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COMPARATIVE ACCESSIBILITY FOR MOBILITY MANAGEMENT

The Structural Accessibility Layer

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ABSTRACT

Urban mobility problems, such as congestion, have been threatening the quality of life and the competitiveness of urban areas as well as their sustainable development. The need to integrate land use and transport policies has been widely recognised as an important approach within the 'predict and prevent' paradigm for mobility management. Nevertheless, such integration is seldom put into practice. The lack of design support tools is pointed out as one of the reasons for this fact.

The accessibility concept is believed to provide a useful framework to support the design of integrated land use and transport policies. This thesis hypothesises that measures of comparative accessibility by transport mode can operationalise the accessibility concept for this purpose. In order to test this hypothesis, a design support tool was developed, based on a measure of comparative accessibility – the Structural Accessibility Layer (SAL). The usefulness of the tool, and thereby of comparative accessibility, was tested. The testbed is composed of the application of the tool to a case study and of expert interviews evaluating that application. The case study provides insight into its potentials as design support tool for integrated land use and transport policies. Expert interviews enable the assessment of the robustness, usefulness and applicability of the tool.

The results of the testbed suggest that the SAL provides a useful operational form of the accessibility concept for design support. The use of comparative accessibility has clearly a key role in the ease of understanding and design support abilities of the SAL. This research concludes that measures of comparative accessibility by transport mode seem to provide a useful design support framework for integrated land use and transport policy, shedding light on the sustainability of potential mobility enabled by land use and transport conditions.

RESUMO

Os problemas de mobilidade urbana como, por exemplo, o congestionamento de tráfego, têm posto em causa qualidade de vida das populações bem como a competitividade e o desenvolvimento sustentado das grandes áreas urbanas. No contexto do novo paradigma de gestão da mobilidade – 'previsão e prevenção' – a necessidade de integrar políticas de uso do solo e transportes tem sido amplamente reconhecida; porém, na prática, esta integração tem sido escassamente implementada. Uma das razões para esta situação é atribuída à falta de instrumentos de apoio à decisão.

O conceito de acessibilidade é tido como um instrumento com o potencial de apoiar o desenvolvimento de políticas integradas de uso do solo e transportes. A hipótese subjacente a esta tese sustenta que a utilização de um instrumento baseado na comparação de acessibilidade por modo de transporte poderá operacionalizar o conceito de acessibilidade para o apoio ao desenvolvimento de políticas integradas de uso do solo e transportes. De forma a testar esta hipótese é criado um instrumento de apoio ao desenvolvimento de políticas com base na comparação da acessibilidade por modo de transporte – o Mapa de Acessibilidade Estrutural (*Structural Accessibility Layer* – SAL). A hipótese é testada com base numa aplicação do SAL a uma caso de estudo e com base em entrevistas a peritos avaliando os resultados dessa aplicação. O caso de estudo é usado para avaliar o potencial do SAL como instrumento de apoio ao desenvolvimento de políticas, enquanto que as entrevistas são usadas para avaliar a robustez, utilidade e aplicabilidade prática do instrumento.

A avaliação sugere que o SAL se afigura como um instrumento capaz de operacionalizar o conceito de acessibilidade para o apoio ao desenvolvimento de políticas integradas. O uso de medidas de acessibilidade comparativa por modo de transporte teve um papel primordial na transparência e na capacidade de apoio ao desenvolvimento de políticas do SAL. Esta investigação permite concluir que as medidas de acessibilidade comparativa por modo de transporte constituem um quadro de referência favorável ao desenvolvimento de políticas integradas de uso do solo e transporte funcionando como medida do potencial de sustentabilidade da mobilidade.

RESUMÉ

Les problèmes de mobilité urbaine, tels que les embouteillages, sont une menace pour la qualité de vie et la compétitivité des zones urbaines ainsi que pour leur développement durable. La nécessité d'intégrer l'usage du sol et les politiques de transport a été largement reconnue comme une approche importante au sein du paradigme du 'prévoir et prévenir' la gestion de la mobilité. Néanmoins, une telle intégration peut se révéler difficile à mettre en pratique. Le manque d'outils d'aide à la conception est souvent souligné comme une des raisons de cette difficulté.

La notion d'accessibilité est souvent présentée comme pouvant proposer un cadre utile pour la conception intégrée de l'usage du sol et les politiques de transport. Cette thèse émet l'hypothèse que les mesures comparatives de l'accessibilité par mode de transport peut rendre opérationnel le concept d'accessibilité dans cette optique. Afin de tester cette hypothèse, un outil d'aide à la conception a été mis au point, fondé sur une mesure comparative de l'accessibilité – *Structural Accessibility Layer* (SAL). L'utilité de l'outil, et donc de l'accessibilité comparative, a été testée. Le banc d'essai se compose de l'application de l'outil à une étude de cas et d'entrevues avec des experts de l'évaluation de cette application. L'étude de cas donne un aperçu de son potentiel comme outil d'aide à la conception intégrée de l'usage du sol et les politiques de transport. Des entrevues avec des experts permettent d'évaluer la solidité, l'utilité et l'applicabilité de l'outil.

Les résultats dune étude de cas donnent à penser que le SAL fournit une forme opérationnelle utile de la notion d'accessibilité dans le design. L'utilisation de l'accessibilité comparative a clairement un rôle clé dans la facilité de la compréhension et le soutien des capacités de conception du SAL. Cette étude conclut que les mesures comparatives de l'accessibilité par mode de transport semblent constituer un bon cadre pour soutenir la conception intégrée de l'usage du sol et de la politique de transport en tant qu'éclairage sur la durabilité du potentiel de la mobilité rendue possible par l'usage du sol et les conditions de transport.

ACRONYMS

CP – Rail public transport operator (*Comboios de Portugal*)

GIS – Geographical Information System

GO – Greater Oporto

LUT – Land use and transport

METRO – Light-rail public transport operator (*Metro do Porto*)

NM – Non-Motorized transport modes

PSS – Planning support systems

PT – Public Transport

SAL – Structural Accessibility Layer

STCP – Road public transport operator (*Sociedade de Transportes Colectivos do Porto*)

TDM – Travel Demand management

TMB – Travel Money Budget

TTB – Travel Time Budget

INDEX

Acknowledgments i
Abstract iii
Resumo iv
Resumé v
Acronyms vii
Index ix
Index of Figures xiii
Index of Tables xvii

Chapter 1 1
Introduction 1
1.1. Background 1
1.2. Research Scope 4
1.3. Research question 8
1.4. Methodology 9
1.5. Structure of the Thesis 11
1.6. Conceptual Discussion 13

Chapter 2 19
Land Use and Transport factors influencing travel behaviour 19
2.1. Theoretical evidence 20
2.2. Empirical evidence 25
2.2.1. Evidence of Interaction of Land Use and Transport 26
2.2.2. Evidence of the combined influence of Land Use and Transport on mobility patterns 31
2.3. Synthesis: Implications for policy making 45

Chapter 3 49
Accessibility Measures 49
3.1. Components used 50
3.2. Types of accessibility measures 51
3.2.1. Discussion of advantages and disadvantages of all measure types 56
3.3. Operational detail for accessibility measures 60

3.4. Synthesis: implications for the development of accessibility measures 64

Chapter 4 67

Structural Accessibility Layer 67

4.1. The concept of Structural Accessibility Layer 70

4.2. The Measures 71

4.2.1. The accessibility measure 71

4.2.2. The sustainability measure 81

4.3. SAL's stakeholders 88

4.4. Synthesis: theoretical discussion of SAL's potentials and limitations 89

Chapter 5 93

Testbed 93

5.1. The case study region 94

5.2. The case-specific SAL 102

5.3. Results of the application of the SAL 110

5.3.1. Analysis of current conditions for mobility 110

5.3.2. Use of the SAL for strategy design 121

5.3.3. Data-related limitations of the case-specific SAL 138

5.4. Expert assessment of the behaviour of the SAL 139

5.4.1. Main results 140

5.5. Synthesis: Outcomes of the testbed 143

Chapter 6 145

Lessons Drawn from Research 145

6.1. Feedback for the development of the case-specific SAL 146

6.2. Feedback for the conceptual framework of the SAL 150

6.3. Feedback for a second test of the SAL 159

6.4. Feedback for theoretical discussion 162

Chapter 7 167

Conclusion 167

7.1. Future Research 170

References 173

Annex A **185**

Case-Specific SAL – Choices **185**

A.1. Activities considered for each activity type 187

A.2. Disaggregation of statistical data at census track level 191

A.3. Disaggregation of percentage of trips by activity types 193

A.4. Calibration of average driving speed 195

Annex B **197**

GO Case Study Application - Maps **197**

Annex C **221**

Expert Interviews **221**

INDEX OF FIGURES

Figure 1.1: Research scope ... 8
Figure 1.2: Methodology ... 11
Figure 1.3: Structure of the thesis ... 12
Figure 2.1: Land Use Transport (LUT) feedback cycle ... 20
Figure 2.2: Zahavi's theory of TMB and TTB ... 22
Figure 2.3: The Brotchie Triangle ... 23
Figure 2.4: Amount of literature on the relationship between land use, transport and mobility patterns ... 25
Figure 2.5: Two-way interaction between land use and transport according to Kockelman *et al*. (2002). ... 31
Figure 2.6: Expected effects of land use and transport factors on sustainability indicators ... 47
Figure 3.1: Choice of components used ... 51
Figure 3.2: Choice of type of accessibility measures ... 53
Figure 3.3: Rectangular function (cut-off point) ... 55
Figure 3.4: Comparison of accessibility measure types ... 59
Figure 3.5: Choice of operational details ... 60
Figure 3.6: Overview of the choices for accessibility measures ... 65
Figure 4.1: The SAL's framework ... 69
Figure 4.2: Main choices for the development of the accessibility measure ... 73
Figure 4.3: Accessibility boundaries by transport mode drawn for two example origin points ... 78
Figure 4.4: Balance between soundness and plainness of the accessibility measure ... 80
Figure 4.5: Case-specific choices for the accessibility measure ... 80
Figure 4.6: Potential combinations of accessibility values by three transport modes ... 81
Figure 4.7: Benchmarking cube and accessibility classes by transport mode ... 82
Figure 4.8: Benchmarking cube and accessibility clusters ... 84
Figure 4.9: Level of detail used during the process ... 87
Figure 4.10: Case-specific choices for the sustainability measure ... 88
Figure 4.11: Some examples of stakeholders ... 89
Figure 4.12: Potentials and limitations of the SAL ... 92

Figure 5.1: Europe / Portugal / GO / Municipalities 94
Figure 5.2: Population Density (by square kilometre) 95
Figure 5.3: Employment Density (by square kilometre) 96
Figure 5.4: Road Infrastructure and Public Transport routes of the GO 98
Figure 5.5: Modal split for the main modes of the GO in 1991 and 2001 (considering only work and school trips) 99
Figure 5.6: Interdependency of municipalities 100
Figure 5.7: Distribution of trip purpose 101
Figure 5.8: Case-specific benchmarking cube 109
Figure 5.9: Diversity of Activities Accessible by non-motorized modes and by Classes 113
Figure 5.10: Diversity of Activities Accessible by public transport and by Classes 115
Figure 5.11: Diversity of Activities Accessible by car 117
Figure 5.12: Categories and clusters of accessibility 119
Figure 5.13: Proposed urban centre structure for the general strategy for GO 125
Figure 5.14: Strategy for the structure of public transport 126
Figure 5.15: Proposed urban structure of the general strategy for GO 128
Figure 5.16: Strategy groups 131
Figure 5.17: Aimed accessibility categories for each sub-region 137
Figure 6.1: Extra map with DivAct=1 152
Figure A.1: Road type and congestion limits 195
Figure B.1: Diversity of activities within each sub-region 199
Figure B.2: Sub-regions containing activity type 1 – Infant and Elementary schools 200
Figure B.3: Sub-regions containing activity type 2 – High schools 201
Figure B.4: Sub-regions containing activity type 3 – Universities 202
Figure B.5: Sub-regions containing activity type 4 – Parks, Public Gardens and Squares 203
Figure B.6: Sub-regions containing activity type 5 – Restaurants 204
Figure B.7: Sub-regions containing activity type 6 – Cinema 205
Figure B.8: Sub-regions containing activity type 7 – Shows / Theatres 206
Figure B.9: Sub-regions containing activity type 8 – Sports 207
Figure B.10: Sub-regions containing activity type 9 – Other leisure activities 208
Figure B.11: Sub-regions containing activity type 10 – Shopping (food) 209
Figure B.12: Sub-regions containing activity type 11 – Shopping (other) 210

Figure B.13: Sub-regions containing activity type 12 – Pharmacies.......................... 211
Figure B.14: Sub-regions containing activity type 13 – Hospitals and Clinics........... 212
Figure B.15: Sub-regions containing activity type 14 – Public / Municipal administration offices... 213
Figure B.16: Sub-regions containing activity type 15 – Postal offices 214
Figure B.17: Sub-regions containing activity type 16 – Banks 215
Figure B.18: Sub-regions containing activity type 17 – Other activities..................... 216
Figure B.19: Existing urban centre structure 217
Figure B.20: Proposed urban centre structure (general strategy for GO).................... 218
Figure B.21: Proposed urban structure (general strategy for GO).............................. 219
Figure B.22: Accessibility categories and unitary diversity of activity index by mode.. 220

INDEX OF TABLES

Table 3.1: Main advantages and disadvantages of accessibility measures..................... 57
Table 4.1: Examples of detail that can be used for cut-off criteria................................ 76
Table 4.2: Formulations of the diversity of activity index 79
Table 5.1: Activity types considered 104
Table 5.2: Total travel time cut-off values 105
Table 5.3: Cut-off criteria and values for the public transport 106
Table 5.4: Average speed used for each operator and route.. 108
Table 5.5: Average driving speed (km/h) 108
Table 5.6: Accessibility classes for each transport mode by area and by population... 111
Table 5.7: Categories and clusters by number of sub-regions, area and population 120
Table 5.8: Summary of main choices for general strategy 123
Table 5.9: Summary of strategy and action for each strategy group 133
Table A.1: Activity types and activities... 188
Table A.2: CAE classification and designation... 189
Table A.3: Activity types considered 194
Table C.1: List of experts interviewed... 223
Table C.2: Main questions used to guide the interview.. 227
Table C.3: Main advantages and disadvantages 228

Chapter 1

INTRODUCTION

1.1. Background

Urban passenger mobility has undergone significant changes over the past few decades. Travel distance and frequency have been increasing and the car has become the main means of travel in most European and North American cities, due to its spatial and temporal flexibility. Furthermore, the rate of work-related trips has decreased considerably with commuting representing less than half of all journeys in many of these urban regions. Concerning non-work related activities, leisure makes an important contribution to the increasing complexity of travel patterns, fostered by the generalisation of private car use. As a consequence, travel patterns are becoming difficult to predict and therefore difficult to serve by traditional public transport.

Changing travel patterns have been driving urban mobility away from sustainability. A range of new mobility problems have arisen in urban areas, such as congestion, increasing pollution (air and noise), degradation of landscape quality and social exclusion. These mobility problems jeopardize the quality of life and competitiveness of urban areas. There is therefore a need for policy intervention to steer travel behaviour.

Transport Policy has traditionally been responsible for the management of mobility patterns, even though it originally aimed simply at providing an answer to travel needs by offering necessary transport infrastructure and services. In this context, transport planning was directed by the 'predict and provide' paradigm. With the revolution of motorized transports after World War II, there was a need for a swift and efficient response to rapidly increasing travel demand in order to assure economic development. However, the inherently slow development of new infrastructures brought about congestion.

Nowadays, planning has shifted its role from steering to encouraging economic development. The slowing of economic development was followed by a reduction of public budgets for the construction of transport infrastructures. Furthermore, new social and political concerns with environmental issues, social equity and quality of life, have emerged. New mobility problems and public concerns have led to the decline of the 'predict and provide' paradigm.

Within new requirements for sustainable development, there has been a general recognition of the need to manage the demand side of travel. The concept of Travel Demand Management (TDM) was introduced in the 1980s gearing policy strategies towards 'predict and prevent' actions. Banister (1994b) believes that, nowadays, there is a general recognition that the need to travel must be reduced. In addition, the European project TRANSPLUS (Greiving and Kempre, 1999) points out the need to make the remaining travel more sustainable. Consequently, this paradigm requires a broader approach to mobility management, which clearly surpasses the boundaries of traditional transport planning.

From the variety of constraints and motivations influencing travel behaviour, land use and transport systems provide the baseline exogenous conditions steering travel patterns. Land use raises the need to move in order to participate in disperse urban activities, while the transport system offers the conditions to satisfy these mobility needs. Thus, mobility patterns are constrained by the land use and transport system[1], defining a range of potential mobility patterns. The choice of specific travel patterns within the potential mobility patterns is further influenced by other aspects, such as

[1] Although recognizing the existence and importance of non-derived demand in urban travel behaviour, this study focuses solely on derived demand and therefore potential mobility patterns are considered to be defined by the land use and transport system.

socio-economic and demographic characteristics (which are generally considered to be among the most important factors influencing travel behaviour). Nevertheless, sustainability of travel patterns is primarily constrained by the land use and transport system (or urban structure)[2]. If urban structure does not provide the necessary conditions to enable mobility to be sustainable then other policy actions on socio-economic and demographic characteristics have only limited potential. Consequently, from the aspects influencing travel behaviour, mobility management must primarily consider land use and transport systems.

It is also important to bear in mind that land use and transport systems have a mutual influence on each other, besides their influence on mobility patterns. Thus, Rodenburg *et al.* (2002) argues that the design and implementation of land use and transport polices individually will not be sufficient to cope effectively with mobility problems. Conversely 'A combination of carefully stated policies that reinforce each other and avoid adverse side-effects will be required' (Rodenburg *et al.*, 2002; 463).

As a result, the need for the integration of land use and transport policies has been recognized by several authors (e.g. Banister, 1994a,b; ISIS, 1999; Wegner and Fürst, 1999; Halden, 2002; Stead, 2003; Cervero 2003). Integrated land use and transport policies can provide the necessary (albeit not sufficient) conditions for sustainable mobility patterns, without which complementary policy action would have limited to no effect. According to Geerlings and Stead (2003), the European Union has shown a special interest in policy integration since the early 1980s.

A study developed by NEA (2003), on the integration of public transport, suggests that increasing level of integration may increase efficiency and enable a better achievement of common objectives. Furthermore, Stead *et al.* (2003) state that 'There is an increasing recognition that inconsistent policies entail a higher risk of duplication, inefficient spending, a lower quality of service, difficulty in meeting goals, and, ultimately, of a reduced capacity to govern.' (Stead *et al.*, 2003; 16).

There are clear theoretical and empirical evidences of interaction between land use and transport systems and of their combined effect on mobility patterns. In addition, there is

[2] In this thesis, 'urban structure' will be used as synonymous of 'land use and transport system'.

a broad political and academic recognition of the need to integrate land use and transport policies to foster more sustainable mobility patterns. According to Martens and Eijkelenbergh (2002), most planning documents include at least the desire to integrate land use and transport. In spite of these facts, integration is seldom put into practice. 'Successful implementations of integrated planning concepts are still rather scarce in most of the EU member states' (ISIS, 1999; 9).

Numerous implementation barriers have been identified for policy integration, such as, legal, institutional, financial, political, cultural, practical and technological barriers (May, 2003). According to Brömmelstroet (2007) the most relevant aspects responsible for the lack of implementation in practice of integrated land use and transport policies are: the existence of conflicting interests, the lack of common land use and transport language, the absence of political commitment for integration, the existence of institutional barriers and the lack of good support instruments (Brömmelstroet, 2007).

1.2. Research Scope

This research focuses on one of the implementation barriers for integrated land use and transport policies, aiming to contribute to the translation of theory and rhetoric into practice. The implementation barrier addressed is the lack of design support tools.

In contrast to the abundance of analysis and evaluation tools, there is a lack of tools supporting the design of integrated land use and transport policies. In addition, it is generally believed that very few of the developed policy design support tools are actually used in practice. Literature on Planning Support Systems (PSS) identifies the dichotomy between supply and demand of PSS as the main reason for this phenomenon. On the one hand, planning practitioners (potential users of PSS) are generally unaware of and inexperienced in the use of PSS, not recognising their value and potential (resulting in low intention to use them). On the other hand, developers of PSS have little awareness of demand requirements. [Vonk *et al.*, 2005; Geertman, 2006; Brömmelstroet, 2007; Hoetjes, 2007; Vonk *et al.*, 2007].

The effective use of PSS is currently suffering from a 'rigour-relevance dilemma', with developers mainly concerned with rigour while users are mainly concerned with relevance (see for instance, Hoetjes, 2007; Brömmelstroet, 2007). The increasing complexity of planning in addition to technological developments (especially in computer sciences) has stimulated the development of complex PSS. There seems to be a pursuit for scientific rigour in order to contain ever-growing complexity. The resulting 'black-box effect' seems to be enlarging the gap between supply and demand.

This argument is supported by a list of criticisms made by practitioners (see Vonk *et al.*, 2005; Geertman, 2006; Brömmelstroet, 2007; Hoetjes, 2007). These believe PSS to be technology-oriented, pursuing the use of technological improvements instead of the resolution of current problems. Moreover, PSS are stated to be too abstract, generic and complex, producing inflexible systems for the support of planning which are narrowly focussed on strict rationality. In these conditions potential users are sceptical of the usability of the PSS for planning practice. They believe PSS to be inadaptable to the changing needs of planning (concerning the unpredictable/flexible nature of most planning and information needs). [Vonk *et al.*, 2005; Geertman, 2006; Brömmelstroet, 2007; Hoetjes, 2007]

On the other hand, according to Vonk *et al*. (2007) planners perceive PSS to be useful for information storage and retrieval, as well as simple information visualization, arguing that non-analytical uses are given higher value.

Brömmelstroet (2007) developed a study of PSS's desired characteristics for integrated land use and transport policies. This study provided insights into the relative importance of several bottlenecks believed to limit the use of PSS. Among the most important limitations are the lack of transparency, the low communication value, the lack of user friendliness and the lack of interactivity of the developed systems. This study also provides better understanding of the desired characteristics of PSS to improve support abilities. The most important aspects are the ability to evaluate ideas, playability, transparency, the creation of new insight for problems being handled and speed. Aspects such as objectivity, precision and detail are found to be within the least important PSS characteristics (although still important). [Brömmelstroet, 2007]

It seems clear that the design of PSS for the development of integrated land use and transport policies must take into consideration this discussion, overcoming the main bottlenecks and providing theoretically rigorous as well as usable instruments. This thesis proposes the use of accessibility measures for this purpose.

Several authors such as Halden *et al*. (2000), Bertolini *et al*. (2005) and Straatemeier (2006) believe that accessibility measures provide a useful framework for the design of integrated land use and transport policies. Accessibility measures are considered to describe the link between transport and land use (Handy and Niemeire, 1997; Halden *et al*., 2000; Halden, 2002; Bertolini *et al*., 2005). In addition, Geurs and Wee (2004) argue that these measures are easy to interpret and operationalise. Finally, Straatemeier and Bertolini (2008) believe accessibility measures have the potential to deal with current limitations in the development of integrated land use and transport policies. They argue that accessibility has the potential to address the need for a common language between land use and transport, for a link of transport planning to broader policy concerns and for more emphasis on the policy design phase.

Although accessibility has long been used in the academic and planning debate 'the translation of such concepts in performance measures that can be usefully employed to improve integration of transport and land use plan making in practice is still very limited (Handy and Niemeier, 1997; Geurs and Wee, 2004)' (Bertolini *et al*., 2005; 209-210). The importance of searching for helpful accessibility measures for policy design can be justified by the lack of operational forms of accessibility measures for planning and policy design purposes (in spite of the vast academic research). Geurs and Wee (2004), argue that accessibility is often misunderstood, poorly defined and measured, which supports the need for further research in this field. The lack of translation has been attributed, by Stanilov (2003), to the lack of consensus on the best accessibility measures to be used.

In order to develop useful accessibility measures, Straatmeier and Bertolini (2008) defend that these should be goal oriented and based on a collective agreement on the data and measure types used. Another important aspect is the interactivity of the measure which should provide real time insight into accessibility changes with policy action. Finally, 'Accessibility indicators should directly relate to both the policy issues and goals as defined by participants and to validated knowledge on actual travel behaviour and location behaviour' (Straatemeier and Bertolini, 2008; 10).

Makrí (2001) believes that there is a need for accessibility measures to be simple, plain and easy to understand and apply in order to cope with the lack of application of accessibility concepts in planning situations. This author also defends the importance of the legitimacy of operational forms of accessibility measures, stating that measures should concern issues relevant to urban development and planning process as well as being valid and reflecting real travel behaviour. Geurs and Wee (2004) define the following criteria to evaluate the usefulness and limitations of accessibility measures in the evaluation of land use and transport condition: theoretical basis, operationalisation, interpretability and communicability and, finally, usability in social and economic evaluation. According to Bertolini *et al*. (2005) the accessibility measure 'must be consistent with the use and perceptions of residents, workers, and visitors of an area, and it must be understandable to those taking part of the plan-making process' (Bertolini *et al*., 2005; 210).

Summarizing these statements into keywords, two distinct groups of characteristics can be found as required for accessibility measures; they must be:

- meaningful, consistent, legitimate, valid and consider relevant issues, as well as,
- simple, plain, understandable and usable.

These requirements are, in my opinion, perfectly summarised by Bertolini *et al*. (2005) using the concepts of 'soundness' and 'plainness', respectively. These authors define *soundness* as the *'consistency of the measure with the behaviour of households and firms'* and *plainness* as the *'transparency of computing procedures and ease of calculations – or the communicative qualities of the measure'* (Bertolini, *et al*., 2005; 218). These requirements push towards opposite complexity levels of accessibility measures being developed. Thus, finding the right balance between soundness and plainness of an accessibility performance measure is a key choice. The balance between soundness and plainness transcribes the rigour-relevance dilemma of PSS discussed before.

In summary, taking into consideration the background as well as the selected theme, Figure 1.1 schematizes the research scope. The primary concern of this research is the sustainability of urban mobility patterns, more specifically the lack of sustainability of current passenger mobility within urban areas[3]. Within the several approaches believed to help bring about sustainable mobility patterns, this research focuses on policy action, specifically on the integration of land use and transport policies. This is based on the assumption that the integration of land use and transport policies can be used to provide the necessary (albeit not sufficient) urban structure conditions for sustainable mobility. Being aware of the dichotomy between the recognized importance of integrated land use and transport polices and the lack of implementation in practice, the research focuses on coping with one of the identified implementation barriers: the lack of design support tools. With regard to identified requirements as well as the potentials and limitations of PSS, this research centres on the potential of accessibility measures to enable the development of efficient design support tools for integrated land use and transport policies.

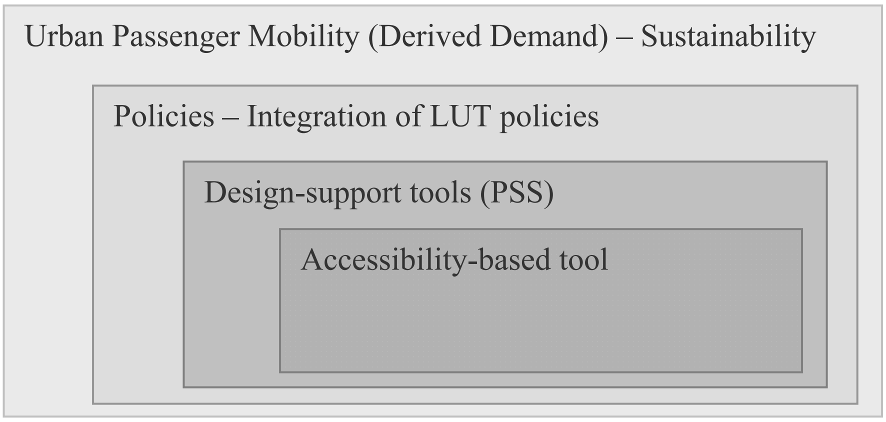

Figure 1.1: Research scope

1.3. Research question

Two strategic objectives serve as motivation for the development of this thesis: to contribute to the effective integration of land use and transport policies and thereby to contribute to the management of urban mobility towards sustainability.

[3] A choice was made to limit the research scope to urban passenger mobility, excluding cargo, and to derived demand.

This research is based upon three general assumptions:

- First, the integration of land use and transport policies is able to provide the necessary urban structural conditions to enable sustainable travel behaviour;
- Second, the development of theoretically sound as well as usable and relevant design support tools can help to bridge the gap between theoretical and political rhetoric of policy integration and its use in practice.
- Third, the concept of accessibility is able to frame the development of theoretically sound design support tools which are usable and relevant in practice.

In this context, the research question and hypothesis underlying this thesis are the following.

Research question: How can accessibility measures be operationalised in order to built a useful design support tool for the integration of land use and transport policies?

Research Hypothesis: A measure of comparative accessibility by transport mode may provide a useful design support framework for the integration of land use and transport policies by shedding light on the sustainability of potential mobility enabled by land use and transport conditions.

1.4. Methodology

In order to test the research hypothesis the methodology used is based on, first, a literature review; second the development of an accessibility-based design support tool for integrated land use and transport policies using comparative accessibility by transport mode; and third a case study application of the tool to test the research hypothesis.

The research starts with a literature review in search of the theoretical framework for the development of the accessibility-based design support tool. This literature review includes two main fields. The first field refers to land use and transport and their influence on travel behaviour while the second research field centres on accessibility measures. The aim of the former literature review is to find the most relevant land use and transport aspects influencing travel behaviour. The aim of the latter is to search for a useful form of accessibility measure.

The literature review provides the necessary background for the development of the conceptual framework of the accessibility-based design support tool[4] (using comparative accessibility by transport mode). The conceptual framework combines theoretical and empirical knowledge gathered during the literature review. At the centre of this process is the balance between theoretical soundness and plainness for the development of a useful tool.

Once theoretically defined, both the design support tool and the research hypothesis are tested in a case study. The testbed is composed of the application of the tool to the case study and of the expert interviews evaluating that application. The case study provides insight into the ease of translation of the theoretical concept into a practical tool, supplying an overview of practical implications. Expert interviews enable the assessment of the robustness[5], usefulness and usability of the tool.

The testbed enables the evaluation of, firstly, the potentials and limitations of the tool (including analysis and design support abilities), and secondly, the research hypothesis. Additionally, the testbed provides feedback for the improvement of its theoretical framework and recommendations for application in practice (regarding the learning cycle). Finally this testbed provides clues for further research concerning the consolidation of the developed tool and the usefulness of comparative accessibility measures as design support instruments.

Figure 1.2 summarises the methodological chain used for this research.

[4] The development of a PSS involves a long process including the theoretical development of the tool, the test of the tool using multiple case studies and the evaluation of its interaction with users during real planning applications (with the two latter providing the so called 'learning cycle'). While case studies provide valuable feedback for the improvement of the PSS, real planning applications (after consolidation of the tool) provide further insight into the usefulness and usability of the tool. Within this thesis, considering time constraints and purpose, the development process of the design support tool will be limited to the first step of the learning cycle. This step involves the development of the conceptual framework incorporating feedback of a first case study application.

[5] Robustness refers to the ability of the measure to provide a suitable representation of local land use and transport conditions.

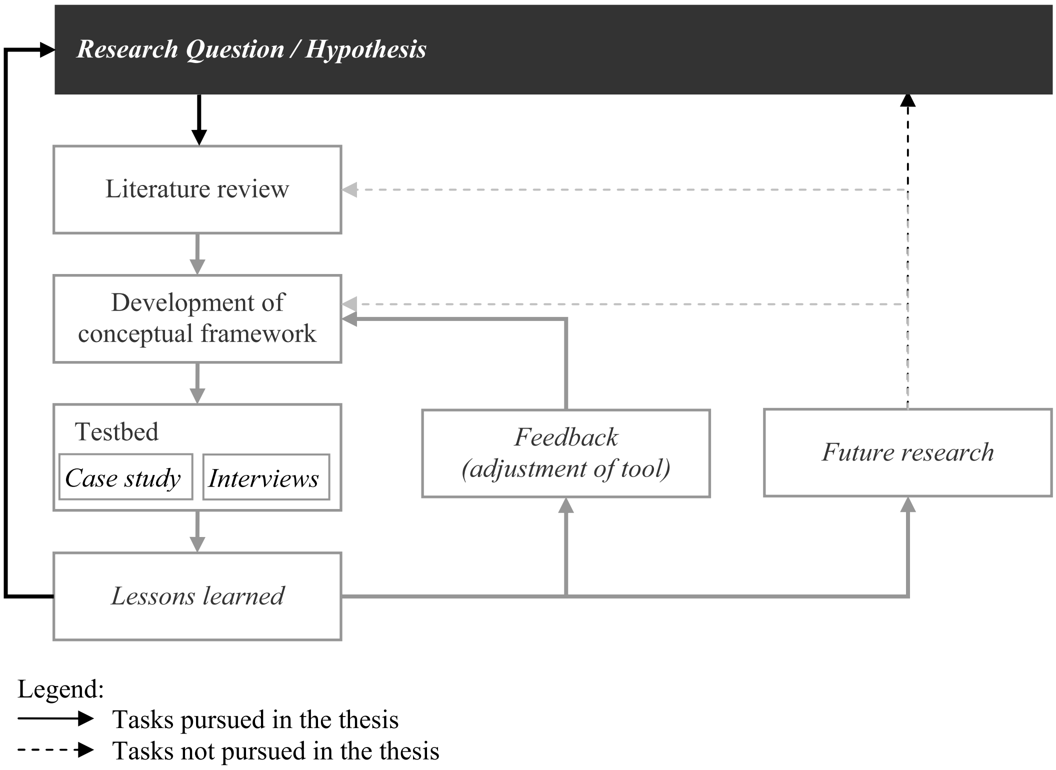

Figure 1.2: Methodology

Future research enables the development of further steps in the learning cycle of the design support tool (required for its maturity) and further discussion around the operationalisation of accessibility-based design support tools.

1.5. Structure of the Thesis

This thesis starts by presenting the background and motivation for the research theme. Chapter 1 defines the research question and methodology. This chapter concludes with a conceptual discussion clarifying the baseline concepts of this research. The following two chapters present the literature review in two main fields, land use and transport factors influencing mobility patterns and accessibility measures. These provide the necessary background information for the theoretical development of the design support tool in Chapter 4. Chapter 5 presents the details of the used testbed, reporting the development of the case-specific design support tool and presenting the main results of the case study application and of the expert interview evaluation. Chapter 6 discusses the feedback provided by the testbed for the development of the design support tool as well as for scientific knowledge. With regard to the learning cycle of the design support tool three aspects are discussed: lessons for the practical application of the tool, lessons for the improvement of the conceptual framework of the tool, and lessons for the development of a second test of the SAL. With regard to scientific knowledge, the discussion focuses on the influence of land use and transport on mobility, accessibility-based policy design support instruments and new mobility management approaches. Finally, Chapter 7 presents the main conclusions of the thesis, providing an answer for the research question. In addition, the chapter provides clues for future research.

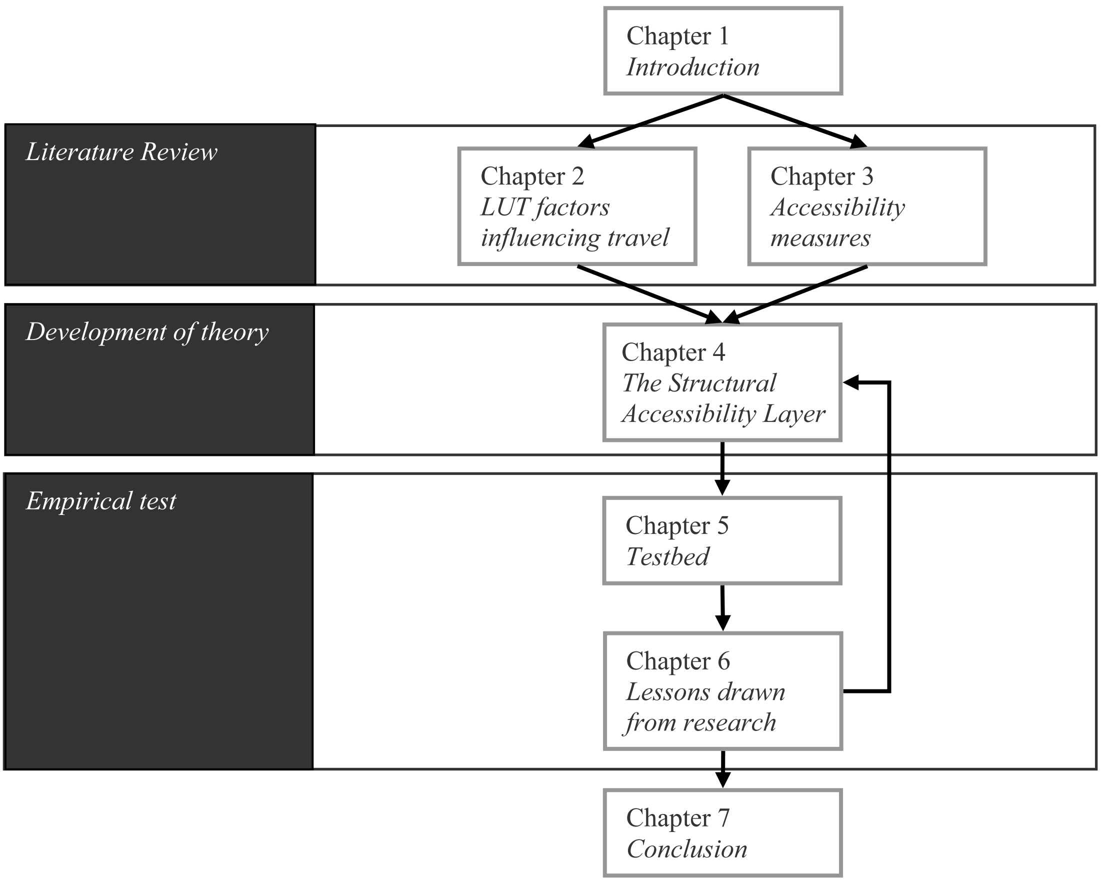

Figure 1.3: Structure of the thesis

1.6. Conceptual Discussion

Within the research field of urban mobility several of the most frequently used and most important concepts are found to be ill defined, frequently resulting in indiscriminate use. Within these concepts, sustainability, integration of policies, transport, mobility and accessibility, are at the baseline of this research. Therefore, before entering the main discussion of the thesis a conceptual clarification is required.

Sustainability

The problem with the concept of sustainability is concerned with the trivialization of its use, not always referring to all three dimensions of sustainability (environment, economy and society). Sustainability is a core concept underlying this research, considering the strategic objective to contribute to sustainable urban mobility. In this thesis the following concepts of sustainable development and sustainable mobility were used.

Several definitions of sustainable development can be found. The original concept developed in the Brundtland Report in 1987 defines *sustainable development* as *'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'* (World Commission on Environment and Development, 1987 cited in EC, 2001; 6).

EC (2001) defines *sustainable mobility* as a *'transport system and transport patterns that can provide the means and opportunities to meet economic, environmental and social needs efficiently and equitably, while minimising avoidable or unnecessary adverse impacts and their associated costs, over relevant space and time scales'* (EC, 2001;7).

Policy Integration

Although integration is commonly considered to have positive effects on policy making, there is no generally accepted definition of policy integration. Stead (2003) goes even further, stating that there is also some ambiguity on the most suitable concept to be used when referring to different types of integration. 'In most cases, the meaning of 'integration' is assumed to be understood and shared by the members of the community to which it is addressed' (NEA, 2003; 14). This might also be the main reason why so few authors engage in conceptual discussions or even present a simple definition for this concept. Schnurr (1998) adds that this concept has been overused without a good enough understanding of its appropriateness and practical implications. This lack of thoroughness in the comprehension of the concept of policy integration has clearly been a result of policy rhetoric fashion. This phenomenon can also be recognized for the concept of sustainable development in spite of several proposed definitions.

An important contribution for the clarification of the concept of policy integration is given by authors, such as NEA (2003) and Stead *et al*. (2003), who distinguish the concept of integration from other concepts – cooperation and coordination – frequently considered to be similar, and classifying them as three different levels of 'working together' (Davison and Lindfield, 1996; referred to in NEA, 2003). According to Stead *et al*. (2003) the main differences between these three concepts are related to the level of interaction and the outputs.

A quite general definition of policy integration was developed by Stead *et al*. (2003): 'Policy integration concerns the management of cross-cutting issues in policy-making that transcend the boundaries of established policy fields, which often do not correspond to the institutional responsibilities of individual departments.' (Stead *et al*., 2003; 17).

This definition refers to policy integration as a management process of issues transcending the boundaries of traditional policy sectors, which is evidently the core motivation for integrating policy-making[6]. Besides the integration between sectors of the same governmental level (horizontal integration), integration is also generally considered to have a vertical dimension involving different governmental levels (vertical integration). Additionally, other dimensions such as spatial and temporal integration seem to have an increasing importance in urban policy. The increasing complexity of the planning context calls for ever more integrated planning approaches, involving several dimensions.

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[6] An extensive review of large number of concepts of policy integration can be also found in Stead *et al*. (2003).

The complexity of the policy integration concept is even more evident considering the diversity of types and levels of integration which are suggested by the literature (e.g. Schnurr, 1998; Geerlings and Stead, 2003; NEA, 2003, Potter and Skinner, 2000; Stead *et al*., 2003; Meijer and Stead, 2004; Stead and Meijer, 2004; Hull, 2005). As policy integration is found to have a scalar nature it seems evident that no single definition can be provided for its concept (in accordance with Potter and Skinner, 2000). Therefore a scale of policy integration concepts may be the practical solution to enhance scientific validity and avoid misunderstandings of what is entailed in each case.

The lack of a clear concept of policy integration can recurrently justify the existence of conflicts between stated aspirations and achievements of policy action. It is clear that the lack of understanding of the process of policy integration, and what it entails in order to achieve certain objectives, may lead to overexcitement about the potential of the real actions proposed under the general concept of policy integration. Considering the regular use of this concept within political rhetoric it would even seem that any kind of integration would bring about sustainability.

In the absence of a broad ranging and well-defined scale of policy integration concepts this thesis proposes its own concept. An extension of the definition of policy integration, developed by Stead *et al*. (2003), is proposed for the general definition of *Policy Integration*:

'Policy integration concerns the management of cross-cutting issues in policy-making that transcend the boundaries of established policy fields […]' (Stead *et al*., 2003; 17), *involving the production of a coherent joint policy, combining policy measures of individual policy fields and new cross-cutting measures, taking advantage of positive synergies and complementarities in order to maximise efficiency in the achievement of pre-defined objectives.*

Policy integration for mobility management combines the general definition used for policy integration (mainly related to integration between sectors) to a more general integration requirement involving spatial and temporal integration. Mobility management calls for an inclusive view and action upon mobility catchment areas following a jointly defined action chain to bring about desired outcomes.

Therefore, an *Integrated Policy for mobility management* can be considered a *coherent policy action entailing several cross-cutting actions and measures on one or several policy fields, involving a wider spatial strategy and a detailed chain of actions, enabling higher efficiency in the achievement of the desired goals*.

Transport vs Mobility

The conceptual confusion between transport and mobility has been recurrent in literature. The concept of transport has been used within a broad meaning, frequently including mobility. In addition, transport has even been used with the single meaning of mobility in several publications. In this thesis the concepts of transport and mobility are used with the following meanings: while *transport* refers to the *system enabling travel*, *mobility* is refers to the *use made of that system to access spatially disperse opportunities* (considering only derived demand).

In recent years the need to clearly distinguish mobility from transport has grown. The traditional transport planning paradigm defining a 'predict and provide' strategy has shared the responsibility for this conceptual mismatch. Within a paradigm defining the development of transport systems as response to mobility needs, transport and mobility are somehow overlapped. The new 'predict and prevent' paradigm has shrunk the overlapping of transport and mobility, reducing the potential fallacy between these concepts. Nonetheless, this conceptual mix-up can still be found in current literature, as was confirmed during the literature review developed for this research. Several authors studying the influence of land use on travel behaviour define their study theme as the influence of land use on transport. This reasoning seems to be based on the traditional land use and 'transport feedback cycle' (see Figure 2.1) which is the baseline for this and other research themes.

Mobility vs Accessibility

In addition to the recurrent conceptual confusion between transport and mobility, there is a thin dividing line between the meaning of mobility and accessibility. Considering the perceived change of the transport planning approach from 'planning for mobility' to 'planning for accessibility' it is important to clearly distinguish accessibility from mobility.

In spite of the importance of the accessibility concept for the current planning context no universally used definition can be found in the literature. According to Gould (1969, p.64; cited in Ingram, 1971; 101) 'Accessibility … is a slippery notion … one of those common terms that everyone uses until faced with the problem of defining and measuring it'. In contrast to the notion of mobility, commonly related to the 'ease of movement' which can easily be operationalised, accessibility is commonly related to the 'ease of reach of desired opportunities' (Levine & Grab, 2002). Accessibility has a far more ambiguous notion than mobility, implying a range of aspects such as, the distribution of potential destinations; the magnitude, quality and character of activities; the performance of the transportation system; the characteristics of the individuals; and the times at which the individuals are able to participate in activities (Handy and Niemeier, 1997; Liu and Zhu, 2004).

Authors such as Geurs & Eck, 2001 argue that the definition of the concept of accessibility depends on the objective for which it is intended. Considering the aim of the accessibility measure developed for this thesis (to work as a design support tool for integrated land use and transport policies) the following general definition is proposed:

Accessibility is the *extent to which the land use and transport system enables individuals to reach different types of opportunities* (based on the concept by Geurs and Eck, 2001, p. 36).

This definition of accessibility reflects the spatial distribution of opportunities as well as the availability and service level of different transport modes.

Chapter 2

LAND USE AND TRANSPORT FACTORS INFLUENCING TRAVEL BEHAVIOUR

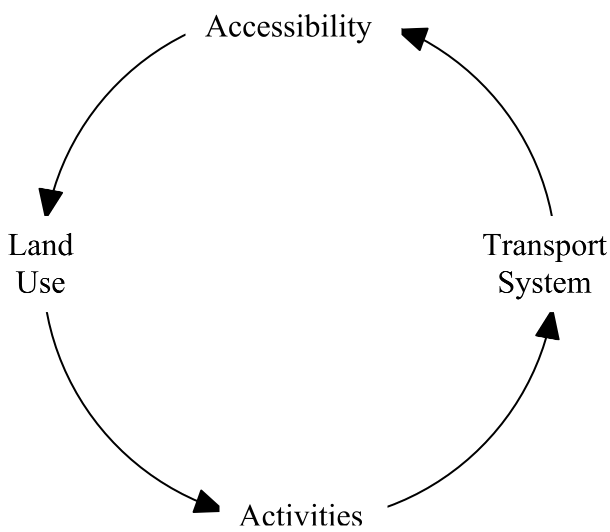
The development of a design support tool for integrated land use and transport policies requires an understanding of the interaction between these two fields as well as of their combined influence on travel behaviour.

Sections 2.1 and 2.2 present the main findings of the literature review on land use and transport interaction and on their combined influence on urban mobility patterns. While the first reviews theoretical evidences the second reviews empirical evidences. Theoretical evidence of the interaction of land use and transport was found in spatial development theories. Some illustrative examples of spatial development theories are presented, showing how the mutual influence of land use and transport shapes the evolution of urban structure. Empirical evidence was collected from a broad range of empirical studies on the effects of land use and transport (combined or individually) on travel behaviour. Section 2.3 presents some concluding remarks and the main implications of land use and transport interaction for urban mobility policy making.

2.1. Theoretical evidence

In human history, cities arouse with the division of labour due to the specialization enabled by technological innovations. It has been generally believed that, while originally city size was conditioned by travel distance on foot and horse powered vehicles, the development of transport technology has been responsible for the enlargement of urban areas and dispersion of activities. The consequent separation of human activities led to the generalization of the need to travel.

Theories of spatial development present several evidences of the interaction of land use and transport. One of the earliest work on the interaction of land use and transport was developed by American researchers in the 1950s, following the 'first real conceptual breakthrough in transport planning' (according to Banister, 1994a). This work recognised that urban traffic was a function of land use leading to the development of the 'Land Use and Transport feedback cycle'.



Source: Adapted from Wegner and Fürst (1999)

Figure 2.1: Land Use Transport (LUT) feedback cycle

According to Wegner and Fürst (1999) the set of relationships implied by the term 'Land Use and Transport feedback cycle' can be briefly summarised as follows:

– 'The distribution of land uses, such as residential, industrial or commercial, over the urban area determines the locations of human activities such as living, working, shopping, education or leisure.

– The distribution of human activities in space requires spatial interactions or trips in the transport system to overcome the distance between the locations of activities.

– The distribution of infrastructure in the transport system creates opportunities for spatial interactions and can be measured as accessibility.

– The distribution of accessibility in space co-determines location decisions and so results in changes of the land-use system.' (Wegner and Fürst, 1999; 5)

A recurrent point in several urban development theories is the recognition that interaction of land use and transport systems has shaped urban development. Furthermore, this interaction is believed to have an important influence in the current configuration of urban areas. According to Wegner and Fürst (1999) economic theories of spatial development are based on the fundamental assumption that '[…] locations with good accessibility are more attractive and have a higher market value than peripheral locations' (Wegner and Fürst, 1999; 11). This assumption goes back to von Thünen (1826)[7] who studied agricultural location and was the first to consider the influence of distance (and therefore of transport) on spatial organization. According to this author, the choice of crops for a certain land (or vice versa) is dependent on price, production volume and transport cost. For this assumptions land prices decrease with distance from the market. [Lopes, 1980]

Later economic location theories, such as central place theories from Christaller (1933)[7] and Lösch (1940)[7], also considered transport cost as a fundamental factor in explaining spatial development patterns. These authors defined a hierarchy of market areas around central places on the assumption that people use different activities with different frequencies and that therefore different hierarchy of centres should have different hierarchy of activities (which is the reverse of its frequency of use). The most frequently used activities can be found in all local centres while less frequently used activities can only be found in centres of higher hierarchical level (agglomerating a range of other

[7] Referred to in Lopes (1980).

activities of the same level and all other lower levels). Centres are distributed according to their influence area which is a result of the combination of transport costs and hierarchical level of offered activities. More complex urban development theories based on the economic paradigm consider economies of scale and land prices besides of transport cost. [Lopes, 1980]

An example of social science theories of the urban development showing the interaction of land use and transport and their influence on urban mobility is Zahavi's travel behaviour theory (Zahavi, 1974, 1979; Zahavi *et al*., 1981; referred to in Wegner and Fürst, 1999). Contrarily to conventional theory of travel behaviour, this author proposed the hypothesis that daily mobility decisions result not of the minimisation of travel cost and time but of the maximization of the access to activities and opportunities within a certain travel time and money budget. These two budgets are considered by the author to be the fundamental constrains of travel behaviour. His studies of several cities around the globe found Travel Time Budgets (TTB) and Travel Money Budgets (TMB) to be remarkably stable over time. This stability over time in association with increasing income levels explain the shift towards faster and more expensive transport modes over the last decades (see Figure 2.2). According to Wegner and Fürst, (1999) these budgets make clear why '[…] gains in travel speed have not been used for time savings (as is usually assumed in transport cost benefit analysis) but for more and longer trips' (Wegner and Fürst, 1999; 17).

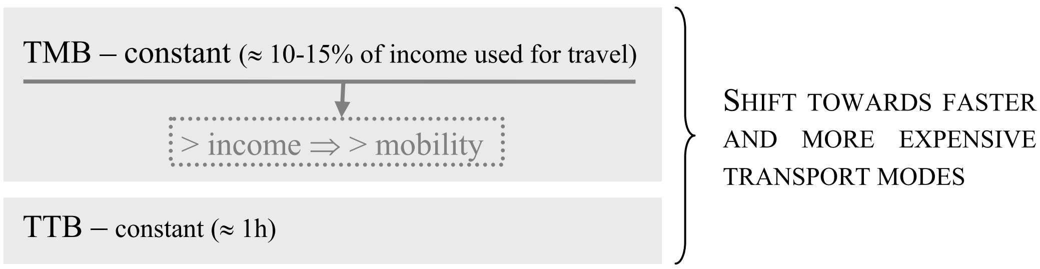
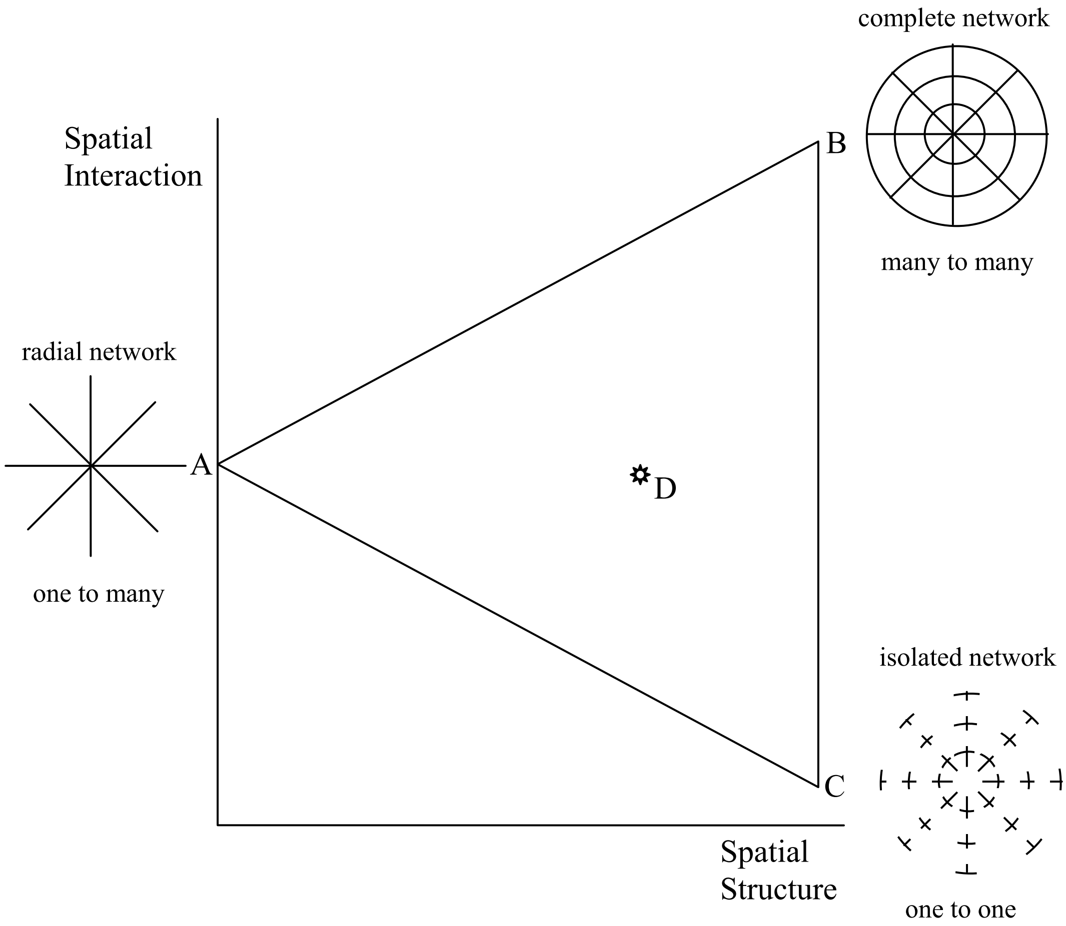


Figure 2.2: Zahavi's theory of TMB and TTB

Another example of urban development theory showing the interaction of land use and transport and their influence on urban mobility is the 'Brotchie Triangle' developed in the 1980s. The Brotchie triangle relates spatial structure (e.g. mean travel distance of employment to the centre of the region) with spatial interaction (e.g. mean travel distance to work) (see Figure 2.3).



Source: Adapted from Wegner and Fürst (1999) and Simmonds and Coombe (2000)

Figure 2.3: The Brotchie Triangle

Each city can lie between three extreme points of the Brotchie Triangle – A, B and C. The horizontal axis represents the dispersion of working places from the centre and the vertical axis represents dispersion patterns of travel. Point A represents the city with total concentration of jobs in city centre and radial commuting patterns, point B represents the city with decentralized employment and dispersed commuting and point C represents the city with decentralized employment and workers choosing nearby working and housing locations. Point D represents the spatial structure and interaction of a given city. The combinations of spatial structure and interaction found in line AC present the minimum need to travel for the city. The Brotchie triangle shows that decentralization of working places does not automatically induce shorter travel distances, it may even increase travel distance if spatial interaction increases. While spatial structure may not be enough to influence travel patterns transport policies hindering long distance travel and promoting slow transport modes may shift spatial interaction of a city in line BC towards point C. The Brotchie triangle also shows that spatial structure (in other words, land use), the transport system and spatial interaction (which could also be referred to as mobility patterns) co-determine each other.

Finally, another example of social theory of urban development, showing the interaction of land use and transport and their influence on urban mobility, is the so called 'systems approach', which is framed by the more generic 'ecosystems approach'. 'Brugmann (1992) and Tjallingii (1992) propose that a city can be considered as an ecosystem, and that ecological concepts can be used for understanding the problems of urban sustainability and for choosing approaches to solving them' (Expert Group on the Urban Environment, 1996; 46). In this idea three interrelated strands can be identified: physical, social and systems. In the first two strands the city is recognised to be a physical and a social ecosystem, respectively, to which techniques of empirical ecology can be applied in order to understand its behaviour and evolution, such as urban development. The third strand '[…] seeks to understand the *continuous processes* of change and development in cities by treating cities as complex systems to which concepts of systems theory can be applied' (Expert Group on the Urban Environment, 1996; 47). The transport and land use interaction is presented as an example of the systems effect on urban development/evolution in the 'Sustainable European Cities' report (Expert Group on the Urban Environment, 1996): 'the more people use cars, the more important it becomes for employers, shops and other services to be accessible by car, and the less important to be accessible by bus. Services tend to relocate to sites more accessible to cars than to public transport. This in turn encourages more people to switch from bus to car - and so on.'(Expert Group on the Urban Environment, 1996;49).

Looking back at the land use transport feedback cycle, it seems to be in complete accordance with the systems approach of urban development, more specifically with regard to the mutually influencing development of transport and land use.

These examples of theories of urban development illustrate the theoretical background for the integration of land use and transport policies in order to shape mobility patterns. From the origins of town and country planning it has become clear to many authors that the transport cost and therefore, the transport system influences the evolution of urban occupation. Likewise, transport planning developed based on the awareness that urban traffic is a function of land use. Nevertheless, these theories simply uphold the broad perception of interaction of land use and transport systems providing no additional background for a thorough understanding of this interaction. These details are further pursued in the following section reviewing empirical evidence.

2.2. Empirical evidence

Besides theoretical evidence, empirical evidence of the interaction of land use and transport and of their combined influence on mobility patterns can be found in the literature. In the several research fields found, concerning this topic, the study of the influence of land use on urban mobility is by far the most developed. There is also some research on the influence of transport systems on land use patterns. Few studies were found on the influence of land use on the evolution of the transport systems, of transport on mobility patterns and of the combined effect of land use and transport on mobility patterns.

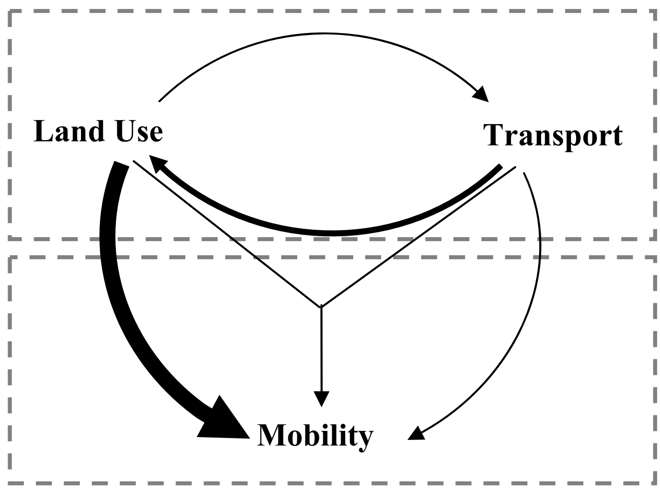


Figure 2.4: Amount of literature on the relationship between land use, transport and mobility patterns

The upper section of the scheme, referring to the interaction between land use and transport, will be discussed in section 2.2.1, while the influences on mobility (the lower section of the scheme) will be discussed in section 2.2.2.

2.2.1. Evidence of Interaction of Land Use and Transport

Considering the empirical evidence of the interaction of land use and transport, most studies are concerned with the **influence of transport systems**, especially the construction of large road infrastructure, **on land use patterns**.

According to urban economic theory, the construction of large road infrastructures will increase land prices because of accessibility improvements. Higher land prices around transport infrastructure induce higher density of urban development (Boarnet and Chalermpong, 2001).

Boarnet and Haughwout (2000), Boarnet and Chalermpong (2001) and Boarnet and Crane (2001b) suggest that the debate on the link between motorways and urban development has been focused on the phenomenon of decentralization. The discussion of the influence of motorways on decentralization divides opinions between those believing that they do and those believing that other factors, such as socio-economic characteristics, are more important.

There is a generalised idea that land use has evolved according to transport system developments. The literature review of Boarnet and Haughwout (2000) revealed several authors arguing that urban employment locations '[…] were originally concentrated near points of access to waterway transportation, then increasingly at rail junctions near the fringes of central cities and finally have clustered around highway interchanges on the edges of metropolitan areas (Jackson 1985; Cronon 1991; Garreau 1991)' (Boarnet and Haughwout, 2000; 4). Other authors, such as Kockelman *et al*. (2002), suggest that networks of major road transport infrastructure have encouraged the development of multicentred regions, concentrating urban development around their main intersections. This vision of the influence of the development of transport systems on land use structure, is mostly found in US literature were low density development policies have stimulated stronger urban dispersion.

Several recent studies in the US have revealed significant influences of motorway construction on the location choice of homes and economic activities. An extensive literature review by Boarnet and Haughwout (2000) assembled several studies (such as, Boarnet 1994a and 1994b; Singletary, et. al, 1995; Boarnet, 1996; Geho, 1998; Bollinger and Ihlanfeldt, 1997; Henry, *et al*., 1997; referred to by Boarnet and Haughwout, 2000) finding a consistent relationship between population and employment change and motorway location. Two decades earlier, the literature review conducted by Weisbrod *et al*. (1978) led to the conclusion that, although, empirical results suggest that transportation services were significant factors influencing residential location, their role was small compared to other factors, such as socio-economic and demographic characteristics.

A major research field of the influence of transport on land use has been the study of the effect of major road infrastructure construction on land prices. Boarnet and Haughwout (2000) conclude, form their literature review on the influence of motorways on land use that motorways influence employment and population change, and increase land prices near major road projects. A case study developed by Boarnet and Chalermpong (2001) found that motorway construction increased accessibility and thereby increased land prices. These authors conclude that people are willing to pay for increased accessibility. The literature review developed by Kockelman *et al*. (2002), also reaches the conclusion that the existing studies show substantial and measurable impacts on nearby land prices.

Besides road infrastructure, case studies of the influence of public transport service improvement on surrounding land values can also be found. Giuliano (1989) states that most empirical studies of the impact of rail on urban development in the 1970s (in San Francisco, Washington, DC and Atlanta) found little impact on land values. This review identified authors, such as Hamer (1976) and Meyer and Gomez-Ibanez (1981) (both referred to in Giuliano, 1989), that believed that rail had no significant impact on accessibility and therefore no effect on land prices should be expected, in spite of several methodological problems which might explain the results of these case studies. According to Cervero and Landis (1995) 'Studies of how proximity to urban transit affects property values have produced wildly divergent estimates' (Cervero and Landis, 1995; 7). The study developed by these authors on the BART (Bay Area Rapid Transit System) showed an increase of land prices. Nevertheless, these authors argue that not all public transport systems have similar effects. They believe that this is dependent on public transport service level and market area. These authors doubt that the increase in land prices brought about by public transport investments will be enough to stimulate the necessary urban development around public transport infrastructure to increase their economic viability. Two decades earlier, a literature review developed by Weisbrod *et al*. (1978) found several case studies (Boyce *et al*., 1972; Dornbusch, 1976 and Lerman *et al*., 1977; referred to by Weisbrod *et al*., 1978) on the effect of public transport on land prices which concluded that public transport has a small but statistically significant influence on land prices.

In the several studies developed on the influence of transport systems on land use, literature reviews by Giuliano (1989) and also Huang (1994; referred to in Boarnet and Haughwout, 2000) have identified two generations of studies of the impact of highways on urban development. Earlier studies (in the 1950s and 1960s) have showed larger land price increases with motorway construction than later studies. According to these authors, later studies often show statistically insignificant effects of motorways on urban development. There has been a debate on whether the influence of transport on land use has been weakening. Giuliano (1989) argues that this influence weakens when motorway systems mature. This author suggests that high accessibility rates in the USA have diluted the connection between transport and land use, and that this connection is now too weak to matter in terms of policy making. Holl (2004) found similar opinions on the influence of transport on industrial location. The literature review developed by this author cites Banister and Berechman (2000) as some of the authors arguing that dense transport networks may have small influence on firm location, especially considering decreasing transport cost and increasing importance of non-material flows. Boarnet and Haughwout (2000) disagree, arguing that there is new evidence of the influence of motorway construction on land use. According to these authors, the difference between earlier and new evidences is on the geographic scale of that influence, which seems to be somewhat smaller than before.

Stephanedes and Eagle (1987; referred to in Boarnet and Haughwout, 2000) found that road infrastructure improvements may have positive and negative effects on certain areas and that the state-wide effects may therefore not be significant. Other authors, such as Boarnet and Haughwout (2000) and Holl (2004) further suggest the existence of negative cross-country spillover effects at distant localities besides of positive effects nearby transport infrastructure. This idea is sustained by several other authors found in their literature review (Stephanedes and Eagle, 1987; Rephann and Isserman, 1994; Boarnet, 1998; reviewed by Baornet and Haughwout, 2000; Mas *et al*. 1996; Mikelbank and Jackson, 2000; Chandra and Thompson, 2000; reviewed by Holl, 2004). A literature review developed by Kockelman *et al*. (2002) found authors, such as Payne-Maxie Consultants (1980) and Boarnet (1997) (both referred to in Kockelman *et al*., 2002), arguing that urban development attracted by new transport infrastructure may result of urban redistribution of development and not of new regional development. Thus these authors argue that transport improvements merely redistribute economic activity that would take place elsewhere, had transport investment not shifted it to nearby. Cervero and Landis (1995) have a slightly different contribution to the argument of spatial divergence of transport effects on urban development. This authors found several studies that show that, on an even smaller scale, proximity to transport infrastructure may have negative effect on urban development when problems brought about by increased traffic (such as, pollution, noise, congestion, etc.) offset accessibility premiums.

Summarizing, the empirical discussion on the influence of transport on land use has mainly been centred on the discussion of the influence of motorway construction on improvement on land prices. Empirical studies of the influence of public transport provision and improvement on land use development have been somewhat limited, and their results mixed. Several authors identified a decreasing influence of transport on land use through the last decades. While some suggest the weakening on the influence of transport on land use, others recognize a change in geographical scale of that influence with the maturation of the transport system. Furthermore, negative cross-country spillover effects were identified by several authors, suggesting that transport may have a redistributing effect on economic development instead of a stimulating effect. In the current context several authors agree that, although the influence of transport on land use is weaker, the connection between land use and transport still matters. Cervero and Landis (1995) defends that although '[…] new transport investments no longer shape urban form by themselves, they still play and important role in channeling growth […]' (Cervero and Landis, 1995; 3).

Although there are several empirical studies on the influence of transport on land use, there is a lack of studies on the **influence of land use on transport systems** and also of their **mutual influence**. This lack of empirical studies is easily understood knowing that traditional transport planning aimed to satisfy mobility needs and generally considered travel to be 'derived demand'. In theory, transport development tries to accommodate the complexity of mobility patterns which are believed to result of the need to participate in geographically disperse activities. Thus, in theory, transport development is a consequence of land use development. '[…] the people who actually build our streets and cities assume, as a matter of course, that the built environment does indeed influence travel behavior' (Boarnet and Crane, 2001b; 35). In the reasoning of traditional transport planning, research on the influence of land use on transport development has limited, to no interest, since transport developments are planned reflexes of urban development. However, the paradigm of transport planning has been shifting from 'predict and provide' to 'predict and prevent', in accordance with the change of mobility problems and requisites. Nowadays, economic development is no longer taken for granted and, therefore, transport planning has acquired a new strategic role in the economic development of countries and urban areas. In this context, transport development can no longer be a simple reflex of urban development assuming a more proactive attitude.

There has been an increasing complexity of travel motivations which has been worsened by the emergence of undirected travel (free travel, not necessarily fulfilling the need to reach an activity – Moktharian and Salomon, 2001). In addition, economic development has been slowing down changing the role of transport planning. In this context, the interaction of land use and transport has become more intricate and more difficult to comprehend. Authors, such as Giuliano (1989, 1995) suggest that the connection between land use and transport is now too weak to matter in terms of policy making. Contrarily, Kockelman *et al*. (2002) state that 'Transportation and land use are inextricably linked' (Kockelman *et al*., 2002; 6). These authors argue that there is a two-way interaction between land use and transport, identifying an influence cycle (see Figure 2.5), very similar to the LUT feedback cycle.

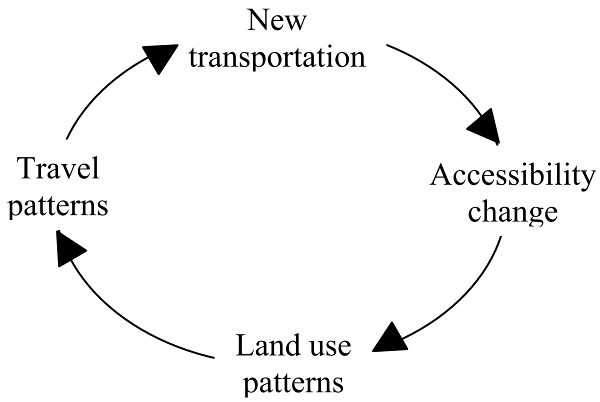


Figure 2.5: Two-way interaction between land use and transport according to Kockelman *et al*. (2002).

In addition, Cervero and Landis (1995) state that 'Much recent research supports the land use-transportation connection, highlighting some of its subtle complexities. Further, these studies expose the vital role for public policy in shaping that connection.' (Cervero and Landis, 1995; 3).

2.2.2. Evidence of the combined influence of Land Use and Transport on mobility patterns

Considering the influence of land use and transport systems on mobility patterns, the study of the influence of land use on urban mobility is by far the most developed. Few studies were found on the influence of transport on mobility patterns and of the combined effect of land use and transport on mobility patterns.

The research on the **relationship of land use and travel behaviour** is based on the theory of 'derived demand'. People are considered to travel to reach activities necessary to fulfil their needs. Utility-based theories suggest that travel will only be engaged when positive utility of the participation in the pursued activity exceeds the disutility of travelling (generally expressed in time and money spent). In this theory, land use has considerable influence since spatial structure affects both activity utility and travel disutility.

'The volume of literature on how land-use patterns and built environment influence urban travel demand has exploded over the past decade' (Cervero, 2002; 265). In the literature reviewed on the influence of land use on urban mobility, most publications present the results of case studies searching for the main land use factors influencing travel choice. These case studies developed mainly aggregate analyses. Other publications present broad literature reviews, complementing the results found in the reviewed case studies (Handy, 1996; Stead *et al*., 2000; Ewing and Cervero, 2001; Wee, 2002). Considerably less research was found on land use policy implications and recommendations.

It is fair to say that in this research field most authors believe that land use has influence on travel behaviour (e.g. Handy, 1996; Cervero and Kochelman, 1997; Ewing and Cervero, 2001; Wee, 2002). Nevertheless, many are sceptic of the identified factors mainly because of research methodologies, including conditions and constraints in which case studies are developed. Many case studies have produced inconclusive results (e.g. Cervero, 1995; Boarnet and Crane, 2001a; Handy and Clifton, 2001) reinforcing the scepticism of the influence of land use on travel choice. Usually these studies evaluate a limited set of variables, which may, as a matter of fact, not be the most indicated for the intended purposes.

In the reviewed case studies on the influence of land use on urban mobility, density was the most frequently evaluated land use factor. Boarnet and Crane (2001a) studied the influence of population and activity density on non-work travel behaviour and reached inconclusive results. Nevertheless, these authors recognize the influence of geographical scale on these results. Furthermore, they argue that the absence of a systematic analytical framework considerably limits the clarification of the relationship of land use density and travel behaviour. Simmonds and Coombe (2000) also reached inconclusive results while comparing the influence of urban concentration and dispersion on modal choice using the Brotchie Triangle. On the other hand, case studies developed by Kenworthy and Laube (1999) and Giuliano and Narayan (2003) revealed considerable influence of land use density on mode choice, and on travel frequency and distance, respectively. The conclusion of the latter case study must be looked at with prudence since a very high aggregation level was used. The former study showed that economic development is not necessarily synonymous of increasing car dependent cities, defending the role of public policy in avoiding car dependent urban structures. These authors argue that higher urban density is consistently associated with less car use and higher public transport use, besides of providing better operational conditions for public transport (enabling reduced operating costs for urban passenger systems). Nevertheless, although this case study only compared mode choice with urban density, the authors suggest that the increase of urban density without activity diversity may not produce encouraging results.

In a related topic, Cervero (1995, 2002) studied the influence of self-containment policies on modal choice, for commuting trips, reaching inconclusive results. This author defines self-containment as the production of communities enclosing a variety of activities which require no travel outside that community. According to this author 'Europe's new towns show that job housing balance and self-containment are not prerequisites to reducing automobile dependency […]' (Cervero, 1995; 1159). In addition other combined measures, such as, a multi-centred, public transport oriented urban form, may have stronger influence on car use reduction than balanced development or self-containment.

More complex evaluations, simultaneously considering the influence of land use density, diversity and design on travel behaviour, were developed by Cervero and Kockelman (1997); Boarnet and Sarmiento (1998) and Stead (2001). Boarnet and Sarmiento (1998) studied the influence of neighbourhood level activity and population density, land use mix and street patterns on trip frequency for non-work trip purposes, finding inconclusive results. These authors argue that if there is a link between land use and travel behaviour it is a complicated one and therefore, contemporary case studies have not yet been able to identify its main influential aspects. They suggest that current literature shows only weak evidence (at best) of a linkage between land use and travel behaviour, at the neighbourhood level. Nevertheless, these authors believe methodological aspects to considerably hinder current case studies and that 'The possibility that land use and urban design might influence non-work travel is important enough that it ought to be taken seriously, but it is still not well enough understood to inform policy' (Boarnet and Sarmiento, 1998; 1167). Cervero and Kockelman (1997) conceptualized land use density, diversity and design, as the '3Ds of the built environment'. They studied the influence of the 3D's on travel frequency and modal choice for non-work trip purposes, finding statistically significant but marginal results. These authors found that density had the strongest effect on business trips, while diversity, although generally having a modest impact, had more significant influence on travel behaviour than density, in certain circumstances. Furthermore, these authors suggest that '[…] the synergy of the 3Ds in combination is likely to yield more appreciable impacts' (Cervero and Kockelman, 1997; 217) although the combined effect of several land use factors was not analysed. Finally, Stead (2001) also found that land use characteristics (settlement size, urban mixture and design) influence travel distance. This author believes that '[…] land use characteristics such as mixed-used development, settlement-size and the provision of local facilities have a role to play in promoting sustainable development' (Stead, 2001; 518). Besides of land use characteristics, several individual/household characteristics were also considered (e.g. age, gender, household composition and size). This author found that the influence of household characteristics is even stronger than that of land use characteristics.

The influence of land use diversity on travel behaviour was analysed by Van and Senior (2000) with a case study evaluating the influence of diversity on travel frequency and modal choice. Their results reinforce the sceptical tone of recent American research on this topic. Another case study developed by Handy and Clifton (2001), evaluating the influence of local shopping on modal choice, travel time and distance, showed that this specific strategy of land use diversity is not particularly effective. There was no proof that shopping would reduce travel time, distance and car dependency. The results show that local shopping may even induce extra travel, even though by sustainable travel modes, instead of replacing car trips.

In order to clarify the influence of land use on urban mobility, authors, such as, Schwanen *et al*. (2001), Dieleman *et al*. (2002) and Timmermans *et al*. (2003) studied the influence of different urban structure types on travel behaviour. The case study developed by Timmermans *et al*. (2003), comparing urban and suburban structures around the world with aggregate travel frequency and trip chaining behaviour, suggests that travel patterns are largely independent of land use patterns, at least at the chosen level of aggregation. The case study developed by Schwanen *et al*. (2001) evaluated the influence of monocentric and polycentric urban structures on modal choice and travel distance. This research revealed both, inconclusive results on the influence of urban structure on travel distance, and a positive influence of polycentric urban structures on the reduction of car use. Finally, the case study developed by Dieleman *et al*. (2002), evaluating the influence of residential environments of Dutch cities (classified into: largest cities, medium-size cities, new towns, and suburban/rural) on modal choice and travel distance (similarly to Schwanen *et al*., 2001), found a strong influence. This case study also evaluated the influence of individual/household characteristics on travel behaviour, revealing that both, land use and individual/household characteristics influence travel behaviour being of about the same importance.

Summarizing, these case studies arrived at mixed results and conclusions, either on the land use factors influencing travel behaviour, either on the influence that land use factors have, or even on the very existence of that influence. Several reasons can be identified for this situation. First of all, many of these differences are due to the lack of systematic methodological approaches. Boarnet and Crane (2001a) and Cervero (2002) have argued that the absence of a systematic analytical framework has limited the clarification of the influence of land use on travel behaviour. Many of the results found in the empirical studies are constrained by variable choice and aggregation, geographical scale and by the specificities of local conditions. Cervero and Kockelman (1997) believe that the variables chosen for the case studies have a considerable influence on the results obtained, drawing attention to the need for a careful search of the most adequate variables. Frequently, case studies attempt to clarify the effect of a specific factor in a very specific situation; therefore, results of these case studies can not be generalised. In addition, the evaluation of land use variables without the consideration of other related aspects (such as transport systems and individual/household characteristics) may lead to misleading results since factors from several fields are believed to be mutually influencing. Therefore the real level of influence on urban mobility can only be evaluated considering all main factors simultaneously. This separate evaluation of the land use factors may also be the reason why so frequently inconclusive results are produced.

Handy (1996) presents a broad literature review of case studies on the influence of land use on urban mobility, developing a conceptual and an extensive methodological discussion. This author refers the need to build upon previous research efforts, considering that both, research themes and methods, frequently repeat former mistakes. She argues that research has not always been directed at policy making, which requires the understanding of the relationship between urban form and overall travel (including underlying factors of that relationship). Nevertheless, this author states that 'What the research so far convincingly shows about the relationship between urban form within a community and the travel patterns of the residents of that community is that there is a significant relationship' (Handy, 1996; 161). This literature review identifies neighbourhoods with higher densities, better accessibility and pedestrian-oriented design as being the land use characteristics more likely to influence less car use.

The literature review developed by Stead *et al*. (2000) centred on the link between land use as well as socio-economic characteristics, and travel patterns. These authors agree that there might not be a cause effect relationship between land use and urban mobility patterns and that this relationship might be more complex than suggested by several authors. This literature review identified the following main land use characteristics affecting travel behaviour: proximity of households to urban centre; settlement size; mixed land use; provision of local facilities and services; population density; proximity to main transport networks; and availability of residential parking[8]. Several authors reviewed by this research suggest that the proximity of the household to the urban centre may have an influence on travel distance, for commuting, and on travel frequency, for more discretionary travel. Settlement size seems to influence the range of jobs and services that can be supported as well as the level of public transport service that can be provided, while urban density increases are expected to reduce travel distance and encourage non-car use (density is considered a prerequisite for acceptable levels of public transport services). Although the reduction of physical separation of activities was believed to reduce travel distance, the provision of mixed land uses was

[8] These last two aspects are not land use characteristics, but transport system characteristics.

found to be less influent than density on travel patterns and the mere existence of an influence is even questioned by several authors found in this literature review. Finally, even though little research has been developed on the influence of local facilities and services Stead *et al*. (2000) believe that it may reduce travel distance and increase the use of non-motorized modes. This literature review concludes that, although land use characteristics have a considerable effect on travel patterns, socio-economic characteristics, such as household size and income, car ownership, employments status, gender and age, explain more of the variations in travel patterns than land use characteristics. According to these authors 50% of variations in travel patterns are explained by socio-economic characteristics while only 1/3 of these variations are explained by land use.

The broad literature review developed by Ewing and Cervero (2001) revealed limited to some evidence of the influence of traditional neighbourhoods (which according to these authors present central location, fine land use mix and grid-like street network) on travel distance and mode choice (more walking and public transport use). Trip frequency was found to be largely independent of land use variables, while travel distance was found to be shorter for higher accessibility, higher density or mixed use. Mode choice was found to be the most affected travel behaviour characteristic. This study concludes that land use and socio-economic characteristics both influence travel patterns. While the former has primary influence on travel distance, the latter has primary influence on travel frequency. The authors believe that mode choice depends on both but '[…] probably depend more on socioeconomics' (Ewing and Cervero, 2001; 107).

The literature review developed by Wee (2002) lead this author to state that 'There is enough evidence to conclude that land use can influence travel behaviour' (Wee, 2002; 259) and that there is a relatively strong consensus that the most important land use factors that may affect travel behaviour are density, level of mixed land use, neighbourhood design and distance to railway connections[9]. This author argues that in equal conditions higher densities or higher urban diversity will have the potential of reducing travel distance and thereby time, thus increasing the potential use of slower modes. Neighbourhood design can also improve conditions for the use of slower modes

[9] Once more, this factor is not a land use characteristics, but a transport system characteristics.

by, for example, providing good sidewalks, good conditions for cycling and traffic calming measures. Nevertheless this author believes that these aspects are not sufficient to grant its potential effect on travel behaviour and that many other conditions need to be taken into consideration.

Literature provides case studies on the influence of several aspects of land use on travel behaviour as well as literature reviews of those case studies, aiming to identify general conclusions on this research field and methodological recommendations for further research. Nevertheless, few publications can be found studying land use policy effects on travel behaviour, and even fewer, taken the step towards policy recommendations. There is an apparent disregard for decision making in this research field. This aspect is even more relevant since even within those authors believing that land use characteristics influence travel behaviour there is considerable scepticism on the effect of land use policies and their contributions to sustainable urban mobility. The lack of research on the land use policy effect has encouraged these doubts. Several authors (e.g. Handy, 1996; Van and Senior, 2001; Wee, 2002) have argued that besides studying the potential land use factors influencing travel behaviour there is also a need for research on how this knowledge can be used to provide land use policies. It is important to evaluate the potential travel behaviour change due to land use characteristic changes (Van and Senior, 2001). '[…] finding a strong relationship between urban form and travel patterns is not the same as showing that a change in urban form will lead to change in travel behaviour, and finding a strong relationship is not the same as understanding that relationship' (Handy, 1996; 162). Furthermore, Wee (2002) states that 'Even if land use has an impact on transportation, it does not mean that it is easy to use land-use *policy* as an instrument to influence travel behaviour.'[10] (Wee, 2002; 265).

In the studies found on the evaluation of the effect of land use policies on travel behaviour, Crane (1996) and Crane and Scweitziger (2003) have studied the effects of land use policies based on urban design schools, such as New Urbanism, Transit-Oriented Development and Neotraditional planning. According to these authors, these schools believe in the influence of land use planning on travel behaviour. They even

[10] When the author refers to 'transportation' he is really referring to travel behaviour. This conceptual mismatch between transport (or transportation in American English) and mobility or travel is discussed in see section 1.6.

propose land use policy measures, even though their main aim is to increase quality of residential life. Crane and Scweitziger state that 'New Urbanism aims to address sustainable development by providing compact, socially and functionally mixed neighbourhoods that are pedestrian-friendly at the local scale while offering the choice of public transport or transit at the city or regional scale' (Crane and Scweitziger, 2003; 238). The 'compact development', referred to by these authors comprises high development density of mixed integrated land uses. Compact development is believed to enable higher accessibility to opportunities, activity and employment, favour (an even increase) economic viability of public transport and improve public security while reducing segregation. On the other hand, compact development may increase household expenses with housing while reducing living space and access to green areas. Crane and Scweitziger (2003) argue that the study of the New Urbanism's potential to enhance sustainability of mobility patterns is still at its infancy. Both studies maintain a sceptical tone when referring to the potential of land use policies based on the referred urban design schools to enhancing sustainability of urban mobility: 'Neither the credible empirical nor theoretical research gives us reason to suppose that any broad principles of urban design can deliver on any three of these sustainability goals [ecological integrity, social justice and economic viability], let alone all three in the right measure' (Crane and Scweitziger, 2003; 249-259).

The research developed by Schwanen *et al*. (2004) studied the effect of Netherlands' national physical planning policies on travel behaviour (namely, on travel distance and time, and on modal choice), considering four components of this policy: '[…] the concentrated decentralisation of the 1970s and 1980s; the strict compact-city policy of the 1980s and 1990s; the A-B-C location policy; and the spatial retailing policy' (Schwanen *et al*., 2004; 579). With regard to modal choice, this study found policies such as, the redevelopment of brownfield sites, urban renewal and upgrading the inner-city housing stock, as the most effective policies to increase the use of non-motorised modes for commuting trips. For shopping trips, compact urban development and retail planning were found to be more important. While the compact city policy seems to have been beneficial on modal split, concentrated decentralization has shown mixed results. With regard to travel distance and time, this study revealed that spatial policy may only have had a modest contribution for enhancing its efficiency. '[…]despite the fact that the commute distance and time for car drivers vary with the type of residential environment, the importance of urban form in influencing commuting behaviour should not be overestimated' (Schwanen *et al*., 2004; 592). These authors found that commuting and shopping travel distance was longer for settlements with lower density and that leisure and shopping travel time rises with higher levels of urbanization. This study concluded that planning policy had only a limited influence on travel behaviour and not always as intended.

The research developed by Newman and Kenworthy (2000) tries to establish the link to policy making, developing a range of suggestions to change the 'car city' into a sustainable city. These authors argue that density is a major factor in car dependence, although recognizing that there is more to sustainability than increasing density. They purpose the following policy steps for enhancing the sustainability of urban mobility: '1. Revitalize the inner city; 2. Focus development around the existing rail system; 3. Discourage further urban sprawl; 4. Extend the public transport system and built new urban villages in suburbs' (Newman and Kenworthy, 2000; 115).

The empirical research found on the relationship of land use and travel behaviour does not enable the generalization of the land use factors most influencing travel behaviour. This is generally related to methodological limitations found in the case studies. Nevertheless, three of these factors stand out as being most analysed and frequently showing influence, at least, on some travel characteristics: Density, Diversity (or mixed use) and Design. This is supported by Wee (2002) who also found a relatively strong consensus in the literature that the 3D's are the most important land use factors influencing travel behaviour[11]. He found several authors supporting the importance of each of those three land use factors in influencing travel behaviour (e.g. for density – Newman and Kenwothy, 1988; Cervero, 1996; Gordon, 1997 – for diversity – Anderson *et al.*, 1996; Cervero, 1996 – for neighbourhood design – Kitamura *et al.*, 1994; referred to by Wee, 2002). Also supporting the 3D's as the main factors of land use are several urban planning schools of thought such as the New Urbanism, the Neotradicionalists and other reform-minded designers. In this context it seems reasonable to consider

[11] Wee (2002) also includes a forth factor, the distance to railway connection, but within this thesis that factor is considered a transport system factor and not a land use factor.

density, diversity and design as the potential main factors of land use influencing travel behaviour.

There are several empirical studies on the influence of land use on travel behaviour, however, the empirical research on the **relationship of transport and travel behaviour** is considerably less developed. Although much research can be found on transport policy actions for the management of travel behaviour, there is a considerable lack of studies on the transport system factors most influencing travel behaviour. The research on the influence of transport on travel behaviour seems to already be on the next level, taking that influence for granted and concentrating on the development of policy measures, contrarily to the research in the field of land use and travel behaviour. The relationship between transport systems and travel has always been assumed to exist. Recalling that traditional transport planning develops transport infrastructures and policies in order to satisfy travel needs, transport systems and travel patterns have been considered somewhat similar. An illustration of this is the conceptual mismatch frequently found between 'transport' and 'mobility' (see section 1.6). Only recently has it been recognized that the transport system can actively be used to influence travel behaviour (rather than simply satisfy travel needs) and that there are unintended effects of transport infrastructure development (such as the controversial phenomenon of 'induced travel'). Therefore a clear distinction between transport and travel behaviour is needed as well as a deeper understanding of the real influence of transport infrastructure, service and policy on mobility patterns. Nevertheless, the research on the relationship of transport and travel behaviour is focused on the development of policy measures.

Several transport policy measures have been developed in recent years within the context of TDM. Examples of TDM measures found in the literature, concerning transport and travel behaviour are: Travel Plans and Travel Vouchers (Root, 2001 and Rye, 2002), Park and Ride (Parkhurst, 2000), improvement of public transport and implementation of zone access control (Thorpe *et al.*, 2000), temporary TDM measures, such as temporary free public transport tickets (Fujii and Kitamura, 2003), Integrated Multimodal Traveller Information (Kenyon and Lyons, 2003), Demand Responsive Transport (Mageean and Nelson, 2003), Road Pricing (Calthorp *et al.*, 2000; Thorpe *et* *al.*, 2000; Viegas, 2001; Paulley, 2002; Shepherd, 2003; Raux and Souche, 2004), Parking Pricing (Calthorp *et al.*, 2000; Thorpe *et al.*, 2000) and Vehicle Quota Schemes (Chin and Smith, 1997; Chu, 2002). The European project DANTE (DANTE Consortium, 1998) presents further 64 TDM measures (measures acting on the transport system and other areas), found to be adequate to the European context. No studies have been found evaluating the influence of the available transport system on travel behaviour, nor the main factors of transport system influencing travel choice[12].

Gärling *et al.* (2002) suggest that the classification of TDM measures is a promising mean for understanding potential reasons for behavioural change or lack thereof. Therefore, the categories of TDM measures can be used to identify the transport factors (and also other factors, such as land use and socioeconomic factors also included in TDM approaches) which authors believe to have the most influence on travel behaviour. Several categorizations of TDM measures have been proposed over time. Traditionally TDM measures are divided into 'push' (enhancing the attractiveness of alternative modes) and 'pull' measures (deteriorating the attractiveness of the car). The literature review developed by Gärling *et al.* (2002), highlights the TDM measures classification suggested by Vlek and Michon (1992; referred by Gärling *et al.*, 2002): '*physical changes* such as, for instance, closing out car traffic, providing alternative transportation; *law regulation*; *economic incentives*; *information, education and prompts*; *socialization and social modelling* targeted at changing social norms; and *institutional and organizational changes* such as, for instance, flexible work hours, telecommuting, or 'flex places' ' (Gärling *et al.*, 2002; 60). The European project DANTE identified 10 main categories of travel reduction measures: capacity management; pricing/taxation; land use planning; communications and technology; policy measures; physical measures; subsidies and spending; location, time and user restrictions; public awareness; other measures (DANTE Consortium, 1998). Meyer (1999) identified the following broad categories: offer alternative transport modes and services (intended to increase vehicle occupancy); provide incentives / disincentives to reduce travel; accomplish trip purpose without trip (e.g. Telecommuting). Considering

[12] Excluding some scarce considerations of transport system characteristics as built environment characteristics in case studies evaluating the influence of land use on travel behaviour (e.g. Newman and Kenworthy, 2000).

these examples of different TDM categories and the remaining reviewed literature, the following transport system factors can be used to summarise those most influencing travel behaviour: Service Level or Quality, Availability, and Price. Service level or Quality refers to, for instance, the capacity of every transport mode (road capacity or passenger capacity of the public transport system) and the quality of that service including, for instance, speed, reliability and flexibility, road construction quality and available services or public transport quality associated, for instance, to ticket technology, information systems, comfort and security. Everett & Watson support the choice of this factor claiming that: 'A long number of TDM measures are based on the assumption that the use of travel mode can be influenced by improving the service level of public transport and/or reducing the service level of automotive transportation' (Everett & Watson, 1987, cited in Fujii & Kitamura, 2003; 81-82). Availability refers to, for instance, the existence of a viable transport option for the required travel pattern, within a viable access distance. Stead *et al.* (2000) also identified availability (referred to as 'proximity to main transport network' and 'availability of residential parking') as one of the main factors influencing travel behaviour, although it was identified in the evaluation of land use influence. The Price refers, naturally, to the monetary cost of the transport service purchase and is one of the main transport system aspects changed by congestion charging and public transport subsidy TDM measures.

Although the existence of an influence of the transport system on travel behaviour is clear and therefore might be exempted from evaluation, the lack of research on the main factors responsible for that influence is one of the main flaws of this research area, especially knowing the void this lack of understanding represents for policy making. There is also a need to give more attention to the interconnection and the mutual influence of the transport system, land use and household characteristics.

The empirical research on the **combined influence of transport and land use on travel behaviour** is even less developed than that of transport systems and travel behaviour. This considerably hinders the full understanding of travel motivations and therefore limits the potential effect of policy measures based on the current knowledge of travel motivations. Considering the increasing complexity of urban mobility and its role in urban economic development and in quality of life, the thorough understanding of travel behaviour has been gaining importance. In the research for understanding travel behaviour the study of the combined influence of land use and transport systems reveals itself as a fundamental aspect. Limiting this research to the influence of its parts disables the understanding of potential indirect impacts of policy measures due to the mutual influence of transport and land use discussed in section 2.2.1, and therefore the understanding of potential synergetic or cancelling off effects of combined land use and transport policy measures.

Although no studies of the combined effect of land use and transport were found in the literature, some studies were found to consider both land use and transport variables in their case studies, such as Cervero and Kockelman (1997), Simmonds and Coombe (2000), Stead (2001) and Timmermand *et al.* (2003). These studies, although using transport variables, did not consider them as such; some authors classified these variables as land use variables, while others considered them just to enable the comparison of the effect of land use variables in similar transport system contexts.

The research developed by Cameron *et al.* (2004) studied the evolution of private motorized mobility in several cities around the world relating these changes to policy initiatives. They found several examples of the potential of combined land use and transport policies to produce more sustainable mobility, stopping or even inverting increasingly unsustainable travel patterns. Evidence in this paper suggests that '[…] arguments about the inevitable growth in urban sprawl and motorisation are overly deterministic and that urban systems are responsive to land use and transport policies and other strategies that can reduce the growth in automobile dependence' (Cameron *et al.*, 2004; 296). These authors concluded that, within public policies, land use and transport policies are a powerful tool, which can invert car dependency in the context of income growth. For instance, they defend that, 'In physical planning terms, Munich and Stockholm both demonstrate how integrated land use and transport planning, especially transit-orientated nodal development around rail stations, traffic calming measures, parking restrictions and widespread urban redevelopment to restrict the growth in urban land area, can reduce the growth in private motorised mobility (see Lyons *et al*., 2003 […])' (Cameron *et al.*, 2004; 296). In a similar study, concentrating on the reasons for low car dependency in Hong Kong, Cullinane (2003) also found land use and transport policies (such as high land use densities, rail based public transport), within other public policies, to have a significant influence on the level of car ownership and use.

Other authors suggest the potential contribution of a particular combination of land use and transport policies to sustainable mobility patterns: the densification of urban development near public transport service. Newman and Kenworthy (2000) argue that public policy aiming to change the 'car city' to a sustainable city should focus urban development around existing rail systems, increasing density around strategic corridors and nodes. In accordance with this idea, Wee (2002) found the 'distance to public transport connection' to be an important factor influencing travel behaviour.

Even though little research has been developed on the combined effect of land use and transport on mobility patterns, several authors are convinced that combined policy action will contribute to enhance sustainability of urban mobility. For instance, Kenworthy and Laube (1999) suggest that, land use planning, transportation infrastructure policies, service delivery policies and economic policies charging auto ownership and use, have a central role in the sustainability of urban mobility. Marshall and Banister (2000) defend that 'Solutions to achieve travel reduction must […] explore transport options in conjunction with policies related to land use planning and technological innovation' (Marshall and Banister, 2000; 337). Kitamura *et al*. (1997) argue that land use and transport (as well as lifestyle) determines travel behaviour because they are inter-connected, mutually affecting each other in the evolutionary process of urban structure and behaviour.

2.3. Synthesis: Implications for policy making

Theoretical and empirical evidences of the influence of land use and transport on urban mobility illustrate the theoretical background for the integration of land use and transport policies for mobility management. From the origins of town and country planning it has become clear that transport systems influence the evolution of urban occupation. Likewise, transport planning developed based on the awareness that urban traffic is a function of land use. Nevertheless, as changes were expected to be gradual and at a low rate, planning of land use and of the transport systems has been developed separately (considering the other as sufficiently stable over time). This assumption has no particular unacceptable effects on the expected outcomes of land use and transport planning, however it has been responsible for increasingly unsustainable mobility patterns, endangering economic competitiveness and quality of life in urban areas.

The understanding of the motivations of travel behaviour in general, and of land use and transport factors influencing travel behaviour in particular, is still very limited. Although several authors believe that land use and transport influence travel behaviour, the details of this influence are scarcely explored. This literature review enabled a 'tentative' identification of some of the main factors influencing travel behaviour. With regard to land use factors, density, diversity (or mixed use) and design where recognized by several authors as having an important role in travel choice. Within otherwise constant conditions, increased density is believed to reduce travel distance and time and to enable the economic viability of public transport and therefore its use (due to higher service level). Increased diversity is believed to reduce the need to travel long distances and enable the use of non-motorized and slower travel modes. Design is believed to encourage the use of slower modes. With regard to transport system factors, service level / quality, availability and price where identified as the most important aspects influencing travel choice. Within otherwise constant conditions, increased service level / quality of a strategically preferred transport mode will increase the demand of that transport mode with decrease of demand for other modes. Availability of a strategically preferred transport mode will enable its use. Finally, increasing the price of a transport mode will reduce its demand (the reverse is also valid).

The change of more than one of these factors may have various effects on travel behaviour. First of all, direct and indirect effects may occur resulting of the change of one or several of the presented factors. For instance, the reduction of travel distances (direct effect) brought about by increased density and diversity may induce the use of slower modes, such as non-motorized modes and public transport, within certain constraints (indirect effect). On the other hand the increased used of the private car (direct effect) resulting of increased service level of local road infrastructure may induce longer travel within constant travel time constraints (indirect effect).

Second, action upon one or several land use and transport factors may produce complementary, contradictory or synergic effects. In the first case, actions complement each other resulting in effects which are the sum of the individual effects. Contradictory effects occur when actions cancel of each other resulting in less then the expected effects of each individual change. Finally, synergic effects occur when actions produce results greater than the sum of the individual effects.

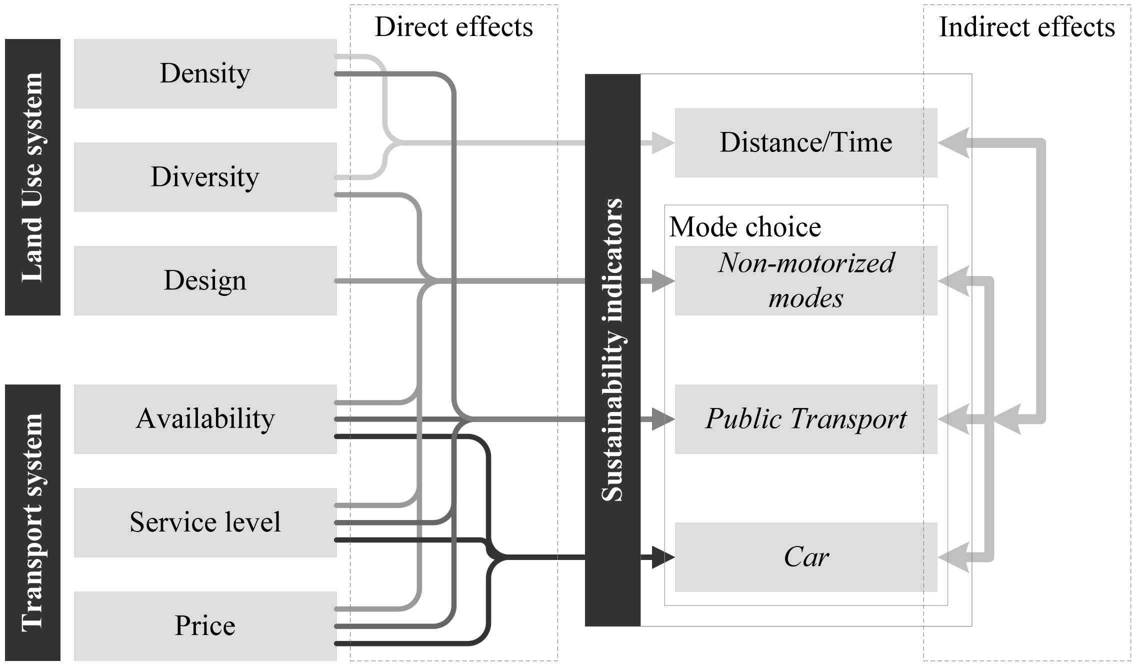


Figure 2.6: Expected effects of land use and transport factors on sustainability indicators

Complementary effects, enhancing sustainability of travel, are produced, for instance, by the increase of density and of diversity, or by the reduction of road infrastructure service level and the increase of private car travel price. On the other hand, an example of complementary activities reducing sustainability of mobility is the simultaneous reduction of availability and service level of public transport (for instance, were public transport companies are reducing their network and service). Contradictory effects occur when, for instance, density is increased but simultaneously, diversity is reduced. Although a reduction of travel distance might be expected due to density enhancement, this may not occur in highly mono-functional urban areas. To have access to activities which are no longer present, travel distance will increase in spite of higher density, although for remaining activities travel distance may reduce. Synergic effects are produced, for instance on public transport use, by increasing land use density and increasing availability and service level of public transport. The increase of density on its own has but a residual effect on public transport use by contributing to higher congestion levels constraining private car use. The increase of availability and service level of public transport have a considerable effect on public transport use (depending on the network and service level which is reached). When these measures are used simultaneously density has the potential of increasing economic viability of public transport. Therefore, while the service level is enhanced by measures on the public transport system, the potential demand is increased by increasing density around public transport access nodes.

These examples clearly show the importance of understanding the factors underlying travel behaviour, as well as the importance of the integration of land use and transport policies to produce more sustainable travel patterns. Although a full understanding of all factors influencing travel behaviour is not yet available, as well as the exact range to which each factor influences travel, it seems fair to say that Figure 2.6 summarises the main factors influencing travel behaviour.

The knowledge gather in this chapter will be used for the development of the accessibility-based design support tool for integrated land use and transport policies presented in Chapter 4. The land use and transport factors influencing travel behaviour have a fundamental role in the definition of a theoretically sound accessibility measure. Thus, instead of directly supporting the development of integrated land use and transport polices, the literature review supports the development of the design support tool for those policies.

Chapter 3

ACCESSIBILITY MEASURES

This chapter presents an overlook of the current theory on accessibility measures believed to be a useful framework for the design of integrated land use and transport policies.

According to Geurs and Eck (2001) the definition of the concept of accessibility depends on the objectives for which it is intended, resulting in the general ambiguity of the concept. For the same reason several different approaches to measuring accessibility can be found in the literature. Handy and Niemeire, (1997) and Makrí (2001) argue that there is no best approach to measuring accessibility. In this context, the development of an accessibility measure for policy design purposes involves several choices which give the adopted concept of accessibility an operational form. These choices depend on the situations and purposes for which it is meant.

This chapter provides a selective overlook of the literature on this research field, strongly oriented towards the choices involved in the development of an accessibility measure intended to support the design of integrated land use and transport policies. There is no intention to produce an exhaustive review of theory[13]. A framework for the development of accessibility performance measures is defined aiming to bridge the gap

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[13] For more detailed reviews of the literature on accessibility measures see, for instance, Halden *et al*. (2000) and Geurs and Eck (2001).

between academic literature and practical application of accessibility measures. The choices to be made for a definition of the measure could be grouped into:

- components used;
- type of accessibility measure used; and,
- additional operational detail for the accessibility measure.

All of these choices are interdependent and mutually influencing, combining themselves into the final definition of the operational accessibility measure. Each of these choices will be further discussed in the following sections.

3.1. Components used

Although there is no one best measure of accessibility there is a general understanding on the main components of accessibility measures. According to Handy and Neimeier (1997) and Stanilov (2003), measures of accessibility generally consist of two parts, the land use component (also named activity, motivational or attraction component) and the transport component (also named resistance or impedance component). The land use component is related to the distribution of potential destinations, the magnitude, quality and character of activities and therefore to the supply of opportunities. This component is also related to the demand for opportunities at origin and therefore to the confrontation between supply and demand, which can be responsible for developing competition effects. The land use component is generally measured by the amount and location of these opportunities. The transport component, like the land use component, is related to the confrontation between the supply and demand, in this case, of the transport system. Therefore the performance of the transport system is a central element in this component, which is generally measured in travel time, distance or cost, expressing the disutility of travel by mode.

Other authors include two further components of accessibility measures. Geurs and Eck (2001) and Geurs and Wee (2004) defend the importance of considering temporal and individual components in accessibility measures. The temporal component reflects the times at which the individuals are able to participate in activities as well as the availability of opportunities at different times of the day. The individual component reflects the characteristics of the individuals, including the needs (which are dependent on characteristics, such as age, lifecycle and lifestyle), abilities (related to physical capacity and specific skills) and opportunities (related to income and travel budgets) depending on individual characteristics. Nevertheless, these authors recognize that it would be difficult to consider all four components in accessibility measures since it would imply high levels of complexity; nonetheless it is important to recognize the implications of excluding one or more of these components when using accessibility measures.

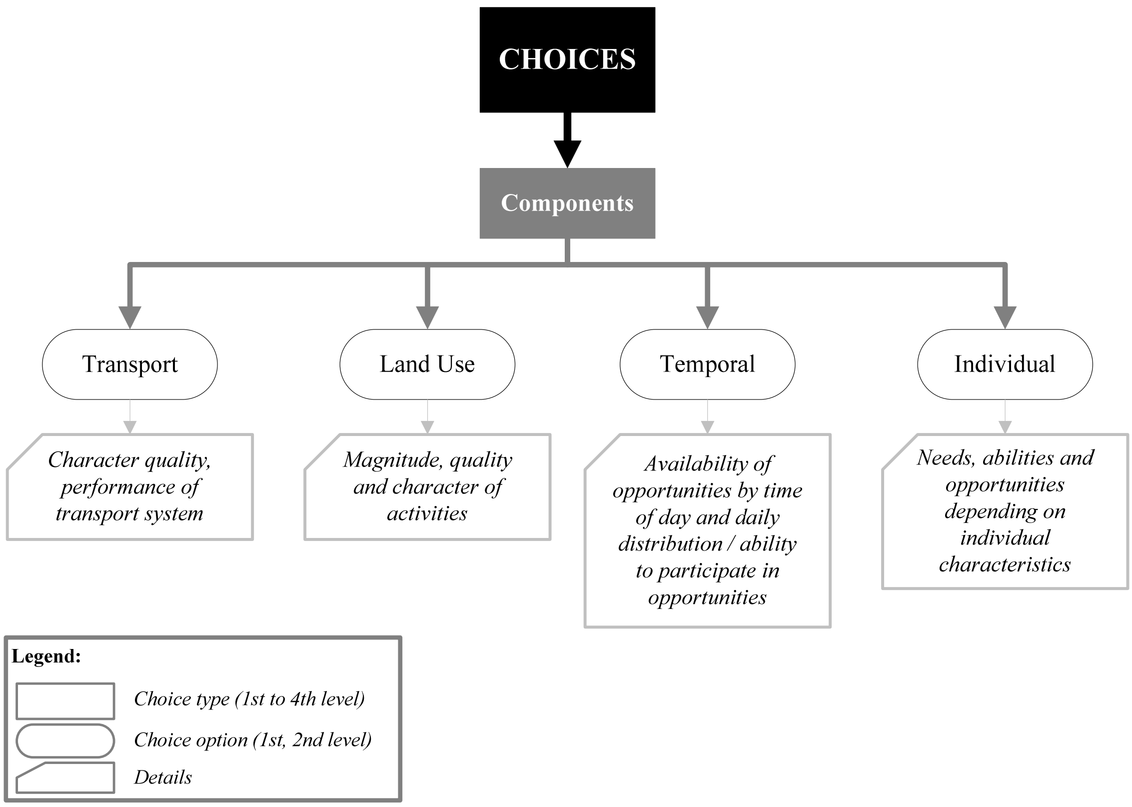


Figure 3.1: Choice of components used

3.2. Types of accessibility measures

The variety of accessibility measures currently known, and which can be considered for the development of measures to support the design of integrated land use and transport policies or plans (having to include at least transport and land use components), can be grouped into the following main categories (based on the main categories defined by Geurs and Eck, 2001)[14]:

- *Activity-based accessibility measures*, considering the availability of opportunities to satisfy individual needs, their spatial distribution and the impedance of travel;
- *Utility-based accessibility measures*, considering the utility theory and measuring the benefits individuals may drive from the land use and transport system.

Some examples of types of *Activity-based accessibility measures* are for instance (see Geurs and Eck, 2001):

- Distance measures;
- Contour measures;
- Potential measures;
- Inverse balancing factor;
- Measures derived from time-space geography.

Both these lists of accessibility measure types are ordered by increasing behavioural consistency and increasing difficulty of use. Among activity-based accessibility measures the first four examples of measure types are, so called, location-based accessibility measures, which analyse the accessibility of given locations to spatially distributed opportunities. The last activity-based accessibility measure is a person-based measure, considering individuals instead of locations.

The *distance measure* is the simplest activity-based accessibility measure considering either distance or travel time between two known places. This type of measure can be used for one single and fixed origin or destination.

[14] Infrastructure-based accessibility measures were not considered here because this type of measure does not take into account the land use component and is therefore inadequate for the purpose of this review.

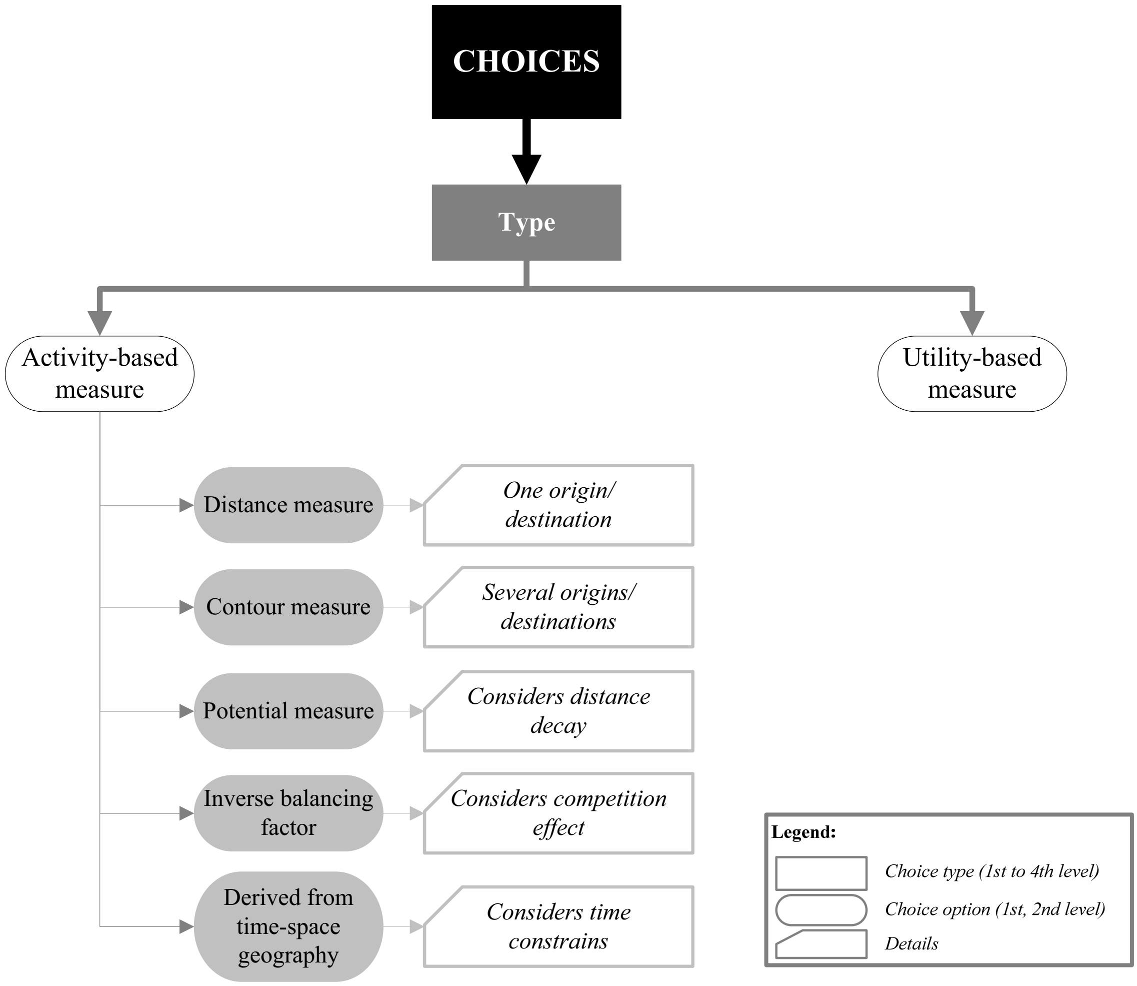


Figure 3.2: Choice of type of accessibility measures

The *contour measures* are also known as, for instance, isochronic measure, cumulative opportunity measure or proximity distance measure. This measure appraises the amount of opportunities reachable in given time, distance or price budgets (referred to as cut-off values). Alternatively, this measure can also be appraised as, the time, distance or costs required to reach a fixed number of opportunities. The first form of contour measures (which is the most frequently used) uses time and distance as boundaries for the quantification of accessibility levels (in number of opportunities). The general form of contour accessibility measures can be as follows:

$$A_i = \begin{cases} \sum_j O_j & \text{if } d_{ij} \leq L \\ 0 & \text{if } d_{ij} > L \end{cases} \qquad \textbf{[3.1]}$$

With A_i being the accessibility at point i to all points j; O_j the number of opportunities at point j; d_{ij} is the time, distance or price necessary to travel between i and j; and L is the time, distance or price budget.

The second form of contour measure uses the number of opportunities as boundary for the quantification of accessibility levels (in time and distance). This measure, also referred to as 'travel cost accessibility measure', is an extension of the distance measure for more then one origin and destination.

Potential accessibility measures reflect distance deterrence of accessibility and are therefore more complex and sound than contour measures. Opportunities are not considered to be equally accessible in a defined time, distance or price budget. Instead accessibility levels are considered to decay with distance of opportunities from origin. The general form of potential accessibility measures can be presented as follows:

$$A_i = \sum_j O_j f(d_{ij}) \qquad \textbf{[3.2]}$$

With A_i being the accessibility at point i to all points j; O_j the number of opportunities at point j; and $f(d_{ij})$ the distance decay function between i and j (also referred to as impedance functions).

Distance decay functions can be, for instance, potential functions ($d_{ij}^{-\alpha}$), negative exponential functions ($exp(-\alpha d_{ij})$), Gaussian functions or logistic functions. These functions must be calibrated for each situation of analysis.

A contour measure is actually a specific form of potential accessibility measure with the distance decay function equal to 1 if the opportunity is within given time, distance or price budgets and zero if not (Koening, 1980, referred to in Handy and Niemeire, 1997). Ingram (1971) presents a rectangular decay function (see Figure 3.3) for this.

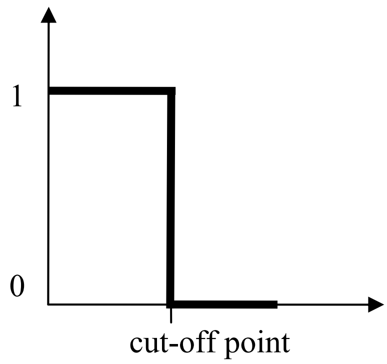


Figure 3.3: Rectangular function (cut-off point)

In this context the general form of contour accessibility measures can be as follows:

$$A_i = \sum_j O_j \delta_{ij} \qquad \textbf{[3.3]}$$

With A_i being the accessibility at point i to all points j; O_j the number of opportunities at point j; and δ_{ij} the decay function which is *one* if opportunities are within boundaries of accessibility and *zero* if otherwise.

The *inverse balancing factor* accessibility measures cope with one of the major limitations of the former activity-based measures, being able to consider competition effect at origin and/or destination. These effects are frequently found in urban areas where users compete for opportunities (when opportunities are less than users at reach) and/or opportunities compete for users (when users are less than those necessary to make all reachable opportunities viable). The increase in accuracy of this accessibility measures results in higher complexity of the measure and therefore limits its operationalisation.

The accessibility measures *derived from time-space geography* consider time constrains when defining if opportunities are accessible, besides of land use (distribution of potential origins and destinations) and transport system characteristics. It is therefore a person-based instead of a location-based accessibility measure.

Finally *utility-based accessibility measures* are founded in the economic theory, and, such as measures derived from time-space geography, are individual-based measures.

Being based on economic theory, accessibility levels are dependent on utility levels of each mobility choice set. These utility levels vary with the individual making the choice, and the choice will result from the selection which maximises the utility for each individual. A simple form of utility-based accessibility measures is that of Ben-Akiva and Lerman (1979, referred to by Geurs and Eck, 2001):

$$A_n = E(Max U_k) \quad \textbf{[3.4]}$$

With, A_n being the value of accessibility for each individual n; and E the expected value of the maximum utility of the choice set of alternatives k.

3.2.1. Discussion of advantages and disadvantages of all measure types

Table 3.1 presents the main advantages and disadvantages of each accessibility measure discussed above. Distance decay measures are the simplest accessibility measures. Simplicity is their main advantage at the same time as it limits the applicability of the measure to situations in which only one origin/destination is considered and its location known. Being simple measures, both distance and contour measures have the disadvantage of not considering the decay of accessibility with distance to origin or destination, nor competition effects at origin and/or destination. Furthermore, these measures do not consider the individual component of accessibility measures. They either define accessibility for an aggregate level of the population or for different levels of disaggregation by socio-economic groups. The objectivity of contour measures is seriously hindered by the arbitrary selection of accessibility boundaries. Nevertheless, both distance and contour measures present two of the most important advantages regarding the operationalisation of accessibility measures for the planning contexts: firsts, the ready availability of data, and second, the ease of understanding and communicating these measures and their results. These advantages result from their simplicity.

The potential accessibility measure copes with one of the disadvantages of distance and contour accessibility measures. This measure has the advantage of considering impedance introduced by distance in accessibility, using a distance decay function to enhance the soundness of the measure. On the other hand, the use of distance decay functions reduces the objectivity of the accessibility measure. The calibration of this function is highly controversial. Notwithstanding, it has a very strong influence on the results of the accessibility measure. In addition, to this disadvantage, the potential accessibility measure upholds the two main disadvantages presented by the former measures.

Table 3.1: Main advantages and disadvantages of accessibility measures

Measure	Advantages	Disadvantages
Distance measures	Very simple Easy to understand and communicate Data readily available	Only usable for one (know) origin or destination No distance decay No competition effects No individual disaggregation*
Contour measures	Easy to understand and communicate Data readily available	Arbitrary selection of accessibility boundaries (cut-offs) No distance decay No competition effects No individual disaggregation*
Potential measures	Easy to communicate (less then contour measures because of decay function) Modest data requirements	Distance decay function chosen has significant influence on the accessibility measure No competition effects No individual disaggregation*
Inverse balancing factor	Accounts for competition effects	Not easily understood or communicated No individual disaggregation*
Derived from time-space geography	High disaggregation (individual-based measure)	Requires large amounts of data No competition effects
Utility-based accessibility measures	Sound theoretical basis High disaggregation (individual-based)	Not easily understood or communicated It is difficult to compare different utility functions

Note: * Although disaggregation can be introduced by using socio-economic groups.

The inverse balancing factor accessibility measure, further copes with the lack of consideration of competition effects, which is its main advantage. Nevertheless this measure does still not consider the individual component of accessibility. The employment of competition effects considerably increases the complexity of the accessibility measure, which is its main disadvantage.

The accessibility measures derived from time-space geography is the only activity-based measure to take into consideration the individual component of accessibility measures, which is its main advantage. Nevertheless, this measure does not regard competition effects as well as requires large amounts of data.

Finally, the use of economic utility theory in accessibility measures considerably enhanced its theoretical soundness, while enabling the development of individual-based accessibility measures. On the other hand, the complexity of the measure is one of its main disadvantages, becoming very difficult to understand and communicate.

Figure 3.4 presents a comparison of the accessibility measures discussed in this section. There is a growing complexity of accessibility measures along the list of measure types presented in section 3.2. This complexity arises from the enhanced theoretical soundness of these measures, considering a growing number of aspects relevant for the definition of accessibility. The smaller arrows between measure types (see Figure 3.4) identify the aspects introduced for each accessibility measure with the increase of complexity. Nevertheless, with the increase of complexity and theoretical soundness of accessibility measures other important aspects for the operationalisation of accessibility measures are lost, such as the ease of understanding and communicating of the measures themselves and their results, as well as the simplicity of use and the availability of data.

This comparison supports the statement (argued in section 1.2) that finding the right balance between soundness and plainness of an accessibility performance measure is one of the key choices for the development of an operational accessibility measure.

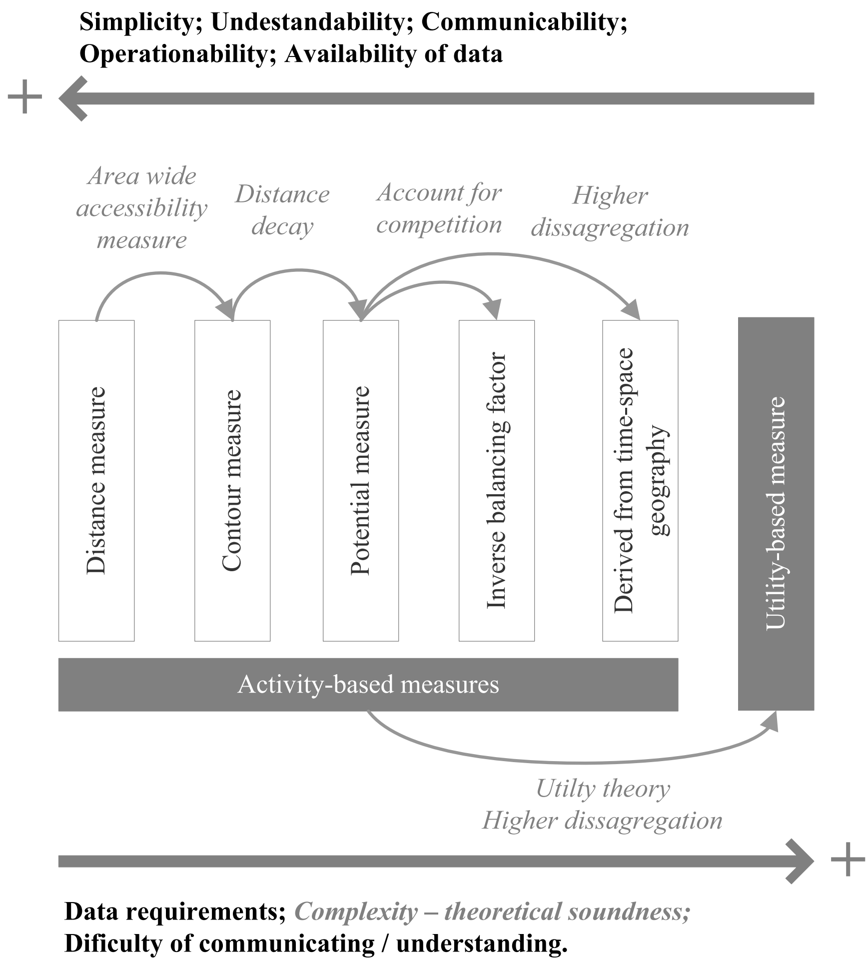


Figure 3.4: Comparison of accessibility measure types

Although no one best choice for the referred balance can be found, Stanilov (2003) states that simple empirical conceptions of accessibility 'have been found to offer significant advantages over more sophisticated theoretical approaches' (Stanilov, 2003; 785). Bertolini *et al*. (2005) choose a contour measure for their accessibility study. These authors justify their choice based on the easiness of understanding and communicating the measure and its results. At the same time this measure 'allows dealing with essential trade-offs and interdependencies between interventions in the transport and land use systems' (Bertolini *et al*., 2005; 211). Handy and Niemeire (1997) also defend that simple measures give a good, if rough, indication of accessibility and are easy to understand and use. 'Complexity can be added by using a series of simple measures, for example, for different types of destinations, or different measures of attractiveness' (Handy and Niemeire, 1997; 1182).

3.3. Operational detail for accessibility measures

Besides choosing accessibility components and type other details need to be specified in order to produce an effective operational accessibility measure. According to Handy and Niemeire (1997) these operational details can be grouped into choices of specification, calibration and interpretation.

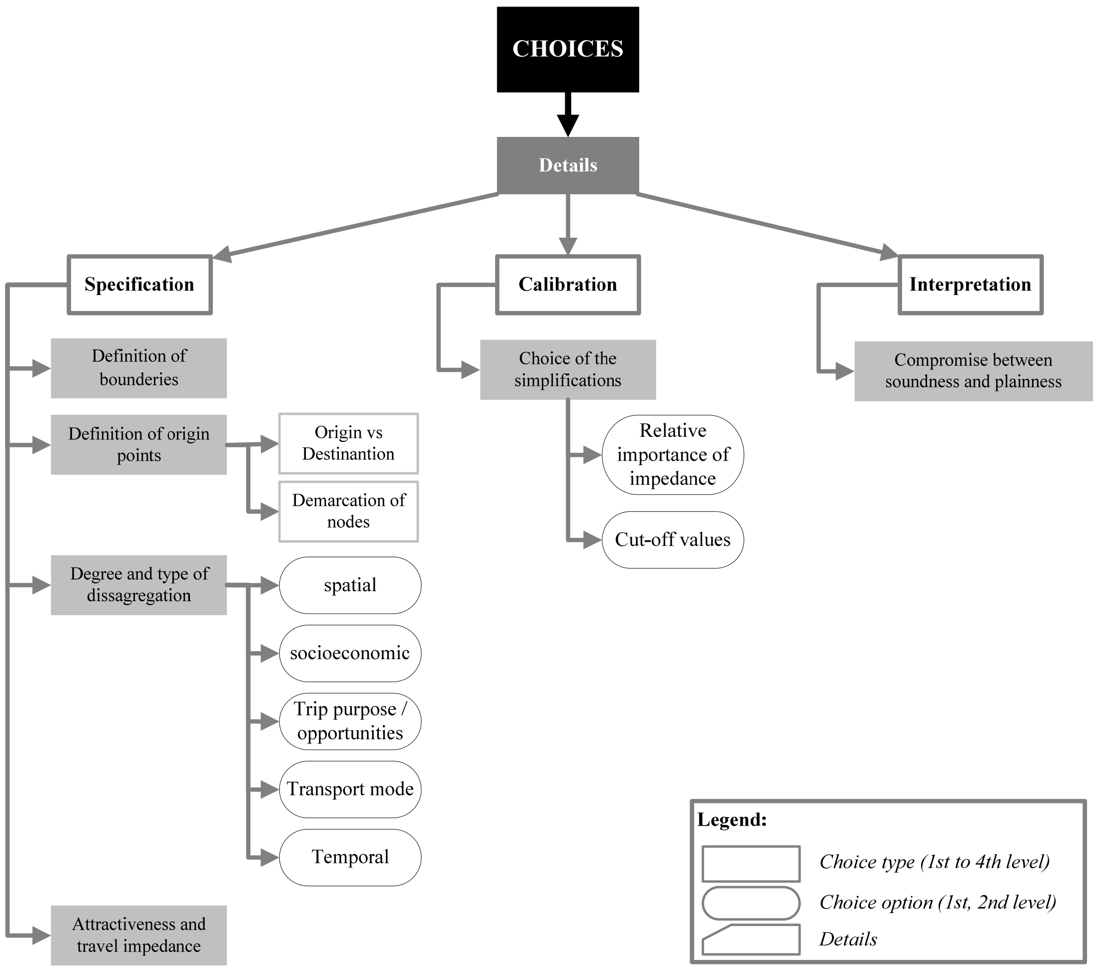


Figure 3.5: Choice of operational details

The main specification needs could be summarised as follows:

- the definition of study area boundaries (Halden *et al.*, 2000; Geurs and Eck, 2001);
- the definition of sub-regions or nodes in the study area (region) working as origin and/or destination points (Handy and Niemeire, 1997; Geurs and Eck, 2001; Bertolini *et al.*, 2005);

- the detail and disaggregation of data and of resulting accessibility measures (Handy and Niemeire, 1997; Halden *et al*., 2000; Bertolini *et al*., 2005); and,
- the measurement of attractiveness of opportunities and of travel impedance (Handy and Niemeire, 1997; Halden *et al*., 2000).

The definition of the study area for the implementation of an accessibility measure is naturally an important choice for the accuracy of the measurement. Special attention must be given to the production of artificially low accessibility values for regions or nodes near the boundaries of the study area. Therefore, the study area chosen must be wider than the area being analysed. This allows no region in analysis to be affected by the artificial reduction in accessibility values due to border effects.

Besides of the definition of the study area boundaries, special attention must be given to the definition of origin or destinations points. First of all a choice between home-based and non-home-based accessibility indicators has to be considered. According to Handy and Niemeire (1997) most accessibility measures use home-based indicators. Nevertheless, these type of indicators do not take account of non-home-based travel (which has been increasing), nor of multipurpose travel or trip chaining. Furthermore, these authors suggest that the use of non-home-based indicators has the potential of considering, for instance, socio-economic or time constraints of use of potential destinations.

Geurs and Eck (2001) refer another choice concerning the definition of origin or destinations points. These authors refer the need for the demarcation of regions or nodes in the total research area representing the total amount of potential origins and/or destinations. According to these authors three approaches are possible for this demarcation: first using network nodes or using centroids to represent cities or regions; second, using raster-based GIS technology; and third, a combination of the former two. The number of representative regions or nodes used depends on another choice of specification related to the disaggregation.

Choices related to the disaggregation level of accessibility measures can be of varied nature, such as spatial units, socioeconomic groups, trip purpose, opportunity types, transport modes, temporal, etc. Considering spatial units, disaggregation can be defined by zones (place-based accessibility measures) or by households or individuals (individual-based accessibility measures); the higher the disaggregation the more accurate the measure. Socioeconomic disaggregation can be, for instance, by age, income, education or occupation groups. The disaggregation by trip purpose or opportunity types can basically be divided into work and non-work travel, or furthermore into, for instance, shopping, leisure or health activities. The extensive literature review developed by Geurs an Eck (2001), involving all referred types of accessibility measures, shows that generally only one type of opportunity is considered at a time. These authors found very few publications in which two types of opportunities where considered (with separate analysis of accessibility) and no publications considering more than two types. The opportunities most frequently taken into account in accessibility analyses where those of population and employment. Disaggregation by mode (for example, into car and non-car or into car, public transport and non motorized modes) can be a useful toll for the comparison of accessibility levels by transport mode which is a very important factor in sustainability analysis. Higher disaggregation levels give higher accuracy and soundness to accessibility measures, enabling more detailed knowledge, and therefore a better understanding of accessibility patterns. Nevertheless, increasing disaggregation enhances the complexity of the measure as well as reduces its ability to be operationalised.

Interdependencies are very strong between node choice and spatial disaggregation. The higher the spatial disaggregation chosen, the less node choice influences results of accessibility measure. In this case nodes may be located using raster-based approaches. The lower the spatial disaggregation used the more node choice influences the validity of the accessibility measures' results. In this case, the location of nodes must be very carefully chosen (instead of randomly placed), in order to be a representative location of the accessibility of the sub-region it represents.

Finally, specification of the attractiveness of opportunities and of travel impedance are further choices in the development of accessibility measures for the design of integrated land use and transport policies or plans. Regarding the attractiveness of opportunities an accessibility measure may simply consider the number of reachable opportunities or may consider the physical or economical size of opportunities (such as area or employment). For the definition of the travel impedance function, besides of the choice of the type of function (see section 3.2 – potential accessibility measures) further choices must be made, regarding the form of estimating the function.

Besides of the specification of accessibility measures, choices regarding the calibration and interpretation of the accessibility measure must also be made. The calibration process validates the accuracy and soundness of the measure of accessibility, adjusting the measure to real accessibility patterns. For contour measures, the key element of calibration is the choice of the cut-off values (threshold travel distance, time or cost for which a destination is considered reachable). According to Handy and Niemeire (1997), cut-off values can be defined, for instance, by calculating a series of accessibility measures for different cut-off values and choosing those producing the most accurate one. Alternatively, these authors suggest the definition of cut-off values based on frequency distributions of travel times (using surveys). The calibration of potential measures involves finding the right adjustment of the relative importance of travel impedance to destination choice.

Handy and Niemeire (1997) present interpretation as the final process of development of useful accessibility measures. This last process involves interpreting and translating the measure into a form useful to policy makers. A simple approach is to use relative instead of absolute accessibility, evaluating accessibility comparatively across places or time. For the purpose of developing integrated land use and transport plans or policies, the interpretation process is of key relevance, being responsible for the comprehensibility and communicability of the measure and its results.

3.4. Synthesis: implications for the development of accessibility measures

The development of an accessibility measure to support the design of integrated land use and transport policies involves a series of choices balancing soundness and plainness. The main choices include the components, the types of measure and the operational detail.

Accessibility measures used as design support instruments for integrated land use and transport policies must at least include land use and transport components. In addition, individual and temporal components may be considered, increasing complexity and soundness of the measure.

Several accessibility types can be found in the literature with potential to support the design of integrated land use and transport policies. This chapter presents five activity-based accessibility measures and a general utility-based measure, comparing their advantages and disadvantages as design support tools. Different levels of complexity and soundness as well as understandability and operationability were found.

Finally, a list of choices regarding operational details is presented as well as some suggestions with regard to these choices are presented. Figure 3.6 provides a general overview of the main choices as well as some alternatives and examples concerning the development of accessibility measures for the design of integrated land use and transport policies or plans.

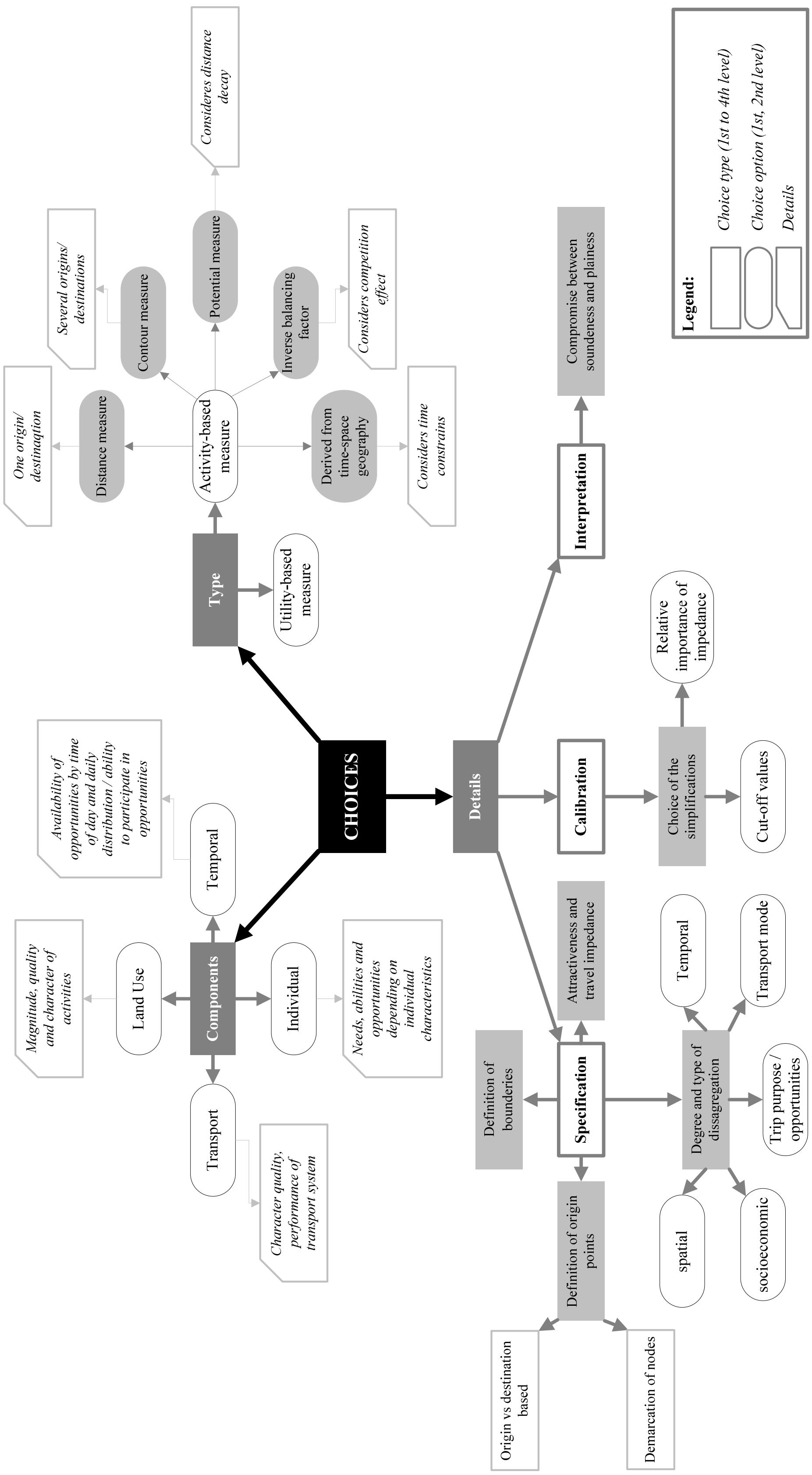


Figure 3.6: Overview of the choices for accessibility measures

Chapter 4

STRUCTURAL ACCESSIBILITY LAYER

This chapter presents the accessibility-based design support tool that was developed for this research – the Structural Accessibility Layer (SAL). It was built upon the assumption that the concept of accessibility is able to frame the development of useful design support tools. Theoretically sound as well as usable and relevant design support tools are believed to bring about policy integration in practice. The integration of land use and transport policies is assumed to be able to provide the necessary urban structural conditions to enable sustainable travel behaviour.

The development of the SAL involves a new approach to land use and transport planning for mobility management. This research proposes that the interaction of urban structure and mobility be regarded from the perspective of the *constraint* instead of the *influence*.

This is in contrast with the current research approaches, which consider the primary aim of integrating land use and transport policies to be the influence of mobility patterns. In addition, traditional research on the interaction of urban structure and mobility is also centred on the influence land use and transport has on travel behaviour. However, research has been unable to understand or prove the cause-effect of urban structure on travel behaviour, not within the influence-based approach. The ambiguity of the traditional approach as argument for the integration of land use and transport policies has contributed to the lack of implementation of these policies. Although the influence of a certain urban structure on travel behaviour is uncertain it is clear how that same urban structure constraints (enables or disables) certain mobility choices, and therefore the sustainability of that mobility. For instance, while on the one hand the availability of public transport service may influence the use of public transport it is clear that the absence of the same service disables such mobility choices (constraining mobility to other modes).

This thesis argues that the assessment of land use and transport constraints on urban mobility provides a far more objective and realistic approach for mobility management than the traditional influence-based approach. The development of the SAL is based on this constrained-based approach, which enables higher objectivity of analysis as well as provides a wider consensus for policy making.

For the SAL to work as a design support tool of integrated land use and transport policies (in the new approach) it requires a measure able to analyse how the urban structure constraints the sustainability of potential mobility. This measure should be able to analyse if the conditions given by the land use and transport system enable or, otherwise disable, the sustainability of travel behaviour. It is important to highlight that the object of analysis of the SAL is potential mobility, i.e. travel behaviour enabled by urban structure (and not real travel behaviour).

Thus, this measure requires a twofold capability: first, to analyse the present constraints of urban structure on the sustainability of potential mobility patterns; and second, to support the identification of policy action options (conditioned by policy strategies) enhancing conditions for sustainable mobility patterns. These capabilities define the two purposes of the SAL: analysis and design support (see Figure 4.1).

These capabilities were brought about by the use of accessibility measures. The new approach to mobility management proposed by this thesis is made operational by the comparison of accessibility levels by transport mode. Comparing accessibility by mode, in certain land use and transport conditions, seems to provide a measure of the potential of use of each transport mode in those conditions. As mode choice is one of the determinant factors of sustainable mobility, this measure presents an interesting appraisal of urban structure constraints for mobility to be sustainable.

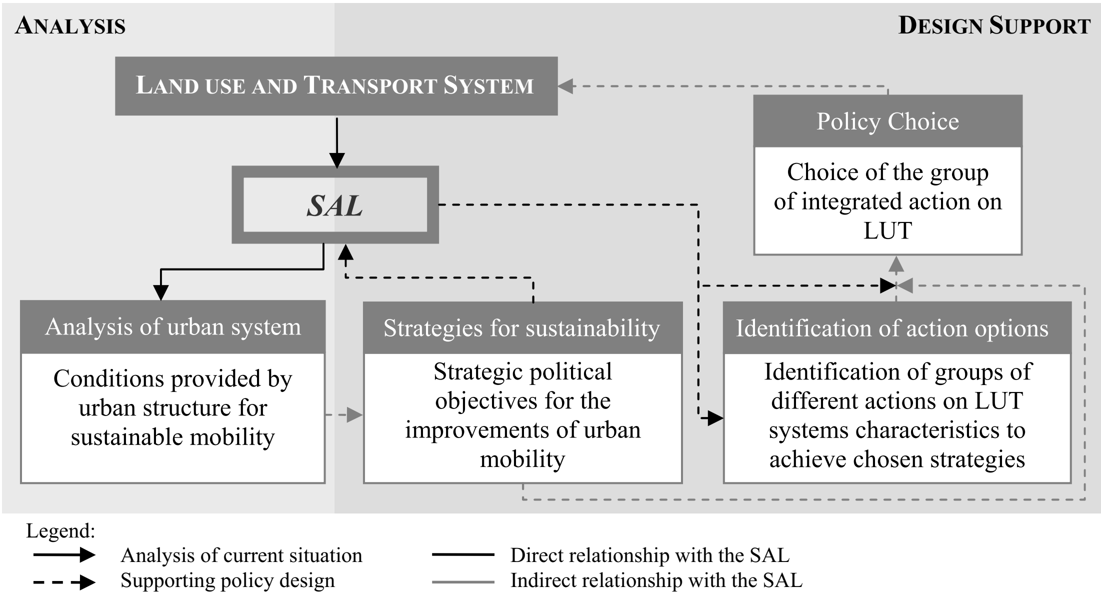


Figure 4.1: The SAL's framework

The SAL was developed to test the **hypothesis** guiding the research of this thesis, as defined in section 1.3:

A measure of comparative accessibility by transport mode may provide a useful design support framework for the integration of land use and transport policies shedding light on the sustainability of potential mobility enabled by land use and transport conditions.

The SAL does not measure mobility itself, neither its sustainability, it rather measures the extent to which the urban systems provide the necessary conditions to enable sustainable mobility patterns. Furthermore, the SAL is believed to enhance the understanding of local authorities concerning the aspects of urban structure conditioning mobility patterns.

The next section introduces the SAL's concept, followed by the presentation of the developed measures in section 4.2. Section 4.3 discussed potential stakeholders of the instrument. This chapter ends with a theoretical discussion of the potentials and limitations of the tool from a theoretical and a practical point of view[15].

4.1. The concept of Structural Accessibility Layer

As has been mentioned before, the Structural Accessibility Layer is a policy design support tool based on the concept of accessibility. The following general definition can be presented:

The *Structural Accessibility Layer* is a *geographical representation of comparative accessibility levels by types of transport modes to different types of opportunities generating travel.*

This definition highlights the three fundamental aspects of this instrument which used jointly offer the SAL its originality:

- the production of **geographically represented** (GIS based) results;
- the use of **accessibility measures** (section 4.2.1);
- and, the comparison of accessibility values by transport mode, defining the **sustainability measure**[16] (section 4.2.2).

The geographical representation of the results of comparative accessibility measures is fundamental to provide a global view of the territory in analysis and of variations of accessibility conditions throughout the study region. The use of an accessibility based instrument is fundamental to reveal the link between urban structure and the potential mobility patterns in, both, the analysis and the design support purpose of the SAL. The use of comparative values of accessibility (by transport mode) is fundamental to measure the potential of urban structure to enable sustainable travel behaviour.

[15] The definition of the theoretical potential and limitations of the SAL already comprise feedback from the testbed presented in the following chapters, considering the learning cycle methodology as presented in section 1.4.

[16] This measure is called *sustainability measure* as a simplification of *measure of sustainability of potential mobility enabled by land use and transport conditions*.

According to the definition presented in section 1.6, *accessibility* here is considered as the *extent to which the land use and transport system enable individuals to reach different types of opportunities* (based on the concept by Geurs and Eck, 2001; 36). This definition reflects the spatial distribution of opportunities as well as the availability and service level of different transport modes in accordance with the main land use and transport factors found to influence travel behaviour identified in Chapter 2.

4.2. The Measures

The SAL uses accessibility-based measures to gauge the conditions given by the land use and transport system for mobility. Two main indexes are used for this measure: the *diversity of activity index* (the accessibility measure) and the *comparative accessibility index* (the sustainability measure). The diversity of activity index is used to measure the accessibility level by each transport mode, while the comparative accessibility index uses the results of the first index to develop the comparative analysis of accessibilities by transport modes. This comparative index is then used as a measure of sustainability of potential mobility patterns enabled by land use and transport conditions (defining the sustainability measure).

These measures are theoretically defined in the following sections. It is essential to point out that the SAL is highly adaptable to local conditions and perceptions of accessibility. Therefore, several aspects will have to be locally defined for each application case in order operationalised the SAL for the local context. These case-specific choices are clearly identified along the following sections (for a summary see Figure 4.5 and Figure 4.10; general recommendations for the development of the case-specific SAL is also provided along the following sections).

4.2.1. The accessibility measure

Accessibility by transport mode is measured using the *diversity of activity index*. This index was developed for the SAL based on the 'dissimilarity index' of Cervero and Kockelman (1997). It *counts the number of types of activities which can be reached within a defined number of activity types* found to be the most relevant for travel demand generation. It is therefore an aggregate measure of accessibility to several activity types, whose values range within specific (pre-defined) boundaries.

The general form of the diversity of activity index is the following:

$$DivAct = \frac{\sum_y (Act_y * f_y)}{\sum_y f_y} \qquad \textbf{[4.1]}$$

Where, y is the activity type, Act_y a value representing the existence or not of the activity type y inside accessibility boundaries[17] ($Act_y \in \{0;\ 1\}$) and f_y the potential frequency of use of the activity type[18].

The diversity of activities index considers the potential frequency of use of an activity in addition to the accessibility to that activity. Therefore, the access to activity types with higher frequency of use provides higher values of diversity of activities than the access to activity types with lower frequency of use. Thus, the diversity of activity index provides an average of the number of activity types accessible, weighted by the potential frequency of use. Results of this index range from zero (no accessible activities) to one (all activities are accessible). Potential frequency of use must be defined for each application case of the SAL and is therefore the first of several case-specific choices, required for the operationalisation of the tool.

> <u>The case-specific choice of potential frequency of use:</u> In order to enhance the soundness of the measure, this choice should be based on the knowledge on local travel behaviour, for instance the percentage of trips per trip purpose.

[17] This measure is based on a simplification which considers that people choose the closest destination among the same activity type (regardless of quality, price and other personal preferences). In addition, aspects with the potential to enhance personal perception of accessibility, such as the number or area of establishments of the same activity type (i.e. density besides diversity), where not considered for this indicator. The potential of using further detail in the activity type indicator (Act_y) to improve the soundness of the SAL was recognised during its application for the testbed of the thesis (see section 6.2 under "more complex accessibility measures"). Nevertheless, further research is required to study the balance between soundness and plainness of the resulting accessibility index, especially taking into account the reduced comprehensibility which may compromise the design support purpose of the SAL. Future research should thoroughly study the surplus value of these details.

[18] The potential frequency represents the potential use of an activity type in comparison to others, i.e. the average number of trips of a population for each activity type. For instance, the percentage of trips for each activity type may be used.

Figure 4.2 summarises the main characteristics of the diversity of activity index used as accessibility measure regarding measure type, options and disaggregation level. These characteristics were defined based on the main choices for the development of an accessibility measure as outlined in Chapter 3 (see Figure 3.6).

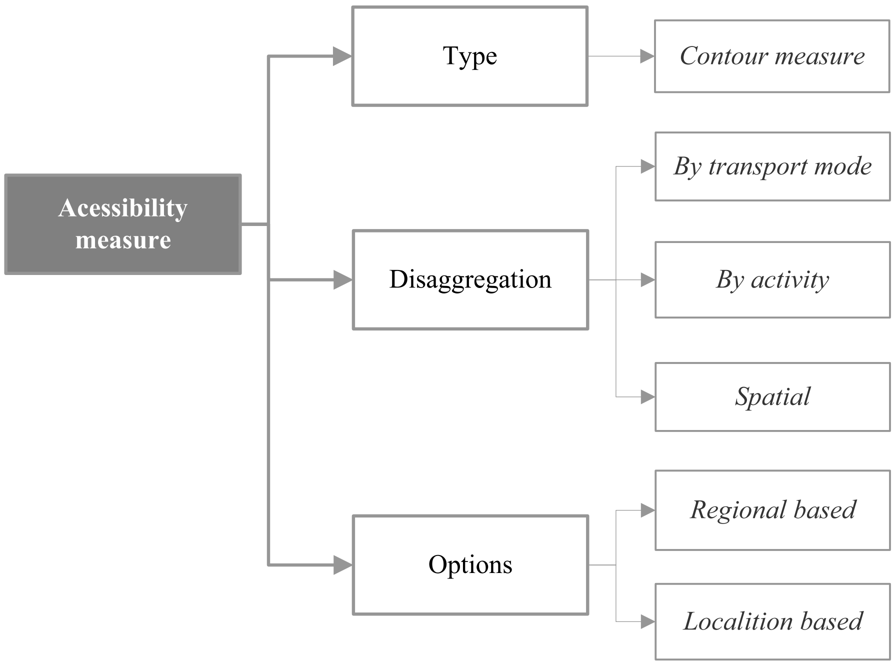


Figure 4.2: Main choices for the development of the accessibility measure

In practice, the diversity of activity index may use any preferred accessibility measure type available in the literature, requiring a necessary adaption of the formulation defined in equation [4.1]. The enhanced soundness of the use of more complex accessibility measure types is welcome and should even be encouraged. Nevertheless, the conceptual framework of the SAL is built upon a contour accessibility measure type for the diversity of activity index. As has been presented before, the basic form of this measure type counts the number of opportunities at reach. This choice is a result of the theoretical recommendations for plainness of PSS, discussed in section 1.2, in order to enhance practical application. Once bottlenecks to practical use are overcome any improvements in complexity and soundness are encouraged and a case-specific choice. Therefore, the choice of this type of measure is related to its main advantages (as presented in section 3.2.1), both, the ease of interpretability and of communicability, and the ready availability of required data. According to authors, such as Pirie (1981), Geurs and Eck (2001), Makrí (2001), Stanilov (2003) and Bertolini *et al*. (2005) the ease of operationalisation of these measures into policy design tools is a clear argument for the use of contour measures in order to fight the lack of implementation of PSS[19]. Bertolini *et al*. (2005) choose a contour measure for their accessibility study because it is 'easy to understand and nevertheless already allows dealing with essential trade-offs and interdependencies between interventions in the transport and in the land use system' (Bertolini *et al*., 2005; 211).

Taking into consideration the discussion around the interaction of urban structure and mobility (see Chapter 2) it is evident that the simple count of accessible activities provides only a partial measure of mobility conditions. In this context a measure evaluating the reachable diversity of activities was considered to be more adequate, presenting an aggregate measure of the ability of urban structure to satisfy most travel generating needs. Furthermore, theoretical soundness of the measure was enhanced by adding a series of simple operational details such as, high disaggregation level of analysis regarding transport mode, activity types and spatial scale."

Disaggregation of accessibility levels by transport mode and by activity type is fundamental to enable the thorough understanding of land use and transport conditions for mobility. The comparison of accessibility levels by different transport modes, in different urban structure conditions, enables the appraisal of the sustainability of potential travel patterns (with regard to transport mode and distance). In the urban context and considering only personal travel, three groups of transport modes are defined for the SAL: non-motorized transport, public transport and the car. The potential of use of each of this transport mode types is related to different sustainability conditions for mobility. While disaggregation by transport mode is conceptually

[19] As discussed in section 1.2, the effective use of PSS is suffering from a 'rigor-relevance dilemma' with many of the developed policy design support tools for integrated land use and transport not being used in practice. According to Vonk *et al*. (2005), Geertman (2006), Brömmelstroet (2007) and Hoetjes (2007) planners consider most of these tools to be too abstract, generic and complex, producing inflexible systems for support of planning. Furthermore, most PSS are believed to be technology oriented, pursuing the use of technological improvements instead of resolution of problems. Stanilov (2003) states that simple empirical conceptions of accessibility 'have been found to offer significant advantages over more sophisticated theoretical approaches' (Stanilov, 2003) by avoiding some of the weaknesses of highly deductive models and taking advantage of the ease of understanding which is critical for application of the concept.

defined, the choice of activity types (and of the activities considered for each activity type) is case-specific.

> The case-specific choice of the level of activity disaggregation: Chosen activities should provide the most faithful portray of local travel demand (regarding statistical data constrains). In general, activities considered to have the most influence on travel behaviour are work, school, leisure and free-time activities, shopping, healthcare and other public and private services. Activity types should at least include these basic activities, and at least at this disaggregation level. The use of more activity types or of higher disaggregation of the same activity types, provide higher detail of the land use conditions.

To identify the activity types which are reachable from a particular origin, accessibility boundaries must be defined. As in regular contour measures, the limit of the accessibility area is dependent of the cut-off elements considered as well as of their values. The cut-off elements generally used for contour measures are time and cost. The choice of each of these criteria as well as their values is case-specific.

> The case-specific choice of cut-off criteria and values: The following table presents some examples of time and cost cut-off criteria using the disaggregation by transport mode proposed by the SAL[20].

[20] Further detail may be used disaggregating cut-off criteria by activity type considered, since accessibility limits may vary across activity types. This choice is also case-specific and its added value for the soundness of the measure. Nevertheless, increased soundness should be balanced against increased costs and efforts.

Table 4.1: Examples of detail that can be used for cut-off criteria

	NM	PT	CAR
Time	walking time	Total travel time In-vehicle time Access time (to and from PT) Waiting time Walking interchange time Waiting interchange time	Total travel time Walking time (to and from the car) Parking time
Cost	Land slope Ratio between Manhattan distance and straight line distance Existence of obstacles	Distance at interchange Comfort/quality Price	Total travel price (considering travel distance, petrol price, tools, maintenance, parking, etc.) Price of tolls Parking price

Some of the examples presented in Table 4.1 can be included in one another. For instance, total travel time for public transport includes waiting time. Nevertheless, both may be used simultaneously for the same measure. For instance, people may consider destinations with total travel time, by public transport, higher than 30 minutes as inaccessible and simultaneously not consider the use of public transport if waiting time is higher than 10 minutes (with 10 minutes being included in the 30 minutes travel time).

The choice of the criteria for each case, as well as the maximum value of the criteria, is therefore a very important issue. This choice should be based on the knowledge of local travel behaviour in order to have a realistic choice of the most important aspect dictating accessibility boundaries. Still, the balance between soundness and plainness of the measure must also be considered for this choice. There is a limit imposed by plainness in the choice of cut-off criteria increasing the soundness of the measure.

Regarding the aim of measuring land use and transport conditions for mobility, the diversity of activity index provides a location based measure of accessibility. This means that the accessibility measure does not evaluate accessibility of people or activities but of places. This measure is conceptually defined for the regional scale, therefore measuring accessibility of places in the study region. The regional scope enables a global view of land use and transport conditions for mobility in a wider mobility region[21]. It is therefore not based on administrative divisions of the territory providing a view of mobility catchment areas instead of municipal planning areas. The exact limit of the study region has to be defined for each application case of the SAL.

> The case-specific choice of study region boundaries: The region must be wide enough to encompass the main potential mobility patterns of an urban agglomeration. The object of the SAL is travel behaviour enabled by urban structure (and not real travel patterns). Therefore, the study region must comprise essentially internal travel patterns, holding merely residual cross, entry and exit patterns.

Aiming to provide an effective way to identify small-scale variations of accessibility levels, a high level of spatial disaggregation is used. Therefore the study region must be divided into small enough sub-regions, for accessibility levels of their central points to be a good representation of sub-regional accessibility. These central points are the locations used for the location-based measure. The level of spatial disaggregation is another case-specific choice in the development of the SAL.

> The case-specific choice of the level of spatial disaggregation: Spatial disaggregation is conditioned by the level of disaggregation of statistical data available in each case. Nevertheless, considering the soundness of the measure, spatial disaggregation should be at least at the census track (or even grid based, using cells of at most 1km2)[22].

Once the accessibility measure is completely defined, a GIS-based technology can be used to identify accessibility areas for each sub-regional origin (as schematized in

[21] Because this methodology develops at the regional scale, it does no consider micro-scale issues such as the influence of urban design aspect on mobility patterns.
[22] Soundness regards the detail of accessibility variations as well as the ability of central points to represent the entire sub-region.

Figure 4.3). This requires the calibration of the local transport system for each transport mode type.

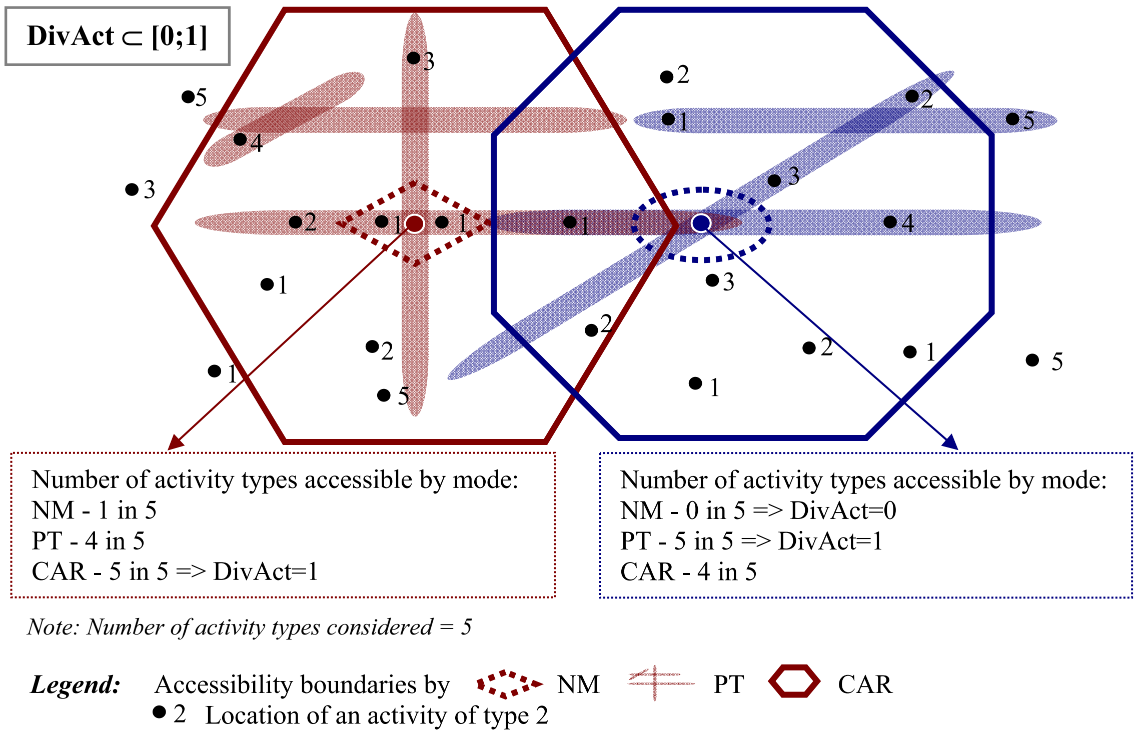


Figure 4.3: Accessibility boundaries by transport mode drawn for two example origin points[23]

Accessibility levels for each transport mode can be aggregated by scale to generate a *regional diversity of accessibility index* using as weighted average, based on population[24], as illustrated in the following equation:

$$RDivAct = \frac{DivAct_i * P_i}{P} \qquad \textbf{[4.2]}$$

Where, $DivAct_i$ is the diversity of activity index for a given transport mode of the origin representing sub-region i, P_i is the population resident in the sub-region i, and P the regional population.

[23] Public Transport boundaries are represented by continuous linear areas, to simplify the scheme; in reality they are a set of, approximately, circular areas around public transport stops of accessible routes.
[24] This is possible because accessibility is measured for a limited number of potential origin points and these points represent an approximate value of accessibility of all points in its sub-region because of high spatial disaggregation of the measure.

The range of formulations used for the diversity of activity index is presented in the following table. Instead of one single index, six are used in the SAL.

Table 4.2: Formulations of the diversity of activity index

	NM	PT	CAR
Sub-regional	$NMDivAct_i$	$PTDivAct_i$	$CARDivAct_i$
Regional	NM_RDivAct	PT_RDivAct	CAR_RDivAct

The accessibility measure of the SAL culminates in the production of three accessibility maps for the study region, one for each transport mode (NMDivAct, PTDivAct, and CARDivAct). These maps generate the geographical representation intended for this tool, providing an overview of small scale variations (by sub-region) of accessibility levels to diversity of activities by each transport mode.

The following scheme summarises the conceptual choices made in the development of the SAL with regard to the balance between soundness and plainness of the accessibility measure. Considering the rigour relevance dilemma of PSS discussed in Chapter 1, the balance between soundness and plainness is central to the development of the conceptual framework of the SAL and of its accessibility measure. Soundness of the basic contour measure was enhanced by using disaggregated spatial analysis of accessibility levels by different transport modes to several types of activities. These choices (which to some extent are case-specific) provide the necessary detail for the thorough modulation of small scale variations of local land use and transport conditions for mobility. Aggregation of accessibility measures is used, on the other hand, to recover simplicity and the communicative qualities of the measure.

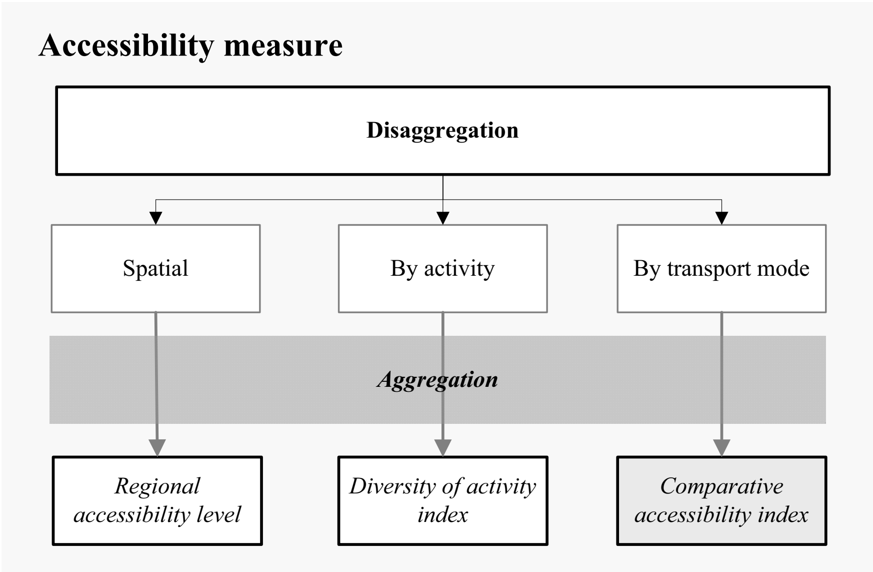


Figure 4.4: Balance between soundness and plainness of the accessibility measure

The high level of disaggregation by scale is complemented by a general indicator of accessibility for the entire study region. The range of disaggregation of activities is made usable and understandable by the measure of diversity of activities. Finally accessibility levels by transport mode are combined through a comparative measure presented in the following section.

Finally, the range of choices required for the development of a case-specific SAL is summarised in the following figure.

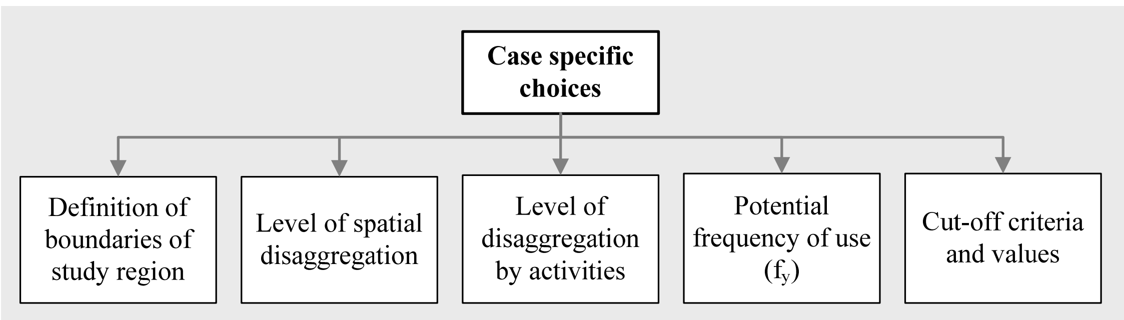


Figure 4.5: Case-specific choices for the accessibility measure

4.2.2. The sustainability measure

The use of accessibility measures disaggregated by transport mode type (NM, PT and CAR) enables the comparison of accessibility levels between them. This comparison provides a measure of potential use of transport mode and of potential travel distance. Therefore comparing accessibility by mode enables the assessment of sustainability of potential travel patterns constrained by local land use and transport conditions (with regard to mode choice and distance).

In this sense it is fair to say that the potential combinations of accessibility by the three modes establish a framework for the classification of the sustainability of potential mobility patterns (enabled by urban structure). All potential combinations of accessibility by the three modes are comprised in a cube with values ranging from zero to one (see Figure 4.6).

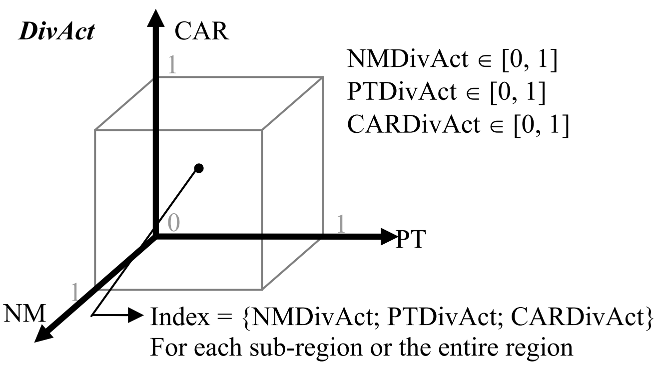


Figure 4.6: Potential combinations of accessibility values by three transport modes

The classification of sustainability of potential mobility patterns is brought about by the *comparative accessibility index*, which groups different combinations of accessibility levels by each transport mode. This index brings about the aggregation of the accessibility measure for all transport mode types considered, producing the final aggregate value of (comparative) accessibility.

In order to cope with the variety of potential combinations, accessibility levels of each transport mode were divided into 3 *accessibility classes*: high accessibility level being class A; medium accessibility level being class B:, and low accessibility level being class C. Accessibility class limits can only be defined for a specific application case with regard to local understanding and perception of high, medium and low accessibility levels.

The case-specific choice of division of accessibility classes: The choice of accessibility class limits should operationalise the meaning of accessibility classes. These can be chosen based on a debate of the meaning of high, medium and low accessibility to diversity of activities (by experts on local mobility, land use, transport and mobility management). For instance, identifying the activity types which could be absent for a high accessibility level and defining the values of the class limit as the percentage of the potential frequency of use (f_y) of the activities that must be reachable for accessibility to be considered high. Accessibility class limits are the same for all three transport mode types, since they have an absolute meaning. Furthermore, the dispersion of sub-regional accessibility in the cube can be used to calibrate class limits. In any case, class A should be as narrow as possible to ensure proximity of accessibility values in this class and thereby enable high comparability between transport modes for this class.

The use of accessibility classes reduces the number of potential combinations of accessibility values to 27, forming the benchmarking cube presented in Figure 4.7. These 27 combinations of accessibility values were named *accessibility categories*. Each category represents *different conditions provided by the land use and transport system for travel behaviour*, concerning the potential choice of transport mode and the potential travel distance.

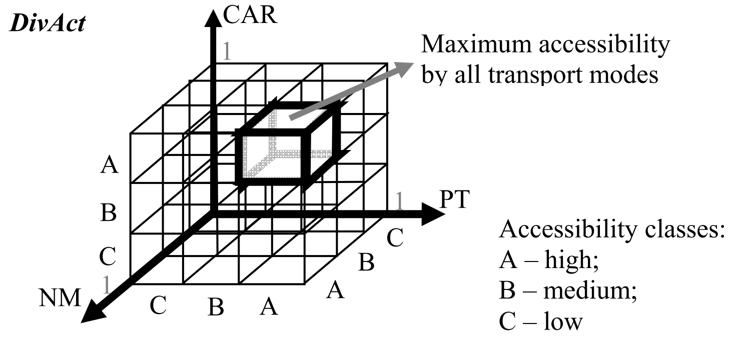


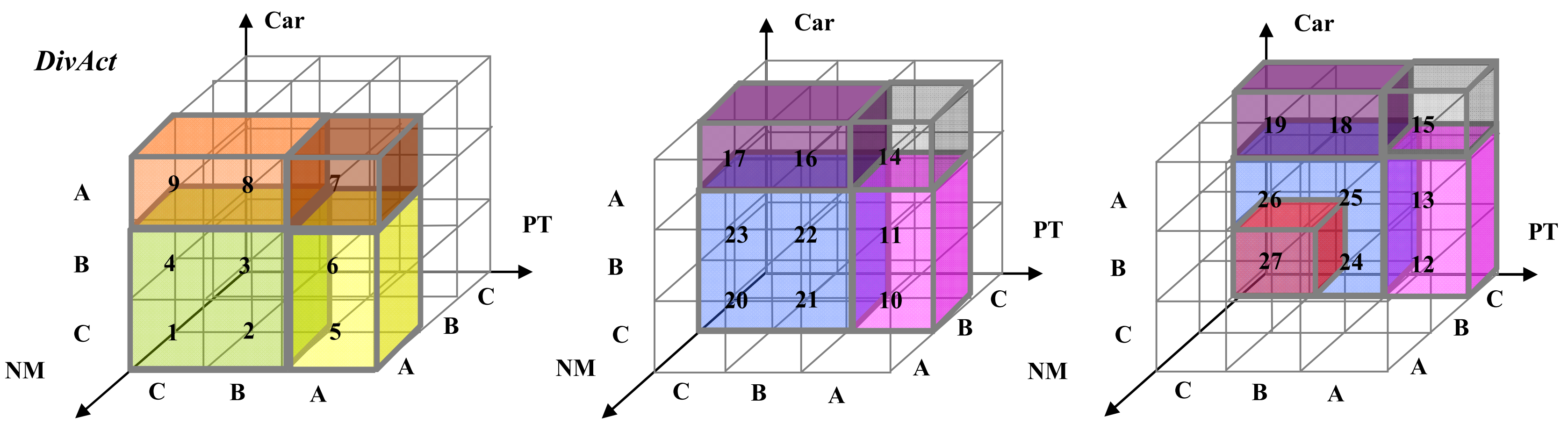
Figure 4.7: Benchmarking cube and accessibility classes by transport mode

The 27 categories are grouped into 9 *accessibility clusters* defining *different levels of sustainability of potential mobility (regarding mode choice and distance) enabled by land use and transport conditions*.

Accessibility categories and clusters are used to make the comparative accessibility index operational. The 27 accessibility categories and the 9 accessibility clusters are presented in the Figure 4.8[25]. In this figure, accessibility categories are numbered from 1 to 27 and presented inside the benchmarking cube (one for each smaller cube). The nine clusters are numbered from I to IX and defined by nine colours used in the benchmarking cube.

Clusters I to VII are a result of the grouping of accessibility categories representing land use and transport conditions favouring the use of the same transport mode (or modes). A transport mode is considered to be favoured by land use and transport conditions when it provides high accessibility levels. These clusters are ordered according to decreasing sustainability of mode choice favoured by the urban structure. Land use and transport conditions unable to provide high accessibility levels by any transport mode are grouped into clusters VIII and IX according to the highest level of accessibility provided. With regard to these clusters, mobility management centres on increasing accessibility by providing sustainable urban structure conditions for mobility. The classification of sustainability of current conditions becomes irrelevant with regard to the lack of accessibility. In this context the main concern rests on the sustainability of the path chosen to achieve high accessibility levels. Contrarily to cluster numeration, the category number has no associated meaning besides of the position in the benchmarking cube.

[25] The figure represents the same benchmarking cube three times to provide a clear view of all categories and clusters, by representing three different slices of the cube.



Accessibility classes: A – high; B – medium; C – low.

Accessibility Category: 1 to 27

Clusters

- I - Favourable conditions for the use of NM modes
- II - Favourable conditions for the use of NM modes and PT
- III - Favourable conditions for the use of all modes
- IV - Favourable conditions for the use of NM modes and the CAR
- V - Favourable conditions for the use of PT
- VI - Favourable conditions for the use of PT and the CAR
- VII - Favourable conditions for the use of the CAR
- VIII - Medium accessibility levels
- IX - Low accessibility levels

Figure 4.8: Benchmarking cube and accessibility clusters

The benchmarking cube, including accessibility categories and clusters, is the central element of the SAL. Considering the analysis purpose of this instrument, the benchmarking cube works as a **synthesizing measure** of the conditions given by the land use and transport system for potential mobility to be sustainable. This measure enables the sought development of a geographical representation of land use and transport conditions for mobility, using a single aggregate map.

Besides of the usefulness of the benchmarking cube for the analysis purpose of the SAL it also has the main role in the design support purpose. The benchmarking cube, and its categories and clusters, **serve as a framework for the selection of objectives** for sustainability of potential mobility enabled by land use and transport conditions. This selection is supported by the comparison of the current position and other potential position in the cube (considering levels of comparative accessibility). It provides a support for choice of objectives by defining a concrete and limited number of possible sustainability conditions for mobility, defined by clusters.

Additionally, it also **serves as a framework for policy action choice** necessary to attain desired sustainability levels (defined objectives). This framework is twofold: first, it supports the development of different strategy and policy scenarios to bring about previously defined objectives; and second, it tests the outcomes of the developed scenarios. In the former aspect of the framework for policy action choice, the SAL supports the identification of major land use and transport features requiring action to attain the desired position in the cube. This results from a direct relationship between the change of position in the benchmarking cube and specific variations in mode accessibility. These variations in accessibility by mode can be brought about by a variety of land use and transport policies. Thus, the SAL provides a somewhat objective relationship between sustainability of potential mobility and land use and transport features. This enables the development of strategy and policy scenarios to bring about the required changes in urban structure. In the latter aspect of the framework for policy action choice, policy action scenarios can than be tested on the SAL as to their ability to attain the desired change. The choice of concrete policy action from the variety of measures able to attain desired objectives is based on local political, social and economical constraints. In this stage the SAL works as a measurement instrument, assessing the results of potential policy action.

The intermediate step of strategy and policy development, although following general guidance from the results of the category map, must be based on further information. Guidance provided by the SAL is limited to its scope (land use and transport constraints on sustainable mobility) based on the assumption that, if urban structure condition enabling mobility are not provided, sustainable travel behaviour cannot be brought about. Mobility management must consider a variety of complementary information for policy choice. The range of essential complementary information required for the development of land use and transport measures for mobility management should be locally defined for each case.

> The case-specific choice of complementary information for strategy design: Complementary information must be chosen according to the local context as well as to the general purpose for policy design. Some examples of complementary information are population and employment distribution and density, current land use and transport constraints, current mobility patterns, as well as current socio-economic and political constraints.

It is important to highlight that policy action scenarios are not a direct result of the SAL, neither does the SAL develop strategies itself. Instead, it is reasonable to say that the **SAL works as a framework of thought** for the development of integrated land use and transport policies for mobility management.

The sustainability measure of the SAL culminates in the production of a map synthesizing land use and transport constraints on potential mobility. This map offers an overview of small scale variations of sustainability levels, proving an instrument for the understanding of urban structure conditions for mobility. It is the main outcome of the SAL and its key instrument. It provides the necessary information for the analysis purpose of the SAL and can be used for the design of land use and transport strategies, when complemented by further information for policy choice. New category maps (as well as mode accessibility maps) can be produced to test the effect of policy action on local conditions, working as interactive tools to support policy action choice.

The benchmarking cube works as the final step in the aggregation of data concerning the constraint of land use and transport conditions on the sustainability of potential mobility. The analysis process pursues this purpose of simplification and systematisation of information and detail. Nonetheless, instead of diluting information, the analysis process develops a range of levels of aggregation of information for the study region, producing multiple layers of information with different levels of detail. Inversely the design support process uses these several levels of disaggregation produced during the analysis process for the design of increasingly detailed policy.

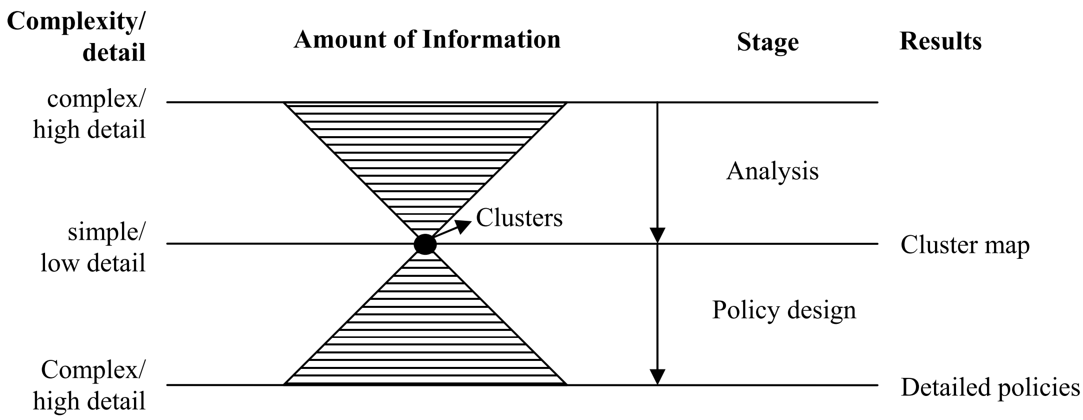


Figure 4.9: Level of detail used during the process

Figure 4.9 illustrates this process of aggregation and disaggregation of data during the use of the SAL. During the analysis process the data is aggregated into clusters (highest level of aggregation) producing a highly visual measure of sustainability of potential mobility. During the policy design process, accessibility clusters provide a very aggregate framework for the development of a general strategy. This strategy is then detailed resorting to higher disaggregation of land use and transport conditions systematised during the analysis process.

Finally, the following scheme presents a summary of the case-specific choices required for the development of the sustainability measure and its use as design support tool.

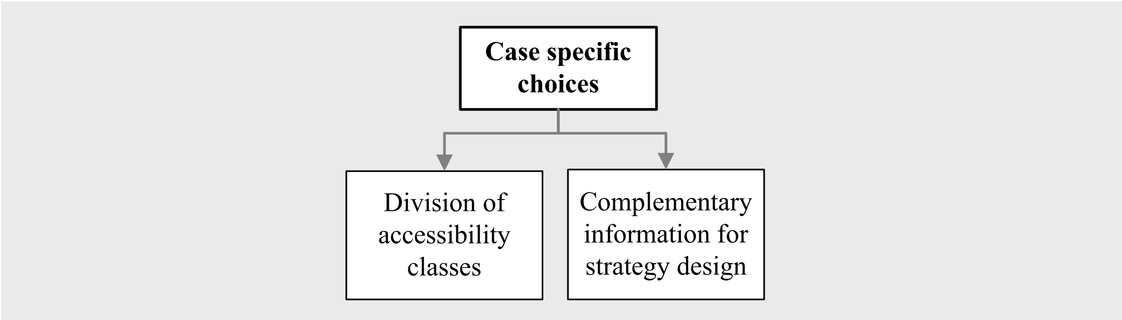


Figure 4.10: Case-specific choices for the sustainability measure

4.3. SAL's stakeholders

It is fundamental to have a clear understanding of the potential stakeholders of the SAL and of their role in the development and use of this instrument for policy design. Considering the regional nature of the measure, there is clearly a need for a regional level authority with effective power and resources for the SAL to be used[26].

In theory local strategies could be defined by each local authority (independent of neighbouring strategies), once analysis maps of the SAL are produced at regional level. Nevertheless, a regional scope for policy action or, at least, a general regional strategy framing local strategy is required. Once regional strategy is defined, small scale strategies can be defined for specific conditions of each municipality in the regional mobility catchment area, and in accordance with the general regional strategy.

Besides of municipalities of the region other potential actors may be involved in the regional or local design process, such as public transport operators, infrastructure providers, urban developers and also the general population. With regard to, for instance, public transport operators, they work as partners for the definition of the general strategy in the regional context, while at the local context they are final user of the SAL and of the regional strategy (using it for the development of their own transport service strategy). Local planners can use the analysis maps of the SAL for every day urban management (for instance when deciding the location of public establishments or traffic management) taking into account the general regional strategy and municipal

[26] The regional level of the SAL is also fundamental with regard to the regional nature of mobility patterns.

strategy. It seems clear that the SAL can be used at several levels of decision making (as a more strategic or immediate approach) involving several actors. The same actors may have different roles at different decision making levels, changing between an active role (influencing the SAL) and a passive role (being influenced by the SAL).

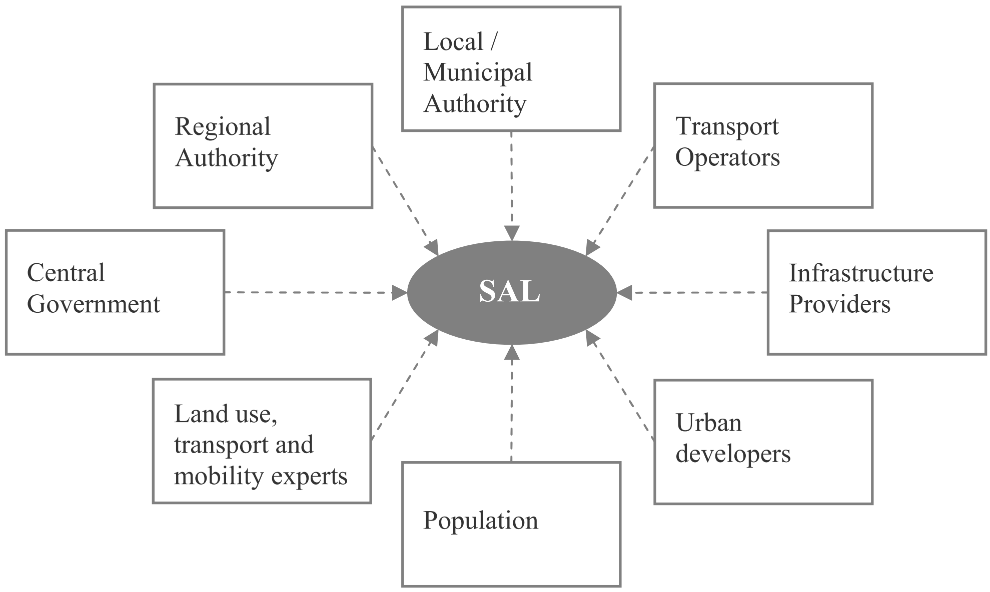


Figure 4.11: Some examples of stakeholders

In this context, the usability of the SAL seems to require some kind of formal regional authority (with effective power and resources) to develop the analysis maps of the SAL and a general regional strategy. This second aspect requires, apart from the regional authority, local will or the existence of integration practice at the institutional level (vertical and horizontal). Furthermore, the resource demanding nature (regarding data, money and time) of the SAL is another argument for its development at regional level. In this context it seems that the use of the SAL by municipalities requires the previous regional application of the instrument.

4.4. Synthesis: theoretical discussion of SAL's potentials and limitations

The SAL, as a design support tool for integrated land use and transport policies, is build upon the following conceptual choices:

- geographical representation of measures;
- regional analysis scope (considering small scale variability);
- use of a simple accessibility measure;
- consider high disaggregation level of the land use and transport conditions;
- use of a single aggregate measure of comparative accessibility;
- and, leave several aspects to be defined for each context of application.

As has been mentioned before, the geographical representation of the results of comparative accessibility is used to enable the essential spatial comparison of accessibility levels. Furthermore it provides a global view of the entire territory in analysis. This measure has the advantage of supplying an image of the variability of land use and transport conditions for mobility to be more or less sustainable.

The SAL is conceptually defined for the regional scale. It is therefore not based on administrative divisions of the territory giving a view of mobility catchment areas. It is at this level that mobility policy must be defined and coped with. This approach enables the spatial integration of mobility policy, besides of the integration of policy sectors (namely land use and transport) for which the SAL has been developed. On the other hand, the choice of the regional scale disables the support of the design of local, street level, actions. As a result, this tool excludes micro scale aspects of mobility such as urban design. Therefore, and in spite of the geographical representation of small scale variations of accessibility levels, the SAL provides a limited local view.

The choice of a simple accessibility measure to baseline the development of the SAL is related to the potential given by these measures with regard to the ease of understanding and communicating the process and its results. As this is considered a requisite for the development of practical design support tools, aspects such as competition effects and accessibility decay with distance were not considered for the conceptual framework of the SAL. Nevertheless, the complexity of the accessibility measure can be enhanced in case the usability of SAL is not jeopardized[27].

[27] In this context even the accessibility measure choice is seen as case-specific.

The high disaggregation of land use and transport conditions (considering activity types and transport service) are used to enable a thorough understanding of local land use and transport constraints for mobility. This is naturally a fundamental feature of the SAL considering its aim to support the design of integrated land use and transport policies. Detail on existing conditions is therefore essential, although the extent of this detail is chosen for each case (and naturally dependent on the concrete objective of use of the SAL). Nevertheless, the choice of the level of disaggregation of land use and transport conditions is limited by the availability of local data (especially considering the high spatial disaggregation required). This is an important limitation of the SAL with regard to the soundness of the tool, threatening local applicability of the measure. The soundness of the SAL is limited not solely regarding its analysis purpose but also, and more importantly, regarding its design support purpose. The level of detail of land use and transport data used for the calibration of the accessibility measure influences the ability of the SAL to test certain policy scenarios. For instance, if parking effort is not considered for the car accessibility measure, the effect of parking management policies can not be tested using the SAL. On the other hand, considering parking effort in car accessibility may require a high detail of data and the use of more complex measures (for instance generalized cost) to calibrate accessibility.

The use of one single (and simple) comparative accessibility measure holds the main advantages of the SAL as both, analysis and design support tool. For the analysis purpose, the use of accessibility clusters provides a synthesizing measure of land use and transport condition for sustainability of potential mobility. The benchmarking cube enables the combination of a variety of information and its analysis in a workable and understandable way. Therefore, the geographical representation of the accessibility categories and clusters potentially provides a good diagnosis tool. For the design support purpose, the benchmarking cube is a potential framework of thought for the development of integrated land use and transport policies. It facilitates the definition of objectives for sustainability of potential mobility and serves as a framework for policy action choice in order to attain desired sustainability levels. Nevertheless, the ability to test action scenarios is limited by the detail used in the accessibility measure.

The choice to leave several aspects to be defined for each context of application was made in order to give the SAL a high level of adaptability to local conditions, which is essential for any policy design support tool as well as any accessibility measure. Nevertheless, additionally to other limitations related to local choice presented before, the amount of choices required for the calibration of the SAL, as well as the potential controversy around these choices may limit the usability of the SAL. Lack of agreement around choices may hinder its application while disagreement with choices made during the calibration of the SAL may limit its use as a design support tool for mobility policy.

Figure 4.12 summarises the main theoretical potentials and limitations of the SAL.

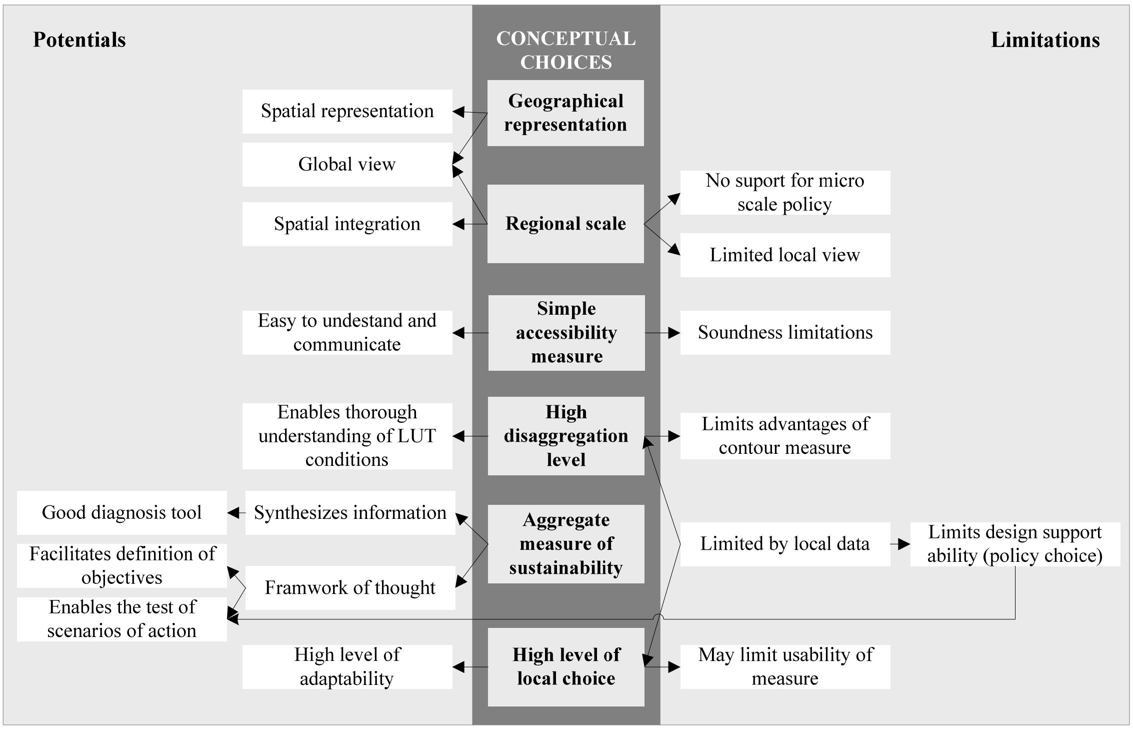


Figure 4.12: Potentials and limitations of the SAL

Chapter 5

TESTBED

This chapter presents the testbed developed for the assessment of the research hypothesis defined in chapter 1. The testbed comprises the case study application of a comparative accessibility-based design support tool – the SAL – and expert interviews evaluating that application. The case study provides insight into the ease of translation of the theoretical concept into a practical tool, supplying an overview of practical implications. Expert interviews enable the assessment of the robustness, usefulness and usability of the tool. This testbed provides the necessary approach for the assessment of the potential of the SAL, and therefore of comparative accessibility measures, as design support tools for integrated land use and transport policies. Furthermore, it provides a case-specific insight which enables the refining of the conceptual framework of the tool.

The chapter starts with the presentation of the study region justifying its choice and relevance for the purpose in hand. The following section (section 5.2) presents the case-specific SAL, identifying the list of choices involved in its development. Section 5.3 develops the test of the SAL, presenting the results of its application to the study region. This section illustrates the abilities of the tool and provides feedback for the use of comparative accessibility measures (discussed in the following chapter). It starts by analysing current mobility conditions provided by the local land use and transport system. The section continues with the development of a policy strategy based on the analysis results (intended as an illustration of the potentials and limitations of the SAL as a design support tool). Finally, the section discusses data-related limitations of the case-specific SAL. Section 5.4 presents results of the assessment of robustness, usefulness and usability of the tool by experts on local mobility patterns as well as land use, transport and mobility management.

5.1. The case study region

The region chosen for this case study comprises the core municipalities of the metropolitan area of Oporto (see Figure 5.1), which could be called Greater Oporto (GO). This region is located in the north-west of Portugal, encompassing the municipalities of Gondomar, Maia, Matosinhos, Oporto, Valongo and Vila Nova de Gaia, in an area of about 560 km^2 (around 70% of the metropolitan area). In this region live almost 1.1 million people (representing 90% of metropolitan population) with a workforce of around 500 thousand people.

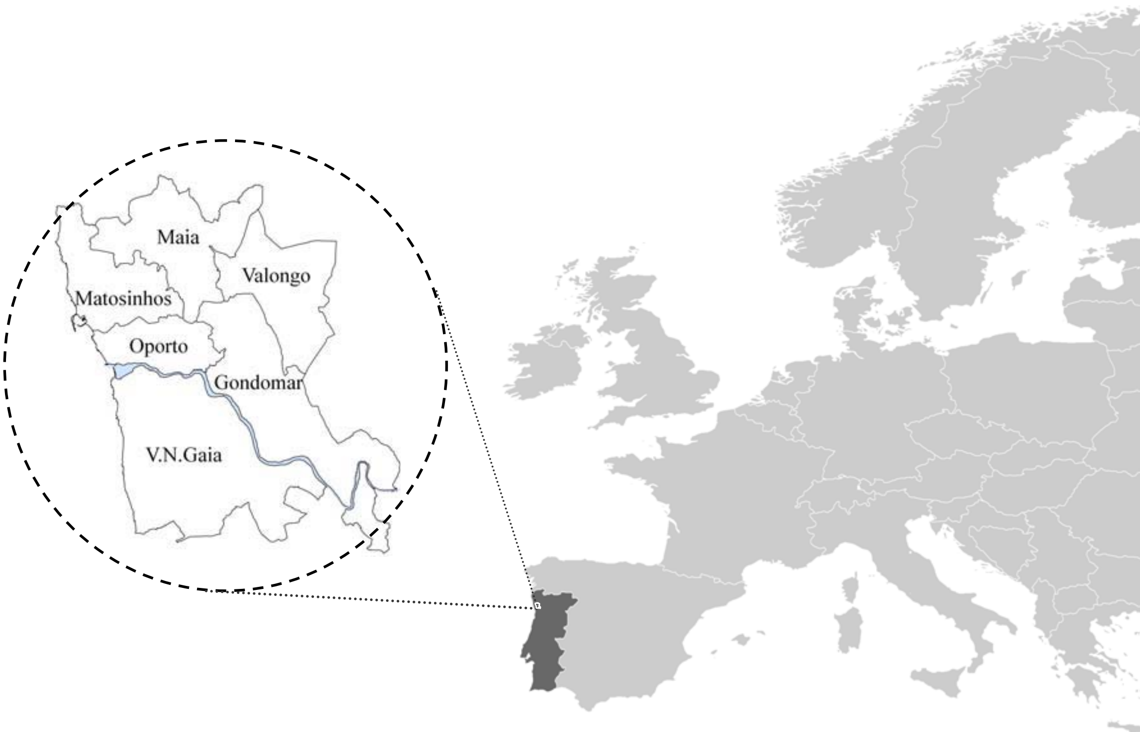
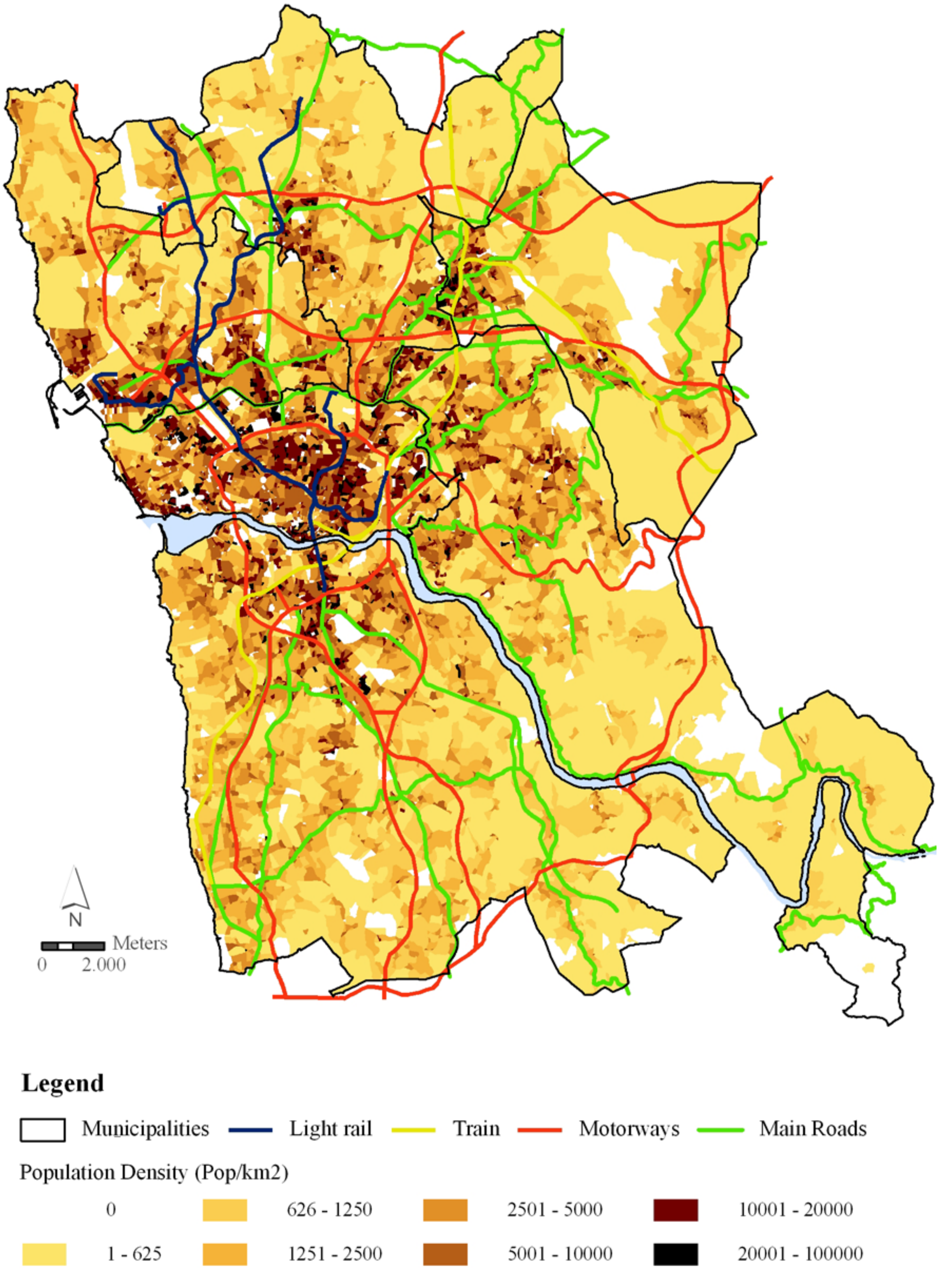
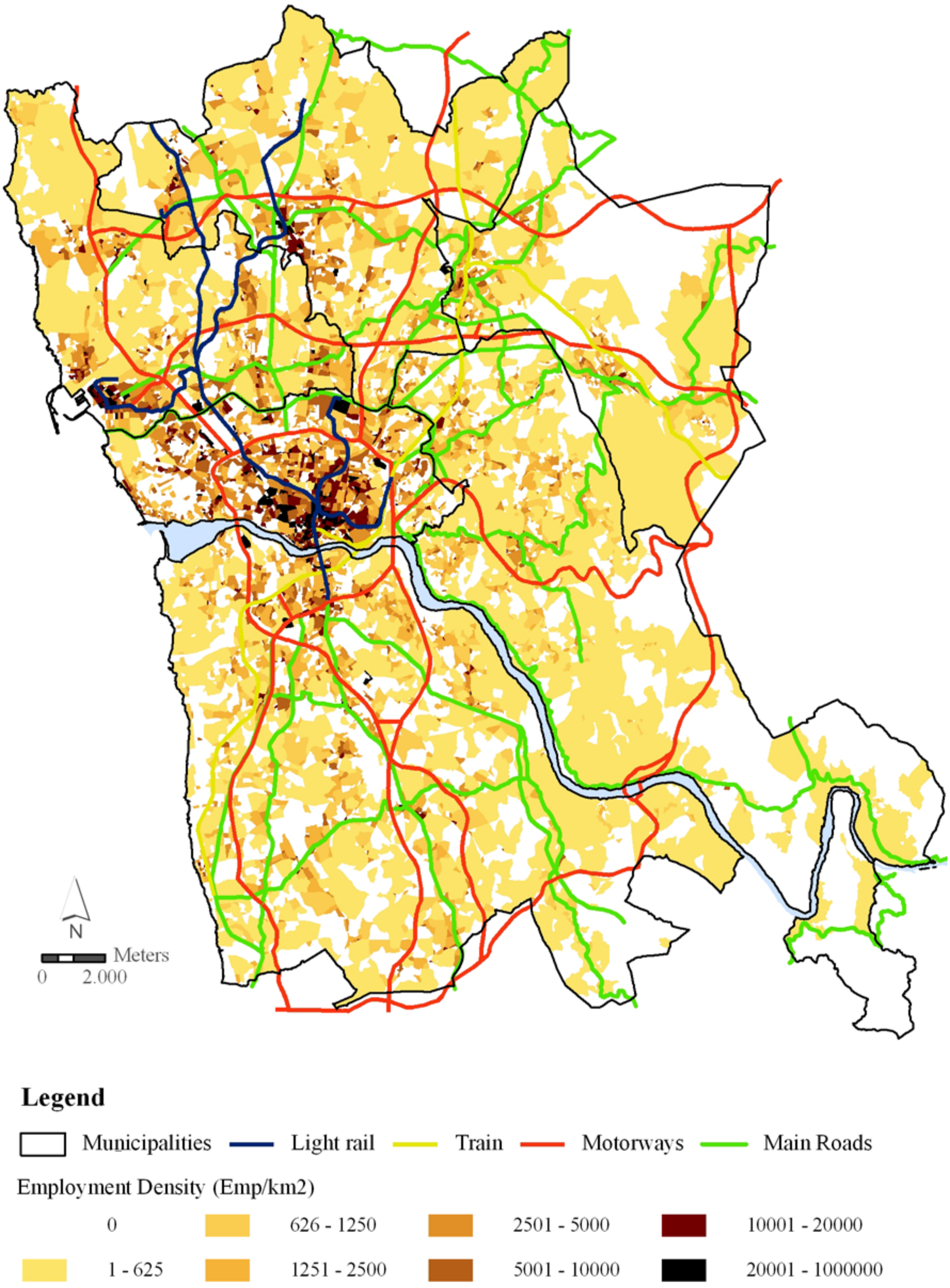


Figure 5.1: Europe / Portugal / GO / Municipalities



Data Source: INE (2001)

Figure 5.2: Population Density (by square kilometre)



Data Source: DGAP(1999) and DGEEP(2004)

Figure 5.3: Employment Density (by square kilometre)

GO reveals high population and employment densities (see Figure 5.2 and Figure 5.3[28]) in the central area of the core municipality (an area framed by the internal ring-road motorway and the river). Employment is clearly more centralized in this area than population, which in the last decades has been spreading outwards along the main road transport corridors. This phenomena is not that visible for employment density but has also had its effect on the employment layout of the study area. Population of GO is more densely concentrated in the municipality of Oporto and in a land strip surrounding this municipality. Other agglomerations, somehow detached from the main population centre, can also be found. Asymmetries in employment geography are considerably stronger. The central area of Oporto is clearly dominant, although several other areas with high employment densities can be found scattered across the study region.

The transport system of the region has suffered important changes in recent years. The last two decades have been marked by the construction of several motorways, considerably reducing time-distance between places. In general, it is fair to say that the case study region has a high road density, which intensifies towards the centre (see Figure 5.4). The motorway structure is based on two ring-roads and several radial systems. This structure is also visible for the remaining main roads of the region. Growing car use rates have brought about congestion which is mainly felt during peak-hour inside the central ring-road motorway as well as on this motorway and its main radial access motorways.

Public transport service has also suffered several changes in the last few years, with the introduction of the light-rail system (in 2002). A network service has replaced the established door-to-door service (including, for instance, pricing integration and network redesign), mainly among the public transport operators. The reach of the light-rail and train system is limited to the central area of the Oporto city and to a few radial corridors departing from this central area (see Figure 5.4). The network oriented strategy linked to public operators is mainly found in the central municipality and to the north of Oporto. The remaining study region is mainly served by private operators following the traditional door-to-door strategy (around 50 different operators).

[28] All full page maps are presented at the scale of 1:200.000.

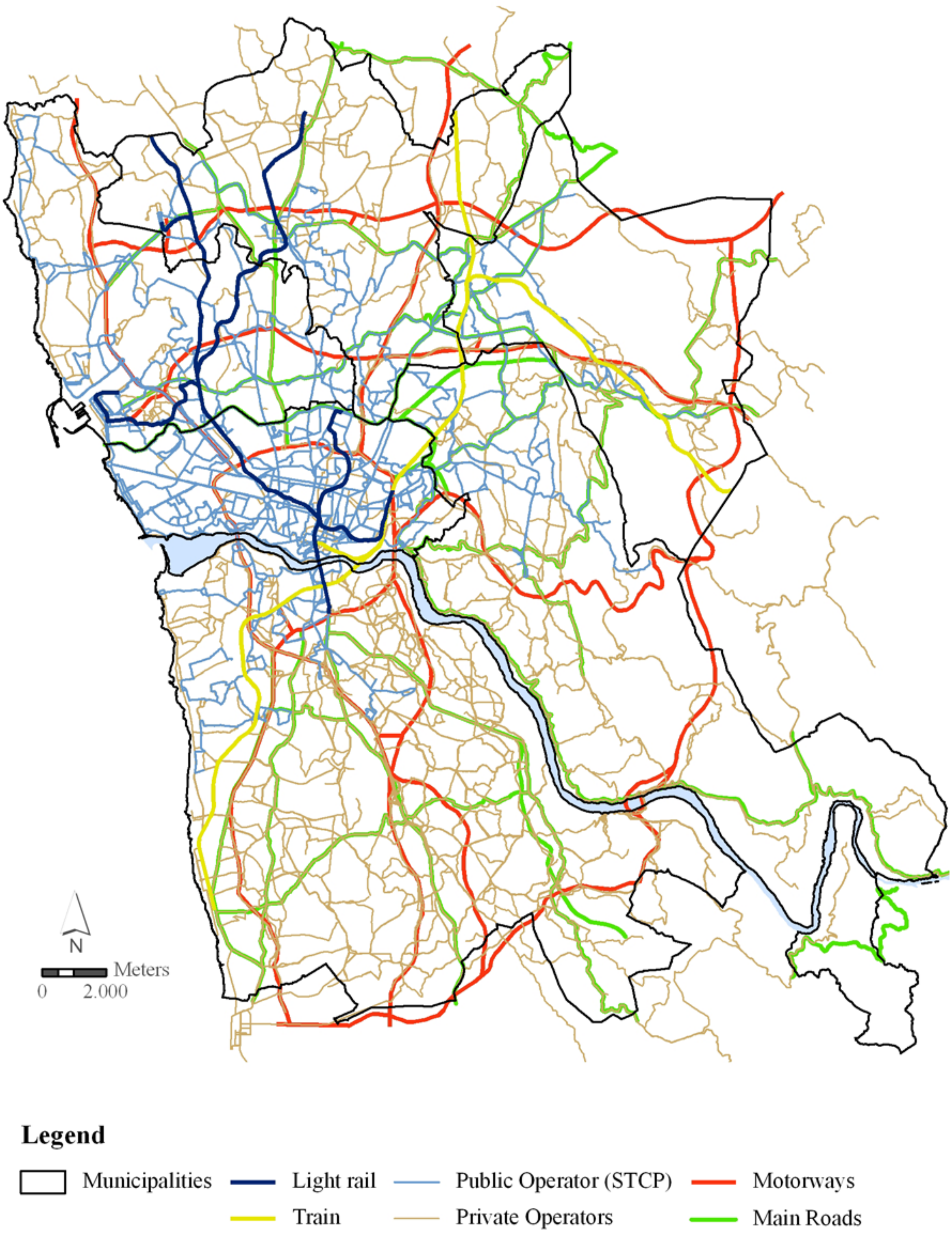
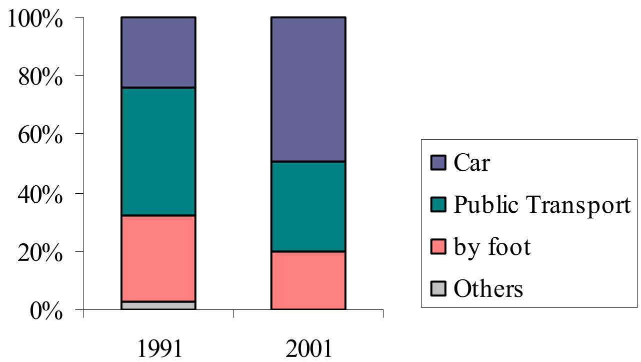


Figure 5.4: Road Infrastructure and Public Transport routes of the GO

The current land use and transport conditions hold responsibility (jointly with aspects such as, socio-economic and cultural constraints) on the car use dependency of the study region. More than half of the trips engaged by its inhabitants are made by car, while public transport is used for less than 1/5th of the trips. Less than a quarter of the trips are pursued by foot (INE, 2000). In one decade public transport has largely been replaced by the car for the satisfaction of work and school travel needs (see Figure 5.5). According to a report from the City Council of Oporto (CMP, 2003), since pedestrian infrastructure offer poor condition for walking and urban structure does generally not provide activities at walking distances, the still high level of travel by foot reflects the low efficiency of public transport service.



Data Source: INE (1991) and INE (2001)

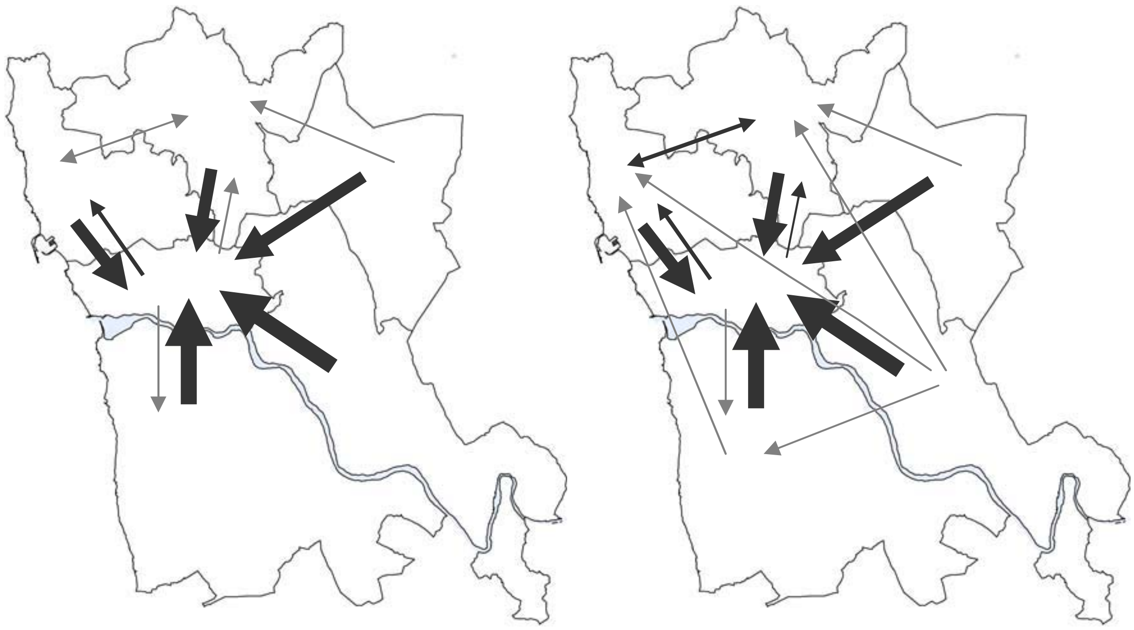
Figure 5.5: Modal split for the main modes of the GO in 1991 and 2001 (considering only work and school trips)

Travel time has evolved differently for different transport modes, although in average it is increasing. While travel time by car and public transport is increasing, travel time by foot is dropping in the GO. A survey in the year 2000 shows an average of 14, 24 and 35 minutes of travel time by foot, by car and by public transport (INE, 2000).

Figure 5.6 shows the main inter-municipal travel patterns with regard to work and school related activities in 1991 and 2001[29]. A strong interaction between Oporto and the surrounding municipalities is visible in the last decades. Nevertheless, travel is becoming more complex. This is a result of changing land use patterns, with population dispersion occurring at a much higher rate than employment decentralization.

[29] Although not presented in Figure 5.6, mobility within each municipality is still the most important travel pattern for all municipalities.

Furthermore, complexity of travel is a result of strong road infrastructure development and car based mobility, enabling the referred land use phenomena. It is clear that mobility patterns have been growing in complexity, while at the same time, travel time and distance has also been growing (Cardoso and Silva, 1997), resulting from the car oriented development of the last decades. Besides of the strong polarizing effect of Oporto (which slightly decreased in the last decade), mobility patterns between surrounding municipalities are becoming significant, especially between Matosinhos and Maia.



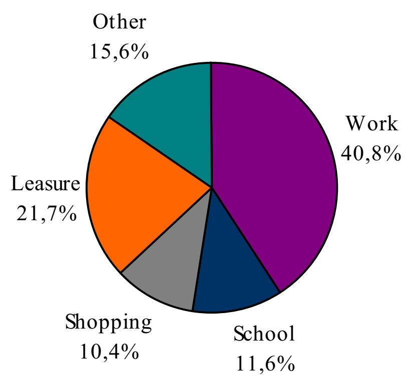
Source: INE (1991) Source: INE (2001)

Legend: Number of trips for work and school trip purposes (per day)

3.000 - 5.000 5.000 - 10.000 10.000 - 25.000 >25.000

Figure 5.6: Interdependency of municipalities

The large majority (more than 80%) of trips in the GO are internal trips, i.e. have origin and destination in the municipalities of the GO. With regard to trip purpose, work trips are clearly dominant in the GO, although these represent less than half of travel of the study region (see Figure 5.7). Other relevant activities for travel generation are leisure, school and shopping activities. Complexity of travel behaviour is also visible in the high importance of other trip purposes (more than 15%).



Source: INE (2000)

Figure 5.7: Distribution of trip purpose

There is an increasing lack of sustainability of travel behaviour in the metropolitan area of Oporto. This phenomenon has several interrelated origins such as, the increase of distance between households and activities (related to land use and transport phenomena and the vicious cycle of car use), as well as the increasing complexity of travel needs (related to the increase of income and quality of life standards) and the high car dependency (related to pour public transport service but also to social status). In this context, this metropolitan area provides an interesting case study to test the SAL, being clearly a region in need of an integrated land use and transport action to manage travel demand.

In the metropolitan area the GO clearly stands out due to its strong interrelations, creating complex travel behaviour at a supra-municipal level. These municipalities build up an urban continuum strongly bound together by travel (presenting the lowest level of intra-municipal travel of the northern region). With more than 80% of travel in the GO being internal (by origin and destination), it is fair to assume that conditions for travel behaviour can be studied in isolation of the surrounding region. This is a fundamental aspect for the choice of the GO as the case study to test the SAL.

Traditionally policy actions concerning mobility have been mainly concentrated on road development and, from the last decade on, advanced to the management of the existing infrastructure as a complementary action of road building. Strategy on mobility management has been almost exclusively car oriented.

Current mobility strategy rhetoric has, however reflected a new orientation, recognising the importance of alternative transport modes and of the need to integrate land use planning. Nevertheless, it could be argued that car oriented development is still the forward prescription for all urban development actions. Once more, there is a lack of translation of rhetoric into practice. In this context, the SAL finds an interesting environment to test its potential as a design support tool.

5.2. The case-specific SAL

As defined in section 4.2, the choices required for the definition of the case-specific SAL are the following:

- the study region;
- the spatial disaggregation level;
- the disaggregation of activities;
- the potential frequency of use of activities - f_y;
- the cut-off criteria and values;
- the division of accessibility classes;
- and, the complementary information for policy design.

The first five aspects close the definition of the case-specific accessibility measure, while the sixth aspect provides the case-specific boundaries for the sustainability measure. The last aspect, in combination with the latter, is essential for the design support purpose of the SAL.

As defined in the previous section, the study region defined for this case study was the Greater Oporto[30]. GO presents manly internal travel patterns as well as strong interdependencies of its municipalities. It is therefore a good example of a mobility catchment area, as required by the SAL. Furthermore the interest of the case study lies

[30] It could be argued that sub-regions near the limit of the study area will present artificially reduced accessibility values due to the artificial boundary limiting the study area. Nevertheless, considering that current behaviour presents a low rate of travel to municipalities outside the GO (about 6% of total internal, exit and entrance travel of the GO), artificial reduction may be a good representation of reality.

on the lack of sustainability of current mobility patterns, which have strongly deteriorated over the last decade.

For this case study, spatial disaggregation was taken to the census track level. This choice followed standard recommendations defined for the SAL (see section 4.2.1). The use of census track spatial disaggregation implies the division of the study region into areas enclosing similar ranges of population. This seems to be an interesting spatial disaggregation criterion for the SAL (considering population-based instead of area-based measures) since measures used are concerned with land use and transport conditions given to people for their mobility to be more sustainable. The use of the census track level for the GO case study region involves sub-regions with areas ranging from 125m^2 to 6km^2, with an average of 0,06km^2. Larger sub-regions (with areas exceeding 1km^2) are rare resulting from areas with very low population density, therefore having a low constraint on the soundness of the SAL.

With regard to disaggregation of activities for this case study, 18 activity types were considered to have the most relevant influence on travel generation. These activity types are presented in Table 5.1 regarding mainly work and school activities, leisure, shopping and healthcare activities as well as other activities including main public and private services[31].

This table also presents the potential frequency of use of activities f_y considered in the measurement of the diversity of activity index. This correction factor was based on real local travel behaviour, namely on the distribution of trips by travel reason. According to the National Institute of Statistics (INE, 2000; see Figure 5.7) trips of the GO population were mainly related to work activities (41%). The remaining trips were divided into the following travel reasons: school (12%), shopping (10%) and leisure (22%). There is an evident importance of non-work and non-school related activities in this study area. Furthermore, a variety of other travel reasons, besides of work, school, shopping and leisure, are relevant in travel generation, representing approximately 15% of all trips. In order to define the values of the potential frequency of use of activities

[31] Information regarding the activities considered in each activity type as well as the disaggregation of statistical data (number of activities and employment) to census track level is presented in section A.1 and A.2 of Annex A.

(f_y), the distribution of trips by travel reason were disaggregated according to activity types considered to be included in each travel reason[32].

Table 5.1: Activity types considered[33]

	Activity type (y)	f_y
Schools:		
• Infant School and Elementary school	1	4
• High school	2	5
• University	3	3
Leisure/Entertainment:		
• Parks, public gardens, squares	4	8
• Restaurants	5	2
• Cinema	6	2
• Shows / Theatre	7	1
• Sport	8	8
• Others (ex: Museums, Libraries, Night clubs, etc)	9	1
Shopping:		
• Food	10	8
• Others	11	2
Healthcare		
• Pharmacies	12	2
• Hospitals and Clinics	13	2
Other Activities		
• Public/Municipal administration offices	14	2
• Postal Office	15	2
• Banks	16	5
• Others (ex: Insurance, Lawyers, Architects, financial advisers, etc)	17	2
Employment		
• Employment	18	41
Total		100

The transport modes considered for each transport mode type are walking for non-motorized modes, public and private collective transport (including road and rail) for public transport modes and the private car for car transport modes. Among non-

[32] For detail on distribution by activity types of the percentage of trips by travel reason, see section A.3 of Annex A.
[33] For a geographical representation of diversity of activity present in each sub-region see Figure B.1 of Annex B. For a geographical representation of each activity present in each sub-region per activity type see Figure B.2 to Figure B.18 of Annex B.

motorized modes other modes such as bicycles were not considered since local data on road slope were not available. Topography is generally considered as one of the main limitations to cycling in the GO. This data constraint considerably limits the soundness of the accessibility measure for the bicycle in this case study since GO is highly declivous. In these conditions, the bicycle was excluded from the analysis of non-motorized modes for this case study. From public transport were considered all routes of the public road transport (STCP), public light-rail (METRO) and public train (CP) operator as well as some routes of the private road transport operators[34].

Table 5.2: Total travel time cut-off values

	NM	PT	CAR
Total travel time cut-off value (min)	20	45	30

With regard to cut-off criteria, all three transport mode types use the criterion of total travel time (see Table 5.2). These values were chosen based on the real average travel time by transport mode measured in 2000 (INE, 2000). This study identified an average of 14, 24 and 35 minutes for walking, car use and public transport use for the study region (see section 5.1). It seems reasonable that admissible travel time is higher than real average travel time. Based on this fact and on personal awareness, values in Table 5.2 were estimated to be slightly higher than real average travel time[35]. For the definition of the boundaries of accessibility by public transport, further detail was used, besides of total travel time. For this transport mode, accessibility boundaries were also considered to be dependent of: walking time at entrance and exit of public transport system; the number of acceptable interchanges; the acceptable increase of travel cost with interchange; the acceptable walking distance at interchange; the acceptable waiting

[34] Among private road transport routes only 90 of approximately 250 existing private routes were considered due to lack of availability of GIS-based layout for the remaining routes.

[35] Considering the lack of data on the time limit for personal perception of accessibility by each transport mode, the natural time and budget constraints of a PhD research and the exclusive illustrative purpose of the application of the SAL to GO, it seemed acceptable to use personal awareness fine-tuned by experts on local mobility for the definition of the cut-off values. A real case application would require further research for the definition of these cut-off values, resorting to, for instance, stated preference surveys or at least to sensitivity analysis. Both, sensitivity analysis and stated preference surveys were discarded due to time and budget constraints. In case of sensitivity analysis, it is relevant to register that the production of basic mode accessibility results for the study region took 6 month alone to be processed, due to budget restraints, considerably hindering sensitivity analysis within these conditions.

time at interchange; and, the total time from entrance to exit of the public transport system[36];.

Table 5.3: Cut-off criteria and values for the public transport

Cut-off criteria	Value
Total travel time	45min
Total time from entrance to exit of the public transport system	30min
Walking time at entrance and exit of public transport system	5min + 5 min
Number of interchanges	2
Increase of travel cost with interchange	0€
Walking distance at interchange	100m
Waiting time at interchange	5min

Total travel time is composed of the total time from entrance to exit of the public transport system (30min), of walking time at entrance and exit of public transport system (5+5min)[37] and of an average of 5 min waiting time at entrance of the public transport system[38]. The total time from entrance to exit of the public transport system includes the in-vehicle time as well as potential interchange waiting and walking time (5+1min for each interchange). Interchange was only allowed to routes presenting

[36] This limit was introduced due to GIS software limitations (*network analyst* of the ArcGIS 9.2), not being able to perform multi-criteria accessibility analysis. This led to the use of a combination of instruments in a complex sequence. In order to reduce complexity, the entrance and exit of the public transport system was simplified as the approximate 400m radius around public transport stops. Therefore, instead of using the general criteria of maximum 45min travel time, a 30min travel time limit from entrance to exit of public transport system was used (excluding 15min for access and exit distance and waiting time).

[37] Considering the generally used criteria for the catchment area of public transport stops of 400m, and an average walking speed of 5km/h, it is reasonable to presume access and exit walking time to be around 5min.

[38] An average waiting time was considered for all public transport service instead of a waiting time of half the headway for each route because of required simplifications of the public transport accessibility problems due to limitations of the GIS technology used (*network analyst* of the ArcGIS 9.2). It seems reasonable to use 5min for average waiting time, considering both headway based routes and timetable based routes. In the first case because the majority of routes have headways of 10min or less and in the second case because with timetable based routes people are expected, in average, to arrive 5 min earlier.

maximum headways of 10min[39] in order to grant an average maximum waiting time of 5min at interchange[40]. Additionally interchange was only allowed between routes of public and private operators using the new integrated travel ticket (called 'andante', which is the general travel ticket of the light-rail system) assuming that any increase in travel price would be considered unacceptable[41].

The definition of boundaries of the accessibility measure for each transport mode requires also the calibration of the transport network. For non-motorized transport modes (walking) road infra-structure were considered (excluding roads without pedestrian access such as motorways and expressways) in addition to pedestrian streets[42]. In absence of detailed walking conditions accessibility was calibrated for an average walking speed of 5km/h (based on the average value proposed by EC, 2000; 20).

The calibration of the public transport network was based on the layout of the routes of private and public, and road and rail operators, in addition to the layout of public transport access nodes and interchange walking facilities (pedestrian accessible road network around stations[43] and purpose build access corridors to underground access nodes). These layouts were integrated in order to work as one single network enabling interchange between different collective transport routes, resorting, or not to interchange walking facilities. The calibration of the accessibility limits were based on: values of average speed for each route and for walking facilities (see Table 5.4), information on the number of performed interchanges along the network (limited to a maximum of 2), information identifying interchangeable routes (only allowing interchange to routes with headway lower than 10min) and information identifying

[39] Exception was made for interchange to the light-rail and train system. In case of the light-rail, people were expected to render as acceptable higher interchange waiting times than 5min. In case of the train, people were expected to know the timetable of the train service and therefore choose the public transport access service most suitable for interchange.

[40] In accordance with the value found by Silva (2004) as limiting the acceptability of interchange in public transport service (for the STCP network).

[41] Also based on the conclusions of Silva (2004).

[42] This is based on the consideration that all road infra-structure with pedestrian access provide acceptable conditions for walking. Presence of sidewalks as well as slope was not considered for walking conditions due to absence of detailed data. This was considered as a valid simplification for the analysis of walking conditions.

[43] In this case a radius of 60m of pedestrian accessible road infra-structure was left around each public transport access node to enable an average distance of 100m for on-street interchange.

routes using the integrated tariff system (hindering interchange between routes not using the ‘andante’).

Table 5.4: Average speed used for each operator and route

Operator	Average Speed
STCP	Average speed per route as estimated by STCP on online timetables (February, 2007)
CP	Average speed per route as estimated by CP on online timetables (February, 2007)
METRO	Average speed of network as estimated by METRO online, (February 2007) used for all routes – 29km/h
Private Operators	Average speed of public road service (as estimated in STCP 2007) used for all routes – approximately 15km/h[44]
Walking facilities	5km/h (the same as the average for walking)

The calibration of the car network was based on the layout of road infrastructure as well as information on direction and intersections between routes. In addition, roads were divided into those with direct access from parking and those without[45]. For the calibration of accessibility limits average travel speed was estimated for two different levels of congestion and for two road types (see Table 5.5)[46].

Table 5.5: Average driving speed (km/h)

	Congested	Not congested
Without direct access	40	80
With direct access	15	25

[44] Due to the absence of data on travel speed for private operators, speed was considered to be approximately the same as that of the public operator (STCP) for the same path. Having no data of speed by path, the average speed of STCP service for 2006 was used.
[45] Motorways and expressways were considered to be not directly accessible from home or activities, with access made through other roads which can be access directly from parking.
[46] For further detail on estimates for driving speed, as well as on road type and congestion limits see section A.4 of Annex A.

This summarises all case-specific choices for the accessibility measure. The choices made for the specification of the sustainability measure include the definition of accessibility classes and of complementary information. Accessibility classes were defined for the following values of diversity of activity index ranging from 0 to 0.5 for class C (low accessibility), from 0.5 to 0.85 for class B (medium accessibility) and from 0.85 to 1 for class A (high accessibility).

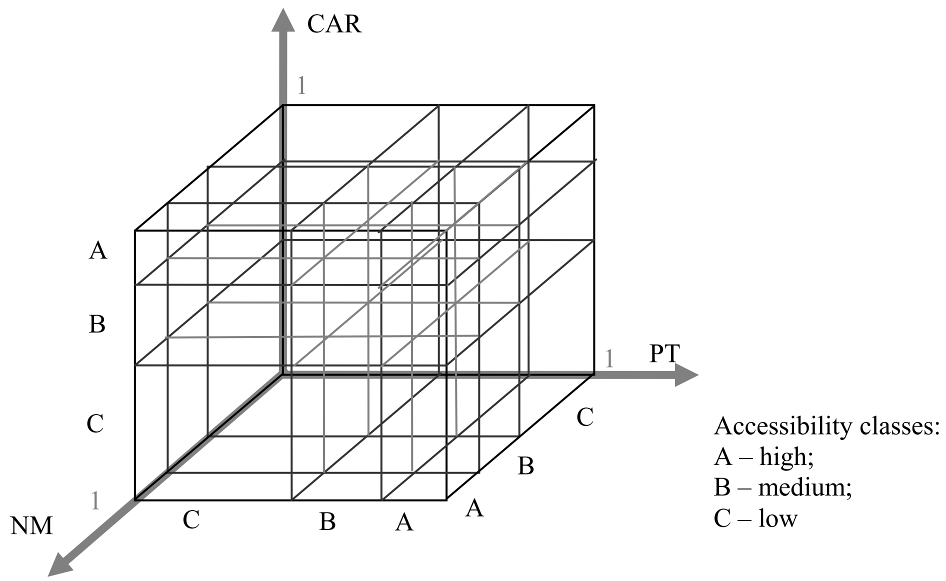


Figure 5.8: Case-specific benchmarking cube

The choice of the two values working as threshold of the three classes (0.5 and 0.85) was based on the case-specific diversity of activity index (activity types chosen and the potential frequency of use of each activity type). Furthermore, the dispersion of sub-regional results in the accessibility cube was also taken into consideration. Following the recommendation stating that the accessibility class A, should be as narrow as possible, its lower limit was defined for a diversity of activities index of 0.85. This value was defined based on the cumulative value of the potential frequency of use of each activity type not considered to be necessary at local level (walking distance), namely activity types 3, 5, 6, 7, 9, 11, 15 and 17. These define 15% of activities (considering the potential frequency of use) and thereby limit the accessibility class A to 0.85. The value of diversity of activity index of 0.5 was found to be an acceptable upper limit for low accessibility levels. This choice was based on the importance of employment for travel generation (41%). For this case the absence of employment and of a few other activities was considered to define low accessibility. In accordance the absence of activities accomplishing the same diversity of accessibility index (which implies a large amount of activity types) would also represent low accessibility. In this context, 0.5 was considered to be a reasonable value for this limit.

Division of accessibility classes provides the final decision for the development of the case-specific SAL. This enables the development of the accessibility levels maps by transport mode as well as the synthesising category and cluster map. The use of the SAL as design support tool, however, requires further, complementary information. Land use and transport decisions for mobility management must be developed in a wider context of local strategies for urban development. Being a decision of the utmost importance it is also a strategic decision which should be framed within a political and technical perspective. Being made outside the local authority environment, a thorough understanding of local objectives and constraints is essential. In this context it is clear that choices made for the case-specific complementary information are clearly limited. Nevertheless, as the application of the SAL, as design support tool, for the case study simply aims to illustrate its capabilities[47], it seems reasonable to limit complementary information to a minimum, for strategy development. The following aspects were chosen to complement the information provided by the main result of the SAL:

- population density (by sub-region);
- real travel patterns;
- detailed value of diversity of activity index by transport mode (by sub-region);
- and, detail on activities accessible by each transport mode (by sub-region).

5.3. Results of the application of the SAL

5.3.1. Analysis of current conditions for mobility

The use of the SAL for the analysis of current land use and transport conditions for mobility produced two main results. First, the values of diversity of activities accessible

[47] Recalling that this case study works as an illustration of the abilities of the SAL, as well as a framework for the study of the potential and limitations of the use of this conceptual framework,

by each transport mode and second the comparative accessibility index (for each sub-region as well as an average regional value). The diversity of activities accessible by each transport mode is presented in the following three figures.

Figure 5.9 presents the geographical distribution of accessibility levels as well as of accessibility classes by non-motorized modes. A first analysis of the map shows almost no area with low accessibility levels (class C) and a more or less even distribution of high and medium accessibility levels (see Table 5.6). Nevertheless, analysing the amount of population subject to the conditions of accessibility the scenario changes a little. The large majority of the population of the study region (78%) lives in good accessibility conditions by non-motorized modes, while less than 22% live in medium accessibility conditions. In average the study region provides high accessibility conditions by non-motorized modes with a regional value of diversity of activity index higher than 0.9.

Table 5.6: Accessibility classes for each transport mode by area and by population

	Analysis by Area (% of 563km^2)			Analysis by Population (% of 1.089.118 inhabitants)		
	NM	PT	CAR	NM	PT	CAR
A	43,5%	47,8%	100,0%	77,6%	83,4%	100,0%
DivAct=1	*7,3%*	*31,3%*	*86,5%*	*25,2%*	*71,2%*	*98,1%*
B	48,6%	4,0%	0,0%	21,3%	1,7%	0,0%
C	7,9%	48,2%	0,0%	1,1%	15,0%	0,0%
DivAct=0	*0,0%*	*48,2%*	*0,0%*	*0,0%*	*15,0%*	*0,0%*

Good accessibility conditions can be mainly found in Oporto and several corridors stretching from this municipality north and east. To the south good accessibility conditions are more scattered with a larger continuum is found stretching from Oporto to the northern part of the municipality of Vila Nova de Gaia.

The diversity of activity index by non-motorized modes provides a clear picture of the urban centres' structure of the study region. Urban centres of different levels are clearly highlighted by the geographical representation of this indicator. This outline of the main urban centres seems to be strongly related to traditional urban agglomerations along the main national road network (excluding motorways). While to the north these agglomerations are closer together forming urban corridors instead of centres, urban development has been more disperse to the south enabling a clear recognition of boundaries of each urban centre.

The best accessibility conditions (with accessibility to all activity types by foot) are presented in an area stretching from the municipality of Oporto north to the city centre of Matosinhos and south to the city centre of Vila Nova de Gaia. One quarter of the population of the study region lives in this privileged area (representing only 7% of the study region), were all activity types are accessible by foot and in theory all main daily activities could be pursued within the neighbourhood.

Sub-regions with diversity of activity index within 0.9 and 1 are generally lacking activity types 3, 6 and 7, referring to graduate schools, cinemas and theatres. In some cases other activity types, such as, parks or public gardens (4), postal offices (15) or sport facilities (8) are also missing. Although these areas still give good conditions for the use of non-motorized modes for most daily activities they force their inhabitants to choose other less sustainable modes to reach some activities (although, with the exception of sport facilities, these have generally low frequency of use).

Remaining class A accessibility level areas (NMDivAct=]0.85;0.9]) mainly lack the same activity types as those areas with accessibility level within 0.9 and 1, combining the absence of several of the mentioned activities at once.

Less than 22% of the population of the study area lives in areas presenting medium accessibility levels, being unable to walk to several every-day activities. The only activity types with nearly guaranteed availability at short distance are infant and elementary schools (1), restaurants and cafés (5) and shopping activities (10 and 11). Activity types missing in more than half of sub-regions of this accessibility class are high schools and graduate schools (2 and 3) as well as cinemas (6) theatres (7) and sport facilities (8).

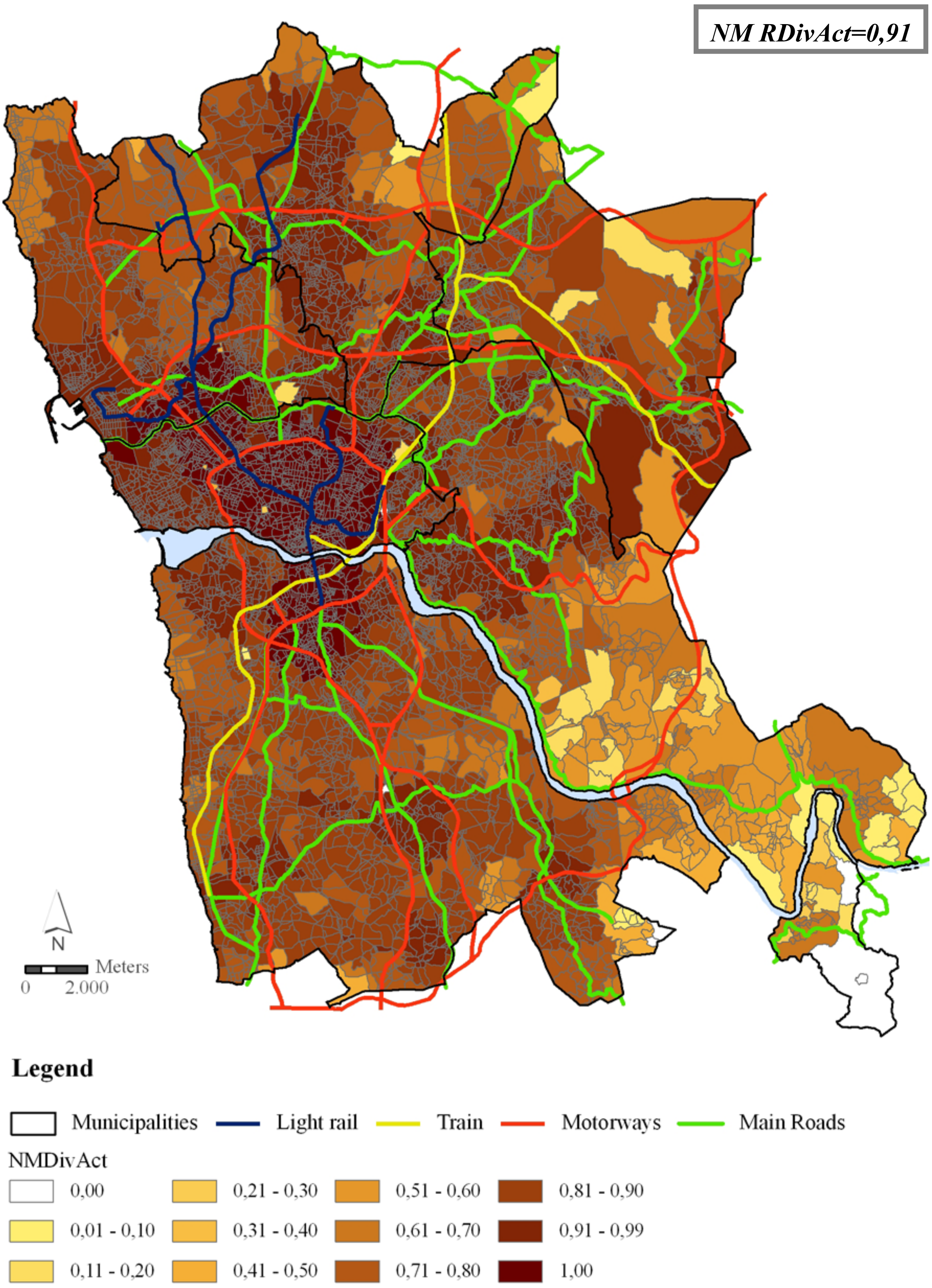


Figure 5.9: Diversity of Activities Accessible by non-motorized modes and by Classes

The remaining 1% of population living in conditions of low non-motorized accessibility is scattered on an area representing 8% of the study region. This area includes sub-regions without access to employment (18) as well as to many of the other activity types. The activity type most frequently found to be accessible by these sub-regions (even so in less then 80% of the sub-regions) is that of infant and elementary schools (1).

Figure 5.10 presents the geographical distribution of accessibility levels as well as of accessibility classes by public transport modes (including public and private operators[48]). This measure clearly marks the spatial distribution of public transport availability, with almost half of the study region area having no access to public transport service. Although a very large area has no access to public transport service, this area only holds 15% of the overall population., The vast majority of the remaining 85% of the population lives in areas with high levels of accessibility to diversity of activities by public transport (83%). 71% live in conditions of maximum accessibility to activities by public transport. Only 2% of the population lives in medium accessibility conditions by public transport in 4% of the study area. In average the region presents an accessibility index of 0.84 (accessibility class B but very close to class A).

For the public transport the diversity of activity index gives us a representation of spatial distribution of public transport network as well as of public transport service level and activity density around public transport access points.

Public transport operators generally follow objectives of profit maximization resulting in routes along both high population and activity densities. Therefore it is only natural that most population has access to public transport and that accessibility levels in these areas are high.

[48] Recalling that in the this study only 1/3rd of the routes of Private Operators due to unavailability of data, the results underestimates the service level of the public transport system, especially for the southern municipalities (Vila Nova de Gaia and Gondomar), were the public operator (STCP) does not reach and were public transport is delivered solely by private operators.

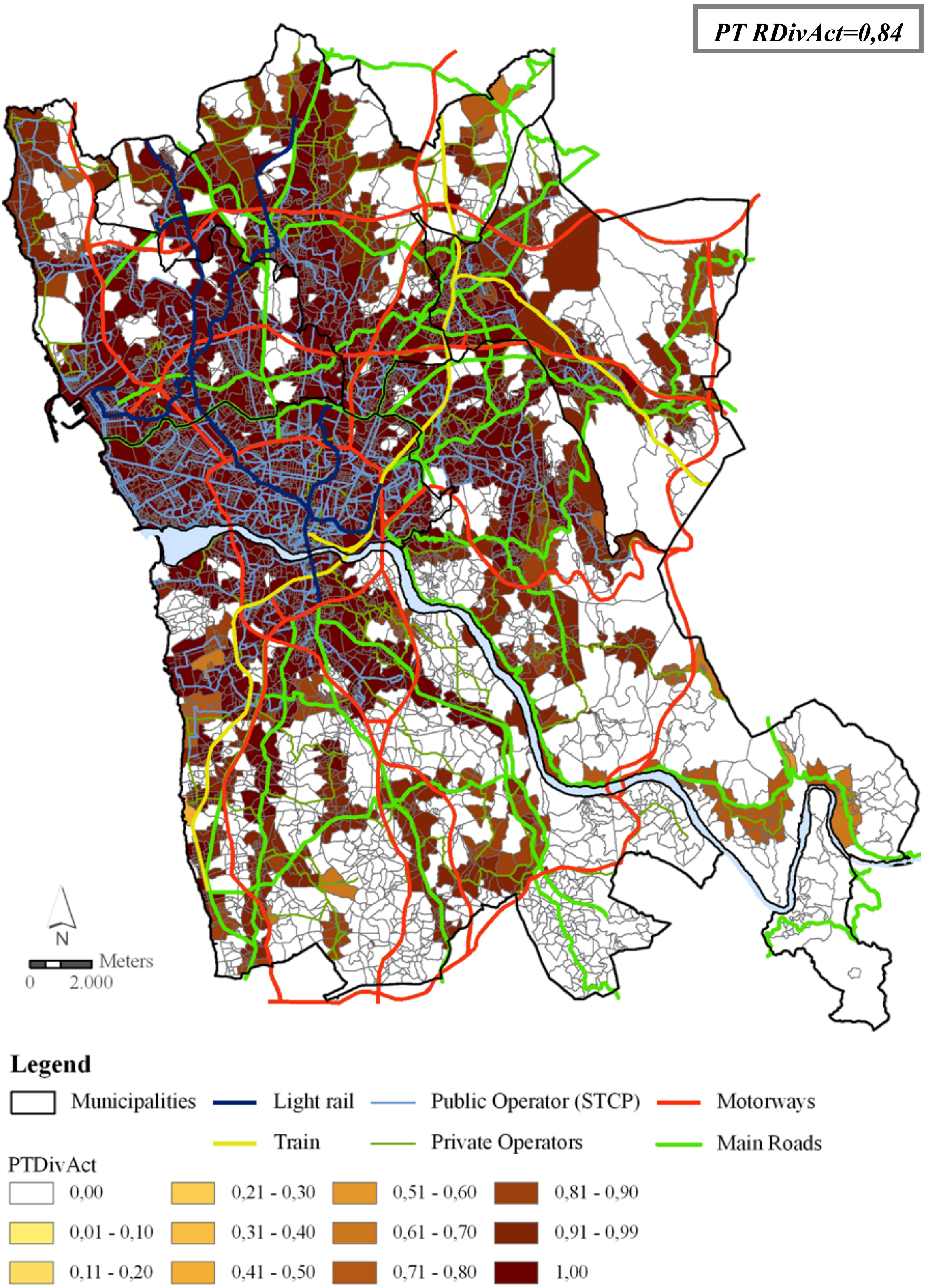


Figure 5.10: Diversity of Activities Accessible by public transport and by Classes

Additionally, the public transport service of the study area has recently suffered, important changes, based on the construction of a light-rail system and supported by a reformulation of the transport network and service level of the public road transport operator (STCP). These changes introduced a network effect-based service (in opposition to the traditional door-to-door service) increasing travel options by public transport. Therefore, it is natural to find the highest accessibility levels around the public operators of public transport.

The best accessibility conditions (with accessibility to all activity types by public transport) can be found in almost the entire municipality of Oporto, stretching mainly to the north along the main public transport corridors and in a small part to the south. The remaining area in high accessibility conditions (containing 12% of the population) show almost irrelevant accessibility restrictions to high schools (2), cinemas (6), theatres (7), sport facilities (8) and postal offices (15) and more relevant accessibility restrictions to graduate schools (3).

Sub-regions presenting medium conditions of public transport accessibility are generally lacking accessibility to activities, such as, graduate schools (3), cinema (6), theatres (7), sport facilities (8) and postal offices (15). Sub-regions with low accessibility condition present no accessibility to all activity types considered resulting from the lack of available public transport service.

Figure 5.11 presents the geographical distribution of accessibility levels by car. Almost the entire study area provides their inhabitants with accessibility to all activity types by car (98% of the population living in 87% of the study area). Excluded from these conditions are two peripheral areas, one at the northeast and the other at the southeast, and several small areas scattered across the study area. Almost 93% of the study region presents high accessibility levels giving good conditions to 99% of the population for the use of the car as access mode for every day activities. In average, the study region present almost maximum accessibility level, with a value of 0.99 regarding activities accessible by car.

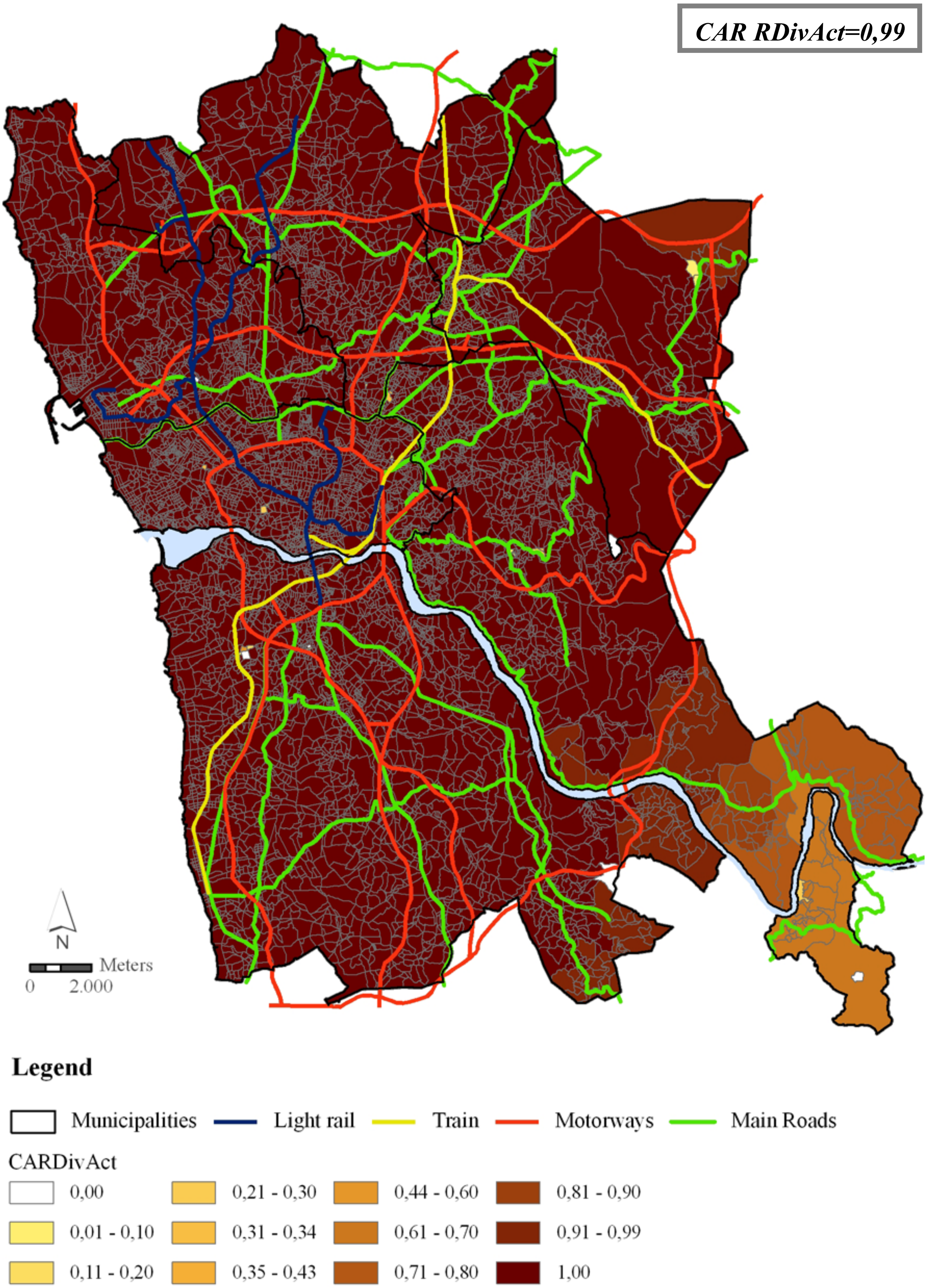


Figure 5.11: Diversity of Activities Accessible by car

The remaining 7% of the territory mainly includes sub-regions with medium accessibility levels on the far south-eastern side of the study area. The low values of accessibility for these sub-regions seem to be a result of severe artificial boundary effects, aggravated by the Douro River. The barrier effect imposed by the river is falsely high since the nearby bridge providing access to the remaining study region is located outside the study area. This artificially reduces accessibility levels.

Low accessibility levels are presented by a residual number of sub-regions scattered across an otherwise homogeneous accessibility map of the study area. Nevertheless, the classification of accessibility levels of these areas results from network errors. Examples of errors are, for instance, cul-de-sacs classified as one way streets or conflicting travel direction isolating some areas. Therefore, these errors mainly result form inaccuracies of the used database which where not detected beforehand. In these conditions it is fair to say that the entire study area provides high accessibility levels to all its inhabitants (class A), with 98% having access to all activities by this transport mode. Considering the maximum travel time of 30 min (cut-off value for this accessibility measure) as well as the small study area, the high density of motorways and the small area affected by congestion, this result is only natural. There is, therefore, a clear homogeneity of the accessibility levels by car for the entire study region, with few sub-regions presenting some accessibility problems to activity types such as graduate schools (3) and theatres (7).

Figure 5.12 represents the comparative accessibility index or category, resulting from the comparison of modes accessibility. This map illustrates the land use and transport conditions constraining the higher or lower sustainability of mobility. In other words, it represents the sustainability of potential mobility. Considering the same accessibility class by car for the overall study area (class A), only 9 of the accessibility categories defined by the benchmarking cub can be found. Consequently only 4 of 9 accessibility clusters are attainable in these conditions – cluster III, non-motorized, public transport and car favouring conditions (represented in brown), cluster IV, non-motorized and car favouring conditions (represented in different shades of orange), cluster VI public transport and car favouring conditions (represented in different shades of grey) and cluster VII, car favouring conditions (represented in different shades of lilac).

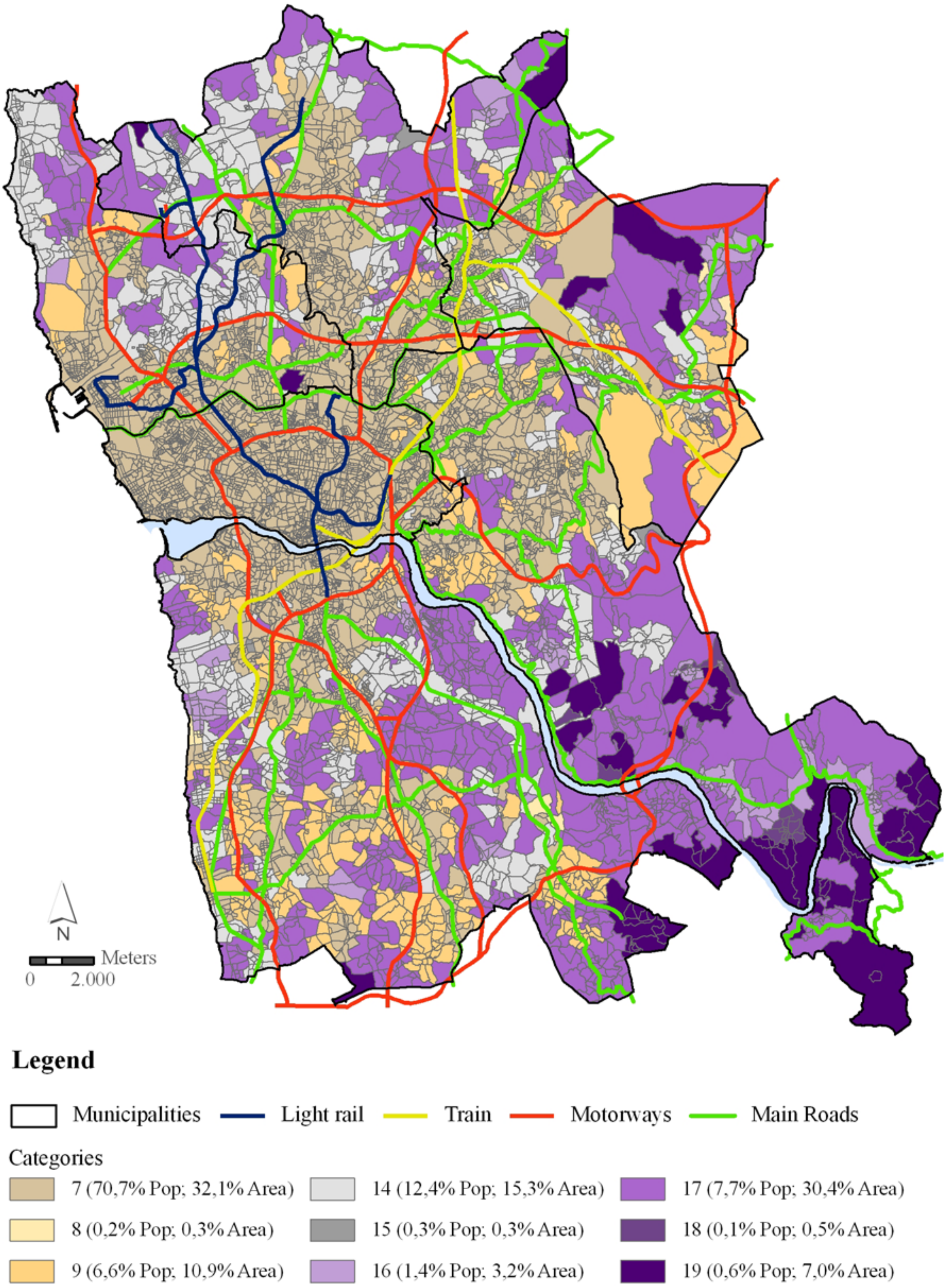


Figure 5.12: Categories and clusters of accessibility

The clear majority of the population lives under land use and transport conditions providing high accessibility by all transport modes (category 7; 71% of population), in an area smaller than 33% of the study region (see Table 5.7). The most frequent accessibility categories provided by land use and transport conditions are categories 7, 9, 14 and 17. Categories 9, 14 and 17 are present in almost 60% of the study region, defining accessibility conditions of nearly 27% of the regional population. Remaining accessibility categories have residual importance in the study area.

Table 5.7: Categories and clusters by number of sub-regions, area and population

		Sub-regions	%	Area km^2	%	Population	%
Category	7	6084	63,5%	181	32,1%	769691	70,7%
	8	22	0,2%	2	0,3%	1996	0,2%
	9	740	7,7%	61	10,9%	72331	6,6%
	14	1389	14,5%	86	15,3%	135082	12,4%
	15	19	0,2%	2	0,3%	2810	0,3%
	16	204	2,1%	18	3,2%	15148	1,4%
	17	1030	10,7%	171	30,4%	83599	7,7%
	18	23	0,2%	3	0,5%	1539	0,1%
	19	71	0,7%	39	7,0%	6922	0,6%
Total		9582	100,0%	562	100,0%	1089118	100,0%
Clusters	III	6084	63,5%	181	32,1%	769691	70,7%
	IV	762	8,0%	63	11,3%	74327	6,8%
	VI	1408	14,7%	87	15,5%	137892	12,7%
	VII	1328	13,9%	231	41,0%	107208	9,8%
Total		9582	100%	562	100%	1089118	100%

Around 70% of the population lives in areas providing land use and transport conditions favouring all transport modes (cluster III) while the remaining population live mainly in public transport and car favouring conditions (cluster VI). Around 7% of the population live in non-motorized and car favouring conditions (cluster IV) and almost 10% live in car favouring conditions (cluster VII).

The map clearly shows areas of the study region providing land use and transport conditions which enable travel behaviour to be sustainable – areas in cluster III, IV and VI – although real travel patterns may still have low levels of sustainability since car use is an available mode choice (there is almost no constrain to car use except for moderate congestion in a small central area). The remaining region does not provide the necessary land use and transport conditions to foster sustainable travel behaviour. Even if inhabitants would be willing to pursue more sustainable travel behaviour land use and transport conditions would disable them from doing so (without loss of quality of life).

In average the study region falls into category 8 of accessibility to diversity of activities, resulting from accessibility class A for non-motorized modes (NM_RDivAct=0.91) and for the car (CAR_RDivAct=0.99) and from accessibility class B for public transport (PT_RDivAct=0.84). This places the study region as a whole in accessibility cluster IV, with land use and transport systems providing non-motorized and car favouring conditions.

Summarizing, the region has clearly two distinct areas with regard to land use and transport conditions for sustainable travel behaviour. Nevertheless, on average, it is fair to say that the region provides already good conditions for the use of both non-motorized modes and the car, although conditions for car use are considerably better then for walking. On the other hand public transport accessibility is still not at acceptable levels and considerably lower than car accessibility, offering a clear advantage for car use and therefore for non-sustainable travel behaviour.

5.3.2. Use of the SAL for strategy design

As mentioned in the introduction of this chapter, the use of a real case study for the design purpose of the SAL is intended as an illustration of some of its abilities as well as an exercise for the improvement of the practical applicability of the tool. Therefore, this section develops an illustrative exercise to test the policy design support purpose of the SAL. This exercise is centred on the support provided by the tool for the definition of the objectives for policy action (strategy). The final step of use of the SAL, regarding the definition and test of policy measures, will not be pursued in this illustration. It would be unreasonable to define policy measures for this illustration since their choice is highly dependent on local and political conditions, objectives and constrains, which are not reproducible for this research.

The development of objectives for policy design followed two main steps: first, the definition of a general strategy for the entire study region, and second, the development of a detailed strategy for groups of sub-regions in similar conditions. Each of this steps were developed based on the analysis results of the SAL, the accessibility and sustainability measures and the complementary information enumerated in section 5.2.

The development of the general strategy for the study regions involved four main aspects:

- definition of a time range;
- choice of the general objective on the benchmarking cube (choice of the desired accessibility category for the entire region at the time range horizon);
- definition of the general path on the benchmarking cube (strategy for the general evolution of accessibility categories, from the current to the desired status); and,
- general strategy for the urban structure (essentially choosing between homogenizing and differentiating strategies for urban occupation).

It is essential to highlight that, given the limited insight on local and political constrains and objectives, strategies defined are somehow theoretical and must be regarded simply as an example develop for the illustrations of the abilities of the SAL.

The following table summarises the core choices made for the main aspects involved in the definition of the general strategy. First, 10 years were chosen for the time range horizon. This was considered to be a reasonable value for the development of an integrated mobility management strategy plan focussing on land use and transport measures. Into consideration was taken the fact that the standard procedure for land use planning in Portugal (and the metropolitan area of Oporto is no exception) generally involves a 10 year span.

Table 5.8: Summary of main choices for general strategy

Aspect	Choice
Time range	10 years
Objective on cube	Category 7
Path on cube	From category 8 to 7 (increase accessibility by PT)
Urban Structure	Decentralized concentration

Recalling the average accessibility category of the study area – category 8 (with a regional diversity of activity index of 0.84 for public transport, 0.91 for walking and 0.99 for the car) – it seems reasonable that accessibility levels could reach category 7 in the defined time range. This would provide favourable land use and transport conditions for the use of all transport modes (including public transport) providing potential for sustainability gains. Considering that category 7 would be brought about by a small increase of the public transport diversity of activity index (from 0.84 to at least 0.85) this is clearly not a difficult task. In more detail, the aimed position within the benchmarking cube should reflect average non-motorized and public transport accessibility levels closer to 1 and a slight decrease of average car accessibility[49]. In the current social and political context it is unlikely to expect a relative loss of average car accessibility which would make it less accessible than walking and public transport. Moreover, more ambitious objectives, such as category 6, are almost impossible to foresee in the near future, especially in the absence of a strong social and political will to change travel behaviour towards higher sustainability. Any of these scenarios would envisage strong car restrictions in order to enable the decrease of car accessibility in conditions of high walking (local) accessibility.

[49] For instance, strive for values above 0.9 for PT, for values above 9.2 for NM and for values below 0.98 for the CAR. Considering the illustrative scope of the application of the SAL to the GO, these values are mere examples of the detail usable during policy design. A real application of the SAL should resort to a debate including mobility experts and politicians for the definition of concrete objectives.

The general path on the cube envisages a clear increase of public transport accessibility in the region which is the transport mode providing worst conditions. Furthermore, it seems necessary to further improve walking accessibility as well as to define the first steps of a long range strategy for car use management. Summarizing, the path on the cube considering this general strategy, involves the increase of accessibility levels by public transport and non-motorized modes while at the same time taking the necessary steps to enable the decrease of car accessibility level. This means that the study region's position in the cube should move slightly down and to the front, and considerably to the right.

Considering the size of the study area and the considerable heterogeneity of locally available activities it is unreasonable to expect a homogenization of accessibility levels. On the other hand the general strategy of decentralized concentration seems to be a sound strategy to enhance general accessibility levels in the area. This strategy enables the concentration of population around activities as well as provides conditions for the concentration of activities near high population densities. Furthermore, concentration of population and activities in limited areas provides an interesting urban system for the development of efficient and economically sound public transport systems. This urban structure, therefore, offers the necessary conditions to improve general accessibility levels without demanding more activities or, the virtual, unlimited expansion of the public transport system.

The general idea was to promote the development of an urban structure based on a network of urban centres supported by a network of major public transport routes. In current urban structure conditions, the strategy proposed for the GO involves the reinforcement of the main urban centralities, inverting recent trends of decentralization and urban sprawl. The public transport structure should provide services for this network of centralities scattered throughout the study region.

Besides of the reinforcement of the existing structure of urban centres, new centralities can also be suggested based on several criteria or local objectives. Figure 5.13 provides an overview of the urban structure proposed for the case study. It defines a network of urban centralities, divided into 3 levels. This map was defined based on the local accessibility map (NMDivAct) identifying centralities in areas of accessibility class A.

The first level centrality provides local accessibility to all activities considered in this study. The second and third levels, although providing good walking accessibility, have limited local access to some activity types[50]. As long as these activities have low influence on every day travel demand, it is reasonable to assume that these travel needs are conveniently served by a public transport structure providing fast and direct access to other centralities offering the missing activities.

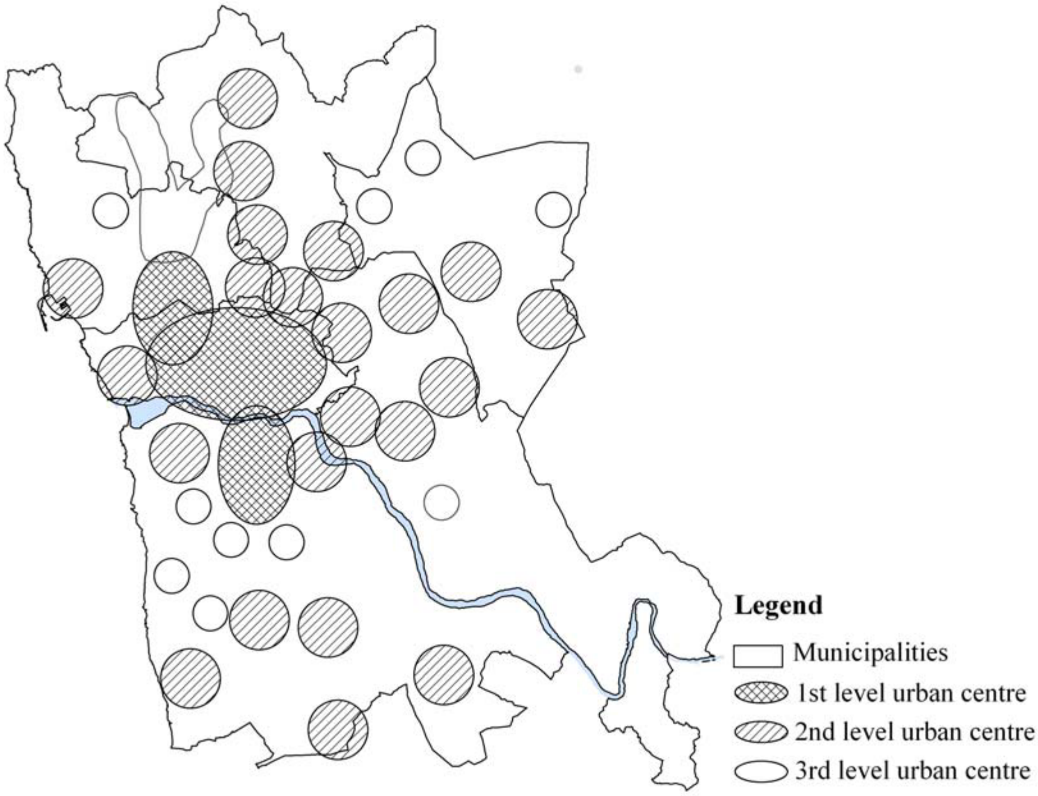


Figure 5.13: Proposed urban centre structure for the general strategy for GO[51]

For this strategy, two examples of new third level centralities are proposed (presented in gray in Figure 5.13). One new centrality is proposed for the municipality of Gondomar to cope with the lack of centralities in the south-eastern part of Gondomar which would seriously compromise an efficient public transport system based on a network of urban centralities. Another new centrality is proposed for Matosinhos and Maia along the corridor of the light rail, were no centrality has yet developed. This second example

[50] With the second level centrality defined among accessibility levels between 0.9 and 1 and the third level centrality defined among accessibility levels between 0.85 and 0.9.
[51] For an overlay of existing and proposed urban centre structure on local accessibility (NMDivAct) and on main public transport structure see Figure B.19and Figure B.20 in Annex B.

provides a strategy to take advantage of an important (and highly sustainable) existing transport facility. These examples intend to illustrate the range of possible choices (based on local interests and objective) which could have been engaged.

The general structure for the public transport system must be defined in accordance to the proposed structure of urban centres. Figure 5.14 presents the main public transport structure which in combination with the structure of urban centres will define the baseline urban structure. A four level structure is present for the public transport connecting the main urban centres as well as the remaining region.

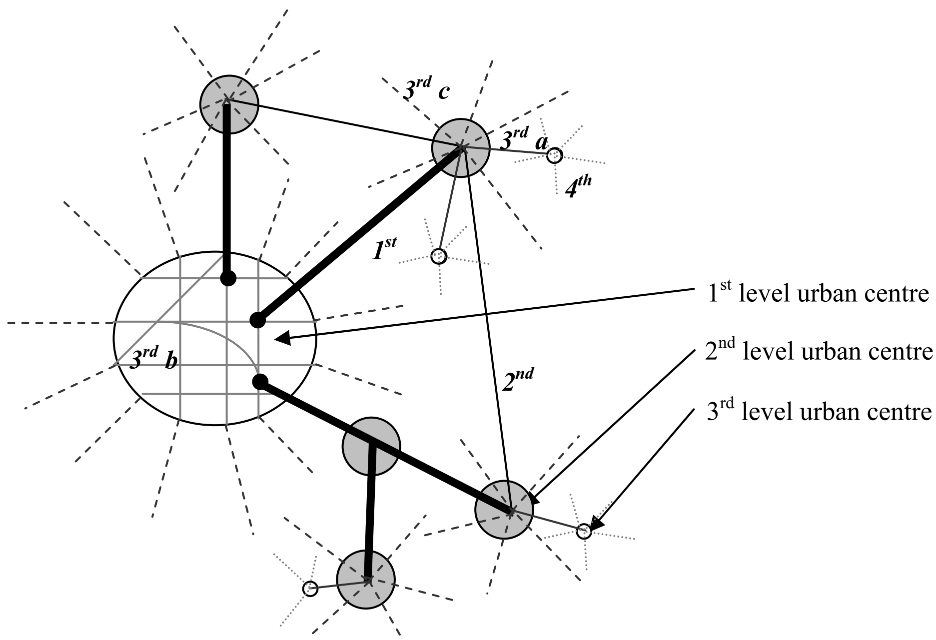


Figure 5.14: Strategy for the structure of public transport

The first level connects the second level urban centres to the main centre of the region (through major public transport interchanges located at strategic points of the public transport network of the main centre). The second level connects a selected number of second level urban centres between each other[52]. Both levels are conceptually designed for high frequency and speed (through a reduced number of intermediate stops and, when required, segregate infrastructure) as well as high capacity, working as highways of public transport service. The importance of frequency, speed and capacity is dependent on local interdependencies.

[52] The choice of 2nd level centres to be interconnected by this network type is based on the level of interdependency of these centres.

The third level works as local public transport access and can be divided into three types: a) connecting third level urban centres to the most convenient second level urban centres; b) urban network within an urban centre; and c) radial access of the remaining region to the most convenient first or second level centrality. The first type of third level network is conceptually a direct access between urban centres (no intermediate stops) with low frequency and medium capacity. The second type requires high frequency, wide network range (based on short, high capacity routes instead of traditional resource demanding door-to-door service), medium capacity and infrastructure segregation. The third type works as a radial, low frequency service, with medium capacity and traditional door-to-door service.

The fourth level is one of local access within low population density. This service requires case-specific, tailor based solutions such as, demand responsive public transport or community service.

Figure 5.15 presents a scheme of the general strategy for the main public transport structure. Fundamentally it presents the backbone for a regional public transport system. The first level public transport service is proposed along the main corridors of urban centres to the north of the main centre and with a more complex structure to the south (opening branches towards the south of Vila Nova de Gaia and connecting these centres to the light rail network). In combination with the existing rail and light rail system these new first level routes form the main radial system of the region. One major circular route is proposed connecting Maia and Matosinhos in answer to the strong interdependency between these two municipalities (see Figure 5.6). This second level route can be extended eastward from Maia to Valongo (more specifically Ermesinde holding a major rail station were rail routes to the north diverge), and southward from Matosinhos to Oporto. This circular system would work as an extension of the rail route coming from the east, ending at an inner circular route of the light rail (third level system). This service can be provided by high capacity busses on segregated lanes to enable the quality of a rail service in lower population density and travel patterns, which are not economically viable for the train or light rail. No other second level connections are proposed for this urban structure, with connection between second level urban centres being served by the first level public transport system.

Regarding third level public transport service, only one route is proposed[53]. This route is a circular route for the light rail network belonging to the urban network of the major urban centre and ringing the municipality of Oporto. This route ties the second level transport network to the urban centre network (light rail and bus) by providing an increase in choice for travel to the main centre. Furthermore it ties the second level transport network together and to a larger regional transport service providing a public transport service which is tailored to encompass some of the complexities of current travel patterns. The provision of real network-based public transport service is essential for the preparation of car use restriction strategies. Without a public transport service working as a real network and providing a quality service for the complexity of travel demand, the flexibility of car mobility cannot be rivalled.

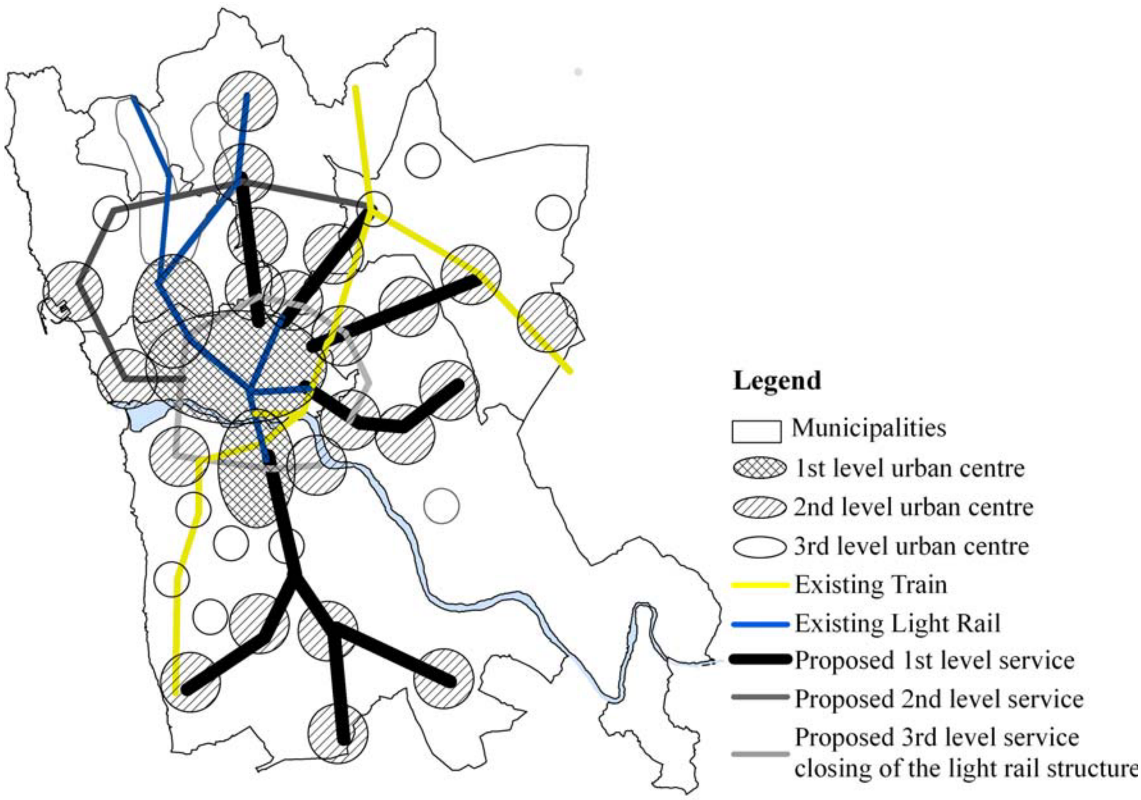


Figure 5.15: Proposed urban structure of the general strategy for GO[54]

[53] Further proposals are dependent on further local data and knowledge which at the time is not available (regarding cost and time).
[54] For an overlay of the proposed urban structure on local accessibility (NMDivAct) see Figure B.21 in Annex B.

Summarizing, to achieve the desired accessibility levels (cluster III) the general strategy envisages the development of a transit oriented urban structure at the regional scale. This large scale urban structure is based on high accessibility levels at local level for a limited number of urban centres. These urban centres work as preferential locations for population and activities. Urban development outside urban centres is to be discouraged. With regard to public transport, a general structure is proposed aiming to provide sustainable medium distance travel which enables sustainable access to all activities (especially non-local activities) by enabling a variety of travel patterns. Additionally there is a requirement for a larger range of public transport and better service levels of the existing service. Besides of concerns regarding the major public transport structure (working as the backbone of the system) special attention is also required for low density areas, which disable traditional public transport solutions.

The detailed strategy for groups of sub-regions will be defined based on the outlined strategy for the entire study region. Figure 5.16 presents 10 groups of sub-regions in similar conditions. These groups were defined based on:

- accessibility category,
- detailed values of accessibility by non-motorized modes and public transports[55],
- level of urban centre as defined in the general strategy, and
- population density.

Groups 1 to 8 encompass the proposed structure of urban centres, with 6 and 8 being the two new proposed centralities. Groups 9 and 10 enclose the remaining study area outside the structure of urban centres. Higher detail is required for strategy design for urban centres (enclosing 8 of the 10 strategy groups) due to population (travel origin) and activity (travel destination) concentration. On the one hand, the reinforcement of the system of centralities can be based on strategies ranging from urban concentration, to activity allocation, public transport service and car use restriction. On the other hand, strategies for the remaining region are mainly based on the reinforcement of public

[55] Besides of aggregate measures on accessibility levels, detailed strategy design used several levels of details of information used to develop the category map, such as, mode accessibility maps using higher disaggregation of scale (between 0 and 1) and detailed information of accessible activity types by each sub-region, for each transport mode.

transport accessibility and on the limitation of urban development. Therefore the former require further detail on existing conditions than the latter.

Accessibility levels by mode have a key role in the definition of strategy groups. Four groups of sub-regions were defined as providing accessibility to all activities by non-motorized modes and/or public transport (groups 1, 2, 3 and 5)[56]. Urban centre levels were also used for the division of strategy groups (groups of sub-regions for detailed strategy design). First level urban centres (NMDivAct=1) define groups 1 and 2, second level urban centres (NMDivAct=[0.9;1[) define groups 3 and 4 and third level urban centres (NMDivAct=[0.85;0.9[) define groups 5 and 7.

Accessibility by public transport shows considerably lower variability along the study region. Almost all sub-regions with availability of public transport services have accessibility to all activity types by this transport mode (with very few exceptions). In this context, and contrarily to non-motorized accessibility, it was considered sufficient to divide groups into those having accessibility to all activities and into the remaining cases. Every sub-region presenting accessibility index by public transport of less than 1 was considered to require a reflection on possible strategies for public transport improvement.

Finally, groups were also influenced by sub-regional population density. Here it was considered important to define two population density limits; one defining low density and another defining high density[57]. The low density limit was used to distinguish strategy group 10 from group 9 (within the sub-regions excluded from the structure of urban centralities). The high density limit was used to identify groups of sub-regions in strategy groups 2 to 8 having population densities considerably higher than the average. This division was considered important to define urgency and relevance of certain strategies and measures defined for each group.

[56] Group 6 also presents accessibility to all activities by public transport but the definition of this group results from the definition of the new urban centre enclosing sub-regions with high public transport accessibility and not directly of the maximum accessibility.

[57] Values for these limits were defined approximately for the 10^{th} and 90^{th} percentile of population density by sub-region. These defined the limits at $150inh/km^2$ and $20000inh/km^2$, respectively.

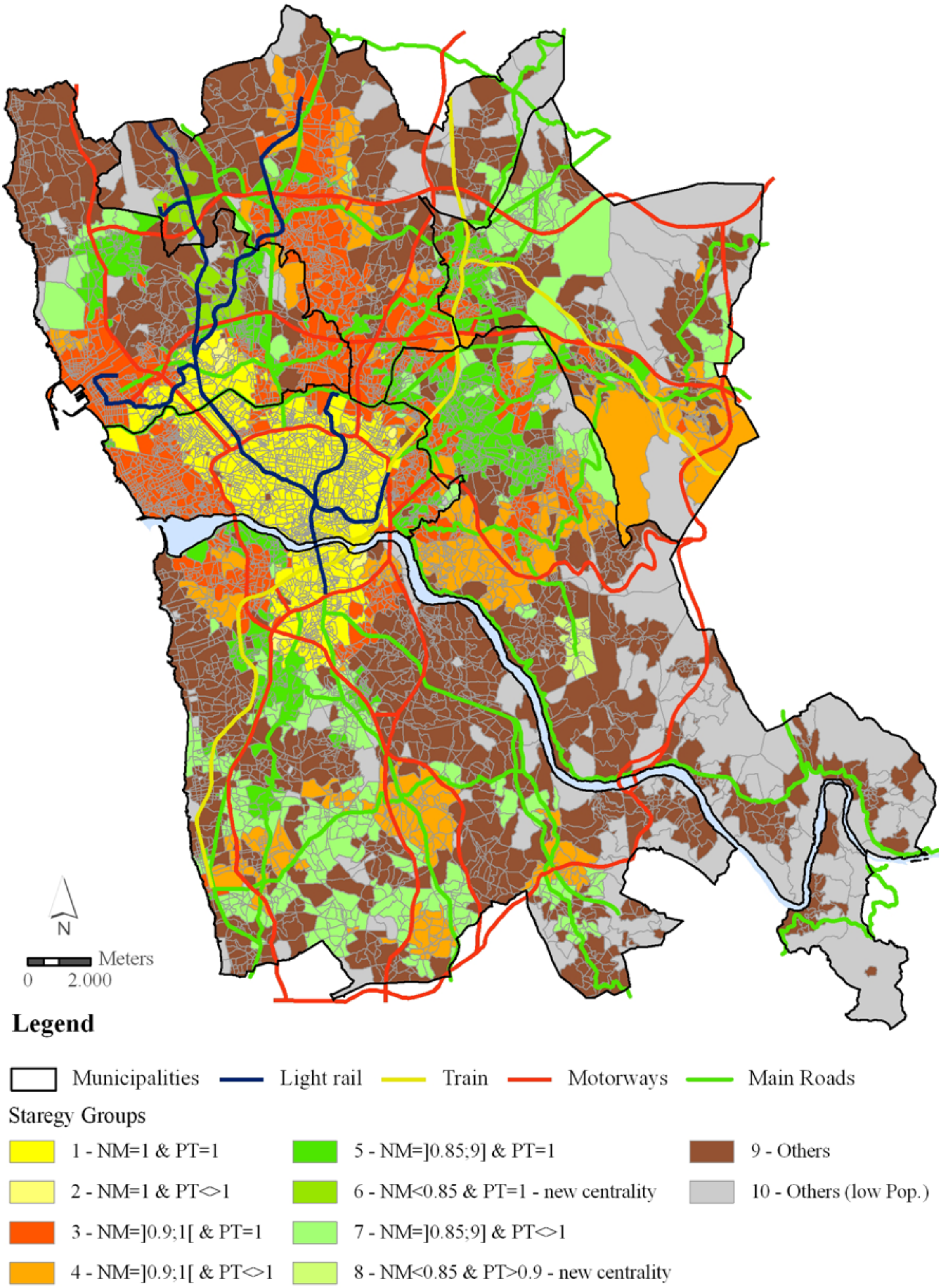


Figure 5.16: Strategy groups

Once the study region was divided into groups of sub-regions (or strategy groups) the development of the detailed strategies involved the following main aspects for each group (in accordance with the general strategy):

- Choice of the objective on the benchmarking cube;
- Definition of the path on the benchmarking cube;
- Choice of action.

Table 5.9 presents a summary of the choices defined for the detailed strategy. For each of the 10 groups the aimed accessibility category is presented (defining the required accessibility classes for each transport mode). Furthermore, the path to achieve the objectives is defined (as in most cases, current and desired accessibility categories are side by side in the cube, the path resumes to the point of departure and the point of arrival). This information is complemented by the required changes in accessibility classes for each transport mode. Exception is made for group 10 which presents no intended change in accessibility levels. The main concern with regard to this group of sub-regions is to disable any further occupation (and preferentially envisage its future reduction of occupation).

The three last columns define the level of the urban centre for each strategy groups as well as the chosen action types, aiming to achieve desired accessibility levels. With regard to the level of urban centres, groups 9 and 10 represent sub-regions outside the structure of urban centres. These were therefore classified as ‘remaining region’ and ‘rural areas’, respectively.

Group	OBJECTIVE				PATH				Urban Centres	ACTIONS	
	Category	Class			Category	Class				Main	Detail
		NM	PT	CAR		NM	PT	CAR			
1	7	A	A	A	7→7	-	-	A ↓A	1st level	1 4	1.1 4.1
2	7	A	A	A	7/9→7	-	A ↑A C→A	A ↓A	1st level	1 2 4	1.1 2.3.2 4.1
3	7	A	A	A	7→7	A ↑A	-	A ↓A	2nd level	1 3 4	1.1 3.2 4.2
4	7	A	A	A	7/8/9→7	A ↑A	A ↑A B→A C→A	A ↓A	2nd level	1 2 3 4	1.1 2.1/2.2 3.2 4.2
5	7	A	A	A	7(5) →7	A ↑A	-	A ↓A	3rd level	1 3 4	1.1 3.3 4.3
6	7	A	A	A	14→7	B→A	-	A ↓A	3rd level	1 3 4	1.1 3.3 4.3
7	7	A	A	A	7/8/9(5) →7	A ↑A	A ↑A B→A C→A	A ↓A	3rd level	1 2 3 4	1.1 2.3.1 3.3 4.3
8	7	A	A	A	14→7	B→A	A ↑A	A ↓A	3rd level	1 2 3 4	1.1 2.3.1 3.3 4.3
9	14/15	B/C	A	A	14/16/17(20-23) →14 15/18/19(24-27) →15	-	A ↑A B→A C→A	-	Remaining region	2	2.3.3/2.4
10	-	-	-	-		-	-	-	rural	1	1.2

Table 5.9: Summary of strategy and action for each strategy group

With regard to actions, these were chosen to bring about changes to four main aspects: urban occupation or population density (1), public transport network and service (2), distribution and diversity of activities (3), and, car use convenience (4). These main actions are then further detailed in the last column[58].

The first group, providing accessibility to all activity types by public transport and walking, encompasses the best conditions for sustainable mobility in the study region. Further urban development and population density should be encouraged in these sub-regions. Additionally, considering the availability of viable alternatives, car use should be discouraged and even hindered through the reduction of car infrastructure capacity. The second group, should follow a similar strategy to the one defined for the first group

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[58] Action types considered:

1 Act upon urban occupation (population density):

1.1 Action stimulating occupation (increasing population density);

1.2 Action restricting occupation (maintaining or even decreasing population density);

2 Act upon public transport service:

2.1 Develop a 1st level network providing direct and fast access of 2nd level centralities to the main urban centre (service characteristics: high frequency, speed and capacity, few stops; favoured mode: train, light rail or segregated bus routes);

2.2 Develop a 2nd level network providing direct and fast access between the main 2nd level centres (service characteristics: high frequency, speed and capacity, few stops; favoured mode: light rail, segregated or not segregated bus routes);

2.3 Develop a 3rd level network

2.3.1 Providing direct access from a 3rd level centre to the most convenient higher level centre (service characteristics: low frequency, few stops, medium capacity; favoured mode: bus);

2.3.2 Providing frequent and wide ranging access between larger urban centres (service characteristics: high frequency and reliability, network service in opposition to a door-to-door network; favoured mode: light rail and segregated or not segregated bus);

2.3.3 Providing interurban access to the most convenient centre (service characteristics: radial, low frequency, many stops, door-to-door network, medium to low capacity; favoured mode: bus);

2.4 Develop a 4th level network providing local access in low population density (service characteristics: time table based or on-demand frequency, low capacity, many stops, door-to-door network; favoured mode: small busses, vans or taxis);

3 Act upon activity diversity (in connection with urban centre level)

3.1 Providing local access to all activity types in the 1st level urban centres; Aim NMDivAct=1

3.2 Providing local access to almost every activity type in 2nd level centres; it is reasonable that activity types such as universities (3), cinema (6) and theatre (7) are not present at this centralities (at least not the guarantee of access for all its population); aim NMDivAct>0.95

3.3 Providing local access to most relevant activity types in 3rd level centres; it is reasonable that activity types such as universities (3), cinema (6) theatre (7), other leisure activities (9), non-food shopping (11), hospital and clinics (13), postal office (15) and other activities (17) are not present at this centralities (at least not the guarantee of access for all its population); aim NMDivAct>0.85.

4 Act upon car use restriction (in connection with urban centre level)

4.1 Reduce capacity of road network (for instance, reduce parking spaces, reduce width of roads and number of lanes) – indicated for 1st level urban centres;

4.2 Increase travel price (for instance increase parking prices) – indicated for 2nd level urban centres;

4.3 Traffic calming measures (such as the reduction of maximum travel speed, the use of roundabouts) – indicated for 3rd level urban centres.

adding public transport service improvement, in order to provide accessibility to all activity types by this mode. Public transport improvements should centre on the expansion of the network as well as on increasing frequency of the existing network (even if at the expense of door-to-door service). The third group should follow a similar strategy to the one defined for the first group, adding possible improvements to local accessibility levels. Being a second level urban centrality, not all activity types must be at walking distance. Therefore a more detailed survey of lacking activities (provided by the SAL) as well as the assessment of the need for these activities at walking distance (which is a local decision) is required. This information can then be used to detail the activity types which should be encouraged (if any) as well as there preferred location. Furthermore, car use restriction should also be more limited than for first level urban areas with measures mainly centred on travel price.

The fourth group should follow a similar strategy to the one defined for the third group adding the improvement of public transport service. The improvement for second level urban centralities, involves the development or reinforcement of the first and second level public transport structure (improving frequencies and speed while providing direct service between centres). The fifth group should follow a similar strategy to the one defined for the third group but with lower expectations on locally accessible activities, regarding that third level centres are involved (see action 3.3). Furthermore, car use restrictions should also be more limited than for second level urban areas with measures mainly centred on traffic calming. The seventh group adds public transport accessibility concerns to the general strategy of the fifth group. Considering the level of urban centre involved, public transport strategy should centre on the direct access to higher level urban centres providing access to lacking activities. The sixth and eighth strategy groups should follow the general strategy of the fifth and seventh group, respectively. Aiming at the development of new third level urban centres, special attention is required for the development of strategies attracting new activities, as well as on the activity types required. One further sub-group may be identified for each of these eight sub-groups, highlighting sub-regions with high population density (exceeding 20.000inh/km^2). The definition of theses sub-groups identifies sub-regions requiring urgent action within those already mentioned for each strategy group, with exception for strategies increasing population density. The ninth strategy group should act solely upon the public transport aiming to provide a viable alternative to the car (which is currently the only viable transport mode). These sub-regions require a viable alternative transport offering access to the nearest urban centre providing most activities and also access to higher level transport service. This requires door-to-door public transport systems or even ‘on demand’ transport services. Giving the low density of urban occupation in these areas it is unreasonable to strive for high levels of walking accessibility. The tenth strategy group is characterized by very low density of occupation (less than 150inh/km^2) therefore, excluding viability of public transport measures. As a result no aim is defined for these rural sub-regions, were action should centre on disabling any further occupation (or even reversing any prior urban development).

Figure 5.17 present the accessibility category map which should be attained at the end of the 10 year time range. Sub-regions presenting accessibility categories 16, 17 and 19 were those included in strategy group 10, and therefore are expected to suffer no changes over this period. For the remaining sub-region, desired accessibility categories are presented.

The general strategy for the entire territory and the detailed strategy for the 10 strategy groups can subsequently be used for the final step supported by the SAL – the definition and test of policy measures. Strategies defined in this section provide a framework for the choice of policy measures able to bring about the required changes. Preferred integrated land use and transport measure packages (from the variety of possible measures) could then be tested on the SAL as to assess their impact on accessibility and sustainability levels. For instance, with regard to public transport, the effect of new public transport routes or frequencies on accessibility and sustainability levels could easily be tested. Considering measures aiming to increase density or attract new activities, expected outcomes can be included in the data used for the analysis maps of the SAL in order to measure changes in accessibility and sustainability. With regard to defined car use restriction measures and considering the definition of the SAL, the potential effect of any measure must be converted into travel speed, which introduced into the SAL enables the measure of the effect on accessibility and sustainability levels. Nevertheless, the final step of use of the SAL, regarding the definition and test of policy measures, will not be pursued in the illustration example developed for this thesis.

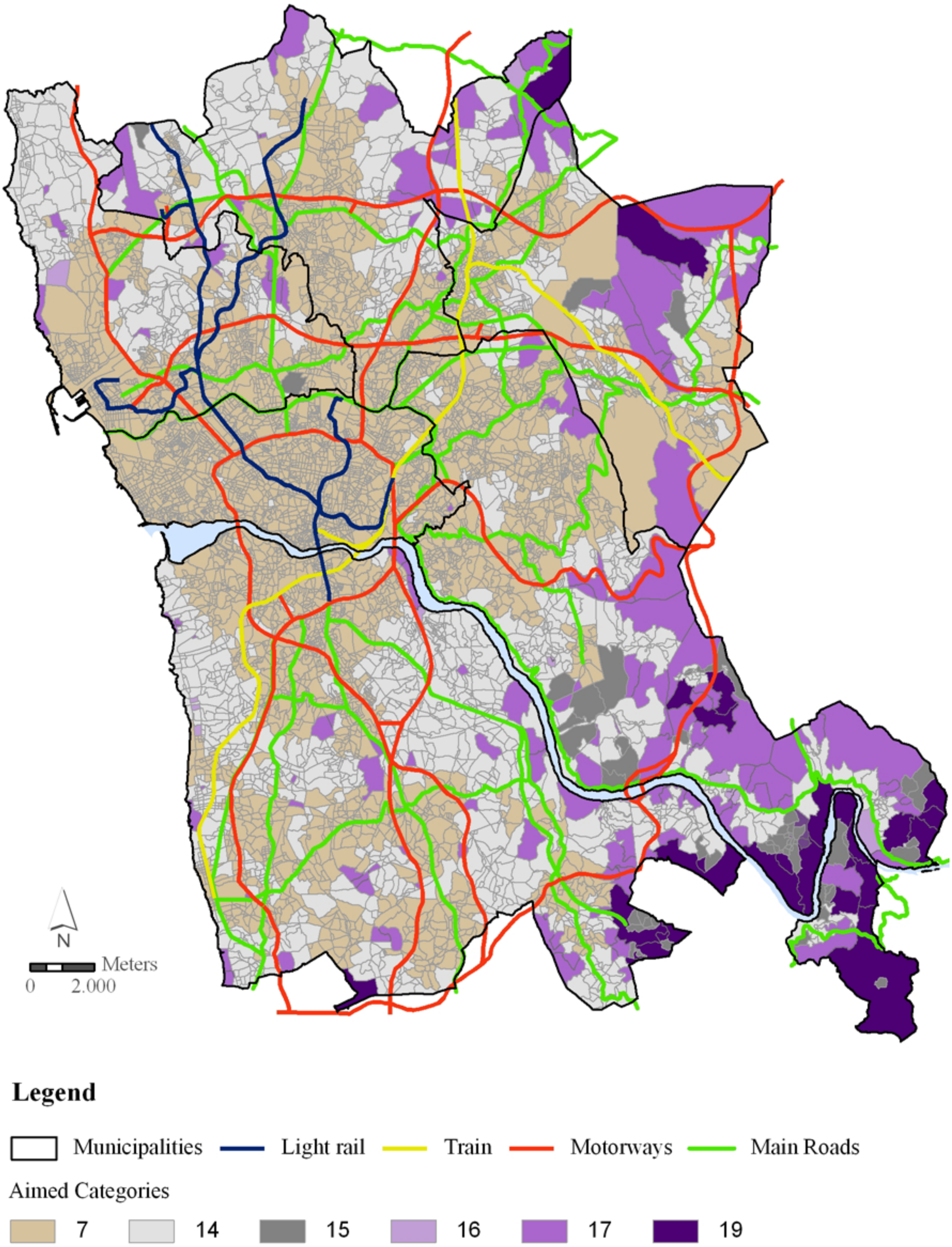


Figure 5.17: Aimed accessibility categories for each sub-region

5.3.3. Data-related limitations of the case-specific SAL

The application of the SAL provides an illustration of the variety of possible limitations of the tool, with regard to data-related limitation for its calibration. In the context of the case study, the discussion of the data-related limitations of the case-specific SAL is a fundamental requirement to understand the limits within which policy design was developed (referring to the illustrative example of policy design presented in the previous section).

Several data limitations can be identified for this case study. First, data concerning the number of activities and their spatial location are only available at the parish or municipality level. In order to develop the study at the desired disaggregation level (census track) an approximate disaggregation of data was developed (as presented in section 5.2). Second, data concerning importance of activity in travel generation (potential frequency of use of activities f_y) presents a very low disaggregation level (into work, school, leisure, shopping and other activities). An estimate was made to disaggregate these values according to the disaggregation of activity types considered as influencing travel. These limitations of available data constraint the soundness of the measures used for the SAL and therefore its results. Besides of statistical data, travel condition data by mode are also limited. For instance, data on walking conditions (or even biking conditions), such as slope, security and pleasantness are unavailable. The same can be said for data on the layout of routes of some private transport operators, as well as on road congestion, average travel speed, parking availability and price, and on time spend searching for parking. Limitations of data on travel conditions constraint the soundness of the SAL and, furthermore, constraints its design support ability. The SAL can only be use to test policy scenarios for conditions which are incorporated in the tool. For instance, as car accessibility for this case study only considers average travel speed, the effect of policy measures involving parking prices cannot be assessed.

Data limitations are an unavoidable fact and will be a general constraint of any case-specific SAL. Therefore, the application of the SAL requires a management of these limitations. Awareness of data-related limitations is essential to enable an adequate definition of the SAL and an understanding of interpretation constraints of its results. The soundness of the SAL and its design support ability is highly dependent on the quality of the information. Therefore, the SAL is as good an instrument as the data used to define it.

Finally, besides of data-related limitations, the use of the SAL for this case study suffered also technological limitations. The instrument uses GIS based technology for the management of geographical data and for accessibility analysis. The capabilities of the GIS software used are somehow limited for accessibility analysis, due to its single criterion approach. These limitations demanded some simplifications for the public transport accessibility measure. These technological limitations should be overcome on future applications, either by resorting to more adequate software or by resorting to the development of the necessary software tools to complement present software.

5.4. Expert assessment of the behaviour of the SAL

Having applied the case-specific SAL to the study region an assessment of the results (as well as of the SAL itself) is considered fundamental. This assessment was developed based on semi-structured interviews to experts in core fields. The aim was to discuss three main aspects concerning the SAL: first, the *robustness* as analysis tool (assessing the ability of the used accessibility and sustainability measures to provide a suitable representation of local conditions); second, the *usefulness* as design support tool; and third, the *usability* and *practical applicability* by local planners and politicians. Taking into consideration these aims, interviewees were chosen within experts on mobility patterns as well as local urban structure conditions for mobility, experts on mobility management, local policy makers and planning officials. The 17 experts interviewed were chosen from academic (10), technical (4) and political (3) backgrounds, with a mix of land use (8) and transport (9) expertise fields[59].

Semi-structured interviews were chosen to enable a more informal discussion around the main three themes. Furthermore, these enable the gathering of feedback and even suggestions. The interviews were structured around the three themes preceded by a brief presentation of the conceptual framework of the SAL. Robustness was discussed based

[59] For more detail see Table C.1 in Annex C.

on the layer of walking accessibility levels (NMDivAct map) and on the layer representing categories of accessibility by sub-region of the GO. Interviewees were asked to comment on the ability of these layers to represent local conditions as perceived by them, thereby assessing the case-specific accessibility and sustainability measures proposed. Additionally, personal opinions were collected on the ability of the NMDivAct indicator to provide a representation of urban centralities, on the ability of categories to work as sustainability indicators, and on the ability of categories to supply understanding of the land use and transport conditions provided for mobility. The conceptual framework was also permanently under discussion[60].

Usefulness as design support tool was discussed after the presentation of the conceptual framework and of the diagnosis maps produced by the SAL for GO. Discussion on the usefulness of the tool was conducted before and repeated after the presentation of an example of strategy development for the study area, aiming to identify potential changes in opinion. Additionally, personal opinions were collected on the utility of quantified objectives for policy making (arguing that the SAL provides a framework for the development of quantitative objectives), and on the utility of accessibility based measures for policy design.

Finally, usability and applicability of the SAL in a practical situation was discussed. General suggestions for the tool as well as for the development of the case-specific SAL were requested, additionally to the specification of the main advantages and disadvantages[61].

5.4.1. Main results

The SAL was in general very well accepted by the interviewees and in some cases even enthusiastically. There was a clear interest on the conceptual framework of the SAL as well as on its application. Some interviewees even recognised their interest in applying the SAL within the general purpose it was build for and within other purposes related to their professional activities. For instance, the definition of public transport service (and in particular public service duties), the definition of land prices, and the design of urban

[60] For further detail on interviews see Annex C.
[61] For further detail on questions guiding the semi-structured interview see Table C.2 in Annex C.

projects were some of the suggestions made regarding further usefulness of the tool. Nevertheless some experts were sceptical with regard to some operational aspect of the SAL.

With regard to the three main aspects under discussion it is fair to say that in general robustness, utility and usability were recognised as abilities present in the SAL[62]. The clear majority agree with the robustness of both SAL measures (accessibility and sustainability measure) as defined for the case study. NMDivAct was generally considered as a good indicator of urban structure, while categories were considered to be a good indicator of land use and transport conditions for mobility. Although the general panorama provided by the layers seems to accurately define local conditions, some locations were pointed out as exceptions. Possible reasons for this can be related to the level of spatial and data aggregation as well as on the level of detail considered for activities. Some doubts were raised concerning the time thresholds chosen for cut-off criteria for the measure of accessibility levels as well as for the activities considered as influencing mobility. The use of several scenarios of cut-off values for accessibility time instead of one single time per transport mode was suggested as improvement of the robustness of the measure. Some experts suggested the exclusion of employment from activity types regarding the low added value of this measure for the analysis (only absence of accessible employment seems to be significant). Furthermore, suggestions were made regarding lower aggregation of activities, for instance, grouping activity types (for the diversity of activity indicator) in several groups depending on the nature of activities (local or regional) considering the market range or depending on the frequency of use, instead of aggregating all activities into one indicator. Other suggestions involve increasing the detail in activity type choice or increasing the detail in public transport service quality considered for the cut-off criteria, as well as, including more aspects influencing car use. Furthermore, the use of percentile analysis and cluster analysis was suggested for the definition of classes and clusters for the benchmarking cube.

[62] For further detail on answers to the main questions guiding the semi-structured interview see Table C.2 in Annex C.

There was a general believe in the usefulness of the SAL as design support tool, although many agree that there is a need to complement this tool with further information (including real mobility patterns) for policy design. The use of complementary information for policy design is part of the conceptual framework of the tool. Thus the need for complementary information is no a real limitation of the SAL (it conceptually provides a framework to support policy design, not design itself). Usefulness of the SAL was recognized as being based on two of its main advantages: systematising land use and transport conditions for mobility and providing a tool to test scenarios. According to one of the experts the land use and transport variables are strong but not enough to define integrated policy, only providing clues for planning. Again, this is in accordance with the aims defined for the SAL. Experts suggested other potential purposes for the tool besides of the design support of integrated land use and transport policies, such as, help in the definition of public transport service and land prices, and help in the design of urban projects. The general agreement on the usefulness of the SAL may be based on the agreement on the utility of quantitative objectives and of accessibility based measures for policy design also revealed by these interviews.

With regard to the third aspect there is a general believe in the usability of the SAL. Contrarily to what was expected the measure was not considered to be too complex for practical applicability. Some experts even envisaged an increase in complexity without having negative effects on usability. Nevertheless, some interviewees felt that the SAL could be too complex for politicians, requiring more appellative indicators (using, for instance, relative instead of absolute values relating to the improvements provided for accessibility). Politicians interviewed were not the least unmotivated by the believed complexity of the indicator nor by their abstract meaning, being within the most enthusiastic interviewees. In addition to low complexity, the potential interactivity of the tool was also considered to support its usability. Nevertheless, interviewees recognise the need to cope with current software limitations which have jeopardized this ability due to long computation times[63].

[63] It is important to point out that recent runs of the SAL on new desktop computers have taken up to 95% less time meaning that software limitation of interactivity have considerably weakened.

The main advantages of the SAL referred to by experts were the ease of use, understanding and communicating of the tool and the coherence of the measures[64]. Some authors recognize the ability to support thought for policy development, especially with regard to integration. According to these interviewees the SAL offers a framework of thought providing a combined approach to land use and transport aspects influencing mobility. Furthermore, a framework for territorial integration for urban mobility policy is provided, regarding the regional scope of analysis. The main advantage of the SAL was ascribed to its synthesising capacity as a diagnosis tool and to the ability of testing different policy scenarios.

Many of the aspect referred to as advantages are also responsible for some disadvantages. For instance the capacity of synthesising information of the diagnosis tool is responsible for the loss of important detail. The regional scale of analysis limits micro-scale approaches. Furthermore, as Portugal has no regional-based public authorities, there is a void of political power at this level for the use of the tool. Finally the SAL is data and time consuming and therefore expensive, being out of reach of average local authorities.

5.5. Synthesis: Outcomes of the testbed

This chapter presents the testbed used for the assessment of the SAL's potential as design support tool for integrated land use and transport policies and of the research hypothesis. In addition, this testbed illustrated the abilities of the SAL, providing insight for its improvement.

The GO case study was chosen because of rapidly decreasing sustainability of mobility patterns in addition to ideal conditions for the application of the tool (being a good example of mobility catchment area). Moreover, the application of the SAL to the GO case study provided an illustration of the amount and importance of the choices involved for the development of the case-specific instrument. The full meaning of the accessibility and sustainability measures are only materialized at this point showing that

[64] For a list of the main advantages and disadvantages see Table C.3 in Annex C.

this tool is a local construct. Its use in practice requires a clear definition of local perception of accessibility (highly disaggregated by mode and opportunity type).

The testbed supplied insight into the information provided by diagnosis maps. Mode accessibility and category layers provide a clear regional picture of sub-regional variation of accessibility conditions. These maps are highly visual tools synthesising a large amount of information.

The testbed involved the development of strategies for the GO as an illustrative exercise of the design support abilities of the SAL. This exercise shows some of the capabilities of the instrument providing an example of how it can be used for design support. The geographical representation of strategy groups and aimed categories, again providing highly visual tools, are examples of how the tool can be used for this aim. This exercise also made clear how the diagnosis maps and the benchmarking cube can be used to support the design of strategy.

Finally, the expert assessment of the behaviour of the tool confirms the realism of mode accessibility and category maps. Interviews confirm that comparative accessibility supplies and interesting illustration of regional heterogeneities, regarding land use and transport conditions for mobility. Furthermore, interviews provided feedback on the main advantages and disadvantages of the tool to baseline the improvement of the SAL. The outcomes of the testbed will be further discussed in the following chapter summarizing the lessons drawn from this research.

Chapter 6

LESSONS DRAWN FROM RESEARCH

Having tested the SAL on a case study, this chapter presents a discussion on the lessons drawn from this application on four main subjects:

- the development of the case-specific SAL;
- the conceptual framework of the SAL;
- the development of a second test of the SAL (in the learning cycle for the development of a PSS); and,
- the theoretical discussion (concerning urban structure and mobility management as well as the concept of comparative accessibility).

The first section presents general recommendations for the development of any case-specific SAL, as well as the discussion of the clues provided by the test of this tool for the improvement of the GO case-specific tool. The second section presents a discussion of the lessons learnt through the testbed for the improvement of the theoretical framework of the tool (some of which were already incorporated in the thesis). The third section presents a discussion of the improvements for a second case application of the SAL within the learning cycle for development of this PSS. The last section provides the feedback of this research for the current theoretical discussion concerning the influence of land use and transport on mobility patterns, the policy design support instruments, the mobility management approach and the concept of comparative accessibility. These discussions are a result of the experience developed during the application of the SAL combined with the suggestions and critiques obtained from the interviews.

6.1. Feedback for the development of the case-specific SAL

The testbed used provided some valuable lessons for the development of a case-specific SAL. Some aspects concerning the development of the GO case-specific tool were questioned in result of the experience of the application and of the comments of interviewees. The main aspects questioned were related to **activity types** and **accessibility limits** considered.

With regard to **activity type**, expert interviews revealed several suggestions and critiques (some contradicting others). It is clear that, although activity choice is a fundamental aspect for the development of any case-specific SAL, it is neither straightforward nor free of conflict. One single criterion must guide the case-specific choices of the activity structure: soundness. However there is no direct relationship between soundness of the accessibility measure and complexity or disaggregation level of the activity structure used. For instance, low disaggregation of activity types can make them too inclusive, while high disaggregation can result in the inclusion of activity types with low influence on travel. There is a need for a selective choice of activity types and activities considered, which must have effective and important influence on travel generation. Therefore, it is fair to say that the development of an activity structure (representing main travel generators) requires sensibility and thorough knowledge on local travel behaviour. In these circumstances it seems reasonable to believe that a compromise-building debate, involving experts on travel behaviour, would be an interesting approach for the definition of local activity structure for the SAL. Activity and activity type choice is therefore a case-specific problem which can only be managed for each case. Nevertheless, regarding its role in the general soundness of the tool it must be thoroughly coped with. Finally it is important to refer that activity and activity type choice is also dependent on quality and disaggregation of available data. This aspect can not be directly controlled by the users.

Although it is useless to discuss in detail the choice of any particular activity, one exception will be made for employment, which generated an interesting discussion during interviews as to whether it should or not be included. Doubts were raised about the importance of this activity type for the GO case-specific SAL although no doubts exist of the influence of this activity in travel generation (more then 40% of trips are generated by work related reasons). In this particular case, soundness of the accessibility measure is limited by the ability to correctly define how employment location influences travel. The simple presence of employment[65] does not have the same relevance for travel generation as other activities. Travel generated by employment has a weaker relationship with location than other activities such as infant schools or postal offices. The weak effect of location on travel generation is also present in activities such as universities or sport facilities. Nevertheless, influence on travel generation is even more complex for employment than for activities presenting higher relationship with quality than proximity in travel generation. In the case of employment the main aspect in travel generation is, generally, neither proximity nor quality but many other factors such as the relationship of employment type and level of education or proficiency. As the SAL is purely a structural measure of accessibility (independent of personal characteristics) it is virtually unreasonable to attempt any further specification in this analysis. Nevertheless, the used approach for the GO case-specific SAL limits the soundness of the measure, giving arguments to those defending the exclusion of employment. Work accessibility is a very poor indicator for accessibility conditions since variability of interest is too high and choice is weakly related to location of employment. On the other hand, as employment still represents almost half of current travel generators it seems somehow paradoxical to simply exclude it from the analysis. Discussion developed during the interviews lead to some alternative approaches to cope with this problem, such as the use of employment in another level of analysis[66], or the use of employment simply to distinguish sub-regions with absence of employment[67].

[65] For the GO case-specific SAL employment was considered accessible when the number of accessible employment exceeded the number of half of the population of each sub-region (approximately population in working age).

[66] Instead of using employment in the accessibility measure, use it at the strategy development level as complementary information for decision making and policy design.

[67] The absence of employment seems to be a more interesting measure than the presence of employment giving a clear understanding of regions with deficient accessibility to employment, while the complementary analysis has less real meaning.

Once more, the approach to deal with this activity related choice is case-specific. Nevertheless given the importance of employment for travel generation it seemed relevant to register the results and main ideas gathered to cope with this problem.

Still with regard to activity choice and soundness of the accessibility measure, other suggestions were presented and discussed during the interviews. Some experts discussed the high level of aggregation used by the diversity of activity index, building one single measure from accessibility levels to several different activities. Some argued that activities should be aggregated by groups of activity types related by, for instance, frequency of use, similar access time limit, or nature of activity (local or regional). Some even discussed the need to consider the same activities for all transport modes, arguing that some activities have an intrinsic link to certain kinds of transport modes (or no link at all to others). Although the use of aggregation groups (instead of one single aggregation) is not presented in the conceptual framework of the SAL, it is naturally possible and does not collide with the general concept developed. Nevertheless, the conceptual exclusion was on purpose, believing that it should be, when possible, avoided. The presented arguments or suggestions, aim to enhance the soundness of the SAL by increasing the soundness of the accessibility measure. Nonetheless any action which divides the synthesizing result of this tool into several maps should be avoided, because such actions would considerably reduce plainness. Another option is to use aggregation groups as complementary information, supporting the design of mobility policy and not being considered for the synthesising analysis maps.

With regard to **accessibility limits** interesting discussions and suggestions emerged from the expert interviews. Three main themes came into discussion: the use of different time limits instead of one single time limit (per transport mode in the GO case); the use of different times of day in the same analysis of accessibility limits; and the use of other aspects besides of time as accessibility limits.

With regard to the use of different time limits, alternatives to the use of a single time limit by transport mode (used for the GO case-specific SAL) were suggested. The use of time limits by activity type or by groups of activity types (distinguishing activities of local nature from regional activities) was suggested. Some experts defended the use of time limits by transport mode and activity type (or group), simultaneously. Finally, time limits by purpose, using different limits for analysis and for policy design support, were also suggested.

In addition to the use of accessibility limits by activity type, suggestions were made to further differentiate accessibility limits by time of day. In this context, it would be possible to measure accessibility conditions with regard to preferred use of activity along time of day. The GO case-specific SAL defined the measure of accessibility conditions during morning peak hour (considering the worst case conditions for mobility). The critic arguments gathered during the interviews refer that some activities, such as going to the cinema, are generally pursued outside this period[68].

Finally, some interviewees suggested that the soundness of the SAL could be enhanced by increasing the range of aspects considered as influencing accessibility. In some cases the soundness of the measure of accessibility boundaries are limited by availability of data[69]. In other cases data is available but a way must be found to combine different aspects of the perception of accessibility, such as cost and convenience (besides of time). As discussed during some interviews this can be accomplished using generalized cost functions (which convert cost, time and convenience into one of the three; generally cost).

As with activity type, accessibility limits are a fundamental aspect in the development of any case-specific SAL and must be chosen for each case. The choices to be made, regarding accessibility limits are also neither straightforward nor free of conflict. They require both sensibility of local planners and a thorough knowledge of local travel behaviour (depending on quality and disaggregation of available mobility data). As with activity types it seems reasonable that a compromise-building debate, involving experts on travel behaviour, should be the chosen approach.

As has been argued before the choice of extra soundness of the measure must be balanced with the extra work and cost. Nevertheless, contrarily to the use of aggregation groups, disaggregation of travel time limits, use of different times of day for the

68 In these conditions the accessibility measure of the SAL produces an artificially reduced value of accessibility to these activities.

69 Such as the exclusion of the slope for walking accessibility, or the exclusion of time searching for parking in car accessibility.

measure of accessibility and the use of other aspects besides of time as accessibility limits does not interfere with the synthesising abilities of the SAL. These kinds of actions do only make the process longer but do not really change the process.

This entire discussion sheds light on a very important aspect, which is the importance and influence of the choices made during the development of the SAL for its potential and therefore its soundness. The choices regarding activity types and accessibility limits are of the utmost importance, requiring a thorough reflection. If these choices are made by the same team that later uses the SAL as design support tool, awareness of analysis and design support limitations is guaranteed. If several teams are involved (one for the calibration of the tool and another using its results for strategy development) these aspect should be left clear in the analysis results. So there is a need to specify a list of simplifications and data-related limitations of the analysis results of the instrument.

In summary, activity and activity type choice should be based on the relevance of the activity for travel generation, considering essentially frequency of use and rate of users, level of influence of location on travel, as well as the quality and availability of data. Accessibility limit choices should be based on relevance of detail, considering essential average travel times by activity, level of influence of usual time of day in which activities are used on travel time and level of influence of other aspect on accessibility perception. As with activity and activity type choice, quality and availability of data is naturally also a fundamental factor. The single criterion for the development of the case-specific accessibility measure is soundness. All discussed choices are case-specific depending on the balance between the increase in soundness and the extra work and cost involved. Finally, the best practice for building the accessibility measure seems to be a compromise-building debate involving experts on fields such as, local mobility behaviour, land use, transport and mobility management.

6.2. Feedback for the conceptual framework of the SAL

The testbed used for the SAL provided some valuable feedback for its conceptual framework presented in Chapter 4. First, interviews provided **suggestions for the improvement of the concept of the SAL**. Some of these suggestions have already been incorporated in the present concept. Furthermore, the testbed enabled the **verification of the theoretical potentials and limitations** of the tool, based on both, the application to a real case and the discussion with experts during the interviews. Finally, interviews provided the necessary feedback on the **robustness, utility and practical applicability** of the instrument.

With regard to **suggestions for the improvement of the conceptual framework**, the following main aspects were brought to discussion:

- definition of accessibility classes and clusters;
- definition of the accessibility measure type;
- use of complementary information for design support; and
- definition of political indicators.

Searching for increased soundness of the accessibility measure the definition of accessibility classes and clusters was frequently discussed during interviews. Aiming to enhance the detail of the measure, the use of more accessibility classes or even sub-classes was discussed. This idea was discarded due to exponential increase in complexity of the benchmarking cube. The simple increase from 3 to 4 classes by transport mode would raise the number of categories from 27 to 64. This increase in complexity is clearly not worthwhile with regard to the gain in detail of the measure. Not even the use of sub-classes instead of extra classes is recommendable. For instance the use of a sub-class in class A for all transport modes would involve 25 extra categories in the benchmarking cube (which leads to a total of 52 categories). This is still a high price to pay in complexity for a meagre enhancement of detail.

In any case it is hard to say beforehand how many classes can be required for a specific case analysis. Therefore, at least at the conceptual level, it seems unreasonable to define any further disaggregation besides of the three classes proposed in Chapter 4.

Nevertheless, the application presented in this thesis provides evidence of the importance of distinguishing total accessibility (DivAct=1) from the remaining accessibility class A. This detail on accessibility level was widely used in the definition of strategy groups for detailed strategy (see section 5.3.2). Bearing in mind this example it is easy to conclude that detail on accessibility levels is not compromised by the use of a limited number of classes, which enable systematisation of analysis. Detail can always be recovered for strategy design without compromising the plainness of the analysis measure.

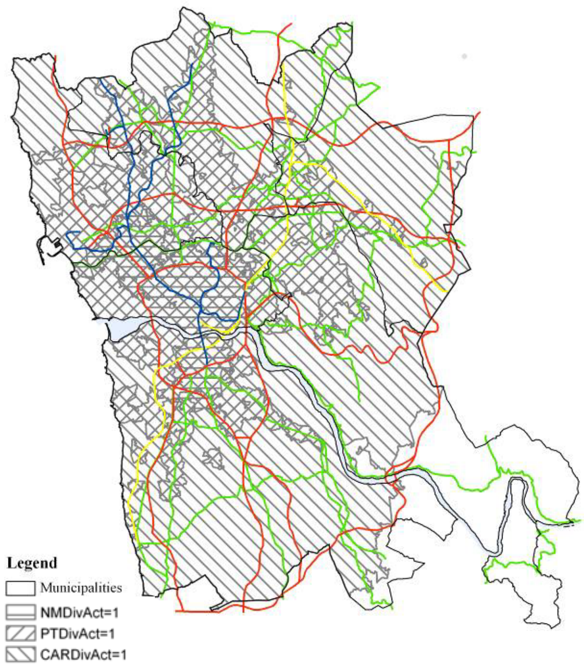


Figure 6.1: Extra map with DivAct=1

In additions, the use of an extra class or sub-class can be replaced by the use of an extra map (to overlap the category map of the SAL) identifying the areas where accessibility level reaches 1 by each transport mode (as shown in Figure 6.1)[70]. Taking into consideration these alternative approaches to recover detail of accessibility levels, the use of more than 3 accessibility classes (or even sub-classes) seem clearly unnecessary. This extra map (complementing mode accessibility levels and category detail) can be included as complementary information used for design support.

Besides of the number of classes, definition of <u>class limits</u> was also discussed during expert interviews. One suggestion made was that of using percentiles to define the three classes. Considering the conceptual meaning of the classes, high, medium and low accessibility (class A, B and C, respectively), the use of percentile 25 and 75 was suggested by interviewees. The first idea was to use percentiles on diversity of activity measure for each transport mode. This would result in different class limits for each transport mode which would weaken the comparative meaning of the sustainability measure (namely of categories and clusters). It seems difficult to produce a categorization of sustainability of potential mobility (based on urban structure

[70] For a detailed map of categories and unitary diversity of activity index by mode, see Figure B.22 in Annex B.

conditions) founded on accessibility classes with different meanings. Therefore, this idea was readily discarded. The second idea was to use percentiles on the cloud of accessibility values in the benchmarking cube. This would define the value separating class A from B as the value of accessibility to diversity of activity exceeded by 25% of the sub-region by all transport modes. The value separating class B from C would be the accessibility to diversity of activity which is not exceeded by 25% of the sub-regions using all transport modes. For the GO case-specific SAL this resulted in a lower limit of accessibility class A of 1 (DivAct=1), meaning that only total accessibility by all transport modes would be included in accessibility class A. The low accessibility class (C) was found for DivAct<0.8. The use of these class limits does not help in the understanding of mobility conditions. It makes no sense to say that only accessibility levels of value 1 are high and that accessibility levels of value 0.99 are medium.

Although the percentile analysis has its virtues for dividing data it cannot be used for the division of the benchmarking cube. In our analysis besides of a relative analysis of results the scale used for the classes is also absolute in meaning (high, medium and low) and therefore can not simply be defined by percentile analysis. There is a need for some sensibility to choose the limits of accessibility classes, but they have to be chosen and adjusted according to local context (results) in order to provide a good view of the general accessibility variations across the study area.

For the GO case-specific SAL the choice of the two values limiting the classes (0.5 and 0.85) was based on the case-specific diversity of activity index (activity types chosen and the potential use of each activity type). Furthermore, the dispersion of results of the sub-regions of the case study in the accessibility cube was also taken into consideration (a detailed description was provided in section 5.2). In practice, limits were chosen based on activities considered more or less important for the measure of everyday accessibility, and considering their influence of the diversity of activity index (based the values of f_y).

Therefore it is reasonable to conclude that the use of percentile or other mathematical methods is inappropriate for the choice of accessibility class limits (nevertheless it can be used to help understand the current distribution of values, which may help in the choice of accessibility class).

With regard to accessibility clusters, experts suggested a slight redefinition of clusters as well as the use of cluster analysis for its definition. The need for redefining some clusters became obvious afters several interviews. The first definition of clusters involved only 7 clusters, reducing the detail of land use and transport conditions provided with regard to mode choice (and distance), mainly centred on walking and car use and giving less attention to public transport use. Basically, categories with high accessibility by both car and public transport were considered to favour only car use. Discussion with experts revealed the obvious imprecision of this simplification. This led to the definition of two new clusters (one for category 7 and another for categories 14 and 15; see Figure 4.8) already incorporated in the conceptual framework of the SAL.

With regard to the use of cluster analysis for the definition of the clusters, this suggestion was discarded. Similarly to the use of percentiles for the definition of classes, the use of any automatic method was excluded for the division of categories into clusters. Clusters have a clear and absolute meaning, resulting from the comparative analysis of accessibility classes by the three transport modes. Division into groups of categories with the same meaning can therefore not be obtained by an automatic method but must be decided in absolute terms.

Another recommendation centred on the use of more complex accessibility measures, considering quantity of activities for the diversity of activity index (i.e. density besides of diversity). This suggestion was based on the argument that for some activity types, the number of establishments of the same activity could have a positive influence on the perception of accessibility. This enhances the probability of neighbourhood establishments to satisfy personal needs, by increasing the available choice. Being so, this suggestion seems an interesting idea for improvement of the soundness of the SAL, which simultaneously does not seem to compromise the plainness of the measure. Naturally, the accessibility measure will become more complex but without increasing the complexity of the tool itself neither of its interpretability and communicability. Nevertheless, within current time constraints, no such formulation for the accessibility measures was found in the current literature. Believing in the interest of this idea, it should be thoroughly studied in future research.

Another suggestion regarding the increase of complexity of the accessibility measure centred on the use of measures considering the influence of distance on accessibility levels. This suggestion implies the use of *potential accessibility measures*, as defined in section 3.2. The enhanced soundness of this accessibility measure is naturally balanced by increased complexity. Regarding theoretical recommendations for plainness of PSS to enhance practical application, the conceptual framework upholds a contour measure for accessibility. However, in practice more complex accessibility measure types can be used in the SAL, as it is defined as a case-specific choice.

With regard to complementary information for the design support component of the SAL, several suggestions were presented by interviewees. One type of information believed to be fundamental by some experts was that of real local travel patterns. Although not being included in the conceptual framework of the SAL, because of its limited contribution for a tool measuring land use and transport conditions for mobility, local travel patterns are fundamental for mobility policy design. Conceptually the tool does not consider real mobility patterns, at least not from a 'predict and provide' perspective. They are neither necessary for the characterization of local land use and transport conditions for mobility, nor for the development of general strategies based on the SAL. On the other hand, this information is essential to ground strategies into concrete policy measures. The general idea behind the SAL is to enable the development of land use and transport conditions which support the variety of patterns in the most sustainable way. This requires the shaping of current mobility patterns within the paradigm of mobility management. In summary, in spite of the importance of real mobility patterns as complementary information they have no role in the SAL itself, as suggested in some discussions.

Another aspect present in the discussion of complementary information was that of employment, considering the possible exclusion of employment as activity type. One idea was to use employment as complementary information for the design support purpose (similarly to how population is used by serving in the identification of strategy groups). Following the same line of thought, an indicator combining employment and population was suggested as a criterion for the division of strategy groups. These ideas have not been explored yet, considering that employment has not been excluded from the testbed. Nevertheless, they should be thoroughly studied in future research.

Another suggestion was the development of political indicators, translating technical indicators into political concerns. One example of political indicators could be the measure of population increase with high non-motorized accessibility, or, even more specifically, the measure of population increase with local access to schools. It is naturally very important to have indicators which are more meaningful to politicians and even to the general population. The use of these indicators enhances the practical usability of the SAL. Nevertheless, political indicators are not conceptual elements providing no extra information to policy design. Therefore, these indicators should be locally developed, according to local interests and concerns. The development of these indicators involves a simple translation of one measure into another, which is easily performed. Therefore, although political indicators can play an important role for the application of the tool, their use and development is a local choice.

Besides of suggestions for the improvement of the conceptual framework, the testbed enabled the **verification of the theoretical potentials and limitations of the SAL** (see Figure 4.12).

The testbed clearly showed the global view and spatial representation enabled by the use of a geographical representation of accessibility measures on a regional scale. Furthermore, the choice for a regional scale enabled the spatial integration of the analysis and development of strategies for the study region (not limited by municipal boundaries). On the other hand, the regional scale of analysis provides no support to micro scale policy (such as street level design). This fact was verified through personal experience and was also stated by several interviewees.

Several experts mentioned the easy of understanding and communicating the measure when asked for advantages of the SAL. This potential was also verified by the application itself, considering that the concept and the results of the tool were easily understood by all interviewees (of different backgrounds). On the other hand, the simplicity of the measures clearly reduced the soundness of the SAL, as referred to by several interviewees during the presentation of the accessibility measure.

The general results on the discussion of the robustness of the SAL revealed, among other aspects, an agreement on the ability to provide a thorough understanding of land use and transport conditions. So being, the potential of high disaggregation levels of data was supported by the results. On the other hand, high disaggregation of data was shown to limit the advantages of using contour measures (namely the ready availability of data). Another limitation clearly shown in the discussion of data-related limitations, presented in section 5.3.3 is that related to the design support ability of the SAL. As discussed in this section, design support abilities are limited to the available data and its reliability. Another drawback of this tool arising from data-related limitations in combination with the high level of local choice involved in the design of the case-specific instrument is related to the usability of the SAL. As discussed before, many choices required for the development of the case-specific tool are not straightforward and are even controversial. These choices should then be a result of a compromise-building debate, involving experts. Nevertheless, according to some interviewees, the amount of choices and the limitation of available data may, in some cases, discourage the use of the SAL. On the other hand, it is clear that the high levels of local choices provide high levels of adaptability of the tool to the analysis of local conditions. Both, the interviews and the real case application provide evidence of this aspect. For instance, the amount of suggestions for the improvement of the GO case-specific SAL (summarised in the previous section), clearly confirm the adaptability of the measure.

Finally, the main advantages of the SAL were confirmed by experts during the interviews. As referred to in section 5.4.1 these main advantages involve the ability to synthesize information, working as an excellent diagnosis tool, and the provision of a framework of thought for the development of integrated land use and transport policies for mobility management. Besides of expert opinion, these aspects were also verified based on the experience of application of the tool to the study region and the development of the illustrative example of strategy design. In fact, the produced analysis maps defined an interesting outline of the main conditions for mobility to be sustainable. The category map provided an interesting diagnosis, identifying regions with better and worst conditions for sustainable mobility. Furthermore, the remaining geographical information enables the detailed knowledge of the reasons behind better and worst conditions for sustainable mobility. Experience of strategy design also revealed the usefulness of the analysis maps of the SAL as well as of the benchmarking cube, providing an interesting framework for the development of strategies.

With regard to **robustness, usability and practical applicability** of the SAL, expert interviews provided a positive evaluation (regardless of some suggestions for improvement of the tool and of sporadic uncertainty concerning some of these aspects). The study of robustness, usability and practical applicability enabled a better definition of the conceptual framework as well as provided a better understanding of the capabilities and scope of application of the SAL. The analysis of robustness provided confidence in the ability of the tool to illustrate land use and transport conditions for mobility. It is fair to say that the sustainability measure defined by the benchmarking cube has passed its first expert evaluation. The enthusiasm with which the SAL was evaluated as useful for policy design support (with experts suggesting even further uses of the SAL) enhances the confidence in its capabilities and in the interest of this instrument for future policy design. Finally, the SAL seems to have a real potential to become a design support tool for regional use, regarding positive evaluations on practical applicability as well as usefulness. The interest shown by some expert in using this tool also reinforces this idea[71].

In summary, it is fair to say that the SAL passed its first test and seems to present interesting potential and capabilities to support the design of integrated land use and transport policies for mobility management. Several improvements have already been studied based on the testbed, some of which are already incorporated in the conceptual framework of the SAL. Nevertheless, further research is still required in practical and theoretical terms.

[71] Another argument in favour of the interest of the SAL is the use of the SAL for the research Project MOPUS (financed by the Portuguese foundation for science and for technology) studying urban mobility patterns in Oporto and Copenhagen.

6.3. Feedback for a second test of the SAL

Personal experience of the first test of the SAL supported by expert interviews provided valuable insight on potential improvements for the test of the SAL on a case study[72]. The underlying idea is to increase complexity and detail essentially with regard to **calibration of the land use system**, **calibration of transport system, accessibility limits** and **involvement of planning practitioners and experts**.

Taking into account the feedback provided by the testbed in sections 6.1 and 6.2 several suggestions can be put forward for the second test application of the SAL. With regard to the **calibration of the land use system**, soundness should be enhanced, for instance, by making the measure of diversity of activities reflect the influence of the number or area of establishments of the same activity type on accessibility perception. This change would produce a continuous measure for each activity type ($Act_y = [0;1]$) instead of the simpler measure of presence or absence of the activity type ($Act_y = \{0;1\}$). As argued in section 6.2 some interviewed experts believe that the number of establishments of the same activity type can have positive influence on the use of that activity by a specific transport mode and therefore a positive influence on the perception of accessibility. In spite of the recognition of the importance of this enhancement to soundness of the SAL such improvement requires further study for the development of an adequate accessibility measure, considering both diversity and density. Therefore, the second case study application must be preceded by a thorough search for ways to operationalise this measure. In addition, a study on the balance between soundness and plainness of the resulting accessibility index is required, especially taking into account the reduction of comprehensibility which may compromise the design support purpose of the SAL.

In addition complexity and detail of the land use system should be enhanced by increasing the disaggregation of activities used. As stated in section 6.1 higher disaggregation levels can have counterproductive effects on soundness if disaggregation is taken too far. In case of the first application to GO there seems to be some room for

[72] These improvements were not put into practice during the PhD research due to time and money constraints. In effect, this thesis simply launches the development of the SAL not intending to finish it. In addition, in spite of the simple case application used for this thesis, results were significant enough to discuss the research question and hypothesis.

higher disaggregation of several activity types as well as a higher selectivity of used activities within each activity types. These actions would bring to light some relevant activities disguised within too inclusive activity types. For instance activity type 14 “Public/Municipal administration offices” should be disaggregated into different public services using strictly those most relevant to travel generation.

Any of these improvements to the soundness of the SAL regarding land use should be based on realistic data of activity types influencing travel generation and influence of density and diversity on accessibility perception. This data should ideally be assembled through stated preference surveys. A high level of involvement of local planning practitioners as well as mobility experts is also desirable to ensure the best possible calibration of the SAL. Their involvement would enable the compromise-building debate suggested in sections 6.1 and 6.2 in the definition of several of the case-specific choices of the SAL as well as in searching for improvements for the SAL.

Another aspect which should be improved for a second test application of the SAL is the **calibration of the transport system**. A more accurate calibration of the transport system should involve the calibration of travel speed considering for instance, slope, existence and quality of sidewalks and crossings for walking speed. With regard to car speed, calibration should consider, for instance, time spend searching for parking (average values by small areas which could be converted into extra travel time and therefore lower average speed) and more detail on congestion, besides average driving speed. The calibration of the public transport system for the first test of the SAL was the most detailed. Nevertheless, improvements are still required. These should involve, for example, the consideration of public transport frequency per route for travel speed (resorting for instance to a composite index such as *speed*vehicles/hour*).

With regard to **accessibility limits**, enhanced soundness of the second test of the SAL can be brought about by the use of more detail. One suggestion is to define accessibility limits for each activity type instead of one single cut-off value for each transport mode. As discussed in section 6.1, this measure would considerably enhance the soundness of the tool without compromising its synthesising abilities of the SAL. Nevertheless it requires a large amount of not readily available information. As with activity type, stated preference surveys are suggested to bridge this gap. Again, high levels of involvement of local planning practitioners as well as mobility experts are also desirable to ensure the best possible calibration of the SAL. Furthermore, a sensitivity analysis of used cut-off times is required. This analysis, although not developed during the first test of the SAL due to time restrictions, is mandatory for the second test.

The use of detailed time limits by activity type could be further enhanced by the use of other accessibility limits besides time, such as cost and convenience. As argued in section 6.1 this improvement of the soundness of the SAL requires frequently unavailable data as well as the development of a measure combining different features of the perception of accessibility into a single measure, such as generalized cost measures. Therefore, prior to the use of several accessibility limits a thorough study is required as to which should be considered and how they should be combined.

Another idea to enhance the soundness of the SAL would be to measure accessibility levels for different times of the day. This would enable the consideration of different traffic conditions for each activity type, with regard to the time of day activities are generally pursued.

In alternative to the use of simple accessibility limits (in the form of cut-off values) a more complex and theoretically sound accessibility measure type could be used, such as the potential accessibility measure. This measure uses distance decay function instead of accessibility limits requiring a calibration based on accessibility perceptions (again not readily available data). Required information should be gathered through stated preference survey (although different from those identifying cut-off criteria and their values) and assembled into the decay function through a compromise-building debate by local planning practitioners and mobility experts. Sensibility analysis is also a requirement in this case.

The application of the SAL to its first test region rendered clear that further steps of the learning cycle require a close **involvement of planning practitioners and mobility experts**. This would enable a thorough test of the usability as design support tool and practical applicability of the SAL as well as enable a faster and sustained improvement of the SAL. Additionally, most improvements suggested in this section for the test application of the SAL require a closer collaboration of planning practitioners and expert on local mobility patterns for the development of the case-specific SAL. Furthermore, it is clear that there is a need to involve experts and planning officials in the design process in order to test the usefulness of the SAL as design support tool in practice and to study the analysis and design abilities of the SAL.

In summary, a second test application of the SAL (for development of this PSS) would require high investment into the soundness of the tool (exploring its capabilities). The diversity of activity index should consider density besides diversity of activities, using a continuous measure of activity type (Act_y = [0;1]). Activity type should be more disaggregate and more selectively chosen. In addition, more attention should be given to the calibration of the transport system, using higher detail, relevant to the accessibility measure. The soundness of the accessibility measure should be improved by the disaggregation of accessibility limits by activity type and time of day, and by using a theoretically sounder accessibility measure type, such as potential accessibility, considering the influence of distance on accessibility. Finally, the second test application of the SAL requires a close involvement of planning practitioners and mobility experts in order to, both, enable and support the soundness improvements, and provide a thorough test of the abilities of the SAL as well as suggestions for further improvements.

6.4. Feedback for theoretical discussion

The testbed used for the SAL provided some valuable lessons for the current theoretical discussion, namely on the **influence of land use and transport on mobility**, on **policy design support instruments** and on **mobility management approaches**.

Regarding the **influence of land use and transport on mobility**, the test used for the SAL supports the importance of several aspects identified in Chapter 2 as influencing mobility. The accessibility measure developed for the instrument incorporates the influence of several land use and transport factors. Among these factors, the case-specific SAL considers diversity of land use as well as availability and service level of the transport system. As argued in Chapter 5, the accessibility maps were found to provide a good representation of real mobility constraints. These results provide support for the importance of the land use and transport factors considered. Other factors, such as land use density, though not studied through the SAL, were suggested by some experts for the improvement of the tool.

This study also provides evidence of the need for a more comprehensive approach to current research on the influence of urban structure on mobility, as a replacement of the complexity and detail driven research approach. High levels of detail and contradictory results have made it almost impossible to find a global view of the influence of land use and transport on mobility. Therefore, there seems to be a need for a comprehensive approach to the influence of urban structure on mobility, one that could be more useful for mobility management.

Finally, with regard to the influence of urban structure on mobility, this research shows that sustainable land use and transport conditions have but modest influence on sustainable travel behaviour. While analysis results of the SAL show that only 10% of the population has no viable alternative to car use, the current modal split of the study region shows that more than 50% of trips are being made by car (see figure 5.5). These results suggest two things: first there seems to be a need for push instead of pull land use and transport measures (i.e. to disable car use instead of simply enable sustainable alternatives); and second there seems to be a need for policy measures on complementary field (influencing for instance lifestyle) in the absence of urban structure push measures.

It is clear that in the absence of an urban structure enabling the use of sustainable modes, sustainable travel cannot be expected. However, it seems also true that the simple presence of those conditions has low influence on sustainable travel. The results of this research support the importance of complementary policy actions (such as policy focussed on changing personal attitudes). In the absence of complementary actions, larger effect on travel behaviour can only be brought about by severe urban structure constraints to car use (using push instead of pull land use and transport measures). The 'necessary but not sufficient' condition of land use and transport for sustainable mobility is left clear by these results.

Concerning **policy design support instruments**, this research supports the contemporary discussion on bottlenecks and recommendations for the use of PSS in the design of integrated of land use and transport policies (see section 1.2). The SAL seems to follow several of the recommendations and cope with some of the main critiques[73].

It is reasonable to say that the SAL does not have some of the traditional bottlenecks of PSS, such as the black box effect, or the low communication value and the lack of interactivity. These are actually some of its advantages. The black box effect, for instance, is avoided by using a simple measure of accessibility which, in addition, is highly adaptable to local contexts (concerning what influences accessibility and how it can be measured). Although the definition of the case-specific SAL requires difficult consensus building, once defined it provides a clear understanding of complexity of the aspects at hand (land use and transport aspects considered relevant in the perception of accessibility). Interviews revealed considerable interest on the case-specific definition of the accessibility measures. All interviewees understood the accessibility measure and even had an opinion on how if should be defined (disregarding of their theoretical knowledge on accessibility measures). This suggests that this measure seems to enhance comprehensiveness of PSS for integrated land use and transport policies.

Additionally, the tool is in accordance with several general recommendations for PSS, such as, using regional level of analysis and policy action, using simple measures, allowing the test of scenarios (interactivity), being transparent and enabling the creation of new insight. The results of the first case study test of the SAL seem to support the importance of these aspects considering the encouraging feedback obtained and the positive personal experience. For instance, the case study test clearly confirms the importance of the regional scale for analysis and policy action, in accordance with Straatemeier and Bertolini (2008). Mobility management requires large scale study areas, enclosing most mobility patterns (mobility catchment areas). The use of the regional scale was fundamental for the soundness of the accessibility measure and for the complete understanding of mobility conditions. Furthermore, the regional scale of

[73] It is important to highlight that some of the evidences of the referred research are contemporary to this research and therefore have been developed almost simultaneously.

analysis enabled a strategic planning approach which according to these authors is also fundamental.

Finally this research provides feedback to the theoretical discussion by creating and testing the usefulness of a **new approach to mobility management** based on the concept of comparative accessibility by transport mode.

The results of this research provide support for the usefulness of the concept of comparative accessibility by transport mode for both, the understanding of urban structure constraints for sustainable mobility, and the design of integrated land use and transport policies.

Interviews suggest that the use of a comparative accessibility measure enables the understanding of current constraints of urban structure on mobility. It also seems to enable the development of a conception of desired urban structure.

This research suggests that the usefulness of comparative accessibility as design support tool results from both, the ability to synthesise large amounts of information providing a meaningful sustainability measure of urban structure conditions for mobility, and the interesting balance between soundness and plainness.

The case-specific application of the SAL suggests that comparative accessibility measures provide a framework for the development of integrated land use and transport policies. The use of a comparative measure of accessibility has an important role in the ease of use and understanding of the SAL, being central to its synthesising ability. Accessibility clusters defined by the benchmarking cube (see Figure 4.8) were considered by experts as a good representation of the conditions for particular mobility patterns. Furthermore, the relationship of clusters with the sustainability of potential mobility patterns was recognized and was also considered interesting for policy building.

The comparative accessibility measure plays also a key role in the balance between soundness and plainness of the SAL. It enables the use of simple measures of accessibility (easy to use and understand) which are then combined in a comprehensive measure (which is also easy to use and understand). Therefore, the results of the first case study test of the SAL suggest that the comparative accessibility measure is very useful as an operational form of accessibility for policy design support.

In summary, it seems fair to say that this research provides evidence of the importance of the referred land use and transport factors for mobility. Consequently, a comprehensive approach to the study of the influence of urban structure on mobility was found to be more useful for mobility management. Additionally, this research shows that the SAL is in accordance with and confirms contemporary research on PSS (namely bottlenecks and recommendations for use in practice). Finally, this research suggests that the concept of comparative accessibility by transport mode provides a useful design support tool for integrated land use and transport policies (being a measure of potential sustainability of mobility patterns).

Chapter 7

CONCLUSION

This research was motivated by a personal concern on the growing lack of sustainability of urban mobility patterns. It is grounded on the assumption that the integration of land use and transport policies has the potential of providing the necessary urban structure to steer mobility within sustainable patterns. In a context of lack of implementation of integrated land use and transport policies, this research aims to cope with one of the implementation barriers: the lack of design support tools. Therefore, it studies the potential of the accessibility concept to provide a suitable framework for the development of design support tools for integration of land use and transport policies.

This thesis hypothesises that measures of comparative accessibility by transport mode are able to operationalise the accessibility concept for this purpose. In order to test this hypothesis, a design support tool was developed, based on a measure of comparative accessibility – the Structural Accessibility Layer (SAL). The comparative measure was made operational by the benchmarking cube.

The test of the SAL provided insights into its potentials as design support tool for integrated land use and transport policies. From a personal perspective (as user for the GO case study), the SAL was found to be a suitable diagnosis tool and useful for strategy development. The accessibility maps by transport mode provided an adequate representation of local conditions for mobility. The synthesising map (representing categories and clusters) provided insight into mobility constraints for sustainability from a whole new perspective. Finally, the SAL, as well as its results from the analysis stage, was useful for strategy development supporting the construction of a vision for the study region.

Personal perceptions of the capabilities of the SAL were supported by expert opinions. The SAL was in general well accepted by interviewed experts. There was a clear interest on the conceptual framework and on its application. The interest and capabilities of the SAL as design support tool for integrated land use and transport polices were confirmed. Expert interviews revealed a general recognition of the robustness, usefulness and applicability of the tool. The GO case-specific accessibility maps and the category map were considered to be a good representation of local conditions providing interesting insights for policy design purposes. In addition, some experts mentioned other potential purposes for the tool, such as, support the definition of public transport services and of land prices, and support the design of urban projects.

It is fair to say that the SAL passed its first test and seems to present interesting potentials and capabilities to support the design of integrated land use and transport policies for mobility management. A range of theoretical potentials and limitations were identified during this first stage of development (see Figure 4.12). Several improvements have already been identified based on the testbed, some of which are already incorporated in the conceptual framework presented in Chapter 4. Nevertheless, further research is still required in practical and theoretical terms.

The results of the testbed also provide support for the research hypothesis. The comparison of accessibility levels by transport mode is a key element of the SAL. This element has revealed itself essential for design support by enabling the development of simple and understandable aggregate measures and synthesising a large amount of detailed information. The benchmarking cube, build upon the idea of comparison of accessibility measures by mode, provides a useful measure of sustainability of urban structure conditions for mobility. This measure links land use and transport conditions to sustainability of potential mobility (based on potential mode choice).

Additionally, two other elements contribute to the design support capability of the SAL besides the use of comparative accessibility by transport mode. First, the use of a simple and locally defined accessibility measure – the diversity of activity index – and second the fact that the values of this accessibility measure ranges within specific (pre-defined) boundaries.

The use of the diversity of activity index provides a clear measure of the proportion of main travel generating opportunities which are accessible by each transport mode. This index provides an absolute measure (in contrast to relative 'the higher the better' measures) enabling a realistic comparison of viability of transport mode use. This aspect was essential for the definition of accessibility clusters based on their sustainability meaning. Therefore, the use of an accessibility concept whose value ranges within fixed boundaries was fundamental for the design support abilities of the SAL.

In addition, the use of a simple and locally defined accessibility measure is essential to support the translation of objectives into required actions. As the accessibility measure of the SAL is a local construct (dependent on several local choices), users possess a thorough understanding of its meaning, thus, understanding how desired variations in accessibility (objectives) are translated into variations of land use and transport conditions.

Although the use of comparative accessibility by transport mode is not solely responsible for the usefulness of the SAL as design support tool, it is clearly a baseline element. Furthermore, it facilitates the use of another essential element contributing to the capability of the SAL as a design support tool – simple accessibility measures. Comparing accessibility provides a simple form of aggregation of data avoiding the use of complex accessibility measures.

In conclusion, the use of comparative accessibility provides three clear advantages:

- it enables the categorization of urban structure conditions for sustainable mobility;
- it enables the development of simple and understandable aggregate accessibility measures; and,

- it enables the use of simple accessibility measures (without jeopardizing the soundness of the tool).

In summary, the SAL seems to provide a useful operational form of the accessibility concept for design support, using comparative accessibility by mode and the diversity of activity index as accessibility measure. The use of comparative accessibility has clearly a key role in the ease of understanding of the SAL, being central to its synthesising ability. In addition, it is fundamental for the design support purpose of this tool by supporting the development of the benchmarking cube and enabling the use of simple accessibility measures.

The **main conclusion** to be drawn from this research is that:

Measures of comparative accessibility by transport mode seem to provide a useful design support framework for integrated land use and transport policy shedding light on the sustainability of potential mobility enabled by land use and transport conditions.

Finally, the **main contributions** of the thesis could be summarised as follows:

- a design support tool for integrated land use and transport policies: the SAL (in development);
- a new accessibility measure: the diversity of activity index;
- a new accessibility concept for policy design: comparative accessibility by transport mode;
- and, a new perspective for the study of the interaction of urban structure and mobility: the constraint of sustainable mobility by land use and transport conditions.

7.1. Future Research

The research developed within this thesis opens several new branches for research and raises new questions. One aspect left in its early stage is that of development of the SAL. Considering the positive feedback of the first case study test there is a need to continue the development process started with this thesis. This involves the test of the tool using multiple case studies and finally within a real planning application. One future test of the tool is already assured by the research project MOPUS (MObility Patterns and Urban Structures) funded by the Portuguese Foundation for Technology and for Science. This project includes a case study on the region of Copenhagen. Future stages of the development process will require research on the following aspects:

- Improvement of the accessibility measure used in the SAL (the diversity of activity measures). Study the inclusion of density of activities for the accessibility measure. Study the relevance of this potential improvement.
- Study the inclusion or exclusion of employment as activity for a case-specific SAL (and the alternative use as complementary information).
- Resort to a higher involvement of policy makers for the following case studies to provide a better evaluation of current usability as well as enhance that usability.

It is important to highlight that any further research will need to cope with technological limitations (namely software limitation). This can be done through, for instance, the development of new or complementary software. Current land use or transport software seems to be inappropriate for the used accessibility conception.

Besides of continuing the development process for the SAL, other aspects require further research. The following list provides some suggestions:

- Use the concept of accessibility to clarify the interaction between urban structure and mobility patterns. Study the added value of the use of this concept for this research field.
- Study the relationship between potential mobility enabled by the urban structure and real mobility patterns (developing studies of both aspects for the same case studies) to enlighten the potential and limits of use of accessibility concepts measuring potential mobility as design support tools.
- Study the relationship between comparative accessibility by transport mode and the perception of conditions for sustainable mobility (developing studies of both aspects for the same case studies) to enlighten the potentials and limits of the use of relative accessibility within design support tools.

- Search for other formulations of comparative accessibility measures for design support tools of integrated land use and transport policies (besides the SAL).

REFERENCES

Banister, D. (1994a). Transport Planning. E&FN Spon. London.

Banister, D. (1994b). Reducing the need to travel through planning. *Town Planning Reviews* 65(4). 349-354.

Bertolini, L., Clercq, F. and Kapoen, L. (2005). Sustainable accessibility: a conceptual framework to integrate transport and land use plan-making. Two test-applications in the Netherlands and a reflection on the way forward. *Transport Policy* 12(3). 207-220.

Boarnet, M. and Chalermpong, S. (2001). New Highways, House Prices, and Urban Development: A Case Study of Toll Roads in Orange County. CA. *Housing Policy Debate* 12(3), 575-605.

Boarnet, M. and Crane, R. (2001a). The influence of land use on travel behavior: specification and estimation strategies. *Transportation Research Part A: Policy and Practice* 35(9). 823-845.

Boarnet, M. and Crane, R. (2001b). Travel by Design. Oxford University Press.

Boarnet, M. and Haughwout, A. (2000). Do Highways matter? Evidence and Policy Implications of Highways' influence on metropolitan development. *Discussion paper prepared for the Brookings Institution Centre on Urban and Metropolitan Policy*

Boarnet, M. and Sarmiento, S. (1998). Can land-use policy really affect travel behaviour? A study of the link between non-work travel and land-use characteristics. *Urban Studies* 35(7). 1155-1169.

Brömmelstroet, M. (2007). Desired characteristics of expert knowledge to support the integration of land use and transport planning. *Proceeding of the Bijdrage aan het Colloquium Vervoersplanologisch Speurwerk 2007*, Antwerpen.

Calthrop, E., Proost, S. and van Dender, K. (2000). Parking policies and road pricing. *Urban Studies* 37(1). 63-76.

Cameron, I. Lyons, T. and Kenworthy, J. (2004). Trends in vehicle kilometres of travel in world cities, 1960–1990: underlying drivers and policy responses. *Transport Policy* 11. 287-298.

Cardoso, N. and Silva, P. (1997). O sistema de transportes na Área Metropolitana do Porto. *Estatísticas e Estudos Regionais* 14. INE.

Cervero, R. (1995). Planned Communities, Self-Containment and Commuting - a Cross-National Perspective. *Urban Studies* 32(7). 1135-1161.

Cervero, R. (2002). Built environments and mode choice: toward a normative framework. *Transportation Research Part D: Transport and Environment* 7. 265-284.

Cervero, R. (2003). Growing smart by linking transportation and land use: perspectives from California. *Built Environment* 29(1). 66-78.

Cervero, R. and Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment* 2(3). 199-219.

Cervero, R. and Landis, J. (1995). The Transportation-Land Use Connection Still Maters. *Access* 7. 2-10.

Chin, A. and Smith, P. (1997). Automobile ownership and government policy: The economics of Singapore's vehicle quota scheme. *Transportation Research Part A: Policy and Practice* 31(2). 129-140.

Chu, S. (2002). Auctioning rights to vehicle ownership: Singapore's experience with sealed-bid tenders. *Transportation Research Part A: Policy and Practice* 36(6). 555-561.

CMP (2003). Transportes e Mobilidade. Síntese Final. CMP, Porto.

Crane, R. (1996). On form versus function: will the New Urbanism reduce traffic, or increase it? *Journal of Planning Education and Research* 15. 117-126.

Crane, R. and Scweitzer, L. (2003). Transport and Sustainability: The role of the built environment. *Built Environment* 29(3). 238-252.

Cullinane S. (2003). Hong Kong's low car dependence: lessons and prospects. *Transport Policy* 11. 25-35.

DANTE Consortium (1998). DANTE - Designs to Avoid the Need to Travel in Europe. Project Funded by the European Commission under the Transport RTD Programme of the 4th Framework Programme.

DGAP (1999). Dados de Emprego na administração pública em 1999. DGAP. Lisboa.

DGEEP (2004). Quadros de Pessoal 2004. DGEEP. Lisboa.

Dieleman, F., Dijst, M. and Burghouwt, G. (2002). Urban form and travel behaviour: Micro-level household attributes and residential context. *Urban Studies* 39(3). 507-527.

EC (2000). Cidades para Bicicletas, Cidades de Futuro. European Commission. Belgium.

EC (2001). Integrated Policy aspects of sustainable mobility. Paper 1 of the Thematic synthesis of Transport Research Results. European Commission.

Ewing, R. and Cervero, R. (2001). Travel and the Built Environment. *Transportation Research Record* 1780. 87-114.

Expert Group on the Urban Environment (1996). Sustainable European Cities. European Commission.

Fujii, S. and Kitamura, R. (2003). What does a one-month free bus ticket do to habitual drivers? An experimental analysis of habit and attitude change. *Transportation* 30(1). 81-95.

Gärling, T., Eeka, D., Loukopoulosa, P., Fujii, S., Johansson-Stenmand, O., Kitamurac, R., Pendyalae, R. and Vilhelmson, B. (2002). A conceptual analysis of the impact of travel demand management on private car use. *Transport Policy* 9(1). 59-70.

Geerlings, H. and Stead, D. (2003). The integration of land use planning, transport and environment in European policy and research. *Transport Policy* 10(3). 187-196.

Geertman, S. (2006). Potentials for planning support: a planning-conceptual approach. *Environment and Planning B: Planning and Design* 33. 863-880.

Geurs, K. and Eck, J. (2001). Accessibility measures: review and applications. Evaluation of accessibility impacts of land-use-transport scenarios, and related social and economic impacts. National Institute of Public Health and the Environment, Bilthoven.

Geurs, K. and Wee, B. (2004) Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography* 12. 127–140.

GIASE (2006). Recenseamento Escolar 06/07. Gabinete de Avaliação e Informação do Sistema Educativo. Ministério da Educação.

Giuliano, G. (1989). Research policy and review 27. New directions for understanding transportation and land use. *Environment and Planning A* 21. 145-159.

Giuliano, G. (1995). The weakening Transport-Land Use connection. *Access* 6. 3-11.

Giuliano, G. and Narayan, D. (2003). Another look at travel patterns and urban form: The US and Great Britain. *Urban Studies* 40(11). 2295-2312.

Greiving, S. and Kemper, R. (1999). Integration of Transport and Land Use Policies: State of the Art. Deliverable 2b of the European Project TRANSLAND. European Commission.

Halden, D. (2002) Using accessibility measures to integrate land use and transport policy in Edinburgh and the Lothians. *Transport Policy* 9, 313–324.

Halden, D., McGuigan, D., Nisbet, A. and McKinnon, A. (2000). Accessibility: Review of measuring techniques and their application. Scottish Executive, Edinburgh.

Handy, S. (1996). Methodologies for exploring the link between urban form and travel behavior. *Transportation Research Part D: Transport and Environment* 1(2). 151-165.

Handy, S. and Clifton, K. (2001). Local shopping as a strategy for reducing automobile travel. *Transportation* 28(4). 317-346.

Handy, S. and Niemeier D. (1997) Measuring accessibility: an exploration of issues and alternatives. *Environment and Planning A* 29(7). 1175-1194.

Hoetjes, P. (2007). Planning as a Design Science – Design Science as a Methodology. *Proceeding of the AESOP 2007*, Naples.

Holl, A. (2004). Manufacturing location and impacts of road transport infrastructure: empirical evidence from Spain. *Regional Science and Urban Economics* 34. 341-363.

Hull, A. (2005). Integrated transport planning in the UK: From concept to reality. *Journal of Transport Geography* 13(4). 318-328.

INE (1991). Recenseamento Geral da População 1991. INE. Lisboa.

INE (2000). Inquérito à Mobilidade da População Residente 2000. INE. Lisboa.

INE (2001). Recenseamento Geral da População 2001. INE. Lisboa.

Ingram, D. (1971). Concept of Accessibility - Search for an Operational Form. *Regional Studies* 5(2).101-107.

ISIS (1999). Outline of Concept. Deliverable 1 of the European Project TRANSLAND. European Commission.

Kenworthy, J. and Laube, F. (1999). Patterns of automobile dependence in cities: an international overview of key physical and economic dimensions with some implications for urban policy. *Transportation Research Part A: Policy and Practice* 33. 691-723.

Kenyon, S. and Lyons, G. (2003). The value of integrated multimodal traveller information and its potential contribution to modal change. *Transportation Research Part F - Traffic psychology and behaviour* 6(1). 1-21.

Kitamura, R., Fujii, S. and Pas, E. (1997). Time-use data, analysis and modeling: toward the next generation of transportation planning methodologies. *Transport Policy* 4(4). 225-235.

Kockelman, K., Siethoff, B., Walton, M. and Mahmassani, H. (2002). Research on relationships between transportation infrastructure & increase in vehicle miles traveled: the effects of highway capacity expansion on land development. Final Technical Report for the U.S. Environmental Protection Agency. Center for Transportation Research. University of Texas. Austin.

Levine, J. and Grab, Y. (2002). Congestion pricing's conditional promise: promotion of accessibility or mobility? *Transport Policy* 9(3). 179-188.

Liu, S. and Zhu, X. (2004). Accessibility Analyst: an integrated GIS tool for accessibility analysis in urban transportation planning. *Environment and Planning B: Planning and Design* 31. 105-124.

Lopes, A. (1980). Desenvolvimento Regional. Fundação Calouste Gulbenkian. Lisboa.

Mageean, J. and Nelson, J. (2003). The evaluation of demand responsive transport services in Europe. *Journal of Transport Geography* 11(4). 255-270.

Makrí, M. (2001). Accessibility Indices. A Tool for Comprehensive Land-use Planning. *Proceedings of the TLEnet 5th workshop*. Nynäshamn, Sweden.

Marshall, S. and Banister, D. (2000). Travel reduction strategies: intentions and outcomes. *Transportation Research Part A: Policy and Practice* 34(5). 321-338.

Martens, M and Eijkelenbergh, P. (2002). Assessment of integrated land use and transport planning strategies. Deliverable 2 of the European project TRANSPLUS – Transport Planning, Land Use and Sustainability. European Commission, Brussels.

May, A. (2003). Developing Sustainable Urban Land Use and Transport Strategies. A Decision Makers' Guidebook, Deliverable n.15 of the European project PROSPECTS. European Commission. Brussels.

Meijers, E. and Stead, D. (2004). Policy integration: what does it mean and how can it be achieved? A multi-disciplinary review. Berlin Conference on the Human Dimensions of Global Environmental Change: Greening of Policies – Interlinkages and Policy Integration.

Meyer, M. (1999). Demand management as an element of transportation policy: using carrots and sticks to influence travel behavior. *Transportation Research Part A: Policy and Practice* 33(7-8). 575-599.

Mokhtarian, P. and Salomon, I. (2001). How derived is the demand for travel? Some conceptual and measurement considerations. *Transportation Research Part A: Policy and Practice* 35(8). 695-719.

NEA (2003). Integration and Regulatory Structures in Public Transport. Final Report. European Commission DG TREN.

Newman, P. and Kenworthy, J. (2000). Sustainable Urban Form: The Big Picture. *In*: Williams, K., Burton, E., Jenks, M., Jenks, M. (Ed), Achieving Sustainable Urban Form. Routledge. 109-120.

Parkhurst, G. (2000). Influence of bus-based park and ride facilities on users' car traffic. *Transport Policy* 7. 159-172.

Paulley, N. (2002). Recent studies on key issues in road pricing. *Transport Policy* 9(3). 175-177.

Pinho, P. (Coordinator) (2007). Programa estratégico de desenvolvimento do Metro do Porto. Laboratório de Planeamento, Faculdade de Engenharia da Universidade do Porto. Metro do Porto.

Pirie, G. (1981). The Possibility and Potential of Public-Policy on Accessibility. *Transportation Research Part A: Policy and Practice* 15(5). 377-381.

Potter, S. and Skinner, M. J. (2000). On transport integration: a contribution to better understanding. *Futures* 32(3-4). 275-287.

Raux, C. and Souche, S. (2004). The acceptability of urban road pricing - A theoretical analysis applied to experience in Lyon. *Journal of Transport Economics and Policy* 38. 191-215.

Rodenburg, C; Ubbles, B. and Nijkamp, P. (2002). Policy scenarios for achieving sustainable transport in Europe. *Transport Reviews* 22(4). 229-472.

Root, A. (2001). Can travel vouchers encourage more sustainable travel? *Transport Policy* 8(2). 107-114.

Rye, T. (2002). Travel plans: do they work? *Transport Policy* 9(4). 287-298.

Schnurr (1998). Introduction. *In*: Schnurr, J. and Holtz, S. (Eds.), The Cornerstone of Development. IDRC Books Online. Canada.

Schwanen, T., Dieleman, F. and Dijst, M. (2001). Travel behaviour in Dutch monocentric and polycentric urban systems. *Journal of Transport Geography* 9(3). 173-186.

Schwanen, T., Dijst, M. and Dieleman, F. (2004). Policies for urban form and their impact on travel: The Netherlands experience. *Urban Studies* 41(3). 579-603.

Shepherd, S. (2003). Towards marginal cost pricing: A comparison of alternative pricing systems. *Transportation* 30(4). 411-433.

Silva, C. (2004). Interchange in public transport service: necessary or misjudged problem? Msc Dissertation by the Faculty of Engineering of the University of Oporto. Oporto.

Simmonds, D. and Coombe, D. (2000). The Transport Implications of Alternative Urban Forms. *In*: Williams, K., Burton, E., Jenks, M., Jenks, M. (Ed), Achieving Sustainable Urban Form. Routledge. 121-130.

Stanilov, K. (2003) Accessibility and Land Use: The Case of Suburban Seattle, 1960–1990. *Regional Studies*, 37(8), 783–794.

STCP (2007). Relatório de Contas 2006. STCP, Porto.

Stead, D. (2001). Relationships between land use, socioeconomic factors, and travel patterns in Britain. *Environment and Planning B: Planning and Design* 28. 499-528.

Stead, D. (2003). Transport and land-use planning policy: really joint up? *International Social Science Journal* 55(2). 333-347.

Stead, D., Geerlings, H. and Meijers, E. (2003). Integrated land use planning, transport and environmental policy-making: an international comparison. NOVEM, Utrecht.

Stead, D. and Meijers, E. (2004). Policy integration in practice: some experiences of integrating transport, land-use planning and environmental policies in local government. Berlin Conference on the Human Dimensions of Global Environmental Change: Greening of Policies – Interlinkages and Policy Integration.

Stead, D., Williams, J. and Titheridge, H. (2000). Land use, transport and people: identifying the connections. *In*: Williams, K., Burton, E., Jenks, M., Jenks, M. (Ed), Achieving Sustainable Urban Form. Routledge. 174-186.

Straatemeier, T (2006) Accessibility: an interesting concept to address strategic planning issues in the Amsterdam region? *Proceeding of the AMIDSt: Transportation Planning a Policy Design Challenge*, Amsterdam.

Straatemeier, T. and Bertolini, L. (2008). Joint Accessibility Design: a framework developed for and with practitioners to stimulate the integration of regional land-use and transport strategies in the Netherlands. *Proceeding of theTRB 2008*. Washington D.C.

Thorpe, N., Hillsa, P. and Jaensirisak, S. (2000). Public attitudes to TDM measures: a comparative study. *Transport Policy* 7(4). 243-257.

Timmermans, H., Waerdena, P., Alvesb, M., Polakb, J., Ellisc, S., Harveyc, A., Kurosed, S. and Zandeee, R. (2003). Spatial context and the complexity of daily travel patterns: an international comparison. *Journal of Transport Geography* 11(1). 37-46.

Van, U. and Senior, M. (2000). The contribution of mixed land use to sustainable travel in cities. *In*: Williams, K., Burton, E., Jenks, M., Jenks, M. (Ed), Achieving Sustainable Urban Form. Routledge. 139-148.

Viegas, J. (2001). Making urban road pricing acceptable and effective: searching for quality and equity in urban mobility. *Transport Policy* 8(4). 289-294.

Vonk, G., Geertman; S. And Schot, P. (2005). Bottlenecks blocking widespread usage of planning support systems. *Environment and Planning A* 37. 909-924.

Vonk, G., Geertman, S. And Schot, P. (2007). A SWOT analysis of planning support systems. *Environment and Planning A* 39. 1699-1714.

Wee, B. (2002). Land use and transport: research and policy challenges. *Journal of Transport Geography* 10 (4). 259-271.

Wegner, M. and Fürst, F. (1999). Land-Use Transport Interaction: State of the art. Deliverable 2a of the European Project TRANSLAND. European Commission.

Weisbrod, G., Ben-Akiva, M. and Lerman, S. (1978). Tradeoffs in residential location decisions: Transportation versus other factors. original version, September 1978; later published in *Transportation Policy and Decision-Making* 1(1), 1980.

Annex A

CASE-SPECIFIC SAL – CHOICES

A.1. Activities considered for each activity type

The activities considered as the most important for travel generation were chosen from a list classifying all Portuguese activities – the Portuguese Classifications of Economic Activities (‘Classificação Portuguesa de Actividades Económicas’, in abbreviation CAE). In addition, other important travel generators, not classified as activities by the CAE, were also considered for the activity structure of the SAL.

Employment, school, leisure, shopping and healthcare activities as well as public and private services were considered as the most relevant for travel generation. These larger themes were divided into 18 activity types.

Activity types 4 and 18 (‘parks, public gardens and squares’ and ‘employment’) identify two activity types defined among main travel generators absent for the CAE list. ‘Parks, public gardens and squares’ (activity type 4) was included for the activity structure recognizing the importance of these urban elements for current leisure and free-time activities (although parks are not real economic activities, they are clearly travel generators). ‘Employment’ (activity type 18) was also included due to its importance for travel generation.

The remaining activity types grouped different activities from the CAE list. Table A.1 presents these activity types as well as the detailed activities, identified by its CAE code, of each activity type. The Classification and designation of each activity used for the SAL is presented in Table A.2.

Table A.1: Activity types and activities

	Activity type (y)	CAE associated
Schools:		
• Infant and Elementary school	1	801
• High school	2	802
• University	3	803
Leisure/Entertainment:		
• Parks, public gardens, squares	4	-
• Restaurants	5	553, 555
• Cinema	6	921
• Shows / Theatre	7	923,
• Sport	8	926
• Others (ex: Museums, Libraries, Night clubs, etc)	9	554, 925, 927
Shopping:		
• Food	10	521, 522
• Others	11	521, 524, 525, 526, 527
Healthcare		
• Pharmacies	12	523,
• Hospitals and Clinics	13	851
Other Activities		
• Public/Municipal administration offices	14	751, 752, 753, 853,
• Postal Office	15	641
• Banks	16	65
• Others (ex: Insurance, Lawyers, Architects, financial advisers, etc)	17	66, 67, 93
Employment		
• Employment	18	-

The presence of a given activity type by sub-region of the study area (Act_y; see equation 4.1) was defined based on statistical and geographical data. With regard to activity type 4 (parks) availability was defined geographically, giving those sub-regions including parks, public gardens or important squares the value of 1 (Act_4=1). With regard to activity type 18 (employment), a sub-region was considered to have (enough) employment in case sub-regional employment exceeded 50% of sub-regional population (which is the average rate of population in working age in the GO). For the remaining activity types, their availability by sub-region is evaluated based on sub-regional statistical data of establishments by activity type. If, at least, one establishment is found in the sub-region, of a given activity type, that activity type will be considered available (therefore Act_y = 1)[74].

[74] Statistical data of establishments by CAE are not available by sub-region. See section A.2 for detail on spatial disaggregation of statistical data concerning establishments by CAE.

Table A.2: CAE classification and designation[75]

Division	Group	Designation
52	-	Retail Trade (except automobile) *Comércio por grosso e agentes do comércio, excepto de veículos automóveis e de motociclos*
	521	Retail trade in non specialized shops *Comércio a retalho em estabelecimentos não especializados*
	522	Retail trade of food, drinks and tobacco in specialized shops *Comércio a retalho de produtos alimentares, bebidas e tabaco em estabelecimentos especializados*
	523	Retail trade of pharmaceutical, medical, cosmetic and hygiene products *Comércio a retalho de produtos farmacêuticos, médicos, cosméticos e de higiene*
	524	Retail trade of other products in specialized shops *Comércio a retalho de outros produtos novos em estabelecimentos especializados*
	525	Retail trade of second hand product *Comércio a retalho de artigos em segunda mão em estabelecimentos*
	526	Retail trade of outside regular shops *Comércio a retalho não efectuado em estabelecimentos*
	527	Reparation of personal and domestic goods *Reparação de bens pessoais e domésticos*
55	-	Accommodations and Catering *Alojamento e restauração (restaurantes e similares)*
	553	Restaurants *Restaurantes*
	554	Bars *Estabelecimentos de bebidas*
	555	Canteens and catering *Cantinas e fornecimento de refeições ao domicilio (catering)*
64	-	Post Office and telecommunication *Correios e telecomunicações*
	641	Post Office activities *Actividades dos correios*
65	-	Financial support *Intermediação financeira, excepto seguros e fundos de pensões*
66	-	Insurance, Funds and Pensions *Seguros, fundos de pensões e de outras actividades complementares de segurança social*
67	-	Auxiliary activities *Actividades auxiliares de intermediação financeira*
75	-	Public administration, defence and social security *Administração publica, defesa e segurança social obrigatória*
	751	General Public Administration *Administração publica em geral, económica e social*
	752	Foreign management, defence, justice, security, public order and civil guard *Negócios estrangeiros, defesa, justiça, segurança, ordem pública e protecção civil*
	753	Social Security *Segurança social*
80	-	Education *Educação*

[75] This table presents the CAE version 2.1 (revised in 2003) presenting only the general code until 3 digits (which according to this classification is the 4th level of classification or 'Group', the 3rd level using only 2 digits is called the 'Division'). The table also presents the designation of each activity class. English names are a result of a free translation of the Portuguese designation (presented in italic).

Division	Group	Designation
	801	Infant and elementary schools *Ensino Pré-escolar e básico (1º ciclo)*
	802	High schools *Ensino Básico (2º e 3º ciclos) e secundário*
	803	University *Ensino superior*
85	-	Healthcare *Actividades de saúde humana*
	851	Healthcare *Actividades de saúde humana*
	853	Social security activities *Actividades de acção social*
92	-	Recreational, cultural and sport activities *Actividades recreativas, culturais e desportivas*
	921	Cinematographic and video activities *Actividades cinematográficas e de vídeo*
	923	Other artistic and sow business activities *Outras actividades artísticas e de espectáculo*
	925	Libraries, archives, museums and other cultural activities *Actividades das bibliotecas, arquivos, museus e outras actividades culturais*
	926	Sport activities *Actividades desportivas*
	927	Other recreational activities *Outras actividades recreativas*
93	-	Other service activities *Outras actividades de serviços*

A.2. Disaggregation of statistical data at census track level

Statistical data required at census track level included population, employment and number of establishments by activity type. Data concerning population at census track was provided by the national census developed in 2001 by the National Institute of Statistics (INE, 2001). Data concerning employment is available at parish level for private sector employment (DGEEP, 2004) and at the municipal level (and by institution) for public sector employment (DGAP, 1999). Public employment was disaggregated by census track using the location of each public institution. Private sector employment was disaggregated by census track proportionally to the rate of not exclusively residential buildings (building allowing activities) of each sub-region in the parish[76] (see the following equation).

$$E_i = E_j * \frac{B_i - Bh_i}{B_j - Bh_j} \qquad \textbf{[A.1]}$$

With E_i the employment of census track i, Ej the employment at parish j including census track i, B_i total buildings in census track i, Bh_i exclusively residential buildings in census track i, B_j total buildings in parish j, Bh_j exclusively residential buildings in parish j, and '$B - Bh$' not exclusively residential buildings (i.e. building with activities)[77].

Statistical data on establishments, disaggregated by CAE, are available for the public sector disaggregated by municipality and by public service (DGAP, 1999)[78] and for the private sector disaggregated by parish (DGEEP, 2004). As with employment, the disaggregation by census track of public sector data was brought about by identifying

[76] This disaggregation method is an acceptable simplification for most situations. One exception is that of shopping centres, which hold considerably higher employment density per building (only one building) then general. In order to consider this reality, the value of total buildings, of the sub-regions comprising shopping centres and of the respective parish, is increased by the number of shops in the shopping centre (which are therefore considered as buildings instead of shops) minus 1 (which is the shopping centre itself, now replaced by its shops). The number of shops in each shopping centre was based on data of the project developed by Pinho *Coor*. (2007). Another exception is for instance disaggregation of employment areas in industrial areas. Nevertheless as no general criteria could be found this error was not corrected.

[77] The data required for this disaggregation of employment data was provided by INE (2001).

[78] Due to confidentiality concerns, statistical data on public establishments was limited. Therefore, this data was complemented by data collected for the research project developed by Pinho *Coor*. (2007).

the location on map. The disaggregation of private establishments by census track was a result of the following algorithm:

```
If NEstAct_yj ≥ N
   If cod_SS > N
            Act_yi=0
   Else
            Act_yi=1
   End If
Else
   If cod_SS > NEstAct_yj
            Act_yi=0
   Else
            Act_yi=1
   End If
End If
```

[A.2] (For each activity type *y* and each sub-region *i*)

With $NEstAct_y$ the number of establishments of activity type y in the parish *j*, *N* the number of sub-regions in the parish *j* having buildings with activities (B_i-Bh_i>0), *cod_SS* an increasing code (beginning at 1) representing a decreasing order of sub-regions with regard to the number of buildings with activities, Act_y a value representing the existence or not of the activity type *y* in each sub-region *i* ($Act_y \in \{0; 1\}$).

In the GO case study the number of establishments by activity type ($NEstAct_y$) was generally lower than the number of sub-regions in each parish having not exclusively residential buildings (*N*). Therefore, the criteria chosen for the disaggregation of activity types by sub-region was that the establishments should be allocate one for each sub-regions comprising not exclusively residential buildings, beginning by the sub-region with the highest rate of not exclusively residential buildings in the parish[79]. If there are more establishments of one activity type ($NEstAct_y$) than sub-regions comprising not exclusively residential buildings in the parish (*N*), all of these sub-regions will be considered as having that activity, while for the remaining sub-regions the activity will be considered absent.

[79] Considering that the diversity of activity index only registers the presence or absence of each activity type, this disaggregation criterion is valid.

A.3. Disaggregation of percentage of trips by activity types

For the development of the correction factor f_y for each activity type the percentages of trips by trip purpose (INE, 2000) were disaggregated by each activity type (or trip purpose, as shown in Table A.3). The trip purpose of employment required no especial attention (no disaggregation is required). With regard to school activities, the 12% of trips for this purpose were disaggregated by activity types 1, 2 and 3 according to the number of student in each activity[80]. For the remaining activities, the percentages of trips by trip purpose were disaggregated in proportion to the average frequency of use (days in a month)[81].

[80] Presenting the same average frequency of use (an average of 21 days per month) the division of trips by school level was made based on the number of students in each school level having to use this activity on a daily basis. The number of students in infant and elementary schools (around 91000) and in high schools (around 125000) was found within statistical data concerning the school year of 2006/2007 (GIASE, 2006). The number of student in Universities (around 60000) was estimated based on the information provided by the websites of the two main institutions of public graduate and postgraduate schools, the University of Oporto (www.up.pt, searched in July 2007, revealing around 28000 students) and the Polytechnic Institute of Oporto (www.ipp.pt, also searched in July 2007, revealing around 15000 students). Given the absence of aggregated data of graduate and postgraduate students in private institutions, this value was estimated to be similar to that of students in the Polytechnic Institute of Oporto.

[81] Only integer values were used for f_y requiring sporadic choices for the disaggregation of percentage of trip purpose when this was not straight forward. For instance, the 15% of trips for healthcare and other activities were divided by six activities presenting a global value of use frequency of 7 days. In order to use integer values, activity type 16 (banks) was increased by 1%, in comparison to remaining activities.

Table A.3: Activity types considered

	Activity type (y)	Frequency of Use	Days in a month	% of trips (INE, 2000)	f_y
Schools:					
• Infant School and Elementary school	1	Daily	21	12	4
• High school	2	Daily	21		5
• University	3	Daily	21		3
Leisure/Entertainment:					
• Parks, public gardens, squares	4	Some days per week	8	22	8
• Restaurants	5	Some days per month	2		2
• Cinema	6	Some days per month	2		2
• Shows / Theatre	7	Some days per month	2		1
• Sport	8	Some day per week	8		8
• Others (ex: Museums, Libraries, Night clubs, etc)	9	Some days per month	2		1
Shopping:					
• Food	10	Weekly	4	10	8
• Others	11	sporadic	1		2
Healthcare					
• Pharmacies	12	Sporadic	1	15	2
• Hospitals and Clinics	13	Sporadic	1		2
Other Activities					
• Public/Municipal administration offices	14	Sporadic	1		2
• Postal Office	15	Sporadic	1		2
• Banks	16	Some days per month	2		5
• Others (ex: Insurance, Lawyers, Architects, financial advisers, etc)	17	Sporadic	1		2
Employment					
• Employment	18	Daily	21	41	41
Total				100	100

A.4. Calibration of average driving speed

Average diving speed was estimated for the morning peak hour with the help of a specialist[82] on local travel speed. As a simplification, average speed was divided into two types: congested travel conditions and non-congested travel conditions. The limit of congested and not congested travel conditions was defined separately for motorways and freeways (main road infrastructure not providing direct access to houses and activities) and for the remaining road infrastructure (providing direct access to houses and activities), for the morning peak hour.

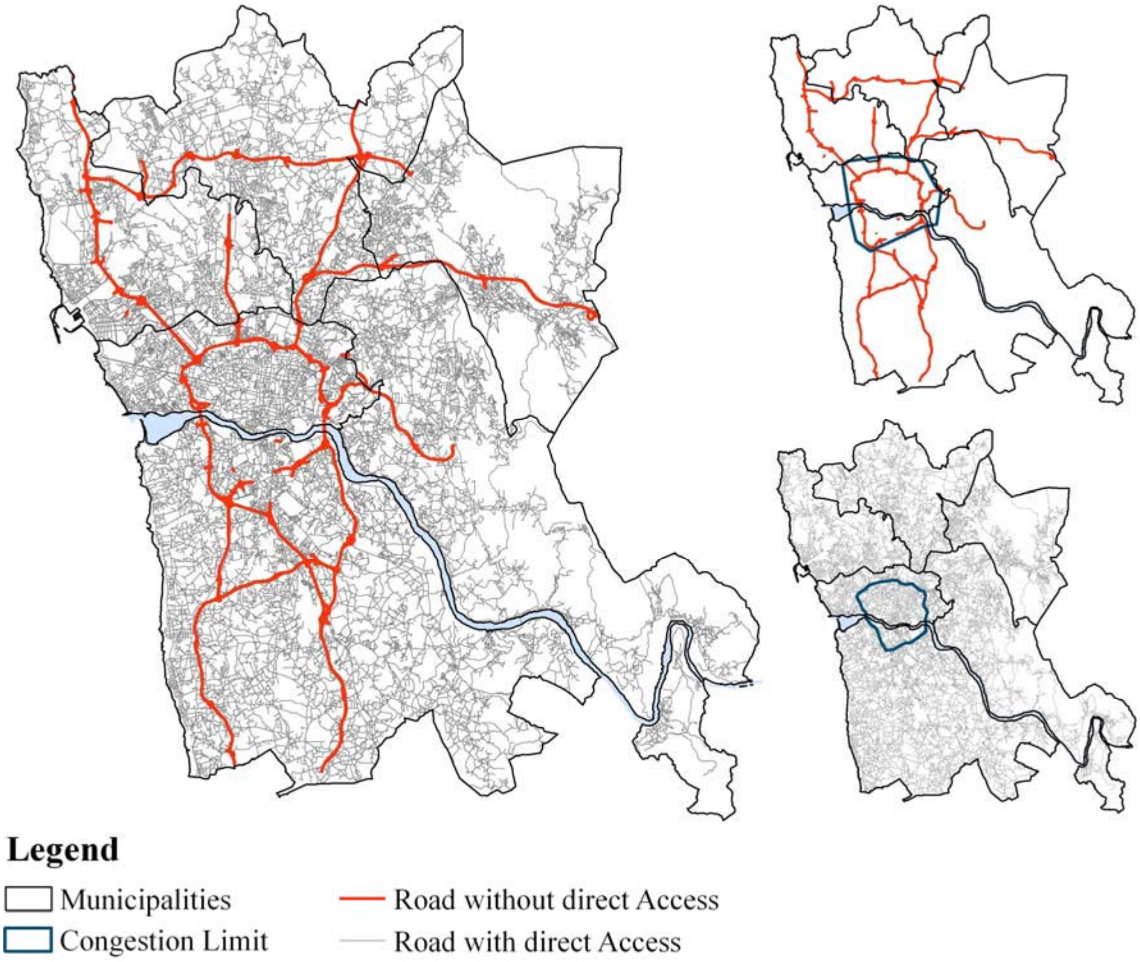


Figure A.1: Road type and congestion limits

[82] Carlos Manuel Rodrigues; Auxiliary Professor at the Faculty of Engineering of Oporto University (Transport and Infrastructure Division).

As shown in Figure A.1 road infrastructure without direct access was considered to be congested within the municipality of Oporto and in the northern part of the municipality of Vila Nova de Gaia. In this area it is reasonable to say that, in the worst case scenario (morning peak hour), average speed ranges 40km/h. For the remaining layout of these roads, 80km/h was considered as a reasonable average speed. Congestion of direct access road infrastructure mainly occurs inside the internal ring road (VCI). Therefore, the layout of the congestion limit for this road infrastructure follows the layout of the referred ring-road with exception made for the western part of Vila Nova de Gaia, were the limit follows another important road (VL8), east to the referred ring road. The road infrastructure inside this limit was considered to have an average speed of 15km/h (in the worst case scenario) while for the remaining network, 25km/h was considered to be a reasonable value for average speed. These values and limits of congestion, for each infrastructure type, were calibrated based on test accessibility maps. Several points of the different regions (congested and not congested) were tested, defining accessibility boundaries by car for different scenarios of travel speed and congestion limits (for both types of infrastructure). Choices were based on the personal experience and sensibility of the expert on local travel speed as well as on some records on local travel speed.

Annex B

GO CASE STUDY APPLICATION - MAPS

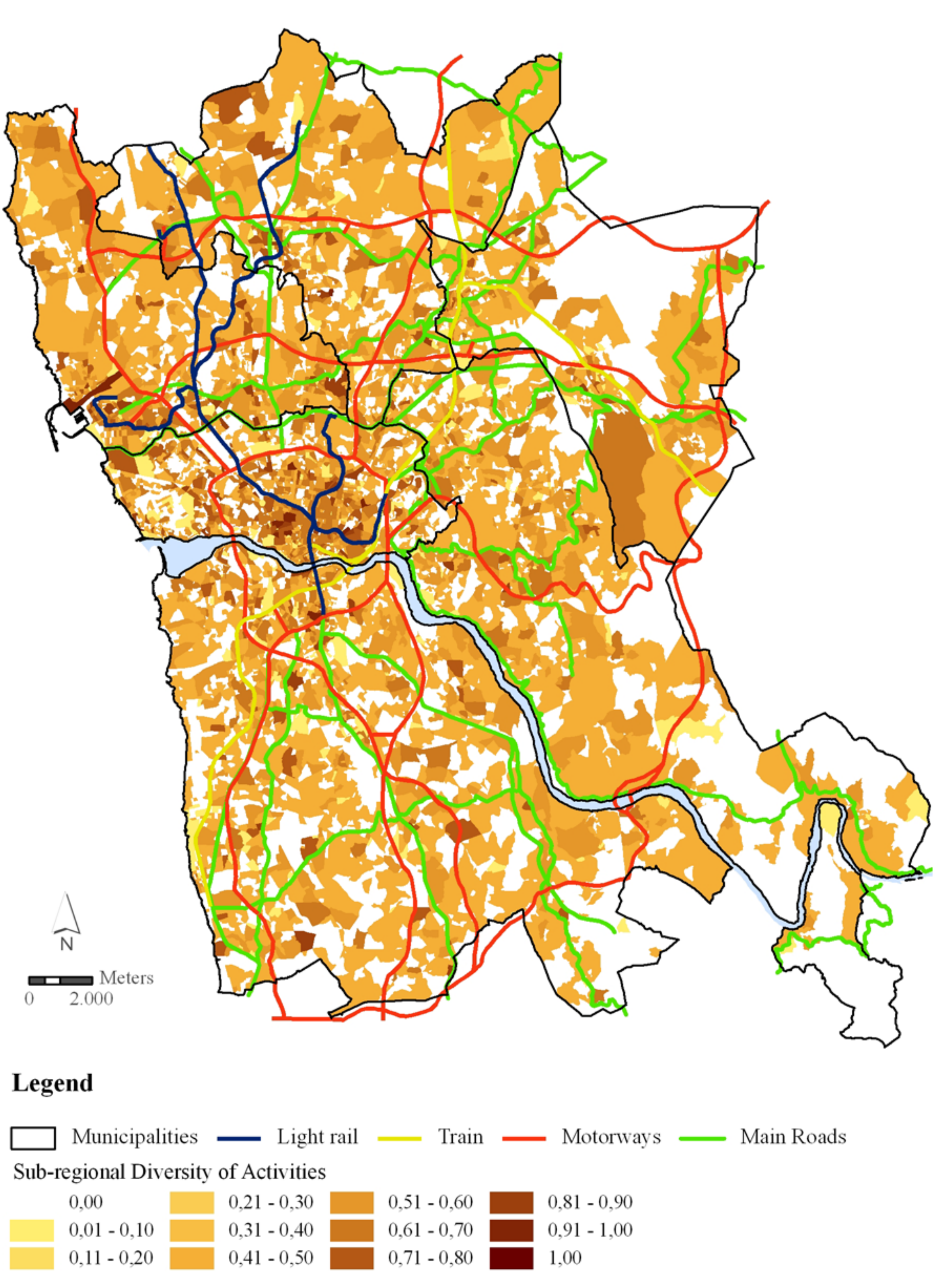


Figure B.1: Diversity of activities within each sub-region

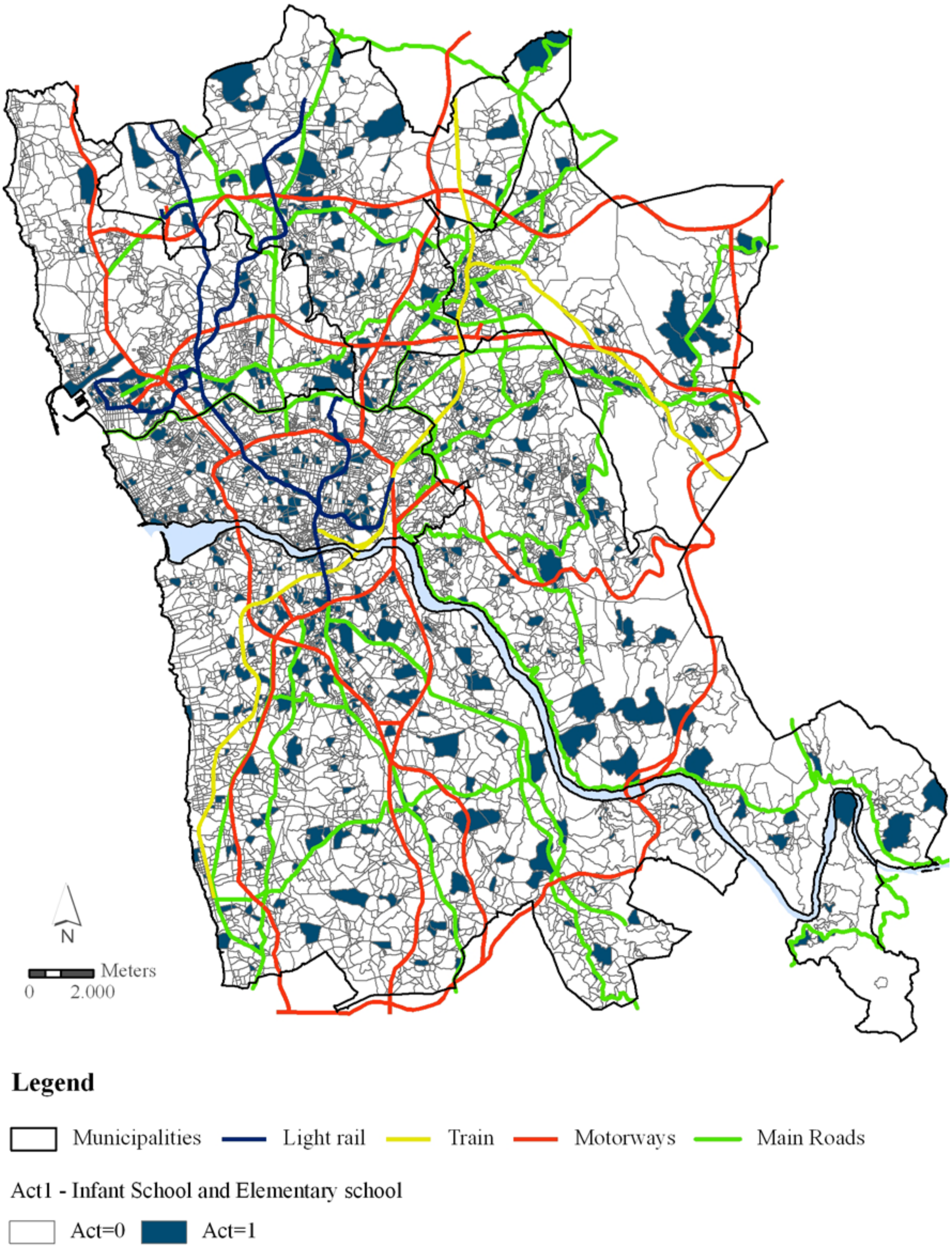


Figure B.2: Sub-regions containing activity type 1 – Infant and Elementary schools

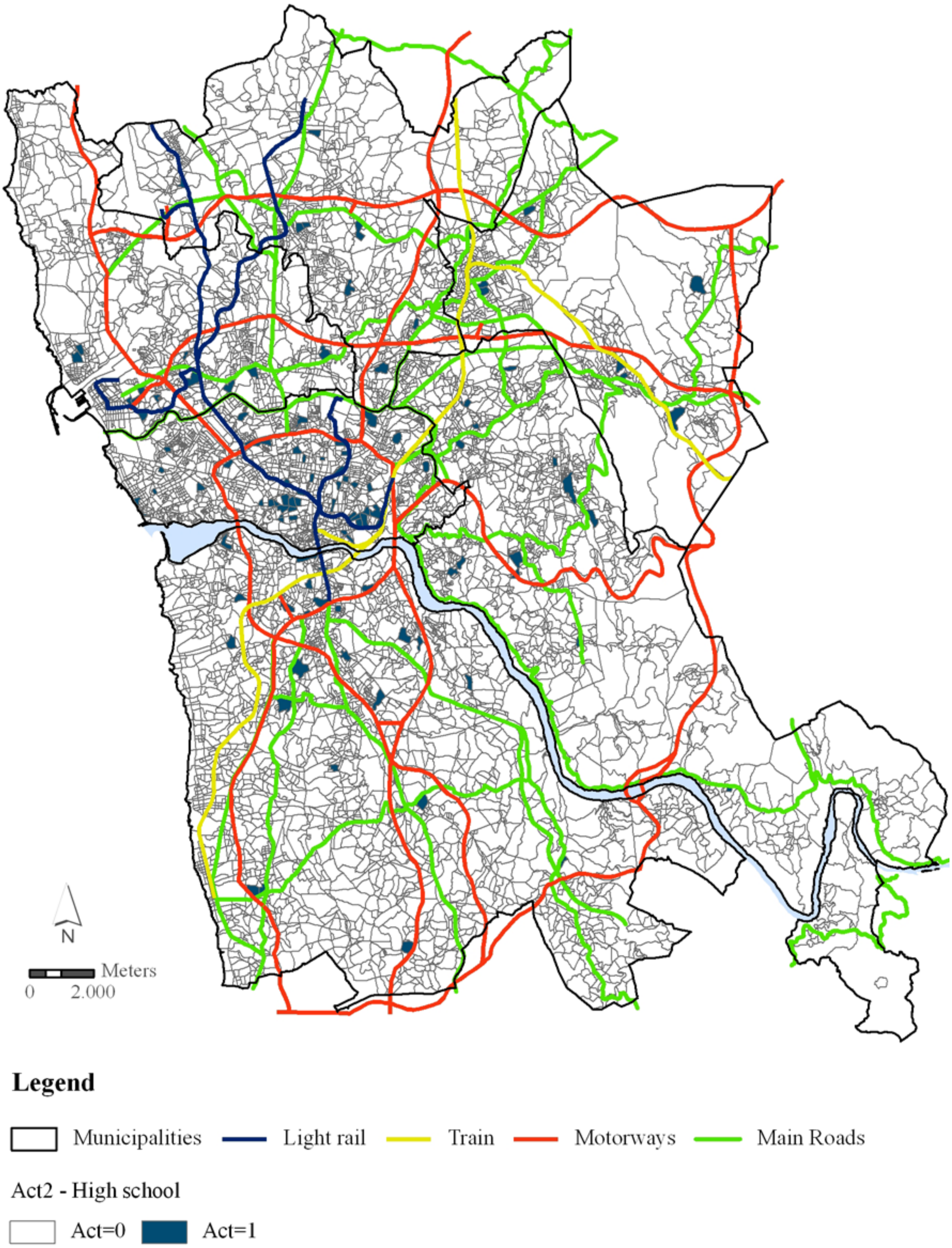


Figure B.3: Sub-regions containing activity type 2 – High schools

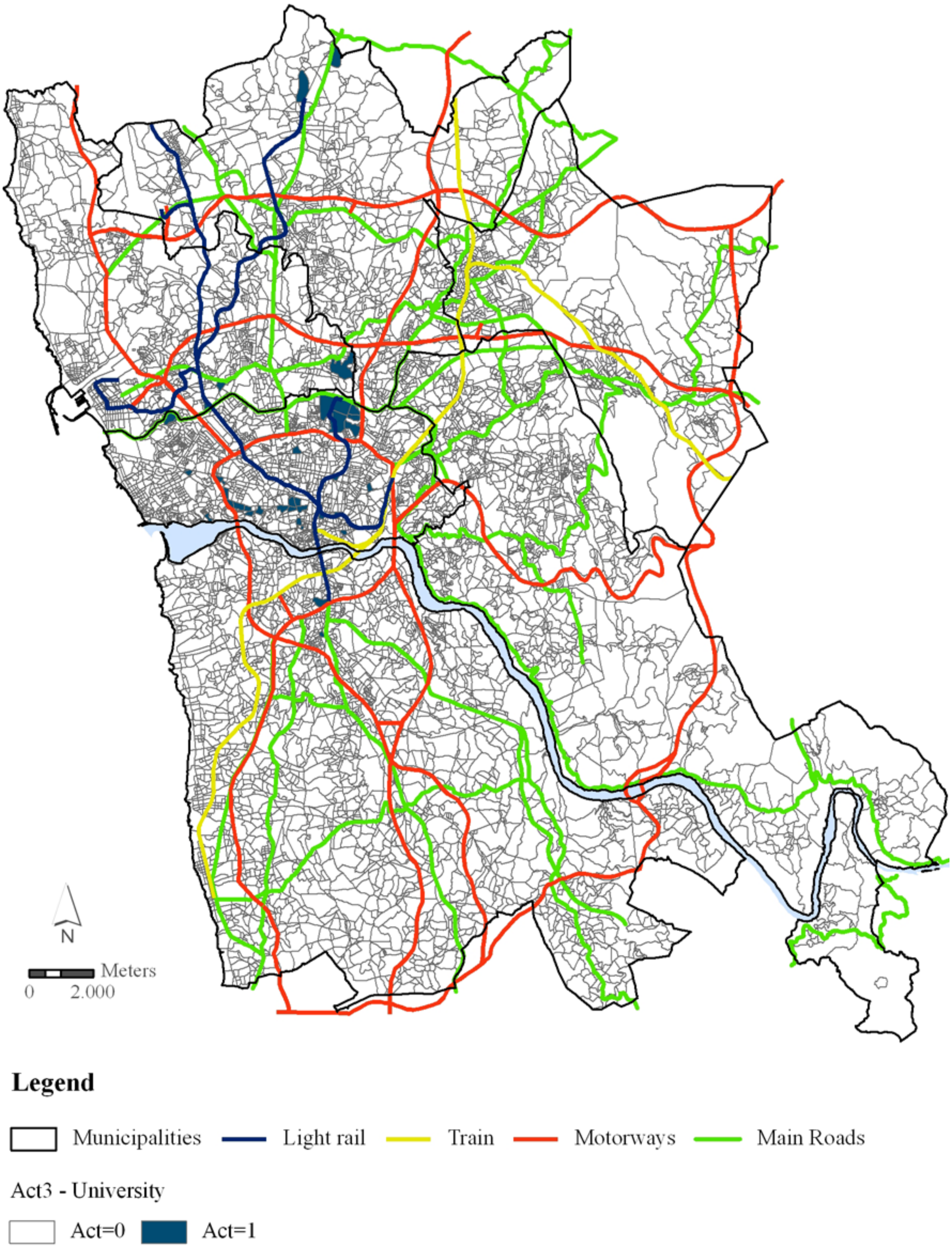


Figure B.4: Sub-regions containing activity type 3 – Universities

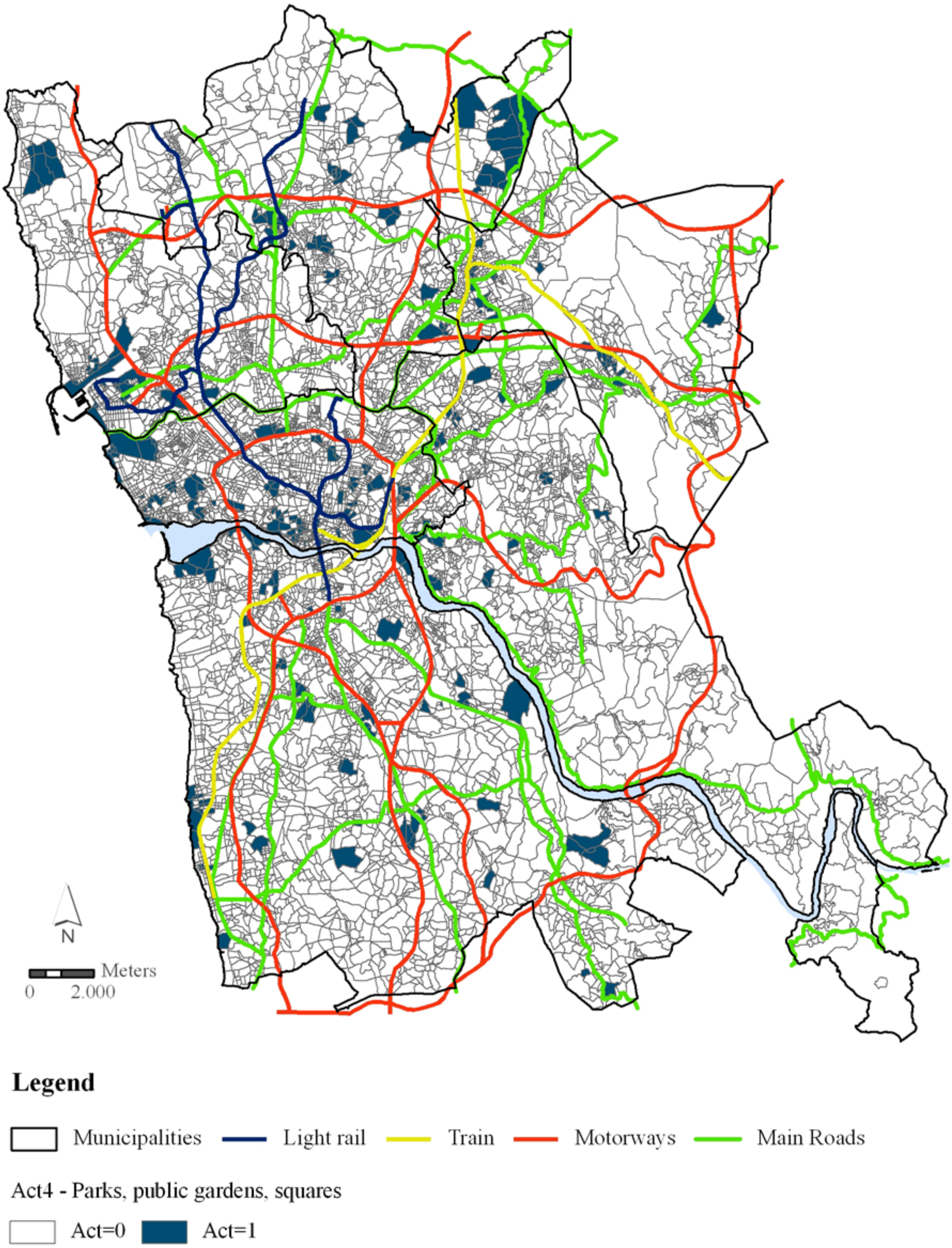


Figure B.5: Sub-regions containing activity type 4 – Parks, Public Gardens and Squares

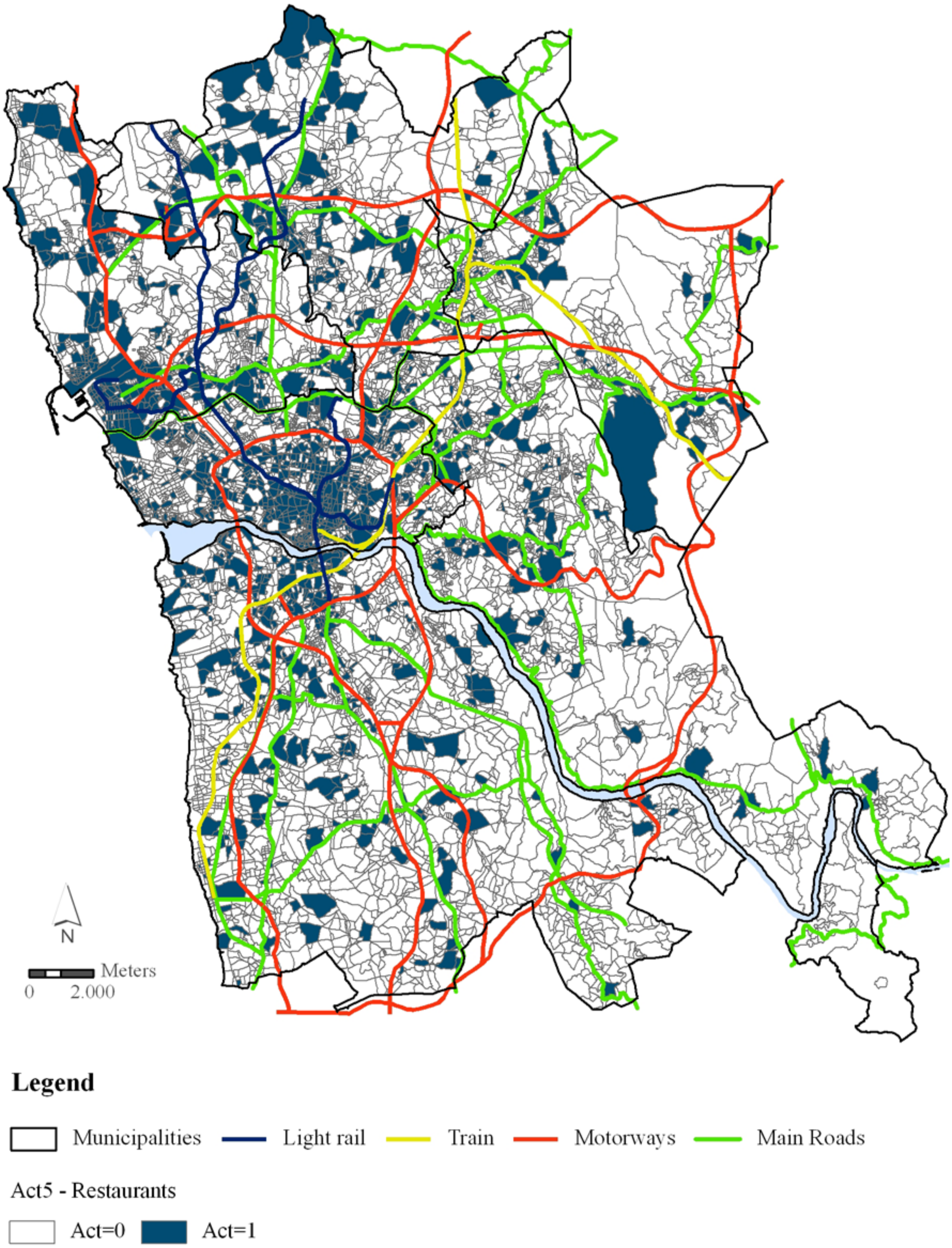


Figure B.6: Sub-regions containing activity type 5 – Restaurants

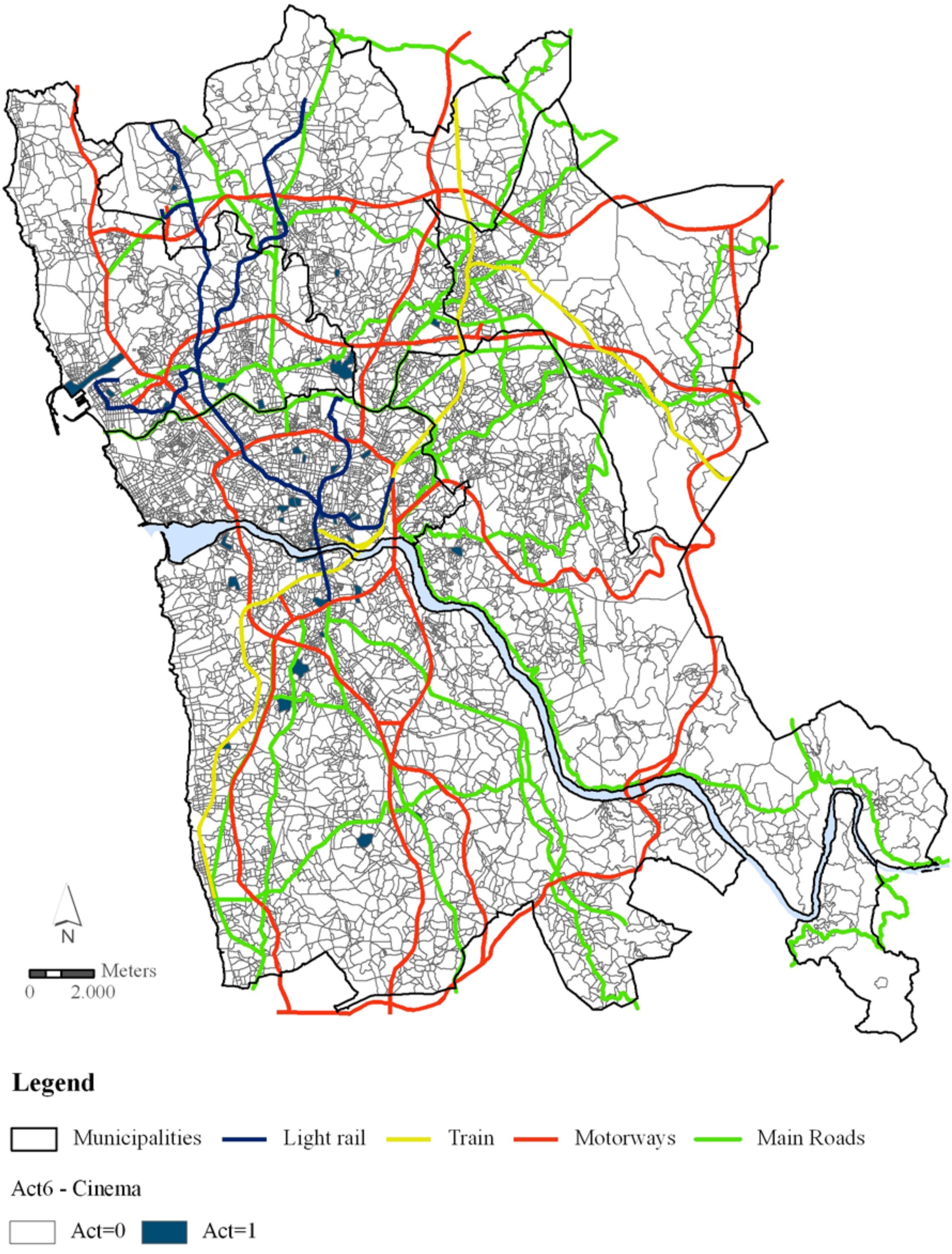


Figure B.7: Sub-regions containing activity type 6 – Cinema

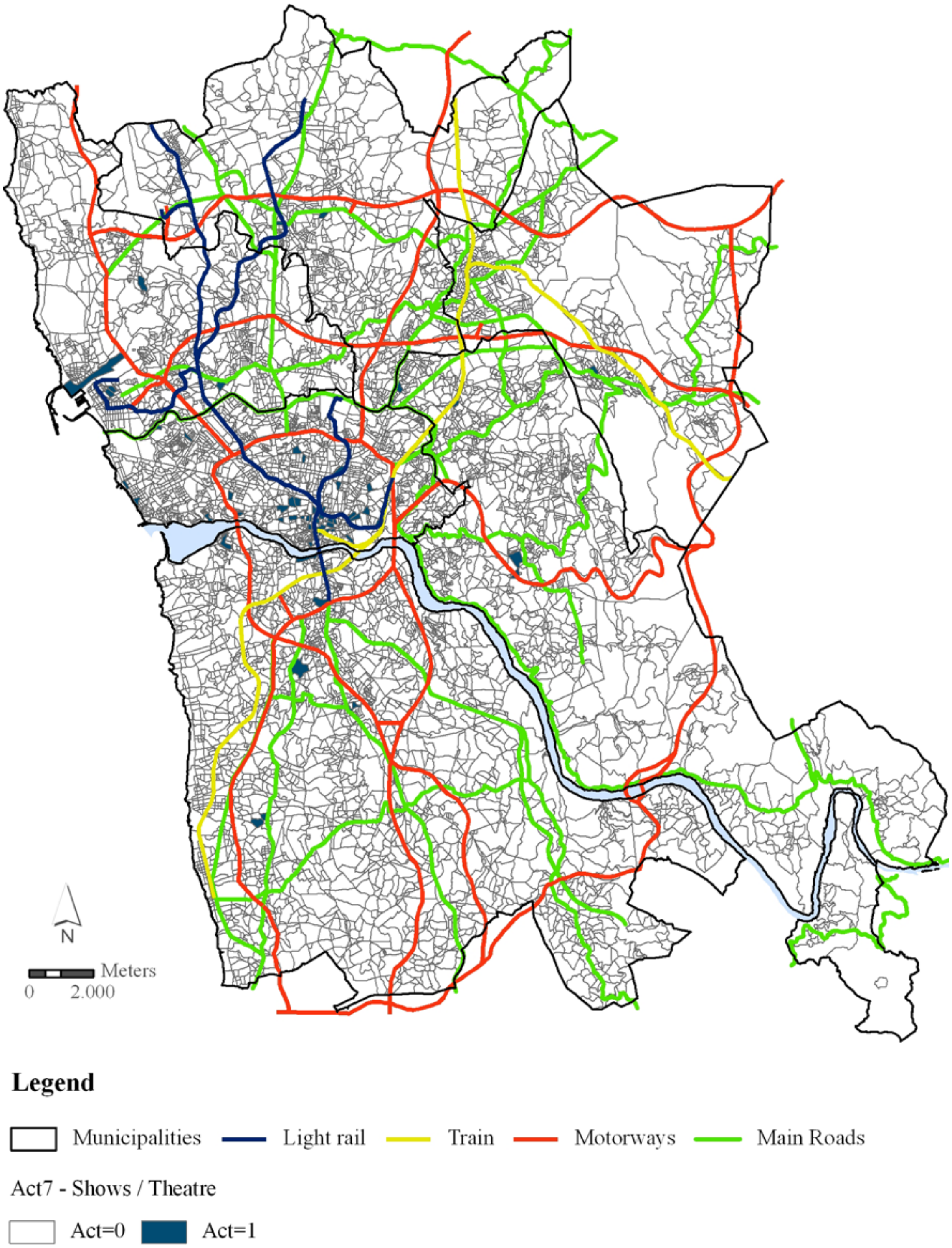


Figure B.8: Sub-regions containing activity type 7 – Shows / Theatres

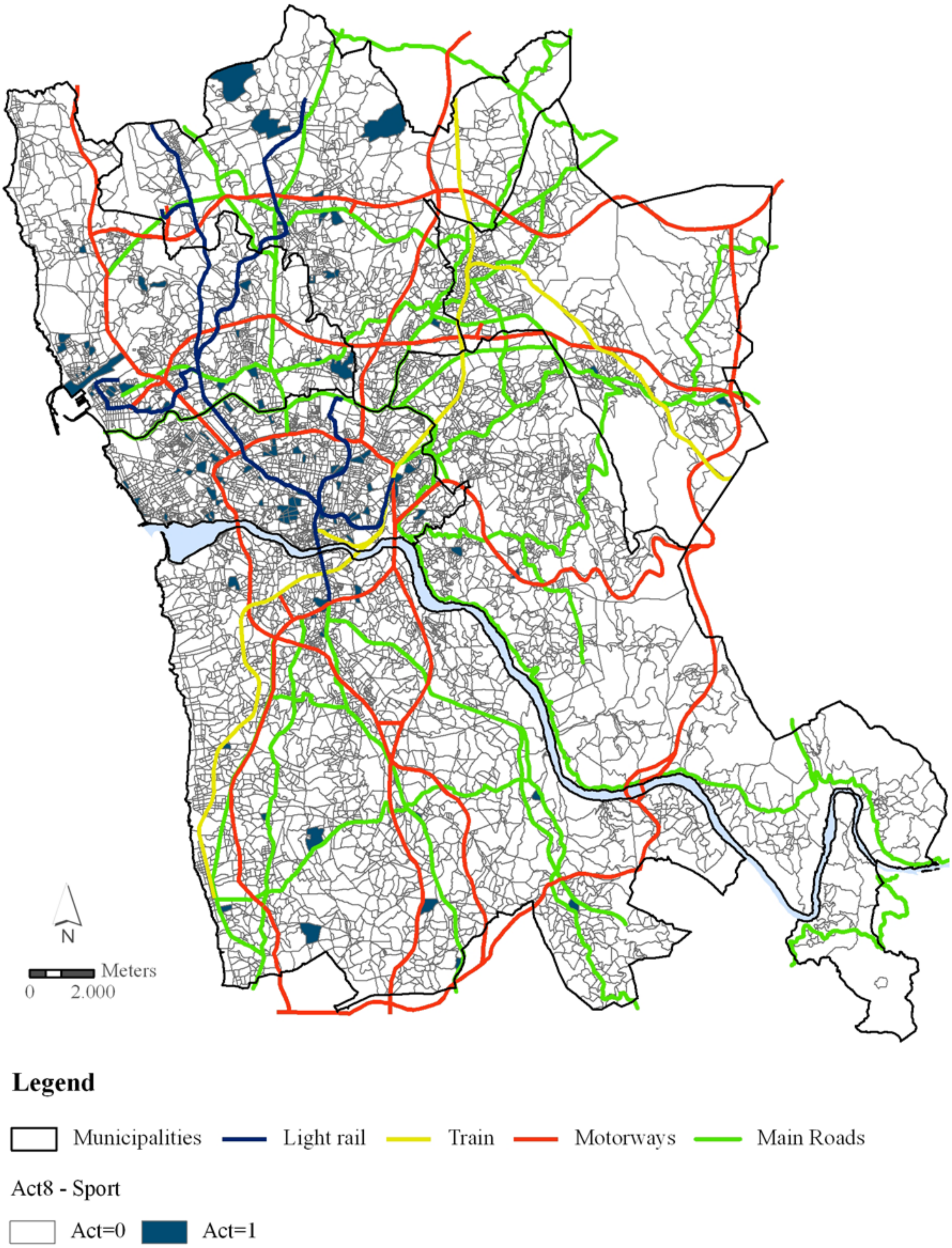


Figure B.9: Sub-regions containing activity type 8 – Sports

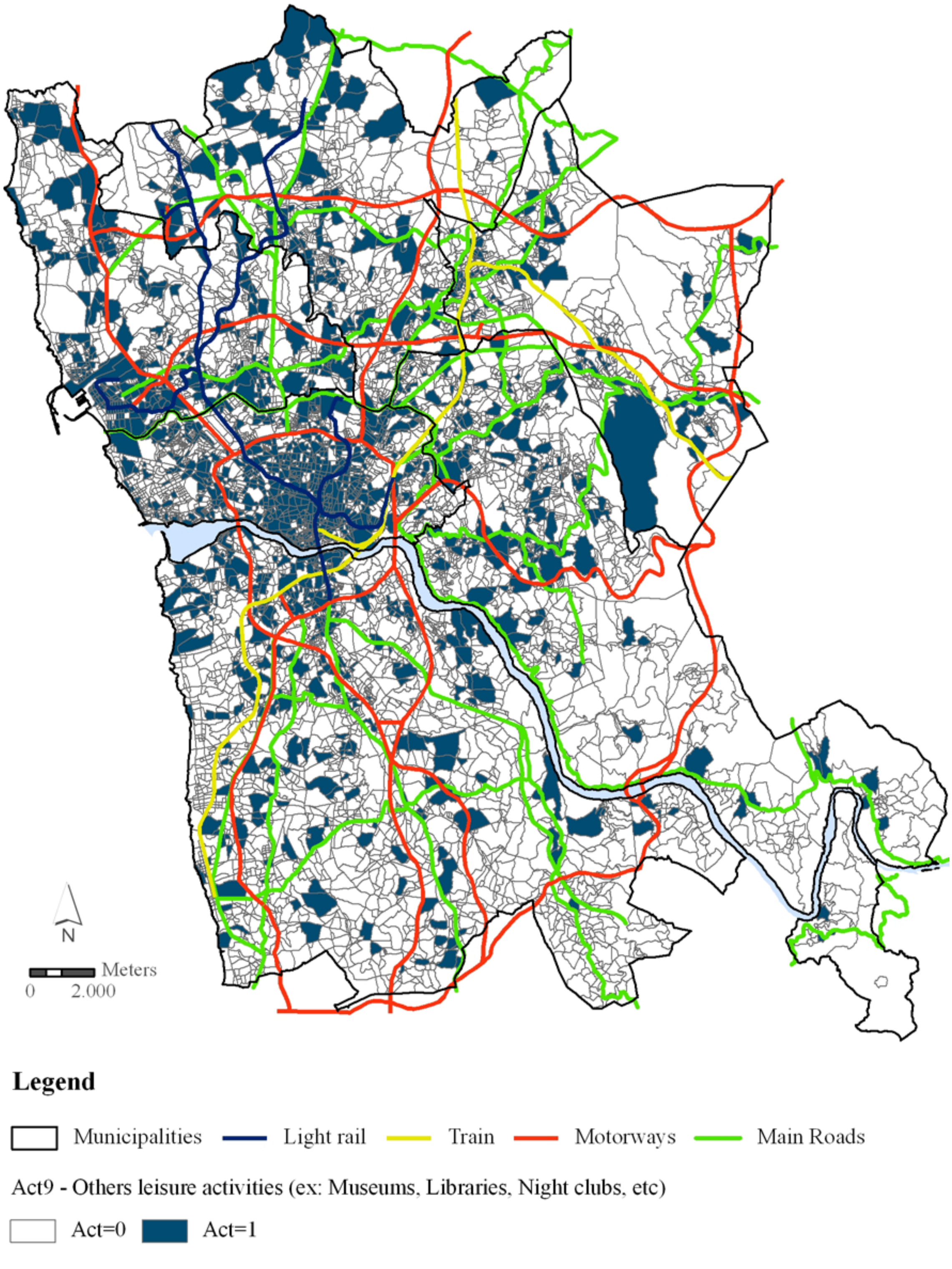


Figure B.10: Sub-regions containing activity type 9 – Other leisure activities

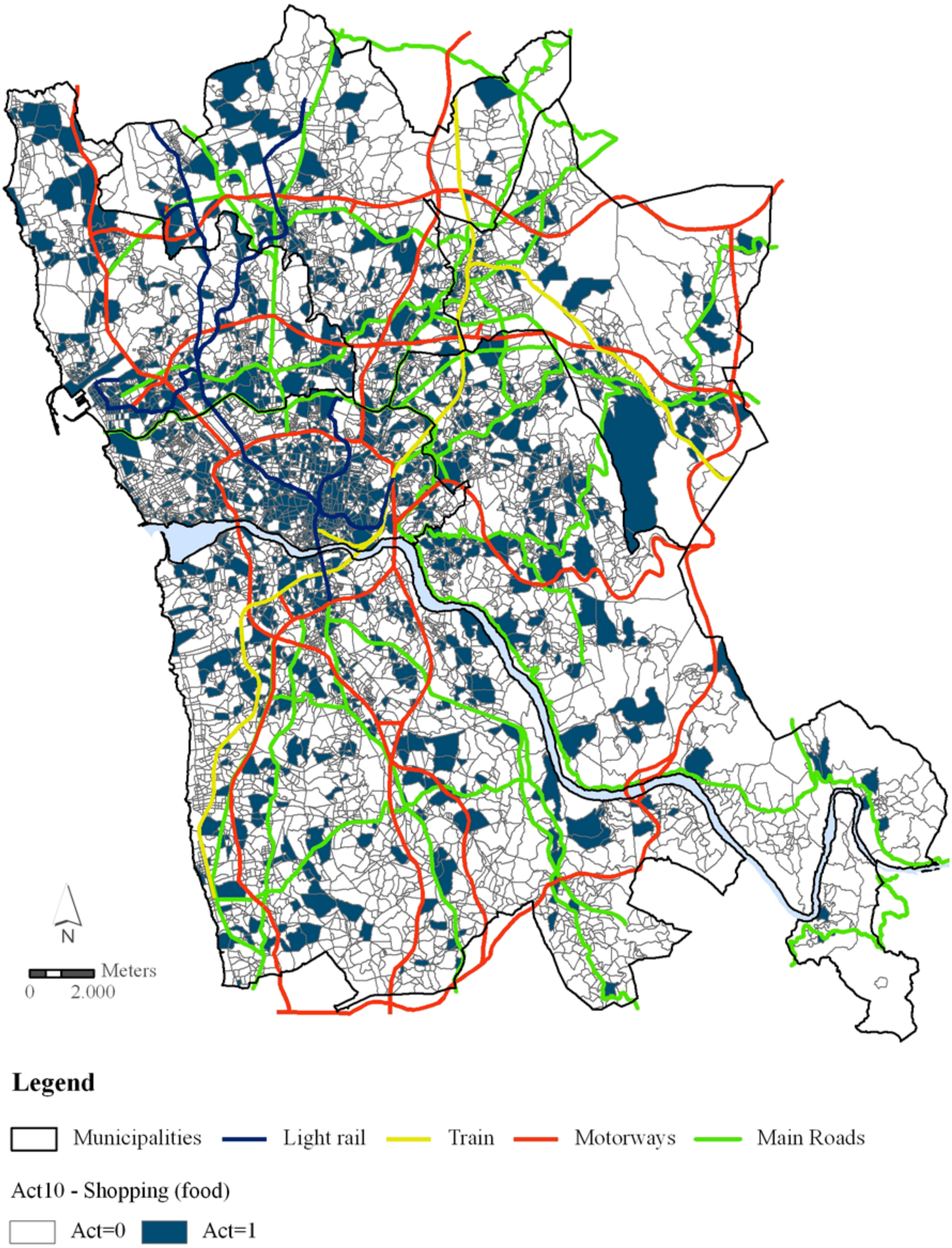


Figure B.11: Sub-regions containing activity type 10 – Shopping (food)

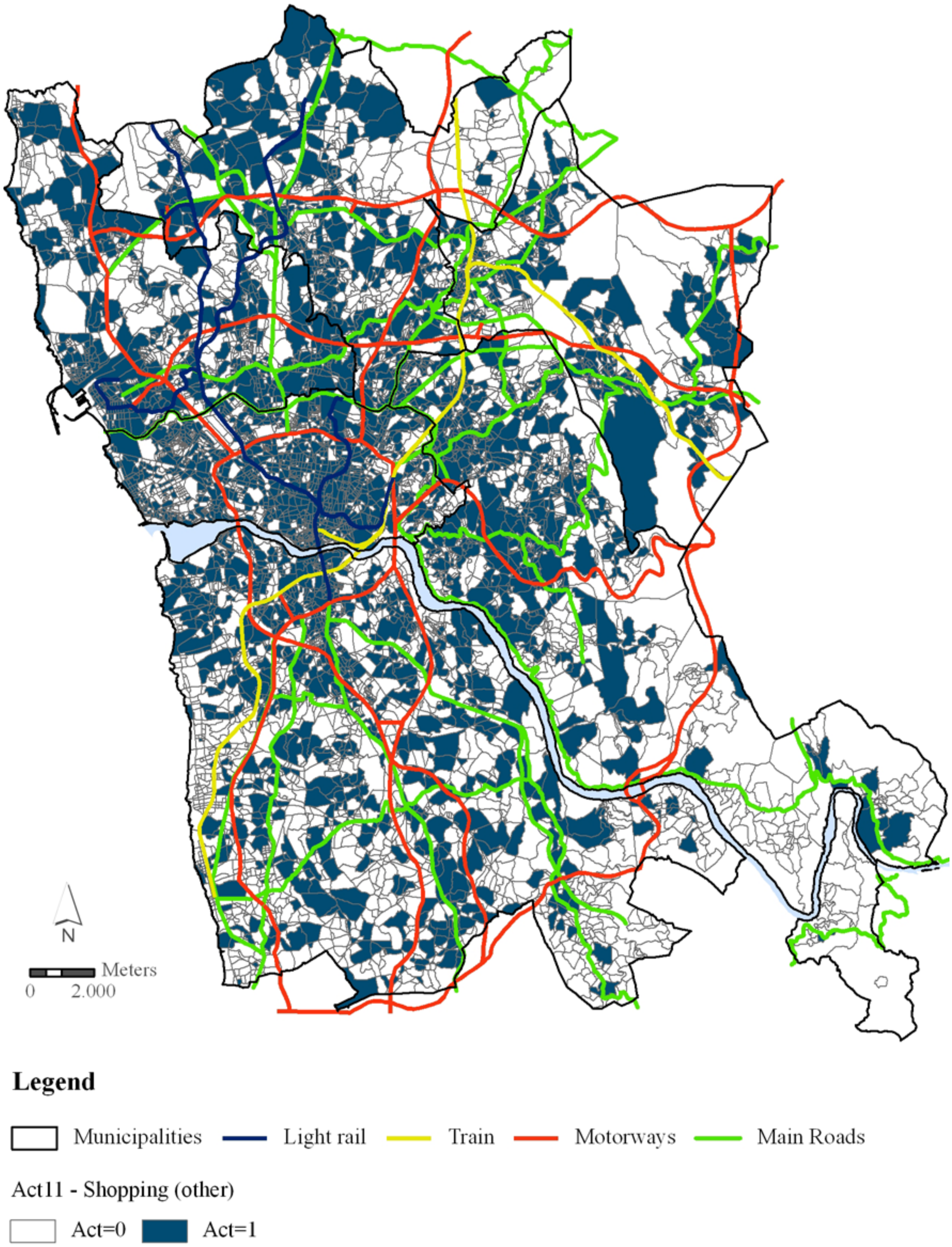


Figure B.12: Sub-regions containing activity type 11 – Shopping (other)

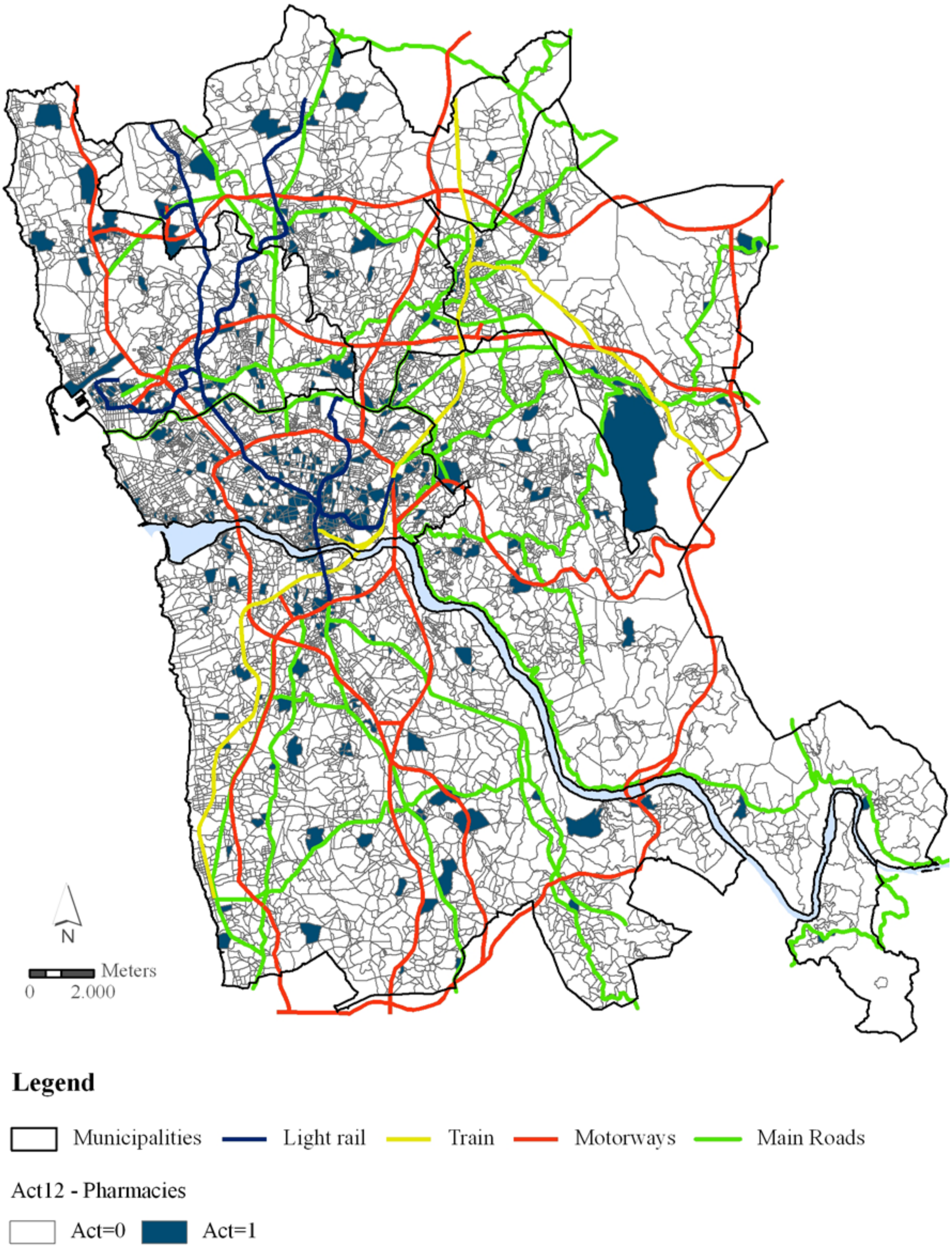


Figure B.13: Sub-regions containing activity type 12 – Pharmacies

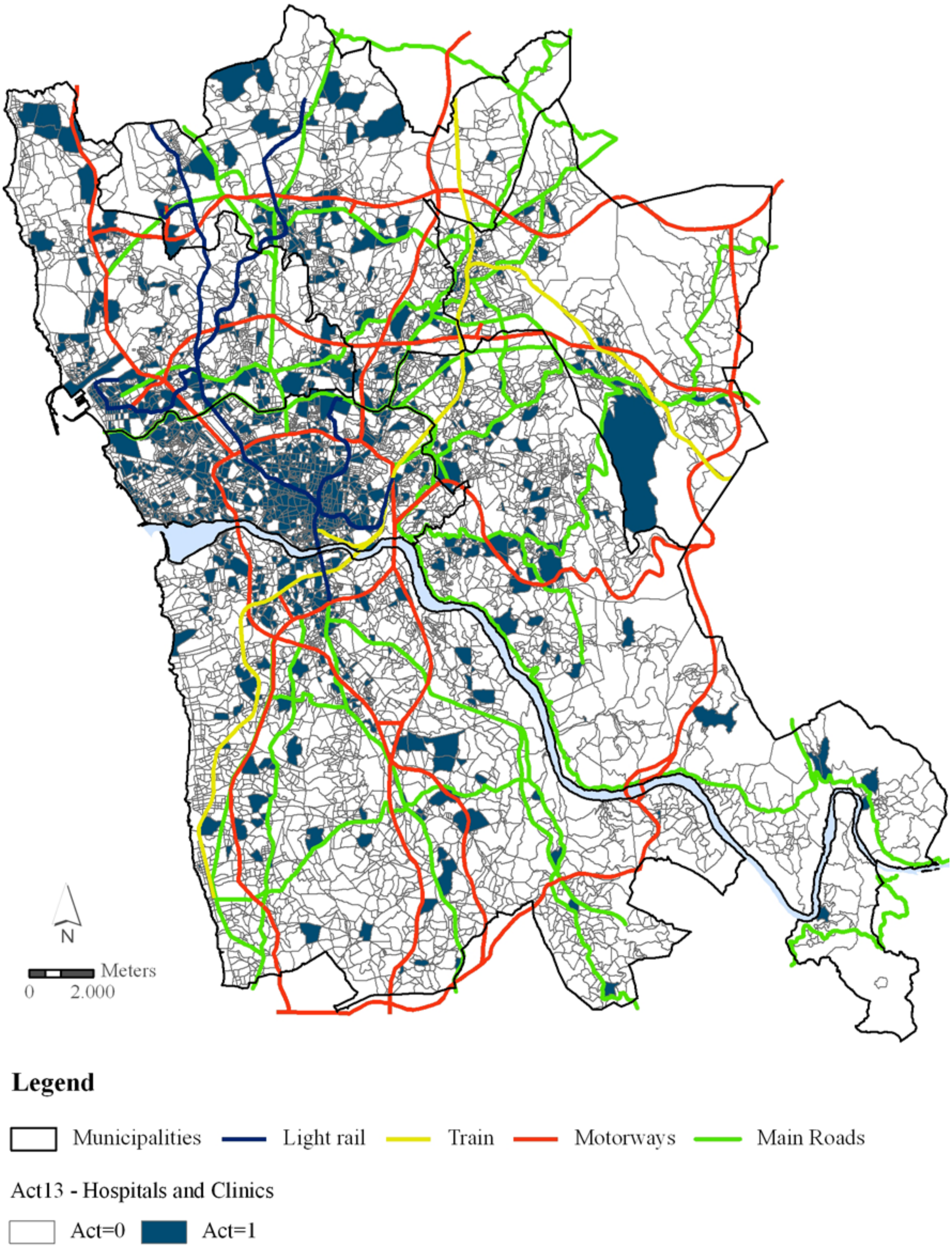
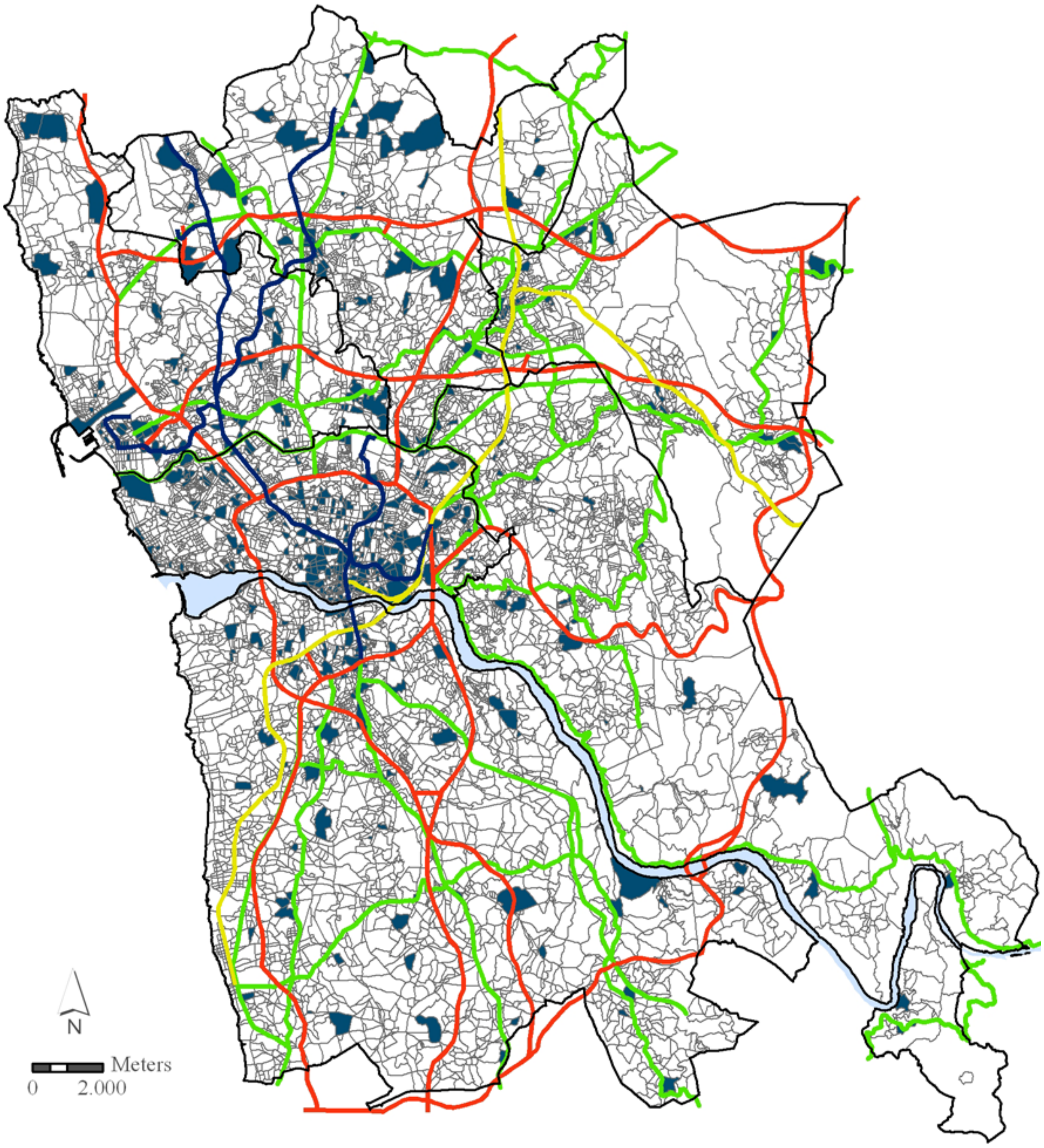


Figure B.14: Sub-regions containing activity type 13 – Hospitals and Clinics



Legend

Municipalities Light rail Train Motorways Main Roads

Act14 - Public/Municipal administration offices

Act=0 Act=1

Figure B.15: Sub-regions containing activity type 14 – Public / Municipal administration offices

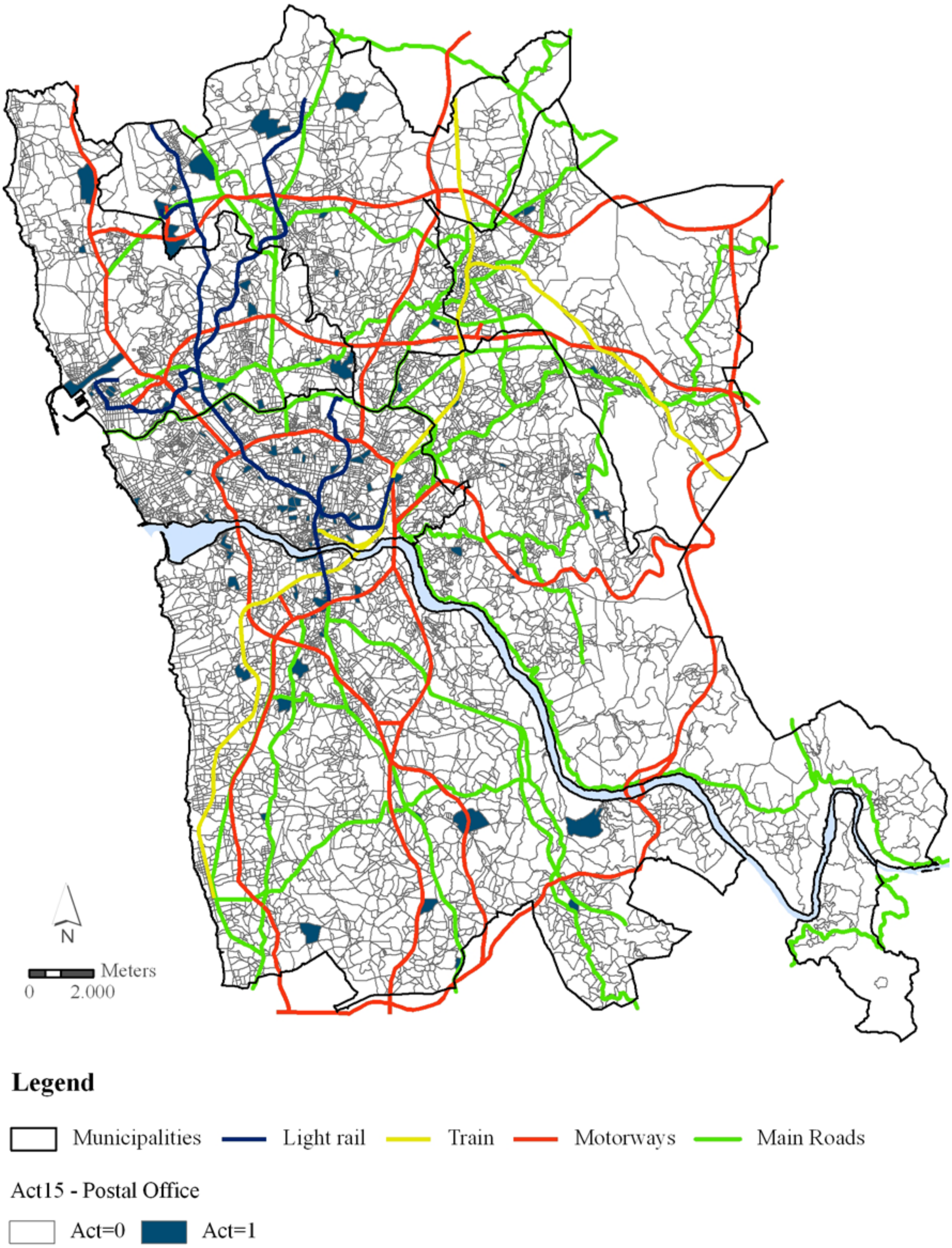


Figure B.16: Sub-regions containing activity type 15 – Postal offices

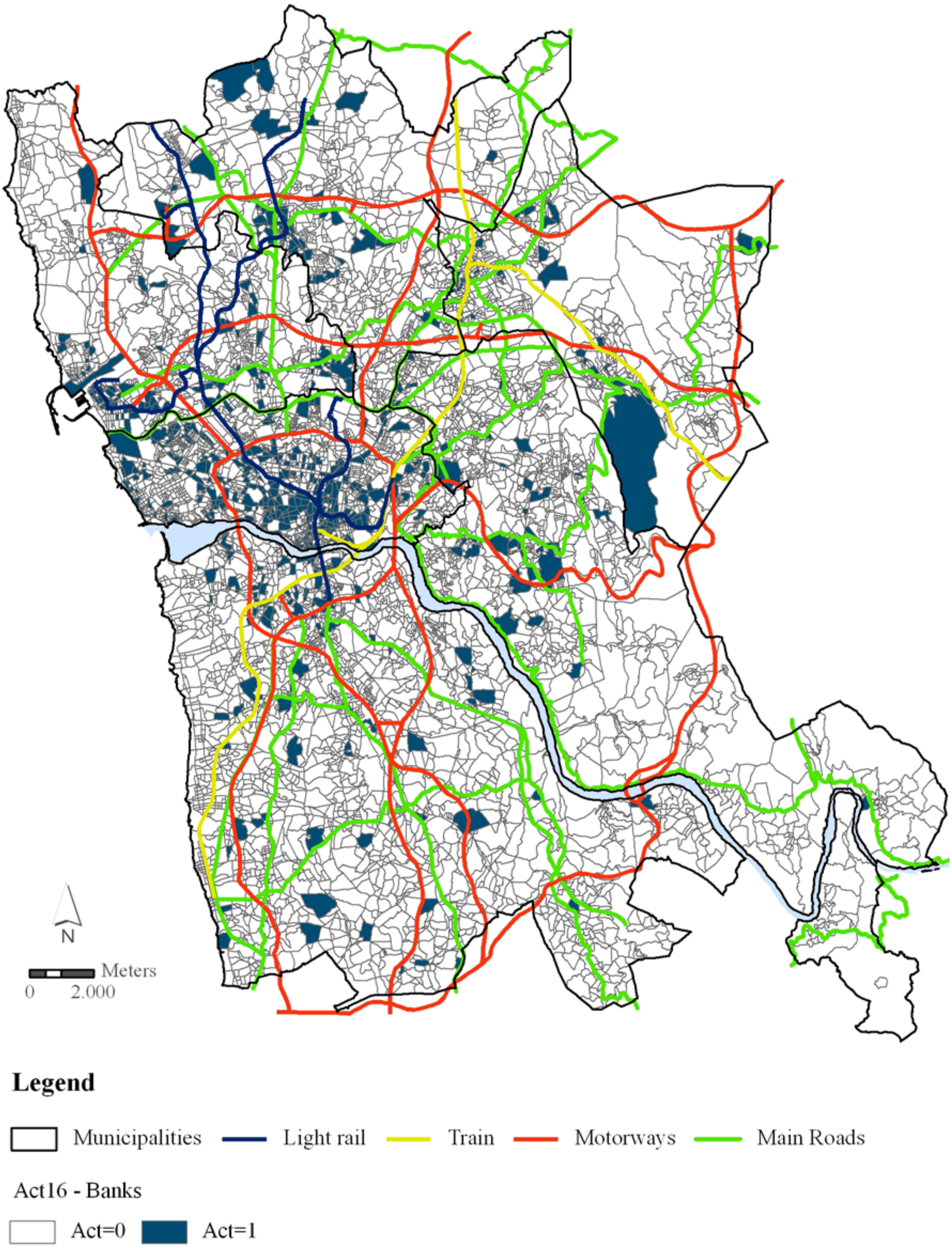


Figure B.17: Sub-regions containing activity type 16 – Banks

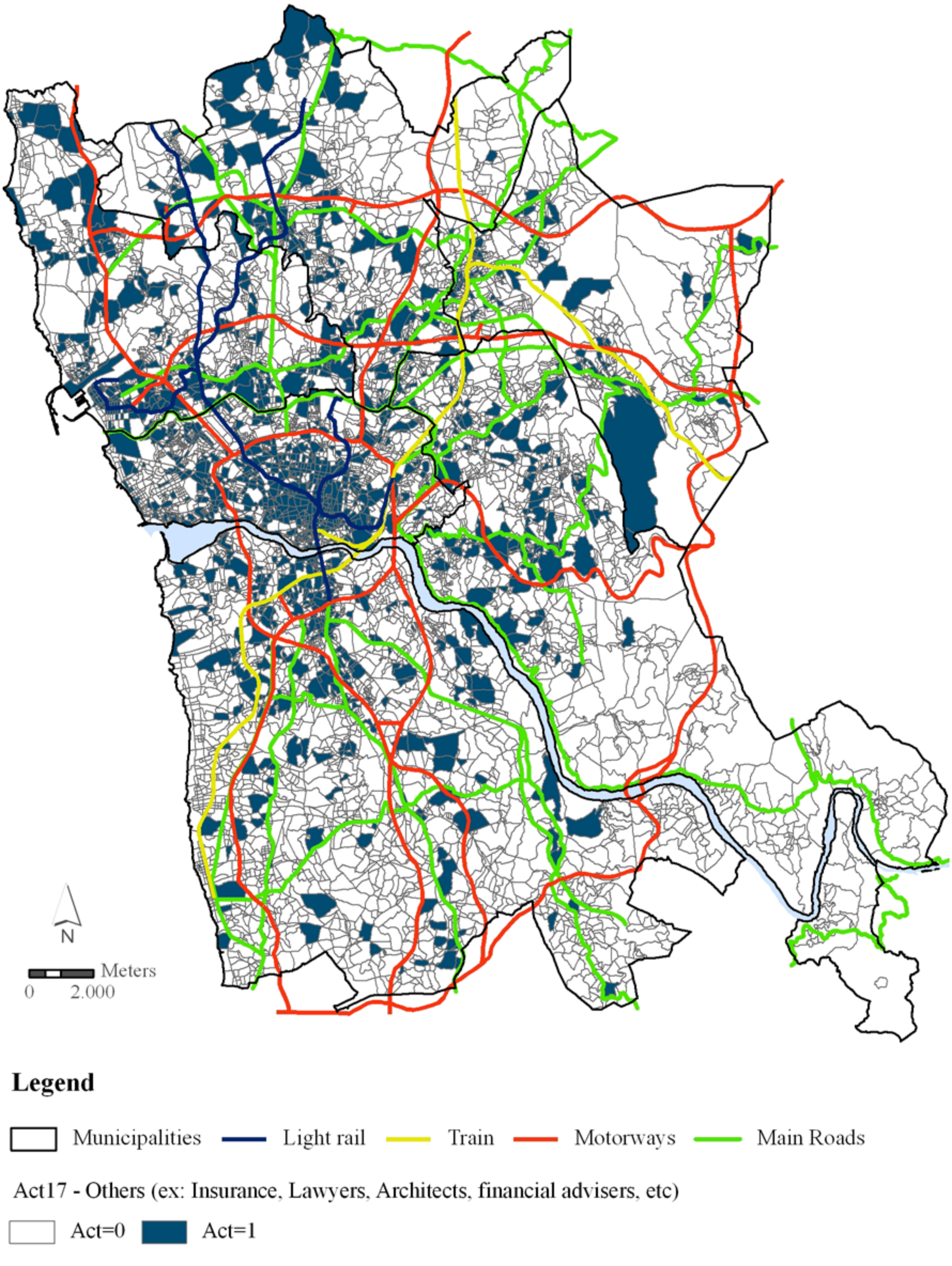


Figure B.18: Sub-regions containing activity type 17 – Other activities

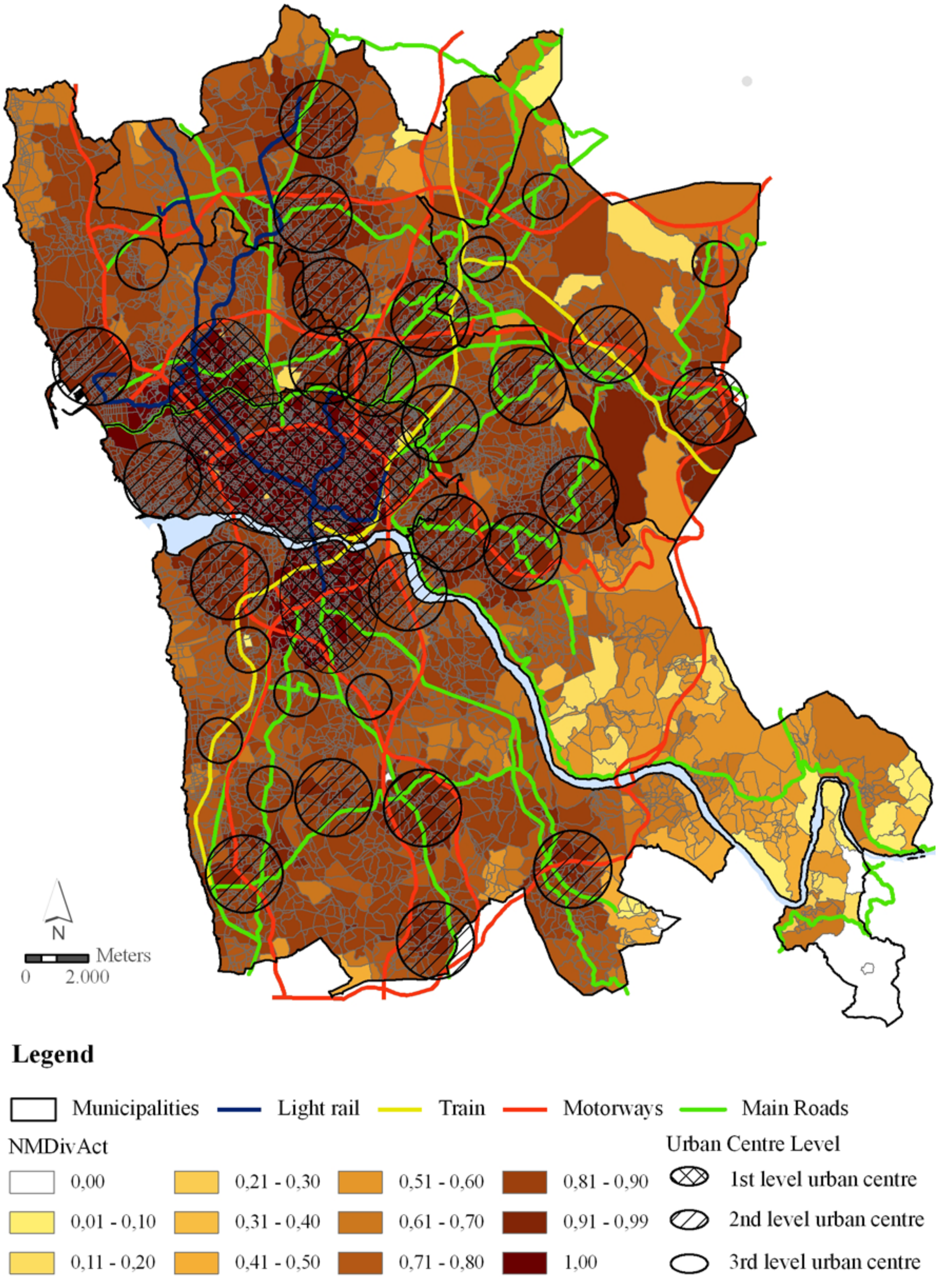


Figure B.19: Existing urban centre structure

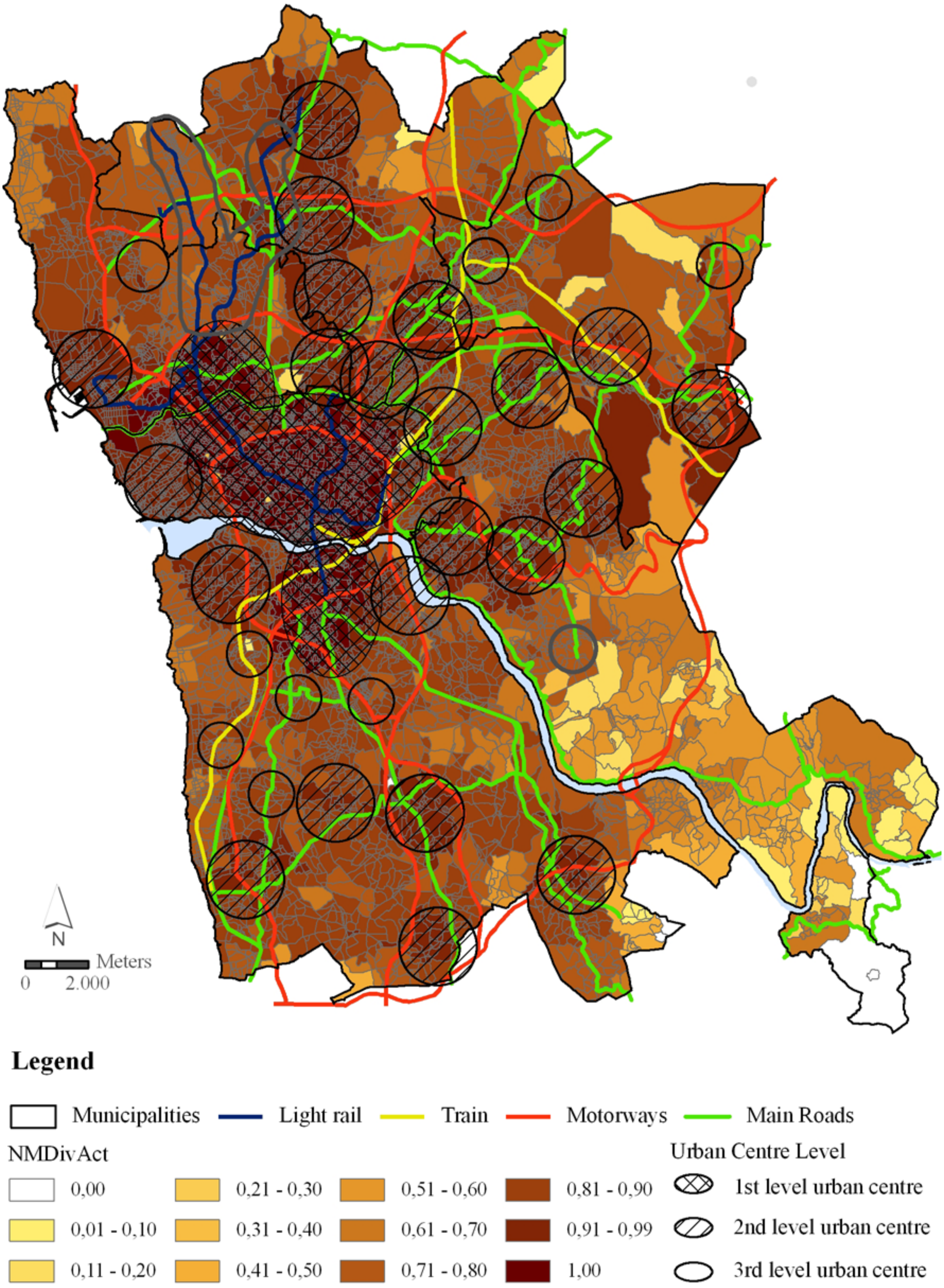


Figure B.20: Proposed urban centre structure (general strategy for GO)

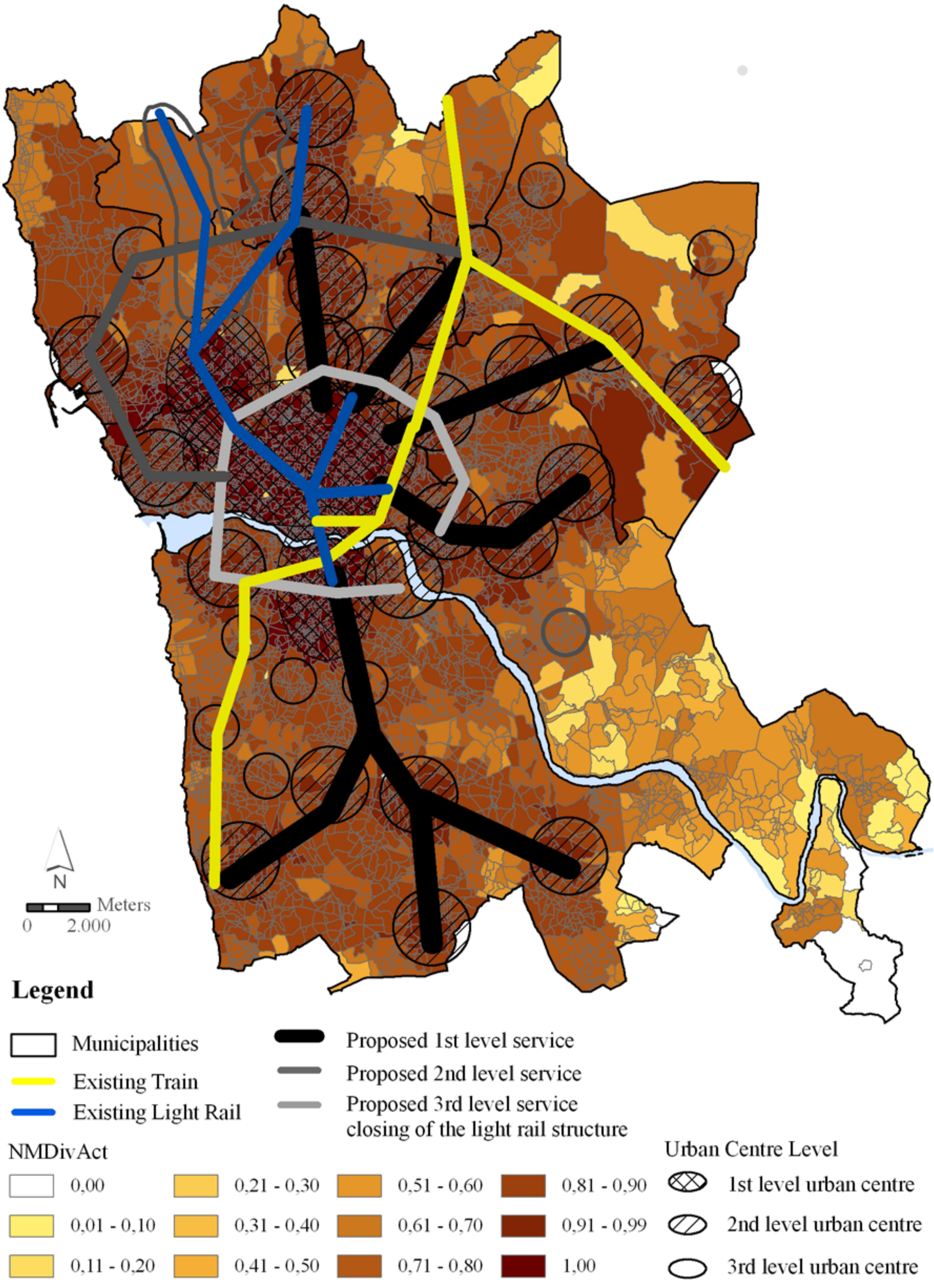


Figure B.21: Proposed urban structure (general strategy for GO)

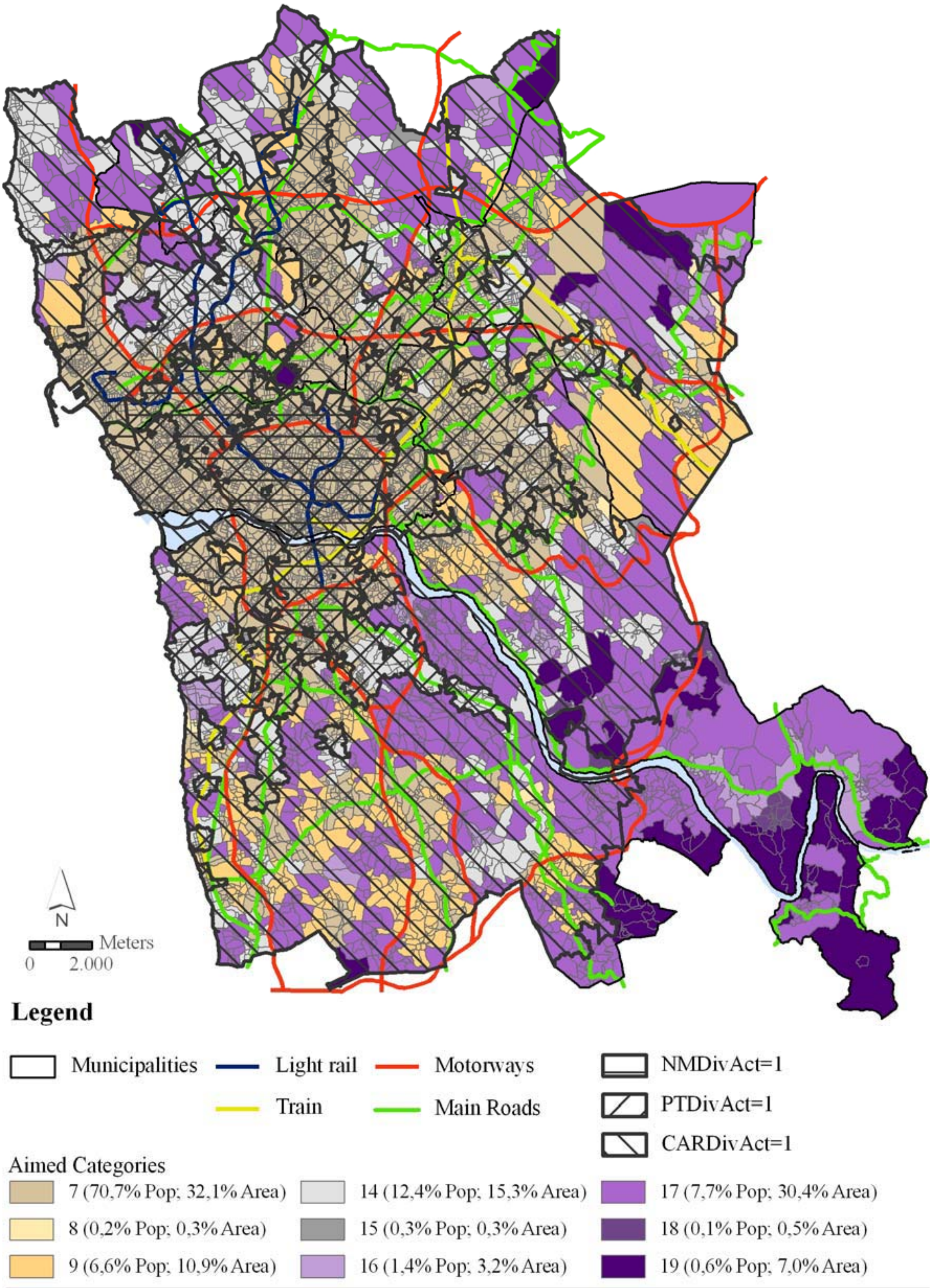


Figure B.22: Accessibility categories and unitary diversity of activity index by mode

Annex C

EXPERT INTERVIEWS

The final step of the testbed involved semi-structured interviews with experts on mobility patterns, on local urban structure conditions for mobility and on mobility management (including policy makers and planning officials). Experts were chosen from two main fields: land use and transport. The list of interviewed experts is presented in Table C.1.

Table C.1: List of experts interviewed

Name	Expertise field	Background	Interview location and date
Pais Antunes	Transport	Academic	Coimbra, 25th September 2007 (10:30h)
José Viegas	Transport	Academic	Lisbon, 25th September 2007 (17:00h)
Pedro Santos	Transport	Technical	Lisbon, 26th September 2007 (14:00h)
João Marrana	Transport	Technical	Oporto, 27th September 2007 (15:00h)
Rute Teixeira	Land Use	Technical	Oporto, 1st October 2007 (14:00h)
Álvaro Santos	Land Use	Technical / Political	Maia, 2nd October 2007 (11:00h)
Artur Costa	Land Use	Technical	Matosinhos, 2nd October 2007 (15:00h)
Isabel Vasquez	Land Use	Academic	Oporto, 3rd October 2007 (15:00h)
Pires da Costa	Transport	Academic	Oporto, 9th October 2007 (10:00h)
Robert Stussi	Transport	Academic	Algés, 10th October 2007 (14:00h)
Carlos Rodrigues	Transport	Academic	Oporto, 16th October 2007 (10:00h)
Silva Tiago	Land Use	Political	Maia, 18th October 2007 (11:30h)
António Babo	Transport	Academic	Oporto, 19th October 2007 (12:00h)
Lino Ferreira	Land Use	Political	Oporto, 23rd October 2007 (16:00h)
Álvaro Costa	Transport	Academic	Oporto, 29th October 2007 (11:00h)
Rui Azevedo	Regional economy	Academic	Oporto, 29th October 2007 (14:00h)
Brandão Alves	Land Use	Academic	Oporto, 29th October 2007 (15:30h)

Experts were first contacted by email, in early September, providing the purpose of the interviews and attaching an abstract of the PhD research. Direct contact followed in late September to schedule the interviews.

Interviews were conducted between late September and late October 2007, including the presentation of the SAL, its application to GO and the discussion of the main themes. As referred to in section 5.4 the main themes under discussion were robustness, usefulness and applicability. Table C.2 summarises the main questions guiding these semi-structures interviews.

Interviews started with a brief presentation of its aim (to evaluate the SAL as design support tool for integrated land use and transport policies for mobility management). Following, the SAL was presented, starting with the concept of comparative accessibility by transport mode.

The operational form used for the measure of accessibility was clearly schematized, to avoid potential misunderstandings or misinterpretations. This was believed to be a fundamental step regarding the variety of accessibility measures available and the ambiguity of the accessibility concept as well as the originality of the high disaggregation scale of opportunities considered for the tool. The presentation of the SAL was interrupted at this point for the first robustness assessment, regarding mode accessibility results for the GO. Experts were confronted with the non-motorized accessibility layer of the GO region, and asked to asses the ability of the measure to provide a good representation of walking accessibility levels (according to their personal experience and knowledge) (question 1, Table C.2). The answer to this first inquiry was generally preceded by the clarification of some doubts or misunderstandings regarding the accessibility measure. In some interviews an extra questions was launched for debate, concerning the ability of this measure to provide a good representation of urban centralities. Discussion was limited to the non-motorized layer, which is the most meaningful of the three mode accessibility layers produced by the SAL. The public transport accessibility layer was only discussed with experts of public transport operators. The car accessibility layer was discarded due to the homogeneity of the map.

Following this discussion, the presentation of the SAL was resumed. The benchmarking cube was defined as the key element for the comparison of accessibility levels by mode. Furthermore the meaning of accessibility categories and clusters was presented in detail. Again the presentation was interrupted for the second robustness assessment, with regard to comparative accessibility results for the GO. Experts were confronted with the category layer for the GO region, and asked to asses the ability of this measure to provide a good representation of land use and transport conditions for the sustainability of mobility (according to their personal experience and knowledge) (question, 2 Table C.2). This assessment generally involved further clarification of the benchmarking cube, and of the choices made in the development of the case-specific SAL such as activities and cut-off values. Many choices made during the application of the tool were discussed and some were questioned (this is further discussed in see sections 6.1 and 6.2). Furthermore, theoretical aspects regarding the development of the Benchmarking cube were also discussed. Several recommendations arouse from these discussions.

Following the discussion of the analysis abilities of the SAL, interviewees were asked to provide their opinion on the design support ability of this instrument (question 3, Table C.2). Some interviewees immediately hypothesis on how the instrument could be used as design support tool. This question was followed by the presentation of an illustration of policy design supported by the tool for the GO case study. A short presentation was made of the illustrative example of general strategy (for the entire GO) and of how it was developed based on the benchmarking cube, on the mode accessibility layers and on the regional accessibility levels. The detailed strategy (by groups of sub-regions), as well as the use made of the components of the SAL for the definition of that strategy, were also presented. Afterwards, interviewees were asked again to provide their opinion on the design support ability of this instrument (question 4, Table C.2). The discussion was complemented by questions regarding personal opinion on the usefulness of accessibility measures, in general, and of quantifiable objectives for policy making. In addition, interviewees were asked to provide general suggestions for the improvement of the SAL (question 5, Table C.2).

Finally, experts were asked to give their opinion on the practical applicability of the SAL (question 6, Table C.2). The ability of the SAL to work as an incentive to policy integration was also discussed with some experts. Once again, some suggestions were made for improvements. Experts were also asked to define the main advantages and disadvantages of the SAL (question 7, Table C.2; for a summary see Table C.3).

In average, each interview had duration of about 90 minutes, with approximately half used for discussion, while the other half was used for presentation of the SAL and the application to the GO case study. Around half hour was used for the presentation of the tool, divided into two parts. Around 15 minute were used in the presentation of the illustrative example of policy design based on the SAL. The discussion of robustness and usefulness of the tool took up almost all discussion time (around 40 minutes), in average 20 minutes each, leaving about 5 minutes for the discussion of applicability. All interviews were recorded and further on transcribed.

The following tables present the main questions used to guide the interviews, including the amount of positive and negative answers (Table C.2), as well as a summary of the main advantages and disadvantages suggested by experts (Table C.3) during the interviews.

Table C.2: Main questions used to guide the interview[83]

	Questions (optional questions)	Answers (count)					
		(a)	(b)	(c)	(d)	(e)	(f)
1	Does the non-motorized accessibility layer provide a good representation of your knowledge on local walking accessibility?	17	16	13	1	2	1
	(Does this measure provide a good indicator to identify urban centralities?)	17	8	6	2	0	
2	Do categories supply a good representation of land use and transport conditions provided for the sustainability of mobility?	17	15	11	4	0	2
3	Do you think that the SAL is useful to support policy design? (before presentation of strategy)	17	16	14	1	1	1
4	Do you think that the SAL is useful for support policy design? (after presentation of strategy)	17	15	13	1	1	2
	(Do you think that accessibility measures (in general) are useful of for policy design?)	17	6	6	0	0	11
	(Do you think that quantifiable objectives are useful in policy making?)	17	12	12	0	0	5
5	General suggestions for the improvement of the SAL.	-	-	-	-	-	
6	Do you believe the SAL is usable in practice?	17	16	15	1	0	1
	(Could the use of the SAL incentive the integration of land use and transport policies?)	17	8	4	2	2	9
7	Define the main advantages and disadvantages of the SAL.	-	-	-	-	-	

Legend: (a) Number of interviewees, (b) Number of responses, (c) Positive opinions; (d) Uncertain; (e) Negative opinions; (f) Not answered/not asked; with (a) = (b) + (f) and (b) = (c) + (d) + (e)

[83] Free translation of Portuguese questions.

Table C.3: Main advantages and disadvantages

Advantages	Disadvantages
Easy to understand, communicate and work	Synthesis excludes relevant detail
Synthesising and coherent diagnosis tool	Time and resource consuming
Useful to test scenarios	Limited micro-scale approach
Helps to think	
Drives territorial integration	
Can be used to produce more disaggregated analysis by theme	