new insights, evaluate ideas, be transparent, used as input at the start and is 'easy to play with'.

The timeframe of planning is at a strategic level over considerable amount of time. The uncertainty associated with the future, which is increased due to the long-term planning, requires that data used in the model should be in line with the strategic function, in else, not more specific or detailed than possible. As planning becomes more short term and more concrete, the data should follow suit and become more specific (Healey, 2007; Lee, 1994)

Due to the diversity and multitude of actors involved in planning sufficient people have to buy into the model's frame to gain power, perhaps complemented by the momentum of the current context (Healey, 2007). In addition, planning is long considered as an activity for the people, but it should be with the people. Therefore PSS's should be available for public use and self-teaching as much as possible (Couclelis, 2005; B. Harris & Batty, 1993).

An important bottleneck is also the adaptability of the PSS to different situations (B. Harris & Batty, 1993; Vonk, 2006). Te Brömmelstroet (2010a) has conducted a survey among PSS users and developers regarding the bottlenecks blocking the usage and implementation of PSS in practice. Lack of transparency, low communication value, not user friendly or interactive were the

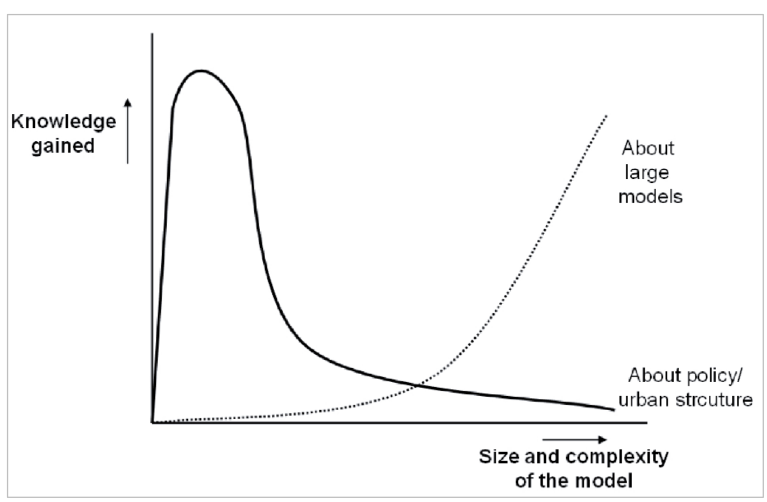


Figure 7. The dilemma of model development and the knowledge gained by the model (Lee, 1973)

most important bottlenecks. They conclude that not the technological qualities are the most important, but rather the adaptability of the tool to end-users demands is more important.

Moreover, a PSS, or any model, should be as simple as possible, but not too much (B. Harris, 1989; B. Harris & Batty, 1993; Te Brömmelstroet, 2010a). In the landmark paper of Lee (1973) he describes the tradeoff between complexity of the model and the knowledge gained. Science is often developing highly detailed models with many relationships modeled. However, in practice the most knowledge is already gained by simple models and, often, detailed modeling does not improve the planning process. However, a model should still be capable of accommodating research and allowing the introduction of new methods of simulations and sources of data as science progresses (B. Harris & Batty, 1993).

In developing countries expertise and resources are severely limited and the spatially data is hard to obtain, and organizational structures are not in place. Therefore an incremental approach with step-by-step introduction of the system and emphasis on data infrastructure, information, and training is essential (Klosterman, 1995).

2.4 MODEL DEVELOPMENT AND EVALUATION

Models can play an important role in integrating knowledge from different fields of research and at the same time communicate scientific knowledge to policymakers. Models function as an intermediate operator in which the balance has to be found between the specific decision situation and the abstract scientific knowledge. The purpose of models is not solely quantifying the effects of an alternative, but providing also non–quantitative support by conceptualizing the situation and context (Kolkman, 2005). Models are supporting the policy analysis and are often only a small step within the whole process of policy making (Walker, 2000), and as Couclelis (2005), put it: "Models are based on science; planning is about policy." The model should be therefore to make knowledge relevant and helpful for decision makers (Jäger, 1998).

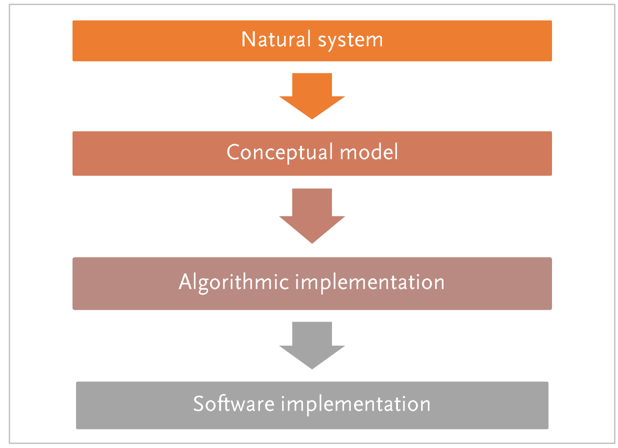


Figure 8. Levels of conceptualization and implementation of the natural system (Dee, 1995)

Unfortunately, many models fail to be used in policy analysis (Rogers & Fiering, 1986; Vonk & Geertman, 2008). Because the model is hard to understand by the end-users and do not reflect the end-users wishes (Kolkman, 2005; Walker, 2000). Second because it is often unclear what the assumptions and values are behind the model (Schneider, 1997). Thirdly, models fail to recognize and address the wider context in which policy analysis is taking place; the model should be fit to the problem and not the problem to the model (Ackoff, 1974; Walker, 2000).

Dee (1995) recognizes four levels of model development and 'steps' in conceptualization of the natural system to a computer system. The first is the natural system, which is a collection of processes relevant to the modeling purpose. Second level is the conceptual model reflecting the variables, assumptions, and interrelationships of the behavior of the natural system. This can be converted to the algorithmic implementation level describing the conceptual model in various equations, values and equations ready to be processed for implementation. Finally, in the fourth level the algorithm is converted to a computer code, which codes the algorithms and implements the actual data structure. Each level can be calibrated and validated.

2.5 GENERAL REQUIREMENTS FROM MODEL DEVELOPMENT

Various criteria for model development are given in very different studies. However, most studies can be captured in three aspects: the operational aspect in terms of usefulness for the end-users, the theoretical soundness of the model, and the validity and modeling quality of the model (Chan, 2005; Chang & Hanna, 2004; Jørgensen & Bendoricchio, 2001; McIntosh et al., 2008; Supernak, 1983; Walker, 2000).

Moreover, it can be argued that the following two guidelines are the most important ones for any modeling exercise (Walker, 2000):

- The model should be as simple as possible, and as complex as necessary
- The model should be fitted to the problem and context at hand, instead of adapting the problem to the model

This is easier said than done. On the one hand Ortúzar and Willumsen (2011) point out that developing a more complicated, but theoretically sound model is useful and important to use, as it can guarantee stable results and consistency throughout the model, give confidence in forecasting and improve algorithms. On the other hand, these requirements can be too demanding. For instance in terms of complexity, data resources, or it cannot be calibrated to the level of analysis necessary. Hence there is always a trade-off between what is desirable from a theoretical point of view and what is possible in daily life by practitioners (Ortúzar & Willumsen, 2011). It is therefore important to determine the appropriate level of analysis for the problem at hand.

Therefore, it is essential to understand the user needs and make clear the purpose of the tool, work collaboratively and establish and maintain trust (McIntosh et al., 2008).

In detail, the operational requirements would be that:

- The end-users can make use of the model, by implementing the policies and flexibility required by the end-users (Chang & Hanna, 2004)
- A model should be user friendly in input and use of data (Chang & Hanna, 2004; Moussiopoulos et al., 2005) .
- The model can effectively communicate the results and the associated uncertainties to the end-users (Kolkman, 2005); the uncertainties are in particular of importance if the model is used as a supporting tool for decision makers (Borrego et al., 2006).

The theoretical requirements are that the model is correctly implementing the theories and makes the translation from the natural system to the software implementation as described by Dee (1995).

- The model should be verified and validated, verified meaning that the dynamics of the natural system are also reflected in the system, and validation by accepting the reliability of the output as compared to real life observations (Oreskes, Shrader-Frechette, & Belitz, 1994).
- The model is using the right structure (dynamic vs. static, stochastic vs. deterministic, distributed vs. lumped, etc.) to model the natural system and is in line with the policy context (e.g. availability of data) (Jørgensen & Bendoricchio, 2001)

The modeling requirements are that the model is calculating in a consistent manner, is transparent, valid, and applicable for the situations at hand:

- The model should be transparent, consistent and reproducible so that others can verify and reproduce the results (EEA, 2012; IPCC, 2006)
- The model should be flexible enough to be adaptable to various situations and handle multiple sources of data (Friedrich & Reis, 2004; Moussiopoulos et al., 2005)
- The model should be as accurate as possible (Supernak, 1983)

Forrester and Senger (1980) describe from System Dynamics several tests to evaluate a model and built confidence in the model, they classified the 17 tests in three categories: model structure, model behavior, and model's policy implications.

In the following paragraphs the model of Kolkman (2005) and Dee (1995) is used to describe the relationships between the natural system, conceptual model, algorithmic and software implementation of respectively land use, transport and emissions system.

2.6 MODELING TRANSPORT EMISSIONS

2.6.1 CONCEPTUALIZATION

Air pollutants are either directly emitted into the atmosphere from natural or human sources (primary air pollutants) or formed within the atmosphere due to a chemical reaction (secondary air pollutants). The different pollutants are dispersed in the atmosphere, where they remain for the lifetime of the specific pollutant, some pollutants stay only at the local scale; others disperse to a global scale. Depending on the scale and pollutant, it has an effect on the environment and human health. This process is demonstrated in figure 9.

On a global scale, CO_2 is considered as the most important pollutant to monitor, on a local scale various pollutants are of concern. In Asia, the main pollutant of concern is Particulate Matter (PM_{10} and $PM_{2.5}$). In cities with high volume of motorized traffic the levels of nitrogen dioxide (NO_2) and Ozone (O_3) are also important (World Health Organization, 2006). Global pollutants, such as CO_2, require a global spatial resolution and can be measured on an annual scale, while local pollutants, such as PM and NO_x, should be measured at an hourly scale (Hickman, 1999). Hence, the temporal and spatial resolution should match with the pollutant.

The main source of transport emissions is the combustion of petrol and diesel in vehicles. Evaporation of fuel and wearing of tires also contribute to the emission of certain pollutants, in particular VOC's (Hickman, 1999).

2.6.2 MODELING TRANSPORT EMISSIONS

Emission modeling is conducted for a variety of reasons; most often this is undertaken to estimate the local air pollution, which requires the modeling and measuring of locally emitted emissions. Another function of emission modeling is to estimate the magnitude of greenhouse gas effect. Other air pollution problems, such as acid rain and the brown haze are also objectives of estimating the total amount of emissions, but are not considered in this research.

In air quality modeling the first step is to create an emission inventory, second is to take into account the meteorological aspects of the atmosphere and third to estimate the impact of the pollutants to human health, etc. (Moussiopoulos, 2003). Each source of emissions requires a distinct way of measuring, but all have to be considered within an urban emission inventory (Moussiopoulos et al., 2005). These emissions are calculated based on activity and emission factors:

$$E_{pollutant} = \sum_{activities} A_{activity} * e_{activity,pollutant}$$

in which E is the total emission (in g/h/unit), e is the emission factor (EF in g/unit) and A is the activity data of the emitter (could be the volume of fuel burned, number of kilometer travelled, etc.).

Modeling transport emissions can be conducted in several ways. The most simple methodology of estimating transport emissions is to gather fuel sales data (i.e. total activity) and multiply these with the amount of carbon in the respective fuels (i.e. emission factor). This methodology is adopted by the IPCC and is referred as tier 1 top down methodology in which only international

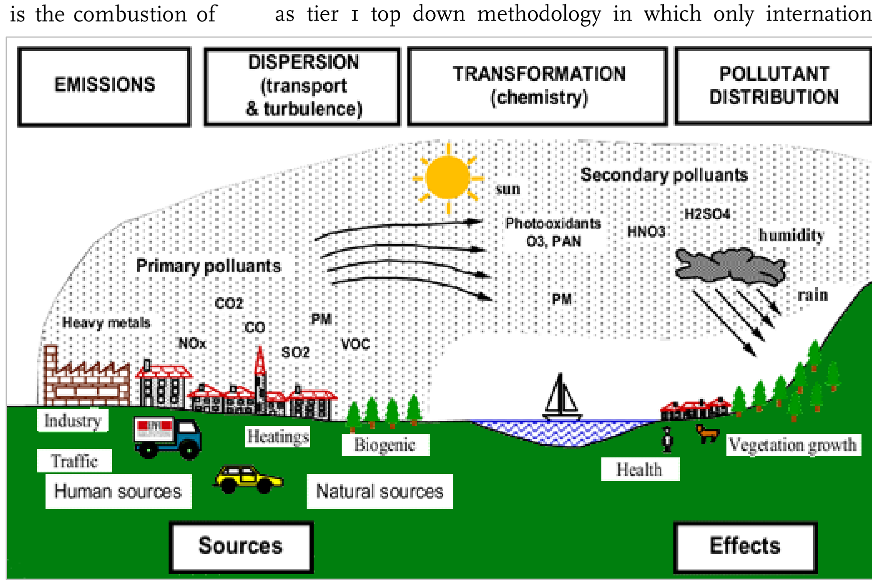


Figure 9 Interactions of pollutants in atmosphere (Ho, Golay, & Clappier, 2010)

default values are used. It does not allow for any further specification to vehicle type, place of emissions, etc. A tier 2 approach would account for national averages of fuel usage and is disaggregated to the level of fuel efficiency, vehicle type and road categories. This methodology is adopted in the models developed by the US Environmental Protection Agency (EPA) and the European counterpart the European Environment Agency (EEA). Tier 3 is the most detailed approach, and makes calculations at the project level, with transport activity modeled per vehicle type, year, fuel etc. The emission factors are determined per vehicle type and make a distinction between hot and cold start emissions (EEA, 2012; IPCC, 2006; Schipper, Fabian, & Leather, 2009).

An alternative method is the use of the ASIF formula developed by Schipper, Marie-Lilliu, and Gorham (2000). Schipper et al. (2000) have analyzed the driving forces behind the growth of GHG emissions in transportation and this has resulted in the following four aspects that are of importance:

- Growth in the total transport activity, the total number of passenger kilometers and freight kilometers has increased in the past decades and keeps increasing every year. An increase of transport activity is the main driver behind the increase of GHG emissions from transportation
- Mode shift towards cars and to trucks for freight. The mix of mode shares has steadily shifted towards the use of private cars instead of public transport or non-motorized transport. For freight similar shifts have been observed (from ships and rails towards trucks). These modes are more energy intensive per passenger- or ton-kilometer, and therefore emitting more carbon per kilometer than alternative modes.
- Reduction of energy intensity (the amount of energy consumed per passenger- or ton-kilometers). This is actually an improvement, cars and particularly trucks have become more energy efficient by consuming less energy per passenger- or ton-kilometer.
- The carbon factor of fuels. This has hardly changed in the past decades, as the predominant fuel in the transport sector is still petroleum-based. However, alternative less-carbon intensive fuels is rising (such as electricity and biomass)

These four factors have resulted in the following formula in which each term can be mathematically assessed in isolation from each other:

$$\boldsymbol{G = A * S_i * I_i * F_{i,j}}$$

where G represents the total amount of emissions from a particular transport sector, A is the total transport activity (in passenger- or ton-kilometers), S is a vector of the modal shares, I is the modal energy intensity of each mode i, and $F_{i,j}$ is the amount of carbon, nitrogen, etc a fuel j in mode i contains.

The energy intensity I_i can be decomposed into several components:

$$\boldsymbol{I_i = E_i * \frac{1}{U_i} * \frac{1}{O}}$$

in which E_i is the technical efficiency of mode i (the energy consumed per capacity ton-kilometre), U_i is the capacity utility of the transport mode (i.e. possible amount of persons or ton per vehicle), and O is the operational optimum coefficient (if the car is driving in optimal conditions or with congestion, on a poor surface, or inhospitable terrains).

In detail, E_i is composed of an engine (N) and a motive (M) intensity component. N describes the amount of energy needed to provide a given amount of power to the engine flywheel, M describes the amount of energy needed to produce a capacity ton- or person-kilometer and relates therefore to the specific characteristics of the vehicle (weight, transmission, etc.). The combination of M/U_i provides how capacity intensive a fleet is, showing if the size of the vehicle is appropriate for the task it is put to (for instance if a vehicle is not oversized).

The term $E_i$is however hard to estimate, therefore most often the energy consumed per vehicle kilometer is used. This limits the analysis since it does not show how appropriate the vehicle is for the task it is assigned to (e.g. the over-capacity of a vehicle fleet).

The modeling of emissions is in some cases not enough, in particular when the local air pollution is required. In that case, it is essential to include also dispersion modeling (meteorology, topography, and chemistry). The emissions inventory in combination with the dispersion modeling could lead to concentrations of a pollutant in an area and give information about the air quality in the area, which in turn can be compared to the standards of the WHO (Davison, Elshout, & Wester, 2008). This requires however of the knowledge of emissions on a rather fine grid (500x500m) and on an hourly basis (Hickman, 1999).

2.6.3 CRITIQUE AND REQUIREMENTS

Modeling emissions is dependent on two aspects: the total amount of activity and the emission factor. The total activity can be calculated in numerous ways for transport, examples of fuel sale are very general and usually only available on the country level. Other ways of estimating transport activity is described in paragraph 2.6.

The emission factor is the second uncertain term in modeling emissions and is hard to obtain in a reliable manner (Hickman, 1999), in particular to developing countries which have often very different vehicle fleets in comparison to European and American vehicle fleets. Therefore, the emission factors are not always transferable one to one.

The ASIF formula provides a more detailed approach in modeling transport emissions and still keeping many aspects simple, but has the same problems as the other model: transport activity can be calculated in numerous ways, the same applies to the modal share, while emission factors and intensity of fuel consumption remain difficult to obtain (see Figure 10)

Figure 10. Example of a bus in India, showing the difficulty of determining the emissions per passenger per kilometer (photo: Singh, 2010)

2.7 MODELING LAND USE AND TRANSPORT

2.7.1 CONCEPTUALIZATION

Land use and transport mutually influence each other (Ewing & Cervero, 2010). Already in the late fifties theories were formulated of how the rise of the private car is a result of urban sprawl and the other way around (Kelly, 1994). The relationship is usually represented by the land-use transport feedback cycle (Figure 12). Land use caters certain activities, such as living, shopping, work, etc. These activities require travel between two places by means of a transport system. The transport system results in the accessibility of the different locations and therefore the different land uses. The feedback and dependency is emphasized in this cycle. Changes in the transport systems result in changes in accessibility of certain locations and results in possible changes in land use activities. Similarly, a change in land use results in different activities and therefore results in different transport systems (Wegener & Fürst, 1999).

Transport demand is derived from the desire to participate in activities that take place in different locations (Ortúzar & Willumsen, 2011). The transport infrastructure provides the access to these different activities. Both, transport demand and transport infrastructure, are often presented as a function of 'generalized costs'. The 'generalized costs' can incorporate the direct costs (e.g. gasoline, maintenance of infrastructure) and indirect costs (e.g. cost of travel time, reliability, convenience, etc.). The equilibrium between these two sides is found to provide the total volume of travel (Figure 11). If the cost of travel is reduced, the demand is expected to increase. However, the cost of supplying transport will increase when demand increases (Hensher & Button, 2000).

Accessibility has become one of the key elements in determining the demand for and structure of travel (Wegener & Fürst, 1999). Geurs and Wee (2004) define accessibility as *"the extent to which land use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)."* Essentially, this captures the meaning in four separate components: land use, transport system, individual, and temporal component. It varies therefore from actor to actor how they will perceive their accessibility and therefore how their mobility is, and how their land use is influenced (where they will live, work, etc.).

Land use and transport change over time, but it is essential to take into consideration the pace in which they change. For instance, land use and infrastructure developments are very slow, while traffic changes every day. These processes have to be considered in modeling the 'urban system' (Wegener & Fürst, 1999).

Knight and Trygg (1977) have given an overview of all possible factors influencing the land use impact. The most important driving forces of the 'urban systems' are the demographics of the population, regional economics, government policies, and the transport system (Miller, Kriger, & Hunt, 1998). In developing countries the largest driver of the changing transport system is the growth in motor vehicle ownership, which is mostly driven by income increases (Zegras & Gakenheimer, 2006). These drivers are often modeled exogenous of the model, as the aim of nearly all land-use transport models is to show the impact of policies on the land use-transport system and not on the demography or economy. Therefore, considering the demography and regional economics as stable (Miller et al., 1998). [2]

Several economic and social theories are put forward to determine how a city will develop, based upon the drivers. Economic theories treat land use as markets and transport as costs. A frequently used economic theory is the bid-rent theory developed by Alonso (1964 cited in Wegener & Fürst, 1999). More recently, Krugman (1991, 1998) has advanced this economic theory, which has been called the "New Economic Geography". It describe the forces attracting people and companies towards of outwards of an area; considering distance, but also the current market size, rents, etc. The theory assumes equilibrium between demand and supply and derives behavior from individual maximization. This theory explains to some extent, why in developing countries there are primary cities attracting all energy, leaving outer cities less developed (Krugman, 1996). Social sciences have also developed theories about urban space and the relation to transport. A well-known theory is the action-space theory developed by Hägerstrand (1970), determining peoples transport behavior on the basis of their capacity, coupling, and institutional constraints. A derived theory is the time-constrained theory which treats transport as something people maximize within their 'daily travel time budget' (Golob, Beckmann, & Zahavi, 1981; Zahavi & Lang, 1974). These theories provide insights and ideas of why and how a city has developed and potentially will develop in further years. But none of these theories have enough predicting power to say how a city exactly will develop; it is rather a myriad of potential insights and requires (re)framing and creativity to translates these insights in a coherent planning strategy (Healey, 2007), as is also described in section 2.3.

Other elements of importance in conceptualizing the land-use transport system are the actors. There are various actors involved in land use planning. Besides the political actors are also the local firms and households involved. They all make decisions within different time frames regarding different aspects of the 'urban system' and are therefore essential in modeling the 'urban system' (Hunt, Kriger, & Miller, 2005).

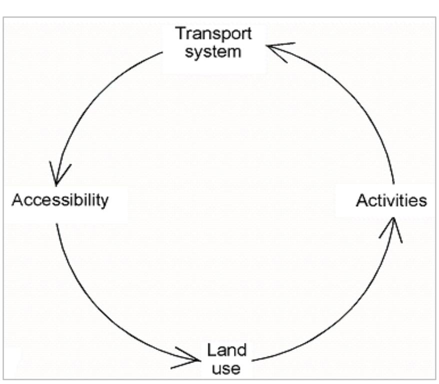


Figure 12 Land-use transport interaction (Wegener & Fürst, 1999)

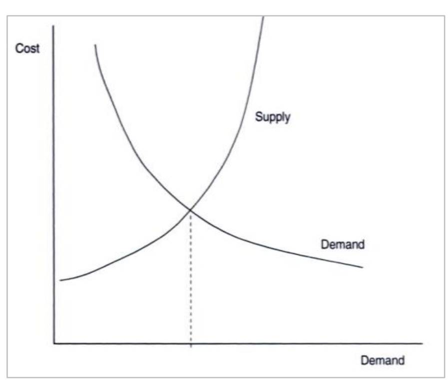


Figure 11. Supply demand relationship (Hensher & Button, 2000)

[2] The local economy is, on the contrary part of land-use transport modeling. In that case, the main emphasis is on how and where economic activity will develop, but not as part of how the economy beyond the study area is influenced.

Table 1. Relationship between land use/urban form and transport (adapted from Wegener and Fürst (1999)

	Trip Length	Trip frequency	Mode choice
Density	Trips become shorter if the density increases	Shorter trips can result in an increase of trips	Public transport becomes more economically viable, an increase in PT ridership is therefore expected
Diversity	Trips become shorter if land use activities are more mixed	The frequency increases when the diversity increases,	More NMT trips are expected with increased diversity of land use
Design	Traditional neighborhoods have shorter trips	Less hierarchical road structures reduces trip frequencies	Traditional neighborhoods with interconnected streets reduce car trips and increase PT ridership
Accessibility	Increased accessibility of suburban regions increases the trip length		Increased service of PT, increases PT ridership significantly,
Distance to transport networks	Trip length increases when transport networks (roads and transit) are nearby		The proximity of main roads and highways increases car trips, while the proximity of transit increases transit ridership

Table 2. Elasticities from VMT, Walking and Transit use with respect to the built-environment variables (Ewing & Cervero, 2010)

		VMT	Walking	Transit use
Density	Household/population density	-.04	+0.07	+0.07
	Job density	0.00	+0.04	+0.01
	Commercial floor area ratio		+0.07	
Diversity	Land use mix (entropy index)	-.09	+0.15	+0.12
	Jobs-housing balance	-0.02	+0.15	
	Distance to a store		+0.25	
Design	Intersection/street density	-0.12	+0.39	+0.23
	% 4-way intersections	-0.12	-0.06	+0.29
Destination accessibility	Job accessibility by auto	-0.20		
	Jobs accessibility by transit	-0.20		
	Job within one mile		+0.15	
Distance to transit	Distance to nearest transit stop	-0.05	+0.15	+0.29

2.7.2 THEORETICAL AND EMPIRICAL RELATIONSHIPS

The quantification and direction of which land use changes the transportation or the other way around is found in various studies, but there is, however, no consensus about the strength of this relationships because of the large variation from region to region (Stead & Marshall, 2001), and because of the multitude of factors influencing land use and transport (Wegener, 2004).

Various studies show the relationships between land use and transport (Cervero & Kockelman, 1997; Crane, 2000; Ewing & Cervero, 2010; Handy, 2002; Kenworthy & Laube, 1999; Stead & Marshall, 2001; Wegener & Fürst, 1999). Central are the aspects:

-density, referring to the density of the built up area,
-diversity, referring to the mix of land use activities within an certain area
-design, referring to the design of the neighborhood and streets
-accessibility, refers to the ease of access of transport modes and the quality of the service
-distance to transport networks, refers to the distance to main roads and transit.

The direction of the relationship between land use and transport is shown in Table 1.

In several studies the impact of the built environment to for instance walking and transit use is quantified. An extensive meta-analysis of Ewing and Cervero (2010) has calculated many of these elasticities, see Table 2. The numbers show the elasticity of the different variables to walking and transit use, for example an increase of 1% in household density would result in 0.7% more walking trips.

Besides the relationship between land use and transport, the land-use transport system is part of a greater urban system, influencing the local economy and to a lesser extent the national economy, social demography, equity, and cohesion, and environmental aspects such as emissions but also access to green spaces, etc. There is only very limited research conducted to the impacts of land use policy on economy and social characteristics. The research mainly focusses on travel, health, and environmental impacts (e.g. Handy, Boarnet, Ewing, & Killingsworth, 2002; Schwanen & Mokhtarian, 2005).

Effects of a compact city policy on the wider context of environmental, sociological, and economic aspects are provided in table 3. From an environmental perspective a compact city policy results in lower greenhouse gas emissions, while it can cause increased local air pollution due to increased transport within the urban area, sometimes called the intensification paradox (Melia, Parkhurst, & Barton, 2011). From the perspective of social sustainability – with social equity and sustainability of community at its core (Dempsey, Bramley, Power, & Brown, 2011) – the effects of a compact city policy are mixed. The study from Dempsey, Brown, and Bramley (2012) concluded that people tend to use more local services and facilities, feel less secure, less social interaction, and fewer green space in neighborhoods with higher densities; they note however that design and layout of the neighborhood influence the perception of safety significantly.

Table 3. Potential impacts of compact city policy (OECD, 2012)

Sub-characteristics of the compact city	**Contribution to urban sustainability**		
	Environmental benefits	Social benefits	Economic benefits
Shorter intra-urban travel distances	- Fewer CO_2 emissions - Less pollution from automobiles	- Greater accessibility due to lower costs	- Higher productivity due to shorter travel time for workers
Less automobile dependency	- Fewer CO_2 emissions - Less pollution from automobiles	- Lower transport costs - Higher mobility for people without access to a car - Improved human health due to more cycling and walking	- Development of green jobs/technologies
More district-wide energy utilization and local energy generation	- Less energy consumption per capita, fewer CO_2 emissions		- Development of green jobs/technologies - More energy independence
Optimum use of land resources and more opportunity for urban-rural linkage	- Conservation of farmlands and natural biodiversity - Fewer CO_2 emissions due to shorter food travel mileage	- Higher quality of life due to more recreational activities	- Rural economic development (urban agriculture, renewable energy, etc.)
More efficient public service delivery		- Public service level for social welfare maintained by improved efficiency	- Lower infrastructure investments and cost of maintenance
Better accessibility to a diversity of local services and jobs		- Higher quality of life due to access to local services (shops, hospitals, etc.)	- Skilled labor force attracted by high quality of life - Greater productivity due to more diversity, vitality, innovation and creativity

They argue that it is important to regard the local context of the neighborhood, in particular as what can be considered a high density varies from country to country. From the economic perspective, the effects are that a compact city policy will reduce transport costs due to improved public transport and shorter travel times, which results in improved accessibility and can therefore stimulate economic growth (OECD, 2012; SACTRA, 1999). The migration of people from rural areas to urban areas is mostly related to the labor market, which in turn is affected by economic growth and especially economic growth due to (international) trade (Mazumdar, 1987). The migration towards urban areas is mostly dependent on the type of work, requiring therefore a specific type of migrant (N. Harris, 1990). There is no correlation found between car usage or car ownership and wealth (Kenworthy & Laube, 1999). The effectiveness and effects of land-use planning are mixed; it heavily depends on the institutional capacity. It appears that land-use planning can successfully alter the course of mobility, improve facilities, services, and reduce poverty, but has difficulties in limiting the demographic growth (United Nations Human Settlements Programme, 2009).

2.7.3 LAND-USE TRANSPORT MODELS

Over the years, the models have developed from spatial interaction models based on the concepts of gravity to econometric models based on random utility, towards micro-simulation: either agent based or cell based models. This is explained in detail in Iacono et al. (2008) and also summarized in Figure 13. Batty (2007) notes that, while the models have become more disaggregated, agent-based and therefore representing more individual based system and very detailed cells; this has not been in line with improved theoretical understanding of the system, but mainly driven by improved computational capacity.

Examples of the early spatial interaction models are the Model of Metropolis developed by Lowry (1964). His model has introduced the basic gravity model, later developed by Wilson (1967, 1970 cited in Iacono et al., 2008):

$$T_{ij} = A_i B_j O_i D_j \exp(-\beta c_{ij})$$

Where T_{ij} represents the number of trips between zone i and j, O_i represents origins at zone i, D_j represents destinations at zone j and A_i and B_j are balancing factors to match the number of trips generated and attracted. The exponential function is a decay function of accessibility. This gravity model is later adopted to determine the likelihood someone is living in zone i and work in zone j, and can be used in a random utility function to determine the number of workers, residents, etc. in a zone.

Most models are using a time-step of a year in which every year the demand and supply are matched in equilibrium, as exemplified in the early Lowry and PLUM models. The behavior of actors is often modeled using the economic theories of random utility or discrete choice theory to explain the behavior (Wegener, 2004). Some cellular automata models consider strong dynamics and do not necessarily require an equilibrium in every time step between demand and supply of transportation, but also land use, services, etc.

Next to the iterative models converging to equilibrium in every time step a new category of models is developed. These are known by using the catastrophe theories. In these models there is a possible equilibrium, but it can also evolve in chaos due to bifurcation. This can be of great interest to see possible states in which a system can develop. Besides this, it can show for what conditions the system is expected to stay stable, which conditions are critical or when the system becomes unstable; this is of particular relevance when considering micro-simulation where several aspects each are modeled on its own dynamic timeframe

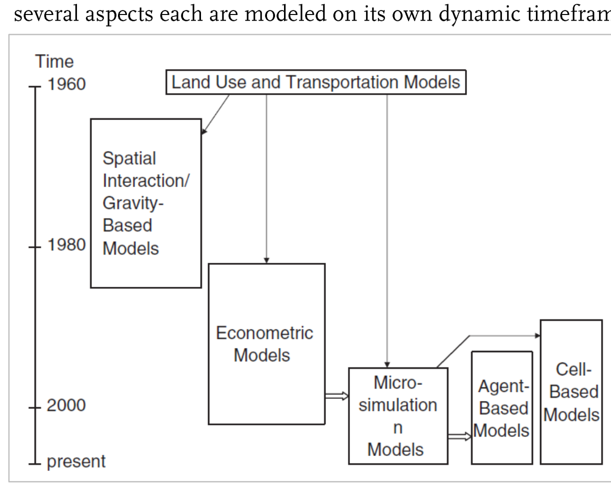


Figure 13. Chronological development of Land use and Transportation models (Iacono et al., 2008)

(Chan, 2005). An example of the application of catastrophe theory to the modal split is given by Wilson (1976), who shows how it is possible that in a continuous function there are certain 'jumps', resulting in certain large and rapid changeovers. These can also be applied to other variables such as the rural urban migration, economic growth (see Andersson & Kuenne, 1987). This is in particular useful to explain how a combination of factors can suddenly result in rapid changes.

The environmental impacts are until now only limited modeled in many current operational land-use transport models. Most attention was paid to the economic impact of land use activities and the transport effects. Recently, LUTI models are incorporating environmental aspects and considering it as important as other parts. In the most detailed version it develops into a urban ecosystem, examples originate from ecology studies and metabolism studies (Lautso et al., 2004).

An overview of the state of the art in operational land-use transport models can be found in Hunt et al. (2005) and Wegener (2004). Other noteworthy studies are the ISGLUTI (unknown[3]) and PROPOLIS (Lautso et al., 2004) studies.

Transport modeling is usually following the four-step model. The idea behind it is to set up a zoning and network system and acquire data of each zone relevant for the modeling purpose (i.e. population size, economic situation, employment possibilities, shopping space, etc. This can be as aggregate or disaggregate as the modeler wants and the data allows). With these data, the total amount of trips generated and attracted for each zone can be estimated (the trip generation). Second step is to allocate these trips to the zones, i.e., they are distributed over the space producing a trip matrix. Third step is to decide by which mode the trip is made, for instance by car or bus, which results in the modal split. And the final stage is the assignment of the trip to the network (Ortúzar & Willumsen, 2011).

Data requisites for this 4-step model are heavily dependent on the level of analysis and aggregation. A more detailed model will require more data, but has a larger measurement error, while a more aggregated model will have a larger specification error, but requires less data and therefore has a smaller measurement error. Trip generation is dependent on car ownership, family size, household structure, value of land, residential density, and accessibility, Trip distribution is usually based on a deterrence function, gravity model and is mainly dependent on a function of accessibility (defined as distance, cost, convenience, etc.). Modal split is based on personal characteristics, journey characteristics, and transport facilities. The final step is the assignment to the current network based on certain criteria such as distance, time, and convenience.

An important requirement of all the models is the need to calibrate and validate the results with the real world.

2.7.4 CRITIQUE AND REQUIREMENTS

The land-use transport models have developed over the decades significantly, but there remains many critiques to the current models (Hunt et al., 2005; Iacono et al., 2008; Supernak, 1983; Wegener, 2004):

- All models are very data intensive requiring data that is not readily available or expensive to collect
- Models should be constructed to advance scientific research, but also be used in policy making (Batty, 1979 cited in Iacono et al., 2008)
- The current theoretical framework is still under development. For instance the use of random utility theory is questioned for choices of residence or mobility (Timmermans, 2003).
- The supply side of transport is only limited researched
- Accessibility is calculated at an aggregate level, while it is clear that is varies from person to person.
- Uncertainty in the modeling is hardly addressed at all, in particular to the certainty of forecasts for decision makers.

In addition to this theoretical viewpoint, Supernak (1983) has pointed out 10 'criteria' of an ideal transport model. These requirements are providing guidelines to which a model should be developed. A similar list is developed by Miller et al. (1998) 15

[3] The author did not have access to the book, but it is mentioned in nearly every study: Webster, F.V., Bly, P.H., Paulley, N.J. (eds.) (1988) Urban Land use and Transport Interaction: Policies and Models. Report of the International Study Group on Land use/-Transport Interaction (ISGLUTI). Avebury, Aldersho

years later, and recently by Waddell (2011). See the overview in table 4.

Much criticism exists to the quality and usefulness of the 4-step model; for instance to the level of aggregation as early versions are developed on extremely aggregate levels without considering much variation in terms of trip purpose, person type, etc. In addition, much criticism focused on the sequential way of calculation and lack of feedback. This is however improved in many modern applications of the 4-step model, for instance by determining simultaneously the trip frequency, destination and trip mode or provide feedback mechanisms regarding congestion or crowdedness (Hensher & Button, 2000; Ortúzar & Willumsen, 2011). Next to this, computational advantages allowed more disaggregated modeling of transport activity.

Table 4 Overview of requirements for a transport model and a land-use transport interaction model according to Supernak (1983), Miller et al. (1998), and Waddell (2011) respectively

Supernak (1983)	**Miller et al. (1998)**	**Waddell (2011)**
- Simple, utilizing easily available data (but not oversimplified or trivial) - Accurate in describing the present situation and reliable as a forecasting tool - Transferable geographically, or easily adaptable for another urban environment - Flexible for aggregation at any geographic level (zone/district/city) - Able to reflect interrelationships between subsequent stages of the urban transportation forecasting process, particularly between car availability (ownership), trip generation and modal split sub-models - Able to reflect the feedback between the transportation demand and supply - Constructed of fully compatible sub-models (e.g. common analysis units) - Able to reflect the interrelationship between transportation and land use - Dynamic rather than static in nature; able to reflect dynamic changes in all the sub-systems involved - Sensitive to transportation and other policies	- Theoretically sound and consistent - Result-driven and precise, but taking into account data availability and other practicalities - Responsive to the issues faced by policymakers, transit operators and other actors involved in urban transport planning - Cognizant of the regional, state, national and global demographic and economic inter-relationships - Practical to operate, resulting in usable outputs and transparent - Sufficiently flexible to accommodate different scales of cities and regions - Presentable outputs for decision makers	- Transparency to gain credibility as a tool in land-use planning - Behavioral validity to be believable as an independent artefact with some clearly defined scope of applicability - Empirical validity, the model should be tested against observed data - Ease of use, it should be possible for staff within planning agencies to become capable users, the easier the better - Computational performance, real time simulation is essential; but not at the cost of realism - Flexibility, the model needs to be adaptable to different conditions - Data availability and quality - Uncertainty to make risk assessments of alternative policy choices or infrastructure investments

3 EVALUATION FRAMEWORK

This chapter determines the criteria of a model that is useful for the actors on deciding upon more sustainable land use patterns and is theoretical sound in modeling transport emissions. It will therefore conclude on the actors involved in land-use planning and set out the context in which they work. Secondly, it determines what the modeling possibilities are and how they can assist in land use planning. The theory described in the previous chapter is synthesized and complemented by interviews with and presentations of Asian Development Bank (2012b); Batangas Municipality (2012); Cities Development Initiative for Asia (2012); Metropolitan Manila Development Authority (2012); Piantanakulchai (2012); University of Moratuwa: Colombo (2013). The first paragraph will apply the problem solving cycle of Kolkman (2005) and describe the problems in urban planning in developing Asian cities, and what the goals and capacities are of the most important stakeholders (the essential first step in policy analysis (Walker, 2000)). The emphasis is on the actors involved and their context. The second paragraph is applying the model development cycle of Kolkman (2005) and shows the possible model development directions, depicted from the current system knowledge and state-of-the-art in land use, transport, and emissions modeling. This provides insights in the current possibilities and limitations in land-use transport emission modeling. The third paragraph derives requirements for a model, which integrates the requirements from the different actors, the context of developing Asian cities and the current possibilities in modeling the land-use transport system.

3.1 LAND-USE PLANNING IN DEVELOPING ASIAN CITIES

3.1.1 PROBLEMS

Developing Asian cities are experiencing various problems with urban development and land-use planning. The main problems are: (1) the demographic growth, (2) the global need to mitigate and adapt to climate change, and (3) a weak institutional framework.

The demographic growth is exemplified in urban areas due to the natural growth of the population, but also because of migration to urban areas, especially to the capital cities. Planning for accommodating all these people is a daunting task in itself, in particular to not marginalize the poor. While the demographic growth is one problem it is also the driver, together with economic development, of various other problems, such as a shift towards private vehicles, hence an increase in emissions.

Secondly, the global problem of climate change due to the emission of greenhouse gasses is rising. To mitigate climate change, action has to be taken and Asia is already contributing more than the world average (United Nations Human Settlements Program, 2011). The biggest driver of these problems is demographic and economic growth. The emissions need to be reduced to not further contribute to climate change; while at the same time, most cities need to adapt to climate change. Most developing cities either will experience flooding from the rising sea level or increased occurrences of extreme weather events.

Thirdly, developing Asian cities have a weak institutional framework for urban planning. This is due to various reasons: i.e. the decentralization of policies from the national government to local governments; while on the contrary the need for metropolitan urban planning encompassing multiple local governments. The decentralization to local governments was not accompanied with the responsibility to collect local taxes, creating a dependence on funds from the national level for the implementation of local policy. The local government bears the responsibility for local planning but lacks the expertise and skills to actually develop such plans. The institutions are weakly cooperating or integrating and sharing knowledge. Final tension is that the urban population and the economy are growing at such a pace that plans, once implemented, are already outdated; the same applies to the collection of data.

These are the problems and the drivers that need to be understood in the planning process in developing Asian cities.

3.1.2 STAKEHOLDERS

Stakeholders are important in the process of land-use planning (Walker, 2000), as it is a political decision (Rondinelli, 1973), the necessary legitimization for and design with the public (Couclelis, 1991, 2005), the influence of land-use planning on other communities (Calthorpe & Fulton, 2001), the balance necessary to find among different stakes (Healey, 2007; Salet & Thornley, 2007) and the need to enable everyone within the planning process (B. Harris & Batty, 1993; Healey, 2007; Roberts & Kanaley, 2006). Kolkman (2005) has identified three groups of actors: decision makers, scientists, and stakeholders. Each group has a different stake and role within the process of policymaking. In addition, each has its own frame and idea from where they rationale which is important to understand.

Roberts and Kanaley (2006) put central the local policymakers, with the respective national context, and the role of international development organizations. In the interview with the University of Moratuwa: Colombo (2013) it became clear that the involvement of an international development organization has a large influence on the way a project is developed.

Therefore, two actors are identified as important in the process of urban planning: local policymakers within the context of the national government and the international development organizations.

The scientist, as identified by Kolkman (2005) as an important actor in model development, tries to integrate the knowledge from different disciplines, and is considered as an important actor regarding the development, but not as an end-user. The knowledge and integration of knowledge will be elaborated on in the next paragraph.

In the following paragraphs these two user perspectives is zoomed in on. A brief introduction with the capabilities in terms of their knowledge and expertise, their institutional structure, and the focus of their objectives/goals is given first.

Local policymakers

There is a lot of variation as to how a city is developing policy and in which context they are operating. However, some generalizations can be made out for most of the developing Asian cities.

1. The knowledge and capacity of local policymakers is limited. Although over the years the conceptual ideas of sustainable transport have been integrated in more and more plans, a coherent story is rarely implemented. For instance, Bangkok has various implementation of light rail systems and implemented a bus rapid transit system, but this is independent from each other and connections between the systems are limited. GIS capacity is limited, and in an early phase of development. Understanding and explanation of the concepts of sustainable development, sustainable land use and sustainable transport is essential in successfully implementing a project.
2. The institutional structure is complex. There is limited coordination between departments. Land use and urban planning are not yet seen as a multidisciplinary task, master plans are developed for one department instead of an integral plan for several disciplines. There is no central institution that gathers all data, each department gathers its own data, and the

data is usually only available for local policymakers and is not shared with other institutions, in particular foreign institutions. Next to this, there is only limited enforcement possibility of land-use planning. The problems of a city usually comprise multiple municipalities. It differs greatly from country to country if there is a metropolitan development authority, which has the power to develop and enforce a land use plan comprising the whole metropolitan region. Final problem with the institutional structure is that most cities do not have sufficient funds to implement projects. It is however possible to provide financial support with loans from national government or development agencies; the local governments are usually able to provide support in kind by providing work force and workspace.

3. The focus and objectives are short term, while long-term planning is mostly developed on the national level; decision-making is limited to time up to the next elections, while land-use planning is requiring a strategic long-term vision, developed in line with the local situation. The focus is also on the most visible problems such as congestion. Anticipation to population growth and economic growth is not known or overlooked. National policies tend to focus on capital regions for economic competitiveness reasons. Smaller cities are therefore overseen, creating an even greater gap between knowledge, expertise, and growth between the capital cities and the smaller cities.

Development agencies

The main development agencies in Asia are the World Bank and the Asian Development Bank. However, there exist many national development agencies, such as US Aid (United States of America), SIDA (Sweden), GIZ (Germany) that are also involved in assisting cities with their urban planning.

1. The knowledge and expertise of development agencies is very different from local policymakers. They have a lot of in-house expertise or the ability to hire external consultants with specific knowledge on urban land-use planning and reductions of emissions. Next to this, the larger development agencies, such as the Asian Development Bank and the World Bank have offices in nearly every country to assist in the countries development. This is also immediate their goal: to eradicate poverty by assisting countries and cities with their development (Asian Development Bank, 2012a; World Bank, 2012). The development agencies do not have the resources to conduct all aspects of a planning process or implementation; they rather use local resources and bring in their expertise. One recent development is the improved recognition of the relationship between land use and transport as sources of emissions, in combination with the new role development agencies are taking to provide more technical assistance instead of providing loans for infrastructure; creating a desire to provide tools and methods for local policymakers to assist them in their urban planning. Requirements are that they can be used in many situations and places, but also specific enough to be of use in the local situation.

2. Development agencies focus on working with national governments, rather than local city governments and tend to be sectorial based instead of multidisciplinary. However, coordination between departments and sectors is better organized. Data collection is dependent upon the local context. They do collect their own data, but that is often national oriented rather than detailed at the local level. A requirement of ADB funding is an assessment of the impacts, also on the environment. In many projects it is therefore essential to calculate the emissions, in scenarios with and without the project. The funding is project focused; the horizon of a project is independent and can be long-term and short term.

3. The goal of the development agencies, however, varies, but focus on eradicating poverty as their mission. However, over the years the goals have expanded to the millennium goals including mitigating climate change, as it is the poor who are affected the most by climate change and environmental damage. As one staff member puts it: “CO_2 is the flavor of the day” hence climate change mitigation and reducing transport emissions is one of the main focus of development agencies.

3.1.3 CONCLUSIONS

Any model assisting in the urban planning should be cognizant of the drivers and aware of the current problems in developing Asian cities. These are:

- Demographic growth, along with economic growth
- Climate change
- Weak institutional framework.

Table 5. Comparison of local policymakers and development agencies

	Local policymakers	Development agencies
Knowledge	Fairly limited	Highly skilled and trained, or ability to hire expertise
Resources	Many human resources, mostly in kind and work force and limited availability of money.	Limited resources in terms of work force, but has more possibilities of funding in cash.
Institutional	Tension between national and local governments, dependence on national funding. Limited coordination between departments.	Mostly focused sectorial on national governments, but more coordination between and required methodologies
Objective	Reduce visible problems such as congestion, informal settlements, and air pollution, etc.	Eradicate poverty and reduce environmental damage, locally and internationally
Focus	Focus on visible short term projects	Focus on sustainable improvement, both short term and long-term
Required details	Very local, on the neighborhood level, quantified if possible.	Quantified and measurable results at the city level

The two perspectives on the stakeholders show some overlapping but also various differences. In developing a sketch-planning tool for land-use planning the two will have different requirements. This is summarized in Table 5.

The problems at hand and the view from stakeholders in urban planning in developing Asian cities do not match completely. Proposing land-use planning as a sustainable manner for reducing transport, hence emissions is possible but there has to be awareness that local policymakers tend to focus short term and on visible problems such as congestion and informal settlements, while development agencies tend to focus on long-term strategic planning in the case of capacity building. The development agencies lack the capacity to finance all infrastructural projects. In developing a sketch-planning tool, the developer should therefore be aware of this contradiction, while still able to address the most important drivers and problems of developing Asian cities.

Translated these problems and drivers into requirements for a model to be useful by the stakeholders:

- It should be cognizant of the drivers of urban land use
- It should be able to be used on a strategic level to improve urban planning by local policymakers, requiring therefore also to be responsive to strategic policy measures
- Decision makers should be able to understand, handle, interpret and communicate the results, requiring therefore a certain 'ease of use' and 'transparency'
- It should be flexible in data input requirements, therefore being able to handle different data sources in terms of aggregation and quality
- The costs of implementing and using the model in terms of money and resources should be acceptable to the local policymakers or the development agencies
- It should cover the whole study area, and the relevant pollutants and sources, considered important by the local policymakers or the development agencies.

3.2 MODELING LAND-USE TRANSPORT EMISSIONS

Important aspect of any model is the integration of knowledge from several disciplines. As noted before there are two important actors in the process of land-use planning in developing Asian cities: local policymakers and the development agencies. They represent the local policy context and therefore the problem-solving context. The third actor in any model development process, as identified by Kolkman (2005), is the scientist. The scientist is part of the model development cycle and represents the system knowledge, which tries to integrate the knowledge

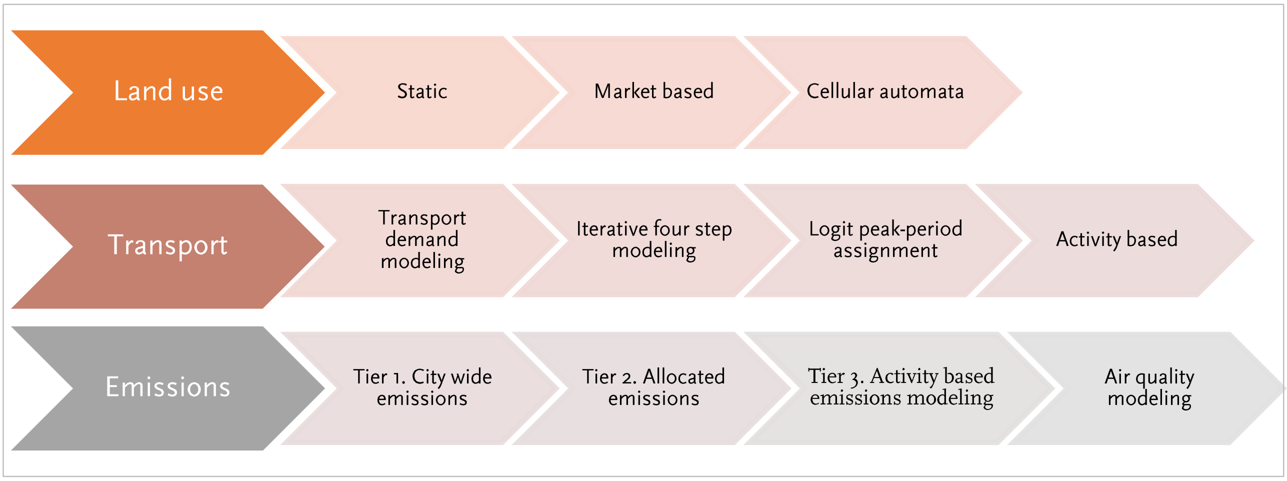


Figure 14. Classification of possible model directions, from simple to advanced models in the categories Land Use, Transport, and Emissions

from several disciplines. The scientist has to understand how to communicate/desires to the local policymakers and stakeholders.

Land use, transport, and emissions are interlinked as described in the literature framework in chapter 2. The modeling of each aspect has also a long tradition. Most recently, these three have become more and more integrated. Efforts of land use and transport interaction exist much longer, but also transport and emissions are becoming more integrated. Recently also models incorporating all aspects have been introduced, such as the models of Calthorpe Associates (2011), SIMPLAN (Adhvaryu, 2010, 2011a, 2011b; Adhvaryu & Echenique, 2012) or UrbanSim (Noth, Borning, & Waddell, 2003; Waddell, 2002)

In detail, the following classification of model direction is made which shows directions of how a model can be advanced (Figure 14); it is from simple to advanced modeling efforts. The classification is however far from complete or absolute; various mixes or alternative models exist, the ones presented are considered by the author as the most important ones.

Several models are put forward to compare a sketch-planning land-use transport emissions tool that exhibits the aspects required by the local context:

- Air quality modeling as an advanced version of emissions modeling
- Emission inventories, from international guidelines such as IPCC, EIA, EPA and EEA
- Land-use transport interactions models, such as LSUM, Cellular automata, etc.
- Planning support systems as a tool for sketch-planning

Various alternative models exist, e.g. greenhouse gas accounting tools or simple land-use transport models. These are however difficult to classify as they have very different characteristics.

The local context of developing Asian cities prescribes that it uses minimal resources; it is without saying that land-use planning as a method to reduce transport emissions needs to be responsive to policy. A local scale is essential in any urban planning process.

The comparison to other models shows that planning support systems is the only type of model that can inhibit all aspects required from a theoretical perspective, as it can integrate land use, transport, and emissions within one model, can be applied to the local context at the local scale, is responsive to policies, and uses minimal data resources. While, the other model types can provide insights into how a model can be advanced and what the limitations/possibilities are of each model.

Hence, derived from the different distinct fields of model development, each model aiming to estimate emissions from transport based on land use has the following requirements:

- It should be able to reflect the relationships between land use and transport, in greater detail:
    - the feedback relationship between land use and transport as described in the theory

Table 6. Comparison of modeling requirements to existing model types

	Incorporate land use maps	Calculate transport	Calculate emissions	Responsive to policy	Local scale	Use minimal resources
Air quality models (Friedrich & Reis, 2004; Moussiopoulos, 2003)	Not directly, mostly emissions inventories	No	Yes	Usually not, but possible	Yes could be	No, very complicated modeling, requiring also additional validation with specific measurements
International guidelines such as IPCC (IPCC, 2006)	No, it uses either fuel sales (tier 1), or traffic counts and emission factors (tier 3)	Yes, that is the objective of the guidelines		No, it is a static estimation of emissions.	No, developed to estimate emissions on a national level	Yes, Via a tier based approach
Land-use transport interaction models (Hunt et al., 2005; Miller et al., 1998; Wegener & Fürst, 1999)	Yes	Yes	Not designed to, it estimates mainly transport activity	Yes	Yes	Usually no, particular 'the ideal' models are requiring a large number of input variables
Planning support systems (Te Brömmelstroet, 2010b; Vonk, 2006)	Yes	Possible	Possible	Yes	Yes	It requires an initial set-up but afterwards is easy to use.

  - calculate correctly the different steps of trip generation, distribution, modal split, and assignment
- It should use one of the good practice methodologies for estimating emissions from transport and implementing it correctly
- It should be empirically and behavioral valid; describing therefore the scope of application and being tested against observed data
- It should be modeled consistently, as in the detail in the input data should be matched with the detail used in the methodology and given in output

These are the basic requirements; the interpretation is dependent on the balance between the usefulness and possibilities as set out in the previous paragraph.

3.3 REQUIREMENTS FOR A SKETCH-PLANNING LAND-USE TRANSPORT EMISSIONS MODEL

This chapter has presented a framework for sketch-planning for land-use transport emissions in developing Asian cities. It has shown the drivers and problems of the cities and directions to which a model can be developed to estimate transport emissions. Next to this, model development guidelines have been developed of what an ideal model has to incorporate. As noted earlier, there is a tradeoff between what is possible theoretically, useful for the end-user and practical in developing Asian cities.

The following criteria are formulated that a sketch-planning tool for land-use transport emissions should fulfill (Chang & Hanna, 2004; EEA, 2012; Fehr & Peerce, 2009; Friedrich & Reis, 2004; Hickman, 1999; Hunt et al., 2005; IPCC, 2006; Lee, 1994; Miller et al., 1998; Moussiopoulos et al., 2005; Supernak, 1983):

1. **Usable: for policymakers and urban planners to be able to decide, use and implement the model in parts of the urban planning process**

1.1. is the model cognizant of the drivers of the problems of the urban planning process in developing Asian cities

1.2. can the model be used on a strategic level for urban planning, and is responsive to different strategic policy measures

1.3. are end users able to understand, handle, interpret and communicate the results

1.4. is the model flexible in terms of data input requirements to adapt to the availability of local data, adapt to different timeframes, and local circumstances such as different vehicle fleets, travel behavior, and land use patterns

1.5. are the cost of implementing and using the model in terms of money and resources acceptable to end users

1.6. is the whole study area and are all pollutants and emissions sources covered that are considered important by the respective end-users

2. **Theoretically sound: incorporating land use, and calculating transport activity and emissions correctly**

2.1. is the model able to reflect the relationships between land use and transport, i.e. reflect calculates land use activity, trip generation, trip distribution, modal split, and assignment

2.2. is the model using good practice methodologies for estimating emissions and implements it correctly

2.3. is the model empirically and behaviorally valid

2.4. is the model consistent throughout the model, in terms of input, methods, and outcomes

The evaluation framework with an explanation of each requirement can be found in Appendix A.

The criteria are translated into a descriptive three-point scale to provide an indication of what is minimal required and when something is considered weak or excellent. Excellent is defined if it exceeds what is minimal required, it meets all core requirements and provides additional features. Satisfactory is the minimum and should be met by a sketch-planning tool: it defines the core aspects of a sketch-planning tool. While weak is defined when a model misses a core aspect or has major deficiencies. This descriptive framework can only be used in assessing the

Table 7. Descriptive evaluation framework, with satisfactory defined as the 'core' of a sketch-planning tool, weak if it has major deficiencies and excellent if it adds aspects to the model which are not necessarily required but improve the quality of the tool

Usable	Excellent	Satisfactory	Weak
1.1 Cognizant of the drivers of urban planning	Models the drivers endogenously or requires them explicitly	Considers all drivers	Misses one of the drivers
1.2 Strategic planning level	Provides easy to use and changeable long-term policies	Provides possibilities for long-term policies	Does not provide long-term policy options
1.3 Easy to use and communication	Provide easy to use and understandable results at various levels of detail, so that both end-users can use the results	Provides easy to use and understandable results for one of the two end-users	Provides unsatisfactory results for both end-users
1.4 Adaptable and flexible	The model can be used in any Asian city and in the lack of local data international back up values are implemented	The model can be used in any Asian cities	The model cannot be adapted to all local situations
1.5 Cost of implementation	The model is able to be set up in a few months using existing or to collect easily data	The model is able to set up in a few months but requires the collection of unusual data	The model takes considerable amount of time to set up
1.6 Complete and comprehensive	All transport sources and all relevant pollutants are included at the right scale, covering a relevant study area	The largest transport sources are included or the most relevant pollutants are calculated and uses a comprehensive study area	The model is only modeling the fuel consumption and only one pollutant at the right scale and is using not using a comprehensive study scale

Table 7. continued

Theoretical sound	Excellent	Satisfactory	Weak
2.1 Modeling land use and transport	The feedback link between land use and transport is completely modeled, and the four steps of transport modeling are included, using detailed disaggregated approaches	The feedback link between land use and transport is completely modeled, and the four steps of transport modeling are included	The feedback link between land use and transport and the four steps of transport modeling are not fully modeled
2.2 Modeling transport emissions	The model is implementing all aspects of the ASIF formula, and calculates the pollutant at the appropriate scale, with allocated emissions to the zonal level	The model is implementing the ASIF formula and the pollutants are modeled at the appropriate scale	The model is calculating emissions based on fuel consumption instead of activity and the pollutants are not modeled at the appropriate scale.
2.3 Empirically and behaviorally valid	The model is fully validated, provides sufficient possibilities of validation and behaves as expected from theory	The model is validated and it behaves as expected from theory.	The model is neither validated and does not behave as expected from theory
2.4 Consistent	All parts of the calculation are made at a similar scale and in similar detail. The data input matches the outcomes, the temporal scales match the spatial scale and the model is sensitive to multiple parameters	The input variables and the outcomes are at a similar scale and dimensional consistent, the calculations are not dependent on one variable	The data input does not match with the outcomes, the temporal and spatial scales do not match and the model is sensitive to one parameter

quality of the implementation of a model; it cannot capture the conceptual idea behind the model.

4 ASSESSMENT: RAPID ASSESSMENT OF CITY EMISSIONS TOOL

RACE calculates emissions from transport and buildings and incorporates land use maps, spatial form, and default values to make the calculations. The results are presented in GIS maps to show how and where emissions will increase in further years and a quantification of the total emission of CO_2, NO_x, and PM. RACE is an ongoing project; the version of RACE under review is of June 2012. The application and results are used from the application in three cities: Ahmedabad, India; Ho Chi Minh City, Vietnam; and Colombo, Sri Lanka. RACE calculates two distinct emissions sources: transport emissions and building energy use with respective emissions. Only the transport calculations are reviewed and part of this research. This chapter is providing a detailed analysis of RACE. Therefore, RACE is confronted with the evaluation framework as described in the previous chapter.

The insights in RACE are gained mainly by the analytical tests described by Forrester and Senger (1980), in particular their core tests, and the methodology report regarding RACE (Clean Air Asia & Chreod Ltd., 2012). This is complemented by:

- the discussions with staff members of Clean Air Asia and the report regarding RACE (Clean Air Asia & Chreod Ltd., 2012),
- presentations of the model for Metropolitan Manila Development Authority (2012) and Batangas Municipality (2012),
- interviews with Asian Development Bank (2012b); Cities Development Initiative for Asia (2012); University of Moratuwa: Colombo (2013)
- comments received from Tan and Van (2013) for the Ho Chi Minh City case study and the interview with prof. Amal Kumarage (2013) from the University of Moratuwa regarding the case study of Colombo.

This provided on the one hand a qualitative evaluation of the functionality of RACE and on the other hand, an analytical analysis of how RACE behaves under different circumstances and shows how RACE is modeled.

A brief introduction to RACE is given in the first paragraph, showing the process and objective of RACE. Detailed information regarding RACE with all requirements is given in appendix B. In paragraph 4.2 and 4.3 RACE is evaluated. Each criterion will describe first how RACE has implemented the criterion and second how this compares to the requirements as set out in the evaluation framework.

4.1 DESCRIPTION OF RACE

4.1.1 OBJECTIVE OF RACE

The objectives of RACE, derived from the draft report of RACE (Clean Air Asia & Chreod Ltd., 2012), multiple conversations with Clean Air Asia staff members and ADB staff members are:

- To provide a rapid environmental assessment of transport emissions
- To give a visual representation through GIS of the implications of land use and transport to identify concrete spatial policies and measures.
- To analyze at a strategic level the implications on energy use and emissions of the actual urban development, land use and transportation infrastructure in place and possible future scenarios.

Sub-objectives:

- To help in localizing Nationally Appropriate Mitigation Actions and identifying appropriate interventions.
- To strengthen the assessment of potential CO_2 reductions of climate change mitigation relevant projects (helping MRV projects).
- To provide good and up-to-date GIS maps.

The model is developed with funding from ADB. The initiative was taken because of the need for planning tools in Asian cities and an increased recognition of the feedback relation between land use and transport. Sustainable development is central in nearly all projects of international development agencies (IDA), in particular a reduction of CO_2 emissions is in the interest of IDA.

Other requirements are that the model should require minimal data collection, or use data input that is readily available in the city and the model should be quick-scan, rapid, and easy to use to minimize time of implementation and provide a preliminary result that can be used in further analysis.

4.1.2 METHODOLOGY OF RACE

RACE is using what-if scenarios to show the impact of possible future developments in terms of emissions. The scenarios are made for a 20-year timespan and cover a 'business as usual' (BAU) scenario and an alternative scenario (resilient and low carbon scenario, LCR). These values are compared to the baseline and provide an understanding of where and how emissions will develop in the coming decades.

The scenarios involve an analysis of demographic and economic development, in combination with expected investments in

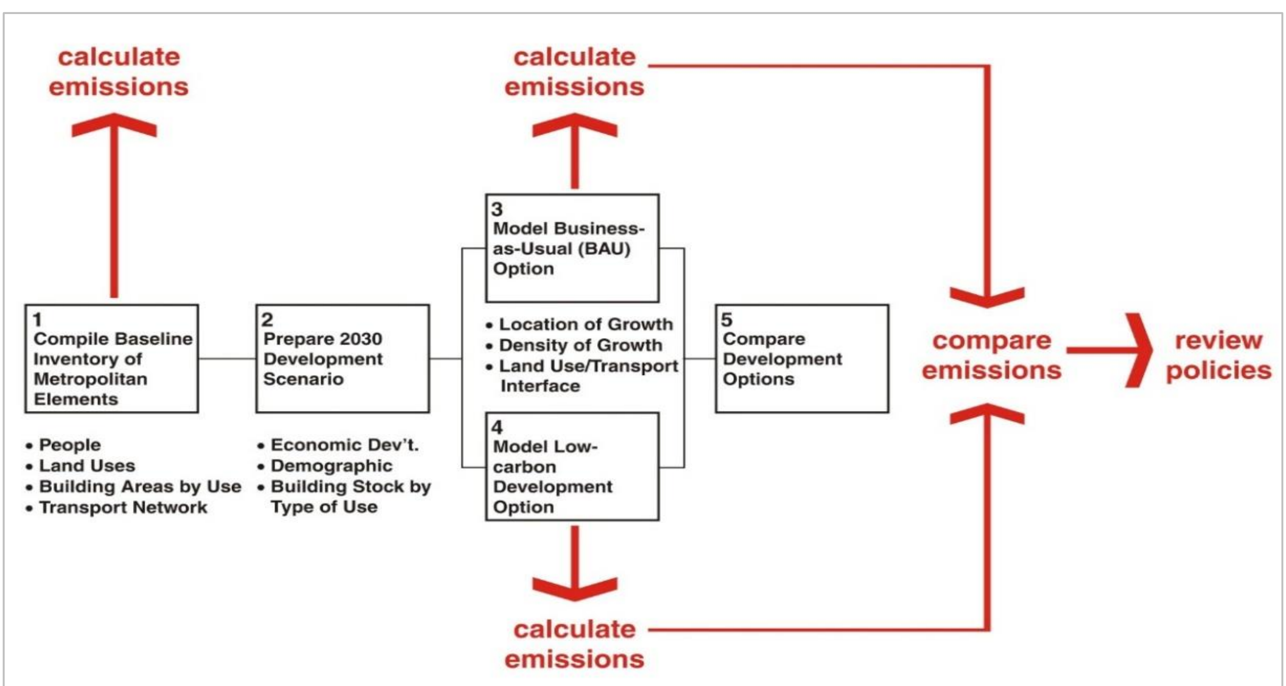


Figure 15. Outline of RACE process (Clean Air Asia & Chreod Ltd., 2012)

transport infrastructure. The emphasis is on a different land use pattern. See Figure 15.

The calculation of transport emissions is following four steps:

1. Determine land use characteristics of current and future developments
2. Calculate emissions from land use activity and transportation
3. Plan for integrated land use and transport measures (e.g. mixed land use developments, increase public transport, etc.)
4. Communicate it visually to stakeholders.

Step 1 starts with determining the land use characteristics of a city. This is conducted by using a 500x500m grid and estimates the gross building areas in the cell for different functions, such as commercial, residential, or industrial functions. In total, the model can handle 21 different land use categories. This is done in a GIS program; the results are transferred to a spreadsheet program (in this case Microsoft Excel 2007).

Step 2 is to calculate the emissions from transportation. This is based on the ASIF methodology as developed by Schipper et al. (2000) and discussed in section 2.6.2. The gross building area per cell determines the production and attraction of a zone for transportation. Based on average number of trips and a simplified gravity model to determine the trip distance between two districts the total transport volume is determined. The gravity model is using a friction factor β and the distance as the main aspects for the trip generation, attraction and the trip distribution. The distance is calculated by measuring the Euclidean distance. See Figure 16 for an overview of the calculation steps made in the spreadsheet.

Step 3 is to construct scenarios with alternative land use developments. It compiles in the total transport activity a similar way as is conducted to determine the baseline. Alternative developments changes the land use patterns according to the 5D's of Cervero and Murakami (2008) as the drivers of a more sustainable urban development. The scenario development is mainly carried out by Chreod Inc. (2011).

Step 4 is to communicate and present the results to city officials to improve the actual planning of the city. The results can be presented at a city level, district level or at the cell level; results presented at the cell level can be shown in a map. In Figure 17 a detailed list of possible outcomes and the sensitivity of these outcomes to all the input variables is shown.

In appendix B, detailed information is provided regarding the flow of calculation, the required parameters, and the model in formulas.

4.2 USABLE

Usable: for policymakers and urban planners to be able to decide, use, and implement the model in parts of the urban planning process

This paragraph will describe the usability of RACE, therefore the criteria of the evaluation framework are used. In each paragraph first the methodology and possibilities of RACE is described and second how this compares to the requirements.

4.2.1 COGNIZANT OF THE DRIVERS OF URBAN PLANNING

Is the model cognizant of the drivers of the problems of the urban planning process in developing Asian cities?

Implementation of RACE

RACE determines the population size for the base year (in the case studies 2011) based on census data available at the district level. The districts are allocated manually to the 500m cells. The population size and economic development in future scenarios are determined based on comparable other cities in the region and expert opinions.

The model can implement a hazard map, including all areas that are prone to earthquakes, floods, tsunamis, etc. This depends however on the availability of such maps. The model does not actually calculate these maps.

RACE has implemented the three case studies with the help of a Canadian firm, Chreod Inc., who developed the GIS maps, with verification by local counterparts. The calculations were carried out by Clean Air Asia. Data was made available by local counterparts. Currently RACE is being implemented by the local authorities, with assistance from Clean Air Asia, hence shifting the responsibility to the local authorities.

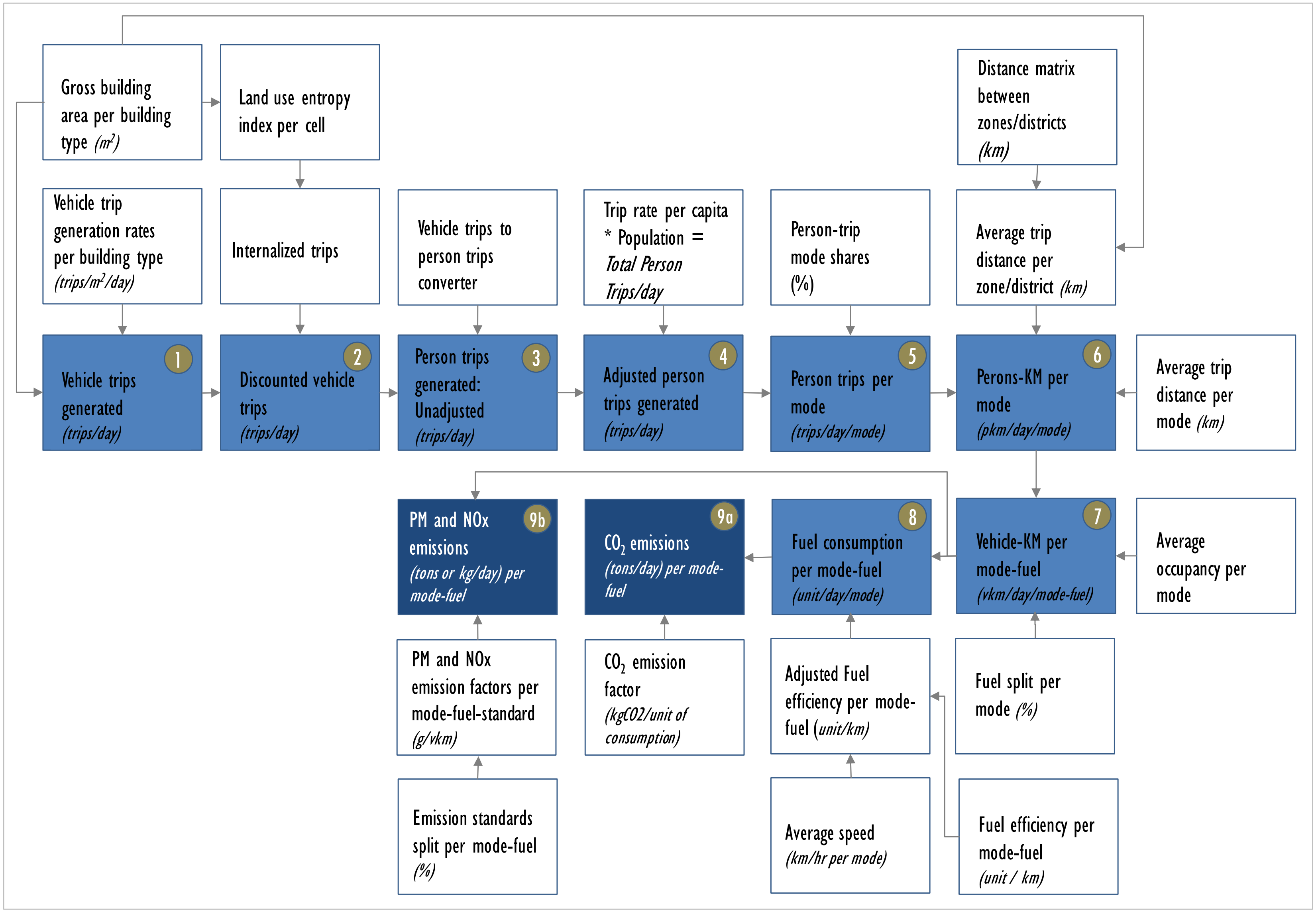


Figure 16. Calculation steps of the transport volume and respective emissions

Assessment of RACE

Cognizant of the drivers of urban planning	Satisfactory: Considers all drivers, but does not model them endogenously or explicitly requires them

RACE is cognizant of the drivers of the problems of urban planning. It does incorporate the demographic and economic changes, climate change is not mentioned specifically but the effects of climate change are included and the objective of RACE is to reduce emissions, hence mitigate climate change. One limitation is that the model does not actively provide the risks of the new urban planning and is therefore relying on locally available data. An improvement would be to include hazard maps explicitly when implementing the model.

The weak institutional framework is partly addressed in RACE. The model integrates various disciplines and requires data from various departments, but it does not specify how the model contributes to creating a stronger institutional framework, besides providing insights. In the current application of RACE in Batangas city (Philippines) the responsibility is shifted, the local authorities are not only required to provide the local data, but also to undertake the implementation in the model. This is a good improvement, as it enables the local policymakers to realize what is changed and how their city will develop. Important to provide in that case is also the necessary theoretical background with the implications of each modification they make, so the tool does not become just a model to provide the right numbers for the wrong policies.

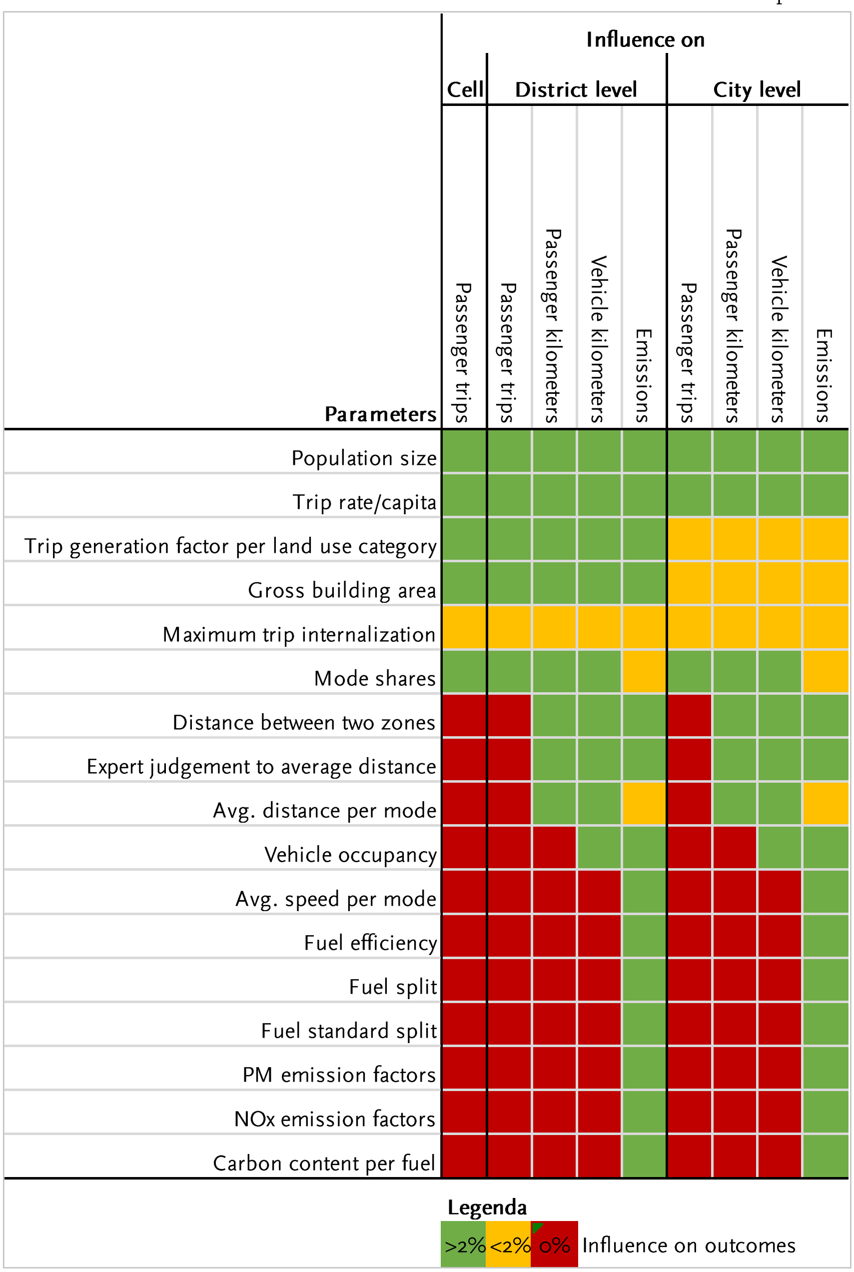


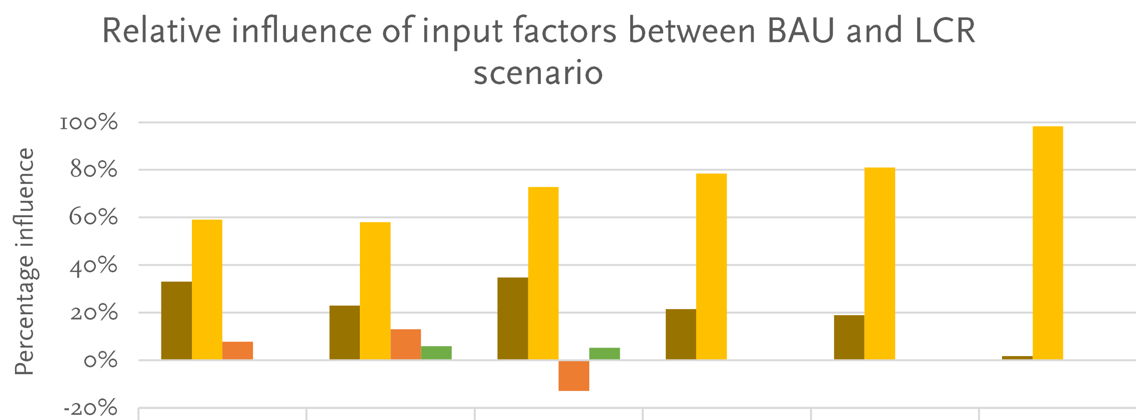
Figure 17. Sensitivity of the outcome variables of RACE, considering a 10% increase of the input variable

4.2.2STRATEGIC PLANNING LEVEL

Can the model be used on a strategic level for urban planning, and is responsive to different strategic policy measures?

Implementation of RACE

RACE calculates the volume of traffic and total emissions for a baseline scenario and develops two scenarios for the year 2030. The future scenarios are a business as usual scenario and a low carbon resilient scenario. The economic growth and



	CO_2	PM	NOx	Vehicle kilometer	Passenger km (motorized)	Passenger trips (motorized)
Land use	33%	23%	35%	22%	19%	2%
Mode shares	59%	58%	73%	78%	81%	98%
Fuel split	8%	13%	-13%	0%	0%	0%
Emission standard	0%	6%	5%	0%	0%	0%

Figure 18. Factors explaining the difference between the BAU and the LCR scenario

population size is considered the same. The difference is made in:

- the location of growth, based on accessibility indices and development constraints
- the density of growth, based on planning assumptions
- the land use mix of growth, also based on planning assumptions
- the extent of integration of land uses with transport infrastructure

However, several other variables are also changed. Between the business as usual scenario and the low carbon resilient scenario four factors are changed: the land use, the mode shares, fuel split, and the emission standards. The changed land use pattern accounts for about 30% in reduction of emissions and 20% in VKM and PKM. The number of motorized passenger trips is only limitedly influenced. The total number of trips is the same in both scenarios. The changed modal split has the largest impact, about 60% of reduction in emissions and accounts for around 80% in the changed VKM and PKM. The fuel split and emission standard explain only 5% of the difference between the two scenarios and do not influence the VKM, PKM, or trips, see Figure 18.

RACE does not provide any standardized scenarios or policy options. It is up to the user what kind of scenario is being developed.

Assessment of RACE

Strategic planning level	Satisfactory: Possible to implement long-term strategy policies, but those are not calculated within the model and are limited to land use projects and no infrastructure projects.

Assessment of RACE on this criterion determines that it definitely involves long-term strategic land-use planning: this is the main variable being changed in the model. The model is able to show alternative land use plans and calculate the volume and distance of trips generated, hence the transport emissions. However, RACE is also influencing the modal split. This is an exogenous variable of the model and there is no clear argumentation to why the modal split is changed, in particular the magnitude of the change. RACE can provide a first sketch plan of directions of development and the implications on a strategic level, but it should be careful to provide exact quantification as the modal split is of great influence and this is one of the factors not calculated within the model, see Figure 18 and the theoretical quality of the model in paragraph 4.3.

The strategic level limits the possibilities of RACE. It can identify areas, which will have presumably a high number of trips because of the land use and are therefore suitable for introduction of public transport and so forth. Infrastructure related projects, such as the influence of the introduction of a new transit line cannot be calculated within the model, only assumptions regarding the modal split can be made and land use can be adapted to the new transit line. Therefore, there are boundaries to what the model is able to do: it can show the impact of land use on trip generation, hence transport emissions. But, it cannot identify possible projects (tactical level) or the implications of the implementation of a project (implementation level).

A comparison to the objectives of RACE shows that these are partly met. RACE can identify and provide a strategic environmental assessment on the city level, but due to the way the calculations are made, it is not possible to identify concrete localized spatial policies. The assessment stretches only the total amount of emissions at a city level and detailed analysis is therefore not possible. The model is able to provide a scenario of how land use could look like in 20-year time, based on analysis of the drivers of urban development: population and economic growth. The scenarios used do not consider the influence of a successful land use policy on the economy and potential increase of migration to the city. This is something the model could provide insights in as well, as a city can fail because of its own successful land use policy.

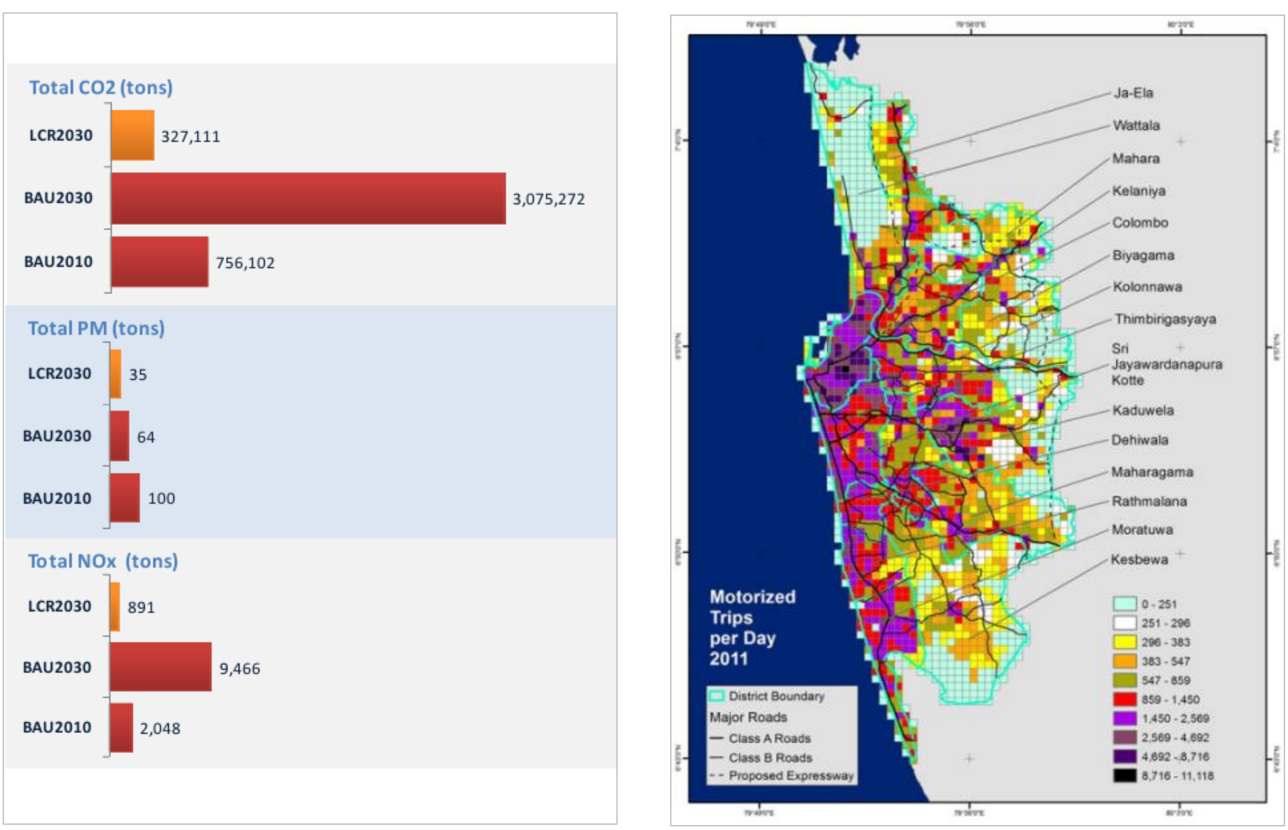


Figure 19. Draft results of Colombo, left: comparison between the three scenarios, right: the number of motorized trips per day per cell in the baseline scenario (Clean Air Asia & Chreod Ltd., 2012)

Table 8. Output variables of RACE

Output	Level of detail1	Detailing
Land use entropy	Cell level	-
Passenger trips	Cell level	Per mode
Passenger km	District level	Per mode
Vehicle km	District level	Per mode
Fuel consumption	District level	Per mode, per fuel
NO_x emissions	District level	Per mode, per fuel
PM emissions	District level	Per mode, per fuel
CO_2 emissions	District level	Per mode, per fuel
Average trip length	City level	Per mode

4.2.3 EASY TO USE AND UNDERSTANDABLE

Are end users able to understand, handle, interpret, and communicate the results?

Implementation of RACE

RACE is developed with funding from the Asian Development Bank and is implemented by Clean Air Asia with assistance from the local counterparts, usually universities. In a current application in Batangas city (Philippines), US Aid is funding the project and it is implemented by local policymakers with assistance from Clean Air Asia. The steps of implementation are described in paragraph 4.1.2.

In the three case studies, trip generation and the developed land use maps are presented on the cell level. All the other variables such as transport volume and emissions are only presented at the city level. However, RACE can present various results also on the district level (Table 8). The passenger trips generated can be shown in GIS maps (Figure 19). In addition, the generation of such land use maps can be presented. Uncertainty is not yet included in RACE.

Assessment of RACE

Easy to use and understandable	Satisfactory: Development agencies can easily implement and use the model; however, it cannot provide the necessary uncertainty for decision making. Local policymakers can implement the model, requiring limited new knowledge, but they cannot see the local problems due to the aggregated calculations.

RACE has incorporated both stakeholders – local policymakers and development agencies – that were identified as important in the land-use planning process in developing Asian cities. In Table 9 a comparison is made of the possibilities of RACE versus the capabilities and focus of local policymakers and development agencies.

Another requirement for a sketch-planning tool is to be easy to modify and see differences in outcomes. RACE is heavily dependent on the land use maps, which are developed in a GIS program. Each scenario or policy requires a separate land use map, which takes a considerable amount of time to develop. This contrasts sharply with the spreadsheet, which is easy to modify. As a result, the risk exists that values are changed in the spreadsheet to improve the results, but without sufficient backing of actual policies. It should either prevent such changes or make clear what the policy implications are to make sure the model is 'self-teaching'. The term sketch planning is therefore not applicable as it cannot easily implement different policies to see what the effects are or is self-explaining.

The model is calculating nearly everything at the district level, except number of trips. Therefore, nearly every result has to be presented at the district level or even city level. The model could greatly benefit from a more disaggregate approach of calculations, this would allow more detailed analysis at the cell and district level. In particular, from the perspective of the local policymakers it is impossible to make detailed analysis, as the transport volume cannot be shown at the cell level. From the perspective of the development agencies, it is however, possible to see the total citywide emissions and in that case, nearly every variable is important; with the remarkable exception of the gross building area which only influence the average trip distance. The

Table 9. Comparison of the possibilities of local policymakers, development agencies to RACE

	Local policymakers	Development agencies	RACE
Knowledge	Fairly limited	Highly skilled and trained, or ability to hire expertise	Requires technical expertise for GIS development, not required for the spreadsheet. Understanding of the methodology is, however, required.
Resources	Many human resources, however mostly in kind and manpower and limited availability of money.	Limited resources in terms of manpower, but has more possibilities of funding in cash.	The GIS part requires substantial resources, in time and man power, this should be tried to be reduced. However, if done correctly the GIS files can be used in other occasions. RACE does require field verification.
Institutional	Tension between national and local governments, dependence on national funding. Limited coordination between departments.	Mostly focused sectorial on national governments, but more coordination and required methodologies	Requires data from various department to make the analysis and requires therefore coordination, in particular from local institutions.
Objective	Reduce visible problems such as congestion, informal settlements, and air pollution, etc.	Eradicate poverty and reduce environmental damage, locally and internationally	Reduce emissions by improving land use and identify possible project. Emissions and VMT are calculated at the city level and detailed analysis is not possible.
Focus	Focus on visible short term projects	Focus on sustainable improvement, both short term and long-term	Focus on land-use planning on the long-term
Required details	Very local, on the neighborhood level, quantified if possible.	Quantified and measurable results, integrated. City level	Mostly at the city level, quantified; however RACE is not yet validated

figures provided by RACE can only be used as indicative as the uncertainty of the results is not provided.

The transparency of RACE is mixed. It is possible to fully retrace the calculations in the spreadsheet. The methodology of allocating future land use to the different grid cells in the GIS files is explained in various presentations and possible to reproduce. The sources of all input variables are not always retraceable.

4.2.4 ADAPTABLE AND FLEXIBLE

Is the model flexible in terms of data input requirements to adapt to the availability of local data, adapt to different time frames, and local circumstances such as different vehicle fleets, travel behavior or land use patterns?

Implementation of RACE

RACE has three levels of detail: city level, district level, and cell level. Only the gross building area is an input variable at the cell level, all other variables are either at the district of city level. RACE has the following requirements regarding the input variables:

The model has the ability to use local data, but it has a fixed level of detail for most input variable. For instance, the population size is an input variable at the city level, while in some cities this data can be available at the district level. In addition, the model cannot provide exceptions for certain cells or districts. The model has the ability to have different vehicle fleets and is adaptable to local emission factors.

The model is a static model and therefore independent from the timeframe; as long as the data is available for a particular year. RACE cannot show any intermediate results, or a complete new land use map has to be developed.

Assessment of RACE

Adaptable and flexible	Weak: The model cannot incorporate physical barriers in the calculation resulting in that the model cannot adapt to all situations, and it is using a fixed format.

The model does not consider any physical barriers that can be of influence on the trips and this cannot be introduced (for instance between two zones/cells). The distance between two zones is the Euclidean distance and does not consider the infrastructure

Table 10. Input requirements for RACE

Input data	Used for:	Input level	Detailing
Vehicle trip generation factors	To calculate number of trips generated per cell	City level	Per land use category
Size of a dwelling	To calculate vehicle trips generated per cell	City level	Per land use category
Gross building area	Calculate for each cell the number of vehicle trips, the attraction potential of the cell and the land use entropy	Cell level	
Population size	Calculate the number of trips	City level	
Trip rate/capita	Calculate the number of trips	City level	
Vehicle occupancy	Converting passenger km to vehicle km	City level	Per mode
Mode shares	Assign the total trips to the different modes	District level	Per mode
Maximum trip internalization per cell for NMT	Calculation of NMT trips within the cell	City level	
Distance between two zones	Average distance	District level	
Expert judgment to average trip length	Correct the average distance	City level	
Average distance	Correct for different distances driven by a mode	City level	Per mode
Average speed	Calculate fuel consumption and total PM and NO_x emissions	City level	Per mode
Fuel efficiency	Calculate fuel consumption	City level	Per mode, per fuel
Fuel split	Calculate fuel consumption	City level	Per mode
Emission standard split	Calculate average NO_x and PM emissions	City level	Per mode, per fuel
PM emissions	Calculate PM	City level	Per mode, per fuel, per emissions standard, per speed
NO_x emissions	Calculate NO_x	City level	Per mode, per fuel, per emissions standard, per speed
Carbon content	Calculate NO_x and PM	City level	Per mode, per fuel

network, resulting in that the distance between two zones can vary a lot between what is modeled and what is the actual travel distance.

It would be good if the model is improved by providing the option to decide on which level of aggregation each input variable will be used; currently this is at a fixed level, while flexibility would be an improvement and is, to the authors understanding, easy to implement.

Hence, the model is adaptable to different cities in terms of vehicle fleets and emission factors, but it lacks the flexibility in the land use maps to make exceptions for certain physical barriers. It also lacks the flexibility to use data at different levels of aggregation; it is using a fixed format.

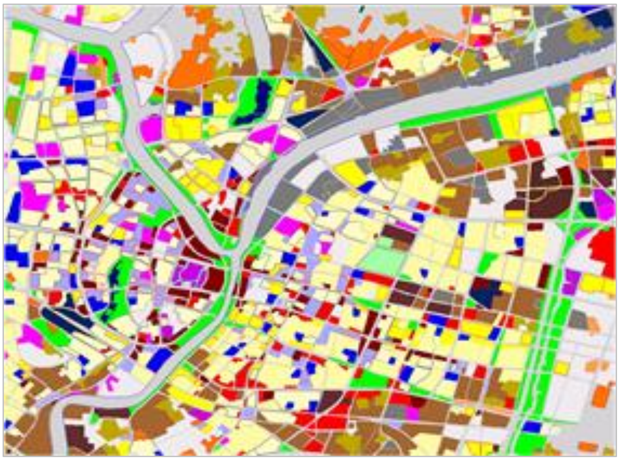
4.2.5 COST OF IMPLEMENTATION

Are the cost of implementing and using the model in terms of money and resources acceptable to end users?

Implementation of RACE

Implementation of RACE takes about 3-7 months. Gathering all the data is the most time consuming part, in particular the development and verification of the GIS maps is very time consuming and takes about 3-6 months. The implementation within the spreadsheet is rather quick and, if all data is available, can be done in a matter of days.

However, the digitization of the land use maps, converting these to the 500x500m cells, is specialized work requiring GIS expertise. Secondly, due to the usage of gross building area



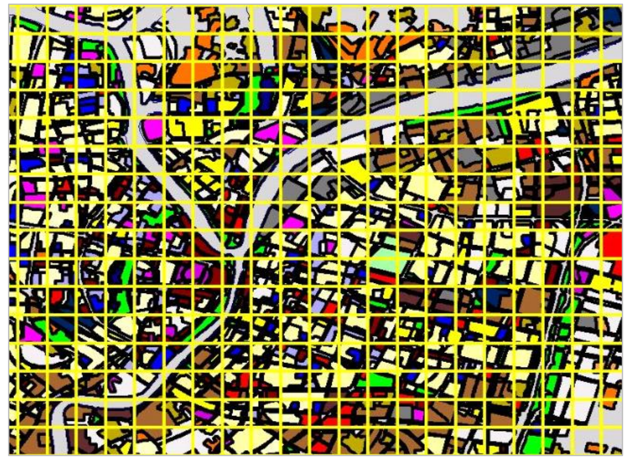


Figure 20. Digitized land use maps converted to the 500x500m grid cell

requiring the heights of the buildings field verification is necessary to verify if the right building densities are used.

Assessment of RACE

Cost of implementation	Excellent: The model can be set up in a couple of months. It does require the development of new GIS maps, but these can be used also in various other occasions.

The model is relatively quick to set up, in a couple of months the tool can produce results and the requirements for data are only extensive regarding the GIS part. The spreadsheet is fairly simple and using available data. This is in comparison to various other models that require advanced and detailed data sets and require detailed calibration before it can be used. However, in the fast changing environments of developing Asian cities 6 months implementation time is still fairly long and the GIS part is resource intensive, this will probably require nearly always financial assistance.

Problem is that the model is focusing on land use changes as driver of transport volume and emission reduction, this can however not easily be changed due to the required land use maps. The spreadsheet can easily be changed, but this should stem from the land use changes. RACE can become resource intensive and costly if it is used as a quick sketch-planning tool with many possible scenarios. This is not the case if only two land use scenarios are calculated.

4.2.6 COMPLETE AND COMPREHENSIVE

Are all pollutants and emissions sources covered that are considered important by the respective end-users for the whole study area?

Implementation of RACE

RACE calculates the emissions from passenger transport only[4] and calculates the emissions of CO_2, PM, and NO_x. The sources of passenger transport are the combustion of different fuels. It is unclear if the emission factors used to determine the emissions include evaporation of fuel.

The application of the three case studies has used a different demarcation of the study area. The demarcation of the study area seems to be arbitrary; the demarcation was based upon available resources rather than stemming from any legislative border.

Assessment of RACE

Complete and comprehensive	Satisfactory: The model is covering the fuel consumption, but not all sources of emissions. It also calculates all relevant sources but the PM and NO_x should be modeled at the local scale. The study area can best be adjusted to the current legislative borders

[4] RACE does have a module to calculate energy consumption by a household, this is not considered in this study.

The model covers NO_x and CO_2, which are the most important pollutants for greenhouse gas effect. However, it does not consider VOC, which is also of high importance for the greenhouse gas effect as it is an ozone precursor. On a local scale, the effects of PM are important, in combination with the NO_x, but also the inclusion of ozone (O_3) is important.

Urban transport consists not only of passenger transport, the transportation of goods and business travel is of significant influence on the total amount of emissions. This has to be included to make a full analysis of the impact on urban transport emissions.

As noted before, the implementation of land use policies is conducted by local authorities. It is therefore useful that the study area covers the same legislative local borders. It is suggested that the study area either is limited to a smaller area but comprehensive for the area under the jurisdiction of the local authority, or expand resources to implement it for the whole metropolitan area, instead of considering parts of a district.

4.3 THEORETICALLY SOUND

Theoretically sound: incorporating land use, and calculating transport activity and emissions correctly

This paragraph will describe the theoretical quality of RACE. In each paragraph first the methodology and possibilities of RACE is described and second how this compares to the requirements as set out in the evaluation framework.

4.3.1 MODELING LAND USE AND TRANSPORT

Is the model able to reflect the relationships between land use and transport, i.e. reflect calculates land use activity, trip generation, trip distribution, modal split, and assignment?

Implementation of RACE

This paragraph is rather extensive, the implementation of RACE of the land-use transport feedback cycle is considered first, and secondly the way transport volume is calculated is described.

The land use component of RACE is a static model using a 500x500m grid cell structure and calculates the gross building area per cell. RACE is using polygon cells, instead of raster cells.

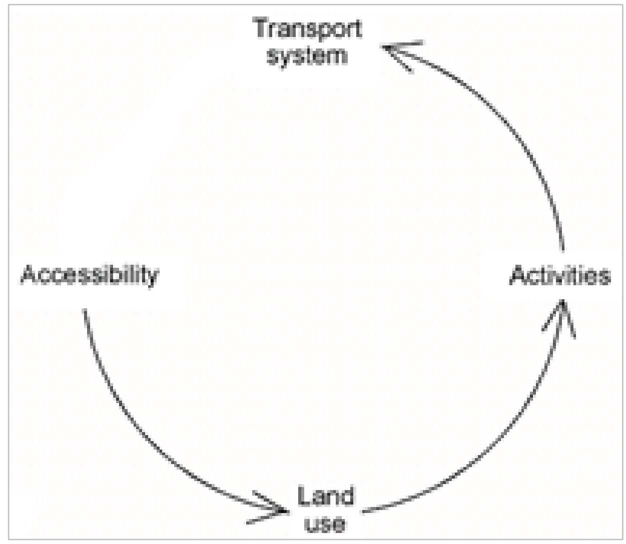


Figure 21. Land-use transport feedback cycle as implemented by RACE

Polygon cells allow more easily the attribution of datasets to each cell and can easily be aggregated or split in cells that are more detailed. The gross building area is calculated by multiplying the land area (m^2) with the land use's cell coverage (%) and the building height; this results in a gross building area (m^2) per cell per land use category (see figure 21). The building heights are verified with field photographs.

RACE considers five different land use categories (residential, mixed, commercial, industrial and institutional), each divided into various sub categories (e.g. low, medium, high density).

The land use activity in future scenarios are based on the drivers of economic and demographic growth, considering physical barriers and other limitations. Land use activity is assigned to each cell based on accessibility. Accessibility is determined by the proximity of transport networks.

From the GIS part, the gross building area per cell is exported to a spreadsheet. In the spreadsheet, the volume of transport and the emissions are calculated.

The total number of trips is calculated at the city level by trips per capita per day multiplied by the total population size; this can be considered as the trip generation. The spatial allocation and therefore trip distribution is conducted by the GBA in a cell and is therefore only based on trip production. The modal split is treated as exogenous and is an input variable at the district level, however, in all three case studies the modal split was the same for all districts. At the cell level, the NMT share is changed based on the land use mix. Cells with a perfect mix of land use activities will generate 2% more non-motorized traffic. Trip assignment is not conducted, as transport infrastructure is not considered in the spreadsheet.

There is an elementary form of the gravity model implemented to determine the average distance between two districts, hence calculate trip volume. The gravity model works by multiplying the distance between two districts with the weighted average of the gross building area in the destination (attraction).

The average distance is corrected with expert judgment and the number of trips generated from a cell to reduce extreme outliers. Finally, the average distance is corrected per mode.

Assessment of RACE

Modeling land use and transport	Weak: The feedback link between land use and transport is not complete. The model is not incorporating all 5D's to model land use, assignment is not conducted, and the modal split is largely exogenous to the model

The model is a static model. The scenarios are fully based on expert judgment and do not consider any dynamic evolvement of cells based on either market principles or adjacent cells as used in cellular automata. This can be considered a strength as the cities develop at such a pace that nearly all land use will change in the next twenty years; nevertheless, it cannot show *how* the city will develop over the years, based on economic or socio-economic theories and is fully dependent on the expert's judgment. RACE can only provide an educated guess of how the land use will look like in 20-years' time.

Accessibility is determined and calculated for each cell in the land use maps, but this is not transferred to the spreadsheet and therefore to the transport and emissions calculations. Hence, the volume of travel is not based on accessibility.

It can be concluded that the model has a relationship from the transport network via accessibility to the land use of a city. The land use influences the activities and therefore the transport demand. However, the transport demand is not matched with transport infrastructure (supply) and is therefore missing the link from transport to activity (see Figure 21).

RACE has been introduced to use the 5D's as developed by Cervero and Kockelman (1997); Cervero and Murakami (2008). Density is included and has a large influence to the outcomes on cell or district level. Diversity is included by a maximum trip internalization, this has however hardly any influence – even on the cell level. This influence can be larger according to the meta analysis of Ewing and Cervero (2010). Design is not included in the model; although it can be argued it is incorporated in the average speed, which influences the emission factors. But this has no influence on transit usage or number of trips. Distance to transit is only included in the land use maps developed in the scenarios, in the spreadsheets the distance of transit is not included. This would be a major improvement if the link between the GIS files and the spreadsheet would be improved, such that the distance to transit can be used in the calculations for mode share and trip volume. The accessibility of destination is not included in the GIS part nor in the spreadsheet.

A comparison of RACE to the classic four-step modeling shows that RACE is using a different approach. Due to the 'cap' in the trip generation, introduced by the calculation trip generation/capita * population size, the number of trips any variation in the emissions and gross building area are not visible when analyzing at the aggregate city level. Analyzing at a more disaggregate level differences become apparent, but also only relative to the other districts or zones. The gross building area in the cell multiplied with standard trip generation factors per land use category per m^2 allocates the trips to a cell. Other than the gross building area there is no other input variable used for allocating trips to a cell; trip purpose or any other socio economic characteristic are not implemented. There is also no variation of trips in time, the model only calculates for a regular day – unspecified what day – and multiplies it with 365 to obtain annual trip volume.

Trip distribution is not conducted. It only considers trip production based on the gross building area. The only aspect that is considering trip attraction is the average trip distance, which is used in that case two times: in trip generation to allocate the number of trips to the cell and to determine the attraction. There is no connection between trip production and trip attraction to determine the number of trips.

$$T_i = GBA_i * trip\ generation\ factor$$

$$T_j = GBA_j$$

$$T_{ij} = ?$$

in which T_i is the trips in cell i (origin), and Tj is the trips in cell j (destination). GBA is the gross building area.

The modal split is not modeled and only limited adjusted per cell based upon the land use mix. So vehicle ownership, income or education level or distance to transit are not of influence. From a theoretical perspective, this is a severe limitation. It would be best to create a more detailed modal split calculation, which incorporates the accessibility of different modes. The accessibility of a mode can be modeled by measuring the distance to the main road and public transit corridors (e.g. highways, BRT and metro systems) and incorporate income classes as there is a strong correlation between personal income and car-ownership. Other potential improvements of modal split are household composition and trip purpose.

Trip assignment is not modeled, because the transport network is not included in the spreadsheet. Therefore, the routes chosen are not visible, although the average trip distance can change significantly due to the availability of alternative routes, such as a highway or due to natural barriers (rivers, mountains, etc.). A suggestion is to include 'corridor modeling', that considers the main infrastructure networks to determine more accurately the distance between two zones and keeps the data requirements to a minimum.

A major revision would be to introduce a comprehensive gravity model based on attraction and production to determine the distribution of trips. This would also enable to create a more realistic approach to where traffic is and where emissions are emitted.

4.3.2 MODELING TRANSPORT EMISSIONS

Is the model using good practice methodologies for estimating emissions and implements it correctly?

Implementation of RACE

RACE calculates transport emissions using the ASIF formula developed by Schipper et al. (2000). How transport activity and the structure (modal split) are modeled is explained in the previous paragraph. Transport intensity is modeled by dividing the total passenger kilometer per mode with the average vehicle occupancy resulting in vehicle kilometers (VKM). And subsequently multiply the VKM with the average fuel consumption per VKM; it is disaggregated per mode and fuel. The model incorporates a speed factor correction to determine the total fuel consumption. Transport emission factors are input variables per mode per fuel. In the case of PM and NO_x this is also disaggregated per emission standard (euro I, euro II, etc.). The emission factors are multiplied with the fuel consumption to obtain the emissions; in the case of PM and NO_x emissions this is corrected for the average speed within a district.

Assessment of RACE

Modeling transport emissions	Satisfactory: The model incorporates all aspects of the ASIF formula, and it models the emissions at an annual district level, but it does not allow disaggregate analysis of where emissions are

A comparison to the original ASIF formula as described earlier in the literature review shows that RACE implements the formula good and correct. The transport intensity is using all factors mentioned, i.e.:

- the technical efficiency of the mode (fuel consumption per VKM)
- the capacity utility of the mode (average vehicle occupancy)
- the operational conditions (speed)

The emission factors are also detailed calculation by providing emission factors per fuel and per emission standard.

However, the speed variation is implemented at a district level, and in the case studies, the speed factor was for all districts the same, therefore not really accounting for differences in design of a city, while this can vary largely from place to place. It does not account for variation in hot and cold start emissions.

The temporal scale does not match with the pollutants. The emissions are calculated on an annual scale while for PM and NO_x an hourly scale is important to determine the local air pollution, currently it can only be used for aggregate analysis. If allocated to the zonal level this would also make the current output more useful as input for air quality dispersion modeling.

4.3.3 EMPIRICALLY AND BEHAVIORALLY VALID

Is the model empirically and behaviorally valid?

Implementation of RACE

None of the three case studies is fully validated. In all cases, the results are conferred with the local counterparts and compared to available studies. During the implementation, all input variables are compared with other studies, and based on expert judgment the data considered most reliable is used.

This research has compared results of the case studies of Ahmedabad and Colombo with respectively 18 and 12 related transport/emissions studies. The results vary a lot, even after correcting for the total population size, with ranges of up to 200%. It was not possible to find adequate disaggregated studies to compare at the cell or district level if the results are valid. This can be due to differences in definition and boundary of area. Even corrected for the population size large differences occur. However, there cannot be claimed that the results of RACE are invalid, as all studies are using limited resources.

Due to the unique design of the model, it is hard to validate the model. As the model currently can produce mainly aggregate results, only these results can be validated to other studies. The model has no road network, so validation with road counts, a usual method of calibration and validation in transport modeling is not possible.

Assessment of RACE

Empirically and behaviorally valid	Weak: The model is not yet validated and provides limited opportunities for validation due to its unique design. The direction and magnitude are in many cases correct, but not always

A study to validate the results is recommendable; also, the opportunities for calibration and validation should be improved.

A comparison of the direction of changes in outcomes between the theoretical expected effect of and the actual results of RACE is shown in Table 11.

The results from the comparison are mixed. RACE is able to correctly model the general direction of increased or reduced VMT, this also holds for the NMT shares. However, transit usage is not always in the same (right) direction. This has to be corrected to have credible results. The order of magnitude of the different variables is in line with what can be expected.

4.3.4 CONSISTENT

Is the model consistent throughout the model, in terms of input, methods, and outcomes?

Implementation of RACE

RACE calculates scenarios and GIS files very detailed, but the spreadsheet is simple in comparison to the work conducted in the GIS part. The spreadsheets are quickly aggregating to district level and several very important variables are not calculated or adjusted within the model; exemplary is the modal split, which has a strong influence on the total amount of emissions, but is hardly influenced by any other factors. Considering all four terms in the ASIF formula:

- Activity is determined in high detail, when looking at the cell level, but at the city level it is only dependent on two variables
- Structure is representing the modal split, which is considered an input variable. This is marginally influenced at the cell level, but not at the city level

Table 11. Comparison of direction of results between theoretical expected influence and RACE

	Expectation	RACE
Increased density	Reduce transport volume and increased walking and transit usage Increased number of trips within the denser area	No influence on total VMT. VMT is not calculated at the cell level. Trips generated in the denser area are increased, but fully offset by reduced number of trips in other areas. No variation in modes is observed.
Increased diversity (Land use mix)	Reduced VMT, and increased walking and transit usage	Reduced VMT, increased NMT share, reduced transit usage
Improved street design	Reduced VMT, increased walking and transit usage, reduced emissions	Not possible to model in RACE
Improved accessibility of destination	Reduced VMT	No influence
Improved distance to transit	Reduced VMT and increased walking and transit usage	Not possible to model in the spreadsheet, however it probably results only in densification around the transit stations; the modal split is normally not influenced (unless manually adjusted)
Increased vehicle occupancy	Reduced VMT and reduced emissions	Reduced VMT and reduced emissions
Increased avg. distance	Increased VMT and increased emissions	Increased VMT and increased emissions
Increased fuel efficiency	Reduced emissions	Reduced emissions
Increased emission standards	Reduced emissions	Reduced emissions

- Intensity is only calculated at the district/city level, but considers all aspects mentioned in the ASIF formula
- Emission factors are only calculated at the district/city level, and considers all aspects mentioned in the ASIF formula

Assessment of RACE

Consistent	Weak: At the city level scale it is consistent and influenced by many factors, although the most important one (Gross Building Area) has hardly any influence, while on the cell level it is not possible to calculate emissions. The temporal scales do not match in both cases.

This shows that there has to be made a distinction to what is possible at a local level and at the citywide level. At the local level, activity is fairly specific and detailed calculated, while the modal split is using exogenous input with a limited variation. Intensity and emission factors are not even considered at the local level.

On the contrary, at the city level, activity is overly simplified due to the 'correction factor' of trips per capita. Modal split is an input variable. Intensity and emission factors are in this case specified up to different vehicle fleets and considering different speeds for different modes and are therefore rather specific.

The design of the model is unique and therefore hard to compare to other models. In particular due to the newly developed GIS maps, although they can match with other studies, these are often Consistent within the model and with other models

Analysis of the dimensions [units] used in the model show that it is nearly correct, but the model is converting at the cell level vehicle kilometers passenger kilometers with a variable that is of no influence. Therefore, passenger kilometer and vehicle kilometer are the same at the cell level.

4.4 OVERVIEW OF RESULTS

Table 12 provides an overview of the results of the current version of RACE according to the evaluation framework.

Table 12. Overview of the results of the evaluation of RACE

Usable	**RACE**
1.1 Cognizant of the drivers of urban planning	Satisfactory: Considers all drivers, but does not model them endogenously or explicitly requires them
1.2 Strategic planning level	Satisfactory: Possible to implement long-term strategy policies, but those are not calculated within the model and are limited to land use projects and no infrastructure projects.
1.3 Easy to use and communication	Satisfactory: Development agencies can easily implement and use the model; however, it cannot provide the necessary uncertainty for decision making. Local policymakers can implement the model, requiring limited new knowledge, but they cannot see the local problems due to the aggregated calculations.
1.4 Adaptable and flexible	Weak: The model cannot incorporate physical barriers in the calculation resulting in that the model cannot adapt to all situations, and it is using a fixed format.
1.5 Cost of implementation	Excellent: The model can be set up in a couple of months. It does require the development of new GIS maps, but these can also be used in various other occasions.
1.6 Complete and comprehensive	Satisfactory: The model is covering the fuel consumption, but not all sources of emissions. It also calculates all relevant sources but the PM and NO_x should be modeled at the local scale. The study area can best be adjusted to the current legislative borders
Theoretical sound	RACE
2.1 Modeling land use and transport	Weak: The feedback link between land use and transport is not complete. The model is not incorporating all 5D's to model land use, assignment is not conducted, and the modal split is largely exogenous to the model
2.2 Modeling transport emissions	Satisfactory: The model incorporates all aspects of the ASIF formula, and it models the emissions at an annual district level, but it does not allow disaggregate analysis of where emissions are
2.3 Empirically and behaviorally valid	Weak: The model is not yet validated and provides limited opportunities for validation due to its unique design. The direction and magnitude are in many cases correct, but not always
2.4 Consistent	Weak: At the city level scale it is consistent and influenced by many factors, although the most important one (Gross Building Area) has hardly any influence, while on the cell level it is not possible to calculate emissions. The temporal scales do not match in both cases.

5 DISCUSSION

The evaluation framework and the assessment of RACE are described in the previous chapters. The results show that in model evaluation is essential to take multiple perspectives on RACE. In this chapter the results are synthesized and from different perspectives discussed. It will discuss the strengths and weaknesses of the evaluation framework. The results obtained from the assessment of RACE are discussed from three points of view: usability, theory, and actors.

5.1 THE EVALUATION FRAMEWORK

This study has developed a descriptive evaluation framework to which a sketch-planning tool for land-use transport emissions can be evaluated. It provides an indication of how the land-use planning process could be assisted by a sketch-planning model, which stakeholders are involved, and what policies can and should be implemented. It incorporates also the requirements from land-use transport emissions modelling, by reviewing the strengths and weaknesses of current models. The framework of Kolkman's model development cycle inherently accepts that model development is designed according to one actor's point of view. Hence, an evaluation can therefore only be as comprehensive as to the perspective of the designer.

For instance, taking a closer look at the discussion around integrated land-use transport models, a debate is going on how to model the urban system while remaining relevant for the planning process. This is already acknowledged in the early 70's and later reconfirmed, see the critiques of Lee (1973, 1994), Supernak (1983), and Timmermans (2003). But this has not withhold the development of fairly detailed land-use transport models, overviews are presented in, e.g. Wegener (2004) and Hunt et al. (2005). Besides these land use transport models, another type of models is developed: Planning Support Systems, which are specifically designed for the planning process but also fail to be used in many occasions. See for some discussions on the usability and quality of planning support systems: Batty (2007); Couclelis (2005); Te Brömmelstroet (2010b); Vonk (2006). Concluding, there is still no comprehensive way of integrating all system knowledge of land use and transport on the one hand and at the other hand being useful for land use policy making.

This research has attempted to find an evaluation framework that is able to capture the most important aspects from the discussions mentioned above, but also learn from the public policy process, the current problems faced by developing Asian cities in land-use planning, and how air pollution and greenhouse gas emissions could be part of the land-use planning process. Also, this evaluation framework cannot be fully comprehensive; from over 100 criteria set out by each field of research, only 10 are selected – these 10 criteria encompass often several criteria from different research fields – omitting therefore criteria considered relevant for some scholars or from some perspectives.

From the policy process, the emphasis is on providing a quantitative comparison of outcomes, requiring therefore a quantitative evaluation framework. This research has provided a descriptive qualitative evaluation framework, in this case to allow a detailed discussion on the strengths and weaknesses of a model. A quantitative analysis would allow comparison of models more easily, but would lose on detail due to the translation from qualitative answers to quantitative criteria. A quantitative analysis would be able to provide a weight to the importance of each criteria and create a complete multiple criteria analysis, while this is only limited possible in a qualitative analysis. The operationalization of the evaluation framework in a descriptive three-point scale makes sure the assessment is reproducible; because of the qualifications given, it can provide an overly simplified view on the model as the table lacks the possibility of providing detailed information.

From the land-use transport modeling perspective, the emphasis is on developing a model as accurately as possible, while from planning support systems the emphasis is on providing an easy to use transparent model. These are not mutually exclusive, but provide difficulties in operating: how to create a fully transparent model, but also reflect all, complex, relationships between land use, transport, and emissions. This conflicting situation has to be researched in greater detail; in particular how disaggregate activity based modeling – often seen as the future of representing the urban system in greater detail – can be transparent and of use in policy processes. The other way around, how the lessons learned from planning support systems can be integrated in a detailed theoretical sound model reflecting the real observed world as close as possible. This tradeoff requires ongoing research and trial-and-error approach of model development.

The evaluation framework is providing a framework to evaluate RACE. This evaluation framework has to be tested on other evaluation studies to show the applicability of the framework on other models and make the framework applicable to more models. The evaluation framework always requires adaptation to the specific model; this can be undertaken by putting the emphasis on one or two specific criteria; alternatively, the evaluation framework can be adapted to include certain criteria highly relevant for the purpose of the evaluation of the model.

These aspects set the basic requirements of a sketch-planning model for land use – transport – emissions. This is a descriptive and evaluative framework and not a prescriptive methodology. To the authors knowledge there is no operational model that has implemented all these criteria adequately. In particular, a model that is adapted to the local context of developing Asian cities with minimal data requirements and large changes in 20-years time are, to the author's knowledge, not yet developed.

In addition, several criteria can possibly have some overlap, although each criterion is defined and independent from others, it is very well possible that there is a direct correlation between two criteria. For instance, the drivers/problems identified, in this case, e.g., the weak institutional framework poses a challenge on the implementation process of policy processes and land-use planning. This is closely related to the 'ease of use' and 'cost of implementation' criteria.

5.2 THE CRITERIA OF THE EVALUATION FRAMEWORK

The criterion that a model is being cognizant of the drivers of the problems in land-use planning was not recognized in the explored literature. The model had to be accurate or be able to reflect current situations and model the right solution for the right problem. However, the identification of the drivers of the problem was not as such identified, while it provides the rationale behind developing a model.

It is known that land-use planning influences transport, hence emissions. However, land-use planning is highly complex and only a few studies were able to show why and how land-use planning has affected transport and emissions (e.g. Schwanen et al., 2001; Schwanen, Dijst, & Dieleman, 2004). The problem is that nearly all known relationships are developed in a Western context, while the most potential for effective land use planning for reducing emissions is in developing cities. More research should be conducted to quantify the effects and empirically validate the effects of long-term land-use planning in a development context.

Besides that it is known that a well-organized city can be successful in the long term and have a higher economic growth. Land use planning can provide a significant contribution to achieving a well-organized city. However, the developments in Asia occur at such a pace, that successful land use planning can improve the local economy in such a manner that it attracts more people and has different demands in terms of land use (e.g. bigger houses, more offices) and transportation (e.g. increased demand for private cars), resulting in that the city can fail under its own success. It is unclear what the strength is of this relationship and what the quantified effects of land use planning are on the economy and migration. Methodologies has to be developed to model dynamically the large changes of demography, economy, land use, and transport endogenously.

It is also important to discuss the relationship between long-term land-use planning in relation to the need for complementary short and medium term policies, such as zoning, pricing, etc. Currently, the evaluation framework focuses on land-use planning as the only strategy, while it is known that complementary policies are necessary to improve the effectiveness of the land use policies.

It is recognized that *"Harder analytical, modeling and GIS-based approaches maybe useful in [land use planning] ..., as an input into discussion and decision-making, but are unlikely on their own to determine outcomes."* (United Nations Human Settlements Programme, 2009). A sketch-planning tool should therefore be aware of this trade-off, is the focus on assisting the land use policy process by developing greater understanding of urban development and the relationship to transport and emissions. Or is it on providing figures for decision making to motivate certain land use plans. These are two different objectives and require different outcomes.

How to communicate and use models within the policy process is conceptualized and made understandable in various studies, but there are big differences between countries, cities, and regions. This study assumes that this is the same for all developing Asian cities. This study has only spoken to academics or staff members from international development agencies. In this research, it was not possible to interview the actual policymakers. In-depth analysis and discussions with the actual policymakers would gain these insights and provide a clearer picture of the planning process. Moreover, it could provide insights to how a sketch-planning tool could assist this process and what the requirements are regarding ease of use, flexibility of input variables, and required outcomes.

Although the evaluation framework does not prescribe the methodology used in a model, it does prescribe that it is behavioral and empirically valid. Therefore, the direction and magnitude should be correct. This is a valuable and essential addition to the requirements regarding the methodology as it ensures that the model reacts to policy changes as can be expected in real life, based upon detailed understanding of how the system works and requires validation from different fields of research.

The final criterion, consistency, is included in the framework to create a 'balanced model'. Consistency requires that a model is scrutinized from begin to end, to ensure that variables use the same units, but also that not only one aspect within the model is modeled in detail, while other aspects are neglected. This consistency criterion should match with the goals of the model. This criterion goes beyond the definitions of IPCC and others, as it includes not only consistency between model applications but also consistency within the model. This is an aspect not covered by most other evaluation frameworks.

5.3 DISCUSSION OF RACE

The results presented in the previous chapter provide a mixed overview of how RACE is performing.

The fundamental design of RACE is good: (1) it is cognizant of the drivers of the problems with land-use planning in developing Asian cities, (2) it recognizes the need for an integrated solution from land use and transport to reduce emissions, (3) the policy measures are on the right strategic level, and (4) it is designed to provide assistance in the early stage of policy analysis. These four aspects show that the design and therefore the usability on the long-term are great.

However, the translation from this concept to a model is not up to par: (1) the model is unable to provide quick alternative options due to the requirement of newly developed GIS maps for each scenario. (2) The link between the GIS maps and the spreadsheet can be improved; in particular, the accessibility and transport network is not present in the spreadsheet. (3) The spreadsheet uses a fixed format for input variables and quickly aggregates the calculations to the district and city level; therefore, RACE is unable to present detailed analytical results. (4) The theoretical and behavioral validation show mixed results, RACE is not always able to reflect the direction and magnitude of change expected from empirical and theoretical research. (5) RACE is not always consistent and heavily dependent upon the modal split for estimating the emissions.

From a third perspective, the end-users, also different results are visible. The local policymaker, as an end-user, is mainly interested in detailed local analysis of how the city is developing and is short term focused. RACE can provide a credible way of how the city could develop, as it is cognizant of the most important drivers of land-use planning. There is however no fixed scenario format or dynamic development of the city; it is therefore completely dependent upon experiences in comparable cities and the experts best guess of how the land use will look like in 20-years' time. It is unable to allocate emissions to the local level, hence unable to provide detailed analysis nor identify any short term/medium term project. RACE is providing long-term scenarios and, if supported by knowledge transfer, can increase the knowledge of sustainable development and improve the land-use planning process in cities. The implementation of RACE is short in comparison to other models, but is still long for many policymakers if it can only provide a direction. The development agencies are interested in emissions reduction and do not need a local analysis, their focus is on funding projects and is shifting towards transferring knowledge. RACE is able to provide a rough estimate of the total citywide emissions and RACE could be used in transferring knowledge to the local policymakers.

6 CONCLUSIONS AND RECOMMENDATIONS

In this research the requirements of a sketch-planning tool for land use transport emissions modeling is studied and the model RACE is evaluated. Therefore, a framework is developed to which a sketch-planning tool should comply. The framework is used to review the current operational model Rapid Assessment of City Emissions of Clean Air Asia. Recommendations for further analysis of requirements of sketch planning and for improvement of RACE are provided.

6.1 REQUIREMENTS FOR SKETCH-PLANNING

A sketch-planning tool has to fulfil two important criteria:

1. *It has to be useful for the policymaker to gain insights in the effects of land use policies and be able to be used in the policy process*
2. *It has to be theoretically sound and valid in modeling land use transport emissions to provide credible results*

These two criteria are operationalized for the context of land-use planning in developing Asian cities. The criteria describe in detail how a model can be useful in land-use planning and can integrate knowledge from land use, transport, and emissions in a theoretical sound manner.

A model is considered useful if it fulfils the following criteria:

- The model has to be cognizant of the drivers of the problems of urban planning process in developing Asian cities. The driver of the need for urban planning is the population growth and related economic development. Second driver of land-use planning is the need to mitigate and adapt to climate change, because of the vulnerability of Asian cities to climate change.
- Next to this, the model has to be cognizant of the weak institutional framework for land-use planning with limited data availability, limited coordination between departments, and a tension between national and local governments.
- The model needs to assess land use policies on a strategic long term level. Land-use planning is an effective way of reducing transport emissions on the long term, but it is most effective way if complemented by other policies. Besides that, the model has to be responsive to strategic land use policies to provide insights in the effects.
- The model has to provide insights for the actors involved in land use planning. In developing Asian cities the most important actors in land use planning are the local policymakers and (international) development agencies. Local policymakers are important because they are the ones ultimately deciding upon the land use plans, and have the workforce to implement the model. Development agencies are important because they fund various projects and have a strong interest in reducing greenhouse gas emissions and sustainable development. They can transfer knowledge to the local policymakers by funding and assisting in the development of land use plans.

- The model should be able to adapt to the local circumstances and allow local data as input, but also provide sufficient flexibility to allow other, aggregated, data as a backup. This is necessary because data is often not available.
- Developing Asian cities develop very rapidly, therefore the model has to be able to provide quick results within a matter of months instead of years; otherwise the results are outdated. Next to this, there are limited financial resources for implementation.
- The model has to be complete, by covering the whole geographical area (preferably in line with any legislative borders), and provide the results for all relevant pollutants: CO_2, PM, and NOx; and preferably VOC on the appropriate scale. These pollutants are emitted the most and have a strong influence on either climate change or local air quality.

The model is theoretical sound if it can integrate the current theoretical and empirical relationships between land use, transport, and emissions can accurately model. This is operationalized in the following criteria:

- The feedback relationship between land use and transport, and the four steps of the 4-step model has to be modeled. The relationship between land use and transport is often defined according to the 5D's of Cervero and Murakami (2008): Density, diversity, design, distance to transit, and destination accessibility. These are also aspects of which theoretical and empirical evidence exists. Transport is usually following the 4-step model, consisting of trip generation, trip distribution, modal split, and assignment to the network. These four steps can be modeled in various ways but each aspect has to be incorporated to provide a credible calculation. More advanced, disaggregated ways of modeling land use, transport or emissions (e.g. activity based modeling) are desirable as it is able to capture more aspects as observed in the real world, but is also more demanding in terms of calibration and input data.
- Activity based emissions modeling is necessary to determine local emissions. A good practice methodology for calculating transport emissions is the ASIF formula developed by Schipper et al. (2000). The temporal and spatial scales of the lifetime of the pollutant should match.
- The model has to be empirically and behaviorally valid, therefore describing the order of magnitude and the direction of changes in policy as what can be expected in real life. Hence, the model should be validated with observed data and behave as expected.
- The model has to be consistent, therefore calculations should be made consistent throughout the model and the model should be in balance so that the outcomes are not highly sensitive to one or two variables, but to multiple. This ensures that the model behaves at all levels and in all parts of the calculation in a similar manner.

6.2 ASSESSMENT OF RACE

RACE puts the emphasis on developing land use maps and calculates in a transparent way the transport emissions. RACE is able to calculate the implications of a land use strategy for the long-term on transport emissions. It cannot provide any concrete policy measures for the short or medium term or policies other than land use related. These will always lead to direct assumptions. Nor can the figures produced by RACE be used as part of the exact quantification of measures. RACE can provide a direction and order of magnitude to the impact of a land use policy in terms of emissions.

RACE is providing relevant outcomes for the development agencies by providing citywide transport emissions and the difference between a sustainable land use form in comparison to a business as usual scenario, however it needs to calculate uncertainty to be of greater use in decision making. For the local policymakers RACE provides them with insights in how and where a city *can* develop. It falls short in identifying local problems, as it is unable to provide a credible allocation of transport volume or emissions to the cells.

The scenario development is conducted in detail and provides a credible way of how a city can develop in 20-year time. However, the detailed scenario development in the GIS is not fully transferred to the spreadsheet; in particular, the detailed accessibility analysis of the land use maps can be used in the spreadsheet to allow more detailed analysis of the trips and modal split. The time consuming development of land use maps limits the ability of possible intermediate results or quick modification of a scenario. The spreadsheet is functioning, although it could be improved by allowing more calculations at the cell level. Currently calculations in the spreadsheet are quickly aggregated to the district and city level, therefore limiting the possibility of using more disaggregate data and limits the presentation of outcomes to only aggregated citywide results.

RACE is comprehensive regarding the pollutants it models; it models the most important pollutants, but it should match the pollutants lifetime with the respective temporal and spatial scale. It is suggested that the model uses the same geographic boundaries as the jurisdictive boundaries of the local municipality to create greater compatibility with other studies and improve the planning process by not deciding upon areas beyond the borders of the local authority.

RACE has implemented the ASIF formula correctly. The activity is modeled in detail at the detailed 500m grid cells, but overly simple due to a cap introduced in the total number of trips generated. For the structure (the modal split), the same is true: at the cell level the calculation is detailed, but at the city level the modal split is exogenous and only an input variable. The intensity and fuel factor cannot be calculated at the cell level; only at the district/city level. At the district/city level this is modeled correctly and accounts for all variables considered in the ASIF formula.

A detailed analysis of the interaction between land use and transport shows that there is no complete feedback link between land use and transport. The four-step model is not completely followed; the trip generation is severely limited due to the introduction of a cap on the total number of trips and allocation to the cells is on the basis of gross building area in the origin (production), while the gross building area in the destination (attraction) is not used to distribute the number of trips. The destination is only used to modify the average distance between two districts. The modal split is exogenous and only modified at the cell level due to the land use mix and is the weakest part of the calculation due to the large influence the modal split has regarding the total volume travelled and the total amount of emissions. Assignment is not possible, due to the omission of the transport network in the spreadsheet.

To provide a first indicative validation of the results of RACE, two of the three case studies are compared to alternative available studies considering transport or transport emissions in the city. The results are inconclusive and a complete validation is necessary. RACE is fully correct in modeling changes to emissions by variation in fuel efficiency, distance between origin and destination, emission standards and vehicle occupancies. RACE is partly correct in modeling changes in density, diversity, and distance to transit: it is correct in the change in volume of private and non-motorized travel, but incorrect in transit usage. The design and destination accessibility is not possible to model within RACE.

In sum, the conceptual idea behind RACE is excellent and provides local policymakers and development agencies, a potential, valuable model. However, the translation from conceptual idea to algorithms and software needs further improvement to provide credible results and be of use in the planning process. RACE is currently in between two goals: (1) providing hard analytical quantification of the effects of a land use policy and (2) supporting policymakers in land use planning and creating greater understanding of urban development. A focus on one of the two goals would benefit the use of RACE.

This discussion above of RACE shows that a model is strongly viewpoint specific and requires the need for a thorough analysis from various perspectives to evaluate a model completely. The conceptual framework of Kolkman (2005) separating the model development cycle and the problem solving cycle has proven very useful to provide insights of the model usability and theoretical quality. It also rightly identifies the importance of the actors in model development; as end-users, stakeholders, and scientists can have a different view on what is necessary and useful.

6.3 RECOMMENDATIONS

Various recommendations can be given, based on the conclusions and the discussion described above.

- The evaluation framework should be verified in other case studies by evaluating other models and determine how generic the current framework is and what specific is for this evaluation.

- It should be analyzed how the policy process of land-use planning is conducted in developing Asian cities. This would allow the model to be more usable in the planning process and target specifically the problems of land-use planning in developing Asian cities. A similar analysis can be made if and how the developing Asian cities differ from other developing cities, and if the current criteria are applicable to these situations.
- To enable a comparison of models the evaluation framework should be further operationalized to perhaps a quantified evaluation framework as it allows easier comparison. It is recommended to identify which criteria are considered more important in a model and which are found lacking in the current operational models in developing Asian cities.
- Currently only two stakeholders are considered important in the planning process. However, Vonk (2006) has identified several other actors involved in the planning process, and divided the 'local policymaker' in various sub groups. The analysis of Vonk can be incorporated in the current evaluation framework and can be expanded to include other stakeholders.
- There is limited empirical knowledge of the influence of land use policy on transport and even on the wider factor such as economy, demography, etc.
- There is not yet an adequate land use model that can model dynamically the changes that are occurring in developing Asia. Most land-use models are developed for a Western context in which marginal changes occur, while in Asia large and rapid changes in economy and demography occur. A model that can model these changes and reflects the influence of the policy on these changes has yet to be modeled, but could provide valuable insights in the influence of land use policy on urban development in developing Asia.

The recommendations specifically regarding RACE are as follows:

- Position RACE as a planning tool to see future city implications on transport, rather than a transport model or a model that can provide exact quantification. RACE can provide insights in future developments and if the calculations are being improved, then where and how transport and emissions will develop. However, exact quantification is inherently not possible and not the goal of RACE. It is not a transport model and should not be used as such, in particular while it omits the transport network in the calculations.
- RACE has to be validated with independent data. Therefore, two aspects have to be conducted: RACE has to improve the ability to compare the results with other studies, firstly by taking similar boundaries and definitions as being used by the local policymakers. Secondly, to conduct a study in a city which has detailed available data and which has already conducted a similar study to estimate the total travel volume and the total emissions. Both results have to be validated as both are important (travel volume for the local policymaker and emissions for the development agencies).
- The link between the GIS analysis and the spreadsheet should be improved. Much time is consumed by the development of detailed GIS maps which contains a lot of information, which is not entirely transferred to the spreadsheet. Complete transfer would greatly improve the calculations, in particular the accuracy of the modal split calculations, which is now exogenous to the model. It would also enable to use the spreadsheet calculations in allocating land use by transferring the information back. Therefore the calculations should also be calculated at the cell level. Besides the theoretical improvement, it would make the outcomes of RACE model more relevant for local policymakers.
- Make the model correctly respond for changes in density, diversity, design, distance to transit, and implement destination accessibility as a factor of influence. In particular the calculations regarding transit usage should be improved.
- Various operational models can model transport and emissions. A comparison of RACE to other transport emissions models could be very useful to see what can be learned and determine in greater detail to what makes RACE unique and strong in comparison to other models. Suggestions are the UrbanSim model and Metronamica, as both are models that are more theoretically advanced, but lack at first sight the transparency RACE has.
- Develop manuals/guidelines which explains how the model is working, but also what the rationale is behind RACE. The policy implications of modifying an input variable has to be explained as well to ensure that the model is used in the right way

and not only to provide the right answers. This can provide a 'coherent story line' and increases the transparency.

- Make the excel file more user friendly and adaptable to different levels of input data. This improves the adaptability of the model to different cities and allows it to become more precise in its calculations. Secondly, manage the security of the spreadsheet to minimize modifications to calculations, to make the model more user friendly to operate.
- If possible, try to create a way to develop/modify land use maps quickly to develop more specific land use policies and really being used as a planning support tool in the early phase of the policy process.
- Create a comprehensive gravity model to distribute trips more accurate. This also allows allocation of transport emissions to the cells.
- Define in more detail the difference between greenhouse gas emissions and local air pollution. Make sure to match the temporal scales; local air pollution is estimated at a fine grid and requires a fine (hourly) temporal scale, while greenhouse gas emissions can be calculated at the city level or even national level, it also requires a less fine (annual) temporal scale.

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Appendix A. EVALUATION FRAMEWORK

The development of a city based land-use transport emissions model in Asian cities is unique. There is no adequate alternative model that incorporates similar features, at least to the authors' knowledge. From an extensive literature review, two aspects are considered essential: it should be useful for the problems at hand and it should be theoretically sound. The following literature is reviewed:

- Air quality modeling and emission inventories: Borrego et al. (2006); Chang and Hanna (2004); Davison et al. (2008); EEA (2012); Friedrich and Reis (2004); IPCC (2006); Moussiopoulos et al. (2005)
- Land-use transport interaction: Hunt et al. (2005); Lee (1973, 1994); Miller et al. (1998); Supernak (1983); Waddell (2011)
- Emissions modeling: Hickman (1999); Schipper et al. (2009); Schipper and Marie-Lilliu (1999); Schipper et al. (2000)
- Planning support systems and policy process: Batty (2007); Couclelis (2005); Fehr & Peerce (2009); B. Harris and Batty (1993); Jäger (1998); Rondinelli (1973); Stead and Meijers (2009); Te Brömmelstroet (2010b); Vonk (2006); Walker (2000)

This has resulted in 10 criteria. Each criterion is explained in detail below.

A.1 USABLE

1. **Usable: for policymakers and urban planners to be able to decide, use and implement the model in parts of the urban planning process**
   1.1. Is the model cognizant of the drivers of the problems of the urban planning process in developing Asian cities?

Land-use planning is a public policy, requiring insights in how the future of a city would look like. There are two determinants that drive the cities future land use: demographic and economic development. Most developing Asian cities are growing very rapidly, adding thousands of people every year to the city.

Secondly, climate change is currently happening, at the current pace this will go well beyond the 2 degree scenario as agreed to be sustainable. Many cities will have to adapt to this changing climate and at the same time try to mitigate dangerous climate change.

Final aspect, as land-use planning is a public policy covering various disciplines, the model should be cognizant of the current political framework and possibly improve the coordination between departments and understanding of sustainable land-use planning.

can the model be used on a strategic level for urban planning, and is responsive to different strategic policy measures

Urban planning is a long-term policy measure to improve the land use, and therefore transport and emissions on the long run. This is also the most effective way of reducing transport emissions. Additional policy measures could be the implementation of the effects of large infrastructural investments, as they will influence land use as well. Alternative policies are more effective on the short or middle term and can be implemented, but are not necessarily be required.

1.2. are decision makers able to understand, handle, interpret and communicate the results

There are two important stakeholders in the process of urban land-use planning in developing Asian cities: the local policymaker and the development agencies. There is a large difference in capacity and knowledge between the local policymakers and the development agencies. Their objectives and focus are also different. Therefore, a different approach with accompanying results is required for each actor:

In the case of the local policymakers, it is important to provide local results, which focus on the local problems such as air pollution and congestion. While for the development agencies, the focus in the results should be on the total reduction in emissions; this requires also different levels of aggregation.

Secondly, the local policymakers have to be part of the process in using the model by providing workshops and guiding materials to use the model and work on the capacity building of the local policymakers. The development agencies have the capacity or have the ability to hire the necessary capacity and they need to be aware of the existence and range of application of the model to suggest it in other projects.

Thirdly, visual results are nearly always easier to interpret, compared to descriptive reports. Visualization of many results would help also the local policymaker to communicate the results to the politicians.

Fourth aspect is the need to provide the uncertainty in the results, as if the model is supporting decisions it is essential to show the uncertainty to know the risks of the decision results.

Finally, the model should minimize the time of calculation to have the ability to use the model interactively and see direct the consequences of a different policy.

1.3. is the model flexible in terms of data input requirements to adapt to the availability of local data, adapt to different timeframes, and local circumstances such as different vehicle fleets, travel behavior or land use patterns

Every city is different; the model should be flexible enough to

- allow the input of locally data, and provide backup of national or even international data.
- allow to be flexible in terms of vehicle fleets and respective emission factors
- allow to incorporate different land use maps and local geographical characteristics
- assess the city on different timeframes

1.4. are the cost of implementing and using the model in terms of money and resources acceptable to the local policymakers or the development agencies

The local policymakers do not have many funds to implement the model, but do have, in general, the work force to implement it. The model should require minimal time to implement to be operational.

1.5. is the whole study area and are all relevant pollutants and emissions sources covered that are important for the respective end-users

Various pollutants and emission sources can be considered, a full list can be given by IPCC (2006)At a local scale the emissions PM and NO_x are important, while on a national and international scale the most important pollutant is CO_2.

Sources of transport emissions is mostly the combustion of fuel, but also in more detailed calculation the evaporation of fuel and wearing of tires is important.

A.2 THEORETICALLY SOUND

2. Theoretically sound: incorporating land use, and calculating transport activity and emissions correctly

2.1. is the model able to reflect the relationships between land use and transport, i.e. reflect calculates land use activity, trip generation, trip distribution, modal split, and assignment

Land use and transport are related to each other and mutually influence each other. In transport modeling the four step of trip generation, distribution, modal split, and assignment is usually followed describing the steps of how many trips, location of trips, mode of transport and the route choice is calculated.

Land use influences transportation. This is mostly described in line with the 5D's of Cervero and Murakami (2008): density, diversity, design, distance to transit, and destination accessibility.

Transport is the movement of people and goods, but this happens over the infrastructure providing it. Conceptually these are in balance and a low supply of transport would result in lower transport or different routes between origin and destination.

Both are essential characteristics in describing the land use of a city, usually a city is developing either because of the presence of infrastructure or because of the other way around: infrastructure is developing because land use is developed.

2.2. is the model using good practice methodologies for estimating emissions and implements it correctly

Estimating transport emissions is often following the formula of Schipper et al. (2000): Activity x Structure x Intensity x Emission factor. Activity and structure are a result of the modeling of transport activity as described in the previous two requirements, while intensity and emission factor depend on vehicle fleets and the city design. This should be reflected in the model.

Alternatively, the model could make use of the fuel consumption as a way to estimate transport at the city level; this does not allow the disaggregation of the results to the local level and is therefore only suitable to estimate emissions that are important at a city level.

2.3. is the model empirically and behaviorally valid

The model has to be empirically validated against observed real world data to gain confidence in the results. This can be done in various ways: for instance comparing the transport activity to other transport studies, emissions to air quality studies.

The model should be behaviorally valid, therefore the model should react to policy changes as can be expected in real life, based upon detailed understanding of how the system works and requires validation from different fields of research. The direction and magnitude to which transport and emissions are influenced by land use should be modeled and be reflected in the results when varying input variables.

2.4. is the model consistent throughout the model, in terms of input, methods, and outcomes

The level of detail should be consistent throughout the model, the input data should match the required results; the results cannot be more specific than the input data. As a model is as reliable as the most uncertain data is.

The spatial scale of the emission calculations should match the pollutant lifetime and the temporal scale.

The calculations should be in balance, so that not one variable is of essential importance while other variables have hardly any influence.

Final aspect is that the model should try to be consistent with other definitions to ensure a greater compatibility with other models.

The model has to be dimensional consistent.

Appendix B. DETAILED DESCRIPTION OF RACE

This appendix describes RACE in greater detail. The process of calculations are written in formulas, the required input variables and possible outcomes are presented. Thirdly a flowchart of the calculation and the relationship between all parameters is presented. Fourth paragraph describes which variables are varied for the sensitivity tests. The final paragraph notes minor mistakes found in the implementation of RACE in the three case studies.

B.1 RACE IN FORMULA

Develop a polygonal raster at a resolution of 500m to determine the land use characteristics. The land use maps are divided in 15 categories (from low residential to health or governmental buildings). The story height determines the density of the area. If building inventory data is available that is used, alternatively very high-resolution images are used in combination with field checks.
The objective is to obtain the gross building area (GBA) per land use category (m) per cell (z).

To every cell a number of residents is allocated ($GBAP$), this is based on census data on district level and the GBA. The results are extracted to a table with the $GBAP$ per cell to be used in a spreadsheet.

Next is to determine the vehicle trips generated per cell. The $GBAP$ is multiplied by a trip generation factor per land use category.

$$Vehicle\ trips_z = \sum_m GBAP_{m,z} * \frac{Trip\ generation\ factor_m}{Average\ size\ of\ the\ dwelling}$$

The vehicle trips are converted to passenger trips (t_z) by multiplying it with the average vehicle occupancy (average of all modes). Next to this, the total trips are corrected. This number to create a preliminary number of trips generated per cell (t_z). The trips generated are corrected to match with the average trips per capita for the whole city.

$$t_z = vehicle\ trips_z * avg\ vehicle\ occupancy * \frac{Trips\ per\ capita * population\ size}{\sum_z (Vehicle\ trips * avg\ vehicle\ occupancy)}$$

Calculate the number of passenger trips (t) per mode (k). Therefore, the mode share is given on a district level (i). The mode share of non-motorized transport is increased by maximum 2% depending on the land use entropy.

$$Land\ use\ entropy = \frac{\sum_i \left(\ln(\frac{GBAP_i}{\sum GBAP}) * \frac{GBA_i}{\sum GBA}\right)}{-\ln(i)}$$

$$NMT\ share = NMT\ share + LUE * 2\%$$

$$t_{i,k} = mode\ share_{i,k} * \sum_{z} t_{z,i}$$

Distribute the trips. The distribution of trips is conducted by using a gravity model on district level. The gravity model is based on the gross building area in the destination (attraction,j). The distance between two districts is determined by GIS using a straight line from the centroid to the other centroid. For internal trips, the distance is determined by the radius of the district.

$$Preliminary\ average\ distance_i = AD1_i = \sum_{j} \left(dist_{ij} * \left(\frac{dist_{ij}^{-2} * GBA_j}{\sum_j dist_{ij}^{-2} * GBA_j} \right) \right)$$

The average distance for all modes (AD) is corrected to match with expert judgment, which will be corrected to the number of trips generated in a particular scenario

, the weighted average of vehicle trips and the distribution of trips and multiplied by the weighted average of vehicle trips in a district (irrespective of the transport mode).

$$Expert\ AD = Expert\ AD * \frac{\sum_i \left(\frac{t_{i,SCENARIO}}{\sum_i (t_{i,SCENARIO})} \right)}{\sum_i \left(\frac{t_{i,BAU}}{\sum_i (t_{i,BAU})} \right)}$$

$$Preliminary\ AD2_i = AD1_i * \frac{\sum_i (AD1_i)}{\sum_i (i)} * expert\ AD$$

$$AD_i = AD2_i * \frac{expert\ AD}{\sum_i \left(\frac{t_i}{\sum_i (t_i)} * AD2_i \right)}$$

The passenger kilometers (PKM) can be calculated by multiplying the average distance with the number of trips generated (t_i). To correct for that some transport modes will have longer trips in comparison to others (imagine bus vs. motorcycle), there is a correction factor implemented (average distance per mode =D_k). This is only undertaken for motorized transport.

$$PKM_{i,k} = D_k * t_{i,k} * \frac{AD_i * \sum_k t_{i,k}}{\sum_k (t_{i,k} * D_k)}$$

The PKM are converted to vehicle kilometer (VKM) by dividing to the average vehicle occupancy:

$$VKM_k = \frac{PKM_k}{Occupancy_k}$$

The VKM are converted to fuel consumption (FC) per fuel (f) by dividing it to the fuel efficiency. The fuel efficiency is corrected for the average speed per district (speed factor impact,SPF).

$$FC_{i,k,f} = \frac{VKM_{i,k} * fuel\ split_k}{fuel\ efficiency_k - (fuel\ efficiency_k * SPF_{i,k})}$$

Last part of the calculation is to estimate the energy consumed, and the amount of CO_2, PM, and NO_x emitted. The amount of CO_2 is calculated by multiplying the total fuel consumed with the carbon content of the fuel. Particulate Matter and NO_x are calculated by multiplying the VKM with the PM emitted per type of emission standard (euro 1, euro 2, etc.) and corrected for the average speed.

$$energy\ consumption_{i,k,f} = energy_f * FC_{i,k,f}$$

$$CO2_{i,k,f} = FC_{i,k,f} * carbon\ content_f$$

$$PM\ content_{f,k} = \sum_{standard} (PM_{f,standard,k} * energy\ standard\ split)$$

$$PM_{i,k,f} = VKM_{i,k,f} * (1 + SPF_{i,k}) * PM\ content_{f,k}$$

$$NOx\ content_{f,k} = \sum_{standard} (NOx_{f,standard,k} * energy\ standard\ split)$$

$$NOx_{i,k,f} = VKM_{i,k,f} * (1 + SPF_{i,k}) * NOx\ content_{f,k}$$

Next to the emissions calculations the total number of injury's per VKM can be calculated ($\frac{total\ injuries}{total\ vkm}$), to be compared to other countries. In addition, the fuel costs can be calculated.

The different calculations can result in a variety of figures, for instance the total amount of CO_2 emitted or the number of trips generated per mode. Standard are the number of trips, passenger kilometers, vehicle kilometers, total amount of emissions, mode shares, fuel consumption, all segregated to different modes or different fuels.

B.2 OUTCOMES

The outcomes are the following[5]:

Table 13. Outcomes of RACE

Outcome	Level of detail		Dependents
Land Use Entropy	Cell level		Gross building area
Mode share	Cell level		Mode shares Maximum trip internalization per cell for NMT Land use entropy
Passenger trips	Cell level	Per mode	Trip rate/capita Population size Gross building area Mode share Size of a dwelling Vehicle trips generated per land use category
Average trip length (km)	District level	Per mode	Distance between two districts Average distance according to experts Gross building area Number of trips per district
VKM and PKM	District level	Per mode	Average trip length Number of trips per mode Vehicle occupancy Distance between two zones Average distance per mode
Fuel consumption	District level	Per mode, per fuel	Vehicle kilometer Average speed per mode Fuel split Fuel efficiency per mode
Energy consumption (thousand PKM/toe)	District level	Per mode, per fuel	Fuel consumption per fuel type and mode Energy per fuel
CO_2 emissions	District level	Per mode, per fuel	Fuel consumption per fuel type and mode Carbon content per fuel Emission standard split
PM and NO_x emissions	District level	Per mode, per fuel	Fuel consumption per fuel type and mode Average speed per mode PM and NO_x emissions per speed per mode Emission standard split

5 Excluding the fuel costs and injuries caused by traffic accidents

B.3 CALCULATION FLOW

This diagram shows how RACE is calculating the emissions and the influence of the input variables

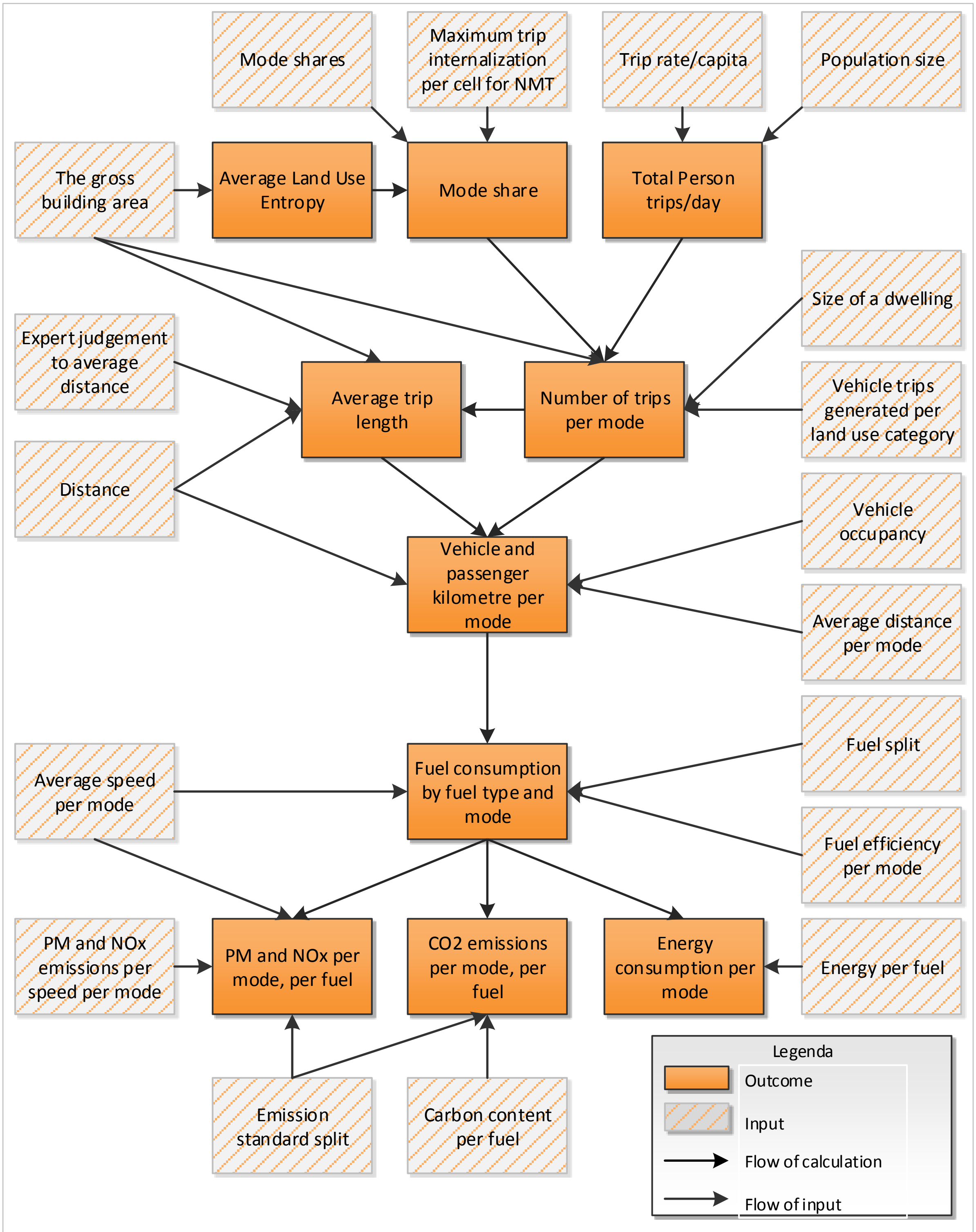

Figure 22. Flow of calculation of RACE

B.4 SENSITIVITY TESTS

The sensitivity tests are conducted, but due to the large number of input variables unable to be part of this research. The following is calculated

- Variation of the outcomes: passenger kilometer per mode, vehicle kilometer per mode, and emissions
- of each input variable:

- **Population size**	- **NO_x EmFactr Bus diesel**
- **Trip rate capita**	- **NO_x EmFactr Bus**
- **Veh occupancy Bus**	- **NO_x EmFactr Public**
- **Veh occupancy Public**	- **NO_x EmFactr Private**
- **Veh occupancy Private**	- **NO_x EmFactr All**
- **Veh occupancy ALL**	- **PM EmFactr Bus, diesel**
- **Mode shares**	- **PM EmFactr Bus**
- **Max trip internalization**	- **PM EmFactr Public**
- **Expert judgement to AD**	- **PM EmFactr Private**
- **Avg Dist Bus**	- **PM EmFactr All**
- **Avg Dist Public**	- **Carbon content Gasoline**
- **Avg Dist Private**	- **Carbon content diesel**
- **Avg Dist All**	- **Carbon content lpg**
- **Avg speed Bus**	- **Carbon content cng**
- **Avg speed Public**	- **Carbon content all**
- **Avg speed Private**	- **Trip generation Informal settlements**
- **Avg speed All**	- **Trip generation Res**
- **Fuel efficiency Bus**	- **Trip generation All**
- **Fuel efficiency Public**	- **GBA IS**
- **Fuel efficiency Private**	- **GBA Residential**
- **Fuel efficiency All**	- **GBA All**
- **Fuel split Bus**	- **GBA District 5 Residential land use**
- **Fuel split Rickshaw**	- **GBA District 5 All land use category**
- **Fuel split Car**	- **GBA District 10 Residential land use**
- **Emis standard Bus**	- **GBA District 10 All land use categories**
- **Emis standard Rickshaw**	

- by variation of -25%, -20%, -15%, -10%, -5%, 0%, 5%, 10%, 15%, 20%, 25% of the input variable.

The results are available digital.

B.5 CALCULATION ERRORS

During the analysis of the RACE model, several small errors are found. These are named below:

- There are differences in the way the average distance is calculated between the scenario and the baseline, see the sheet distance (row: 3036)
- The model is quadrupling the walking and cycling km, see the sheet Backcalcs (columns: AO and AP in Ahmedabad)
- The effect of the conversion factor from vehicle km to passenger km (the factor 1.6) is cancelled out by the calculation: population size * trips per capita, see the sheet cells (column BA in Ahmedabad)
- The average distance per transport mode has only effect with respect to the other average distance of the same category (non-motorized, public or private transport). It is recommended to change the formula that the variable average distance per transport mode has effect with respect to all other transport modes instead. See the sheet backcalcs (Ahmedabad columns: AQ-BD)