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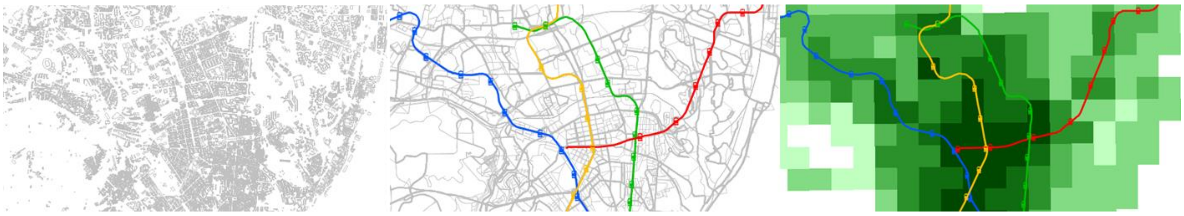

Strategic Assessment of Accessibility on Urban Mobility Networks

Camila Soares Henrique Fontenele Garcia

Supervisor: Doctor Maria do Rosário Maurício Ribeiro Macário
Co- Supervisor: Doctor Carlos Felipe Grangeiro Loureiro

Thesis approved in public session to obtain the PhD Degree in Transportation Systems

Jury final classification: pass with distinction

Jury

Chairperson: Chairman of the IST Scientific Board

Members of the Committee:
Doctor Ann Verhetsel
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Doctor Maria do Rosário Maurício Ribeiro Macário
Doctor João António de Abreu e Silva
Doctor Cecília do Carmo Ferreira da Silva
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Funding Institution
Fundação para a Ciência e Tecnologia – FCT - SFRH/BD/60424/2009

2016

Resumo

O papel estratégico da rede da mobilidade urbana e a avaliação da sua problemática à luz de princípios e valores estratégicos como a equidade e a sustentabilidade da acessibilidade ainda precisa ser formalmente reconhecido e devidamente incorporado~~s~~ no processo de planeamento. Neste sentido, esta tese de doutoramento procurou contribuir para o progresso do planeamento da mobilidade urbana propondo uma metodologia de avaliação estratégica que permite caracterizar e diagnosticar problemas de acessibilidade relacionados com a rede de mobilidade urbana bem como avaliar a sua evolução considerando os impactos que soluções propostas e/ou implementadas possam vir a ter nos mesmos. A metodologia proposta baseia-se em análises espaciais exploratórias e confirmatórias de indicadores de acessibilidade e mobilidade que permitem avaliar, em diferentes momentos do planeamento, um conjunto de quatro tipos de problemas definidos com base nas teorias suficientista e igualitarianista, e nos príncipios da equidade e da sustentabilidade. Tais problemas referem-se à distribuição desigual, inequânime, inadequada e insustentável da acessibilidade e da mobilidade na rede de mobilidade urbana. Uma aplicação ilustrativa da metodologia para uma versão simplificada da rede de mobilidade de Lisboa foi desenvolvida e os seus resultados permitiram demonstrar a adequabilidade dos métodos propostos a uma avaliação consistente e coerente dos problemas considerados.

Palavras-chave: Estratégico, Avaliação, Acessibilidade, Mobilidade, Equidade, Sustentabilidade, Rede de Mobilidade, Problemas, Indicadores e Análise Espacial.

Abstract

The strategic role of the urban mobility network and the assessment of their problematic in light of strategic principles and values such as equity and sustainability on accessibility still needs to be formally recognized and adequately incorporated into the planning process. In this sense, this thesis aimed to contribute to the progress of the urban mobility planning field by proposing a strategic assessment methodology that allows to characterize and diagnose accessibility problems related to urban mobility networks and to assess their evolution considering the impacts that proposed and/or implemented solutions may have on them. The methodology proposed relies on exploratory and confirmatory spatial analysis of accessibility and mobility indicators in order to properly assess, in different moments of the planning process, a set of four types of problems based on sufficientarianism and egalitarianism theories as well as on equity and sustainability principles. These problems refer to the unequal, inequitable, unsuitable and unsustainable distribution of accessibility and mobility on urban mobility networks. An illustrative application of the methodology for a simplified version of Lisbon's Mobility Network was developed and its results allowed to demonstrate the adequacy of the methods proposed for the coherent assessment of the problems considered.

Keywords: Strategic, Assessment, Accessibility, Mobility, Equity, Sustainability, Mobility Network, Problems, Indicators and Spatial Analysis.

Acknowledgements

First and foremost, I would like to thank my supervisors Prof. Rosário Macário and Prof. Felipe Loureiro for their mentoring. The guidance and support of Prof. Rosário, who always has an innovative way of looking at things, as well as the critical thinking and constant advices of Prof. Felipe Loureiro, were invaluable for the development and completion of this research.

I would also like to acknowledge the financial support from the National Science Foundation (FCT) through the scholarship (reference SFRH/BD/60424/2009) that supported me during the development of this research.

Many thanks go to Prof. Filipe Moura and Prof. João de Abreu e Silva who were always available to discuss my issues and to provide insightful suggestions to improve this work. A big thank you goes also to Luis Martínez who helped me with the operationalization of the illustrative case and with many philosophical discussions.

I also wish to express my appreciation to the fellows of the rooms 4.24 and 4.25, the old ones and the new ones, who followed closely the ups and downs of this endeavor. Marisa, Duarte, Luis, Bruno, Liliana, Matheus, Rui, Joana R, Joana C, Marcos and Maria, thanks for listening to me in my countless sessions of questioning and explanations about this work.

I would also like to thank the MITUS group, namely Fernanda and Ezequiel, for their valuable suggestions and critiques on the early versions of the chapters as well as for their own dissertations that inspired me so much during the development of this research.

A warm thank you to my dear friend Susana who was beside me unconditionally throughout the development of this work and whose constant support and encouragement were so precious.

I would like to express my deepest gratitude to my family, especially to my parents for their lifelong love and support.

Finally, a special thank you goes to my loving husband Bernardo who was my biggest supporter during this challenging journey. Without his love and unbelievable patience this dream would have never come true.

Table of contents

1. Introduction ... 1
1.1 Research Scope ... 1
1.2 Research Objectives ... 4
1.3 Research Methodology ... 5
1.4 Dissertation Outline ... 6

2. The Role of Assessment in the Urban Mobility System Planning ... 9
2.1 Paradigm Shifts in Urban Transportation Planning ... 10
2.2 Key Issues in Planning for Accessibility and Mobility ... 12
2.3 Assessment in Current Transportation Planning Methodologies ... 20
2.4 Assessment within the UMS Planning: a Methodological Proposal ... 28
2.5 Summary ... 36

3. Accessibility and Mobility Problems on Urban Mobility Networks ... 39
3.1 Urban interactions through the urban mobility network ... 40
3.2 Equity and Sustainability Issues on Accessibility and Mobility ... 45
3.3 The categories of accessibility restrictions ... 50
3.4 Accessibility indicators ... 55
3.5 Mobility indicators ... 62
3.6 Summary ... 67

4. Strategic Assessment Methodology of Accessibility and Mobility on Urban Mobility Networks ... 69
4.1 Problem-oriented approach ... 70
4.2 Spatial analysis techniques ... 73
4.3 Assessment of problems ... 77
4.3.1 Characterization of accessibility and mobility conditions ... 78
4.3.2 Diagnosis of accessibility and mobility problems ... 80
4.4 Assessment of solutions ... 85
4.4.1 Assessment of accessibility and mobility impacts ... 86
4.4.2 Assessment of accessibility and mobility problems evolution ... 87
4.5 Summary ... 88

5. Strategic Assessment of Accessibility and Mobility on Lisbon's Mobility Network 89
5.1 Lisbon's Mobility Network: scenarios and interventions ... 90
5.2 Database Assembling, Transportation Network Modeling and Spatial Analysis ... 92
5.3 The Strategic Assessment of Lisbon's Mobility Network ... 95
5.3.1 Assessing the problems: Baseline and Do-nothing scenarios ... 96
5.3.2 Assessing the alternative solutions: the ex-ante scenario ... 128
5.3.3 Assessing the implemented solutions: the ex-post scenario ... 140
5.4 Summary ... 156

6. Conclusions ... 159
6.1 General conclusions and contributions ... 159
6.2 Limitations and future research ... 162

7. References ... 165

Annex 1 ... 177
Annex 2 ... 179
Annex 3 ... 180

List of figures

Figure 1.1: Methodology outline 5

Figure 1.2: Dissertation structure 6

Figure 2.1: Conceptual Model for Urban Subsystems Interactions 13

Figure 2.2: Accessibility and Mobility Planning Framework 14

Figure 2.3: Representation of Transportation, Spatial and Mobility Networks 18

Figure 2.4: Decision-oriented transportation planning process 22

Figure 2.5: Logical structure for transportation decision-making 23

Figure 2.6: Integrated planning process 25

Figure 2.7: Urban Mobility Planning Process - Methodological Proposal 34

Figure 3.1: Urban interactions from the UMS perspective 41

Figure 3.2: Causal relationships of accessibility and mobility 41

Figure 3.3: Accessibility levels on the urban mobility network 43

Figure 3.4: The influence of equity and sustainability principles in the UMS planning 45

Figure 3.5: Categories of accessibility and mobility problems 49

Figure 3.6: Causal relationships by accessibility restrictions categories 55

Figure 4.1: Categories of accessibility and mobility problems 70

Figure 4.2: Urban Mobility Network strategic assessment methodology 72

Figure 4.3: Exploratory spatial data analysis tools 74

Figure 4.4: Characterization method of accessibility and mobility conditions 78

Figure 4.5: Diagnosis method of accessibility and mobility problems 81

Figure 4.6: Assessment method of accessibility and mobility impacts 85

Figure 5.1: Lisbon's transportation network and interventions 91

Figure 5.2: Causal relationship and restrictions considered 96

Figure 5.3: Logistic curves for private car and public transport in Lisbon 98

Figure 5.4: Spatial distribution maps of travel time by PC and PT (d, e), number of jobs (f), job accessibility by PC and PT (a, b) and job accessibility ratio (c) in Lisbon 102

Figure 5.5: Box maps (a, c and e) and LISA cluster maps (b, d and f) of job accessibility indicators in Lisbon 103

Figure 5.6: Spatial distribution maps of PT waiting times (a), Stop-station intensity (b) and road network connectivity (c) in Lisbon 104

Figure 5.7: Spatial distribution maps of time-mobility by PC and PT (a, b), time-mobility ratio (c) in Lisbon 105

Figure 5.8: Spatial distribution maps of total daily trips (a, b) and average time traveled (c, d) by PC and PT in Lisbon 106

Figure 5.9: Box maps (a, c and e) and LISA cluster maps (b, d and f) of time-mobility indicators in Lisbon 108

Figure 5.10: Spatial distribution of resident workers (a), car ownership (b), population with university degree (c) and average distance to job places by PC and PT (d, e) in Lisbon. 109

Figure 5.11: Spatial distribution (a, b), Box map (c, d) and LISA cluster maps (e, f) of % of unemployed and low educated people in Lisbon 111

Figure 5.12: Baseline scenario – job accessibility and time-mobility problems areas (a, b, c and d) and their spatial association (e and f) 114

Figure 5.13: Baseline scenario – job accessibility ratio and mobility ratios problems areas (a, b) and their spatial association (c) 115

Figure 5.14: Diagnostics for spatial dependence in the residuals of spatial models 120

Figure 5.15: Do-nothing scenario – job accessibility and time-mobility problem areas (a, b, c and d) and their spatial association (e and f) 126

Figure 5.16: Do-nothing scenario – job accessibility ratio and time-mobility ratio problem areas in Lisbon 127

Figure 5.17: Spatial distribution map (a, b) and LISA cluster map (c, d) of job accessibility by PT changes for the Baseline and Alternative scenarios 130

Figure 5.18: Spatial distribution maps of job accessibility by PT and travel times by PT for the Baseline and Alternative scenarios 131

Figure 5.19: Job accessibility and travel time changes in the “blue zones” 133

Figure5.20: Spatial distribution map (a, b) and LISA cluster map (d, e) of time-mobility changes for the Baseline and Alternative scenarios 134

Figure 5.21: Spatial distribution maps of time-mobility by PT for the Baseline and Alternative scenarios 135

Figure 5.22: Ex-ante scenarios – job accessibility and time-mobility problem areas (a, b, c and d) and their changes in spatial association (e and f). 138

Figure 5.23: Ex-ante scenarios – job accessibility ratios (a, b), time-mobility ratio problems (c, d) and their changes in spatial association (e and f) 139

Figure 5.24: Spatial distribution map (a, b and c) and LISA cluster map (d, e and f) of job accessibility impact in Lisbon 145

Figure 5.25: Spatial distribution of job accessibility, travel times and job place intensity in 2003 and 2011. 146

Figure 5.26: Spatial distribution map (a, b and c) and LISA cluster map (d, e and f) of time-mobility impact in Lisbon 147

Figure 5.27: Spatial distribution map of time-mobility indicators, resident workers and total daily trips in 2003 and 2011 148

Figure 5.28: References for social concern groups 149

Figure 5.29: Ex-post scenario: evolution of job accessibility and time-mobility problems areas (a, b, c and d) and the spatial association between their changes (e, f). 152

Figure 5.30: Ex-post scenario: evolution of job accessibility ratio (a) and mobility ratio (b, c) problem areas and the spatial association between their changes (d, e) 153

List of tables

Table 2.1: Accessibility and mobility definitions 15

Table 3.1: Categories of accessibility exclusion 51

Table 3.2: Relation between categories of accessibility restrictions and accessibility components 52

Table 3.3: Accessibility indicators by approach of analysis 56

Table 3.4: Accessibility indicators by categories of accessibility restriction 62

Table 3.5: Mobility indicators 65

Table 5.1: Public transport network parameters 93

Table 5.2: Complementary indicators 99

Table 5.3: Reference parameters for accessibility and mobility 110

Table 5.4: Dependent vs independent variables correlations 116

Table 5.5: Time-mobility and distance-mobility classic accessibility models 118

Table 5.6: Parameters of time-mobility by PC models - Baseline scenario 119

Table 5.7: Parameters of time-mobility by PT models - Baseline scenario 119

Table 5.8: Elasticities in time-mobility spatial models – Baseline scenario 120

Table 5.9: Diagnostics for spatial dependence in the residuals of classical models 120

Table 5.10: Indicators evolution 123

Table 5.11: Configuration of the public transport alternatives 129

Table 5.12: Characteristics of the interventions in the North region 129

Table 5.13: Resident workers impacted in the North region 133

Table 5.14: Input variables variation from 2003 to 2011 143

Table 5.15: Evolution of workers residing in Lisbon 143

Table 5.16: Unemployment rates 143

Table 5.17: Parameters of time-mobility models – Ex-post Scenario-2011 154

Table 5.18: Elasticities in time-mobility spatial models – Ex-post Scenario-2011 154

List of acronyms and abbreviations

AML	Área Metropolitan de Lisboa
APC	Job accessibility by private car
APT	Job accessibility by public transport
AR	Job accessibility ratio
BRT	Bus rapid transit
CSI	Composite Sustainable Index
EIA	Environmental Impact Assessment
ESDA	Exploratory spatial data analysis
GWR	Geographically weighted regression
I_SUM	Sustainable Urban Mobility
ILUT	Integrated land use and transportation
ISR	Index of spatial regimes
LISA	Local indicator of spatial association
MSDA	Modeling spatial data analysis
PC	Private car
PT	Public transport
SCG	Social concern group
SEA	Strategic Environmental Assessment
SIA	Sustainability Impact Assessment
STO	Strategic, tactical and operational
TMPC	Time-mobility by private car
TMPT	Time-mobility by public transport
TMR	Time-mobility ratio
UMN	Urban Mobility Network
UMS	Urban Mobility System

1.Introduction

1.1 Research Scope

Cities as urban systems can be considered as a set of physical and abstract relations or interactions developed throughout the space (Archibugi, 1998). Such interactions are derived from a series of multiple functions and their connections that together determine the performance of the social and economic activities within the city. The Urban Mobility System (UMS), as the main connector of the urban system, has a vital character by delivering fluidity in the displacements of people and goods through the provision of access to different locations in the city, therefore influencing the performance of all urban activities (residing, working, studying, shopping, *etc.*). It is thus considered an enabler of the cities, an urban subsystem of great autonomy of organization that has a strong symbiotic relationship with other urban subsystems, especially the land use and activity subsystems, acting as a key component of the urban life (Macário, 2005).

Planning the UMS is thus an important activity for the proper functioning of cities, since it helps decision makers understand urban problems and choose interventions that promote urban development. Over the years, the UMS planning effort has undergone a series of conceptual and methodological changes that have been improving the process itself and the quality of its results. These changes refer especially to: the focus shift from mobility to accessibility, emphasizing the importance of considering transportation and land use interactions; the reorientation from a solution-oriented approach, based on the transportation system's demand-supply imbalances, to a problem-oriented approach, based on the identification and analysis of the UMS problems; and the incorporation of equity and sustainability principles in order to achieve a more just and long lasting social and spatial urban development.

All these changes have represented a qualitative leap in the UMS planning process, with the shift of focus to accessibility being perhaps the most significant one. According to Handy (2005), planning for accessibility evidences the interactions between the mobility system and the other urban subsystems, allowing to analyze the influence of the aspects related not only to transportation infrastructure and services, but also to land use/activities and individuals (Geurs and van Wee, 2004). In addition, the association of the concept of accessibility with the principles of sustainability and equity, as the basis of the UMS planning process, provides a more appropriate way of dealing with the complexity of the accessibility problems, either setting minimum levels of accessibility in order to maintain the quality of life of individuals, or promoting a fair distribution of access to prevent the exclusion of certain social groups (Bertolini *et al.*, 2005; Halden, 2009).

The majority of the accessibility planning efforts has concentrated on proposing new ways to operationalize its concept in order to support the planning process development. In general, the approach adopted for quantifying the concept of accessibility has gone beyond the consideration of systems of indicators or indexes developed under multiple criteria frameworks and have considered the use of accessibility instruments. These instruments are considered tools of measure, interpretation and modeling of accessibility that provide meaningful information about the mobility and activity systems through visualization tools and numerical indicators (Hull *et al.*, 2012).

An extensive review carried out by a COST Action on the use of accessibility instruments in the European urban planning practice showed that these instruments are very diverse regarding the components and measures of accessibility, their operationalization and the planning goals addressed (Hull *et al.*, 2012). Most of these instruments consider goals related to locational decisions (urban planning goals) or the use of transport modes (transportation planning goals), and only few are multi-objective and include explicitly economic and social equity goals. Nonetheless, the motivation for developing such instruments has generally been to support strategic planning decisions by integrating land use and transportation planning.

This integration, as pointed by Macário (2007), is one of the driving factors for the long lasting development of urban areas. It brings out the importance of a strategic thinking in the UMS planning in which the interdependence and interactions between the different components of the urban system are emphasized and explored. However, this strategic and systemic view over the urban mobility system is still missing in many cities, with those few sensitive to the subject considering it in a reductionist way as just being the capacity of forecasting demand and controlling the transportation system. As argued by Macário (2007), this misperception, in turn, leads to inefficiencies in the planning results, since the causal relationships are not observed and understood~~,~~ and, consequently, are not adequately articulated within the UMS planning process.

Lopes (2015), in turn, argues that the consideration of a conceptual model representing the mutual dependencies between the urban subsystems can help planners to better understand the urban interactions and therefore identify problems, especially the ones related to accessibility and mobility. By acknowledging the causal relationship between the activity, land use and transportation systems, the model sets the theoretical foundation for the investigation of accessibility and mobility problems. However, two important difficulties arise from the consideration of this complex representation. One is related to how to operationalize this representation and the other refers to how to address the analysis of these problems within the urban mobility system planning process, especially at the strategic level.

The joint representation of the key elements of the urban subsystem responsible for defining the levels of accessibility to urban activities seems to be a possible way to overcome the first issue. Specifically, by considering an aggregated network model, here denominated as Urban Mobility Network (UMN), that represents the spatialized functions or activities as well as the travel resistances or impedances between them. This representation comes up as a way to translate the theoretical model into operational measures of accessibility. On the other hand, the definition of revised procedural planning steps to accurately address the urban interactions seems to be the way forward for the second issue. Precisely, the definition of assessment methods to continuously analyze accessibility and mobility problems framed by equity and sustainability principles can be seen as way to properly address strategic issues and its long-term consequences (Partidário, 2007).

Based on these conceptual and methodological concerns, the following research questions are raised as a way to drive the development of this research:

- What is the role of assessment activities in the UMS planning process?

- How to define accessibility and mobility problems on urban mobility networks considering the equity and sustainability principles?
- How to strategically assess accessibility and mobility problems?

1.2 Research Objectives

The main objective of this research is to develop a methodology to perform the strategic assessment of accessibility and mobility levels in the urban mobility system, and to confirm that this is a critical instrument not only to obtain a better understanding of the accessibility and mobility problems faced by various social groups, but also assess, *ex-ante* and *ex-post,* the interventions proposed to solve these problems.

In order to facilitate the attainment of the main objective, the following specific objectives are pursued:

- Analyzing the role of the strategic assessment in the Urban Mobility System (UMS) planning process;
- Discussing the strategic assessment of accessibility and mobility problems on the Urban Mobility Network (UMN), based on principles of social equity and sustainability;
- Indicating suitable measures to characterize accessibility and mobility problems, and to diagnose their causal relationships;
- Proposing a methodology for the strategic assessment of accessibility and mobility problems in urban mobility networks;
- Validating the proposed methodology through the development of a case study focusing on the assessment of Lisbon's Mobility Network.

The proposal of this methodology represents a significant contribution to the urban mobility planning process. It will constitute a useful tool for the alignment of the strategies for developing the urban mobility network according to user needs while also providing a method for the *ex-ante* and *ex-post* assessment of impacts caused by interventions that change the urban mobility network configuration. This tool can provide decision makers with useful information that will aid them make better decisions about the urban mobility network development both in terms of land use arrangements and transportation network connections.

1.3 Research Methodology

In order to answer the research questions raised and to achieve the objectives set for this research the methodological approach considered is based on an initial literature review followed by the development of a strategic assessment methodology. It ends with a case study where the applicability of the methodology is demonstrated as pictured in Figure 1.2.

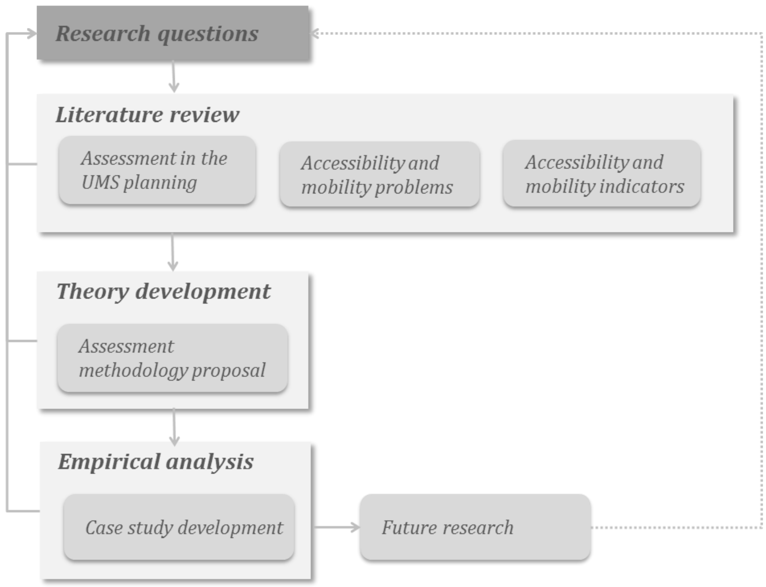

Figure 1.1: Methodology outline

The literature review carried out focuses on three main fields. The first field refers to the planning of the urban mobility system covering the main changes it has undergone, its key strategic concerns as well as the current methodologies proposed to support it with special attention to strategic assessment issues. The second field refers to accessibility and mobility problems at the strategical level while the third field centers on accessibility and mobility measures to support the assessment of the problems considered. Together, these three fields provide the theoretical foundation that allowed to answer the first two research questions.

Moreover, the literature review performed provided the necessary background for the development of the strategic assessment methodology. This methodology was developed in the most generalist way possible in order to be applied to any UMN. It establishes methods and criteria to assess strategic problems of accessibility and mobility considering their intrinsic spatial characteristic allowing an intelligent reading of these problems and the identification, in an early stage of the planning process, of misalignments between the UMN configuration and equity and sustainability principles. The proposal of such methodology allowed to answer the third research question.

Once the methodology was defined, its applicability was demonstrated through a case study carefully chosen, in which was possible to test the assessment methods and criteria in different moments of the planning process. In addition, the added value of the methodology as a strategic planning support tool was also demonstrated by the results obtained as they allowed to identify the mismatching between strategic decisions taken and the strategic problems of accessibility and mobility assessed.

Finally, the results of the case study provide indications for further research regarding the improvement of the proposed methodology in relation to its scope, the methods used and the tools applied. These hints enable the development of future steps within the learning cycle of strategic evaluation of accessibility and mobility, and encourage additional discussion of relevant issues within this research line.

1.4 Dissertation Outline

This dissertation is organized in six chapters (Figure 1.2) that aimed to achieve the objectives set for this research in order to answer the research questions raised. The approach considered for its development relies on a literature review that laid the foundations for the development of the proposed strategic assessment methodology, whose applicability was demonstrated by the development of an illustrative case for Lisbon's Mobility Network.

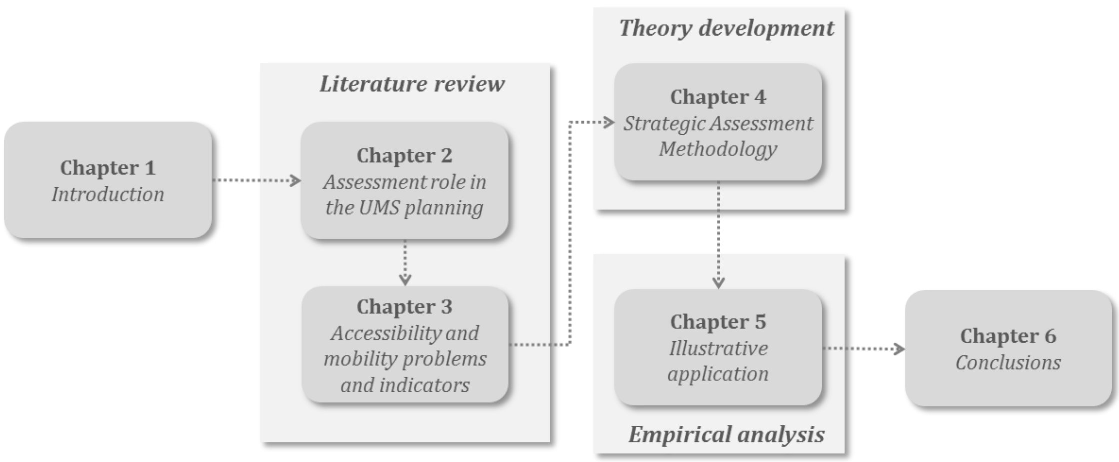

Figure 1.2: Dissertation structure

Specifically, each chapter presents the following contents:

- Chapter 1 presents the research scope including the research questions and objectives pursued throughout this dissertation as well as its structure;
- Chapter 2 analyzes the role of assessment in the urban mobility system planning by reviewing the paradigm shifts that have been occurring in the urban mobility field as well as the gaps regarding the consideration of assessment tasks in the traditional methodological procedures for planning and decision-making. The chapter ends up by proposing a new problem-oriented methodological procedure for the urban mobility planning and decision-making process in which the urban mobility network is recognized as a strategic element and the assessment activities are highlighted.
- Chapter 3 presents a discussion about the relation between urban mobility network and the accessibility paradigm. The implications of considering equity and sustainability principles on accessibility analysis are also reviewed as a way to frame the dimensions of accessibility restriction as well as the definition of accessibility problems. The chapter concludes with a review of accessibility and mobility measures and the indication of the ones more suitable to support the characterization of both phenomena and the analysis of their causal relationship.
- Chapter 4 provides the description of the proposed strategic assessment methodology of accessibility and mobility problems on the urban mobility network. It starts by discussing the problem-oriented approach of the methodology and the theoretical foundation behind the spatial analysis techniques used to support the methods proposed in the methodology. Then, the overall structure of the methodology is presented followed by a detailed description of all the steps, procedures and methods that it comprises.
- Chapter 5 presents the results of the illustrative application of the methodology for Lisbon's Mobility Network. It starts with the description of the scenarios and interventions considered, followed by the description of the database assembling, network modeling and spatial analysis requirements. Then, the strategic assessment of accessibility and mobility on Lisbon's Mobility Network is presented including: i) the diagnosis of accessibility and mobility problems; ii) the *ex-ante* assessment of two alternative configurations of Lisbon's UMN that differ in relation to public

transport solutions; and iii) the *ex-post* assessment of the final configuration characterized by the solutions actually implemented.

- Chapter 6 concludes this dissertation by summarizing the main findings and contributions of the theoretical and empirical chapters. It starts with a discussion upon the general conclusions regarding the proposed methodology and ends up with the acknowledgement of its main limitations as well as possible future research areas.

2. The Role of Assessment in the Urban Mobility System Planning

The process of planning the Urban Mobility System (UMS) has faced a number of paradigm shifts in the last decades usually associated with the consideration of new values and principles in its development. More recently, the integrated urban planning, reinterpreted as the new accessibility planning paradigm, has been pointed out as the most adequate approach to jointly address land use and transport issues affecting the individual's accessibility and mobility. However, there are still some issues that are not adequately addressed in this approach, especially at the strategic level, such as the consideration of the Urban Mobility Network (UMN) and appropriate methods for its assessment, or more precisely, for the assessment of the accessibility levels offered through it. In this sense, the main objective of this chapter is to present an overview of the role of assessment efforts in planning the UMS, especially in relation to the UMN. It starts with a discussion about the paradigm shifts faced by the urban transportation planning field in section 2.1, followed by the analysis of the key issues related to the new paradigm, the joint accessibility and mobility planning, in section 2.2. In section 2.3, the weakness of assessment activities in traditional methodological transportation planning and decision-making procedures is discussed. Then, in section 2.4, a new methodology is proposed to emphasize the role of assessment activities within the distinct phases and levels of the UMS planning process. Finally, the summary of the chapter with the main conclusions is presented in section 2.5

2.1 Paradigm Shifts in Urban Transportation Planning

The need for paradigm shifts in the urban transportation planning field has been pointed out by several authors over time. These shifts are usually associated with the consideration of new values and principles in the development of the planning process. Sometimes these changes are presented in the form of a focus shift from transport supply to mobility, and then to accessibility, in order to make more evident the integrated planning of transportation and land use (Handy, 2005; Macário, 2012). Sometimes the changes are related to the incorporation of sustainability and equity principles to ensure the achievement of more lasting and socially fair strategic objectives (Banister, 2008; Kenworthy, 2007). However, there are some issues that are not explicitly explored, or are even overlooked, on the planning process and this may lead to a poor understanding of the urban accessibility and mobility problems, as well as to a negative impact on quality and efficiency of proposed alternatives and, consequently, of the decisions taken.

Perhaps one of the most underestimated paradigm shifts is the growing use of the expression “mobility system” instead of “transportation system” in both research and technical fields. Sometimes the intention of this change is merely to expand the view of the transportation system for the consideration of non-motorized modes, especially when “mobility” comes associated with the word “sustainable”, as seen in some governmental guidebooks (APA, 2010; MCidades, 2007). But in fact the preference for the use of the word “mobility” over “transportation” can be seen as an attempt to express more clearly the issues related to individual mobility instead of only infrastructures and services offered. This change brings out two important issues in the planning process: the supply-demand dichotomy and the solution vs. problem orientation.

Traditionally, the perception of the transportation system has been related to its supply side, which is often reflected in a planning process aimed at proposing solutions and centered on the achievement of a set of predefined goals, instead of focusing on the identification of the real needs and problems faced by users and other stakeholders. The change towards the use of the mobility concept increases the concerns of the planning process regarding the demand aspects, allowing a more detailed analysis of unbalances in the supply-demand relationship, i.e., the identification, characterization, and diagnosis of problems associated with the system. In this case the planning effort is thus to be oriented first by the recognition and understanding of problems, followed by the proposition of solutions that aim at managing both demand and supply sides of the system in order to reduce the impacts of traffic and enhance mobility options (Meyer and Miller, 2001). Therefore, the use of the expression "mobility planning" seems to be more adequate than "transportation planning" if the purposes are to align both demand and supply aspects in the planning process and to redirect the focus of the process from proposing solutions to resolving problems.

However, there is yet another important issue that becomes more evident when the mobility planning approach is considered: the intrinsic relationship between the transportation and the land-use urban subsystems. The consideration of the dynamic interaction between these two fields have been advocated under the "integrated planning" denomination since the early 1960s (Banister, 2002; Meyer and Miller, 2001). More recently, various authors have considered these interactions in what they call "accessibility planning" (Bertolini *et al.*, 2005; Curtis, 2008; Halden, 2009). This integrated planning approach, besides making evidence of the importance of interactions between transportation and land use, has its emphasis on demand, focusing on planning the access of individuals to their main activities and/or the accessibility of destinations to specific groups. Even so, the consolidation of this integrated approach has faced some difficulties in practice mainly due to the institutional/procedural discrepancies regarding institutional agencies, financial arrangements, *etc*. (te Brömmelstroet and Bertolini, 2008).

Another important paradigm shift from the traditional urban transportation planning field refers to the consideration of sustainability issues. The incorporation of such issues into the mobility planning process broadens its goals by highlighting concerns with the external impacts related to the provision of mobility. Besides, the sustainable mobility planning approach can be seen as a way to strengthen the link between land use and transportation, since to achieve this goal it is not enough to provide mobility, being also necessary to reduce the distances between the desired destinations, or even the need for travel, to encourage modal shifts to more environmentally efficient modes, and to promote technology innovations (Banister, 2008). However, as the primary concern of planning has been changing from mobility to accessibility, some authors have emphasized the combination of sustainable issues with accessibility, instead of mobility (Curtis, 2008; Doust and Black, 2009; le Clercq and Bertolini, 2003). For them, the "sustainable accessibility planning" is the best way to address land use and transportation interactions and to achieve the ultimate goal of providing cities with more sustainable travel options (Bertolini *et al.*, 2005).

Nevertheless, most of the sustainable accessibility planning initiatives still leave out issues of social equity, or considers them in an implicit way. The consideration of the equity concept in the planning process gives it a sense of social justice in relation to the provision of access and allows minimizing the inequitable effects on minority and low-income communities due to the limited access to social and economic opportunities (Sanchez *et al.*, 2003). This can be seen in the UK accessibility planning practice, in which equity issues in relation to distribution of access to the main services are emphasized (Halden, 2009). Thus, the combined use of the accessibility concept with the principles of equity and sustainability in the development of the planning process seems to be the most appropriate one. Together these concepts enable the development of urban policies that consider not only offering good levels of accessibility by more environmentally friendly modes, but also the decrease of spatial and social effects of the accessibility distribution and the improvement of the system's global efficiency.

It can be noticed, therefore, that over time the effort of planning the Urban Mobility System (UMS), herein considered as the urban subsystem that ensures the fluidity in the displacements and provides access to different locations (Macário, 2005), has also undergone some paradigm shifts resulting in the proposal of different approaches that highlight the importance and combination of four key concepts: mobility, accessibility, sustainability and equity. For Litman (2013), the evolution on these conceptual paradigms contribute to redefine the efficiency of the UMS, either by minimizing the total cost of the resources needed to access services and activities, or by offering a range of modes that allow users to choose the most suitable intermodal combination for each trip, or especially by recognizing the need for an integrated planning in which short-term decisions support the strategic goals.

2.2 Key Issues in Planning for Accessibility and Mobility

The accessibility planning approach as a paradigm shift regarding the main values of the planning process, reinforces the need to consider an integrated analysis of the urban subsystems that relate to the urban mobility phenomenon. As argued by van Wee (2002), this phenomenon, or more specifically the mobility behavior, is influenced by three main factors: the travel resistance or impedance (named herein as the Mobility System, instead of the classical Transport System), which mainly depends on travel times, capacity, comfort and reliability of the available modes; the location of activities or the distribution of land uses (Land-use System); and the needs and desires of people to perform activities (Activity System), which depends on socioeconomic, cultural, professional and other personal aspects.

When planning the urban mobility phenomenon, it is thus necessary to consider their complex nature which derives from the inter- and intra-relationships between and within each of these three urban subsystems (Macário, 2007). According to Lopes (2015), these subsystems interact and impact on each other, presenting their own inner dynamics as showed in Figure 2.1. Conceptually, the Mobility System impacts the other subsystems through accessibility; the Land-use System influences the others by the spatial distribution of functions; and the Activity System impacts the others through its attractiveness. Also, these subsystems have their internal supply-demand dynamics that, in the case of the Mobility System, is given by the travel demand and infrastructure supply interactions; in the Land-use System, by the location demand and the space availability interactions; and in the Activity System, by the activity demand (*e.g.*, residing, working, *etc.*) and the economic activities offering interactions.

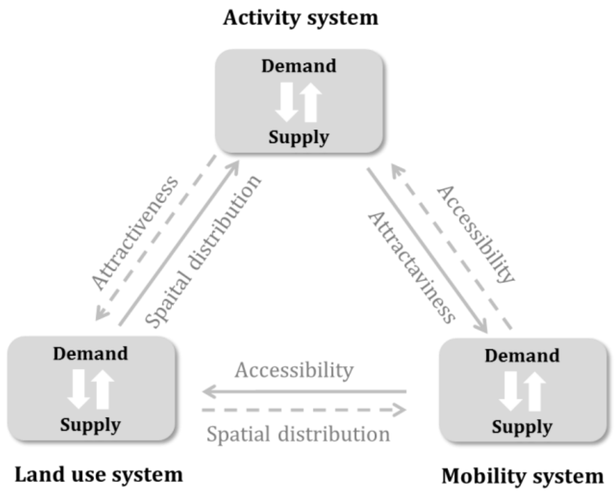

Figure 2.1: Conceptual Model for Urban Subsystems Interactions

(Adapted from Lopes (2015))

The recognition of all these interactions serve as a basis for the definition of causal relationships between and within the subsystems, and thus for the investigation of issues related to accessibility and mobility problems, considered the main values or the focus of the joint accessibility and mobility planning approach, as presented in Figure 2.2. These values help planners to better delineate the objects to be analyzed, as mobility problems can be related directly to the performance of the Mobility System, while accessibility problems are represented by the links between the Mobility System and the Land-use/Activity Systems. Together with the principles of efficiency, equity and sustainability, these values lay the foundation for the development of the urban planning process, setting the path to be followed in order to achieve the ultimate purpose of contributing to the socio-spatial development by promoting quality of life and greater social justice (Souza, 2010).

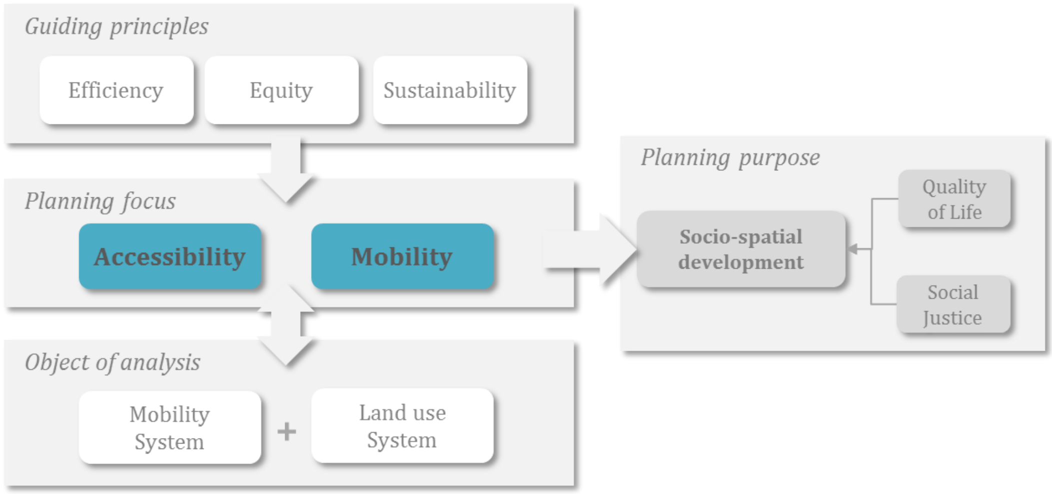

Figure 2.2: Accessibility and Mobility Planning Framework

(Adapted from Soares (2014))

The analysis of **accessibility** and **mobility** values as the center of the UMS planning process requires a clear understanding of their meanings since depending on the definitions assumed different results can be obtained. The consideration of these two different, albeit inter-related, values is crucial for the development of the planning process. According to the definitions considered, or the emphasis they receive, significant alterations can be brought to the planning process regarding the definition of problems, the types of alternative solutions, and how they can be assessed. Therefore, having a clear understanding of their meanings and the consequences that each of them can bring to the planning process is of extreme importance.

A set of definitions for both accessibility and mobility are presented in Table 1. In general, mobility definitions refer to the individual's ability to move, while accessibility definitions relate to the easiness to access destination or to interact. However, some definitions can cause confusion such as the ones about accessibility from Ortúzar and Willumsen (1994) and Vuchic (2000) that highlight the importance of traveling and not of accessing or interacting. Or the definition of Jones (Jones, 1981) that emphasizes the relationship between accessibility and mobility, with the former being considered the cause of the latter. Therefore, in order to avoid any misconception it is considered in this research that mobility express the easiness of movement and is related with the individual ability to move from one place to another, while accessibility represents the easiness to reach destination/activities (and thus of interact) and is influenced by the characteristics of both mobility and land-use systems.

Table 2.1: Accessibility and mobility definitions

Accessibility	Mobility
• Potential of opportunities for interaction (Hansen, 1959) • Potential mobility (Jones, 1981) • Easiness to perform trips from/to a certain traffic zones (Ortúzar and Willumsen, 1994) • Easiness of access from one point to others points in the network (Taaffe et al, 1996) • Ability to travel between different activities (Vuchic, 2000) • Easiness to reach destination/activities (Levine and Garb, 2002) • The extent to which land-use and transportation system enables individuals to reach activities by means of transport modes (Geurs and van Wee, 2004) • Property of the transportation mean (Magalhães *et al.*, 2013)	• Potential for movement (Hansen, 1959) • Capacity of individuals of moving from one place to another influenced by the transport performance as well as by socioeconomic characteristics (Tagore and Skidar, 1995) • Easiness of movement (Levine and Garb, 2002) • Facility of movement or ability to move or to be moved (Handy, 2005) • Capacity of individuals or groups of physically moving from one place to another (EEA, 2006) • Property of something that can be transported (Magalhães *et al.*, 2013)

Additionally, the consideration of guiding principles such as efficiency, equity and sustainability, highlighted in Figure 2.2, is crucial for the establishment of a reference vision of what is to be achieved in terms of urban development. Different from values, considered as moral aspects related to individuals, principles are seen as moral rules that guide individual behavior in a societal perspective (Gyekye, 2011). Thus, framing accessibility and mobility analyses under these principles confers greater robustness to the planning process, particularly in the early stages in which problems can be adequately addressed in order to achieve more efficient, fair and long lasting solutions.

Efficiency is the most common and traditional principle used in planning. Conventionally, efficiency expresses the ratio between benefits and costs, or outputs and inputs. In urban mobility, efficiency can be seen as the ability to fulfill individual accessibility and mobility needs at the minimum possible cost. Macário (2005) considers that efficiency in urban mobility represents the capacity to best transfer the basic resources (financial, technical and material) allocated through strategic decisions into service outcomes at tactical and operational levels. In other words, the best way to provide mobility options to individuals considering the restrictions imposed by the available resources, allowing them to access their activities of interest.

Besides efficiency, **equity** is also a principle of major importance in the planning process. Its relevance arises from the fact that some differences among individuals can often lead them to disadvantageous conditions by limiting their opportunities and/or capacities to participate in society and hence placing them in a position of social exclusion. The equal treatment of individuals is thus considered to be an unfair approach in the analysis of urban problems, requiring a more just or equitable perspective, which can be achieved by incorporating equity concerns into the planning process (Feitelson, 2002). In urban mobility, equity can be considered as been related with the fair distribution of both system's resources and impacts among individuals, and differs from equality in the sense that it implies a need for justice in the distribution of gains and losses by the community (Beder, 2000). It tries to balance the benefits perceived by the different actors involved, establishing a state of mutual satisfaction of needs which, when reached at the present time, can be called of **intra-generational equity** (Beder, 2000; Feitelson, 2002; Weiss, 1992).

On the other hand, **inter-generational equity** refers to the maintenance of the state of mutual satisfaction of needs over generations (Beder, 2000; Litman, 2012; Meyer, 2014) without exhausting resources. This implies considering a sense of justice in the treatment of hereditary problems as opportunities of future generations may be harmed by the decisions of the present one. As argued by Beder (2000), such view is considered the central idea behind the **sustainability** principle, which is explicit in the sustainable development definition of the Brundtland Report (WCED, 1987) as the development "that meets the needs of the present without compromising the ability of future generations to meet their own needs". Such principle encompasses the assumption that future generations should not inherit the problems faced by the present one, even when they have resources available to overcome them, with the present generation having the moral obligation to maintain the resources inherited from the previous ones.

In the accessibility and mobility planning approach, the consideration of both intra- and inter-generation perspectives of equity, or simply of social equity and sustainability principles, means providing an adequate distribution of accessibility and mobility levels among individuals in order to guarantee the satisfaction of individuals' particular needs. This satisfaction promotes a stabilization state of possible social tensions arising from accessibility and mobility inequalities, which, if perpetuated over time, partially guarantees the sustainability of the current transportation network and land-use arrangement. The full sustainability, though, is only achieved by considering also the economic and environmental dimensions over time (Bertolini *et al.*, 2005). As argued by Le Clerq and Bertolini (2003), one way of achieving such state is by offering good levels of accessibility through a spatial configuration, i.e., land-use arrangement and transportation connectivity, which shortens the distances traveled or provides more environmentally efficient connections (*e.g.*, by public transport) for long-distance travels (Banister, 2008).

However, despite planning for accessibility, with reference to equity and sustainability principles, has been recognized as the best way to deal with the urban mobility complexity, there is still a gap regarding the representation of transportation and land use/activity interactions at the strategic level. Although, Lopes (2015) conceptually acknowledge these interactions, the definition of a model, in this case a network model, which allows the investigation of these interactions is still missing. The recognition of an urban mobility network, and its consideration as a structural element and central object of the strategic level of analysis in the accessibility planning, comes as a way to fulfill this gap.

This new concept of a mobility network would represent the spatially distributed activities, as well as the impedances between them, which is a representation closer to the users' perceptions, contrasting with the land-use and transportation planners' perspectives of the urban network. Land-use and transportation planners tend to have a more fragmented view of the urban network, using their own languages and metrics to represent and analyze it. At the opposite, users have a more holistic view of the urban network seeing it as a set of spatially dispersed places of activities and their connections (Cheng *et al.*, 2013).

These different views led to three different urban network representations or models, as presented in Figure 2.3. The transportation network usually represents its infrastructures with links depicting roads/railways and nodes depicting intersections/stations. The spatial network represents the spatial connection between places where links are the orthogonal distances between those places and nodes are concentrations of land uses. The herewith proposed concept Mobility Network, in turn, may represent the connections between activities with links describing the impedances (in terms of travel time) and nodes representing the concentration of activities (in terms of attractiveness). Based on the network meanings defined by Camagni and Salone (1993), it can be considered that the transportation network has a physical meaning focusing on the description of the transportation infrastructure, while the spatial and the mobility networks have a more functional meaning focusing on spatial interaction between places, activities and people, with the mobility network having the advantage of incorporating transportation features in the representation of the impedances.

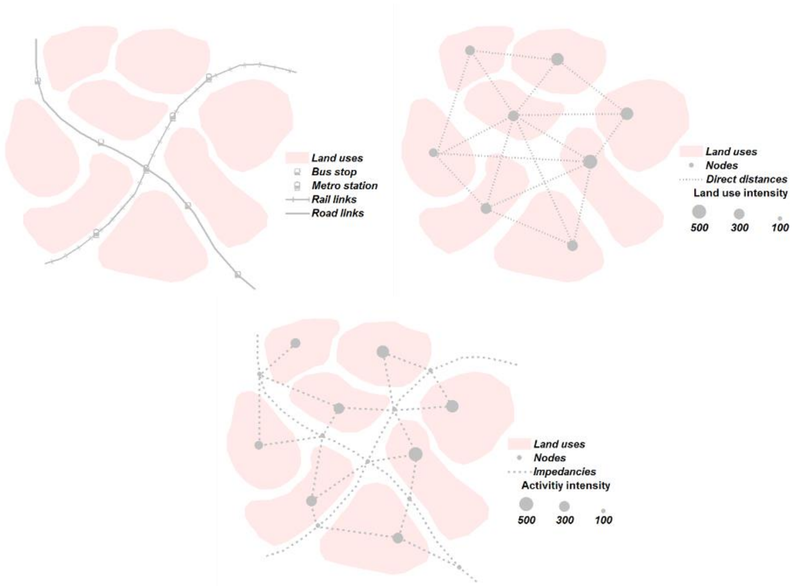

Figure 2.3: Representation of Transportation, Spatial and Mobility Networks

By considering the mobility network model, the analysis of the urban network functionality or, in other terms, the analysis of the spatial interactions between activities, and, hence, of the individual access to those activities, becomes the central object of the strategic analysis in the planning process. Such analysis requires metrics that allow the joint assessment of land-use and transportation aspects. In this sense, accessibility as a measure expressing how the land-use and mobility systems enable individuals to reach their activities of interest (Geurs and van Wee, 2004) constitutes the most appropriate value for the mobility network assessment. Therefore, the consideration of the mobility network as a strategic planning element reinforces the importance of a strategic vision, as well as an integrated perspective, in the UMS planning process, which can only be achieved through the analyses of accessibility and mobility problems.

Furthermore, although the recognition of the urban mobility network as a strategic element of the urban system comes as a way to operationalize the missing strategic vision for UMS (Macário, 2007), it also brings some implications to the sequence of methodological steps of the planning process. Specifically, it demands revised procedural steps, including methods and indicators, to accurately assess accessibility and mobility levels in the urban mobility network, particularly at the strategic level. Such assessment would be helpful to identify the users' real accessibility problems and mobility needs in order to support the proposition of appropriate alternative solutions based on equity and sustainability principles, and to verify if the solutions implemented are contributing to achieve the strategic goals.

This type of assessment has similarities with the Strategic Environmental Assessment (SEA), and its broader version called Sustainability Impact Assessment (SIA), in the sense that these are activities planning activities that allow to consider strategic issues, such as environmental and sustainability ones, in the early stages of the decision making process (Bond *et al.*, 2012; Partidário, 2000; Runhaar and Driessen, 2007; Tetlow and Hanusch, 2012). Such activities, more than just assessing the environmental consequences of pre-defined solutions, as accomplished in Environmental Impact Assessments (EIA) at the project level, serve as processes whose main purpose is to understand and properly address problems in order to meet the intended objectives by considering environmental and sustainable alternative options at the strategic level (Partidário, 2007).

These assessment efforts, especially SEA in their early years, were seen as decision aiding procedures performed apart from planning, but whose integration into the planning and decision making process has been gradually advocated (Tetlow and Hanusch, 2012). Such integration is viewed as an effective way of implementing SEA/SIA or to ensure that the strategic actions considered are sustainable and environmentally benign. However, also according to Tetlow and Hanush (2012), there is a divergent line that argue the need to maintain SEA/SIA as a separate process in order to ensure the transparency and accountability regarding how environmental and sustainability issues are considered in the decision making process

In line with the integration approach, this thesis considers the assessment as an intrinsic activity of the planning and decision-making process that does not need to receive special labels to highlight its importance. In fact, what it needs is to be aligned with the other planning activities within a single process in which their results are taken as input of others planning phases and vice-versa. Moreover, it is recognized that the assessment activities occur at different moments (*ex-ante* and *ex-post*) of the planning process, following a top-down approach (from the strategic to the operational level) and comprising, besides the assessment of problems, the two forms of assessment frequently referred in the planning literature as appraisal and evaluation (Suárez, 2007).

Appraisal has been considered as the *ex-ante* process of deciding how well an alternative solution will perform, while evaluation as the specific application of appraisal to the *ex-post* assessment of implemented solutions (May *et al.*, 2005). However, this classification is not always strictly followed in the planning literature, with the term evaluation sometimes referring to *ex-ante* tactical assessments, such as cost benefit or multi-criteria analyses. In this research, though, assessment is considered as an umbrella term that encompasses all forms of analytical judgment or valuation during the planning process, but that is most suitable for the ones performed at the strategic level, i.e., the assessment or diagnosis of problems, the assessment or appraisal of alternatives solutions and the assessment or evaluations of implemented solutions.

Additionally, in the case of the UMS planning, strategic assessment activities should be focused on accessibility and mobility values and supported by guiding principles such as equity and sustainability, rather than just the environmental one, assuming an important role in the planning and decision making processes, especially regarding the assessment of accessibility in mobility networks. Such activities should open up the planning process by helping planners to analyze, at the strategic level, whether the current network configuration is adequate to attend the users' needs, contributing to formulate and better assess network alternatives having in consideration both land-use and transportation aspects. In other words, the strategic assessment of accessibility in mobility networks may allow to bring to the initial phase of the process issues such as network coverage, level of integration, diversity of land uses, density of activities, *etc.*, which are not usually considered together in traditional assessments, but that must be taken into consideration at an early stage in order to guarantee that the society's principles are observed, as previously discussed.

2.3 Assessment in Current Transportation Planning Methodologies

There are many methodological procedures in the literature to deal with the urban accessibility and mobility complexity, but no single method can be pointed out as the ideal to conduct its planning and decision-making process. Nonetheless, these procedures are based on conceptual or philosophical approaches that define the development of the process (Khakee, 2003; Meyer and Miller, 2001; Willson, 2001). The predominant approach in the transportation field has been the rational or technical one in which decision-makers support their decisions on technical analysis provided by planners. A more recently explored approach is the communicative or deliberative one in which the focus is to obtain commitment and consensus regarding the decisions among all the stakeholders involved (Willson, 2001).

May *et al*. (2005) suggested the organization of the transportation decision-making approaches in three different categories: vision-led, plan-led and consensus-led. The first is based on the decision-maker vision of the system and aims at implementing policy instruments already known as effectively as possible, reflecting a strong solution-oriented character. The second is based on the adoption of an ordered procedure that starts by the specification of objectives and problems and is followed by the identification and choice of possible solutions. The third is based on the discussion among stakeholders to reach an agreement on each of the stages of the plan-led approach. These latter two approaches have a more problem-oriented and assessment-based character, either by prioritizing the identification of problems or allowing the representative participation of stakeholders.

Khakee (2003) argues that within these approaches the assessment effort presents different roles. In a rational or plan-led decision making process assessment corresponds to optimization, and particularly influences the *ex-ante* assessment of alternatives solutions. In a communicative or consensus-led decision making process, in turn, assessment is seen as a form of interactive discourse in which stakeholders can explain their values, problems and concerns, as well as opining on the possible solutions and helping to choose not the optimal, but the best one considering the various interests involved. In this sense, Hildén *et al.* (2004) claim that strategic assessment can be seen as a procedure that helps structure the communication within the planning process.

Nevertheless, the different decision making approaches considered have their own pitfalls and the common practice has been the use of a combination of approaches, with the preference being a mix of rational or plan-led with communicative or consensus-led approaches (May *et al.*, 2005). Owens (2004) argues that the combination of approaches constitutes the most constructive way to adapt the assessment activities to the different moments of the process, as well as to specific problems and situations. However, regardless of the combination of the adopted approaches, the definition of a methodological procedure or logical structure to support the development of the planning process is crucial. In this sense, three different examples of methodologies are analyzed in order to understand the main advantages and drawbacks found in the traditional urban transportation planning methodological procedures, especially in relation to the role of assessment.

The first structure analyzed, proposed by Meyer and Miller (2001) and depicted in Figure 2.4, emphasizes the role of planning activities as supporting tools for the decision making process and is centered on the use of performance measures. Such measures are seen as indicators of effectiveness and efficiency that reflect concerns related either with the system's operation or with its strategic objectives. Moreover, it provides feedback to the decision-making process through the system's performance assessment. For the authors, the general configuration of a decision-oriented transportation planning process is comprised by four phases as described below:

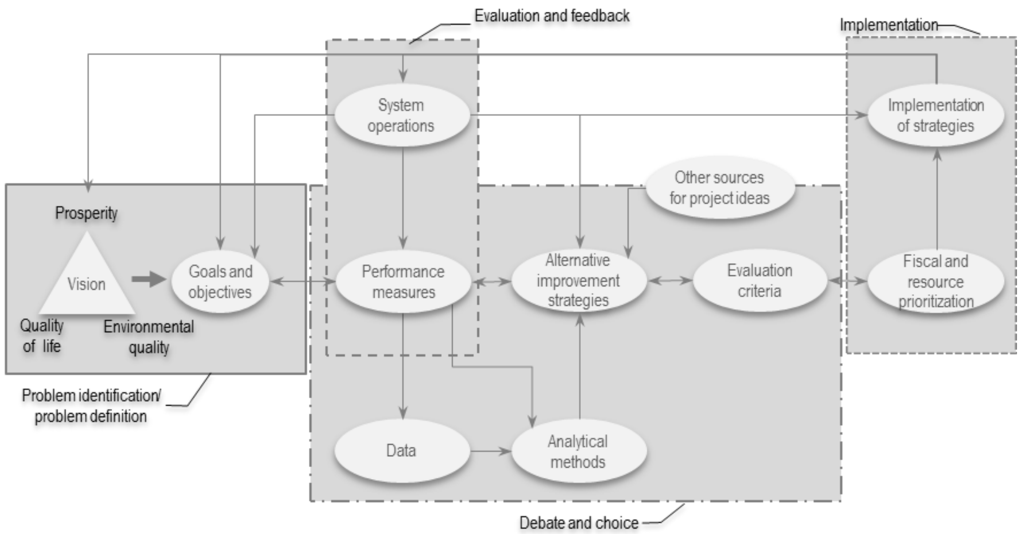

Figure 2.4: Decision-oriented transportation planning process
(Meyer and Miller, 2001)

- The first one is the ***identification/definition of the problems***, which can be understood as the perceived differences between desired states of affairs and the decision maker's perception of the actual situation. To assist in this task two planning actions should be considered: the definition of the vision of what a community desires for the future and the establishment of goals and objectives to achieve the desired state of the system;
- The second phase refers to the ***debate and choice*** of feasible alternative strategies for the system. This process is characterized by a conflict of interests due to the limited resources available and the need for the establishment of

priorities. In this sense, planning can help the decision makers by generating alternative solutions based on analytical methods and establishing evaluation criteria to allow the identification of the best alternatives;

- The third phase is concerned to the ***strategies implementation***, which requires the definition of a detailed execution program based on the financial resources, political priorities and strategic objectives. The program developed by planners can help to determine which and when the strategies should be implemented, but the final decision will always rely on political intuition over the technical analysis;
- The final phase consists in the ***monitoring of the system*** by the systematic operational checking. This supervision allows the evaluation of the impacts and effects of the implemented strategies in order to verify if they are helping to achieve the desired states defined at the beginning of the process.

The second structure, proposed by May *et al*. (2005) and presented in Figure 2.5, incorporates aspects of the three approaches discussed previously, especially the stakeholders' participation. It recognizes the importance of considering the city vision and the sustainability principle in the definition of the objectives. It also emphasizes the use of scenarios to deal with uncertainty and indicators to measure the performance of strategies; most important, it stresses the role of assessment in the process establishing a distinction between appraisal and evaluation. The proposed structure is originally organized as a continuous sequence of steps, but it is described here in the form of groups or phases just to provide a clearer explanation:

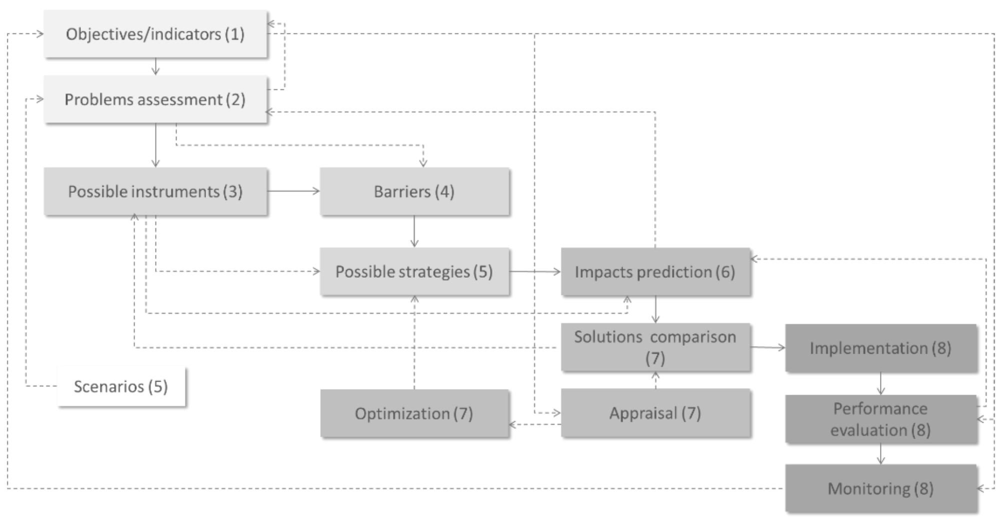

Figure 2.5: Logical structure for transportation decision-making

(adapted from May et al. (2005))

- The first phase in the methodology refers to the definition of objectives and related indicators and the identification of problems. The ***definition and prioritization of objectives*** should be carried out through a participatory process, taking into consideration the city vision when it exists and the ultimate goal of sustainability increase. The definition of scenarios and the specification of indicators should be complementary actions to help measuring the performance of the objectives now and in the future. The ***identification of problems*** can be done through stakeholders' consultation, leading to an identification of areas of major concern for citizens, or through analysis and monitoring of objective which allow a deeper investigation of the causes of the problems. One alternative in this phase is to start by identifying problems instead of defining objectives, which constitutes a problem-oriented approach to the strategies' formulation;
- The second phase consists of the listing of policy instruments, the identification of barriers and the formulation of strategies. The ***selection of potential policy instruments*** should consider the policy type, the city area where it will be implemented and the stakeholders' participation, as they may have new ideas that otherwise would be disregarded. The ***identification of barriers*** helps to define which are the most favorable policies to be implemented and should consider the stakeholder opinions in order to reduce its severity and encourage joint action to overcome them. The ***formulation of strategies*** consists in the combination of policy instruments that reinforce one another in meeting the objectives and in overcoming barriers, and it should be tested for different future scenarios;
- The third phase comprises the prediction of strategies' impacts and its appraisal against the objectives. The ***prediction of strategies' impacts*** should be performed through a model, which can vary in terms of complexity and specialists' skills. The ***appraisal of strategies' impacts*** allows the choice of the best solution and should consider the indicators and scenarios already defined, different methods of appraisal and stakeholders' participation in order to identify the ones adversely affected and avoid potential objections. The use of optimization techniques can also be used to help in identifying better strategies;
- The final phase refers to the implementation and evaluation of strategies or policy instruments, and the system's monitoring as well. The ***implementation of strategies*** should be carried out by following a correct sequence and avoiding the barriers previously mentioned. Its ***evaluation*** against the

objectives is then performed using the same appraisal framework, and the results can be used to improve future predictions. Finally, the ***monitoring of the system*** condition should be carried out in order to assess changes in problems, based on the objectives. Stakeholders' participation in this phase allows consideration of concerns of those adversely impacted by the strategies and their reformulation if necessary.

The third structure, proposed by Magalhães and Yamashita (2009) and depicted in Figure 2.6, consists of an integrated planning, monitoring and evaluation process based on a strategic, tactical and operational (STO) hierarchical framework, similar to the one proposed by van de Velde (1999) and Macário (2005)[1]. As in the other two methodological procedures, the authors also point out the importance of using performance measures, but more than that they stand for the role of the assessment task and consequently the use of a system of indicators to support such analytical effort. These indicators are used to represent the characteristics of the planned object, not the strategies, and can be related to the different levels of decision making. Moreover, their methodology also enables the linkage of the proposed strategies to an existing indicator that facilitates the assessment tasks. The structure of the process can be described as follows:

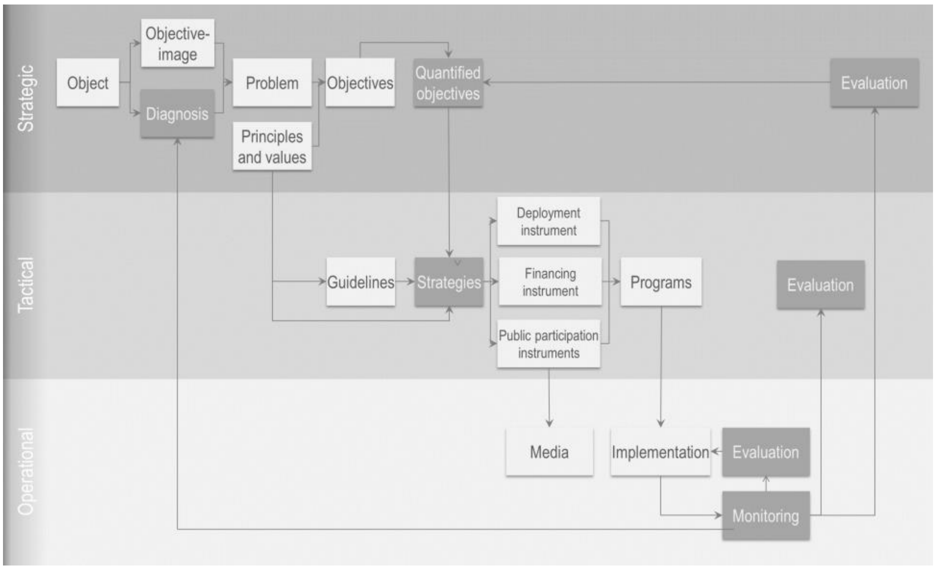

Figure 2.6: Integrated planning process
(adapted from Magalhães and Yamashita (2009))

[1] In the planning and decision making process three distinguishable levels can be identified: the strategic level, in which the political objectives of the system and the means to achieve them are defined; the tactical level, which transforms the previous objectives into operational specifications; and the operational level, whose focus is on production and consumption of mobility services.

- The strategic level is responsible for defining what should be done by setting the solution requirements to be developed during the planning process. Its main steps are the definition of the ***image or vision for the object*** considered in the planning process, in this case the Urban Mobility System; the development of a ***diagnosis of the system*** based on performance measures that will guide the exploration of the most relevant issues in the process; the identification of the ***problems*** considered as the differences between the current state of affairs and the stakeholder's expectation or the stipulated reference to the system; the establishment of ***principles and values*** to guide the formulation of the objectives and the development of alternative actions or strategies; the formulation of ***objectives*** to lead the development of the actions envisioned to achieve the expected results, and the specification of ***goals*** to achieve the objectives proposed;
- The tactical level is responsible for developing solutions for the problems posed by the strategic level decisions. It comprises the definition of ***guidelines*** to conduct the development of strategies; the formulation of ***strategies,*** which consists of projects and actions defined to achieve the objectives and restricted by the guidelines, as well as the definition of all ***instruments*** necessary for developing and implementing the proposed strategies; and the development of ***programs*** that comprise the strategies proposed, as well as all instruments necessary for its implementation;
- The operational level is in charge of the execution of the actions established at the strategic and tactical levels, as well as the provision of information for the process's monitoring and evaluation. It consists in the definition and execution of all procedures necessary for the ***implementation*** of the proposed strategies and for the ***information disclosure*** about the plan, as well as for the establishment of a ***monitoring*** tool, which is a result of the development of an evaluation system based on indicators that support the process throughout all its levels.

The three structures analyzed here present different levels of emphasis on the role of their assessment activities. While the methodology proposed by Meyer and Miller (2001) merely considers the assessment as just another planning activity, the other two proposals show a more apparent emphasis on the role of assessment throughout the process, even if it were in an implicit way, as in the case of the methodology proposed by May et al. (2005). Magalhães and Yamashita (2009), however, propose a clearer structure with assessment actions in different moments in the process, but without making the necessary justifications for each of them. Nevertheless, these methodologies also present some weaknesses in their structures that limit the role of assessment and the performance of the methodologies itself.

A first shortcomings is concerned with the consideration of both vision and values/principles in the process. Meyer and Miller (2001), as well as Magalhães and Yamashita (2009), highlight the importance of having a vision for the system, which should not be considered as an activity of the process itself on the risk of trying to anticipate solutions for the system without even having identified its problems. The approach proposed by May et al. (2005), in turn, considers a vision for the city that consists of broad statements about the aspirations of society such as economic competitiveness and opportunities for all. This city's vision may not mention issues of accessibility and mobility explicitly, being developed in a higher sphere of planning. This approach seems more appropriate if the focus is to avoid a solution-oriented planning. Furthermore, although values and principles are considered as important inputs to the process in two of the above methodologies, this occurs sometimes inappropriately, as in Magalhães and Yamashita's (2009) proposal. In this case, values and principles are inputting only the definition of objectives, guidelines and strategies/alternatives; rather, their consideration should be prior to the vision construction and the diagnosis steps.

Another major insufficiency of these methodologies is the absence of a diagnosis of the current situation of the system, and that is essential to define the problems to be addressed, as well as the establishment of objectives. In all three cases, despite the fact that the first stage of the process consists in the identification of problems, it is not derived from an assessment activity in which specific procedures are defined to help identify problems within the system. Even though the methodology of May *et al.* (2005) includes a description of possible methods for identifying problems, they are not regarded in a more systemic approach of diagnosis. Moreover, the authors also suggest defining objectives before identifying problems, which is not necessarily an issue as long as these objectives are adjusted after the understanding of the problems. Meanwhile, Magalhães and Yamashita's (2009) methodology recognizes the diagnosis as an important activity of the process; however, the diagnosis is understood as a separate activity from the identification of problems step.

There is still another weakness in these structures regarding the consideration of the urban mobility network. None of them makes reference to it, recognizing only the existence of the transportation network, which reflects the strong vision of transportation planners. This may be associated to the fact that these methodologies, while acknowledging the importance of integrated planning, are not able to recognize the users' holistic view in relation to the network and limit their approach to the common practice of considering the network merely as a result of the planning process and not as an input as well. Meyer and Miller (2001), although recognizing the importance of multimodality in the planning process, still see the system as a set of different modal networks and do not refer to them in any of their methodological steps. May et al. (2005) and Magalhães and Yamashita (2009) also have a restricted view on the importance of the network by regarding it only as an element to be considered in the formulation of strategies. Such approaches about the network's view reveal a clear inability of reflecting accessibility as a strategic value in the development of the planning process.

Other minor shortcomings in these methodologies are worth being mentioned. In Meyer and Miller's (2001) proposal, activities such as data collection, use of analytical methods and definition of performance measures are considered as planning activities, while, as a matter of fact, they should be seen as supporting activities. In May et al.'s (2005) methodology, there is no clear indication to a specific level of decision in which the planning activities should take place, and this can cause some confusion regarding who is responsible (institution) for each phase of the process. Finally, in the structure proposed by Magalhães and Yamashita (2009), the assessment of strategies/alternatives before its implementation is not considered in the process. Nonetheless, it is worth highlighting the emphasis by all the analyzed methodologies on the importance of using indicators as a supporting tool in the process.

2.4 Assessment within the UMS Planning: a Methodological Proposal

Considering the advantages and disadvantages identified in the processes described previously and the discussion about the main paradigms shifts in the mobility field, an improved methodology is proposed in this thesis in which the role of assessment is highlighted. The structure of the suggested planning process is presented in Figure 2.7 and is based also in a hierarchical STO framework, but in which it is possible to identify the main decision-making (DM) functions, the assessment activities and their respective supporting activities.

Unlike in the other analyzed structures, the assessment activities in this methodology are more clearly identified, taking place at all decision-making levels and in three different moments of the process: during the understanding of problems as well as before and after the implementation of the alternatives/actions. In the first moment, the assessment occurs both at strategic and tactical levels and refers to the diagnosis of the current situation and the assessment of the alternatives. After the implementation of the selected alternatives, the assessment tasks occur in the three levels and refer to the monitoring of the system (operational), the assessment of the implemented alternatives, as well as the verification of the objectives achievement (tactical/strategic).

The first phase in the process is the **problem understanding or diagnosis** and occurs at the strategic level, which has a strong political focus. It refers to the assessment/diagnosis of the current situation and the definition of the objectives to guide the formulation of alternatives. It comprises the following activities:

- **Diagnosis of the current situation:** refers to the assessment of the present state of the system and helps to identify the set of accessibility and mobility problems it has faced. This is the moment when the current configuration of the **urban mobility network** is assessed allowing the analysis of the mobility and land use systems interactions through accessibility and hence of its impact on the mobility and activity of the users. This first *ex-ante* analysis must be focused on the accessibility and mobility **values** and framed by the **principles** established to guide the whole process, ideally the combination of efficiency, equity and sustainability principles, all embedded into the city vision. Such values and principles, in turn, must be reflected in the definition of a set of **indicators**, especially accessibility ones, which will support not only the diagnosis, but all the subsequent activities in the process, making it more responsive, economical and timely. These indicators are organized under an STO framework, presenting different levels of specification according to the phase they are related to. The development of this phase should start by a consultation with stakeholders (users, service providers, planners, politicians, *etc.*) in order to identify their perception about the problems within the system. In this process, stakeholders must have in perspective the city vision, which consists in the translation of values and principles into general aspirations of society without considering specific actions on the system. However, processes that involve excessive stakeholder consultation may result in overstated problems, which should be avoided by planners. The identified problems, considered as the users' perceived differences between the actual state of affairs and its desired state, must then be characterized through indicators that will allow the verification of whether the problems really exist and, if so, to analyze their intensity and magnitude, as well as to identify their causes and effects.

- **Definition of strategic objectives:** consists in the formulation of comprehensive statements or commitments that reflect the expected user's results for the urban mobility network and whose purpose is to guide the development of the proposed actions to achieve them. These objectives should be restricted by the **values and principles**, associated with an **indicator,** and reflect the problems identified as well as the **city vision**. In case there is a vision for the city, which ideally should be defined through a participatory process and reflect principles such as efficiency, equity and sustainability, the strategic objectives should be formulated as broad statements of what is necessary regarding the urban mobility network to achieve such vision. These objectives can be further translated into more detailed objectives that will conduct the development of the tactical and operational activities. The detailed structure of these objectives is largely dependent on the maturity of the stakeholders involved in the planning process.

The second phase in the process refers to the **strategic analysis and choice** of alternatives at the strategic level which also has a strong political emphasis. It refers to the formulation and *ex-ante* assessment of strategic alternatives of solutions and comprises the following activities:

- **Formulation of strategic alternatives:** consists in the development of alternative solutions based on the strategic objectives and focusing on the mobility and accessibility values and framed by the guiding principles. These alternatives solutions are conceived as simplified ways of overcoming the problems representing macro interventions on the urban mobility network that are considered politically desirable from the efficiency, equity and sustainability perspectives;

- ***Ex-ante* assessment of strategic alternative solutions:** refers to the assessment of the strategic alternatives in order to identify the ones that present the best performance in solving the accessibility and mobility problems related to the urban mobility network. This activity consists in assess the alternative's impact considering the same set of indicators used in the diagnosis. Yet this is also a moment for **problem identification** as the analysis of new alternatives may reveal problems not visible so far. Additionally, it can also be a moment of interaction with stakeholders for problem validation or redefinition. Therefore, the *ex-ante* assessment can be seen as a feedback moment in the process that allows the constant search for problems.

The third phase in the process has a more technical approach and refers also to the **tactical analysis and choice** of the alternatives developed to attend the objectives defined at the strategic level and considering the best alternatives indicated by strategic assessment. It is related to the tactical level of the process and consists in the following activities:

- **Definition of tactical objectives:** correspond to the specification of more detailed objectives constrained by the characteristics of the alternative solutions indicated at the strategic level and in line with the strategic objectives. They can be seen as guidelines that will help to conduct the development of the tactical alternatives by restricting the scope of the solutions to what is considered financially and technically feasible. They are also associated to more disaggregated versions of the indicators used in the strategic level;
- **Formulation of tactical alternatives:** consists in developing alternative solutions guided by the tactical objectives. They may refer to interventions in the transport network or in the spatial network depending on what is established by the tactical objectives. These alternative solutions or projects are developed in a context of limited resources, capacity control and power pressure and should comprise not only the actions proposed to solve the problems, but also the establishment of the role of each actor/institution involved, the alternative of financial resources, and the means of dissemination and public debate of the proposed alternatives;
- ***Ex-ante* evaluation of tactical alternative solutions:** refers to the assessment of alternatives in order to identify the ones that present the best performance in solving the accessibility and mobility problems similar to what is done at the strategic level, but in a more refined manner. It consists in quantifying each alternative’s results by the application of models, considering the same set of indicators used in the diagnosis and in qualifies them through assessment criteria that should reflect the preferences of all stakeholders involved. As in the strategic *ex-ante* assessment this is also a

feedback moment once problems can be again identified, particularly those of regulatory and institutional character, as well as validated or redefined through an interaction process with stakeholders.

- **Development of programs:** comprises a set of articulated actions or measures focused on a defined tactical objective and must include the specification of the funding sources, the actors/agents responsible for each action, the mechanisms for monitoring, the communication plan and the implementation schedule.

The fourth phase is the **implementation of the proposed alternatives** and refers to the operational level of the process. It consists in the execution of the actions established at the strategic and tactical levels and comprises the following activities:

- **Definition of operational objectives**: details tactical objectives taking into account the specifications of the actions proposed in the programs. The operational objectives can also be seen by the institutions responsible for their deployment as guidelines for the implementation of the proposed actions;

- **Execution of actions**: refers to the definition and execution of all procedures necessary for the implementation of the proposed actions and for information disclosure regarding the plan. The responsibility for these procedures is shared by the different entities as discussed in the tactical level.

The final phase is the *ex-post* **assessment and feedback** of the process. It refers to a set of *ex-post* analyses related to all planning levels that helps to verify if the systems are operating adequately, if the alternatives implemented are delivering the expected results and if the strategic objectives have been achieved. It consists in the following activities:

- **Monitoring of the system:** refers to an operational activity and consists in a permanent data collection effort on the system's operation to support the development of the **indicators** used during the process. The monitoring has two purposes: to support the control and supervision by the regulatory entities of the implemented alternatives, and to verify the results of the process by the responsible entities.

- ***Ex-post* assessment of the implemented actions:** corresponds to the analysis of results and impacts obtained after the implementation of the actions considering the same set of **indicators** used in the diagnosis and *ex-ante* assessment steps. This activity allows assessing the effects of each action on the indicators associated with both tactical and strategic objectives, thereby determining whether they are being met. Besides, it also helps to assess if the problems identified in the diagnosis phase are being overcome or even if new ones are emerging.

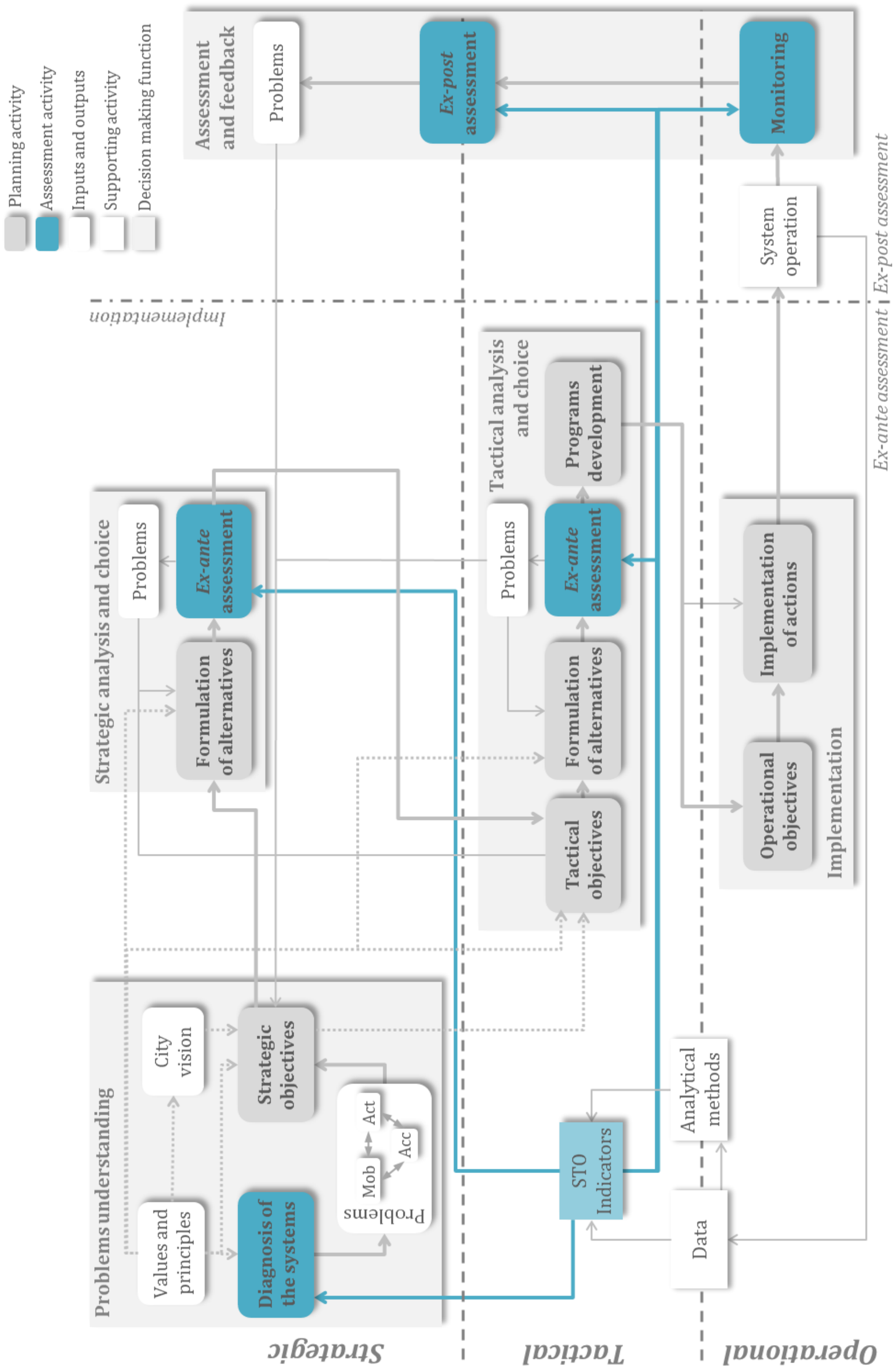

Figure 2.7: Urban Mobility Planning Process - Methodological Proposal

Through the above description of the proposed structure, it is possible to see the clear recognition of the role of assessment activities throughout the process, especially regarding the importance of the diagnosis step, which mainly denotes the problem-oriented character of this methodology. As discussed at the beginning of this chapter, only through the systemic identification of problems, and its proper characterization and analysis, it is possible to define the most adequate solutions for different urban realities. However, this search for problems should not be limited to a single moment in the process; in fact it should be a continuous action that is directly associated with assessment activities.

The premise is that two activities should be simultaneous: **checking** whether there are new problems being incorporated into the process while **assessing** what is being proposed (*ex-ante* assessments) or what has been achieved (*ex-post* assessment). Therefore, the alignment among all assessment activities through the use of indicators (related to objectives and not alternatives), and with the purpose of continuously identifying problems, can be seen as a more appropriate way to carry out the planning of the urban mobility. Such association is clearer during diagnosis and *ex-post* assessment, but it also may occur during the *ex-ante* assessments as highlighted before.

Nonetheless, it should be noted that although the structure herewith proposed is presented as a sequence of steps and activities associated to well-defined feedback channels, actually the mobility planning is an ongoing process without a chronological order of steps. This can be seen in the identification of problems step that, in the proposed structure, may occur in any of the levels, despite being suggested that it should occur initially at the strategic level during diagnosis. The idea is that, although in practice the problems usually appear in the tactical and operational levels, they need to be addressed at the strategic level.

Finally, an important characteristic of this proposal refers to the recognition of the urban mobility network as a strategic element and, hence, of accessibility as the primary concern of the planning process. This consideration allows the assessment of the joint configuration of land uses and transportation aspects through accessibility measures in the early stages of the process leading to the development of more efficient, equitable and sustainable alternative–configurations. Therefore, the acknowledgement of the urban mobility network as a strategic element of the system, and its assessment based on accessibility indicators, results in a more adequate way of performing the urban mobility planning.

2.5 Summary

- In the last few decades many paradigm shifts have been claimed in the field of urban mobility, such as a focus change from mobility to accessibility, the integrated planning and the incorporation of principles as equity and sustainability in the development of the planning process. Although they have been widely explored in the scientific literature and less in the practical field, the joint consideration of all these values in the planning process is still not acknowledged.
- From the literature review performed in this chapter it is recognized as the current paradigm in the urban mobility field the consideration of a dynamically integrated planning effort of the mobility, land use and activity systems. Such effort focus on people's accessibility to urban activities and on assuring acceptable levels of individual mobility based on the social values of equity and sustainability. However, it is believe that to accomplish this paradigm change the adoption of the concept of **urban mobility network** and its strategic role for the system, needs to be formally and adequately incorporated into the planning process.
- Probably one of the main difficulties in considering such a change is related to a lack of strategic approach for the system, as well as methodological procedures that emphasize the role of assessment in the planning process. As discussed in this chapter, some traditional methodological procedures fail to consider these issues together, in spite of recognizing the importance of considering the city vision and incorporating efficiency, equity and sustainability principles. Others have even moved to a joint consideration of these two issues, but still fail to stress the role of assessment as fundamental to the whole planning process. Furthermore, none of the revised procedures recognizes the strategic role of the urban mobility network.
- The proposal of an assessment-based and problem-oriented planning methodology comes out as a way to tackle these issues. First, by recognizing the importance of a strategic approach for the system, in which the urban mobility network appears as a central element. Secondly, by emphasizing the role of assessment as a transversal task within the process. This revised methodology allows the alignment of the alternatives to develop the mobility network according to the city vision while providing a framework for both *ex-ante* and *ex-post* assessments of impacts caused by decisions that change

the network. It also represents a valuable tool as it provides planners and decision makers with useful information, allowing them to assess the consequences of a decision and to identify the system's deficiencies and opportunities for its improvement.

3. Accessibility and Mobility Problems on Urban Mobility Networks

The understanding of accessibility and mobility problems on urban mobility networks constitutes the core of the strategic assessment of accessibility as argued in Chapter 2. Such analysis represents a better way to address accessibility and mobility issues at the strategic level and therefore to contribute for a more robust UMS planning process. However, the establishment of accessibility and mobility problems depends on the consideration of principles such as equity and sustainability that allow to delineate the implications of these problems in the urban system. Moreover, their assessment should be based on appropriate indicators operationalized through the urban mobility network to quantify and analyze their behavior. Therefore, the main objective of this chapter is to discuss the analysis of accessibility and mobility problems on urban mobility networks as the starting point of the strategic assessment as well as to suggest suitable indicators to characterize accessibility and mobility problems and to diagnose their causal relationships. Besides this introduction, the chapter starts with a discussion in section 3.1 about the analysis of urban interactions through the UMN as the base of accessibility and mobility problems assessment. In section 3.2, the implications of considering equity and sustainability principles on analyzing accessibility problems are discussed. Then, in section 3.3 a framework for defining accessibility and mobility restrictions is proposed. In sections 3.4 and 3.5, accessibility and mobility indicators suitable to support the strategic assessment are suggested. Finally, in section 3.6, a summary with the main findings of the chapter is presented.

3.1 Urban interactions through the urban mobility network

The strategic assessment of accessibility and mobility problems as the starting point of the UMS planning process relies primarily on the analysis of a set of problems that need to be adequately represented in order to support the understanding of the UMN problematic. In the accessibility planning approach, the representation of problems involves aspects related to both land use and transportation network components, as well as hypotheses about their causal relationship that evidence the link between accessibility and mobility levels. The structured representation of these problems in the form of a tree diagram is fundamental for the planning process once it facilitates the participation of stakeholders through the provision of systematized information and helps planners to better understand the influences of each urban subsystems in the problems under analysis.

In this sense, the conceptual model of urban interactions proposed by Lopes (2015) can be considered as the departure point for the representation of problems. By acknowledging how urban subsystems interact with the others and with themselves, it is possible then to recognize how accessibility and mobility values that represent inter and inner dynamics of these subsystems are related. Specifically, from the mobility system perspective it is possible to see by the Figure 3.1 that it influences the other subsystems and itself through accessibility in three different ways: a) it influences the land use system by affecting land prices, densities and city size, hence leading to spatial and socioeconomic segregation or integration; b) it influences the activity system by facilitating or hampering social interactions between individuals; and c) it influences itself by inducing the production of more trips and therefore increasing mobility levels that conversely may reduce accessibility by increasing congestion and hence travel times.

On the other hand, it is also recognized that accessibility is the product of the interactions between the urban subsystems and the individuals. Geurs and Van Wee (2004) consider accessibility as the product of four components as follows: a) the individuals, reflecting their abilities, desires and needs (*e.g.*, which activity they want/need to participate in); b) the land use system, denoting the location of activities that the individuals want/need to perform (*e.g.*, where they want/need to go); c) the mobility system, representing the way travels can be performed (*e.g.*, how they can go); and, finally, d)) the time-budget, indicating the time available to perform trips (*e.g.*, when they can go), which can also be considered as part of the individual component.

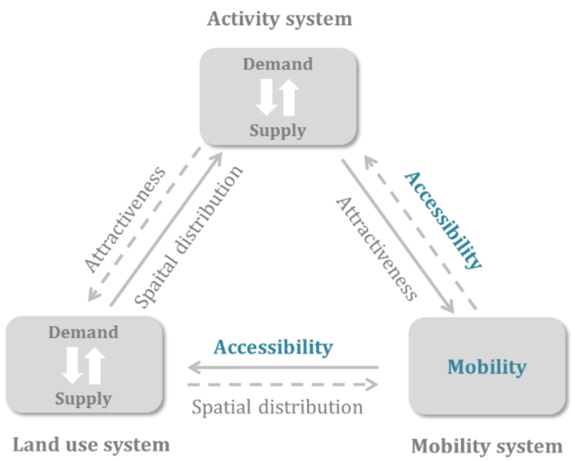

Figure 3.1: Urban interactions from the UMS perspective

Therefore, having accessibility as the focus of planning activities means, from the mobility system perspective, recognizing and analyzing the causal relationships presented in the diagram of Figure 3.2. This implies investigating the aspects related to individuals, land uses and transportation characteristics that determine the provided levels of accessibility as well as the effect that these levels of accessibility and mobility can have on the socioeconomic and environmental dimensions of the urban system (Cervero, 2005). Specifically, considering the bottom of the diagram the focus would be on investigating whether there are restrictions on the provided levels of accessibility and, if so, how transportation inefficiencies, land use distribution inadequacies and personal characteristics influence them. At the top of the diagram, in turn, the analysis would focus on the different effects that (a) accessibility and mobility may have on each other and their impacts on (b) socioeconomic activities as well as on (c) the environment.

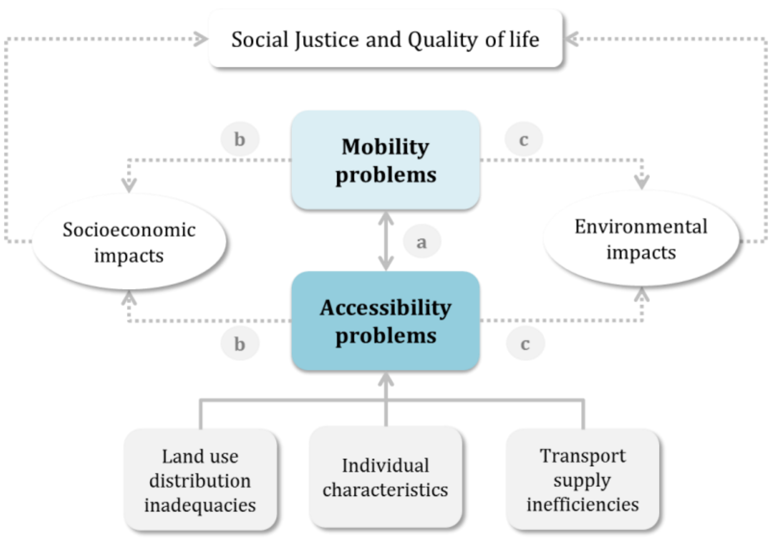

Figure 3.2: Causal relationships of accessibility and mobility

Considering the left side of the diagram the objective is to investigate the effects that accessibility restrictions produces on mobility and hence on socioeconomic activities. The main assumption is that low levels of accessibility may lead to less mobility and hence to less activities, therefore causing social and economic problems such as social exclusion or underperformance of economic production as argued by Macário (2012). However, it is recognized that other possible relationships between accessibility, mobility and socioeconomic activities may occur such as when people do not need to travel to perform activities or when they are forced to travel in congested conditions. In the first case, their mobility levels are low despite their accessibility and activity levels are high, while in the second case their mobility and activity levels are high regardless of the low levels of accessibility offered.

On the right side of the diagram the purpose is to investigate the effects that accessibility restrictions have on mobility and hence on the environment. Here the consideration of accessibility restrictions by different modes is essential as they may have different impacts as follows: i) restrictions on accessibility by car lead to less mobility by car and no environmental impact occurs; ii) restrictions on accessibility by PT may induce more mobility by car causing congestions and their associated environmental impacts such as energy consumption and pollutant emissions (Banister, 2002). The derived congestion from the high levels of mobility by car can thus increase the travel times and reduce the overall levels of accessibility, especially in the cases where there is no segregation between car and public transport traffic (Levine and Garb, 2002). On the other hand, according to Mondschein et al (2011), high accessibility by car can attract more trips to certain areas and therefore promote congestion and thus reinitiating the cycle.

The development of these analyses, in turn, must start from the estimation of accessibility levels on the urban mobility network, which serves as a platform for the operationalization of accessibility indicators as shown in Figure 3.3. Such network is considered the basic element of the strategic analyses that represent in an aggregate way the transport network in conjunction with land uses and activities characteristics. By representing the main elements associated with the urban subsystems, this network allows to analyze how the distribution and intensity of land uses and activities as well as the magnitude of the impedances affect the accessibility levels offered throughout the urban space and hence how it influences mobility and the socioeconomic and environmental dimensions of the urban system.

The relationships between accessibility and mobility can be then better understood when analyzing the components of the urban mobility network. For instance, if the network presents a configuration where activities are dispersed and impedances are high in terms of distance, it will present low overall levels of accessibility, but perhaps high levels of mobility by private vehicles This ensures access to activities for only certain social groups (those who have access to the car) and lead to environmental issues such as energy consumption and pollutant emissions. On the contrary, if the network have a configuration where activities are concentrated and diversified and impedances are low, the overall levels of accessibility will be high and the mobility by non-motorized and public modes will probably be also high. Such configuration can improve the access to activities for more social groups (as more people will have access to cheaper modes) and reduce the environmental impacts (due to the use of less pollutant modes).

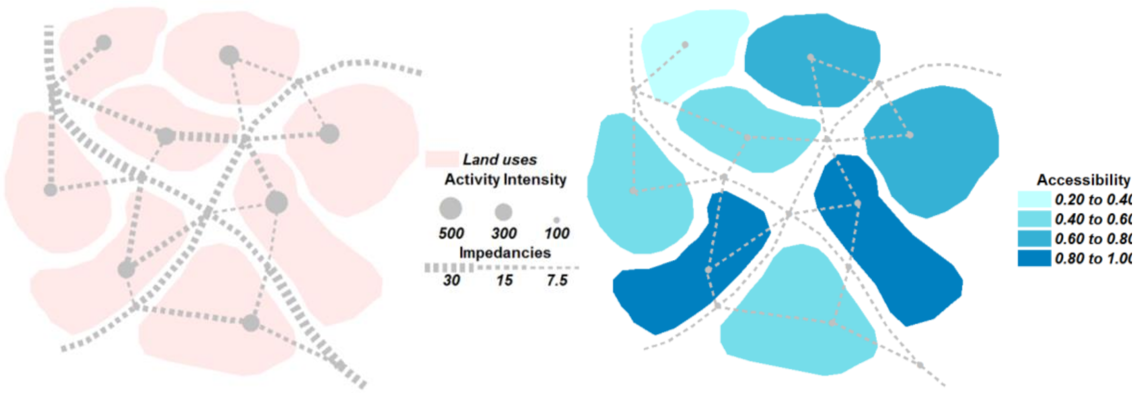

Figure 3.3: Accessibility levels on the urban mobility network

These different configurations demonstrate the important role that distances currently play in urban areas as argued by Salomon and Mokhtarian (1998) and Banister (2011). For them the growing urban sprawl and the resulting increase in distances traveled by private modes together with its environmental consequences have been the major issue that planners have to deal with. Banister (2011) argues that reducing trip lengths by approximating new activities and reorganizing the existing ones as well as promoting the use of slow (electrical vehicles) and active (walk and cycle) modes of transportation help decrease mobility and hence its environmental and health consequences. However, Salomon and Mokhtarian (1998) argue that not always reducing distances and increasing accessibility imply reduce mobility. Sometimes, certain mobility-deprived groups such as the ones impacted by the job-housing imbalances may value more mobility than accessibility, although this brings also problems of social exclusion, often not detected. But this has to do with individual characteristics as well as their attitudes and perceptions regarding mobility and accessibility and not with land use and transportation infrastructure aspects.

On the other hand the traditional transportation planning practice has been the promotion of faster connections as a way to overcome these increasing distances (Banister, 2011). Time instead of distances has been the main focus of planning even though a growing plea in favor of an integrated or accessibility-based view of planning has been advocated as discussed in Chapter 2. This has to do not only with the islanded view of the transport sector, but also with political preferences once the returns of interventions in land use are not as immediate as in transportation infrastructures and services. Clearly, this position contradicts the assumption that shorten distances are the most appropriate way for achieving sustainable urban systems, although it brings contributions if the speed increases are in public transport instead of private. This would reduce the pollutant levels, but would also allow time savings especially for those who are dependent of these modes, thereby increasing their level of activities and leading to more social inclusion.

Therefore, from the possible general UMN configurations in terms of land use and transportation components discussed previously two hypotheses may be formulated about how these components determine the dynamics of mobility and accessibility. The first consider that by promoting concentration of activities it is possible to reduce the distances to be traveled and thus increase accessibility on the network and so the mobility by slow private vehicles, public transport and non-motorized modes. Consequently the environmental externalities associated to this configuration can be diminished since vehicle distance traveled on the network may be potentially reduced. The second consider that by increasing public transport speed, it is possible to reduce travel times and hence increase the accessibility and mobility by public transport. In this case social exclusion and economic productivity impacts may be mitigated once an increase in accessibility can lead to the performance of more activities by the vulnerable social groups and hence of more social and economic participation in overall.

In this sense, the mobility network thus brings a more holistic view over the analysis of the accessibility and mobility dynamics especially in the early phase of the UMS planning. Such analysis yet needs to be driven by principles such as equity and sustainability, which help define which type of accessibility and mobility problems are configured. Additionally, these analysis should be structured in a process that allows first to characterize accessibility and mobility problems to then diagnose their causal relationships. They also need to be supported by the definition of indicators and reference parameters, as well as adequate methods for qualitatively and quantitatively analyze accessibility and mobility as well as the influence that they have on each other. Therefore, this assessment process would allow to identify how the urban mobility network configuration influence the levels of accessibility offered, which of its features are causing the accessibility restrictions and what are the accessibility effects on mobility.

3.2 Equity and Sustainability Issues on Accessibility and Mobility

Although understanding the dynamics between accessibility and mobility can be achieved by a systematic analysis of urban subsystems interactions through the urban mobility network, the definition of accessibility and mobility problem depends on the establishment of certain expectations which vary according to principles set collectively such as equity or sustainability. These principles, as already mentioned in Chapter 2 and illustrated in Figure 3.4, are considered the pillars of the UMS planning process providing a more comprehensive approach to it, helping planners to better delineate accessibility and mobility problems and decision makers to define and prioritize adequate objectives for the system.

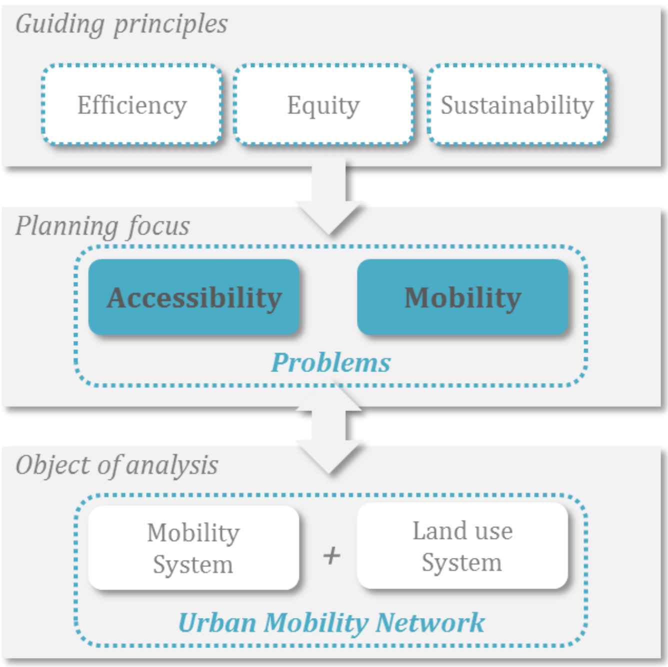

Figure 3.4: The influence of equity and sustainability principles in the UMS planning

Nowadays sustainability is a well-accepted and applied principle in urban mobility planning that is commonly approached by a three-dimensional framework comprising economic, social and environmental aspects (Banister, 2008; Jeon, 2007). These dimensions are usually interpreted as specific objectives that should be pursued together in order to avoid solutions for one problem that exacerbates other problems (Goulias, 2003). This approach denotes a clear solution-oriented character that many of the planning initiatives has recently shown, with each dimensions driving the proposal of policies even before considering the particular problems that different urban areas face. Normally these dimensions in the UMS context have been understood as:

- The economic dimension, which is related to the efficiency of the UMS. As an enabler of the urban system, the UMS need to operate efficiently, offering choice of transportation modes and levels of accessibility that support the urban activities and consequently the economic development of the city. According to Crozet (2009), the accessibility provided by the UMS is the major leverage of the urban economic development and the mobility policies that aim to promote the sustainability should be focusing on its provision instead of limiting their goals on objectives such as improvement of speed.
- The social dimension, which is related to the concept of equity that implies providing the population with the adequate accessibility levels. For Litman (2007), equity can be considered under two different perspectives in the UMS. One related to the distribution of impact between individuals considered equals in their accessibility needs and requirements (horizontal equity) and the other concerned with the distribution of impacts between individuals and groups that differ according to their social classes and income or to their mobility needs. (vertical equity). The consideration of this concept implies that the mobility policies should not contribute to any kind of social exclusion.
- The environmental dimension, which is related to aspects such as the consumption of non-renewable resources, the abusive use of land and the visual impacts caused by the UMS. Schafer (1998) considers that most of these problems are generated by the massive use of cars that are fossil fuel powered and demand more space for the construction of infrastructures which contributes for the urban sprawl. These problems lead to the need of policies that limits the emissions, promote the use of renewable resources, minimize the use of land and encourage the use of public transport and non-motorized modes.

In this traditional perspective of sustainability, equity is seen as just one of its components being related to the social dimension, which has been receiving less attention in both theory and practice of planning when compared to the other dimensions (Boschmann and Kwan, 2008; Martens, 2006; Uteng, 2007; Vallance *et al.*, 2011). This can be noticed in the recent policies of government agencies that have focused their sustainability view on the promotion of economic growth and the reduction of CO_2 emissions (Department for Transport, 2011; European Commission, 2011). This demonstrates how the social dimension and, most importantly, the principle of equity have been considered the weak link in the urban mobility agenda, when it should be in fact the center as it focuses on individuals and their well-being (Jones and Lucas, 2012).

Nevertheless there is a strand defended by some authors that considers equity as the central principle behind sustainability (Beder, 2000; Feitelson, 2002; Weiss, 1992). They argue that in order to achieve sustainability there should be a minimum level of social, economic and environmental basic conditions enforced to all and that no individual or group should carry a greater burden than the rest of the community. They also consider that the burdens of the present living should not be passed to the future ones in order to guarantee the sustainable development. In this view, the distribution of primary goods and their impacts becomes the focus of interest, leading thus to the consideration of equity as the underlying principle of the planning process that functions as a pre-requisite for the sustainability achievement.

From this perspective it is possible to consider that for achieving the UMS sustainability the provision of a minimum level of accessibility and mobility for all must be ensured and the differences in the accessibility and mobility across social groups minimized as well as their impacts such as social exclusion, economic inefficiencies and environmental degradation in the present (intrageneration equity) and in the future (intergeneration equity). This means that accessibility and mobility problems within the UMS should be addressed by establishing equity and sustainability criteria (or reference parameters) that allow indicate whether certain accessibility and mobility conditions should be considered a problem or not.

In this sense, the ethical theories of sufficientarianism and egalitarianism can provide a framework for the definition and analysis of accessibility and mobility problems. According to Meyer and Roser (2009) the sufficientarianism theory assumes that everyone should be well off and advocates the establishment of a welfare threshold below which individuals can be considered as not satisfied or as not well served. Weak sufficientarianism considers that it is important to improve the well-being of those below the threshold, while strong sufficientarianism considers as mandatory the improvement of their well-being. Egalitarianism, in turn, considers that everyone should be treated equal and therefore is related with the differences and not with the absolute values of well-being. It advocates that the relative differences between the states of persons need to be eliminated or reduced. However, it is believed in this research that these differences should be eliminated or reduced considering an equitable and not an egalitarian approach, i.e. greater benefits should be given to those most disadvantaged in order to achieve a fair state for all.

These two theories clearly contribute to frame the assessment of intragenerational and intergenerational equity issues on accessibility. Considering the sufficientarianism theory, it is thus possible to argue the need for setting accessibility and mobility limits or thresholds that allow identifying individuals or regions that are not been well served, while the consideration of egalitarianism allow delineating ways of assessing how different groups are being served in terms of accessibility and mobility. However, Wolf (2009) and Meyer (2014) allege that for the intergeneration equity or sustainability analysis the sufficientarianism approach is the most adequate once the establishment of thresholds allow to compare different generations. By setting minimum thresholds for one generation, it is possible to assess whether other generations (past or future) are more or less well served and therefore if the provision of certain basic needs, *e.g.*, accessibility, is being fulfilled in order to guarantee the sustainability of the mobility patterns.

The application of sufficientarianism and egalitarianism theories in the assessment of accessibility has been recently defended by some authors. Van Wee and Geurs (2011) based on the Rawls' ideas (Rawls, 1971) argue that considering accessibility as a primary social good allows to value not only its utility, but accessibility itself. This means, from an egalitarian perspective, to focus the accessibility analysis on those social groups who have the lowest level of accessibility, while from a sufficientarian perspective the attention would be on the absolute value of accessibility of those who are worse off. Lucas *et al.* (2015) also make a good case for the use of sufficientarianism and egalitarianism theories in the assessment of accessibility by proposing a method that combines these theories with accessibility-based analysis, Loren curve and Gini index. They claim that the use of these ethical perspectives allows to determine the equity of policy decisions and to set minimum accessibility standards in order to improve policymaker confidence on new planning and decision frameworks that promote accessibility over mobility.

In this research these ethical theories combined with the equity and sustainability principles are also considered as the base for defining accessibility and mobility problems, specifically four main categories as described in Figure 3.5: the unequal, the inequitable, the unsuitable and the unsustainable distributions of accessibility and mobility. The first category relies on the sufficientarianism theory and consider that regardless their differences everyone should have a minimum level of access to opportunities as well as of mobility. The second category, in turn, departs from an egalitarian approach and assumes that, considering differences (social, economic, *etc.*), everyone should have access to their desired opportunities and experiencing good levels of mobility. The third and fourth categories are also based on the sufficientarianism theory, with the third one considering that should have a minimum level of accessibility and mobility by non-motorized and public transport compared to private car suitable that allow maintaining low environmental impact and the fourth one considering that future generations should not experience lower levels of accessibility and mobility than the current minimum.

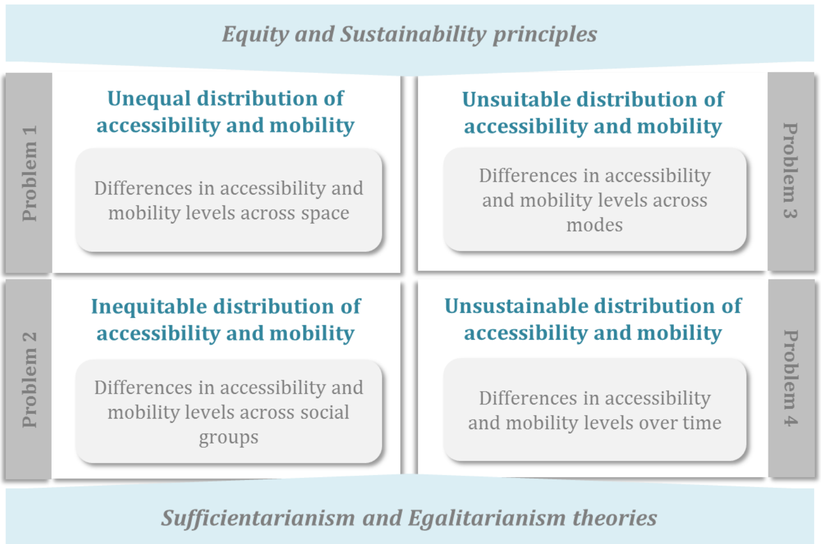

Figure 3.5: Categories of accessibility and mobility problems

These categories can be associated to what many authors call as horizontal, vertical and longitudinal equity and refers to the differences in accessibility and mobility across space, social groups, modes along time for each individual perspective (Litman, 2012; Macário, 2005; Martens *et al.*, 2012; Uteng, 2007). They can be viewed as universally identifiable categories of problems that any urban area may face and whose causes and impacts have to be investigated in order to generate a complete understanding of the dynamics behind them. They can be also associated to the dimensions of sustainability, with the unequal distribution being related to the economic one, the inequitable distribution related to the social one, the unsuitable distribution related to the environmental one and the unsustainable one with the three others in an intergeneration perspective.

The consideration of these problems constitutes a more robust way to conduct the strategic analysis of UMS problematic, once is not enough to know which are the individuals or areas affected by low levels of accessibility, it is also needed to identify the causes of these levels to be able to act on them. In the same way, it is essential to investigate whether these problems are leading to mobility problems and perhaps limiting the social participation of individuals, promoting unsustainable mobility patterns and/or environmental degradation. It is noteworthy that this research does not intend to examine the implications of accessibility problems on the social exclusion and sustainability problems, the aim is just to understand the relationship mechanisms between accessibility and mobility problems that may lead to these larger problems.

3.3 The categories of accessibility restrictions

In order to better understand the dynamics behind accessibility problems the investigation of their causes is fundamental. Once accessibility problems are considered the focus of the UMS problematic, its analysis must be supported by exploring the factors related to the transportation infrastructure and service, land use distribution and individual characteristics that may explain accessibility conditions. Attempts to establish the factors or determinants of accessibility restrictions have been developed by authors who seek to understand the social exclusion phenomenon. In these studies, though, accessibility is seen as just one of the spheres of social exclusion which is a very complex problem that comprise other domains of the urban life (Rajé, 2003), but that it is not the focus of this work as already mentioned.

Kenyon *et al* (2002), for instance, recognize accessibility, although using the term mobility, as one of the nine domains that impose limitations to the social participation of individuals, and consider that it encompasses spatial, temporal, financial and personal factors that affect the personal levels of accessibility and hence their participation in the society. Focusing only in the accessibility domain of social exclusion, Church *et al* (2000) recognize the interactions between the urban subsystems as inter-related processes that determine an individual's ability to access their activities of interest. These processes refer to the time-space organization of individuals (individual component), the influence of the transportation system in the individual mobility (transportation component) and the time-space organization of activities. The authors then consider that these three processes comprise a set of seven categories of exclusion that inter-relate and determine an individual's levels of accessibility as described in Table 3.1.

Although the desegregation of the inter-related processes into seven categories by Church *et al* (2000) can be seen as an attempt to identify the factors influencing the individual's accessibility, it is not easy to see in their proposal a relation between the categories of exclusion factors and the four accessibility components suggested by Geurs and van Wee (2004). It would be easier to investigate the causes of accessibility problems regardless its socioeconomic or environmental impacts, if those categories were directly associated to the accessibility components. In this sense, Table 3.2 presents the relationship between the six categories of accessibility restrictions that can be associated to the different types of accessibility problems and the accessibility components considered as the focus of each category.

Table 3.1: Categories of accessibility exclusion

Categories of exclusion	Factors	Social groups affected
Physical	Physical barriers from the transportation system and the built environment imposed to the individual.	Children, elders, disabled people.
Geographical	Isolation of peripheral population due to inadequate supply of transportation services.	Peripheral population.
From facilities	Location of public and private facilities far from the regions with concentration of disadvantaged groups.	People with income and time restrictions.
Economic	Income and transportation service limitations on accessing the labor market.	Employed and unemployed people.
Time-based	Time limitations to perform trips due to difficulties in organizing commitments.	Caretakers
Fear-based	The incidence of crime creates a sense of fear that influences the use of public spaces and transportation facilities.	Women, elders.
Space	Surveillance and management of public transport spaces can weaken any sense of belonging to those spaces.	Young, immigrants.

Source: Adapted from Church *et al* (2000).

Unlike the disaggregation of Church *et al* (2000), this new proposal differentiates the financial category from the economic one by considering that the first relates to the management of personal funds while the latter refers to the management of goods and services, in this case, accessibility. Also the geographical, facilities and time-based categories are merged into the space-time category, a social category is added and the fear and spatial belonging categories are considered out of the scope of accessibility issues. Moreover, the accessibility components are restricted to the individual, land use and transport, with the time-budget component included as part of the individual one.

Table 3.2: Relation between categories of accessibility restrictions and accessibility components

Component / Categories	Individual	Land use	Transport
Personal ability	Related to individual physical and motor disability to move.		
Physical infrastructure			Related to physical barriers imposed by the transport system.
Space-time	Related to the scarce availability of activities in the spatial and temporal spectrum of the individual's needs.	Related to the inadequate spatial distribution of land uses.	Related to inefficiencies in the spatial and temporal availability of the transport system.
Financial	Related to the incapacity to afford the costs to access opportunities.		Related to the costs charged to access the transport system.
Economic		Related to the spatial distribution of land uses and their ability to attract people (supply side) and people to be attracted by them (demand side).	
Social	Related to the influence of socio-demographic characteristics such as age, gender, occupation, *etc*.		

The ***personal capability category*** of accessibility restrictions is related to the individual components as personal characteristics such physical and motor disabilities (mobility, hearing and vision impairments) that may prevent individuals to access the transport system and to move around. Children, elders and disabled people are the groups with limited personal capacities that may have their accessibility level compromised *a priori*. On the other hand, the ***physical infrastructure category*** is related to the transport component and refers to the barriers imposed by the transport system, specifically those related to infrastructure deficiencies or vehicle inadequacy that may restrict the transport access and the mobility of people in general and especially of those whose personal capacity is already limited.

The ***space-time category*** of accessibility restrictions relates to the individual, land use and transport components. In the first case, it refers to the individual time disposal to perform trips, *i.e*., the time that caretakers such as lone mothers have to travel. In the second case, it refers to the location of activities of interest distant from its target groups, *i.e*., location of schools far from students, hospital and care centers far from elders, job places far from workers, *etc*. In the third case, characteristics of the transport system can be considered as access constraints in both temporal and spatial perspective. Deficiencies in the public transport coverage or in the provision of parking places may affect the spatial micro-accessibility of individuals, while low public transport frequency may limit their temporal micro-accessibility.

The ***financial category*** of accessibility restrictions is also related to both individual and transport components. The personal level of income is considered one of the main constraints for individuals to perform their trips and hence their activities. Transport expenditure may compromise a significant part of an individual's budget reaching sometimes more than 20% of their income as in the case of Bogotá (Bocarejo and Oviedo, 2012). On the other hand, the costs to access the transport system, either due to high public transport tariffs and/or parking prices, may restrict low-income individuals' mobility, leading them to make fewer trips or choose cheaper modes (*e.g*., PT instead of car). The combination of both situations, personal budget constraints and high transport costs, can limit individual's accessibility.

The ***economic category*** of accessibility restrictions relates mostly to the land use component under both demand and supply perspectives. It refers to the spatial distribution and characteristics of opportunities at destination (*e.g*., offices, shops, school, hospitals, *etc*.) as well as demand for these opportunities at origin locations (*e.g*., dwelling and inhabitants) and also the competition for activities due to restricted capacity (Geurs and Ritsema van Eck, 2001). Together, these aspects determine the ability to attract people and of them being attracted to areas where economic activities take place, thus influencing on the accessibility levels of those areas and hence in the economy of the entire urban area.

Finally, the ***social category*** relates mainly to the individual component and refers to the relation of socio-demographic characteristics of individuals such as age, gender, occupation, *etc*., with their accessibility. These characteristics allow identify disadvantage groups and therefore assess the level of accessibility provided to them. For instance, due to several reasons (location, financial capacity, mobility constraints, *etc*.) disadvantages groups (elder, poor, children, *etc.*) may experience lower levels of accessibility than their opposite groups (younger, wealthy, *etc.*). Therefore, although the focus of social category is the individual, other accessibility components have also a clear relation with the distribution of accessibility among social groups, *e.g*., lower-income groups experiencing job accessibility restriction compared to high-income groups due to financial or location reasons.

All these categories of accessibility restrictions inter-relate as already pointed out in the case of the social category. Nonetheless, the separate analysis of each component of accessibility allows to understand more clearly their contribution for the problem in question as represented in Figure 3.6. A complete picture of the causes of the accessibility and mobility problems and of their impacts, though, would only be achieved through the analysis of all these categories. Yet depending on the perspective of the problem considered, a different set of restriction needs to be analyzed. For instance, if the unequal distribution is being analyzed, space-time and economic restrictions need to be considered. If the inequitable distribution is the focus of the assessment, personal capability, physical infrastructure, financial and social restrictions need to be analyzed. If the unsuitable distribution is the core of the assessment, the analysis of space-time and economic restrictions need to be taken in account. Finally, if the unsustainable distribution is the center of the assessment all restrictions need to be investigated.

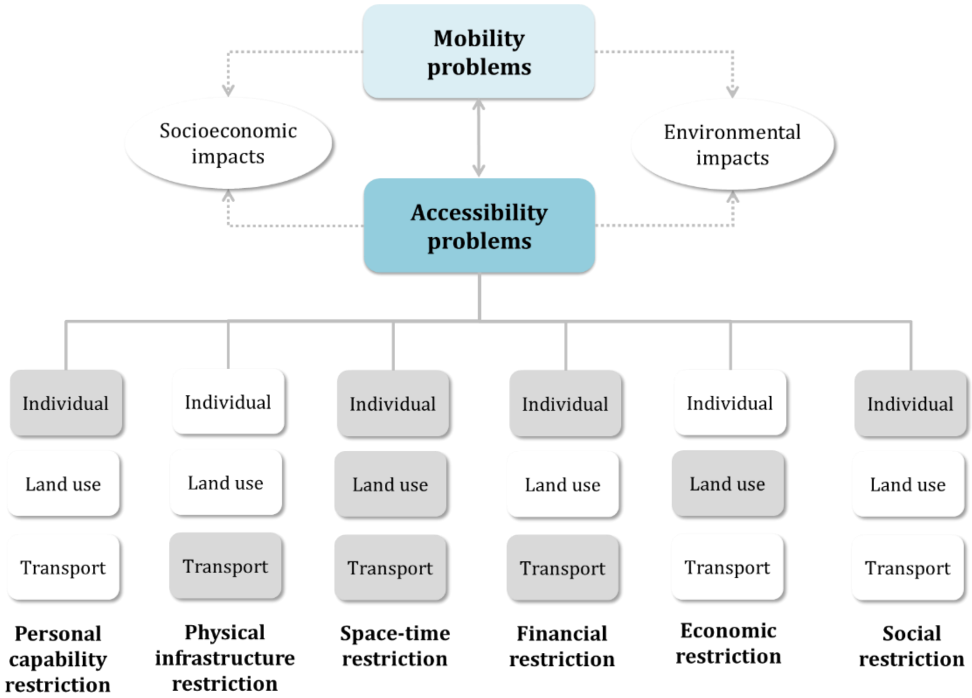

Figure 3.6: Causal relationships by accessibility restrictions categories

(Adapted from Menezes (2015))

3.4 Accessibility indicators

The establishment of the relation between accessibility restriction categories and accessibility components serves as a framework to support the investigation of the causal relationship behind the accessibility problems. This investigation, in turn, must be supported by analytical methods in which accessibility indicators take an important role. There is a variety of approaches for the measurement of accessibility as found in the reviews of Bah *et al* (2000), Baradaran and Ramjerdi (2001), Geurs and Van Wee (2004) and Curtis and Scheurer (2010), and in general they cover at least one of the four accessibility components as indicated by Geurs and Van Wee (2004): land use, transport, time and individual.

Departing from the classification proposed by Geurs and van Wee (2004), a set of seven types of indicators grouped under three different approaches is considered in this work as presented in Table 3. The ***infrastructure-based*** approach relies on analyzing the physical characteristics of the transport supply and/or the performance of the network, therefore being limited to the transport component. The ***location-based*** or aggregated approach focuses on the interaction between spatial distributed activities, thus including the land use component in addition to the transport. In some cases, this perspective also incorporates the individual perception about their travel impedance and/or capacity restrictions in order to incorporate competition effects. The ***person-based*** or disaggregated approach instead is based on perceived utilities or in space-time constraints of individuals, reflecting better their behavior and being able in some cases to incorporate all the four components of accessibility.

Table 3.3: Accessibility indicators by approach of analysis

Approach	Types of indicators	Soundness	Plainness
Infrastructure-based	*Infrastructure indicators*	-	+
Location-based	*Separation indicators*	-	+
	Contour indicators	-	+
	Potential indicators	±	±
	Competition indicators	±	±
Person-based	*Utility indicators*	+	-
	Time-space indicators	+	-

Source: Adapted from Geurs and van Wee (2004)

The indicators presented in Table 3.3 can also be categorized according to criteria that help to assess their usefulness and limitations for different purposes. According to Bertolini *et al.* (2005), indicators must be theoretically sound (soundness) and at the same time should be easy to compute and interpret (plainness). The considered indicators present gradual increase in their soundness from infrastructure-based indicators to person-based indicators, and a gradual decrease in their plainness in the opposite direction. Additionally, the applicability of these indicators for supporting the analysis of accessibility problems considering the different categories of accessibility restriction is also considered and discussed as follows.

Infrastructure indicators are related to physical characteristics of the transport supply (network mileage, number of stops, *etc.*) and/or the performance of transport networks (coverage, travel time, average speed, congestion levels, *etc.*). These indicators are one of the plainest, being easy to compute and interpret, and relying on readily available data and models. However, they are theoretically weak once do not consider the land use component, thus contradicting the premise defended by Handy and Niemeier (1997) that accessibility indicators should at least include the network and the land use components. Nonetheless, this type of indicators has significant relevance in the assessment of transport system performance as-previously pointed out.

In relation to accessibility restrictions, this type of indicator has a clear applicability for the analysis of the physical infrastructure category and partially of the space-time category. They allow measuring the effect of transport infrastructure barriers on accessibility, *e.g.*, through the number of inadequate stations for disabled people. Also, they allow capturing the impact of transport inefficiencies on accessibility under both spatial and time perspectives, *e.g.*, by measuring the spatial coverage and time availability of the transport services. On the other hand, they are not suited for supporting personal capability, financial, economic and social analyses once they do not consider neither the land use component nor the individual component and are focused only in the supply of transport infrastructure in the origin or destination locations.

Spatial separation indicators refer to the spatial degree of separation or the connectivity between locations. This separation can be measured in terms of network connectivity (topological indicators) or considering elements that represent network performance (distance, time and cost). This type of indicators is easy to compute and understand, requiring minimal and easy-to-obtain data input. However, as there is no reference to land use patterns, nor to behavioral aspect of individual travel choices (attraction of activities and value time of time for different groups), spatial separation indicators are considered theoretically weaker (Curtis and Scheurer, 2010).

Regarding accessibility restrictions, spatial separation indicators are suited for a partial analysis of the space-time, financial and social categories. Through measuring the separation between locations it is possible to analyze only the transport perspective of the space-time and financial categories of accessibility restrictions by measuring the connectivity between the location of target groups and their desired activities by travel distance, time or cost (Curtis and Scheurer, 2010). Concerning the social category, separation indicators can be used to analyze the connectivity of different social groups to specific activities, *e.g.*, the connectivity of poor and wealthy to the main job areas. However, it is not possible to capture the personal capability, physical infrastructure and economic categories of accessibility restriction once spatial separation indicators are not able to represent individuals or land use characteristics.

Contour indicators allow determining the number of opportunities that can be reached within a fixed distance/time/cost, or the distance/time/cost required to access a fixed number of opportunities (Geurs and van Wee, 2004). These types of indicators are one of the plainest, being easy to compute and interpret and requiring data that are ready available. Besides, contour indicators include aspects related to both transport and land use components, however failing to assess their joint effects as they ignore that attractiveness of opportunities decays with the increase of travel impedance (Zhang, 2002). This fact leads to the definition of fixed and arbitrary contour thresholds (normative approach), disregarding the individuals' perceptions about the effects of distance in spatial interactions. Consequently, all activities/opportunities inside the contour limit are considered as having the same attractiveness regardless their type and the travel time to reach them. Nonetheless, Bertolini et al (Bertolini *et al.*, 2005) argue for the consideration of a 30-min travel time limit as a benchmark to assess the impacts of transport and land use change on accessibility.

Concerning their applicability for analyzing accessibility restrictions, contour indicators are suitable for a partial analysis of the space-time, financial, economic and social categories. For the space-time category, these indicators are useful from the land use perspective as they allow quantifying the number of activities that are within a certain distance or time from target groups, *e.g.*, the number of health centers within a 10-minute walk from elder residences. They are also particularly helpful from a transport perspective, if contour areas are defined based on transport facilities instead of activity locations, as done by Currie (2010), who estimated catchment areas of bus stops and train stations for analyzing public transport accessibility. The contour approach can also be applied to partially characterize financial issues if contour areas are based on travel costs. They can also be used in economic analysis as they can capture the attractiveness of locations, although considering it homogeneous inside the contour limits, or the number of people attracted by a specific location/activity. From the social perspective, contour indicators are partially useful if they are estimated based on the location of different social groups, *e.g.*, the number of public facilities that poor and wealthy can reach within a certain travel time. However, for the personal capability and physical infrastructure categories these indicators are not appropriate as they are unable to take into account individual characteristics or the transport supply characteristics.

Potential or gravity indicators try to balance the opportunities of a destination by an impedance function related to the generalized cost of travel between locations. They can be seen as an improvement of contour indicators allowing to define areas of contour based on a continuous scale of impedance. Usually a family of distance-decay function is employed to represent the cost of travelling in these indicators with a reasonable precision both empirically and geographically[2] (Martínez and

[2] Five main types of distance-decay function can be found in the literature to model the spatial interactions effects: Power function, Exponential function, Tanner function, Box-Cox function and

Viegas, 2013). The consideration of distance decay functions improves their soundness by considering assumptions on individual perceptions and allowing the evaluation of the combined effects of the transport and land uses components per different groups of individuals (Geurs and van Wee, 2004). This brings complexity to the indicator making it more difficult to interpret than contour indicators. Nevertheless, potential indicators also has the advantages of allowing the differentiation between locations, the comparison of different network configurations and the assessment of changes in accessibility over time (Bhat *et al.*, 2000) and among social groups. They are easy to compute relying on already existing data (*e.g.*, land use) and network model estimated data (*e.g.*, travel time).

In relation to accessibility restrictions, this type of indicator are suitable for the analysis of almost all their categories, except for the personal and physical ones. In the case of the space-time category, potential indicators allow analyzing the interaction between locations (origins *vs.* destinations) considering both space and time constraints (impedances measured by distance or time decay), but only under land use and transport perspectives. Moreover, as potential indicators allow considering the attractiveness of locations, they become particularly suitable for economic analysis. Also, if an affordability component is added in the impedance function, the financial category of accessibility restriction can be analyzed. This was done by Bocarejo and Oviedo (2012) that incorporated a component expressing the percentage of individual income spent on transport in order to analyze their effect in the accessibility of minority groups. Finally, if the impedances are estimated based on the location of different social groups (*e.g.*, poor and wealthy) and also considering some of their personal characteristics (*e.g.*, level of transport expenditure), the social category can be analyzed by comparing the level of accessibility of these different social groups. This was also done by Bocarejo and Oviedo (2012) who estimated impedances functions incorporating a financial parcel for different socioeconomic areas in the city of Bogotá to then assess the offer of accessibility for groups with different income levels.

Competition indicators incorporate competition effects related to both activities and users and can be considered an adaptation of potential indicators (Curtis and Scheurer, 2010). They allow considering cases when, *e.g.*, users compete for medical

Richard function. The first two are the most widespread functions commonly used in gravitational models and requires only the calibration of the parameter β. Tanner and Box-cost functions are more complex functions that depend on two parameters (β and λ). The last function, also known as generalized logistic function, relies on the calibration of four parameters and allows a better representation of interactions in short distances as demonstrated by Martínez and Viegas (2013).

facilities, workers compete for job opportunities, employers compete for skilled workers or even a combination of the last two cases generating a double-constrained spatial interaction model as developed by Wilson (1971) and indicated by Geurs and van Wee (2004). In all cases, the competition approach, allows to include demand aspects in accessibility indicators going beyond gravity indicators that consider only supply aspects, such as land use patterns and transport impedances (Zhang, 2002). However, while considering the demand side meaning that the indicators are sounder, this brings a higher complexity for its operationalization and also for its interpretation.

Regarding the analysis of the different categories of accessibility restrictions, competition indicators can be applied in the same way as potential indicators, although adding complexity in the computation. Such complexity does not justify their choice unless the objective of the analysis is to assess the economic category, once the indicator is able to express more clearly the competition in both demand and supply sides of land use. This type of analysis was performed by Cheng and Bertolini (2013) that incorporated in a potential accessibility indicator the diversity of employments as well as workers and employment competition as way to capture the supply and demand aspects of job activities in the greater area of Amsterdam.

The ***utility indicators*** consider accessibility as the maximum expected utility associated with a set of individual mobility choices (usually destination, mode, route and *etc.*). These indicators are founded on the economic utility theory and derived from the denominator of multinomial logit models (*logsum*), which serves as a summary indicator or utility index of the entire individual mobility choice as defined by Ben-Akiva and Lerman (1979). The main disadvantage of this approach is that different model specifications cannot be compared, which requires a normalization of the accessibility indicators by converting them from the generic utility units to the units of one of the model variables (typically time or money) (Zegras, 2005). Conversely, utility indicators have the advantage of reflecting individual preferences regarding the impedances and attractiveness of locations in their travels choices. Nonetheless, although the consideration of the individual component enhances the soundness of utility indicators, it hampers their operationalization and interpretation.

In respect to accessibility restriction categories, utility indicators are suited for analyzing the personal capability, financial, economic and social categories. In the case of the personal capability category, utility indicators are able to capture the impact that individual disability may have in their accessibility, *e.g.*, the transport utility for disabled persons may be perceived differently from the persons that do not present disabilities even when the transport system conditions are adapted to them. The financial category, in turns, can be considered if the transport expenditure parcel is incorporated in the utility function. In the economic and social categories, the indicators are able to capture user-benefit changes due to transport and land use investments by comparing the gains and losses on individual levels of accessibility to certain locations and by social groups.

Finally, ***time-space indicators*** consider the influence of spatial and temporal constraints on individual level of accessibility. Based on the space–time geography theory of Hägerstrand (1970), the individuals' trip-chaining is examined through a space-time prism taking into account the factors that limit their freedom of action/movement. This type of indicators includes all accessibility components and therefore is the most soundness of the indicators. However, their level of disaggregation requires specific survey and a great amount of data, which consequently reflects in their plainness, making them very difficult to operationalize and interpret. Also their results are difficult to aggregate making it difficult to assess the effects of accessibility changes on large geographical scales (Bhat *et al.*, 2000), which demonstrates their inappropriateness to support strategic analysis.

Particularly suitable for the analysis of the individual space-time and personal capability categories of accessibility restriction, this type of indicator allows capturing the impact of different time constraints on the individual level of access to opportunities. Those constraints can be related with personal limitations (*e.g.*, need to sleep, to care for children, *etc*.), space-time limitations (*e.g.*, need to be in a specific place at a specific time, *etc*.) and authority limitations (*e.g.*, need to obey public facilities opening hours) (Bhat *et al.*, 2000). In the specific case of the personal capability category, the indicators can capture the constraint that a specific disability may represent in time available to perform activities. Conversely, this type of indicator is not suitable for the analysis of the physical infrastructure, financial, economic and social categories.

The adequacy of the indicators discussed here for analyzing the different categories of accessibility restriction is summarized in Table 3.4. From the previous discussion, it is possible to conclude that there is no specific or ideal indicator to support the analysis of the different categories of accessibility restrictions. This conclusion is consistent with the idea already advocated by Geurs and van Wee (2004) and Curtis and Scheurer (2010) on the need to consider the various perspectives of accessibility into common measurements or the application of different accessibility indicators in the same context. This last approach is also advocated by Primerano and Taylor (2005) who argued that the combined use of indicators can reduce or even eliminate the weaknesses of each indicator by using the strengths of others.

Table 3.4: Accessibility indicators by categories of accessibility restriction

Types of accessibility indicators	Categories of accessibility restriction					
	Personal capability	*Physical infrastructure*	*Space-time*	*Financial*	*Economic*	*Social*
Infrastructure indicators	-	+	±	-	-	-
Separation indicators	-	-	±	±	-	±
Contour indicators	-	-	±	±	±	±
Potential indicators	-	-	±	+	+	+
Competition indicators	-	-	+	+	+	+
Utility indicators	+	-	-	+	+	+
Time-space indicators	+	-	+	-	-	-

In this sense, Bertolini et al (2005), indicate the use of contour indicators to assess the effects of policy interventions in land use and transport patterns, but recognize the limitations of using sharply defined contours and recommend the use of gravity indicators as a way to get a more gradual decrease in travel time or cost. Murray and Wu (2003), in turn, acknowledge that public transport accessibility has two competing factors, the local access and the level of network coverage, and argue that these two aspects should be considered in the development of accessibility indicators. Minocha et al (2008) presented a methodology to study gaps in public transport service to employment locations taking into account both the potential accessibility of job destinations (gravity accessibility – macro-accessibility) and the availability of public transport to those destinations (frequency and coverage – micro-accessibility).

3.5 Mobility indicators

Since the introduction of sustainability concerns into the UMS planning process, a series of different indicators have been proposed as a way to support this paradigm shift. A significant effort to define sustainable mobility indicators was carry out by different government agencies and research projects around the world. Extensive reviews about indicator initiatives were developed such as the ones carry out by Jeon (2005), Zegras (2005), Hall (2006) and Costa (2008) in their PhD researches and many others in research projects such as the PROSPECT (2001), SUTRA (2001), SUMMA (2004) and DISTILLATE (2005) or by governmental agencies such as the Centre for Sustainable Transportation in Canada (Gilbert *et al.*, 2002) and the Department for Transport in London (Marsden *et al.*, 2007).

The common practice has been the development of a system of indicators based on multi-criteria approaches and the proposal of an index to support the planning process. These indicators function as assessment tools to help evaluate the current sustainable conditions of mobility systems and to formulate and identify the adequate policies to achieve sustainability objectives. The number of indicators considered in these initiatives varies significantly. For example, the Composite Sustainable Index (CSI) (Jeon, 2007) and the Index of Sustainable Urban Mobility (I_SUM) (Costa, 2008) are comprised by 30 and 87 indicators respectively that are aggregated in partial indexes for each of the sustainable dimensions and then in a global index to allow the comparability between different urban areas.

Both indexes were implemented in real cases with CSI being used to evaluate transportation and land use plans for the Atlanta Metropolitan Region (Jeon *et al.*, 2013) and the I_SUM to assess the mobility conditions of various Brazilian cities (Rodrigues da Silva *et al.*, 2015). The I_SUM has been particularly defended as a benchmarking tool that allows to compare the performance of sustainable mobility conditions across different cities (Miranda and Rodrigues da Silva, 2012). However, despite the fact that the I_SUM is flexible enough to provide reasonable results even without all indicator values being available, which is a common situation in many cities, the consideration of a range that contains the actual value of I_SUM has been used as a way to overcome this issue and allow the comparison of mobility conditions in different cities.

Notwithstanding the contribution of these indexes as a way to incorporate sustainability concerns into the planning process, some issues can be pointed out regarding their usability as adequate indicators for the analysis of the urban interactions, especially those internal to the UMS. First, although accessibility indicators are included in these initiatives, they are not the center of the structure as they have less weight than the mobility ones and are considered with different approaches. While the CSI relates its accessibility indicators to economic and social dimensions of sustainability, the I_SUM considers indicators that represent only micro-accessibility issues such as the access to the public transport system or the universal accessibility.

Second, though both CSI and I_SUM present a set of mobility indicators in their composition they are not explored in a way that allows the analysis of the inner dynamics of the urban mobility system, *i.e.*, the demand and supply dynamics. In the I_SUM for instance demand (*e.g.*, number of trips and travel time, *etc.*), supply (*e.g.*, network density, transit frequency, *etc.*) and performance (*e.g.*, congestion levels and average speed) mobility indicators are considered along its different domains. Undoubtedly, these indicators can be used to characterize the mobility conditions of cities and even to compare them with benchmarking cities as argued by its supporters, but they need to be more deeply examined in order to enable the causal relationship analysis behind the accessibility and mobility problems and hence their better understanding.

Third, the approach considered in the formulation of theses indexes seems to be more objective or solution-oriented than problem-oriented. They have a large number of indicators in their composition that cannot be directly related to problems. For example, the indicator “bicycle fleet” (bicycles/1000 inhabitant) in the I_SUM seems a solution-oriented indicator defined to express the offering of non-motorized modes as a sustainable solution. However, having a small fleet of bicycles may not be a problem in cities whose topography or climate is not favorable to the use of this type of mode. Therefore, the applicability of theses indexes to assess the current conditions of urban mobility systems is limited once they are not completely able to support the identification of problems.

From these reflections, it is believed in this research that more than propose complex structures of indicators to support the planning process, the consideration of general categories of mobility indicators that allow to characterize urban mobility flows and correlate them to accessibility levels is the most appropriate way to support the analysis of mobility and accessibility problems. Thus, considering the categorization proposed by Saloman and Moktharian (1998) the mobility indicators can be organized under the supply and the demand perspectives as indicated in Table 3.5. ***Supply-oriented indicators*** describe the easiness of travel by the transportation alternatives available or the potential of travel denoting the freedom of individual movement. ***Demand-oriented indicators***, in turn, relate to individual travel behavior and express the amount of actual movement performed by them.

Table 3.5: Mobility indicators

Supply-oriented indicators		Demand-oriented indicators
Easiness of travel	Potential of travel	Experience of travel
• Travel alternatives: vehicle ownership or availability (private cars, bicycles and motorcycles), PT pass ownership, number of PT lines offered, *etc*.; • Transportation performance: average speed by mode, congestion level (V/C), *etc*. ratio), vehicle-km of PT service offered, *etc*.	• Space-time indicators: accessibility indicators constraint by time and modes availability.	• Amount of trips: total number of trips, number of trips per household, number of trips by car per household, number of trips by car per household in the morning peak, proportion of trips by modes (modal share), *etc*.; • Trips duration: trips time, trips distance, trip distance per period of times, vehicle-km travelled by inhabitant or household, *etc*.;

Easiness of travel indicators are supply-oriented indicators of mobility that reflect the availability of travel alternatives or the transportation system performance. In the first case, the availability of transportation including several types of infrastructure and services can be expressed by car ownership, mode availability such as bike- and car-sharing systems, public transport pass ownership or roads kilometers by road hierarchy. In the second case, indicators such as average speed by modes, volume/capacity ratio or vehicle-km of public transport service offered, *etc*. are used to indicate the performance of the transportation infrastructure. All these indicators were fully explored during the first wave of planning where the focus was the provision of transportation infrastructure in order to meet an alleged rising demand.

Potential of travel indicators are also supply-based indicators that address the individual ability of travel by using accessibility indicators, especially space-time indicators, as indicators of mobility. They allow quantifying individual mobility considering the modes and the time available to perform trips, *e.g*., the greater the number of modes and personal time available, the greater the potential mobility of individuals. Nonetheless, potential movement or potential mobility indicators do not express travel behavior and therefore can also be seen as supply-oriented indicators. Even so, Jones (1989) indicates the use of accessibility indicators as mobility indicators highlighting their unambiguous nature as opposed to mobility, since increasing accessibility is always preferred whereas increasing mobility can have negative effects such as congestion. Still, the operationalization of this type of indicators, as already mentioned in section 3.4, is very difficult requiring a large amount of data and computational effort.

Demand-oriented indicators of mobility relates to the travel experience reflecting the individuals' travel behavior. These indicators normally express the travel experience by measuring the amount or duration of the trips performed as indicated in Table 3.4. In the first case they express total or ratios of trips per inhabitant or household and can be differentiated by mode (*e.g.,* motorized and non-motorized modes, public and private modes, *etc*.), purposes (*e.g.,* work, leisure, shop, *etc*.) or period of time (*e.g.,* peak and no-peak periods, day, monthly, *etc*.). They can also express proportions/share of trips by modes, the so called modal share, an indicator that has been used to support environmental sustainability analysis (Khanna *et al.*, 2011; Schafer, 1998; Wright and Fulton, 2005). In the second case they express the duration or the length of trips and can be differentiated in the same way as the amount of trip indicators. They have been also used to support sustainability analysis with vehicle distance traveled applied as a single indicator to express sustainable mobility as seen in the works of Black (2002) and Zegras (2005).

Nonetheless, Saloman and Mokhtarian (1998) point out that some of these demand-oriented mobility indicators can be considered as complementary with each of them expressing a different element, which in the context of accessibility may be very different. For example, if the quantity of trips (*e.g*. number of trips) is high the mobility level may be considered as good and apparently no problem is noticed. However, if the duration (*e.g*., average distance) of these trips is also high, a problem of low level of accessibility may be hidden. Therefore, the combination of amount and duration indicators of mobility seems to be a better approach to represent the full dynamics of mobility problems when compared to the use of a single indicator.

Additionally, as argued previously, distance and time represent different aspects of the urban mobility network that need to be considered when defining mobility indicators. For instance, if the focus of the problem assessment is to investigate possible environmental issues in the urban system, mobility indicators based on distance can help quantify the impacts of mobility such as energy consumption or pollutant emissions. On the other hand, if the purpose is to investigate socioeconomic issues, mobility indicators based on time can give a clearer idea of the problems from the individual perspective once they perceive time as trip constraints more easily than distance. Thus, the impact of travel time in the time budget of individuals and hence on their levels of activities can be better assessed.

In this sense, it is considered that all three categories of mobility indicators discussed have an important role in the quantification of the mobility phenomenon. Though, demand-oriented indicators seems to be more preferable for representing mobility as its causal relationship with accessibility can be more easily investigated. Such indicators allow to identify mobility disparities, *i.e.*, the disproportions between amount and duration of trips, being the preferable approach the use of these two types of indicators in conjunction or the use of rates expressing the amount and duration of trips. Nonetheless, the supply-oriented indicators, although not enabling an accurate picture of the mobility behavior *per se*, may be useful to understand the reasons that lead to certain mobility patterns, *e.g.*, vehicle ownership may lead to more private car mobility while number or frequency of subway lines may explain why certain urban contexts present a more intense public transport mobility than others.

3.6 Summary

- As the strategic assessment of accessibility and mobility problems is considered the starting point of the UMS planning, the representation and analysis of their causal relationship is fundamental for the understanding of the UMS problematic. The recognition of the urban subsystem interactions constitutes the base for the representation and analysis of these causal relationships, while the urban mobility network represents the platform for the operationalization of accessibility and mobility indicators and hence for the analysis of the problems. Different configurations of the urban mobility network lead to different hypotheses regarding the possible dynamics between mobility and accessibility problems and therefore for their socioeconomic and environmental implications on the urban system;
- The definition of accessibility and mobility problems, in turn, is depending on the establishment of certain expectations which vary according to principles set collectively such as equity or sustainability. Equity, as the underlying principle of the planning process, serves as a pre-requisite for the sustainability achievement. In conjunction with the ethical theories of sufficientarianism and egalitarianism, a set of four universal categories of accessibility and mobility problems is considered in this research: the unequal distribution, the inequitable distribution, the unsuitable distribution and the unsustainable distribution of accessibility and mobility. Together,

these categories of problems form the basis of the strategic assessment phase whose purpose is to investigate the complex UMS problematic;

- However, for a complete understanding of the mobility and accessibility problems in the urban mobility network it is necessary to investigate the factors related to the transportation infrastructure and service, land use distribution and individual characteristics that may explain accessibility conditions. In this sense, a set of six categories of accessibility restrictions is established in this thesis as a way to better relate them to the accessibility components. The categories refer to personal capabilities, physical infrastructure as well as space-time, financial, economic and social restrictions. The separate analysis of each accessibility component allows to understand more clearly their contribution for the restriction in question, however depending on the perspective of the problem considered, a different set of restrictions needs to be analyzed;
- Finally as a way to support the characterization of mobility and accessibility problems and the diagnosis of their causal relationship, a set of possible indicators is suggested. These indicators allow to quantify the mobility problems as well as the different categories of restrictions of accessibility problems. From the range of accessibility indicators available in the literature an analysis of the ones most suitable for assessing each accessibility restriction is presented. Moreover, contrary to recent planning practice of defining complex structures of indicators to analyze the sustainable mobility, it is considered that for the understanding of mobility problems and its relations to accessibility, the use of single measures of mobility is the best approach.

4. Strategic Assessment Methodology of Accessibility and Mobility on Urban Mobility Networks

The assessment of the urban mobility network based on the accessibility and mobility values is materialized in this chapter in a form of a methodology that aims to support the UMS planning process. Such methodology departs from the assessment of four main categories of accessibility and mobility problems considered in this research as universally identifiable. Those problems are assessed through exploratory and confirmatory spatial analysis of accessibility and mobility indicators, allowing an intelligent reading of them and hence the identification, in an early stage, of the planning process of misalignments between the UMN configuration and equity and sustainability principles. The main objective of this chapter is thus to propose a strategic assessment methodology that allows to assess problems related to accessibility and mobility on UMNs and the associated impacts that the solutions considered may present. It is structured in five main parts. First, the characteristics of the problem-oriented approach considered for the development of methodology as well as its structure are discussed in section 4.1. Then, the main spatial analysis techniques used as quantitative metrics to support the methods proposed in the methodology are presented in section 4.2. Next, the two main phases of the methodology, the assessment of problems and the assessment of solutions, are presented in sections 4.3 and 4.4. Finally, the summary with the main conclusions of this chapter is presented in section 4.5.

4.1 Problem-oriented approach

In line with the paradigm shift discussed in the previous chapter, the methodology proposed here has a problem-oriented approach. As stated by Vriens and Hendriks (2005), the main challenge in a planning process is the understanding of decision problems and not the search for solutions. A deeper analysis of the type of problem as well of its causes and effects is a key action of problem-solving since the understanding and solution of problems are interrelated activities within the decision process. This approach helps to avoid the effort of producing refined solutions for the wrong problems. Therefore, much of the effort of the planning exercise should be focused on ways to envisage the problems and formulate the adequate objectives to solve them, rather than merely develop alternative solutions.

Therefore, this methodology focuses on the four main categories of problems that reflect equity and sustainability concerns as discussed in Chapter 3 and presented in Figure 4.1. These problems are considered as universally identifiable and must be the departure point of a strategic assessment. They are considered as the deficiencies or gaps in the provision of accessibility and mobility and can be related with strategic principles of equity and sustainability. Moreover, these problems can be the cause of other problems such as social exclusion and environmental unsustainable mobility, as well as can be caused by problems related to one or more of the accessibility components (land use, network and socioeconomic). Therefore the causal hypothesis between these problems must be adequately formulated and investigated.

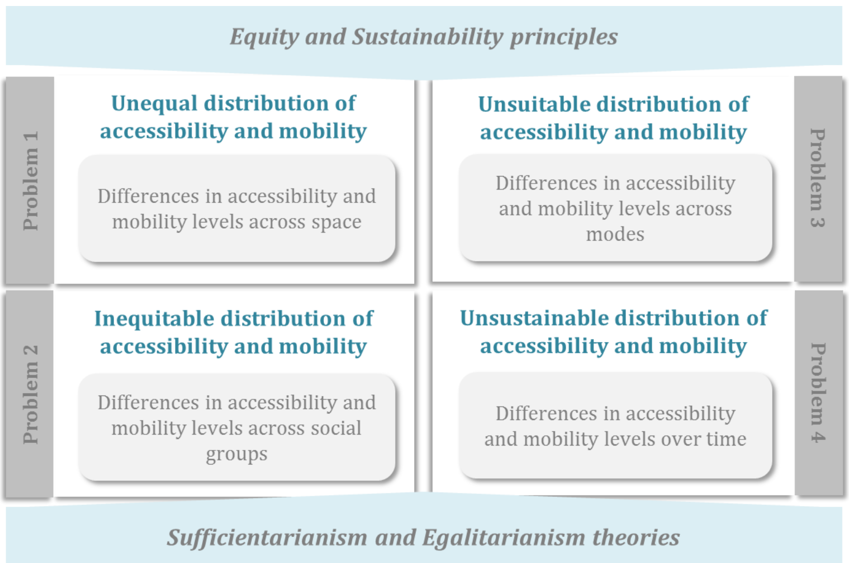

Figure 4.1: Categories of accessibility and mobility problems

The first category of problems relates to the **unequal distribution** of accessibility and mobility or to the differences in their levels across space. It happens when certain regions of the city present low levels of accessibility and mobility to a specific urban function or activity (to jobs, to hospitals, to schools, *etc.*) when compared to other regions or to standard levels, *i.e.*, when areas of insufficient accessibility and/or mobility are detected. The deficient offer of accessibility levels may be related to an inadequate distribution of the land uses or inefficiencies in the transportation supply such as low levels of network coverage or service frequency. Ultimately, these low levels of accessibility can lead to low levels of mobility and activity and consequently impact the overall quality of life.

The second category of problem refers to the **inequitable distribution** of accessibility and mobility or to the differences in their levels across different social groups. It happens when certain minority groups (elder, poor, children, *etc.*) present lower levels of accessibility and mobility compared to their opposite groups (young, wealthy, *etc.*), *i.e.*, when these groups are located in clusters or outliers of low/high levels of accessibility/mobility. This type of problem can be related not only to land use and network problems, but also to socioeconomic aspects like income, level of education, age, *etc*. Such imbalances on the distribution of the accessibility can lead as well to low levels of mobility of minority groups configuring a problem of social exclusion.

The third category of problem refers to the **unsuitable distribution** of accessibility and mobility or to the differences in their levels across modes. It happens when the overall levels of accessibility and mobility by private car are higher than the levels by public transport or non-motorized modes throughout the city. This type of problem is mainly related to disproportions in transportation supply such as imbalances in the offer of private car *vs* public transport or motorized modes *vs* non-motorized modes, and hence on their accessibility levels. These imbalances may then be the cause of mobility imbalances and consequently of environmental issues such noise, CO emissions, acid rain, *etc*.

The fourth category of problem refers to the **unsustainable distribution** of accessibility and mobility or to the differences in their levels across time. It happens when certain social groups present low levels of accessibility in one period compared to other, *i.e.*, when these groups are continually located in clusters or outliers of low levels of accessibility. This deficiency in the provision of accessibility along time can be related to continuous land use, network or socioeconomic problems. These persistent low levels of accessibility, in turn, may be the cause of unsustainable mobility levels.

So, considering these problem categories as the focus of the planning process, the methodology proposed considers that the strategic assessment occurs in three different moments of the process as shown in Figure 4.2: a) during the assessment of the baseline situation when the problems considered are characterized and diagnosed; b) *ex-ante,* during the assessment of alternative solutions proposed for the problems, when the solution results and impacts are assessed; and c) *ex-post,* during the assessment of solutions implemented in order to assess their results and impacts and verify if the problems previously diagnosed were solved.

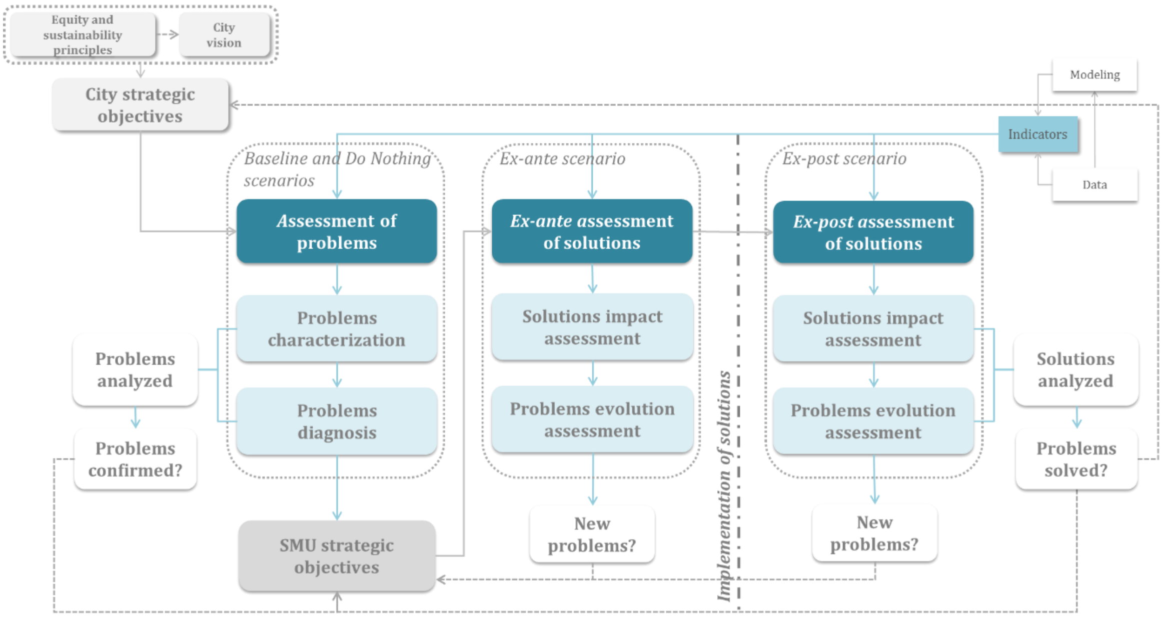

Figure 4.2: Urban Mobility Network strategic assessment methodology

The analysis developed in these three moments is supported by the consideration of different scenarios or temporal representation of the UMN configuration in terms of land use and transportation characteristics combined with of socioeconomic aspects. In the first moment two scenarios are considered: i) a baseline scenario that supports the diagnosis of problems and serves as a reference scenario for the analysis developed during the other~~s~~ moments, and ii) a do-nothing scenario that allows to assess the evolution of the problems when no solutions are implemented. In the second moment, *ex-ante* scenarios for each alternative solutions or alternative UMN configurations are considered. The changes in accessibility and mobility problems from these scenarios to the baseline scenario are compared among them in order to assess their evolution. Finally, in the third moment, an *ex-post* scenario representing the actual configuration of the UMN is considered. This scenario is also compared with the baseline scenario and the evolution of accessibility and mobility problems is assessed.

The method used to carry out the assessment of accessibility and mobility in these different scenarios relies on spatial analysis techniques. These techniques allow to consider the spatial aspect associated with urban phenomena and therefore to better understand the problems as well as their evolution. An overview of these techniques as well as the detailed description of the steps and methods of analysis that comprise each of the phases of the methodology is presented in the next topics of the chapter.

4.2 Spatial analysis techniques

The understanding of spatial phenomena associated to geographical areas like accessibility and mobility requires the use of methods and techniques that allow to know how these events are distributed in space and which are the relations between them. In this sense, spatial analysis techniques represent a powerful tool as they allow the description and modeling of events whose spatial character has an important explanatory role. Its theoretical foundation is based on Tobler's First Law of Geography, which considers that near things are more related than distant things, and from which the concepts of spatial dependency and spatial correlation are derived (O'Sullivan and Unwin, 2002).

The most used techniques for measuring the spatial behavior of these types of events are the exploratory and the modeling spatial data analysis. Exploratory spatial data analysis (ESDA) consists in a collection of techniques supported by global and local statistics that allow to visualize and describe spatial distributions, discover patterns of spatial association (clusters), suggest the existence of spatial heterogeneity and identify atypical observations (outliers) (Anselin, 1998; Cressie, 1993). Modeling spatial data analysis (MSDA), in turn, refers to the specification and estimation of models that allow to investigate the significance of explanatory variables in certain phenomena by incorporating the spatial dependency of the data in linear regression models (Fotheringham *et al.*, 2000).

One of the basic ESDA tool is the spatial distribution maps of the indicator representing the phenomenon in analysis (Câmara *et al.*, 2002). These maps can be produced by varying the limits and the number of classes resulting in different classing methods such as the ones described below and applied to represent crimes (total residential burglaries and vehicle thefts per thousand households) in

Columbus, Ohio (Anselin, 1988). The examples described here are just few of the most common methods available in the majority of the GIS software, however other methods can be found depending on the software used.

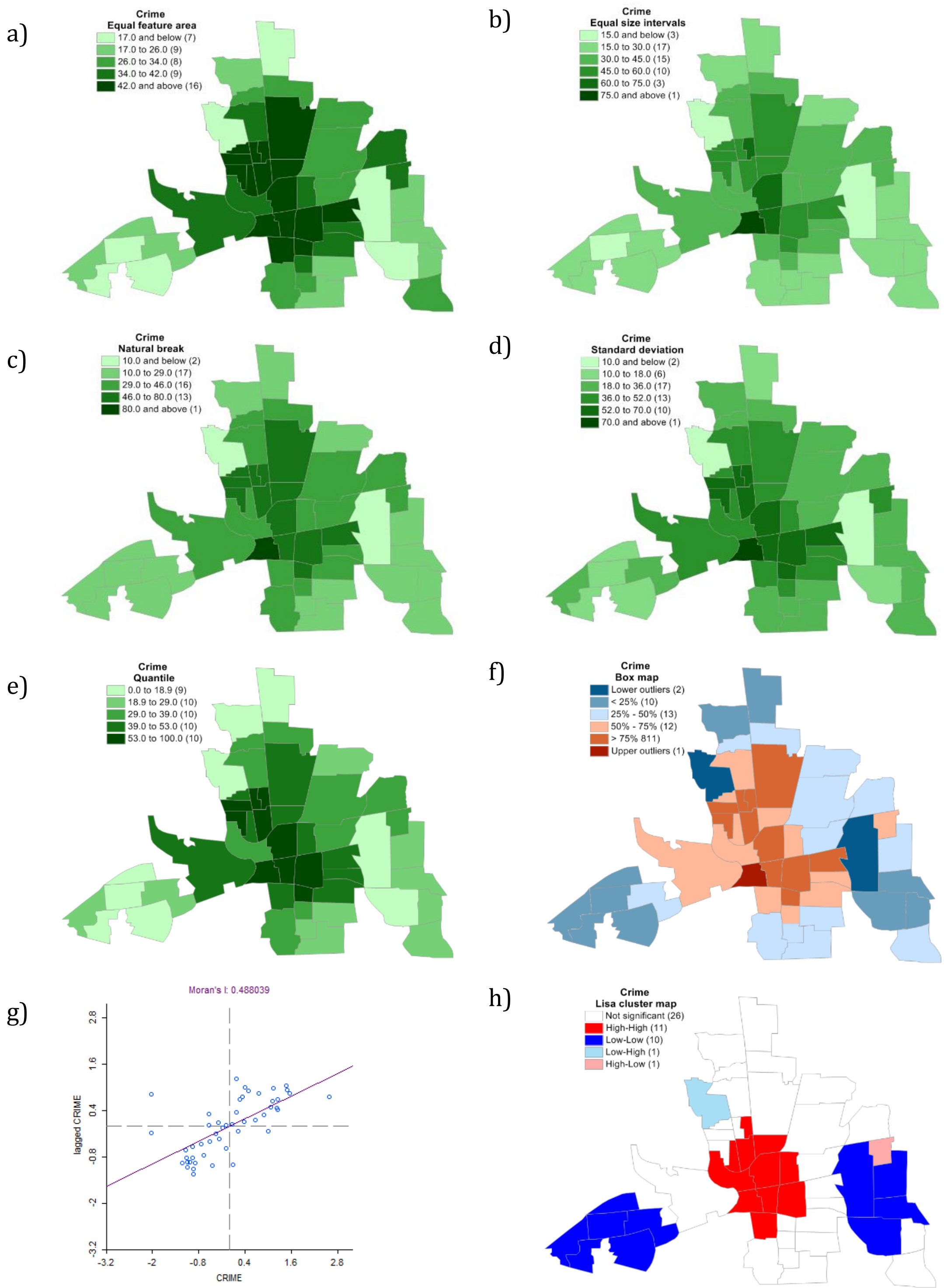

Figure 4.3: Exploratory spatial data analysis tools

- *Equal feature area method*: it classifies data in categories that cover approximately the same total area. This is a very limited method, suitable only for data that have relatively equal size area. Otherwise, the classification produces a very distorted view of the indicator (Figure 4.3a);
- *Equal size interval method*: it classifies data in categories that have equal range, but a different number of features. It is especially suitable for data whose range is already know such as percentages or temperatures. However, it is not suitable for skewed data distributions as almost all values appear in one class (Figure 4.3b);
- *Natural break method*: it classifies data in categories defined according to the Jenks Natural Breaks algorithm, which tries to minimize the variance within each categories. It allows to find groupings and patterns inherent to the data, but are not useful for comparing maps representing different indicators (Figure 4.3c);
- *Standard deviation method:* it classifies data in categories of equal range value that are proportional to the standard deviation, usually intervals of one, one-half or one-fourth standard deviations. It allows an easier comparison of maps of different indicators, but is not suitable for skewed data (Figure 4.3d);
- *Quantile method:* it classifies data into a certain number of categories with an equal number of units in each one, having an intuitive appeal for map readers once they can easily identify the "top 20%" or the "bottom 20%". It allows an equal representation of each class in the map, but may hide the differences in extreme values (Figure 4.3e);
- *Box map method:* it classifies data in quartiles highlighting the outliers in the first and in the fourth quartile separately. It is considered a spatialized version of a box plot being used to complement the interpretation of quantiles maps (Figure 4.3f).

Another set of useful ESDA tools are the global and local version of the Moran's Index. The first version is a global statistic that indicates the degree of spatial dependence or autocorrelation in the dataset through a single value (range from -1 to +1). Its graphical form, the Moran scatterplot shown in Figure 4.3g, depicts the standardized values (z) of the indicator in each unit area and the weighted average value of its neighbor (Wz) or the lagged indicator, with the slope of the regression line representing the Moran's I statistic and the four quadrants the different spatial regimes of association (Anselin, 1996). The second version is a local statistic that has the advantage of decomposing global statistics in individual contributions, featuring in the so-called LISA cluster map shown in Figure 3.4h, the type of spatial association indicated in the Moran scatterplot only for the areas statistically significant (Anselin, 1995). Also, the bivariate form of both version of Moran's Index can be used to analyze the correlation between different indicators. In this case, the Bivariate Moran scatterplot and the Bivariate LISA Cluster map allow to assess globally and locally the spatial dependency between different indicators or phenomena such as the mobility and accessibility, or the space-time behavior of a phenomenon when the bivariate correlation considers temporally lagged values of the same indicator.

The other group of spatial analysis techniques, the MSDA, comprise a set of modeling techniques that intends to better represent the behavior of the phenomenon/indicator under analysis by including the spatial dependency in the regression model estimation. There are two categories of modeling which incorporate the spatial effect: the global and the local regression models. The choice of the most appropriate model depends on the spatial stationarity of the indicator under analysis, *i.e.*, the constant dependency of data along the space. If the phenomenon in question exhibits spatial stationarity, global regression models are preferable once the spatial structure can be captured through the incorporation of a single spatial parameter in the traditional regression models. However, when the global regression models return inaccurate estimates for some locations, the use of local regression models is preferable as it allows to consider the non-stationarity in the data set (Carvalho *et al.*, 2006).

Specifically, the spatial global regression models comprises two main types of autoregressive models: the spatial lag and the spatial error models. While the first considers that the spatial dependency is in the dependent variable, the second consider that the spatial dependency is in the error term. Formally, these models are expressed by Equations 4.1 and 4.2, where y is a vector of values for the dependent variable or the "effect" type indicator (*e.g.,* mobility), X is a matrix of values for the independent variables or the "cause" type indicators (*e.g.,* accessibility), β is a vector of coefficients, ε is a vector of IID errors, μ is a vector of spatially autocorrelated error terms, ρ and λ are spatial parameter, Wy and $W\mu$ are spatial weights matrix for the lagged dependent variable and for the error term. The null hypothesis for the non-autocorrelation in the spatial lag model is that $\rho = 0$ and the main idea is to incorporate the spatial autocorrelation as a model component, while in the spatial error model is that $\lambda = 0$ and the principle is to consider the error term ~~is~~ not spatially correlated.

Spatial lag model: $y = \rho W y + \beta X + \varepsilon$ (4.1)

Spatial error model: $y = \beta X + \mu$ with $\mu = \lambda W \mu + \varepsilon$ (4.2)

The spatial local regression models, in turn, consider the non-stationarity of the phenomenon in question by reflecting the spatial heterogeneity of data set through the regression coefficients in a discrete or continuous form. In the first case, the non-stationarity is approached by dividing the space considered in stationary sub-regions or spatial association regimes identified through the Moran scatterplot and/or the local statistics. Different regression models are then estimated for each spatial regime according to Equation 4.3, where *ISR* is the index of the spatial regimes. In the second case, a geographically weighted regression (GWR) approach is considered in which a regression model is estimated for each observation at location *i* weighting all other observation as a function of the distance to the location *i* (Fotheringham *et al.*, 2002). This is done according to Equation 4.4, where $\beta_{0,i}$ is the local intercept for the observation at location *i* and $\beta_{k,i}$ is the *kth* regression coefficient at location *i*. It is noteworthy that, in general, the local models have better goodness-of-fit to the data compared to traditional and global models, but its interpretation can be somewhat more complicated due to the number of estimated parameters.

Discrete model: $y_1 = \beta_1 X_1 + \varepsilon_1 \quad ISR = 1$ (4.3)

$y_2 = \beta_2 X_2 + \varepsilon_2 \quad ISR = 2$

Continuous model: $y_i = \beta_{0,i} + \sum_{k=1}^{p} \beta_{k,i}\, x_{k,i} + \varepsilon_i$ (4.4)

4.3 Assessment of problems

The assessment of problems is comprised by two main phases: characterization and diagnosis of problems. The first phase aims to characterize the intensity and magnitude of the accessibility and mobility conditions, while the second phase has the objective of identifying problems, estimating their causal relationship as well as analyzing their likely evolution. Ultimately, the results of this first assessment allow a systematized comprehension of the problems considered and hence the validation and/or the redefinition of the strategic objectives. These two phases are described in more detail in the following sections.

4.3.1 Characterization of accessibility and mobility conditions

The characterization method of accessibility and mobility problems is comprised by three main steps as described in Figure 4.4. It starts by the *definition of indicators* to adequately represent the set of problems and as well as it causes and effects. There are a variety of indicators that can be used to express accessibility, mobility, land use patterns, network efficiency and socioeconomics of an urban system. Nevertheless, these indicators should be carefully chosen having in consideration their adequacy to represent properly the values and principles in question, the variables that will compose them, the availability of data for their computation, as well as their power of aggregation, interpretability and communicability. Moreover, they also need to attend the objective of supporting policy development and prioritization and contribute to the monitoring and post-evaluation of those policies as indicated by Royuela (2002).

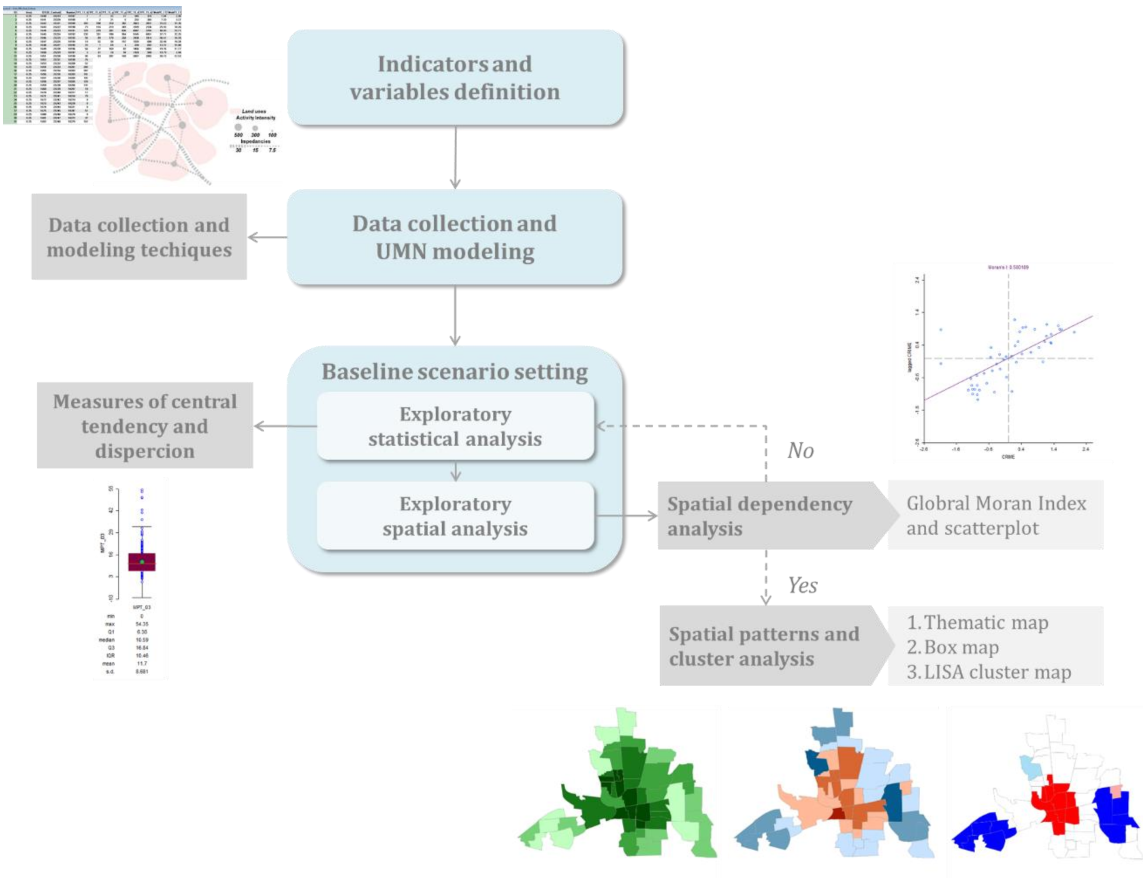

Figure 4.4: Characterization method of accessibility and mobility conditions

Once accessibility and mobility are the central values of this methodology, the choice of adequate indicators to represent them must be the first task to be pursued. There is a vast set of accessibility and mobility indicators available in the literature as indicated in Chapter 3, with each of them being more or less suitable for the analysis of different accessibility restrictions or mobility perspective. Nonetheless, Tables 3.4 and 3.5 previously shown in Chapter 3 provide a structured proposal of accessibility and mobility indicators that can be used to support the assessment of their conditions as well as of the problems and hence of the solutions related to them.

Besides accessibility and mobility indicators, "cause" indicators representing the transportation network, land use and socioeconomic characteristics need to be defined. These are the factors that directly affect accessibility and can be related to its different categories of restrictions. These indicators have the important role of helping understand the possible cause behind accessibility restriction and therefore behind mobility problems. Transportation network indicators both in terms of performance (coverage, travel time, travel distance, generalized cost, *etc.*) and topology (connectivity, centrality, density, *etc.*) have a direct impact on accessibility levels and hence on mobility as indicated in many studies (Derrible and Kennedy, 2010; Parthasarathi *et al.*, 2009). Also, land use indicators such as the ones grouped into the broad categories of density (of population, housing, employment, *etc.*), diversity (mix of different land uses) and design (street network characteristics) (Cervero and Kockelman, 1997; Ewing and Cervero, 2010; van Wee, 2002) can help to understand the levels and patterns of accessibility and hence of mobility. Additionally, socioeconomic indicators used to represent the characteristics of individuals or groups can also help to understand their accessibility and mobility and hence their overall well-being (Arora and Tiwari, 2007; Horn, 1993). Gender, age, years of education, type of occupation, life stage, employment status and income levels are the most common variables for socioeconomic indicators. Depending on the purpose of the analysis to be performed one can be more adequate than other. Nevertheless, both social and economic indicators together or separately can help to understand the accessibility as well as the mobility level of different groups.

Once chosen the indicators to be analyzed, special attention should be given to *data collection and urban mobility network modeling* used to generate the necessary inputs/variables for their calculation. Transportation and land use data have been the pillar of mobility planning and many urban areas already have large database for this type of information, although they are often outdated. Socioeconomic data are easier to get as census data are periodically collected in the majority of cities. Either way the collection of these information demands rigor and should rely on official databases and/or, when possible, in surveys designed specifically to the UMS in question. Modeling techniques (traditional or integrated such as ILUT models), in turn, allow the update or even the generation of missing transportation and land use data, but more importantly the development of assessment scenarios. Specifically, in the characterization phase these techniques allow the representation of baseline aspects of the urban mobility network that determine its accessibility and mobility conditions such as travel distances, travel times, trips flows, land use concentrations, activities distributions, *etc*. Additionally, these same aspects can be projected through the modeling of future scenarios where alternative solutions are assessed as it will be discussed in topic 4.4.

After data have been collected and the urban mobility network has been modeled allowing the operationalization of the defined indicators, the next step in the characterization phase refers to the ***baseline scenario setting*** or the analysis of the indicators in order to assess the basic or current conditions of accessibility and mobility. For this, an exploratory analysis of the indicators should be performed by considering both non-spatial and spatial approaches. In the first approach, measures of central tendency and dispersion allow the identification of the distribution patterns of the indicators considered. In the second approach, spatial distribution maps as well as Global and Local Moran Statistics are analyzed in order to understand the spatial behavior of the chosen indicators. While the spatial distribution maps, more specifically the thematic and Box maps, allow a first glimpse on the spatial behavior of both cause and effect indicators, the Moran statistics help to assess their degree of autocorrelation and to identify regions of similar (clusters) and different (outliers) spatial behaviors through the analysis of their LISA cluster maps. Application examples of these techniques can be found in the studies developed by Grengs (2001), Ramos and Silva (2003), Dou *et al* (2016), Li *et al* (2015) and Cheng *et al* (2016) in which the spatial behavior of accessibility and other land use and socioeconomic indicators are assessed with the purpose of helping understand different urban phenomena such as social exclusion, urban regions definition, environmental impacts and public service access.

4.3.2 Diagnosis of accessibility and mobility problems

Having characterized the accessibility and mobility conditions, the next step is to diagnose the set of problems previously indicated. This process consists in identifying the problematic areas in the city according to the four categories and estimate their causal relationship as well as their evolution and hierarchy considering the steps described in Figure 4.5. The first step for the diagnosis of accessibility and mobility problems is *setting the desired scenario or situation* through the establishment of benchmarks for the indicators. These benchmarks or reference parameters must represent the user's expectations regarding the optimal situation for each indicator considered. They allow to identify the deficit between the baseline and the desired situations and hence determine the problematic areas in the city. For this, a consultative or normative approach can be considered, being the former preferable, although a consultative approach incurs in higher cost due to the need of survey and data processing.

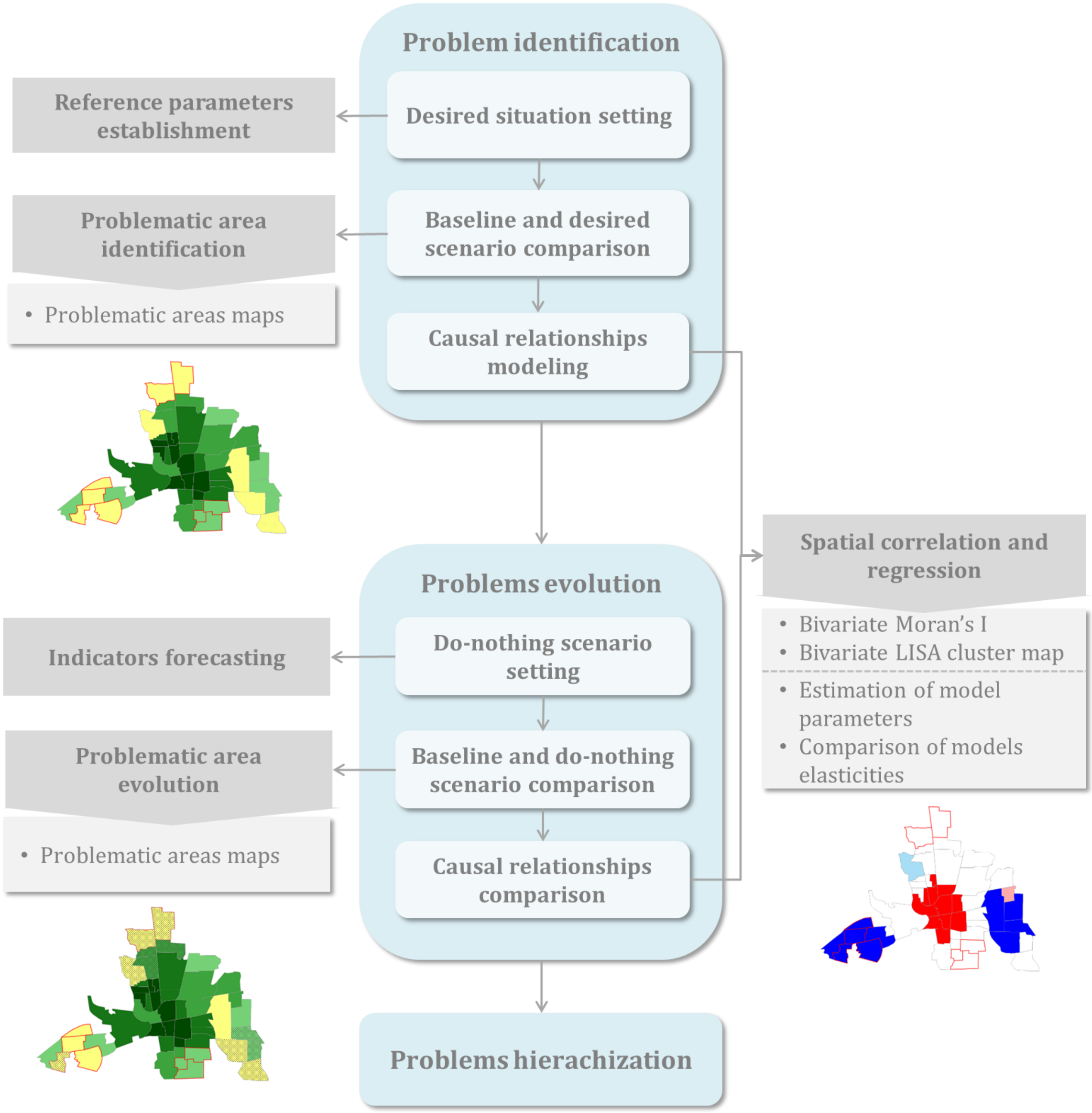

Figure 4.5: Diagnosis method of accessibility and mobility problems

In the first approach, reference parameters are defined through a consultation process where users express the levels of accessibility and mobility they considered is acceptable. Viegas and Martínez (2013) developed a study for Lisbon based on a consultation process where the users' acceptable travel times were categorized by travel purpose (different activities) and transportation mode. The findings of this study indicate that is possible to define acceptable accessibility levels based on the acceptable travel times for different travel purposes. Nonetheless, it would be also important to consider in this kind of approach the acceptable travel budget (time and/or money) for different social groups as demonstrated by Bocarejo and Oviedo (2012) in a study developed for Bogotá.

In the second approach, reference parameters are established based on the values available on the literature or in technical reports as discussed by Paéz *et al* (2012). In this case, reference values are assumed based on conventions or reasonable expectations by planners and not on the actual measures of travel behavior. Normative values for the transportation component of accessibility (travel time, distance to stops, *etc*.) thus depend on the ability or willingness of the planner to verify the assumptions underlying conventional, reasonable, or preferred values. Either way, Paéz *et al* (2012) point out that this approach is not invalidated by the consultative approach and that the combination of both can support the development of better solutions (policy outcomes).

Once the reference parameters are established the next step is the <u>*comparison of the desired and baseline scenarios*</u> or of the desired and characterized levels of accessibility and mobility in order to identify the problems or the problematic areas. For this, different reference parameters and methods of analysis are applied considering the sufficientarianism and egalitarianism theories for each type of problem considered:

- For the unequal distribution problem, a sufficientarianism approach is considered and a non-spatial and unique reference parameter must be set in order to allow the identification of areas in the city presenting accessibility and mobility levels below or above the minimum acceptable. This allows the production of the unequal distribution problem maps in which the insufficient areas of accessibility and mobility are highlighted;
- For the inequitable distribution problem, an egalitarian approach is initially considered and a spatial parameter represented by the clusters (High-High and High-Low) of the social concern group (SCG) in question (low income groups, unemployed, children, elder, *etc*.) must be defined in order to add an equitable perspective to the problem. These clusters are then overlaid on the unequal distribution problem maps in order to assess whether the SCG is located in areas of accessibility and mobility insufficiency or not. This allows

to update the unequal distribution problem maps by highlighting the location of the SCG;

- For the unsuitable distribution problem, a sufficientarianism approach and a non-spatial reference parameter must be considered in order to identify areas in the city where the imbalances of accessibility and mobility levels between different modes occur. For example, areas where the ratios between accessibility and mobility by private car mode and public transport modes are favorable to the latter. This allows to produce the unsuitable distribution problem maps in which the unbalanced areas of accessibility and mobility by different modes are highlighted;
- For the unsustainable distribution problem, the reference parameters must be the same of the other problems, but the problematic areas need also be identified considering the values of the indicators for a past scenario. The unequal, inequitable and unsuitable problematic areas of the baseline and the past scenario are then compared and if an increase in the area of problematic zones is detected, an unsustainable problem is considered to exist in the baseline scenario.

The next step after the identification of accessibility and mobility problems is the <u>*analysis of their causal relationship*</u> considering the causal hypothesis assumed and their confirmation by the estimation of regression models. For the definition of hypothesis, traditional and spatial correlation analysis are performed. Pearson correlation is used to estimate the possible relations between the indicators and Bivariate Moran I's as well as Bivariate LISA cluster maps are used to understand both globally and locally how they relate with each other. An example of this type of analysis is presented by Pritchard *et al* (2014) where spatial correlations between mobility and income indicators are explored using a Bivariate LISA technique. Likewise Zhou and Kim (2013) investigated the spatial correlation between locations of different social groups (African American, Asians, high educated, *etc*.) and access to green spaces through Bivariate Moran's I.

Then, spatial regression models are developed to quantitatively estimate the causal relationships assumed. Both spatial lag models and spatial error models must be used to try to represent adequately the causal relationships and the global and local spatial dependency of the indicators. These models have been used in various studies where the spatial characteristic of the phenomenon analyzed is crucial as pointed by Cardozo et al (2012). Specifically, in urban mobility studies they have been used to estimate mobility based on accessibility, land use, transportation and socioeconomic variables as in the study of Lopes (2005) and particularly for the estimation of public transport mobility as in the works carried out by Chow *et al.* (2006), Moniruzzaman and Paéz (2012), Zhang and Wang (2013) and Sung *et al.* (2014).

After having identified the problems, the next step consists in analyzing their evolution considering the situation in which no intervention is implemented. This allows to assess the need for interventions even in situations where problems currently do not exist or are not critical. It starts by *setting the do-nothing scenario* considering a future scenario (for the horizon year in question) without interventions for which new values of the indicators are forecast. Here, once more, modeling techniques are fundamental, as they allow the simulation of the evolution of both network and land use factors defined in the characterization, ~~and~~ hence generating the inputs for the estimation of accessibility and mobility indicators in future scenarios.

The next step is the *comparison of the baseline and do-nothing scenarios* similarly to what is proposed for the unsustainable problem identification. For this, the three first categories of problems for the do-nothing scenario are identified applying the same statistical and spatial reference parameters established in the baseline scenario. Then, new problematic areas maps are produced by overlapping the problematic areas of the baseline and the do-nothing scenarios. This allows to assess the differences between them, *i.e.*, the increase or decrease in their size. In case of increase, it is considered that problem worsening may occur and therefore an unsustainable evolution is configured. On the other hand, in case of decrease, it is considered that an improvement in the problems may occur and hence a sustainable evolution of the accessibility and mobility is configured.

Having assessed the evolution of the problems, the next step is the *comparison of the causal relationship* in order to assess its evolution. For this, Bivariate Moran's I as well as Bivariate LISA cluster maps are used again to assess how these relationships progress. An increase in the Moran's I value as well as in the size of the cluster's area may indicate an increase in the accessibility and mobility problems causality.

Finally, the results of the problems evolution allow temporally order the attention that should be given to problems by the identification of their magnitude (in relation to the size of the problematic area or the amount of affected population), severity (in relation to reference parameters and to others problems) and tendency. These are criteria that should be considered in the *prioritization of the problems* together with the interests of the stakeholders involved in the process. Due to the limited resources and conflict of interest, the prioritization of problems constitutes an important task that helps to prioritize the objectives proposed or even to redefine them, considering the timelines, the financial resources available and the locals for intervention.

4.4 Assessment of solutions

The assessment of solutions can be performed during two different moments of the planning process: *ex-ante* when alternative solutions are analyzed and future scenarios are considered, or *ex-post* when implemented solutions are analyzed and the current scenario is considered. These solutions refer to interventions formulated to solve the problems diagnosed and to achieve the objectives proposed. They can be related to both land use and transportation network alterations that direct affect the accessibility levels and consequently impact the mobility levels. They are assessed considering not only the changes in accessibility due to their implementation as suggest by Monzón et al (2013), Shaw et al (2014) and Rosik et al (2015) in their regional studies, but also the changes in mobility likewise proposed by Arora and Tiwari (2007) in their socioeconomic impact assessment method.

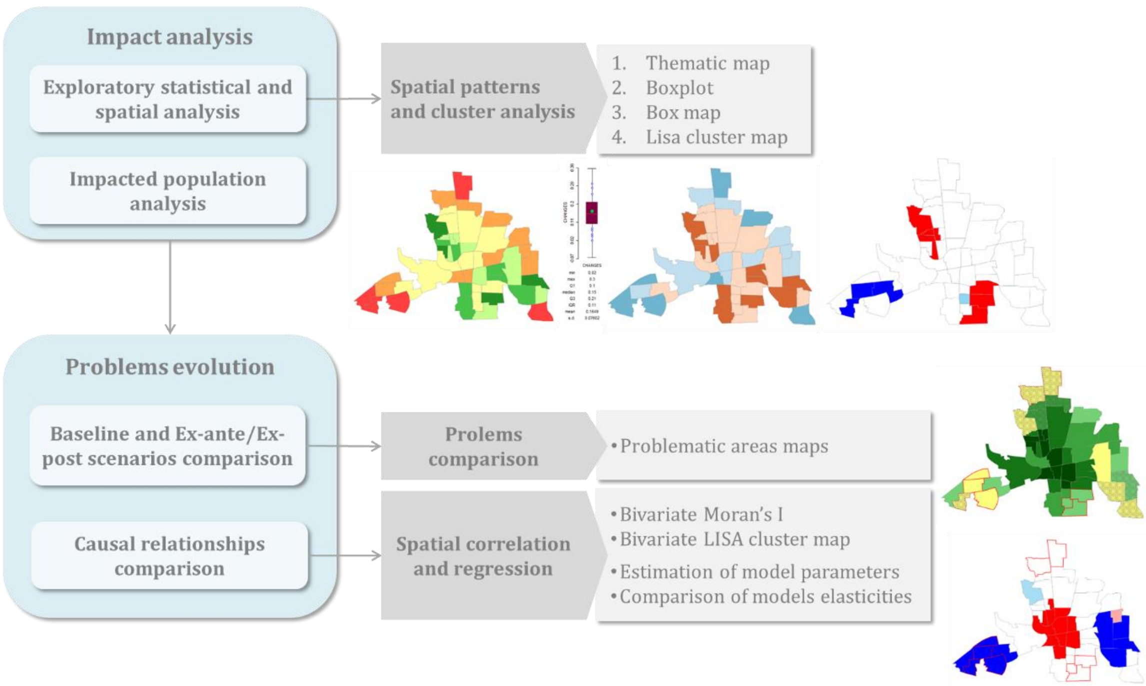

Figure 4.6: Assessment method of accessibility and mobility impacts

This process is comprised by two main phases illustrated in Figure 4.6: the analysis of impacts or changes and the analysis of problem evolution. The first phase aims to assess the direct changes in accessibility and mobility levels derived from the interventions/solutions considered, while the second phase aims to assess the evolution of the unequal, inequitable and unsuitable problems and hence of the unsustainable problems similarly to what is done in the final step of the diagnosis phase. These two phases are described in more detail in the following sections.

4.4.1 *Assessment of accessibility and mobility impacts*

The first step in this phase consists in the *exploratory analysis* of the changes or impacts in accessibility and mobility levels derived from the solutions in question (alternative or implemented) considering both baseline and future (*ex-ante*) or current (*ex-post*) scenarios. For this, the same set of strategic indicators and methods used to characterize the accessibility and mobility conditions and to diagnose their problems are applied and the changes in their values as well as in their spatial behavior from the base to future or current scenarios are analyzed. In the case of an *ex-ante* assessment of alternatives, the indicators should be recalculated based on the assumptions considered in each alternative future scenario in relation to the evolution of land use and socioeconomic aspects as well as the transportation characteristics. On the other hand, in the case of an *ex-post* assessment of implemented solution, the indicators should be updated considering the current figures of the land use, socioeconomic and transportation variables

Spatial distribution maps, Boxplots, Box maps and LISA cluster maps are the main tools for the operationalization of the comparison between base and future or current scenario changes similarly to what is done in the characterization phase. While the first three tools allow to identify the spatial patterns of the increases or decreases in accessibility and mobility levels, the fourth tool enable the identification of alterations on cluster and outliers of changes. These tools allow to characterize the statistical and spatial behavior of accessibility and mobility changes. However, for a more comprehensive understanding of these changes, a comparative analysis of the spatial distributions of the accessibility and mobility indicators as well as their input variables can provide a more detailed picture of the accessibility and mobility changing conditions for the UMN in question.

Additionally, besides analyzing the impacts of the solutions in terms of changes in accessibility and mobility, an *analysis of the impacted population* should be performed. This consists in identifying the proportion of the population that is benefited or harmed by the changes in accessibility and mobility. For this, an estimation of the total number of individuals pertaining to the social group direct affected (*e.g.*, workers, students, elder, poor, children, *etc*.) by the solutions must be performed. This social group will differ according to the type of activity addressed in the analysis. For example, if the accessibility to workplaces is being considered, the social group directly affected would be the workers or if the accessibility to schools is the focus of the analysis the group to be considered should be the students. To implement this analysis the areas directly affected by the alternative solutions need to be identified and the individuals of the affected social group within these areas estimated. Then, the total proportion of individuals within the areas with positive changes (benefited individuals) or within the areas of negative changes (harmed individuals) are estimated.

4.4.2 *Assessment of accessibility and mobility problems evolution*

The assessment of problems evolution in the *ex-ante* and *ex-post* moments follows the same method proposed in the diagnosis phase and starts by the *comparison between the baseline and the future/current scenario.* For this, the first three categories of problems for future or current scenarios are identified using the same statistical and spatial reference parameters established in the baseline scenario. However, for the *ex-post* assessment of the inequitable problem it is recommended to use an updated version of the social concern group, since the size of the clusters representing this group may have changed over the years. This allows to identify: i) the areas of insufficient levels of accessibility and mobility by mode; ii) the areas of insufficient mode ratios of accessibility and mobility; and iii) the areas with insufficient levels of accessibility and mobility for the social concern group. The overlapping of the problematic areas is once more performed in order to identify if there was an increase or decrease in their size. Increases indicate a worsening in the problems and therefore an unsustainable evolution, while decreases imply an improvement in the problems and hence a sustainable evolution of accessibility and mobility.

The next step is the *comparison of the causal relationship* and therefore the analysis of their evolution. For this, the spatial correlation between accessibility and mobility changes is assessed through the analysis of their Bivariate Moran's I and Bivariate LISA cluster maps. This allows to identify the areas where both phenomena are associated and therefore where accessibility changes may be considered as one of the causes of mobility changes. Also, for the *ex-post* assessment, new spatial regression models should be calibrated considering the same specification (*i.e.*, spatial lag, spatial error, *etc*.) of baseline models in order to assess if the causal relationship are still relevant after solutions being implemented. For this, the point elasticities of the variables models are estimated and their relative levels of influence are compared to the ones obtained for the variables of the baseline models. This allows to assess if the same set of explanatory variables or "cause" variables remains relevant and if the relative levels of influence of accessibility on mobility have changed due to the intervention implemented in the UMN.

4.5 Summary

- The strategic assessment methodology described in this chapter relies on two main aspects: a problem-oriented approach and a spatial analysis method. These characteristics give the methodology a more accurate way of assessing accessibility and mobility problems as well as the interventions proposed and implemented to solve them. While the problem-oriented approach allows to focus in the main accessibility and mobility deficiencies faced by the UMN in light of equity and sustainability principles, the spatial analysis techniques provide the adequate means to quantitatively analyze them having in consideration the geographical aspect that all urban phenomena present;
- It is structured in three main phases corresponding to three main moments of the urban mobility planning: the diagnosis and also the *ex-ante* and the *ex-post* analyses. Each of these phases/moments are comprised by steps that allow an intelligent reading of the accessibility and mobility problems as well as of their evolution over time in a sustainable perspective. In the first moment, the focal point is the assessment of the four categories of problems through the characterization of the accessibility and mobility baseline conditions and the diagnosis of the problems by the analysis of their causal relationship. In the second and third moments, the attention is turned to the changes in accessibility and mobility conditions derived from both alternative and implemented transportation interventions as well as its impact on the evolution of the problems considered.

5. Strategic Assessment of Accessibility and Mobility on Lisbon's Mobility Network

The methodology proposed for the strategic assessment of the urban mobility network is applied in this chapter for the case of Lisbon's Mobility Network in order to demonstrate the applicability of the methodology proposed. It consists on the assessment of accessibility and mobility conditions in the city for four different temporal scenarios: the baseline scenario of 2003 and the do-nothing, *ex-ante* and *ex-post* scenarios of 2011. The choice for these four scenarios has the purpose of reflecting the most recent interventions on Lisbon's transportation network regarding both public and private transport and allowing a comparison between them in terms of accessibility and mobility conditions.

The chapter is structured in four main parts. First, the scenarios and interventions considered are presented in section 5.1, followed by the description in section 5.2 of the dataset assembling, transportation network modeling and spatial analysis performed to support the implementation of the methodology. Section 5.3 presents the results of Lisbon's Mobility Network assessment covering the assessment of accessibility and mobility problems as well as the *ex-ante* and *ex-post* assessment of accessibility and mobility changes from the transportation network interventions considered. Then, the summary of the findings of this chapter is presented in section 5.4.

5.1 Lisbon's Mobility Network: scenarios and interventions

Lisbon's Mobility Network, the object of analysis in this chapter, refers to the representation of all transportation networks and land uses/activity elements that together determine the daily movements in Lisbon. However, in this analysis a simplified version of this network containing the transportation network elements and only the land use characteristics related to work activities is considered. This simplified mobility network enables the daily work commuting inside Lisbon, the main activity and employment center of Lisbon's Metropolitan Area (*Área Metropolitana de Lisboa – AML*), whose current population of about 540,000 inhabitants is concentrated in an area of 85km^2 served by a road network organized in three levels of hierarchy as well as a public transport network comprised of buses, trams and subway lines.

In the two last decades, and especially in the period comprised between the 2001 and 2011 censuses, Lisbon presented significant socio-economic changes with a decline of 3% in its total population and 10% in its workforce (INE, 2002; INE, 2012). These changes were accompanied by a contraction of 5% in its job market (GEE/ME, 2011) as well as by the implementation of a series of transportation interventions that jointly may have caused some alterations in its job accessibility levels and hence in its mobility conditions. This hypothesis is based on the fact that relevant alterations in the total daily mobility of Lisbon's inhabitants have occurred between 2003 and 2011, with an increase of 27% in their total daily mobility by private car and a decline of 11% by public transport according to the total figures of the last O-D matrices estimated for the city (CML, 2005; Eiró, 2015)

Therefore, considering this panorama and the fact that the last mobility study developed for the city, the *Plano de Mobilidade de Lisboa* (CML, 2005), did not include any accessibility analysis nor assessment of alternatives, an application of the strategic assessment methodology is presented in this chapter as way to illustrate the method proposed. This exercise considers a simplified version of Lisbon's Mobility Network and assess its accessibility and mobility conditions in relation to job places, based on four temporal scenarios: *Baseline scenario (2003)*, *Do-nothing scenario (2011)*, *Ex-ante scenario* (2011) and *Ex-post scenario (2011).* These scenarios were defined in order to allow the assessment of accessibility and mobility problems (*Baseline and Do-nothing scenarios*) as well as the changes in accessibility and mobility levels (*Ex-ante* and *Ex-post scenarios*) derived from the most recent transportation network interventions implemented in Lisbon (between

2003 and 2011) as well as one hypothetical alternative intervention as indicated by the Figure 5.1 and described below:

- Extension of subway lines comprising the construction of the following sections: *Campo Grande-Odivelas* in 2004 (yellow line), *Baixa-Chiado-Sta. Apolónia* in 2007 (blue line) and *Alameda-São Sebastião* in 2009 (red line). The *Pontinha-Amadora Este* section although built in 2004 (blue line) is not considered as it is outside Lisbon's boundaries;
- Restructuring of the *Carris* bus network through *Rede 7* project through the implementation, modification and elimination of bus lines in order to adapt the services to the extensions of the subway network;
- Completion of the *Eixo Norte-Sul* expressway (IP-7) with the construction of *Avenida Padre Cruz-IP7* in 2007 and the completion of *CRIL* expressway (*Circular Regional Interior de Lisboa*) (IC-17) with the construction of the *Buraca-Pontinha* section in 2011;
- Implementation of a BRT line as an alternative to the yellow subway line extension from *Campo Grande* to *Odivelas*.

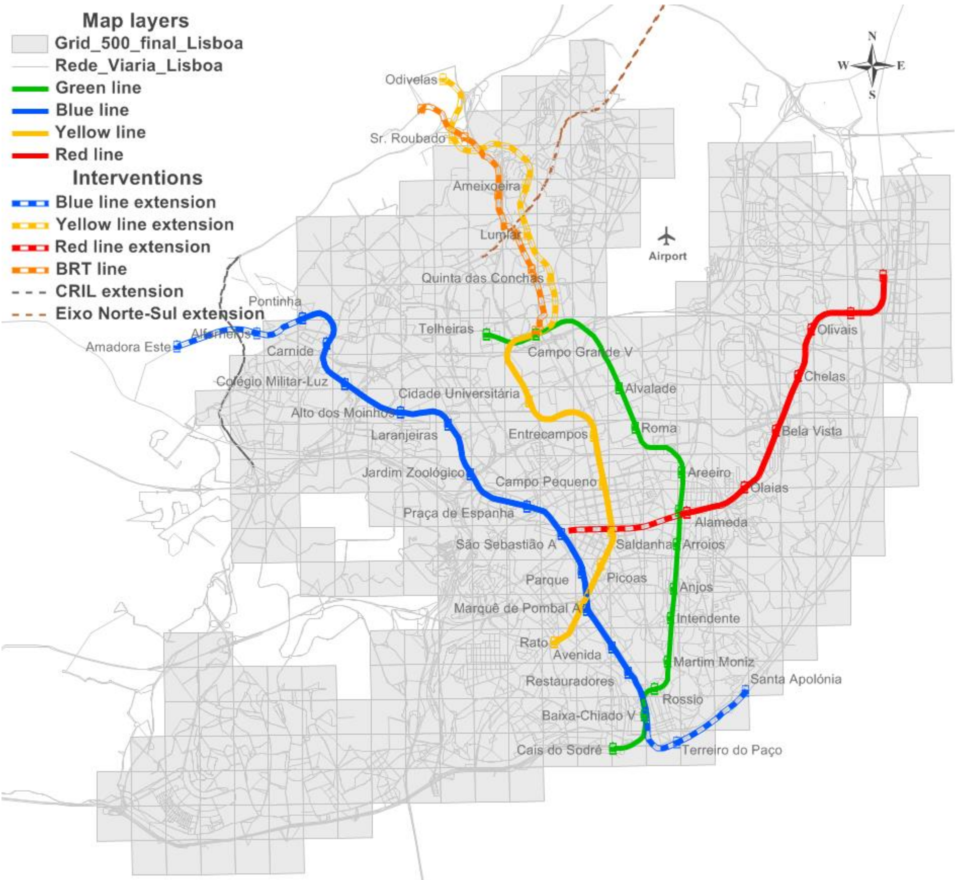

Figure 5.1: Lisbon's transportation network and interventions

The first four interventions, although implemented during the 2003-2011 period, are not part of a unified plan. The subway network interventions are part of the Network Expansion Plans I and II developed by the Metropolitano de Lisboa which contemplate a series of extensions in its lines supported by the development of specific demand studies (MEPAT, 1999). The restructuring of the bus network through the *Rede 7* project, in turn, was carried out by *Carris*, the only bus operator company in Lisbon, which was managed by the state at that time[3]. The project was implemented in three phases starting in 2006 and ending in 2012, and had the purpose of adjusting the bus network to the city's development such as new residential and employment areas as well as expansions of the subway network (Carris, 2006). In this case, the specific objective was to reduce the redundancies between the bus and the subway networks, while maintaining the necessary surface transportation alternatives to the subway connections. Finally, the road network interventions considered are part of a major road network proposal included in the National Road Plan from 1985 (PNR, 1985). This proposal refers to the implementation of fundamental and complementary national roads that have the purpose of assuring the connection among urban centers as well as the access to the main metropolitan areas in the country.

The last intervention refers to an alternative to the extension of the yellow subway line whose purpose is to serve the public transport demand in the northern region of the city and in the Odivelas municipality as well as to minimize the heavy traffic flow in the Loures' corridor and its associated impacts. The choice of a high capacity BRT corridor as a hypothetical alternative to a subway line is based on the fact that this type of solution can provide a high performance service in terms of speed (20 – 40km/h) and hence in travel times and accessibility gains, with capacity levels (15,000 – 45,000 passenger/hour/direction) able to meet the expected demand of 26,000 passengers per hour per direction in the Loures' corridor (ML, 1998; Munoz and Hidalgo, 2013).

5.2 Database Assembling, Transportation Network Modeling and Spatial Analysis

In order to implement the proposed assessment methodology the first step was the assembling of a georeferenced database in Transcad 6.0 (Caliper, 2007) for the three

[3] Currently its management has been transferred to the municipality of Lisbon.

temporal scenarios considered containing the transportation network layers (road network and public transport network) as well as a grid zoning layer for the Lisbon city.

The transportation network layers refer to the representation for both scenarios of the road network and the public transport network containing all modes available in the city (bus, tram and subway). Information regarding the main characteristics of these networks were added to the layers such as the capacity and speed of the road links as well as the operational speed and the frequency of the public transport lines. A layer representing all bus/tram stops as well as subway stations was also included. Based on these layers a transportation network model was developed in order to estimate the travel time by private car (PC) and public transport (PT) considering a shortest path algorithm that minimizes the generalized cost of trips between origin and destinations. For the computation of the travel time by public transport, it was considered the time parcels related to in-vehicle, walking, waiting and transfers, with the respective weights obtained from both the Lisbon Mobility Plan and SCUSSE Project, as indicated in Table 5.1. In the case of the travel time by car, a user equilibrium assignment of vehicle trips was performed in order to estimate the congestion time for the morning peak. The result of this modeling was two travel time matrices for each mode considered used as input for the estimation of the accessibility indicators.

Table 5.1: Public transport network parameters

		Scenarios			
		2003 – Diagnosis[1]	2011 – Do-nothing and *Ex-ante*	2011 – *Ex-post*[3]	
				Light PT[4]	Heavy PT[5]
Value of time (€/min)		0.04	0.04	0.05	0.05
Fare (€)		0.80	1.23[2]	1.40	1.40
Weights	Link time	1.00	1.00	1.00	0.63
	Waiting time	1.10	1.10	1.16	1.84
	Walking time	1.10	1.10	2.10	3.46
Transfer penalty (min/transfer)		3	3	8.16	6.14

[1]CML (2005); [2]Projected based on the inflation rate; [3]Scusse (2011); [4]Bus and tram [5]Subway and rail

The grid zoning layer is comprised by 338 square units of 500-meter sides covering only the area of Lisbon where there is population or buildings. This zoning system was developed by Eiró (2015) with the purpose of obtaining a more homogeneous and reliable characterization of his study area, the Metropolitan Area of Lisbon, compared with the traditional census blocks that present irregular shapes. In the specific case of this thesis, the use of a grid zoning also represents a uniform platform for the comparison between the scenarios considered, once the census block in the last two Portuguese censuses are not consistent.

To this unity of analysis socio-demographic data about the population of Lisbon obtained from the last two Portuguese censuses (INE, 2002; INE, 2012) were added as well as all information resulting from the network modeling (*e.g.,* travel times, travel distances, waiting times, number of transfers, *etc.*) for the 2003 and 2011 scenarios. Also, data regarding O/D trip matrices for private car and public transport for the years of 2003 and 2011 were included in this layer. In the first case, the information comes from the results of the mobility survey performed to support the development of Lisbon's Urban Mobility Plan (CML, 2005) during the final and the first trimester of 2003 and 2004, respectively, and refers to the total trips performed on a normal working day originally aggregated in 40 traffic analysis zones. These trips were disaggregated considering the travel flows between O/D pairs proportional to the areas of intersection between grids and zones. This process resulted initially in several inconsistencies that need to be adjusted case by case taking into account land use characteristics of each grid zone. Specifically, the trips produced by the problematic grid zones were weighted considering the total number of produced trips and the land use characteristics (population, household and employment intensity) of their neighboring grid zones, while the destinations were considered equivalent to the one of the grid zones that had a higher similarity to them with respect land use characteristics. In the second case, the data refer to a synthetic matrix estimated based on the data from the mobility survey developed in 2011 for the SCUSSE project (Santos *et al.*, 2011). The estimation process of this matrix relies on the application of some principles of fuzzy logic to produce a synthetic population of trips with a continuous representation in space and in time as well as a Monte Carlo simulation process for the trip dispersion considering the survey data and the land use characteristics in order to preserve the mobility patterns observed in the survey (Viegas and Martínez, 2010).

Regarding the spatial analysis performed, the software Geoda 1.6.7 (Anselin, 2013) was used to estimate the univariate and the bivariate global and local statistics of spatial association for the accessibility and mobility indicators considering a queen[4] matrix of adjacency as well as the spatial regression models to represent their causal

[4] Adjacency matrix or spatial proximity matrix expresses the spatial neighboring relation between spatial events. There are two forms of estimate this matrix in Geoda: the rook and the queen criteria. The first criterion consider grid areas as neighbors when they have common borders, while the second criterion consider areas as neighbors when they present common boundaries and common corners.

relationship. In the exploratory phase, all spatial statistics produced in Geoda were added to the grid zoning layer and the main visual outputs such as the Box maps, the LISA cluster maps and the Bivariate LISA cluster maps were generated in TransCAD 6.0. In the modeling phase, both Geoda and SPSS software were used to estimate the linear correlations and calibrate the regression models. The Pearson's correlations and the traditional or classical regression models were calibrated using SPSS, while the spatial regression models were calibrated in Geoda.

5.3 The Strategic Assessment of Lisbon's Mobility Network

In this section, an application of the proposed strategic assessment methodology is presented covering two different moments of the UMS planning process. First, an assessment of the accessibility and mobility problems for the *Baseline scenario (2003)* is performed in order to have an overview of the state of the UMS problematic in this period. Then, for the *Ex-ante scenario (2011)*, an assessment of the accessibility and mobility changes derived from alternative configurations of Lisbon's Mobility Network is performed as a way to assess how these alternatives contribute for the mitigation of the accessibility and mobility problems. Finally, for the *Ex-post scenario (2011)*, an assessment of the accessibility and mobility changes resulting from the interventions implemented in Lisbon's Mobility Network is done in order to analyze how these interventions contributed for the mitigation of the problems characterized and diagnosed in the *Baseline scenario (2003)*.

Although a complete understanding of the accessibility and mobility phenomena requires a complete analysis of the relationships in the diagram tree presented in Chapter 3 (Figure 3.6), this application focuses only on the relationships shown in Figure 5.2. It begins by analyzing the current job accessibility and mobility conditions in Lisbon's Mobility Network in order to identify the problems considering space and social restrictions associated with them. Also, some land use, transport and socioeconomic aspects are analyzed so as to have a more comprehensive overview of the features that may contribute to the understanding of the analyzed problems.

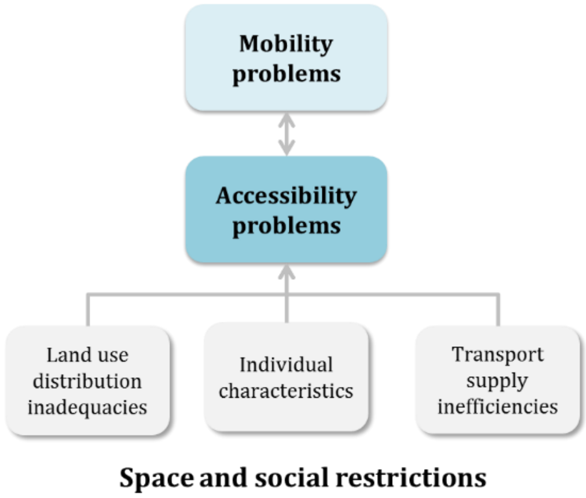

Figure 5.2: Causal relationship and restrictions considered

5.3.1 Assessing the problems: Baseline and Do-nothing scenarios

The assessment of accessibility and mobility problems started with the characterization of the accessibility and mobility conditions on Lisbon's Mobility Network through the analysis of the spatial behavior of a set of indicators chosen to represent these phenomena as well as other land use, transportation and socioeconomic indicators. The diagnosis of accessibility and mobility problems is then performed through their identification as well as by the analysis of their causal relationship based on the quantification of their correlations and the modeling of their causalities. Finally, the evolution of these problems is analyzed considering a future Do-nothing scenario in order to assess their sustainability.

a) Characterizing accessibility and mobility conditions

Defining the indicators

As indicated in the proposed methodology, a set of strategic indicators were chosen to represent the main values of accessibility and mobility as well as a set of supporting indicators to help understand the intensity and magnitude of the accessibility and mobility problems and their causal relationship. Considering the variables available on the database and the four categories of problems to be assessed, the following described indicators were defined.

To represent the ***accessibility*** conditions in Lisbon's Mobility Network two indicators were chosen. The first one is a potential measure that allows the assessment of job accessibility differences between zones for the same modes as indicated in Equation 5.1. The second is an accessibility ratio that allows to assess job accessibility differences between modes for the same zones as indicated in Equation 5.2. The impedance function considered in the indicators is a Richard or generalized logistic function as indicated in Equation 5.3 (Martínez and Viegas, 2013), whose parameters were estimated based on empirical data collected in the SCUSSE Project. The choice of this function over other traditional functions such as the exponential is related to the fact that it better fits the empirically estimated curve of the spatial interaction for both modes in Lisbon. As indicated by the exponential, logistic and empirically estimated curves presented in Figure 5.3 for both PC and PT modes, the logistic curve represents more accurately the willingness to travel to a certain distance/time in Lisbon's Mobility Network, especially for low distance values, a situation that is relevant in Lisbon where 40% of the trips by both PC and PT are shorter than 4 km.

$$A_{i,m} = \frac{\sum(R(T_{ij}) \times E_j)}{\sum E_j} \tag{5.1}$$

$A_{i,m}$= job accessibility of zone *i* by mode *m,* being *m* PT or PC;
$T_{i,j}$ = average travel time between zone *i* and *j*;
E_j = number of jobs offered in zone *j*.
$R(x)$ = value of the Richards or generalized logistic curve for the travel time x as indicated in Figure 5.3

$$A_{i,R} = A_{i,PT}/A_{i,PC} \tag{5.2}$$

$A_{i,R}$= job accessibility ratio of zone i*;*
$A_{i,PT}$= job accessibility of zone *i* by PT;
$A_{i,PC}$= job accessibility of zone *i* by PC.

$$R(t) = C + \frac{K-C}{(1+Qe^{-B(t-M)})^{1/v}} \tag{5.3}$$

C= minimum function value;
K= upper limit or carrying capacity when C=0;
B= growth rate;
V= affects near which asymptote growth occurs;
Q= depends on the value of R (0);
M= *t*-value of the maximum growth if *Q*= *v*.

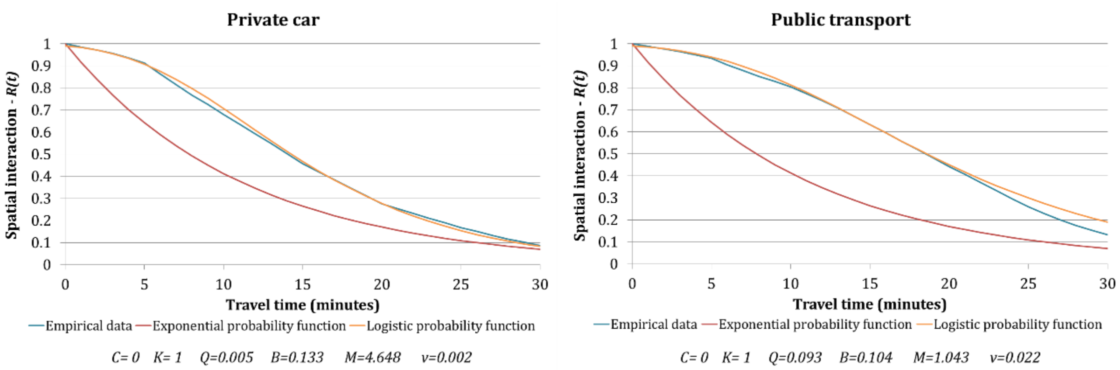

Figure 5.3: Logistic curves for private car and public transport in Lisbon

In the case of mobility conditions, two indicators were also chosen. The first is a time-based mobility indicator, representing the relation between the amount and the time duration of trips in each origin zone as indicated in Equation 5.4. This indicator allows to assess the differences in mobility between zones for the same mode. The second is the time-mobility ratio, as indicated in Equation 5.5, which allows to assess the disproportions or imbalances between PT and PC mobility for the same zones. These indicators were chosen as a way of having an idea of the mobility performance or, in other words, of representing how well the mobility in a specific zone is functioning in terms of the total number of trips and their respective average travel time. According to these indicators, a zone that produces a high number of trips performed in a short time has a better mobility than other zones with the same amount of trips but performed in a longer period of time.

$$M_{T(i,m)} = \frac{\Sigma(P_{ij}/T_{ij})}{n}, \forall P_{i,j} > 0 \tag{5.4}$$

$M_{T(i,m)}$= time-mobility performance of zone i by mode m, being m PT or PC
$P_{i,j}$ = total daily number of trips between zones i and j
$T_{i,j}$ = average travel time between zones i and j
n = total number of grid zones where $P_{i,j}$>0.

$$M_{T(i,R)} = M_{T(i,PT)}/M_{T(i,PC)} \tag{5.5}$$

$M_{T(i,R)}$= time-mobility performance ratio of zone *i*
$M_{T(i,PT)}$= time-mobility of zone *i* by PT;
$M_{T(i,PC)}$= time-mobility of zone *i* by PC.

A set of transportation, land use and socioeconomic indicators were also chosen to represent the conditions that may be causing the accessibility and mobility problems as presented in Table 5.2 and described below:

Table 5.2: Complementary indicators

Type	Indicator	Source/year
Transportation	Travel time by PC and PT (min)	Transportation network modeling (2003)
	Waiting time by PT (min)	
	Stop-station index	
	Road connectivity	
Land use	Job place intensity	Ministry of Economy (2003)
	Resident workers intensity	Census Information Database. (2001)
	Distance to job places by PC and PT (km)	Transportation network modeling (2003)
Socioeconomic	Car ownership	Lisbon's Mobility Plan (2003)
	Percentage of population with a university degree	Census Information Database. (2001)

- From the transportation perspective, the indicators considered were travel time by mode, road connectivity and stop-station density. All these indicators were estimated through the outputs of the transportation network modeling and they give an idea of the performance of the transport network (as defined in Chapter 2) as well of supply conditions. The travel times refers to the average travel time from origin-grid zone to all destination-grid zone in the city. Road connectivity refers to the number of road intersections represented by nodes connecting at least two links, while the stop-station index to the number of bus stops/tram and subway stations available in the grid zone weighted by normative walking distances of 400 m and 800 m respectively;
- From the land use/activity perspective the indicators considered were: job place intensity, resident worker intensity and average distance to job places by modes, which together give an overall idea of the job-worker dynamics in the city. The job place intensity refers to the number of job places available in each grid zone and were provided by the Ministry of Economy without include the jobs in public administration nor the self-employed positions) (GEE/ME, 2011). The resident worker intensity refers to the number of workers residing in each grid and is available in the Census Information Database (INE, 2002; INE, 2012). The distances to job places refer to the average travel distance from origin-grid to the main job grid locations and were estimated based on the outputs of the transportation network modeling;

- Finally, from the socioeconomic perspective, the indicators considered were vehicle ownership and the proportion of high educated population as a proxy of income as a way to have an insight on the influence of individual characteristics in mobility patterns. The vehicle ownership refers to the number of vehicles owned by individuals residing in each grid and was obtained from Lisbon's Mobility Plan (CML, 2005). The proportion of high educated population refers to the percentage of individuals residing in each grid that have a university degree. It was chosen as a proxy of the average income once this information is not publicly available in the Census Information Database.

Assessing the Baseline situation

Lisbon presents a distinguished configuration of job accessibility levels offered throughout the city by public transport and private car, with the job accessibility by PC being overall higher than the job accessibility by PT (Figures 5.4a and 5.4b). In the case of job accessibility by PT, it is possible to notice the strong influence of the subway network in the spatial distribution of the indicator, with all zones where subway stations are located presenting high levels of job accessibility when compared with their neighbor zones. Nevertheless, in both cases, the highest levels of job accessibility are found in the city center, while the periphery presents the lowest levels.

These spatial patterns of job accessibility can be directly related to the spatial distribution of travel times and job places in the city. The travel times by PC in Lisbon are almost half the travel times by PT, which explains in part the higher levels of accessibility by PC compared to PT (Figures 5.4d and 5.4e). In addition, these times are on average lower for the central zones than for the peripheral zones. The offer of jobs in Lisbon, in turn, is mostly concentrated in the city center where the supply of PT is more intense and the connectivity of the road network is higher (Figure 5.4f). This is a very common situation in large urban areas, as companies tend to be located in regions where the accessibility offer is high, although in some cases other variables such as land price may have a more significant role in this kind of decision than the ones related to the transportation system.

The differences in Lisbon's job accessibility offer can be verified through the Box maps of the indicators in which for both modes the zones with the lowest levels of job accessibility (< 25% - first quartile) are predominantly located in the periphery and in Southwest region of the city, while the highest levels of job accessibility (>

75% - fourth quartile) are in the city center (Figures 5.5a and 5.5c). In the case of job accessibility by PT, there are also some zones in the lowest quartiles in the East region, as well as some outliers of high job accessibility in the city center corresponding to the grid zones where subway stations are located.

Such spatial patterns are corroborated by the fact that job accessibility indicators are spatially auto-correlated as indicated by their Global I Moran values: I_{M_APC}=0.94 and I_{M_APT}=0.85 (Figures 5.5b and 5.5d). Locally, this association is expressed through the presence of large clusters of high job accessibility in the Central area and some smaller clusters of low accessibility in the fringes of the city for both modes. Specifically, in the case of job accessibility by PT a small cluster of low job accessibility can be found in the Southwest region as well as one outlier zone of low job accessibility near the cluster of high job accessibility.

These job accessibility patterns can be associated with some transportation network characteristics such as frequency and coverage of public transport, and the connectivity of the road network. The existence of regions of low level of accessibility seems to be related, in the case of public transport, to the low frequency of bus lines and hence to the high waiting and transfer times that users in these regions face in their trips (Figure 5.6a). It also seems to be related to low levels of PT network coverage with low levels of stop-station index being present also in these regions (Figure 5.6b). In the case of private cars, it may be related to the low connectivity of the road network and hence to the decrease in route options and the increase in travel distances and times (Figure 5.6c).

Although the analysis of the spatial behavior of job accessibility by modes allows to have an overall idea of the accessibility phenomenon in Lisbon, the analysis of the ratio between the two indicators can bring new insights for its understanding. The spatial distribution of the job accessibility ratio indicates that in the regions with the highest imbalances (ratio close to 0) between PT and PC, job accessibilities are located in the northern periphery and in the East and West regions (Figure 5.4c). This pattern can also be verified in the Box map of the job accessibility ratio (Figure 5.5e) in which the zones with the highest imbalances (< 25% - 1st quartile, ratio close to 0) are located in the regions previously indicated and the zones with the lowest imbalances (> 75% - 4th quartile, ratio close to 1) located around the subway network, especially around the blue line, and in the Southwest. Also, some outliers of low accessibility imbalance can be found at the end of the blue line, which reflects the fact that in these zones job accessibility by PT is higher than by PC.

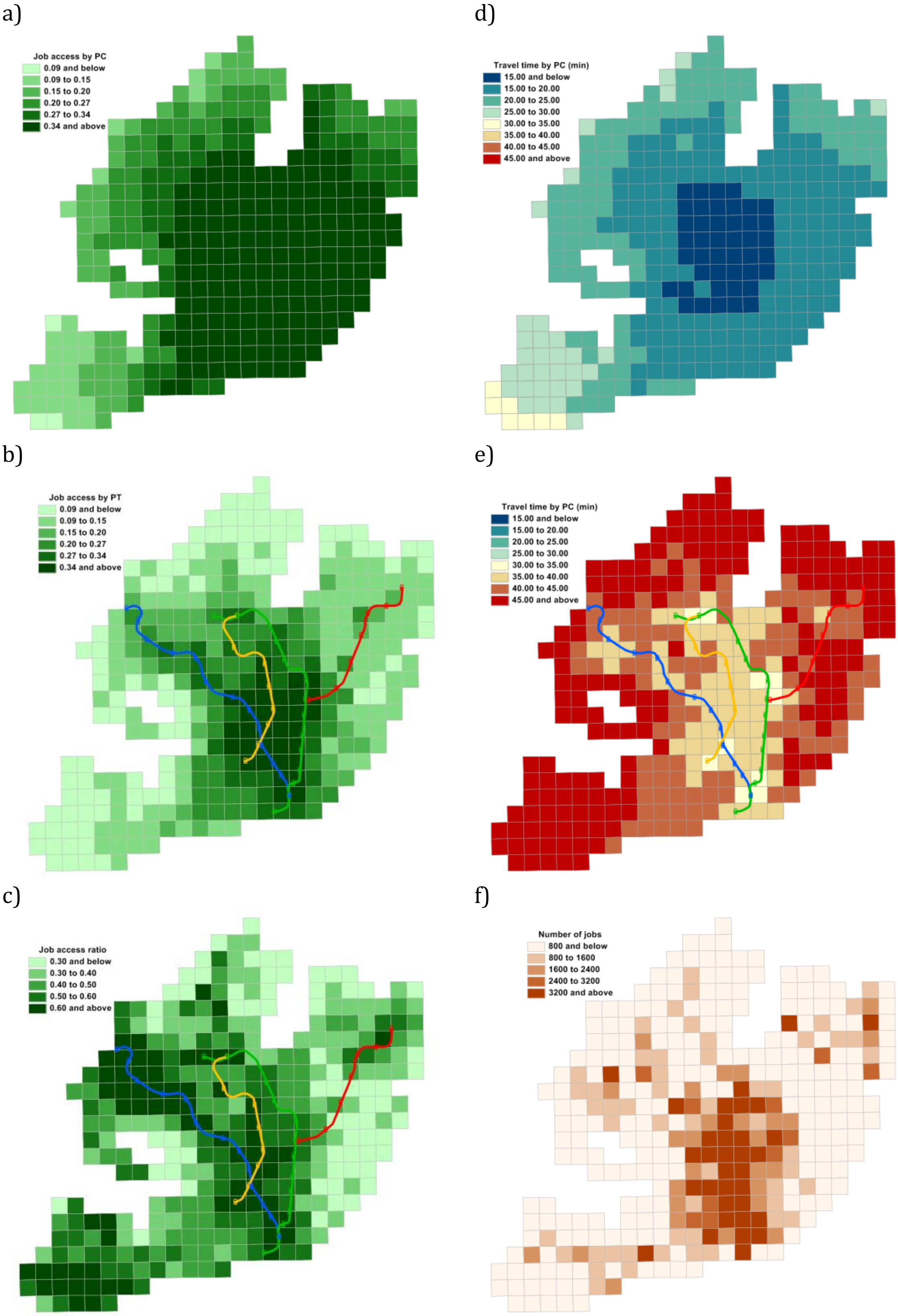

Figure 5.4: Spatial distribution maps of travel time by PC and PT (d, e), number of jobs (f), job accessibility by PC and PT (a, b) and job accessibility ratio (c) in Lisbon

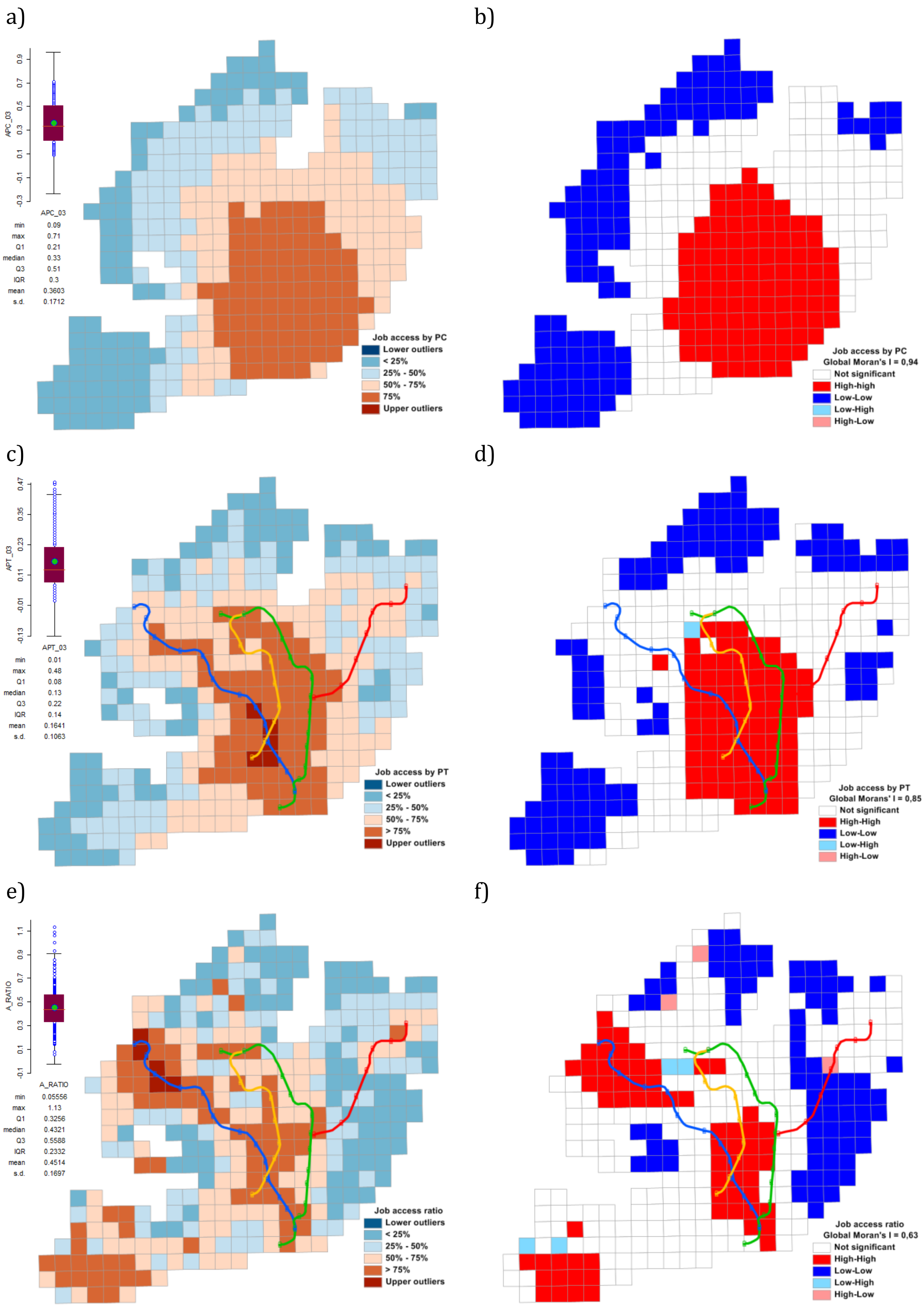

Figure 5.5: Box maps (a, c and e) and LISA cluster maps (b, d and f) of job accessibility indicators in Lisbon

Figure 5.6: Spatial distribution maps of PT waiting times (a), Stop-station intensity (b) and road network connectivity (c) in Lisbon

Additionally, the indicator is highly spatially auto-correlated with an $I_{M\_AR}=0.63$, presenting three large clusters of low job accessibility imbalances (High-High) and several clusters of high job accessibility imbalances (Low-Low) (Figure 5.5f). However, it is noted that only the central cluster of low imbalance is related to areas of high accessibility (both PC and PT), with the other two clusters of low imbalance corresponding to low accessibility areas. This indicates that a given zone, although not presenting problems of low levels of accessibility, may present problems of accessibility imbalance between modes.

Concerning mobility, Lisbon also presents different spatial patterns by modes with more dispersed distributions compared with the job accessibility distributions (Figures 5.7a and 5.7b). In general, time-mobility performance by PC is higher than by PT, with PC mobility presenting a large concentration of zones with high values in the Central and Southwest regions of the city when compared to PT mobility. Also, the influence of the subway network on the performance of PT time-mobility is noticeable once zones near subway stations present higher levels of time-mobility than their neighbor zones, while for distance-mobility this relation does not seem to be so clear.

These spatial patterns of mobility are directly related to the spatial distribution of trips in the city as well as to their associated times traveled. In Lisbon, the total daily number of trips by PT is higher than by PC (Figures 5.8a and 5.8b), with the latter being concentrated mostly in the Central area and the West region, and the former being heavily concentrated in the Central area. The times traveled are also higher by PT than by PC (Figures 5.8c to 5.8f). The association of these two variables representing the amount and the duration of trips leads, in the case of PT, to lower time-mobility values compared to PC, which indicates that the time-mobility performance in Lisbon is better for private cars than for public transport.

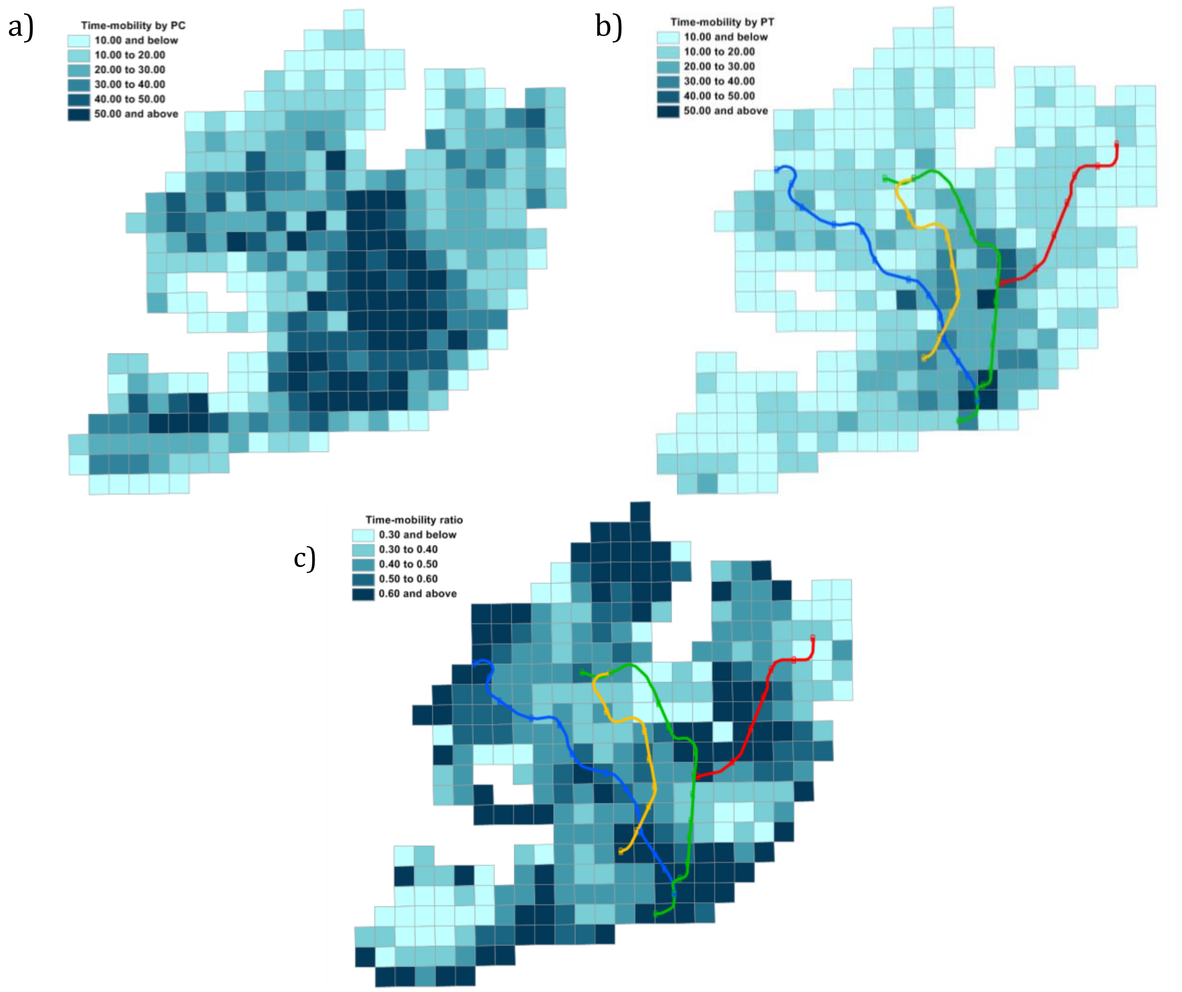

Figure 5.7: Spatial distribution maps of time-mobility by PC and PT (a, b), time-mobility ratio (c) in Lisbon

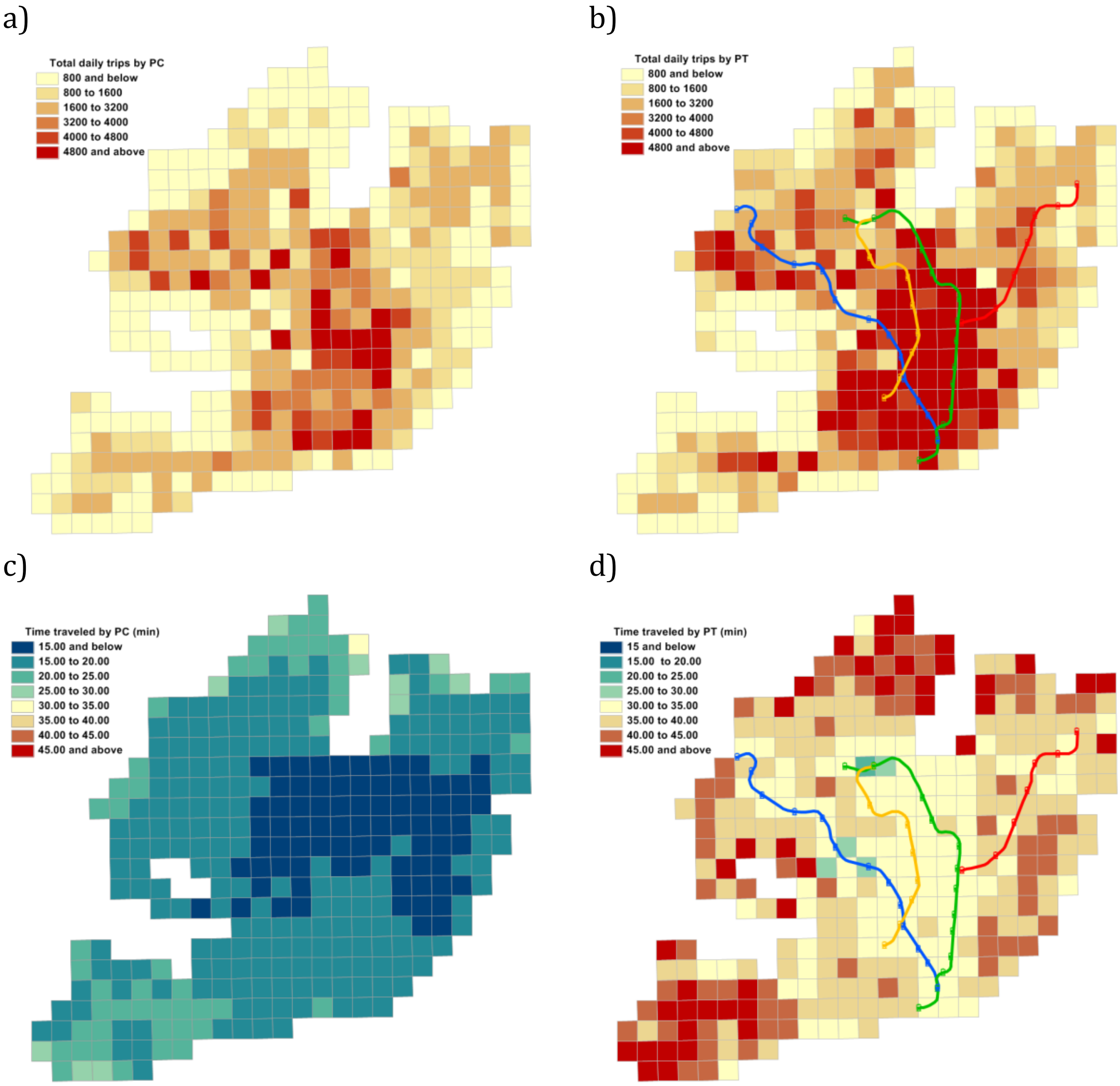

Figure 5.8: Spatial distribution maps of total daily trips (a, b) and average time traveled (c, d) by PC and PT in Lisbon

The spatial patterns of mobility performance can be also verified through the Box maps of the indicators. The highest values (> 75% - 4th quartile) of time-mobility for both modes are found in the zones located in the Central area and in the Southwest and Northwest regions, while the lowest values (< 25% - 1st quartile) scattered along the fringes of the city and in the riverside area (Figures 5.9a and 5.9c). Additionally, both mobility indicators present some outliers of high mobility which can be related to the fact that the OD trip matrix considered counts the trips produced and attracted for both residents and non-residents of the origin zones.

As in the case of accessibility, mobility is also spatially auto-correlated but presents lower values of Global Moran's I if compared to accessibility: I_{M_TMPC}=0.51 and I_{M_TMPT}=0.49 (Figures 5.9b and 5.9d). Locally, the behavior of mobility is characterized by the presence of one large cluster of high time-mobility by PC in the Central area and five clusters of low time-mobility by PC distributed in the North area and in the East and West regions of the city. Regarding time-mobility by PT, one large cluster of high mobility can also be found in the Central area and several clusters of low mobility in the periphery, with also the presence of some outliers of high mobility in the Central area.

In order to understand the disproportions between PC and PT mobility, the mobility ratio indicators were also analyzed. The spatial distribution (Figure 5.7c) and Box maps (Figure 5.9e) of these indicators show that the less balanced zones (values close to 0) in terms of time-mobility are in five distinct regions of the city: in the Southwest, in the Northeast coinciding with the end of the red subway line, in the upper Central area near the green line and in the East and North regions. These mobility imbalances are also auto-correlated as indicated by their Global Moran's I (I_{M_TMR}=0.12) and by the formation of clusters of high imbalances (Low-Low) and low imbalances (High-High) (Figures 5.9c and 5.9e). Four clusters of high imbalances of time-mobility are found in the same areas previously discussed meaning that the time-mobility by PT in these areas is worse than time-mobility by PC. Also, three clusters of low imbalances are found in the South and North regions. In the first case, the low imbalances are related to high levels of mobility, while in the second case to low levels of mobility.

Finally, as a way to try to better understand the time-mobility in Lisbon, the spatial pattern of the complementary indicators previously appointed is analyzed. Resident workers in Lisbon are dispersed throughout the city with a spatial distribution pattern more similar to the spatial distribution of mobility by PT than mobility by PC (Figure 5.10a). Car ownership presents an even more dispersed distribution that in overall is more similar to mobility by PC patterns than to mobility by PT (Figure 5.10b). Population with a university degree, in turn, seems not to have a direct relation with any of the mobility patterns, although locally some similarities may be found in the upper Central area between the yellow and the green subway lines, as well as in some zones in the Southwest and Northeast regions (Figure 5.10c). Lastly, the spatial distributions of average distances to job places by PT and PC present an inverse relationship with mobility, with zones of shorter distances to job places being localized in the Central area where mobility performance for both modes is better regardless the indicator considered (Figure 5.10d and 5.10e).

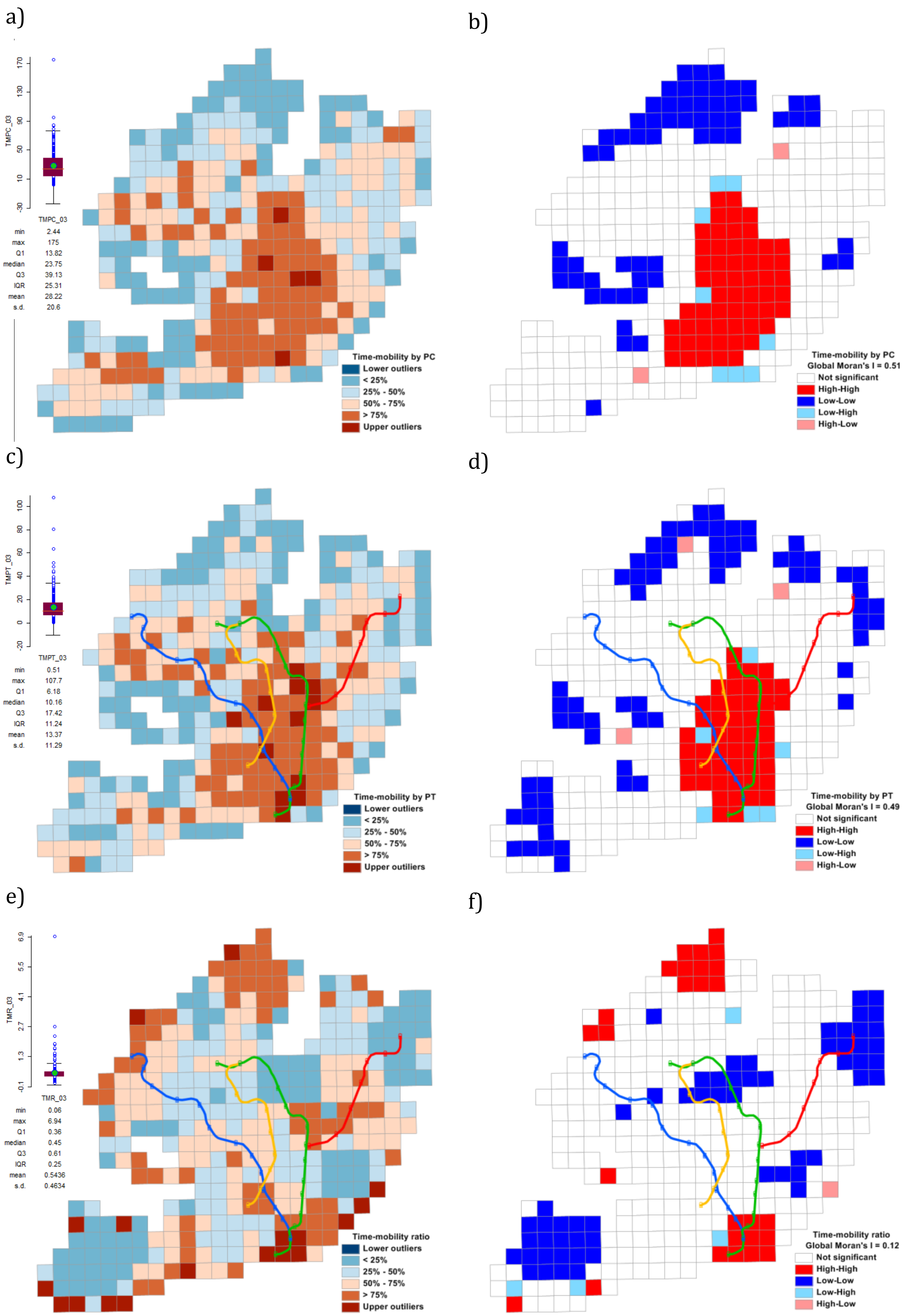

Figure 5.9: Box maps (a, c and e) and LISA cluster maps (b, d and f) of time-mobility indicators in Lisbon

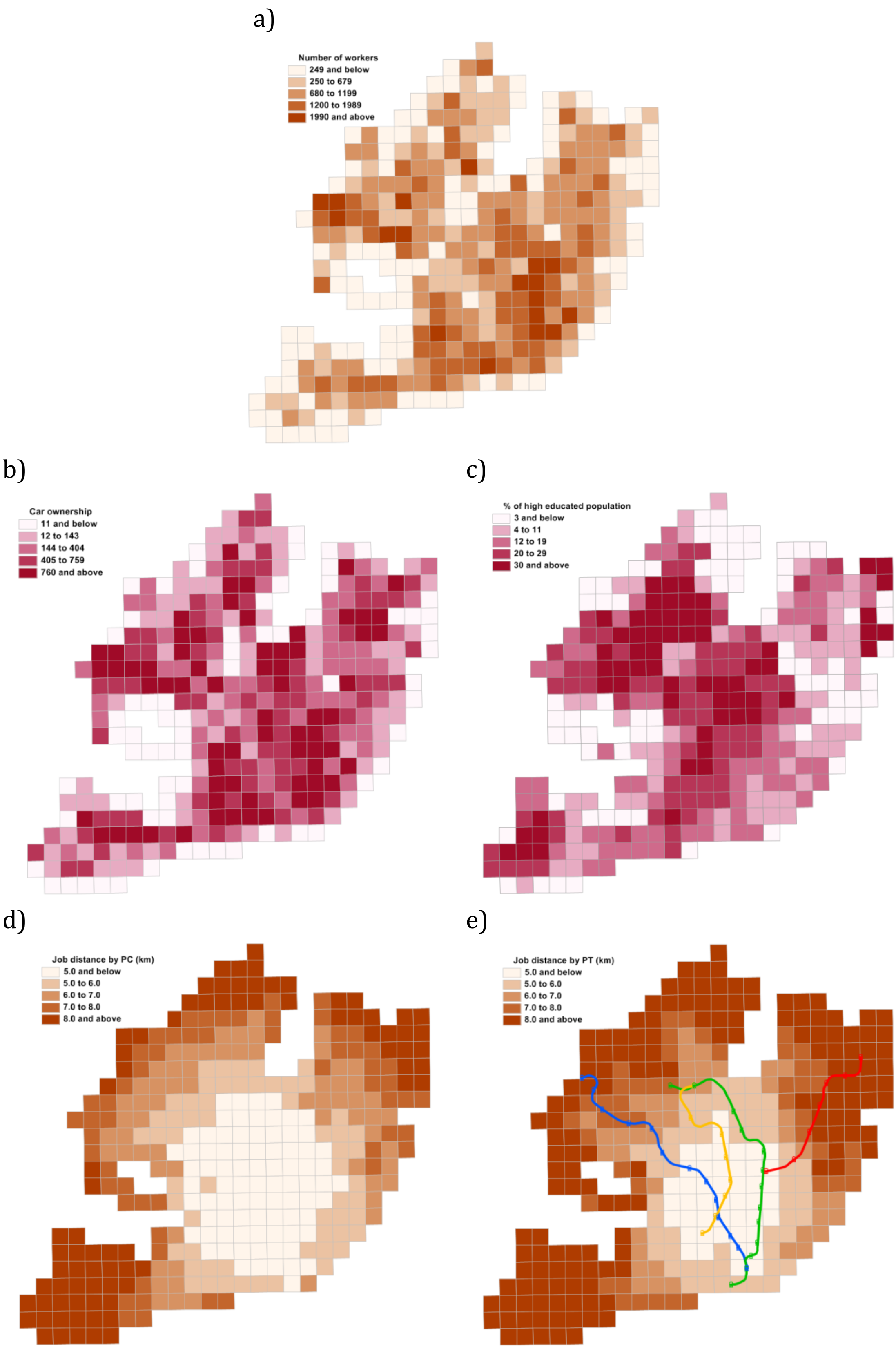

Figure 5.10: Spatial distribution of resident workers (a), car ownership (b), population with university degree (c) and average distance to job places by PC and PT (d, e) in Lisbon.

b) Diagnosing accessibility and mobility problems

Although four categories of problems are considered as the base of the strategic assessment of urban mobility networks, only three of them were diagnosed for the *Baseline scenario (2003)*: the unequal distribution, the inequitable distribution and the unsuitable distribution of job accessibility. The unsustainable distribution problem of job accessibility and time mobility is analyzed only under a future perspective in the *Do-nothing scenario (2011)* as the lack of historical data to support the estimation of the indicators prevents the consideration of a past perspective.

Setting the reference parameters

In order to assess the accessibility and mobility problems a set of statistical and spatial reference parameters were established for each strategic indicator considered. The statistical reference parameters or thresholds of accessibility and mobility are presented in Table 5.3 and are used to assess the unequal and unsuitable problems of accessibility and mobility. These parameters were chosen based on the statistical distributions of the indicators and having the standard deviation as the criteria for its establishment. In the case of job accessibility, it was considered as the minimum levels of accessibility sufficiency the values 0.5 standard deviation below the mean, while for the mobility indicators the criterion was the values 0.25 standard deviation below the mean.

Table 5.3: Reference parameters for accessibility and mobility

Indicators	*Mean*	*Median*	*Std. dev.*	*1st quartile*	*Statistical reference*	*Threshold*
Job accessibility by PC	*0.36*	*0.33*	*0.17*	*0.21*	*0.50*	*0.28*
Job accessibility by PT	*0.16*	*0.13*	*0.1*	*0.08*	*0.50*	*0.11*
Job accessibility ratio	*0.45*	*0.43*	*0.17*	*0.33*	*0.50*	*0.37*
Time-mobility by PC	*28.22*	*23.75*	*20.6*	*13.82*	*0.25*	*23.07*
Time-mobility by PT	*13.37*	*10.16*	*11.29*	*6.18*	*0.25*	*10.55*
Time-mobility ratio	*0.54*	*0.45*	*0.46*	*0.36*	*0.25*	*0.43*

Regarding the spatial reference parameters used to assess the inequitable problem of accessibility and mobility, two indicators representing the social concern groups (SCG) were analyzed in order to define the references: the percentage of unemployed and the percentage of low educated population. The first indicator considered was the percentage of unemployed population in each grid zone as a way to represent the vulnerable group in relation to work conditions. The spatial distribution of this indicator showed a dispersed pattern with a concentration of unemployed population in the East region of the city (Figure 5.11a) and in the North peripheral areas. This dispersed pattern was confirmed by the low value of the Global Moran's I, $I_{M\_\%UNEMP}$ = 0.01, and hence by the absence of clusters of high percentage of unemployed (Figure 5.11c). This demonstrates that the unemployment in Lisbon is a non-spatial phenomenon and that the indicator percentage of unemployed is not suitable for the identification of vulnerable groups.

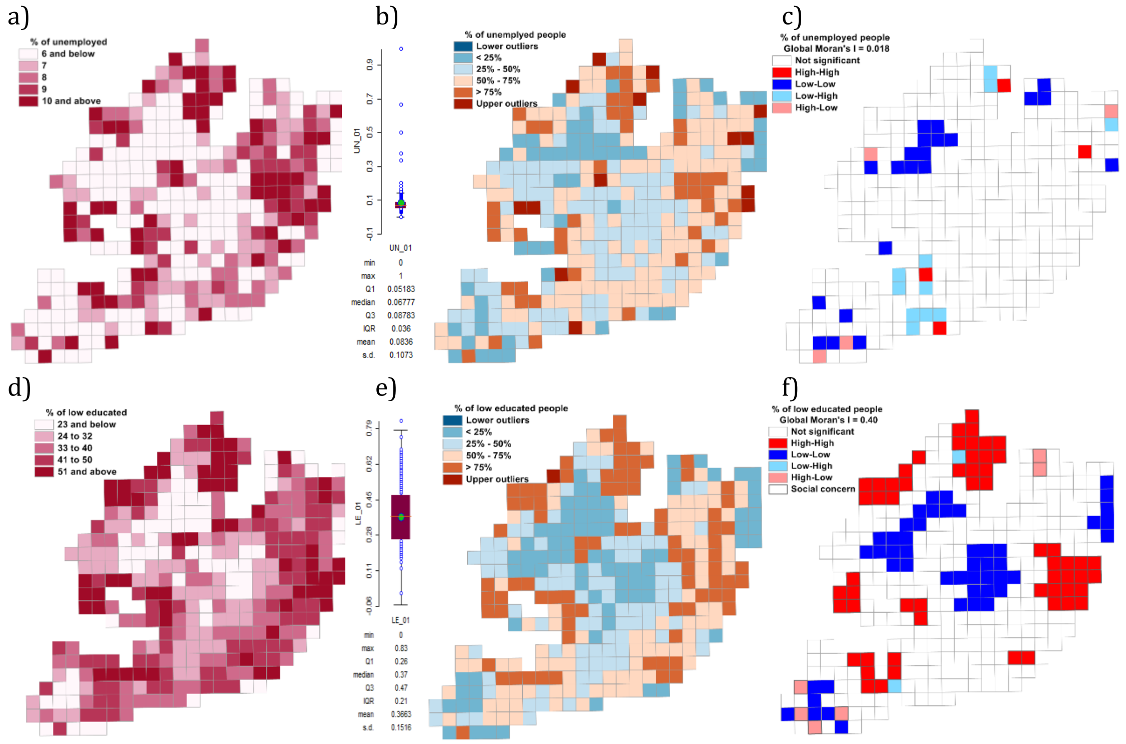

Figure 5.11: Spatial distribution (a, b), Box map (c, d) and LISA cluster maps (e, f) of % of unemployed and low educated people in Lisbon

Alternatively, the percentage of low educated population or the population who only completed the first cycle of education was considered as proxy of low income population. This indicator presents a less dispersed pattern with a concentration of high percentage of low educated population in the North peripheral area, in the Southwest and in the West and East regions of the city (Figure 5.11d). This pattern is also verified through the Box map of the indicator where the zones with the highest percentage of low income population (> 75% - 4th quartile) are located in the regions previously described (Figure 5.11e). The concentration of these zones is also confirmed through the Global Moran's I, $I_{M\_\%LINC}$ = 0.40, and by the presence of several clusters of high percentage low educated population (High-High) and some outliers of low educated population (High-Low) (Figure 5.11f). Therefore, compared to the percentage of unemployed population, the percentage of low educated population seems more adequate for the identification of social concern groups and will be considered as the spatial parameter for the analysis of the inequitable distribution problems.

Identifying the problems

Based on the statistical reference parameters established it is possible to identify regions in the city where the differences in job accessibility and mobility along the space are more accentuated and below the threshold of sufficiency. These differences refer to the unequal distribution problem of accessibility and mobility and are represented by the yellow zones considered as the ones where the levels of accessibility and mobility are insufficient. In the case of job accessibility (Figure 5.12a and 5.12b) these zones are located along all the peripheral area of the city and in the Southwest, as well as in the East region, in the case of job accessibility by PT. The insufficient level of accessibility in these zones can be associated as already discussed previously with the low levels of road connectivity, the high waiting times and the low stop-station intensity.

In the case of time-mobility, insufficient level zones are more dispersed along the city area, although still with a large concentration of them in the periphery (Figures 5.12c and 5.12d). The exception is the Central area of the city where the levels of time-mobility are higher, especially in the case of PC mobility as already identified. The spatial correlation between the zones with insufficient levels of job accessibility and time-mobility can be verified through their Bivariate Global Moran's I ($I_{TMPCxAPC}$ =0.52 and $I_{TMPTxAPT}$ =0.60) and Bivariate LISA cluster maps (Figures 5.12e and 5.12f). In these maps, several clusters of low accessibility and mobility for both PC and PT are found in the periphery, indicating that the low levels of accessibility can be associated with the low levels of mobility in these areas. Also one big cluster of high accessibility and mobility for both modes is present in the Central area indicating once again that this is the best performing region of the city in terms of accessibility and mobility.

Regarding the inequitable distribution problem or the differences of accessibility and mobility levels across social groups, it is possible to notice in the maps of Figure 5.12 that the SCG considered is located in most cases in the areas with insufficient levels of accessibility and mobility by both modes indicating a possible association between the two phenomena in the case of the low educated group. This association can be confirmed by crossing the social concern clusters with the Bivariate LISA cluster maps of accessibility and mobility (Figure 5.12e and 5.12f). By these maps it is possible to confirm that almost all zones of social concern located in the periphery present a direct association (Low-Low) between low levels of accessibility and mobility, configuring a potential social exclusion situation for the low educated people living on those zones. However, regarding the zones of the social concern cluster located in the East region of the city, this association is not so intense, especially in the case of PC, with some zones presenting high levels of accessibility associated with low levels of mobility (High-Low). In the case of PT, the majority of these zones presents a low level of accessibility and mobility, but its spatial association is statistically significant for only three zones.

The statistical reference parameters also allow the identification of regions in which the imbalances or differences between PC and PT job accessibility and mobility are considered inadequate. These differences refer to the unsuitable distribution problem of accessibility and mobility and are also represented by the zones highlighted in yellow. The zones with unsuitable job accessibility imbalances are found in the North and West periphery of Lisbon and in most of the East and Northeast regions with the exception of the zones around the stations of the red subway line (Figure 5.13a). The zones with unsuitable levels of time-mobility, in turn, are concentrated in the Northeast, East and Southwest regions, as well as in the upper Central area (Figure 5.14b).

The spatial association between these problematic areas is not as intense as it is for the others categories of problems as the Bivariate Global Moran's I of the ratios are low (I_{ARxTMR} =0.018). However, locally the Bivariate LISA cluster Maps indicate that problematic areas at the Northeast region are characterized by an association between low accessibility and mobility ratios (Low-Low) (Figure 5.13c). The zones around the red subway line stations, though, are an exception in this region as they present adequate accessibility ratios associated with inadequate mobility ratios (High-Low). The problematic area in the Southwest region is characterized by different regimes of association, but mostly by adequate ratios of accessibility and inadequate ratios of mobility (High-Low) due to the low levels of mobility by PT in this region. Also, the problematic upper Central area presents the same types of association than the Southwest region. Finally, significant associations between inadequate accessibility and time-mobility ratios (Low-Low) are found in the East region.

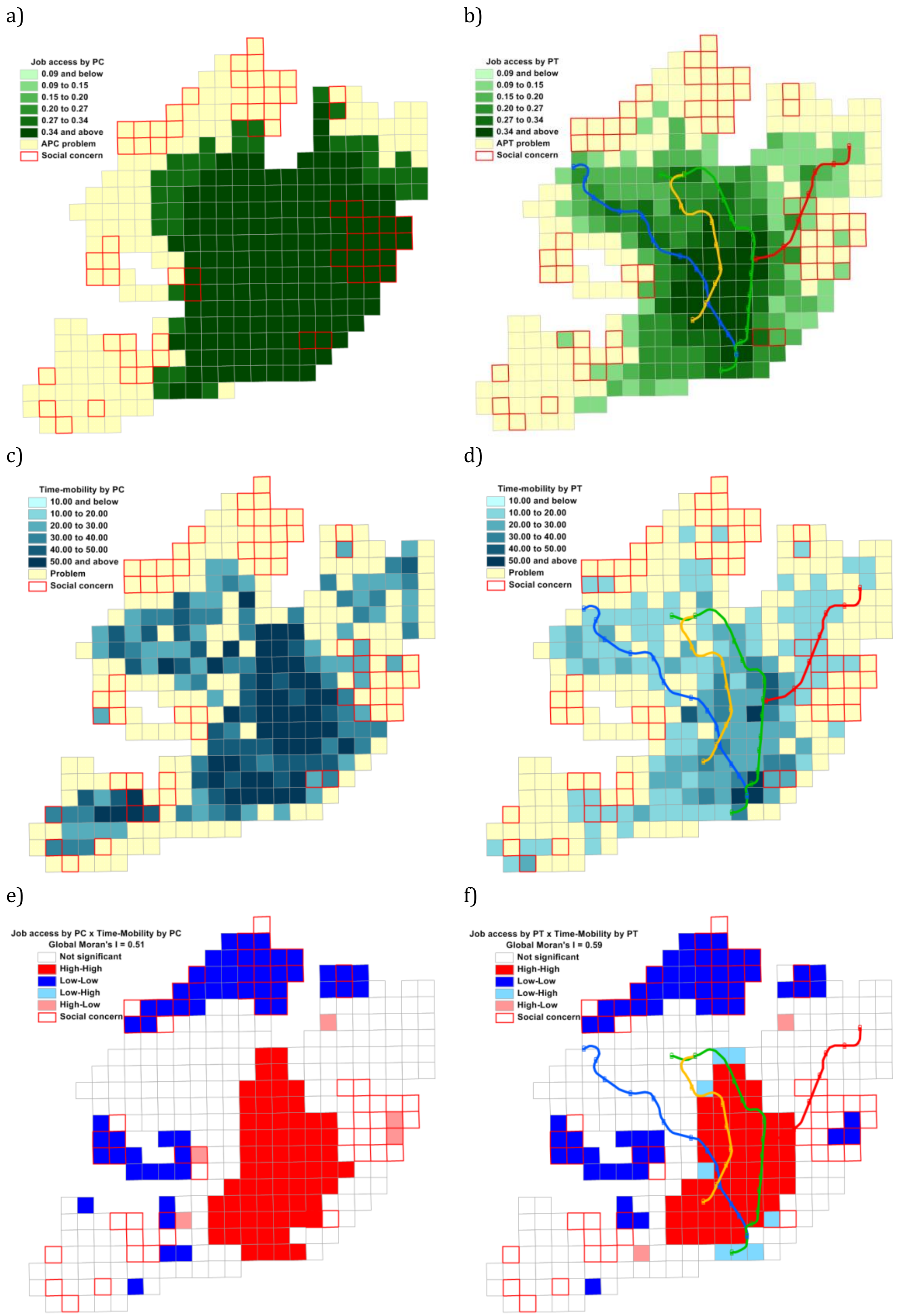

Figure 5.12: Baseline scenario – job accessibility and time-mobility problems areas (a, b, c and d) and their spatial association (e and f).

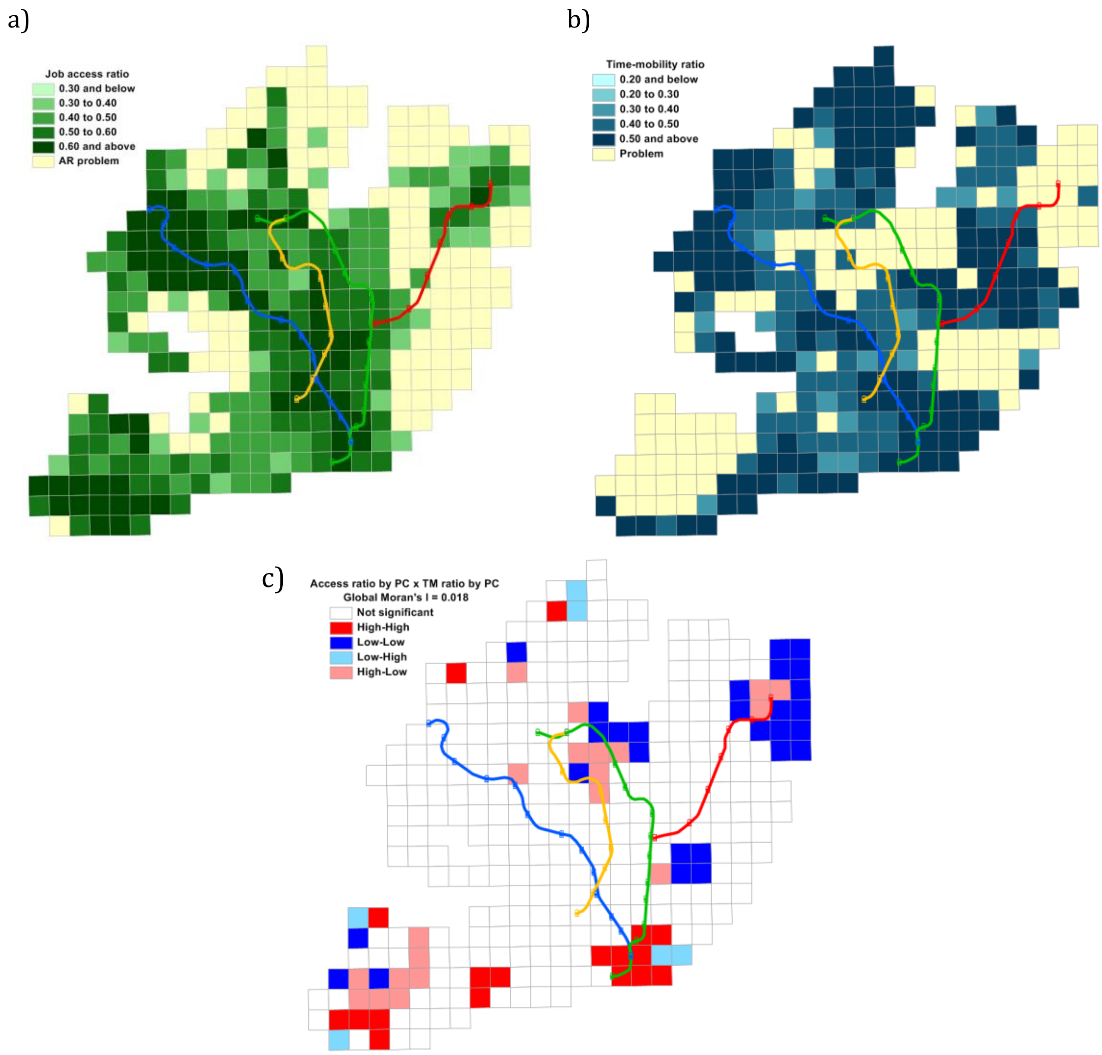

Figure 5.13: Baseline scenario – job accessibility ratio and mobility ratios problems areas (a, b) and their spatial association (c)

<u>Modeling the causal relationships</u>

In order to properly measure the causal relationship between accessibility and mobility, a series of non-spatial and spatial linear regression models were calibrated. The effect or dependent variables (DV) considered were time-mobility by PC and time-mobility by PT (*TMPC_03* and *TMPT_03*). These variables were tested for normality and a series of transformations (logarithm, squared root, exponential, *etc.*) were performed to adjust them to a normal distribution. The logarithm version of the time-mobility indicators were the ones that most closely matched a normal distribution based on the evaluation of criteria such as Skewness, Kurtosis and Histogram as well as on the Kolmogorov-Smirnov test of normality.

The cause or independent variables (IV) considered are the ones in Table 5.2 that represents the transportation, land use and socioeconomic characteristics in each grid zones considered as unit of analysis plus the accessibility indicators for each mode. The linear relationship between these variables and the dependent variables were examined through their scatterplots (see Annex 1), resulting in the need for a squared root transformation of the variables *Resident worker intensity* (*WKR_03), Car ownership (CAR_03)* and *Road connectivity* (*CON_03),* as well as a logarithm transformation of the variable *Job places intensity* (*JOBS_01),* in order to guarantee the linear relationship with the dependent variable. It is noteworthy that the logarithmic transformation of the *Job places intensity* variable returned zero for a set of 20 zones located in the periphery and where no jobs are available, which restricted the size of the dataset used for the calibration of the models to only 318 input records. The non-spatial correlation between those variables was also analyzed based on the Pearson's correlation coefficient (see Annex 2) with the main results presented in Table 5.4.

Table 5.4: Dependent vs independent variables correlations

Cause/independent variables	***Effect/dependent variable***		***Correlation with the remaining variables (> 0.50)***
	Time-mobility by PC (logTM_PC_03)	***Time-mobility by PT (logTM_PT_03)***	
Accessibility by PC (APC_03)	*0.54*	*-*	*sqrtCAR_03, logJOB_03, JDPC_03, DTPC_03, TPC_03*
Accessibility by PT (APT_03)	*-*	*0.68*	*logJOB_03, JDPT_03, DTPTC_03, TPT_03, WAIT_03, STOP_03*
Population with university degree (HE_01)	*0.45*	*0.31*	*-*
Car ownership (sqrtCAR_03)	*0.76*	*-*	*logJOB_03, sqrtWKRS_01, sqrtCON_03*
Resident worker intensity (sqrtWKRS_01)	*0.73*	*0.71*	*sqrtCAR_03, logJOB_03, STOP_03, sqrtCON_03*
Job places intensity (logJOBS_03)	*0.80*	*0.72*	*APC_03, APT_03, sqrtCAR_03, sqrtWKRS_01, JDPT_03, WAIT_03, STOP_03, sqrtCON_03*
Job distance by PC (JDPC_03)	*-0.54*	*-*	*APC_03, logJOB_03, DTPC_03, TPC_03*
Job distance by PT (JDPT_03)	*-*	*-0.57*	*APT_03, logJOB_03, DTPT_03, TPT_03*
Waiting times (WAIT_03)	*-*	*-0.53*	*APT_03, logJOB_03*
Stop-station density (STOP_03)	*-*	*0.58*	*APT_03, logJOB_03, sqrtWKRS_01*
Road connectivity (sqrtCON_03)	*0.57*	*-*	*sqrtCAR_03, logJOB_03, sqrtWKRS_01*

From a non-spatial perspective, it is possible to confirm a strong and significant correlation between accessibility (*APC_03* and *APT_03*) and mobility. This correlation tends to be more intense for public transport mobility than for private car mobility. Regarding the correlations between mobility and the other cause variables, it is possible to infer that *Job places intensity (logJOBS_03)* followed by *Resident worker intensity (sqrtWKRS_01)* are the most correlated variables with mobility. This is an indication of the strong role that the job-worker dynamics play in the daily mobility in Lisbon. *Population with university degree (HE_01),* in turn, is one of the less correlated variable with mobility indicating that in the case of Lisbon, the level of education may not work well as a proxy of income. *Car ownership (sqrtCAR_03)* is the second most correlated variable with PC mobility followed by the *Road connectivity (sqrtCON_03)*. Finally, the PT variables *Waiting times (WAIT_03)* and *Stop-station density (STOP_03)* present an inverse and direct correlation with PT mobility respectively.

From these initial set of variables, the ones presenting negligible correlations (<0.3) with the dependent variables were discarded and only the variables presented in Equations 5.6 to 5.7 were included in the models.

$$logTMPC_{03} = \beta_0 + APC_{03}.\beta_1 + HE_{01}.\beta_2 + sqrt(CAR_{03}).\beta_3 + sqr(WRK_{01}).\beta_4 + log(JOB_{03}).\beta_5 + JDPC_{03}.\beta_6 + sqrt(CON_{03}).\beta_7 \tag{5.6}$$

$$logTMPT_{03} = \beta_0 + APT\_03.\beta_1 + HE\_01.\beta_2 + sqrt(WRK_{01}).\beta_3 + log(JOB_{03}).\beta_4 + JDPT\_03.\beta_5 + WTIM\_03.\beta_6 + STOP\_03.\beta_7 \tag{5.7}$$

However, before testing the full specifications of Equations 5.6 and 5.7 and in order to have an idea of the explanation power of job accessibility in relation to mobility, classic regression models considering only accessibility (APC_03 and APT_03) as explanatory variable were calibrated. The results presented in Table 5.5 (see also Annex 3) indicate that in the case of time-mobility, accessibility is able to explain 30% of the variability of the PC mobility phenomenon, while for PT mobility this increases to 46%. These results corroborate with the Pearson's correlations discussed previously that indicated a higher correlation between accessibility and mobility by public transport by private car mobility. It highlights the fact that mobility is intrinsically related to accessibility, but also that accessibility only explains part of the phenomenon and that other socioeconomic, land use and transportation variables need to be considered in order to have a complete picture of the mobility conditions.

Table 5.5: Time-mobility and distance-mobility classic accessibility models

	logTMPC_03			***logTMPT_03***		
	β	*t-stat*	*prob*	*β*	*t-stat*	*prob*
Constant	*0.94*	*25.40*	*0.00*	*0.65*	*25.72*	*0.00*
APC_03	*1.09*	*11.89*	*0.00*	*-*	*-*	*-*
APT_03	*-*	*-*	*-*	*2.18*	*16.98*	*0.00*
R^2	*0.30*			*0.46*		
Adj. R^2	*0.29*			*0.46*		

The full specifications were then tested through a stepwise process with the resulting model including only the variables that better explained the distribution of the dependent variables. The selection of these variables was based on its sign coherence and statistical significance (p-values<0.05) as well as in the final efficiency of the model (increase in the R^2 and the F-statistic above a predefined threshold). The resulting (or classical) model was then assessed considering the sign and significance of the coefficients (t-test and p-values<0.05) as well as collinearity statistics to avert heteroscedasticity issues (Tolerance and Variation Inflation Index – VIF). Additionally, a series of tests were performed in order to assess the spatial dependence of the residuals (through Moran's I test) and to choose an adequate alternative spatial specification for the resulting model (based on Lagrange Multiplier tests). The spatial model was then calibrated and the variables assessed considering the sign and significance of the coefficients (z-value and p-values<0.10) as well as the model fitness through the Log-Likelihood, AIC and SC measures of fit (increase in the Log-likelihood and decrease in the AIC and SC). The spatial dependence of the residuals was again assessed through its Moran's I statistic in order to verify if the inclusion of a spatial variable helped to eliminate its spatial auto-correlation. Finally, the point elasticities at the mean value (product of coefficients and the means) for each independent variable included in the final model were estimated in order to compare their relative effect on the dependent variable.

The results of the models are presented in Tables 5.6, 5.7 and 5.8 (see also Annex 3). For each dependent variable a classical and a spatial error model were calibrated. This is due to the fact that the results of the spatial dependence test of the residuals in the classical models, shown in Table 5.9, indicated the presence of auto-correlation (Moran's I test significant), and the Lagrange Multiplier tests also indicated the suitability of the spatial error specification as the alternative one (LM Error tests significant). Both classical models presented a high goodness-of-fit (R^2>0.70) and included only statistically significant variables (p<0.05) with no collinearity issues as indicated by the high tolerance values and VIF values (<5).

Table 5.6: Parameters of time-mobility by PC models - Baseline scenario

	log(TMPC_03) models results								
	Classic model						*Spatial error model 2*		
	β	*β st.**	*t-stat*	*Sig.***	*Tol.****	*VIF*	*β*	*z-value*	*Sig.**
Constant	0.513		14.160	0.000	-	-	0.503	10.576	0.000
APC_03	0.335	0.173	5.341	0.000	0.70	1.44	0.394	3.805	0.000
HE_01	0.186	0.074	2.334	0.020	0.73	1.37	-	-	-
sqrtCAR_03	0.011	0.439	12.868	0.010	0.63	1.60	0.011	13.087	0.000
logJOBS_03	0.186	0.401	12.868	0.000	0.40	2.51	0.189	10.363	0.000
λ	-	-	-	-	-	-	0.561	8.502	0.000
R^2	0.77						0.82		
Adjusted R^2	0.77						-		
Log-likelihood	139.16						166.913		
AIC	-268.32						-325.827		
SC	-249.51						-310.779		

** Standardized coefficient ** Significance. ***Tolerance*

Table 5.7: Parameters of time-mobility by PT models - Baseline scenario

	log(TMPT_03) models results								
	Classic model						*Spatial error model 2*		
	β	*β st.**	*t-stat*	*Sig.**	*Tol.***	*VIF*	*β*	*z-value*	*Sig.**
Constant	0.537		6.294	0.000	-	-	0.440	4.837	0.000
APT_03	0.770	0.251	5.578	0.000	0.445	2.247	0.768	4.299	0.000
sqrtWKRS_01	0.010	0.403	10.552	0.000	0.619	1.615	0.010	9.736	0.000
logJOBS_03	0.099	0.217	4.647	0.000	0.415	2.408	0.127	5.907	0.000
WAIT_03	-0.021	-0.124	-3.189	0.001	0.594	1.682	-0.017	-2.340	0.020
STOP_03	0.015	0.090	2.337	0.020	0.615	1.627	0.012	1.961	0.049
λ	-	-	-	-	-	-	0.446	5.880	0.000
R^2	0.72						0.75		
Adjusted R^2	0.71						-		
Log-likelihood	108.980						121.976		
AIC	-205.960						-231.952		
SC	-183.388						-209.380		

** Standardized coefficient ** Significance. ***Tolerance*

Table 5.8: Elasticities in time-mobility spatial models – Baseline scenario

log(TMPC_03)					*log(TMPT_03)*				
IV	*mean*	*β*	*Formula*	*Elasticity*	*IV*	*mean*	*β*	*Formula*	*Elasticity*
APC_03	*0.36*	*0.394*	*βx*	*0.14*	*APT_03*	*0.16*	*0.768*	*βx*	*0.12*
CAR_03	*464.80*	*0.011*	*0,5βsqrt(x)*	*0.12*	*WKRS_01*	*743.14*	*0.01*	*0,5βsqrt(x)*	*0.14*
JOBS_03	*1192.48*	*0.189*	*β*	*0.19*	*JOBS_03*	*1192.48*	*0.127*	*β*	*0.13*
					WAIT_03	*8.48*	*-0.017*	*βx*	*-0.14*
					STOP_03	*2.44*	*0.012*	*βx*	*0.03*

Table 5.9: Diagnostics for spatial dependence in the residuals of classical models

Tests	*log(TMPC_03)*			*log(TMPT_03)*		
	MI/DF	Value	Prob	MI/DF	Value	Prob
Moran's I (error)	*0.27*	*9.34*	*0.00*	*0.17*	*5.90*	*0.00*
Lagrange Multiplier (lag)	*1*	*30.36*	*0.00*	*1*	*6.29*	*0.01*
Robust Lagrange Multiplier (lag)	*1*	*0.02*	*0.89*	*1*	*3.92*	*0.05*
Lagrange Multiplier (error)	*1*	*77.14*	*0.00*	*1*	*29.67*	*0.00*
Robust Lagrange Multiplier (error)	*2*	*46.79*	*0.00*	*2*	*27.30*	*0.00*

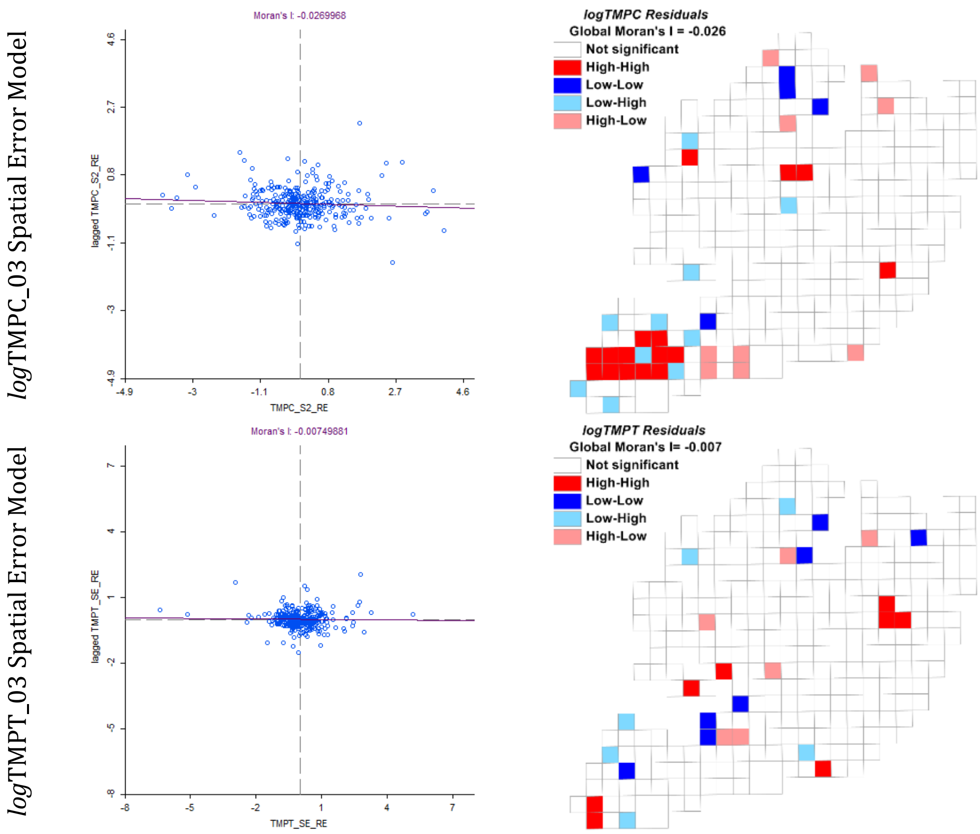

Figure 5.14: Diagnostics for spatial dependence in the residuals of spatial models

The spatial error models also present a high goodness-of-fit ($R^2>0.75$) with a higher predictive capacity than the classical models (higher Log-likelihood) and better values for the information criteria (lower AIC and SC). Additionally, the values of the spatial dependence of the residuals shown in the Moran's scatterplots presented in Figure 5.14 indicated that the inclusion of the spatial error term helped to remove the global spatial effects from the models. However, from a local perspective, specific regimes of association can be found in the residuals of the time-mobility by PC as indicated by the LISA cluster maps of residuals. This means that spatial local models would be probably more accurate to represent the local causal relationships between mobility, accessibility and other variables in the case of private car mode.

Regarding the independent variables, it is possible to notice that *Job places intensity* (*logJOBS_03*) was included in both models showing the relevant relation of mobility in Lisbon with job offer, which corroborates the initial assumption that the majority of daily trips in the city are for working reasons. *Job accessibility* variables (*APC_03* and *APT_03*) were also included in the models, which means that the easiness of travel, in terms of time, impacts the efficiency of mobility. *Population with university degree (HE_01)* was not included in any of the spatial models demonstrating that the level of education does not play an important role in Lisbon's mobility or that maybe this variable is not a suitable proxy for income in the case of Lisbon. The variables *Distance to job places* (*JDPC_03* and *JDPT_03*) were also not included in any of the models which indicates that distances in Lisbon are not so relevant for people's mobility, perhaps due the fact that the average distances traveled in the city are relatively short (~ 6.8 km). The variable *Resident worker intensity (sqrtWKRS_01)* was included only in the PT models indicating that the concentration/location of workers is more relevant to explain the mobility by PT than by PC. The variable *Car ownership (sqrtCAR_03)* was included in the mobility by PC model, as expected, while the variable *Road connectivity (sqrtCON_03)* was not included demonstrating that physical network characteristics are not determinant for the mobility by PC in Lisbon. Finally, the variables *Stop-station density (STOP_03)* and *Waiting time (WAIT_03)* were included in the PT models indicating the strong influence of the micro-accessibility conditions (temporal availability and spatial coverage) in Lisbon's mobility by PT.

For time-mobility by PC (*logTMPC_03*) the variables *Job places intensity* (*logJOBS_03*), *Job accessibility* by PC (*APC_03*) and *Car ownership (sqrtCAR_03)* were the significant ones in the final spatial specification. The variable *Population with university degree (HE_01),* although significant in the classic specification was rejected in the first version of the spatial specification (p = 0.089). All these variables present direct relation with the *logTMPC_03* meaning that positive variations on them imply an increase in time-mobility by PC. According the standardized coefficients in the classical model, *Car ownership* is the most influential variable in the model, followed by *Job places intensity*, *Job accessibility* and *Population with university degree*. This level of influence, however, changes when considering the elasticity based on the spatial model. In this case, the most influential variable is *Job places intensity*, followed by *Job accessibility by PC* and *Car ownership.* Though explaining part of the phenomenon, *Car ownership* is a less important factor for the time-mobility by PC as the availability of private car is a common situation in the city.

For time-mobility by PT (logTMPT_03) the variables included in the spatial specification were *Job accessibility by* PT (APT_03), *Resident worker intensity* (sqrtWKRS_01), *Job places intensity* (logJOBS_03), *Stop-station density* (STOP_03) and *Waiting time* (WAIT_03). The first four variables are directly related to time-mobility by PT, while the last is inversely related, meaning that time-mobility by PT decreases with high waiting times. In the classic specification the most influential variables are *Resident worker intensity* and *Job accessibility by PT* followed by *Job places intensity*, *Stop-station density* and *Waiting time*. However, this sequence changes when considering the elasticities of the spatial model, with the most influential variable still being *Resident worker intensity*, followed by *Waiting time*, *Job places intensity*, *Job accessibility by PT* and *Stop-station density.*

<u>Assessing the evolution of problems and their causal relationships</u>

For assessing the evolution of the problems diagnosed, a *Do-nothing scenario (2011)* of Lisbon's Mobility Network for the year horizon of 2011 is considered in which no transportation interventions or solutions are implemented. This scenario was built projecting the values of land use (*Jobs places intensity, Resident worker intensity)*, and socioeconomic (*Car ownership)* indicators defined as relevant in the regression analysis performed for the *Baseline scenario (2003)* according to the growth figures found in the literature (Table 5.10). Specifically, the following assumptions were considered:

- A uniform increase of 0.5% per year in *Job places intensity* and a uniform decrease of 2% in *Resident worker intensity,* based on the evolution of these two indicators from 1991 to 2003 and 1991 to 2001, respectively;

- A uniform increase of 2% per year in *Car ownership*, based on the model growth of the national GDP per capita from 1991 to 2001.

Table 5.10: Indicators evolution

	1991	2001/2003[4]	Annual growth rate	2011[5]
Employment[1]	381,000	403,000	0.5%	418,368
		5% (01/91)		4% (11/01)
Resident workers[2]	298,669	25,1440	-2%	211,679
	-16%	-19%(01/91)		-16% (11/01)
National GDP per capita (€)[3]	12,887	16,398	2%	20,865
	43%	27% (01/91)		27% (11/01)

Sources: [1](CML, 2005); [2,3](PORDATA, 2015); [4]2003 is used only for employment;[5]Estimated values based on the annual growths.

Regarding the transportation indicators, no evolution is assumed in relation to *Stop-station intensity* and *Waiting times* as no alteration in the public transport network is considered. However, for *Travel time* indicators new values were estimated in order to estimate the *Job accessibility*. For public transport, travel time values were recalculated based on a shortest path algorithm considering the *Do-nothing* parameters indicated in Table 5.1. For private car, the updated figures were obtained through the assignment of an OD matrix projected for 2011. This matrix was estimated in two stages. First, for the internal OD pairs (inside Lisbon) a single constraint growth factor method based on the projected values of the trips produced in the morning peak was applied. These projected values were obtained considering a production model based on car ownership. Second, for the external OD pairs, an increase proportional to the population growth (~1% per year) of each municipality from where the trips are originated was considered.

In the case of time-mobility indicators, new figures were estimated considering the final specification of the spatial error regression model calibrated for the *Baseline scenario (2003)* and the projected value of each explanatory variable (Equations 5.8 and 5.9).

$$logTMPC = 0.50 + 0.39APC + 0.19log(JOB) + 0.01sqrt8(CAR) + \mu \quad (5.8)$$

$$logTMPT = 0.44 + 0.77APT + 0.01sqrt(WRK) + 0.13log(JOB) - 0.02WAIT + 0.01STOP + \mu \quad (5.9)$$

Having projected all the indicators for the horizon year of 2011, the problems were again assessed considering the same reference parameters applied for the problem identification in the *Baseline scenario (2003).* New problematic areas were defined based on the new values of accessibility and mobility indicators and compared with the original ones. This allows to assess how they might evolve over the years under a sustainable perspective if no solutions for the problem are considered.

In the case of the unequal distribution problems, it is possible to notice an unsustainable evolution of job accessibility by PC as an increase in the problematic areas is predicted (Figure 5. 15a). This is due to the growth in the number of trips and therefore in the levels of congestion that the city will face. The increased travel times by PC combined with the decreased job places intensity will lead to a deterioration of the accessibility levels. Job accessibility by PT, in turn, also presents an unsustainable evolution, although less intense (Figure 5. 15b). The majority of problematic areas remains the same with an increase only in the northern region of the city.

Concerning time-mobility, both indicators present an unsustainable evolution with an increase in the problematic areas all over the city despite the improvement in some previous problematic zones (Figures 5. 15c and 5. 15d). The spatial correlation between these indicators and the job accessibility ones will remain strong as indicated by their Bivariate Moran's I ($I_{TMPCxAPC}$ =0.56 and $I_{TMPTxAPT}$ =0.68) and their Bivariate LISA cluster maps (Figures 5. 15e and 5. 15f). Locally, the association of problematic areas will remain significant as demonstrated by the formation of clusters of direct association (Low-Low) in the periphery.

Regarding the inequitable distribution problem, an unsustainable evolution is also noticed as the SCG will remain located in areas of insufficient levels of accessibility and mobility by both modes (Figures 5.15a to 5.15d). Even for the SCG cluster located in the East region, where there was no previous problem of low job accessibility by PC, the tendency is of worsening for both accessibility and mobility. The spatial association between these two phenomena in the SCG clusters located in the periphery is corroborated by the formation of clusters of low accessibility and mobility (Low-Low) in those regions indicating once more a potential social exclusion problem (Figure 5.15e and 5. 15f).

Finally, the unsuitable distribution problem presents a sustainable evolution as in overall the problematic areas of imbalances between job accessibility and time-mobility for both modes will decrease (Figure 5.16a and 5.16b). However, this improvement in imbalances need to be assessed carefully as they are derived from the worsening in private transport instead from improvements in public transport services. This means that the North and Northeast regions of Lisbon where the levels of job accessibility by PT are still insufficient, will be considered as having a fairer balance between modes only because their accessibility levels by PC have worsened.

The same will occur with regarding time-mobility in many zones throughout the city. This clearly demonstrates the reverse relation between mobility and accessibility, with the former negatively impacting the latter by the increase in the amount of trips and thereby the intensification of the congestion levels.

The spatial association between these ratios will improve, as indicated by their Bivariate Global Moran's I ($I_{APRxTMR}$ =0.16). However, locally, the association between problematic zones is demonstrated by few zones with significant association of low ratios (Low-Low), as indicated by the Bivariate LISA cluster maps (Figure 5.16c). They are located in the North and Northeast regions and are characterized by accessibility and mobility ratios that will remain or become unsuitable, which indicates that these zones present an unsustainable evolution regarding the differences between modes opposing the general patterns of sustainable evolution.

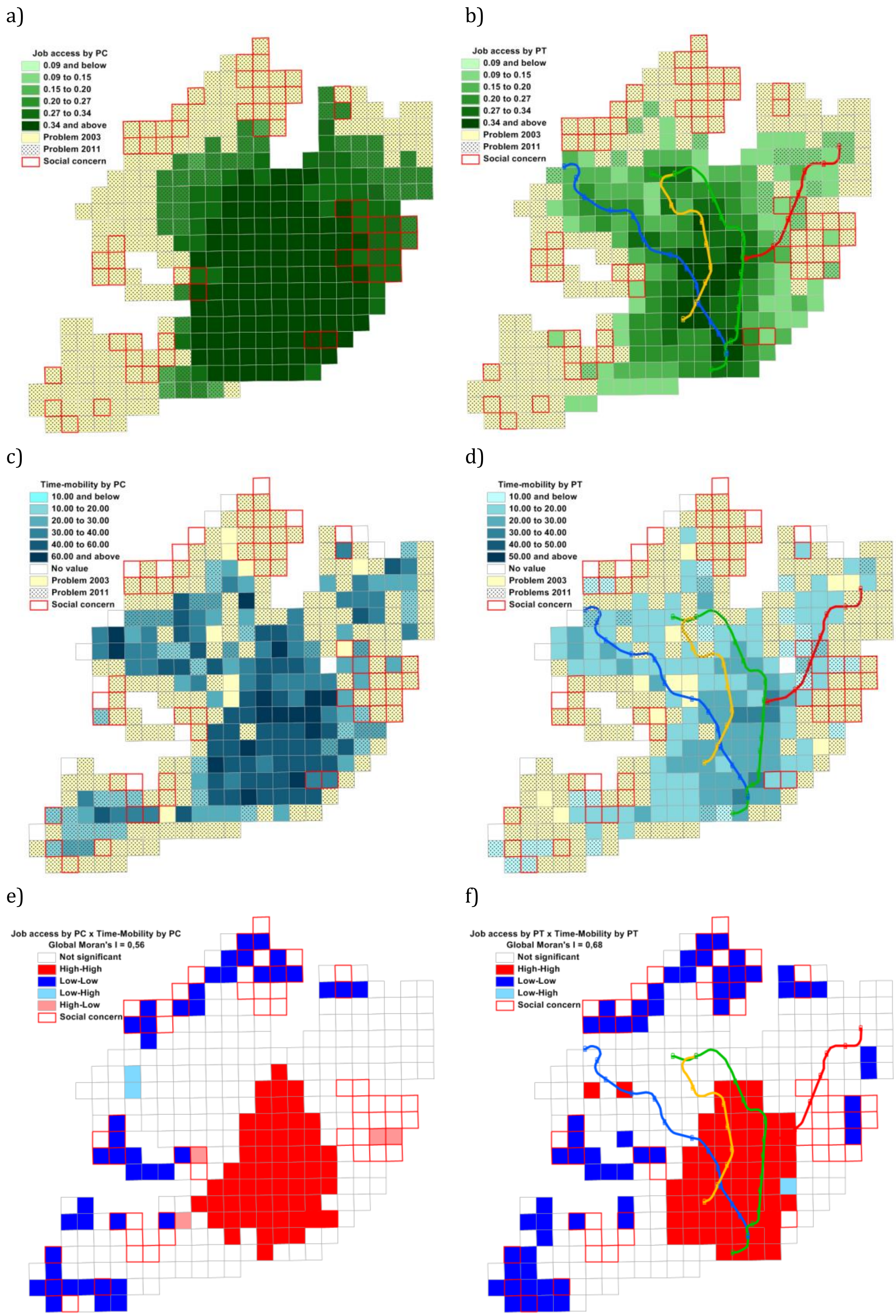

Figure 5.15: Do-nothing scenario – job accessibility and time-mobility problem areas (a, b, c and d) and their spatial association (e and f)

a) b)

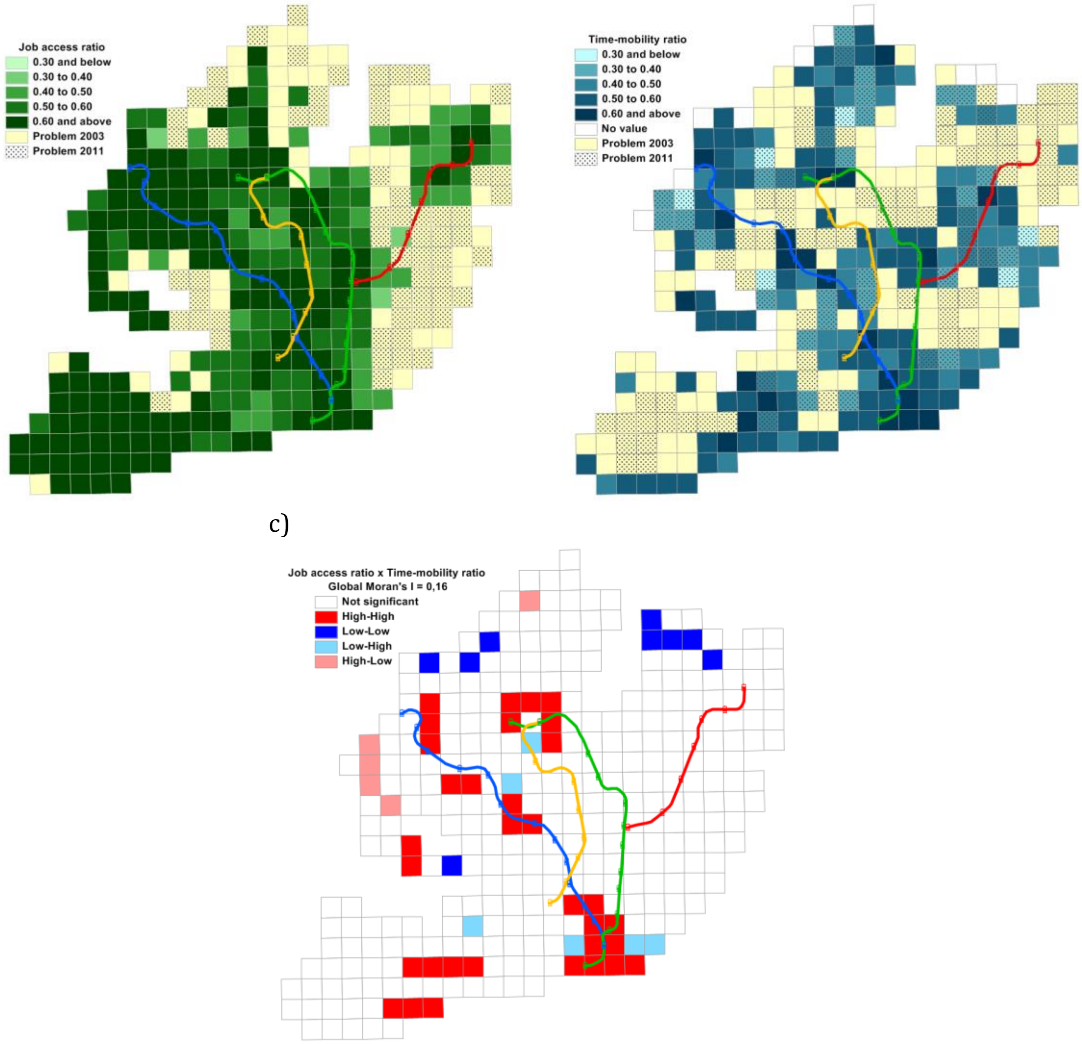

Figure 5.16: Do-nothing scenario – job accessibility ratio and time-mobility ratio problem areas in Lisbon

Main findings from the diagnosis

Lisbon's Mobility Network presents a set of accessibility and mobility deficiencies, as indicated by the diagnosis performed. Problems of equality, equity, suitability and sustainability were found for both accessibility and mobility. Both private car and public transport present accessibility and mobility inequalities that will tend to worsen over the years. However, in general, the accessibility and mobility conditions by PC are better than by PT, especially in the Central area of the city. In a decision-making context, this finding can be used to support the development of strategic objectives as well as alternative solutions that aim to reduce this disproportion by, for instance, enhancing public transport accessibility chiefly in the peripheral areas of Lisbon by intervening in the offer of PT or acting in the spatial distribution of job places offered. It is expected by the relationships established in the diagnosis that these types of policies contribute to improve the city's mobility conditions.

Additionally, the diagnosis revealed inequities in the accessibility and mobility conditions regarding the social concern group represented by the ones with low level of education. These inequitable conditions compared to the unequal conditions tend to worsen even more in the future, indicating that these problems should be prioritized. Therefore, the formulation of strategic objectives and alternative solutions that reinforce the need to improve job accessibility by public transport should be pursued by the decision makers, especially in the areas where the social concern group is located.

Finally, the inadequacies of accessibility conditions between private car and public transport revealed to be mainly concentrated in the North and East regions of the city, while the mobility inadequacies are more distributed indicating that other reasons may be behind these imbalances besides accessibility. However, although an improvement on these inadequacies is expected in the future, their reasons are related to the worsening of the accessibility by private car. Therefore, from these findings it can be concluded that improvements in public transport accessibility should be pursued especially in the North and East regions of the city, which would contribute for the mitigation of the inequitable problem since the social concern group is mostly placed in these regions.

5.3.2 Assessing the alternative solutions: the *ex-ante scenario*

In this section, the assessment of the results from two set of public transport interventions/solutions for Lisbon's Mobility Network is presented considering a projected scenario for 2011, the *Ex-ante scenario*, in which the land use and socioeconomic indicators considered are equal to the *Do-nothing scenario*, but with different public transport characteristics. The results of these alternative solutions are analyzed in terms of accessibility and mobility changes through a spatial analysis of their indicators as well as the analysis of the evolution of the unequal, inequitable, unsuitable and unsustainable problems.

a) Defining the alternative solutions

The alternative solutions assessed in this analysis consist of two alternative configurations for Lisbon's UMN in relation to the public transport component, as described in Table 5.11. Both alternatives consider the extensions of the red and blue subway lines (except the *Pontinha - Amadora Este* section), as well as the restructuring of the *Carris* bus network. However, these alternatives differ in relation to the extension of the yellow subway line that, in the second case, is replaced by a BRT line with competitive characteristics compared to the subway line, as specified in Table 5.12.

Table 5.11: Configuration of the public transport alternatives

Alternative 1 – Yellow line	Alternative 2 – BRT line
• Restructuring of the Carris bus network • Extension of the red subway line (section Alameda – São Sebastião) • Extension of the blue subway line (section Baixa-Chiado – Santa Apolónia) • Extension of the yellow subway line (section Campo Grande – Odivelas)	• Restructuring of the Carris bus network • Extension of the red subway line (section Alameda – São Sebastião) • Extension of the blue subway line (section Baixa-Chiado – Santa Apolónia) • Extension of the yellow subway line (section Campo Grande – Odivelas)

Table 5.12: Characteristics of the interventions in the North region

PT network section	Alternatives	Extension (km)	Number of stations	Operational speed (km/h)	Headway (min)
Campo Grande-Odivelas	Subway line	5.0	5.0	35.0	4.0
	BRT line	4.5	5.0	30.0	5.0

These two alternatives are tested considering a projected scenario for 2011 where the figures for land use and socioeconomic indicators are the same of the *Do-nothing scenario*, but for which new values for *Job accessibility by PT*, *Stop-station intensity* and *Waiting times* were estimated considering the characteristics of each alternative. Additionally, a projection of the time-mobility by PT indicator likewise done in the *Do-nothing scenario* was performed based on the final specification of the spatial error regression model calibrated in the diagnosis phase. This allowed the investigation of the effects that the estimated accessibility levels from both alternatives may have on mobility.

b) Assessing accessibility and mobility changes

The changes in job accessibility by PT conditions, derived from the two alternative solutions, present similar patterns being in overall positive (Figure 5.17 and 5.17b). The more intense positive changes are found in the North, East and Northeast regions of the city, where the interventions have a direct impact due to the decrease in travel times. The spatial association of these changes is confirmed by their Global Moran's I ($I_{M\_CAPT\_A1}$=0.31 and $I_{M\_CAPT\_A2}$=0.23) and by the formation of three clusters of high change values (High-High) and several clusters of low change values (Low-Low) in both alternatives (Figure 5.17c and 5.17d).

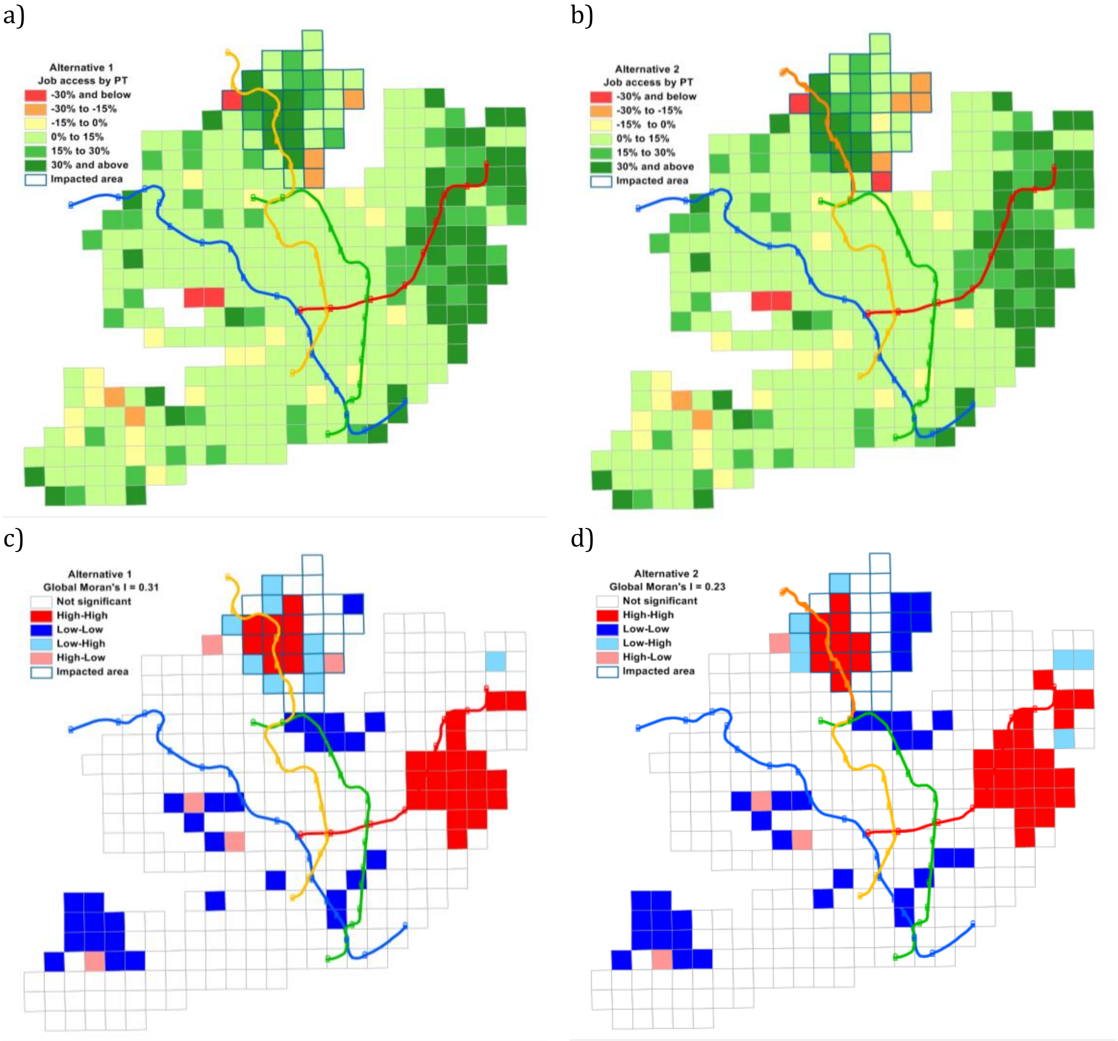

Figure 5.17: Spatial distribution map (a, b) and LISA cluster map (c, d) of job accessibility by PT changes for the Baseline and Alternative scenarios

These spatial patterns are better understood by analyzing the evolution of job accessibility indicators as well as of their associated travel times (Figure 5.18). The implementation of both alternatives imply in an increase in job accessibility by PT, especially in the Central area and in the zones along the subway network. This is due to the extensions of subway lines and the reorganization of buses lines that together contribute for a reduction of 5% (45min to 43min) in the average travel times. Specifically, the extension of the red subway line and its connection with the yellow and blue lines led to a decrease in the average travel times of the zones located in the East and Northeast, while the extension of the blue line led to a decrease in the travel time in the South region. The extension of the yellow line or the implementation of the BRT line, in turn, led to a decrease in the travel times of zones in the North region, especially in the ones along the line/corridor.

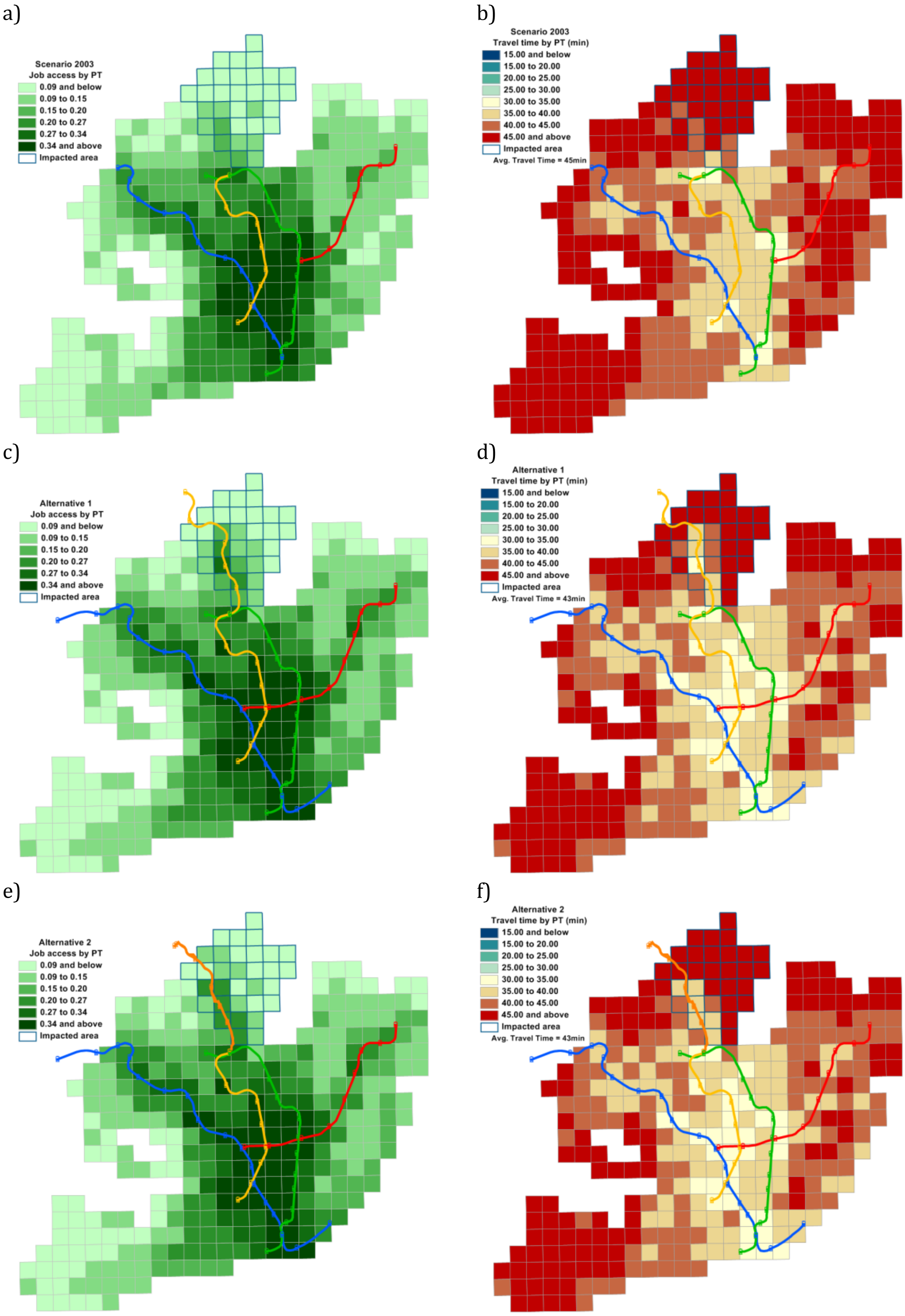

Figure 5.18: Spatial distribution maps of job accessibility by PT and travel times by PT for the Baseline and Alternative scenarios

Looking particularly at the zones in the North region (highlighted in blue), where the pattern of accessibility changes differs, it is possible to notice that each alternative impacts a different set of zones in this region (Figures 5.16a and 5.16b). Alternative 1 presents negative changes for only four zones, while Alternative 2 presents for seven zones (Figure 5.19a). These negative changes are considered low if compared to the positive changes in the remaining zones and are associated with low changes in travel times (up to 6 minutes) (Figure 5.19b). On the other hand, the positive changes derived from the Alternative 1 are in overall higher than the ones derived from Alternative 2 and are associated with high savings in travel times (up to 11 minutes).

These results indicate that, in general, Alternative 1 delivers more benefits in terms of accessibility levels and travel times than Alternative 2. However, more important than the positive changes that these alternatives may cause is how many people can benefit from them. Therefore, by comparing the total number of resident workers impacted by these transportation alternatives it is possible to notice that Alternative 2 impacts positively a larger proportion (72%) of workers than Alternative 1 (63%), but also impacts negatively a larger proportion (8%) of workers than Alternative 1 (4%) (Table 5.13). On the other hand, in terms of implementation cost, Alternative 1 shows more disadvantages compared to Alternative 2 as it implies a total cost of 365 billion € instead of 12.6 billion €[5]. These indicates that by a much more reasonable cost Alternative 2 can help improve the accessibility levels in the northern region impacting positively a larger amount of workers.

Relating to time-mobility, the changes although more dispersed than in the case of job accessibility are in overall positive (Figure 5.20). The larger concentration of zones with positive change are in the North, Northeast and West regions, while the larger concentration of zones with negative changes are in mid-East, South, North and Southwest regions. This dispersed pattern is similar for both alternatives, differing only in the zones of the North region where the pattern of job accessibility also differs. It is confirmed by the low levels of the Global Moran's I ($I_{M\_CTMPC\_A1}$=0.07, $I_{M\_CTMPT\_A2}$=0.07) and by the formation of several little clusters of low mobility values (Low-Low) throughout the city.

[5] Considering only infrastructure costs of 2.8 billion €/km for the BRT and 73 billion €/km for the subway according to ADB (2012). An Infrastructure Road Map for Kazakhstan. Urban Mobility – Technical Annex on Urban Mobility Measures, Asian Development Bank.

Table 5.13: Resident workers impacted in the North region

Changes	***Number of workers affected***							
	Job accessibility by PT				*Time-mobility by PT*			
	Alternative 1		*Alternative 2*		*Alternative 1*		*Alternative 2*	
Negative	653	4%	1,295	8%	6,126	39%	4,964	31%
Neutral	5,338	33%	3,284	20%	-	0%	1,162	7%
Positive	10,276	63%	11,688	72%	9,659	61%	9,659	61%
Total	16,267	100%	16267	100%	15,785	100%	15,785	100%

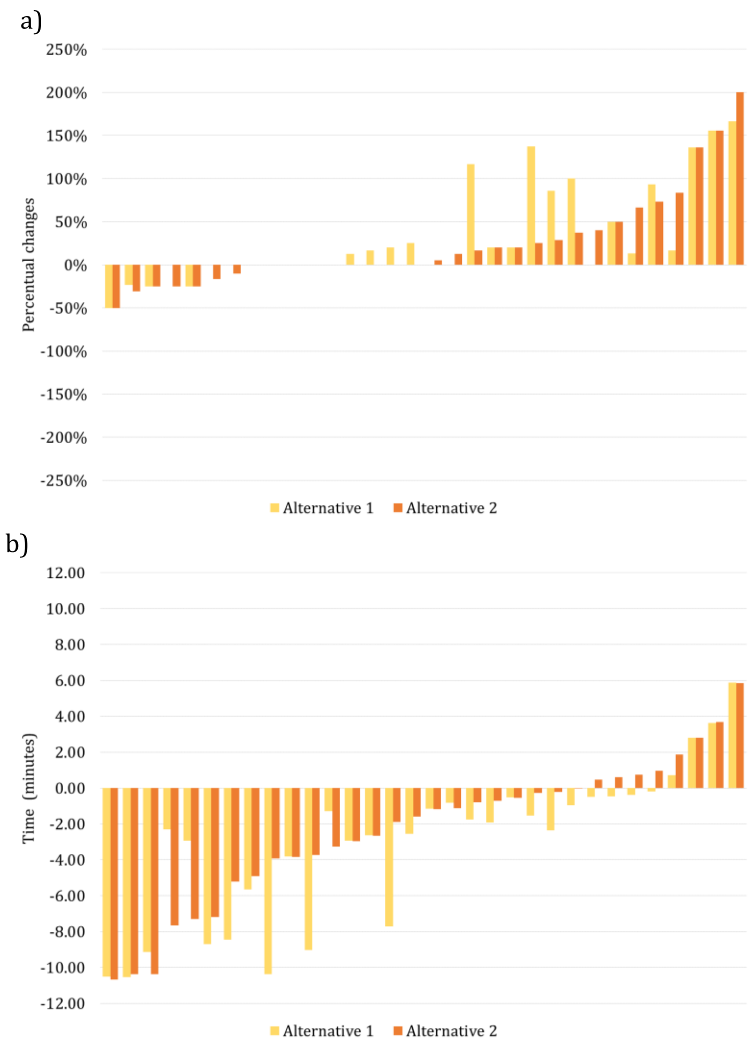

Figure 5.19: Job accessibility and travel time changes in the "blue zones"

These changes are better understood analyzing the spatial distribution evolution of the time-mobility indicators individually (Figure 5.21). In the Central area, the zones with high levels of time-mobility are more concentrated in the Alternative scenarios than in the *Baseline scenario (2003)*. These are the zones that had a significant reduction in their travel times and thus in their accessibility levels, which consequently impacted positively their mobility. In the other regions of the city, the evolution of the indicator is very heterogeneous in both alternatives, with small groups of zones in the same zones presenting both increases and decreases in their values.

Regarding the "blue zones" in the North region, the changes in time-mobility are very similar, but with some more accentuated positive differences in the zones located around the yellow subway line and the BRT lines. Additionally, the time-mobility changes in these zones impact positively the same proportion of workers (61%) for both alternatives (Table 5.13). On the other hand, the proportion of negatively impacted zones is higher for Alternative 1 (39%) than for Alternative 2 (31%), which in terms of mobility performance indicates the latter delivers more benefits than the former.

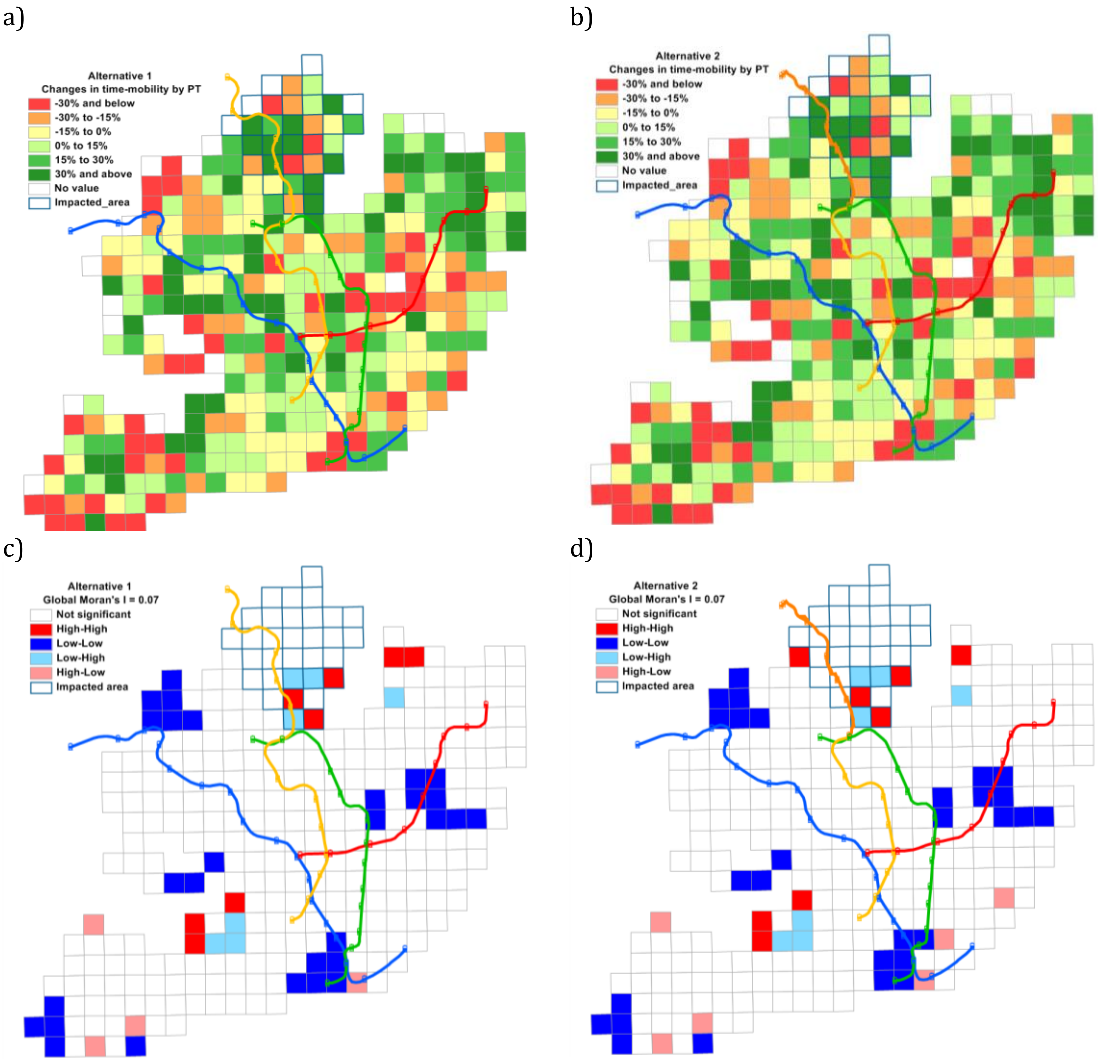

Figure5.20: Spatial distribution map (a, b) and LISA cluster map (d, e) of time-mobility changes for the Baseline and Alternative scenarios

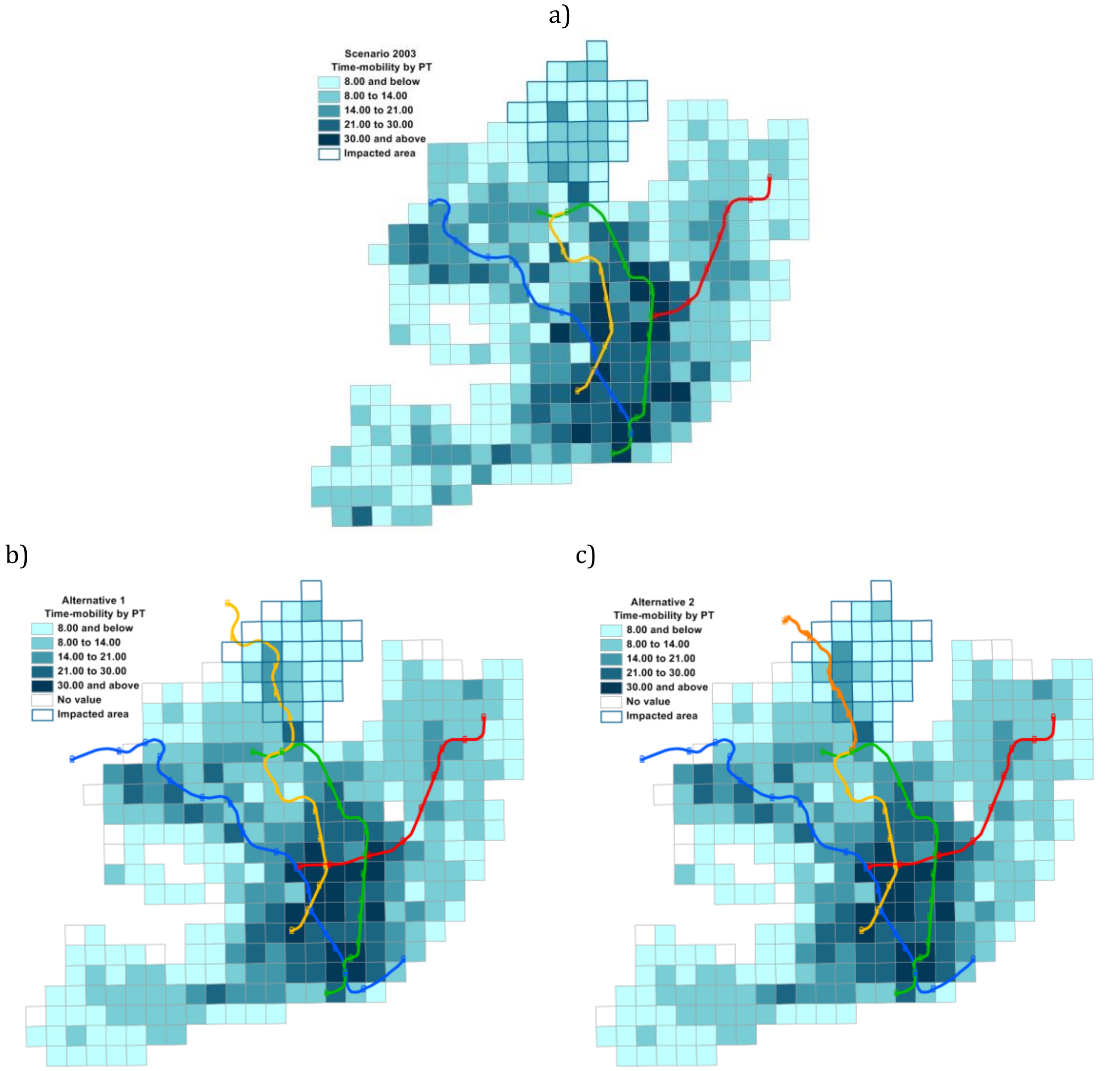

Figure 5.21: Spatial distribution maps of time-mobility by PT for the Baseline and Alternative scenarios

c) Assessing the evolution of problems

The evolution of unequal, inequitable and unsuitable problems is analyzed considering the same reference parameters used to identify them in the *Baseline scenario (2003)*: the sufficient limits of job accessibility by PT (0.11), time-mobility (10.55), job accessibility ratio (0.37), time-mobility ratio (0.43) as well as the clusters of low educated population representing the areas of social concern. For the estimation of ratio indicators, the projected values of PC indicators for the *Do-nothing (2011)* were used as reference since no intervention for this mode was considered. These parameters allow to assess how the problematic areas will evolve if the interventions are implemented giving an idea of which zones may have their accessibility and mobility levels improved or worsened in relation to the *Baseline scenario (2003)*.

The unequal distribution problem of job accessibility by PT present some improvements in both alternatives, especially in the East, Northeast and North regions of the city, indicating that the interventions considered contribute for a more sustainable evolution of their patterns (Figure 5.22a and 5.22b). These are the regions where the public transport network interventions have more impact as discussed previously. In both alternatives the improvements in the problematic areas are very similar excepting the North region, where the interventions are different. Comparing the two alternatives, it is possible to verify that for the Alternative 1 a higher number of zones in the North region had their accessibility improved and are no longer considered as problematic. This is due to the fact that the increases in accessibility for this alternative are more accentuated than for Alternative 2. Therefore, from this perspective, Alternative 1 seems to be the most effective of both in terms of benefits since it delivers higher levels of job accessibility, impacts negatively a lower number of workers and helps to better improve the unequal distribution problem of job accessibility and hence its sustainability.

Concerning the unequal distribution problem of time-mobility by PT its evolution indicates that the problematic areas remain almost the same with some exceptions of zones above the sufficient limit scattered around the city (Figure 5.22c and 5.22d). This result is related to the fact that the estimation of the mobility indicator although influenced by the increase in job accessibility levels and number of job places was mainly impacted by the shrinkage of the labor force, which is the main explanatory variable of the mobility phenomenon according to the considered model. The only exceptions are few zones located in the Northeast, in the Central area near the blue line and in the North region near the yellow line and the BRT line. In this last case, the zones with improvements in mobility also presented improvements in accessibility, suggesting a possible effect of the transportation intervention in the mobility levels. Nonetheless, the evolution of the time-mobility indicators, in general, indicate an unsustainable evolution of the unequal problem of mobility despite the improvements of accessibility derived from the implementation of the transportation alternatives.

The association of the evolution between these two problems is analyzed considering the spatial correlation between the changes in job accessibility and time-mobility by PT (Figures 5.22e and 5.22f). Globally, the evolution of these two phenomena is not associated since their Bivariate Global Moran's I ($I_{CTMPTxCAPT\_A1}$

=0.01 and $I_{CTMPTxCAPT\_A2}$ =-0.01) are very low. However, locally, some correlations of accessibility and mobility changes can be found with the formation of several clusters of positive (High-High and High-Low) and negative (Low-Low and Low-High) changes throughout the city. The positive change clusters are related to the transportation intervention that led to increases in accessibility and in mobility, while the negative changes are mainly related to negative changes in mobility.

Regarding the inequitable distribution problem, it is possible to notice in both alternatives that the majority of the social concern clusters is still located in the regions with accessibility levels below the threshold of sufficiency. However, some zones of the social concern cluster located in the East region had their accessibility level improved indicating a possible positive progression of the inequitable problem and therefore a contribution for the sustainability of the PT accessibility in the city (Figures 5.22a and 5.22b). In relation to time-mobility the evolution of the inequitable distribution problem is similar with the social concern clusters being in overall localized in regions of insufficient levels of mobility, except for some zones of the social concern cluster located in the upper East region where the mobility levels are above the threshold limit as in 2003. Despite this exception this pattern indicates an unsustainable evolution of the PT mobility conditions for the SCG. However, indications of a positive progression of the inequitable problems can be found as clusters of positive changes (High-High and High-Low) of both accessibility and mobility are found for the social concern clusters located in the East and North regions for both alternative scenarios.

Finally, the unsuitable distribution problem seems to improve in both alternatives as the imbalanced areas have decreased in overall, but mostly in the case of job accessibility (Figure 5.23a to 5.23d). This improvement indicates a sustainable evolution of the problem and is directly related to the worsening in the PC job accessibility and time-mobility, as discussed in the Do-nothing scenario (2011). It is also related to the improvements in the PT job accessibility and time-mobility derived from the PT interventions. The combination of these two factors lead to a more balanced ratio of accessibility and mobility. However, the association between the evolution of unsuitable accessibility and mobility problem is globally weak and inverse as indicated by their Bivariate Global Moran's I ($I_{CTMRxCAR\_A1}$ =-0.06 and $I_{CTMRxCAR\_A2}$ =-0.03) and the formation of several clusters of negative association (High-Low and Low-High). Specifically, a High-Low cluster is formed in the impacted area indicating that despite the improvements in PT job accessibility, and hence in the accessibility ratios, the imbalances in time-mobility will remain significant.

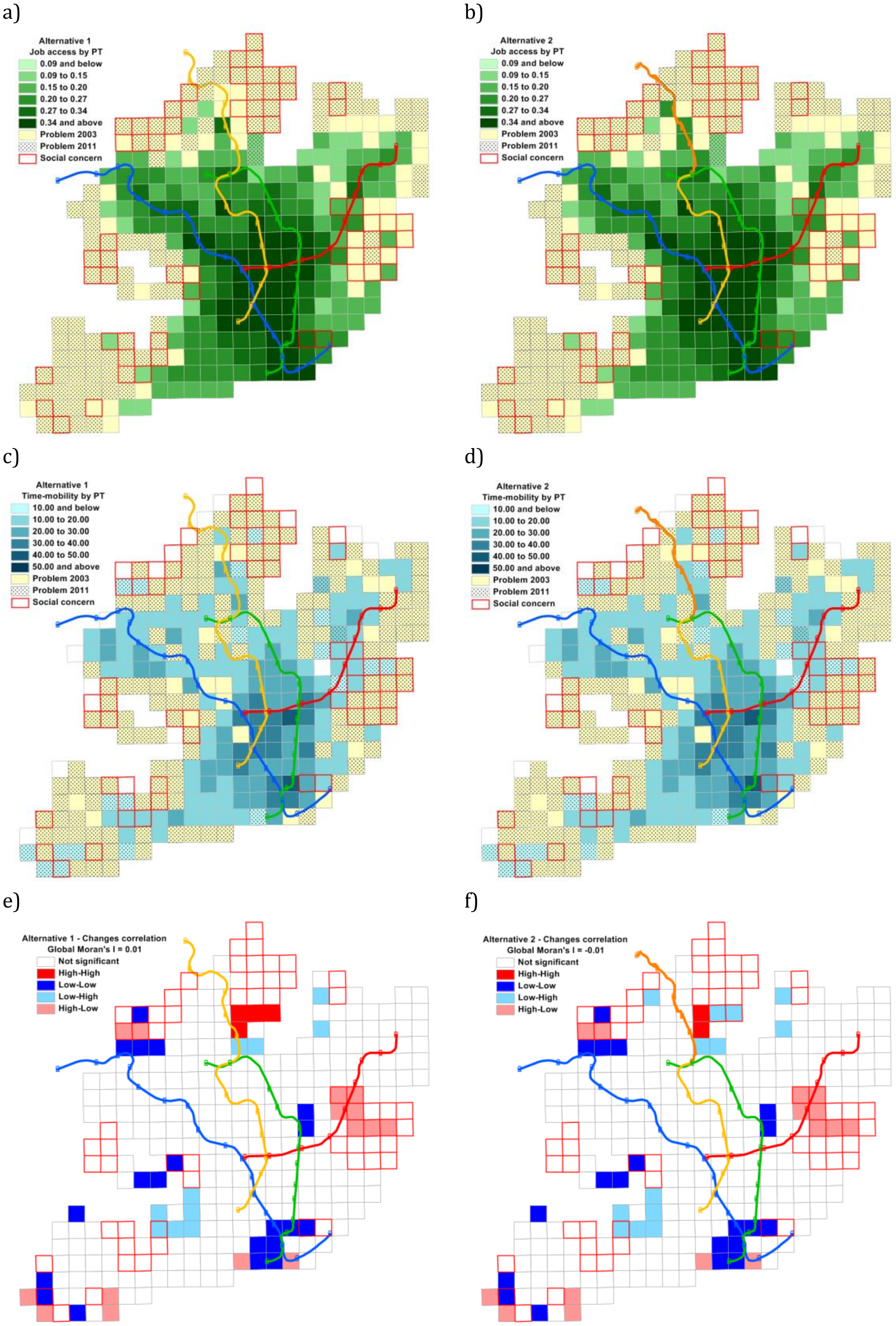

Figure 5.22: ***Ex-ante*** **scenarios – job accessibility and time-mobility problem areas (a, b, c and d) and their changes in spatial association (e and f).**

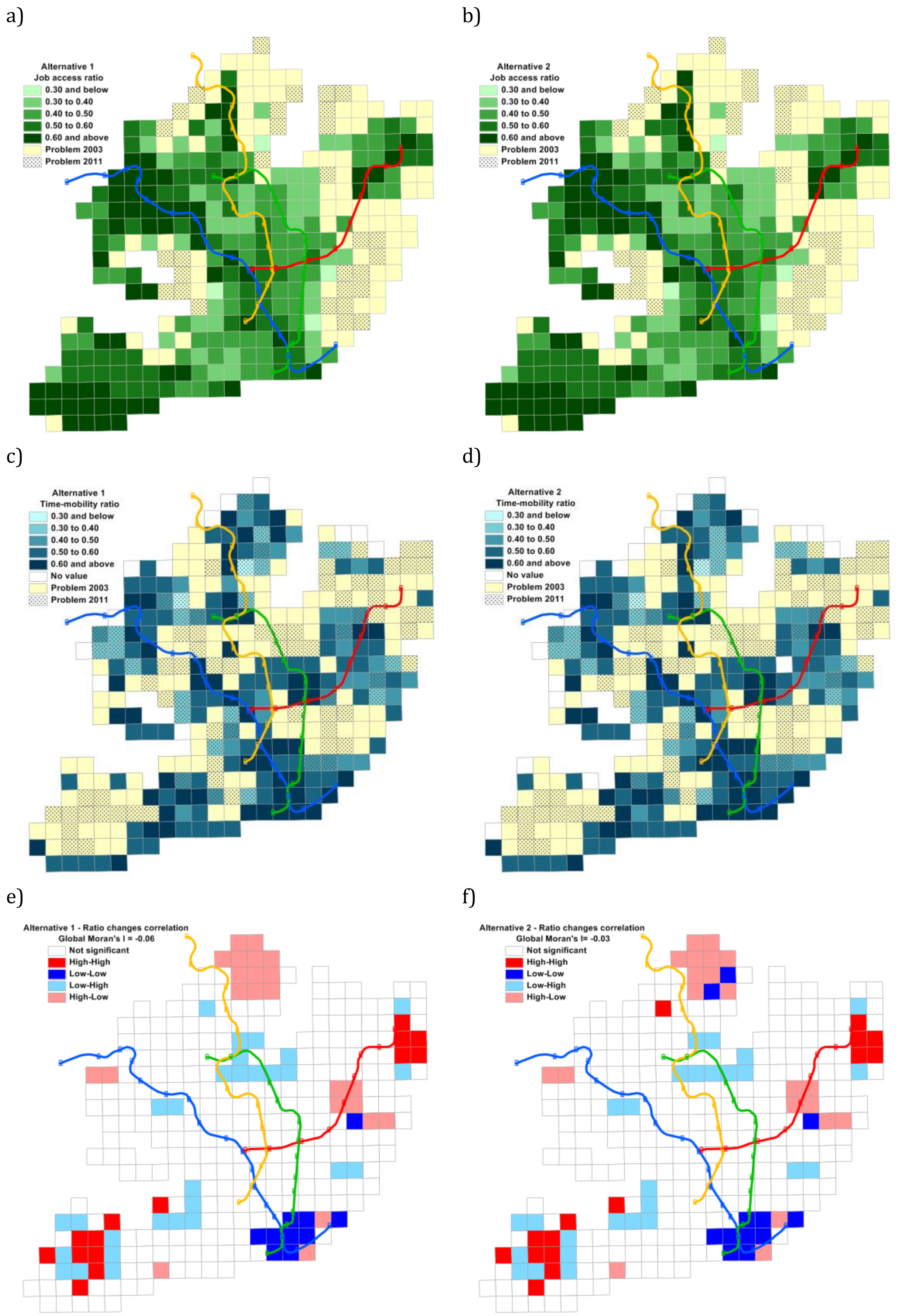

Figure 5.23: ***Ex-ante*** **scenarios – job accessibility ratios (a, b), time-mobility ratio problems (c, d) and their changes in spatial association (e and f)**

Main findings from the ex-ante assessment

Lastly, considering the changes in the accessibility and mobility conditions as well as the evolution of problems derived from the two network alternatives assessed, it is possible to conclude from a strategic point of view that both alternatives deliver acceptable results. Besides the improvement in the overall conditions of accessibility as well as positive evolution of the unequal, inequitable and unsuitable problems, the alternatives also deliver significant improvements in the area directly affected by the extension of the yellow subway line/BRT line. Specifically, it is possible to conclude that Alternative 1 delivers higher levels of accessibility than Alternative 2 in this area, however for a much higher cost. This is an important indication for decision-makers that a BRT alternative needs to be included in a more detailed evaluation of alternatives at the tactical level, in which other aspects such as implementation time, public acceptance, environmental impacts, *etc.*, need to be considered.

5.3.3 Assessing the implemented solutions: the *ex-post scenario*

In this section, the results from the implementation of the transportation interventions considered in the Alternative 1 are assessed in terms of accessibility and mobility changes as well as in relation to their contribution for the evolution of the problems identified in the *Baseline Scenario (2003)*. For this, the spatial behavior of the changes in the accessibility and mobility indicators from the *Baseline Scenario (2003)* to *Ex-post Scenario (2011)* are analyzed. Then, the evolution of the unequal, inequitable and unsuitable problems is assessed in order to have an overview of the sustainability of the accessibility and mobility phenomena in Lisbon. Additionally, the evolution of the causal relationship is also assessed as a way to identify how much accessibility is still impacting the mobility phenomenon compared to other factors. Nonetheless, it is noteworthy that the interventions assessed here do not reflect solutions specially proposed to solve the problems previously diagnosed. In fact, these interventions are the result of temporally and institutionally disconnected proposals supported by different studies and taken by different decision-makers as discussed earlier in section 5.1.

a) Assessing accessibility and mobility changes

The accessibility changes derived from the transportation interventions implemented between 2003 and 2011 in Lisbon present a very different spatial pattern regarding the modes considered. Job accessibility by PC presents an overall decrease or negative change in their levels throughout the city, especially in the zones that go through the Central area to the Southwest region. Few zones with increases or positive changes are found in the Northeast and West regions of the city (Figure 5.24a). This pattern is confirmed by the Global Moran's I of the PC accessibility changes (I_{M_CAPC}=0.88) and by the formation of one large cluster of negative changes (Low-Low) and two clusters of positive or very low negative changes (High-High) (Figure 5.24b). Job accessibility by PT, on the other hand, presents a very different spatial behavior with zones of negative changes concentrated in the Central area and zones of positive changes located in the Southwest, North, East and Northeast regions (Figure 5.24c). The Global Moran's I value for the PT accessibility changes (I_{M_CAPC}=0.34) indicated the presence of autocorrelation in these indicators, which locally is characterized by the formation of three clusters of high accessibility increase or positive changes (High-High) located in the regions previously described and two clusters of high accessibility decrease or negative changes (Low-Low) in the Central area and in the North and the Southwest regions (Figure 5.24d).

The changes in the accessibility indicators have led, consequently, to changes in the accessibility ratios. A general decrease in the imbalances between the accessibility provided by PC ant PT can be noticed since the changes in the ratio in most of the zones were positive (Figure 5.24e). The zones with negative changes in the ratio value and therefore higher accessibility imbalances are located in the North, East and West regions of the city. In the first two cases, this is related to the decrease in PT accessibility, while in the last case to the increase in PC accessibility. The Global Moran's I of ratio changes (I_{M_CAR}=0.47) indicates a strong correlation between them, with the formation of three large clusters of increased imbalances (Low-Low) and three clusters of decreased imbalances (High-High) (Figure 5.24f). The increased imbalances of the first three clusters are due to the decreases in PT accessibility, while the decreased imbalance of the first three others clusters are due to both increases in PT accessibility (region coinciding with the extension of the yellow subway line and the West region favored by the extension of the red subway line) and decreases in PC accessibility (Southwest region).

The changes in job accessibility can be better understood by separately analyzing the evolution of the indicators as well as of their respective travel times and job places input variables (Figure 5.25). From 2003 to 2011, average travel times by PC experienced an increase of 23% and 53% (Table 5.14 and Figures 5.25a and 5.25b), which indicates that in overall the interventions in the road network considered seem not to have contributed to reduce it. In fact, the increase in travel times by PC is due to the higher levels of congestion in the city caused by the increase in Lisbon's internal trips by PC and also in the trips originated in the outskirts with destination inside the city. These external trips come mainly from the municipalities located at the south bank of the Tagus river and at the western sector of the AML entering the city via highways A5 (Cascais Highway) and A2 (25 de Abril Bridge) as well as via the N6 (*Avenida Marginal*/*Avenida da Índia*) impacting directly the travel times in the Southwest region of the city. They also come from the municipalities located at the northern sector of the AML and entering the city using the A40 (*Radial de Odivelas*) causing the increase in the travel times in that area (Figure 5.25h).

In the case of PT, the contributions from the subway network expansions as well as from the restructuring of the bus network are more evident, although the average travel times by PT have practically not changed (Table 5.14 and Figures 5.25c and 5.25d). Nonetheless, local improvements on travel times are noticeable in the zones where new sections of the subway lines were implemented as well as in the East region where those zones were favored by the extension of the red line. The zones served by the stations in the yellow (North region), blue (South region) and red (Central area) lines' extensions were directly impacted by the decreases in their average travel times. The Central area was especially benefited by the extension of the red line linking the yellow and blue lines since this allowed a higher connection of the subway network and thus a significant reduction in travel times by PT in this area.

However, despite the local improvements on the travel times, job accessibility by PT presented an overall degradation due to the reduction of 22,124 job places offered in Lisbon from 2003 to 2011 (Table 5.14 and Figures 5.25l and 5.25m). This phenomenon may be related to two main factors: a downturn in the Portuguese economy and the migration of job places to other AML municipalities. In the first case, the reduction of job places is corroborated by the decrease of 9% in the total number of workers residing in Lisbon, which is accentuated in the case of the ones living and working in Lisbon (Table 5.15), as well as by the significant increase in the unemployment rates from 2001 to 2011 (Table 5.16). In the second case, the migration of job places can be explained by the increase of 8% in the number of workers residing in Lisbon and working in other municipalities of the AML. Although, this increase represents only a minor part of the total reduction of job places, it is an indication that job location plays an important role in the spatial dynamics of workers and jobs in the AML.

Table 5.14: Input variables variation from 2003 to 2011

Input variables	*Scenario 2003*	*Scenario 2011*	*%Δ*
Total daily trips by PC	*597,178*	*756,660*	*27%*
Total daily trips by PT	*971,483*	*866,670*	*-11%*
Average travel time by PC (min)	*19.48*	*24.02*	*23%*
Average travel time by PT (min)	*45.64*	*45.76*	*0%*
Average time traveled by PC (min)	*17.47*	*26.8*	*53%*
Average time traveled by PT (min)	*43.64*	*40.63*	*-7%*
Number of jobs offered	*403,059*	*380,935*	*-5%*
Number of workers	*251,444*	*229,566*	*-9%*
Total population	*564,484*	*538,421*	*-5%*

Table 5.15: Evolution of workers residing in Lisbon

	2001	*2011*	*%Δ*
Resides in Lisbon - Works in Lisbon	*210,415*	*187,703*	*-11%*
Resides in Lisbon - Works in AML	*32,343*	*34,879*	*8%*
Resides in Lisbon - Works out of AML	*8,686*	*6,984*	*-20%*
Total of resident workers in Lisbon	*251,444*	*229,566*	*-9%*
Resides in AML - Works in Lisbon	*325,978*	*304,587*	*-7%*
Resides in AML - Works in AML	*669,418*	*656,494*	*-2%*
Resides in AML - Works out of AML	*37,873*	*32,839*	*-13%*
Total of resident workers in AML	*1,033,269*	*993,920*	*-4%*

Table 5.16: Unemployment rates

	2001	*2011*
Portugal	*6.8%*	*13.2%*
Lisbon Metropolitan Area (AML)	*7.6%*	*12.9%*
Lisbon	*7.4%*	*11.8%*

Different from the changes in accessibility, the changes in mobility are more diffuse throughout the space for both indicators considered presenting a mix of positive and negative changes (Figures 5.26). The dispersed pattern of the time-mobility indicator is confirmed by the low values of their Global Moran's I (I_{M_CTMPC}=0.15, I_{M_CTMPT}=0.01). The changes in time-mobility by PC are in overall positive and derive from the increase in the number of PC trips in spite of the increase in their travel times (Figures 5.26a, 5.27a and 5.27b, and Table 5.14). However, some zones of negative changes can be found in the Southwest, Northeast and East regions of the city and are related to decreases in the number of trips in these regions. These changes are highlighted by the formation of three clusters of negative changes (Low-Low) in these same regions (Figures 5.26b).

Changes in time-mobility by PT, on the other hand, are in general negative and mostly associated with the decrease in the number of trips (Figures 5.27c and 5.27d and Table 5.14). Nonetheless, there is a concentration of zones with positive changes located in the East, North and Northeast regions as well as in the Central area (Figure 5.26c). These concentrations, however, are not statistically significant since no cluster of positive changes (High-High) is formed in these regions. Only two clusters of negative changes (Low-Low and Low-High) are found in the Southwest region (Figure 5.26d).

The mobility ratio presents a negative change meaning that the imbalances of mobility between modes have increased (Figure 5.26e and 5.26f). However, the indicator presents some positive changes concentrated in the Central area as well as in the East, Northeast and Southwest regions. These changes are related to the localized decreases in time-mobility by PC (due to the higher PC travel times) and hence to the increases in the time-mobility ratio (Figure 5.27a to 5.27f). However, the concentration of these changes are low spatial auto-correlated (I_{M_CTMR}=0.06) with only few small clusters of positive change (High-High) scattered along the city and one large cluster of negative change (Low-Low) located in the North region (Figure 5.26f).

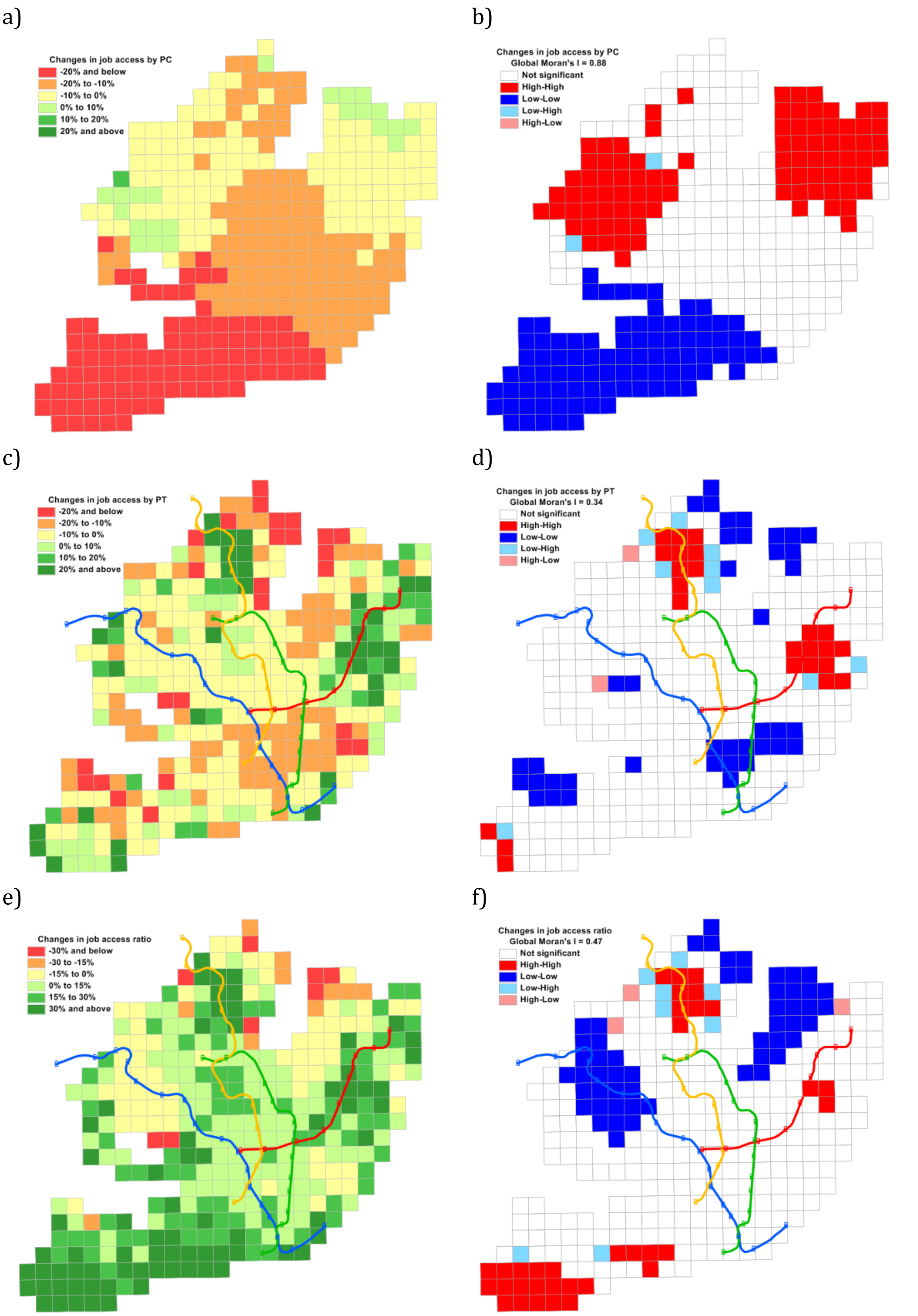

Figure 5.24: Spatial distribution map (a, b and c) and LISA cluster map (d, e and f) of job accessibility impact in Lisbon

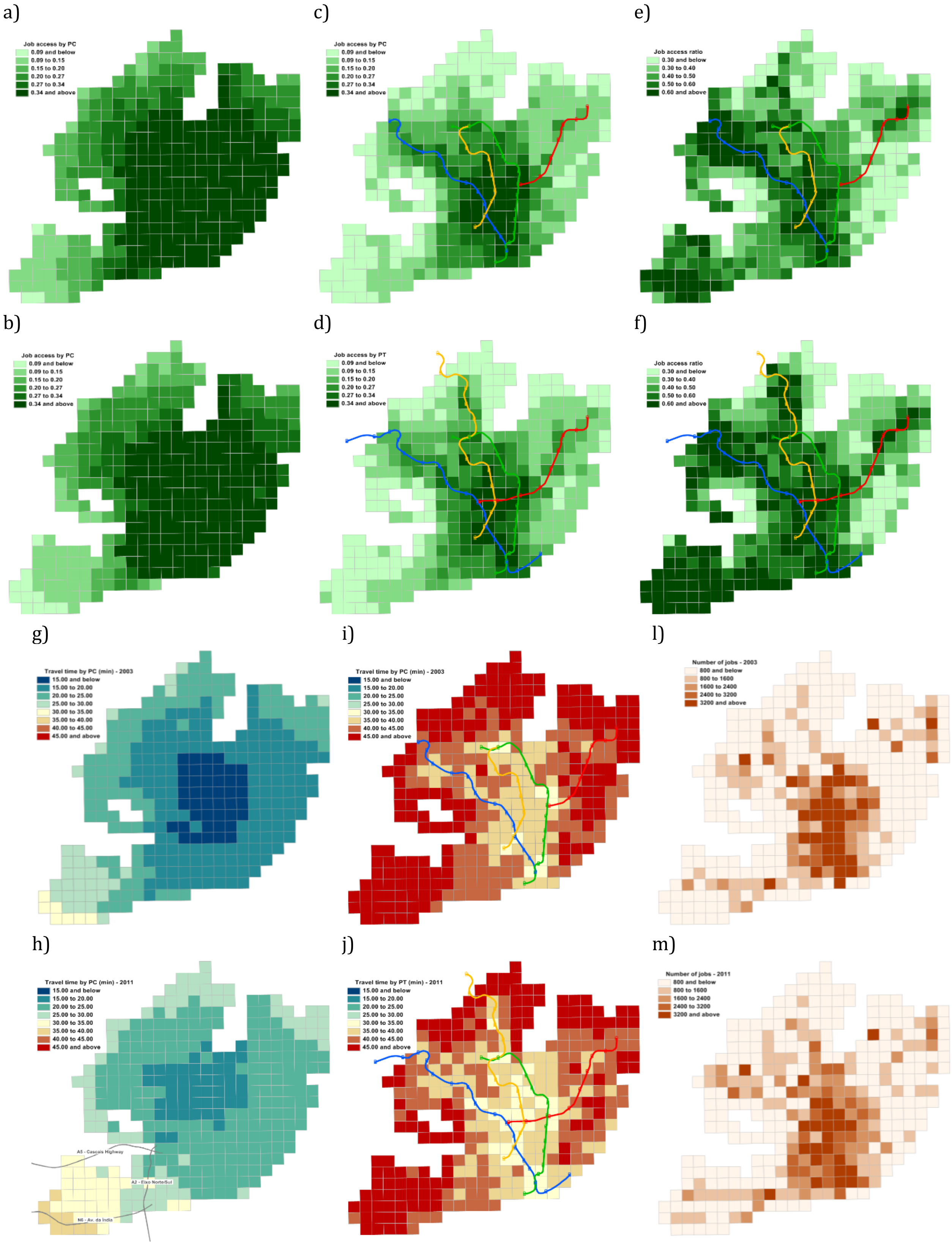

Figure 5.25: Spatial distribution of job accessibility, travel times and job place intensity in 2003 and 2011.

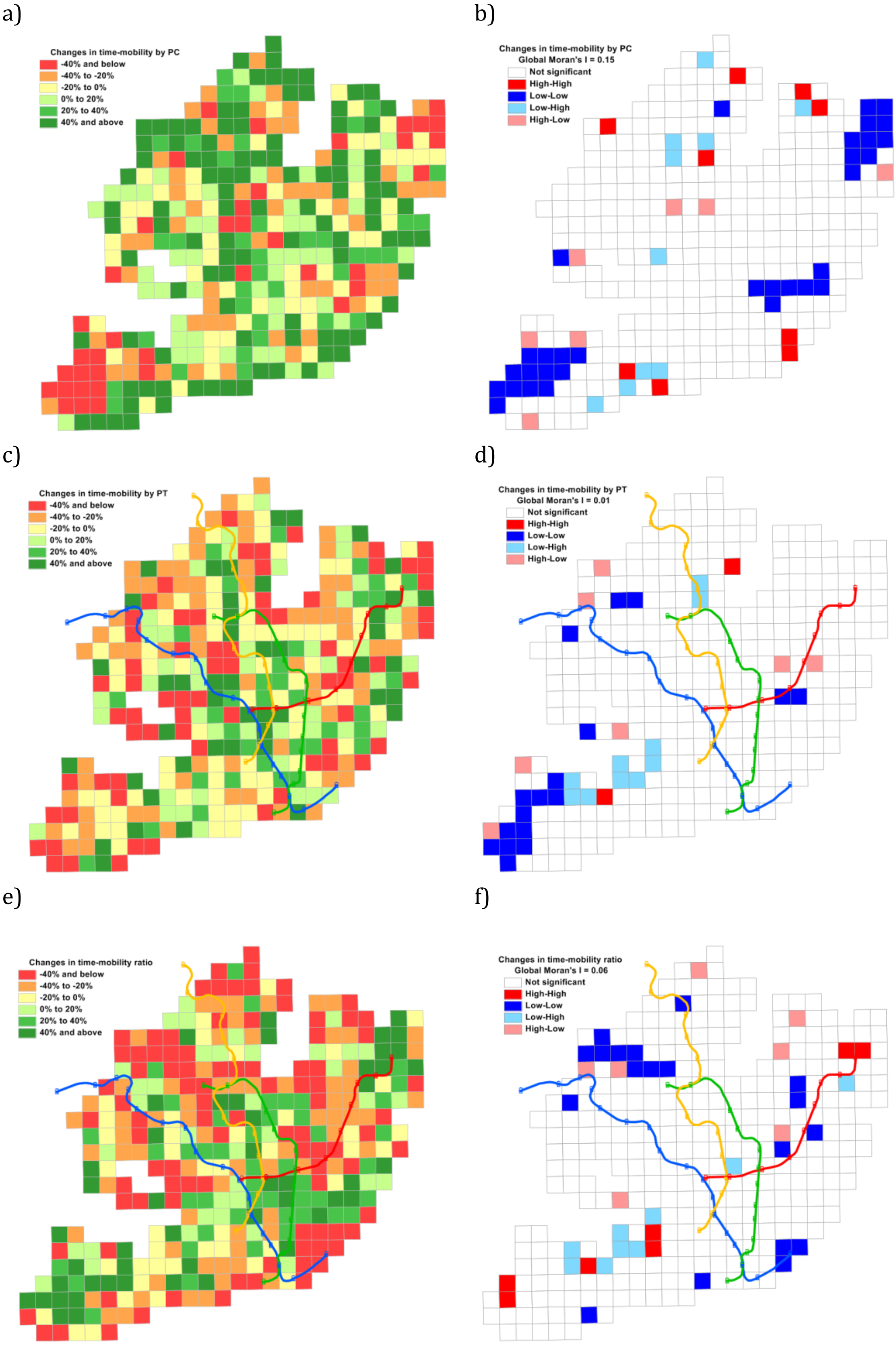

Figure 5.26: Spatial distribution map (a, b and c) and LISA cluster map (d, e and f) of time-mobility impact in Lisbon

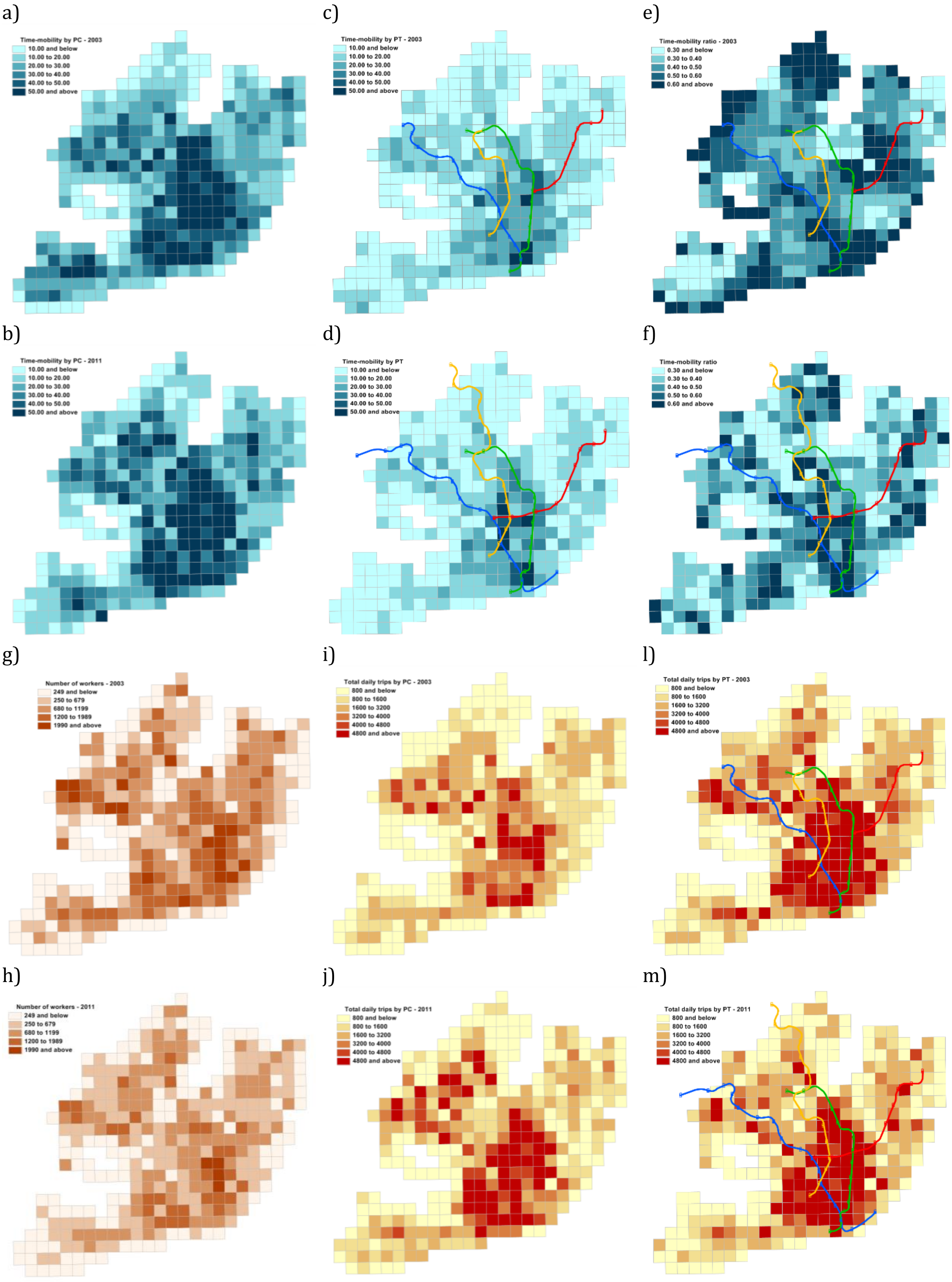

Figure 5.27: Spatial distribution map of time-mobility indicators, resident workers and total daily trips in 2003 and 2011

b) *Assessing the evolution of problems and their causal relationships*

To assess the evolution of accessibility and mobility problems in Lisbon the same non-spatial reference parameters or thresholds of sufficiency used to diagnose the problems were considered. This allows to assess how the levels of accessibility and mobility progressed over time in relation to the minimum values set in the *Baseline scenario (2003)*. However, regarding the spatial reference parameter, an updated version of the clusters of high concentration of low educated population was considered as the spatial concentration of the social concern group may have changed over time. As indicated by the LISA cluster maps in Figure 5.28, this change has actually occurred with the growth of the clusters located in the East and West regions and the decrease of the cluster in the North region. The combination of these two types of parameters applied for two different time periods allowed the assessment not only of the evolution of the three categories of problems examined in the diagnosis phase, but consequently of the sustainability distribution problem.

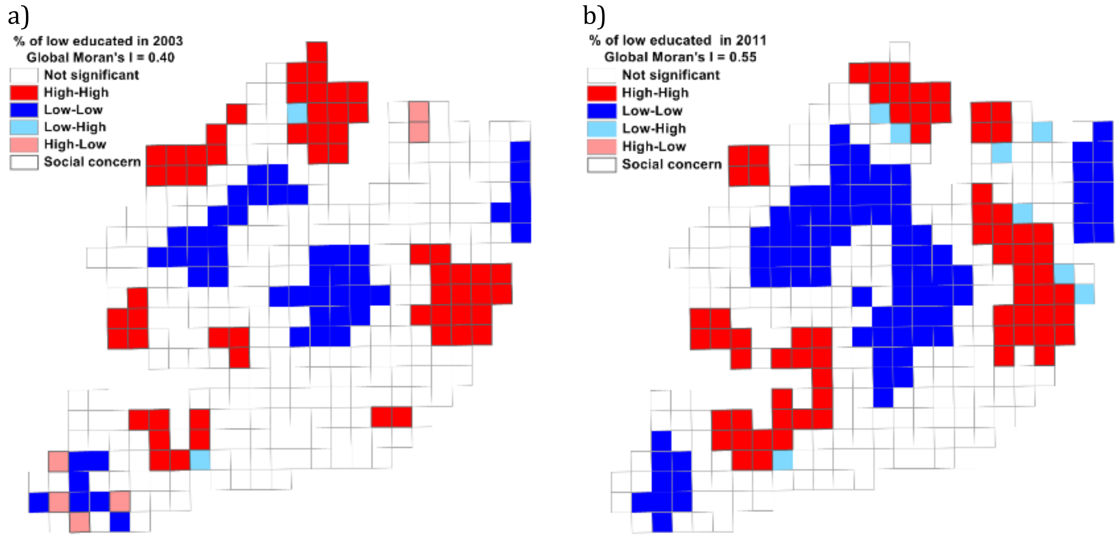

Figure 5.28: References for social concern groups

Regarding the <u>unequal distribution problem</u> of job accessibility, the comparison between zones with insufficient levels for both scenarios (yellow zones in 2003 and dotted zones in 2011) indicates that in overall the problematic areas have increased for PC and decreased for PT (Figures 5.29a and 5.29b). In the case of job accessibility by PC, some zones in the Southwest and North regions that were not previously considered problematic, now are below the sufficiency threshold due to the significant deterioration of their accessibility levels. This evolution of the unequal distribution of job accessibility by PC led to an unsustainable pattern of accessibility with the problematic areas being perpetuated over time. In the case of job accessibility by PT, some zones located in the North region are no longer considered problematic due to the improvement on their accessibility levels derived from the extension of the yellow subway line. Also some zones spread throughout the city are no longer considered problematic due to improvements on the bus network, especially in its frequency. These changes in the problematic areas of job accessibility by PT indicate that the transportation interventions are contributing to mitigate the accessibility differences across space and hence to induce a more sustainable pattern of the accessibility levels by PT throughout the city.

The unequal distribution problem of time-mobility, in turn, presents a more uneven spatial evolution featuring zones of both improvement and worsening of mobility throughout the city. In the case of time-mobility by PC, some zones located in both Northeast and Southwest regions of the city become problematic due to the decrease in the number of PC trips and the increase in their travel times (Figure 5.29c). The zones with improvements in their time-mobility by PC are located mostly in the East and North regions as well as in the upper Central area. In the case of time-mobility by PT, the new problematic zones are dispersed throughout the city with a small concentration of them in the North and Southwest regions indicating that the problem has in general worsened, mainly due to the decrease in the number of PT trips (Figure 5.29d). However, some zones of improvement can also be found throughout the city, especially at the East region. Nonetheless, the improvements on time mobility by PC are not enough to indicate a possible sustainable evolution of its pattern, however the general worsening of the time-mobility by PT indicate an unsustainable evolution despite the improvements on job accessibility by PT.

The spatial correlation between the evolution of job accessibility and time-mobility problem is analyzed through the Global Moran's I ($I_{CTMPCxCAPC}$ =0.002 and $I_{CTMPTxCAPT}$ =-0.03) and the Bivariate Cluster Maps (Figures 5.29e and 5.29f) of accessibility and mobility changes previously discussed. Globally these changes are not spatially correlated, but locally some correlations can be found. The main regions where the unequal problem of time-mobility by PC has worsened are characterized by different regimes of association: a direct relation between negative changes on accessibility and mobility (Low-Low) at the Southwest region, and an inverse relation between positive changes on accessibility and negative changes on mobility (High-Low) at the Northeast region. In the first case, accessibility can be considered as one of the main reasons for the decline of the mobility levels, while in the second case others factors may be associated with the worsening of the mobility problem.

Also one cluster of direct association between positive changes in accessibility and mobility (High-High) is found at the Northeast region, however, these changes were not enough to place the zones above the threshold of sufficiency. Regarding time-mobility by PT, two cluster with different behavior are found at the Southwest region: one cluster of direct association of negative changes (Low-Low) and one cluster of inverse association of changes (High-low) between accessibility and mobility. In the first case, both accessibility and mobility conditions have worsened through time, while in the second case despite the positive change in accessibility by PT, mobility conditions have worsened meaning that other factors are affecting the phenomenon.

The evolution of the <u>inequitable distribution problem</u> is assessed by crossing the updated social concern clusters with the evolution of the accessibility and mobility problem areas (Figures 5.29a to 5.29d). In general, the SCG is still located in problematic areas of accessibility indicating an unsustainable evolution of the inequitable problem, with exception of the social concern cluster located at the East region that do not experience low levels of accessibility by PC. In relation to time-mobility, the SCG is also in general still located in the problematic areas of mobility with the subgroup located in the East region presenting improvements in time-mobility by PC in their upper zones and in time-mobility by PT in their lower zones. Also, the subgroup located at the West region presents improvements in their mobility by PC and deterioration in their mobility by PT. However, the association between the declines in accessibility and mobility for the SCG cannot be confirmed since only part of the two clusters of direct spatial correlation (Low-Low) between the negative changes in accessibility and mobility by PC match the social concern clusters (Figures 5.29e and 5.29f). On the other hand, the social concern cluster located at the Southwest region coincides with a cluster of inverse association (Low-High) where the changes in PT accessibility are more negative and the changes in PT accessibility are more positive. This may indicate a positive progression on the inequitable conditions of PT accessibility for this subgroup, although they are still located in zones of insufficient levels of accessibility and mobility. From this analysis, it is possible to conclude that an unsustainable evolution of the equity problem both in terms of accessibility and mobility have occurred, since the localized improvements on the problematic areas are not enough to characterize a sustainable progression of the accessibility and mobility conditions of the social concern group.

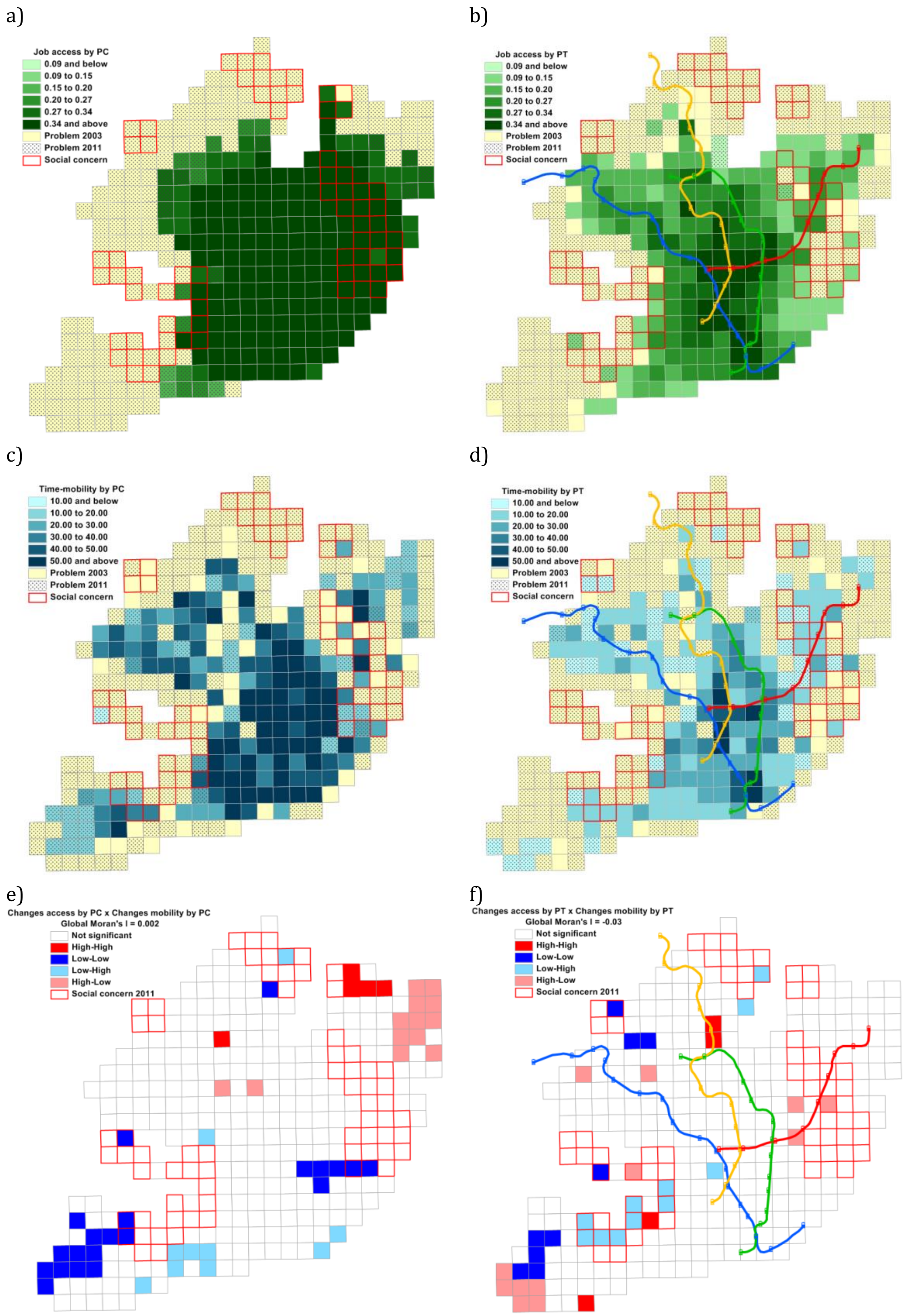

Figure 5.29: *Ex-post* scenario: evolution of job accessibility and time-mobility problems areas (a, b, c and d) and the spatial association between their changes (e, f).

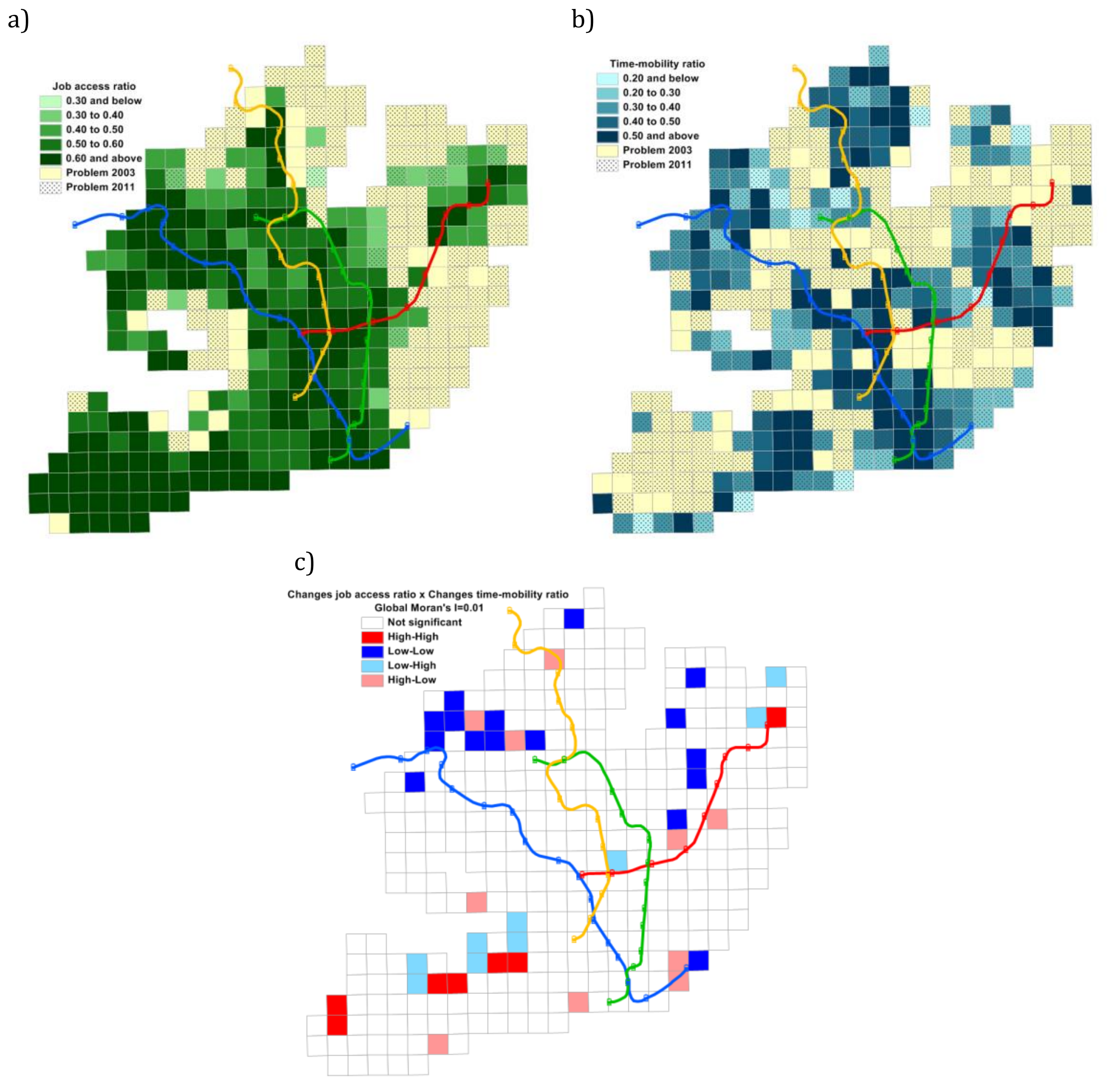

Figure 5.30: *Ex-post* scenario: evolution of job accessibility ratio (a) and mobility ratio (b, c) problem areas and the spatial association between their changes (d, e).

In relation to the <u>unsuitable distribution problem</u> it is possible to note that the problem areas of unsuitable accessibility have in overall decreased throughout the city due to the positive changes in the accessibility ratio (Figure 5.30a). This can also be understood as a global decrease of the unsustainable problem in terms of differences across modes. However, some improvements on the unsuitable accessibility problem are especially noted in the North region due to increase in accessibility by PT relating to the extension of the yellow subway line, in the East region due to the extension of the red subway line and in the West region due to the decrease of PC accessibility. The problem areas of unsuitable mobility, in turn, present an overall increase which can be understood as unsustainable patterns of mobility across modes (Figure 5.30b). This negative evolution of mobility ratios is clearly linked to increase in PC trips and the decrease in PT trips that lead to small ratio values than in 2003 regardless the differences in travel time. Nonetheless, some changes in the unsuitable problematic areas are worth to be highlighted such as the worsening of the time-mobility ratio at the North region between the blue and yellow lines confirmed by the cluster of negative changes associations (Low-Low) between accessibility ratio and time-mobility ratio (Figure 5.30c).

Finally, in order to assess the evolution of the causal relationships, new spatial regression models for the *Ex-post scenario (2011)* were estimated. The estimation of these models departure from the same full classic specification considered in the *Baseline scenario (2003)*. The parameters of the resultant spatial models as well as the point elasticities of the variables included are presented in Tables 5.17 and 5.18 (see also Annex 3). The elasticities allow to assess the changes in the comparative levels of influence that each explanatory variable has on the mobility indicators.

Table 5.17: Parameters of time-mobility models – *Ex-post* Scenario-2011

log(TMPC_11) Spatial lag model				*Log(TMPT_11) Spatial error model*			
	β	*z-value*	*Sig.**		*β*	*z-value*	*Sig.**
ρ	*0.330*	*5.501*	*0.000*				
Constant	*0.199*	*3.220*	*0.001*	*Constant*	*0.177*	*1.849*	*0.064*
APC_11	*0.302*	*3.343*	*0.000*	*APT_11*	*1.188*	*6.018*	*0.000*
sqrtCAR_11	*0.006*	*7.964*	*0.000*	*sqrtWKRS_11*	*0.011*	*8.305*	*0.000*
logJOBS_11	*0.183*	*10.098*	*0.000*	*logJOBS_11*	*0.165*	*6.601*	*0.000*
				WAIT_11	*-0.016*	*-2.542*	*0.011*
				STOP_11	*0.027*	*4.107*	*0.000*
				λ	*0.263*	*2.977*	*0.003*
R^2	*0.72*			*R^2*	*0.75*		
Adjusted R^2	-			*Adjusted R^2*	-		
Log-likelihood	*128.202*			*Log-likelihood*	*121.976*		
AIC	*-246.403*			*AIC*	*-231.952*		
SC	*-227.593*			*SC*	*-209.380*		

Table 5.18: Elasticities in time-mobility spatial models – *Ex-post* Scenario-2011

log(TMPC_11)				*Log(TMPT_11)*			
Variables	*mean*	*Formula*	*Elast.**	*Variables*	*mean*	*Formula*	*Elast.**
APC_11	*0.36*	*βx*	*0.09*	*APT_11*	*0.17*	*βx*	*0.20*
CAR_11	*464.80*	*0,5βsqrt(x)*	*0.08*	*WKRS_11*	*555.01*	*0,5βsqrt(x)*	*0.13*
JOBS_11	*1192.48*	*β*	*0.18*	*JOBS_11*	*1127.03*	*β*	*0.17*
				WAIT_11	*9.40*	*βx*	*-0.15*
				STOP_11	*2.56*	*βx*	*0.07*

Both time-mobility models present the same significant variables that were included in the *Baseline scenario (2003)* models. In the case of time-mobility by PC the significant variables were again: *Car ownership (CAR_11)*, *Job accessibility by PC (APC_11)* and *Job places intensity (JOBS_11)*. The comparative levels of influence that these variables have on *time-mobility by PC* according to their point elasticities also remain with *Job place intensity* being the most influential one followed by *Job accessibility* and *Car ownership*. In the case of *time-mobility by PT* the same occurs with the variables *Job accessibility* by PT (*APT_11*), *Resident worker intensity (sqrtWKRS_11)*, *Job places intensity* (*logJOBS_11*), *Stop-station density (STOP_11)* and *Waiting time (WAIT_11)* being included in the new model. However, in this case, the comparative levels of influence of these variables have changed. While in 2003 the most influential variables of time-mobility by PT were *Resident worker intensity* and *Waiting times*, in 2011 the variables with more impact are *Job accessibility by PT* and *Job places intensity* with *Stop-station density* being again the one with less impact. This change in the comparative levels of influence indicates a change in the dynamics of the explanatory variables over time, with *Job accessibility by PT* playing now a more important role in explaining the time-mobility by PT phenomenon in Lisbon. These alterations in the causal relationships for time-mobility by PT in Lisbon are related to the land use and socioeconomic changes that have occurred in the last years such as the shrinkage of labor force as well as the fall in the number of job places, and more importantly the significant changes in travel times by PT due to the transport interventions and hence on job accessibility levels by PT.

<u>Main findings from the ex-post assessment</u>

The *ex-post* assessment of accessibility and mobility conditions on Lisbon's Mobility Network allowed to have an overview of the implications from the PC and PT interventions implemented. First of all, it is emphasized that these interventions are not derived from the diagnosis developed, although a number of PT interventions have been implemented as suggested before. In general, PC job accessibility have worsened, but not as much as expected in the diagnosis and indicated by the evolution of the inequality problem. This deterioration is directly related to the growth in the number of PC trips, which, in turn, may have resulted from a series of behavioral and cost factors not considered in this analysis. Moreover, the PC interventions considered did not contributed for improving job accessibility, which may be related to the fact that they result from choices aimed at improving the AML connections and not specifically the job accessibility in Lisbon.

On the other hand, improvements in the PT job accessibility indicated that although implemented interventions have not been supported by a diagnosis based on accessibility values and mobility, they demonstrate two important points: i) interventions should be aligned in order to improve network performance and therefore accessibility such as in the case of the subway and bus networks adjustments; and ii) disconnected interventions between PC and PT as those occurred in the last years should be avoided in order to prevent significant imbalances between modes. The development of a diagnosis such as the one developed in this research can help planners and decision makers in this sense, providing them with a global picture of the accessibility and mobility problems to be avoided.

In addition, the implementation of specific solutions such as the extension of the yellow subway line, suggests that this choice may not have been supported by a similar analysis as the one presented in section 5.3.2. This is an indication that makes the quality of the strategic decisions taken be questioned. Clearly, the extension of the yellow subway line brought accessibility gains to the directly affected area and have contributed to the localized solution of some problems. However, the option for implementing a BRT line could have brought the same types of benefits, though on a smaller scale, but certainly at a much reduced cost.

5.4 Summary

- The assessment of Lisbon's UMN in the *Baseline scenario (2003)* allowed the characterization of their job accessibility and time-mobility conditions as well as of the unequal, inequitable and unsuitable problems. The results of the analysis indicated that the conditions of both job accessibility and time-mobility by PC are better than by PT. Regarding the problems, Lisbon presents an unequal distribution of both job accessibility and time-mobility by PC and PT with the majority of problematic areas located in the periphery. Inequitable problems were also detected with the social concern group considered being affected both in terms of accessibility and mobility conditions. Unsuitable problems, in turn, presented a distinguished spatial configuration for job accessibility ratios and time-mobility ratios indicating that the disproportion between PC and PT accessibility and mobility conditions are not so correlated. Additionally, the modeling of the causal relationship between time-mobility and job accessibility as well as with other socioeconomic and transportation variables indicated that although accessibility have a significant influence on both PC and PT time-mobility, the spatial distribution of job places is the most influential factor in the mobility of Lisbon's workers. Also, the analysis of the *Do-nothing scenario (2011)* indicated that the unequal and inequitable problems will have an unsustainable evolution, while the unsuitable problem will have a sustainable evolution. However, in this last case, the positive evolution is biased by the worsening in private car conditions over improvements in public transport. These results can be used to support the development of strategic objectives and therefore of alternative solutions that aim at balancing the offer of job accessibility between PC and PT in Lisbon, especially in the North and East regions, where the disproportions are higher and the social concern group is located;

- Concerning the assessment of alternative configurations for Lisbon's UMN in the *Ex-ante scenario (2011)*, the results indicated that the changes in job accessibility levels derived from the two set of PT interventions are in overall positive and led to very similar spatial configurations of changes, except in the North region where the interventions are divergent. The analysis also pointed out that Alternative 1 results in greater benefits in terms of accessibility and travel time savings, while Alternative 2 positively impacts a larger share of workers although with lower levels of job accessibility. The changes on time-mobility were also in general positive for both alternatives with accentuated positive differences in the zones located in the North region. However, regarding the impacted group, Alternative 1 impacts negatively a higher proportion of workers than Alternative 2. The evolution of the unequal problems indicated a sustainable progression of the job accessibility conditions derived from both alternatives, but an unsustainable progression of the time-mobility conditions. These divergent patterns are confirmed by the low spatial correlation between the changes in the indicators. The evolution of the inequitable problem of job accessibility and time-mobility also presents an overall unsustainable progression, except for the social concern group located in the East region of the city. Finally, the unsuitable problems present a sustainable evolution due the decrease in the ratios between both job accessibility and time-mobility indicators. These results suggest that from a strategic point of view both alternatives deliver overall good results in terms of job accessibility. Specifically, the consideration of a BRT line as an option to the extension of the yellow subway line is a feasible solution in terms of accessibility improvements and should be regarded in a more disaggregated assessment process of alternatives;

- Finally, the assessment of Lisbon's UMN considering the interventions implemented in the *Ex-post scenario (2011)* indicated very distinguished patterns of job accessibility changes by modes. While job accessibility by PC presented an overall negative change, job accessibility by PT presented a mix of negative and positive changes. These changes are associated with the reduction of job places offered as well as with the increase in congestion and hence in travel times in the case of PC, and with the decrease in travel times due to the interventions in the case of PT. The changes in time-mobility, in turn, are in overall positive for PC and derives from the increase in the number of PC trips despite the increase in their travel times, while for PT they are in general negative and mostly associated with the decrease in the number of trips. Regarding the evolution of problems it was noticed that: i) the unequal problem presented an unsustainable evolution for job accessibility by PC and a sustainable evolution for job accessibility by PT, while for time-mobility the evolution is considered unsustainable for both modes; ii) the inequitable problem presented an unsustainable evolution both in terms of accessibility and mobility; and iii) the unsuitable problem presented a sustainable evolution of job accessibility ratio, but an unsustainable evolution of time-mobility ratio. Additionally, the analysis of the evolution of the causal relationships indicated that for time-mobility by PC the comparative levels of influence of the variable remain the same with *Job place intensity* being the most influential one followed by *Job accessibility by PC*, while for time-mobility by PT this has changed with *Job accessibility by PT* playing now a more important role followed by *Job place intensity.* This result is an indication of the changes in the dynamics of the PT mobility and PT accessibility phenomena in Lisbon's UMN and of the influence that public transport interventions may have on accessibility and hence on mobility. Moreover, from a decision maker point of view this analysis shows that the implementation of institutional and temporally disjointed solutions may lead to unfavorable results such as the continued imbalance between PC and PT accessibility and mobility. This reinforces the utility of an ongoing planning process based on a diagnosis that allows the understanding of accessibility and mobility problems as well as an *ex-ante* assessment that supports the indication of the best strategic alternative solutions in terms of accessibility.

6. Conclusions

6.1 General conclusions and contributions

The urban mobility planning field has been experiencing a series of changes over the past decades with the most recent one being the accessibility planning paradigm. This paradigm has positively reflected in the performance of the planning process as well as in the quality of its results. However, some issues are still neglected in this field especially regarding the understanding of the urban mobility system problematic and its framing within the planning process. In this sense, three research questions were considered in the development of this thesis whose answers led us to conclude that: *i)* assessment should be seen as an intrinsic activity of the UMS planning process helping planners to diagnose problems and to appraise/evaluate the impact of solutions in their evolution; *ii)* these problems should be defined as gaps or differences in accessibility and mobility levels in relation to the space, modes, social groups and time, in order to express equity and sustainability concerns; and, finally *iii)* they should be assessed through consistent and aligned methods based in spatial analysis techniques and supported by adequate indicators during the three different moments of strategic analysis (diagnosis, *ex-ante* and *ex-post*) within the planning process.

While the first two findings were achieved through a careful literature review of important topics within the UMS planning field such as accessibility, mobility, equity and sustainability, the last conclusion was supported by the development of the main product of this thesis, the strategic assessment methodology. Such methodology represents an important contribution for the urban mobility planning field and is characterized by three main features: the consideration of accessibility as the main value to be analyzed, the emphasis on problem understanding as the starting point of the process and the highlighting of the assessment activities within the planning process.

Similarly to many other studies, this thesis also advocates *accessibility as the fundamental value* of the urban mobility system planning process. It defends the suitability of the accessibility concept to represent the urban interactions, mainly the ones between the land use, activity and mobility subsystems, as well as its capacity to support the analysis of strategic issues that may have an impact on the socioeconomic and environmental dimensions of the urban system. However, it goes beyond that and acknowledges the need for defining a network model to represent at the strategic level the main urban elements and to operationalize the investigation of the urban interactions through accessibility measures.

This model, called *urban mobility network* model, is the representation of the urban network from the urban mobility system perspective. It consists in an aggregated or strategic representation of the spatialized activities and the impedances between them, and has a more functional meaning if compared to the physical meaning of the traditional transportation network models. The consideration of such network model places the analysis of urban activity interactions and hence of accessibility, the product of such interactions, in a prominent position within the planning process. From this, it becomes clear that the strategic planning effort should focus on the accessibility analysis as well as on their causes and effects.

In this sense, the proposed methodology focused not only on the analysis of the accessibility itself, but also on the investigation of the aspects related to individuals, land uses and transportation characteristics that determine the provided levels of accessibility as well as the effect that these levels may have on mobility. For this, a set of six categories of *accessibility restrictions* is proposed in this thesis as a way to better relate them to the accessibility components. They refer to personal capabilities, physical infrastructure as well as space-time, financial, economic and social restrictions that allow to better understand the causes of accessibility deficiencies or problems and thus of mobility problems. Together these restrictions build up a complete representation of the accessibility conditions on the urban mobility network and, therefore, of their assessment.

The above mentioned *problem oriented approach* is the second and perhaps the most important characteristic of the proposed methodology. Contrary to the traditional decision-making practice of proposing solutions to preconceived problems, the strategic assessment methodology focuses on the understanding of the UMN's accessibility and mobility problems giving greater emphasis to the intelligence or diagnosis phase of planning. By that, the main challenge in the planning process is no longer the search for solutions, but rather the understanding of problems affecting the urban system. It is claimed that only through the proper identification, characterization and diagnosis of problems, along with their causal relationships, one is able to better understand the urban mobility reality and therefore to enhance quality of decisions.

In this sense, supported by the sufficientarianism and egalitarianism theories and by the equity and sustainability principles, a set of four types of problems representing the main accessibility and mobility deficiencies on urban mobility networks were defined. These problems are considered as the basic problems that any urban mobility networks may present and the investigation of the causal relationships behind and among them is fundamental for their full understanding. Therefore, the assessment of these problems is defended as the starting point of the planning process once it allows planners to have an overview of the main strategic issues related to accessibility and mobility and consequently to propose better policies for their solving.

Another important feature of the proposed methodology is the *emphasis given to the assessment activities*. Three different assessment moments in the planning process have been recognized by several transportation planning methodologies. However, none of those methodologies have so far defined clear methods for their alignment or have recognized them as the ones to be performed mostly at the strategic level. At most, they have suggested the consideration of the same indicators to support these activities throughout the process. As a way to overcome this issue, this thesis was beyond that and proposed the systematic application of spatial analysis techniques as a mean of harmonizing the development of assessment activities at the strategic level.

In this way, one of the main features of these techniques is the consideration of the spatial aspect of the phenomenon under investigation. Such consideration brings to the strategic analysis one of the most important features of urban events that is not always considered: their intrinsically spatial characteristic. Additionally, as they are grounded by statistical criteria, the quantification of these events as well as of their causal relationships can be investigated in a more proper manner, either by measuring the spatial behavior of the indicators representing them or by estimating the cause and effect relations between events through spatial regression models. In the specific case of the proposed methodology, spatial analysis techniques allow the understanding of the accessibility and mobility problems in the diagnosis phase as well as the assessment of their evolution according to the solutions proposed or implemented in the *ex-ante* and *ex-post* assessment phases, respectively. Thus, planners become more able to consistently assess the accessibility and mobility conditions on urban mobility networks, either when the problems are diagnosed or when the *ex-ante* or *ex-post* impact solutions are assessed.

Moreover, regarding the results obtained through the case study it was possible to demonstrate the added value of the proposed methodology once it was showed that: *i)* the methods applied in the diagnosis phase would help to better understand the problems and its causal relationships as well as to prioritize the interventions proposed towards more equitable solutions; *ii)* the hypothetical alternative solution tested (BRT corridor) would results as good as the alternative implemented (Yellow metro extension), but for a much lower cost, meaning that the decision taken in practice would be likely different if this method had been applied; and *iii)* the implemented solutions did not contribute to solve the problems diagnosed, especially the inequitable one, revealing a mismatching between the strategic decisions taken and the strategic problems of accessibility and mobility in Lisbon.

Finally, considering all the above discussed contributions, it is believed that the end product of this thesis, the strategic assessment methodology of accessibility on urban mobility network, constitutes a valuable contribution for the urban mobility planning field. By clarifying the role of this type of activity inside the process it becomes easier for planners to know when and how to approach the accessibility and mobility problems. Besides, the alignment of the methods considered through the consistent assessment of problems and the application of the same analysis techniques confer a much more robust way of addressing the strategic issues of the urban mobility network. Moreover, the results of the illustrative application for Lisbon's Mobility Network allowed to demonstrate the usefulness from a decision maker point of view of a continued planning process based on the understanding of accessibility and mobility problems as well as on the *ex-ante* and *ex-post* assessment of the solutions proposed and implemented

6.2 Limitations and future research

As any complex research this thesis also presents some shortcomings that can be directly related to potential future research efforts. First of all, the proposed methodology relies on the consideration of four categories of accessibility and mobility problems regarded as the basic problems that any urban mobility network may present. These problems, as already discussed, allow the assessment of the urban mobility network problematic in terms of accessibility and mobility and in light of equity and sustainability principles. However, the possible impact that these problems may have on the socioeconomic and environmental dimensions of the urban subsystem is not explored in this research.

This means that apart from the basic accessibility and mobility problems, major socioeconomic and environmental problems need to be investigated if the purpose is to assess the social justice and the quality of life of the urban system. It is believed that these major problems such as social segregation, social exclusion or environmental degradation are directly related to the basic accessibility and mobility problems and that their causal relationship must be examined. For example, social exclusion can be directly related to the inequitable distribution problem of accessibility and mobility in the same way that environmental degradation can be associated with the unsuitable distribution problem of accessibility and mobility.

For this, specific indicators to represent socioeconomic and environmental problems need to be defined, but the methods of analysis can be the same as the ones comprised in the proposed methodology. In other words, sufficientarianism and egalitarianism theories combined with spatial exploratory and confirmatory analysis techniques can be used to characterize and diagnose these problems, as well as to quantify the causal relationships between them and the basic problems. This constitutes, therefore, a potential study area where specific indicators for the major urban problems can be defined and a series of empirical spatial analysis performed in order to investigate the possible causal relationship between accessibility and mobility problems as well as between them and the social and environmental ones.

Another limitation of this research refers to the ex-ante assessment of alternatives phase of the urban mobility planning process. Although this phase is properly addressed in the proposed methodology of strategic assessment, it is recognized in the urban mobility planning process presented in Chapter 2 that the ex-ante assessment occurs also at the tactical level. This implies a need to define how the strategic assessment methods can be declined in tactical assessment methods. It is thought that this process should include other aspects related to the alternatives solutions in addition to accessibility and mobility conditions and their associated impacts. Therefore, regardless the type of intervention considered, whether in the transportation or in the land use component, aspects such as cost, implementation time and public acceptance, *etc*., also need to be considered. On the other hand, specific aspects of each type of intervention can either be added in the evaluation.

Only through the consideration of those other aspects, combined with a phased projection of the accessibility and mobility problems and their impacts, one will be able to have a full picture of the advantages and disadvantages of the solutions considered. It is believed that this more detailed assessment or evaluation of solutions can be supported by multi-criteria analysis techniques. These techniques allow the consideration of multiples aspects and conflicting objectives in the evaluation of proposed solutions. However, their alignment with the proposed strategic assessment methods needs to be investigated in order to ensure consistency between them, i.e., assuring that the main characteristics of the strategic analysis (problem-based and spatial approaches) are reflected in the tactical ones.

Finally, one last issue worth mentioning that is not necessarily a limitation of the proposed methodology refers to the use of traditional modeling techniques in the development of the illustrative application. Although the models considered have supported a good representation of the baseline conditions allowing an adequate characterization and diagnosis of the accessibility and mobility problems, their use in the simulation of future scenarios was much more limited as they do not account for the dynamic relation between land use and transportation aspects. For example, the trip production model used for projecting the demand in the do-nothing scenario disregarded the influence that land use variables could have on future travel patterns.

An alternative to this traditional approach would be the use of integrated models as they allow to simulate jointly the effects that land use and transportation components have on each other. These models have been used to support ex-ante assessments of alternatives by measuring the accessibility effects that both land use and transportation interventions may present in future scenarios. However, their use to support the diagnosis of problems in baseline scenarios has been much more limited. This is a contradictory situation as the representation of causal relationships between UMN components and thus between accessibility and mobility problems should be the starting point of the planning process. Therefore, it is suggested the use of integrated models, as they are a more robust way of simulating these relationships in both baseline and future scenarios and hence of better performing the assessment of urban mobility networks.

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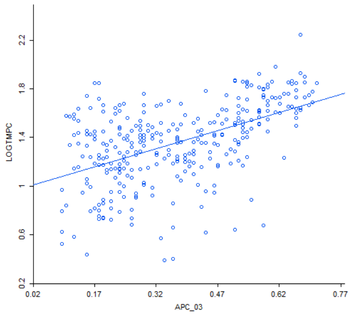
Annex 1

logTMPC_03xAPC_03



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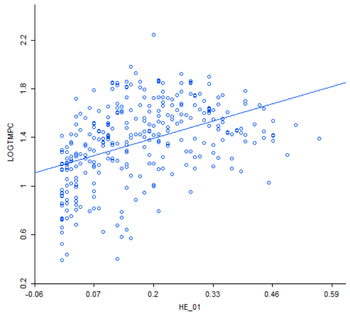

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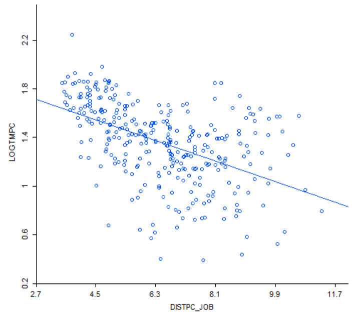

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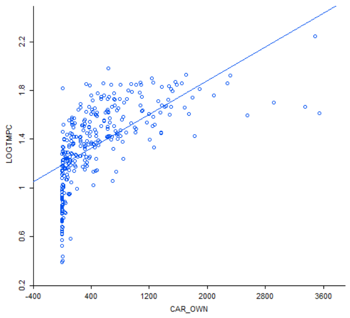

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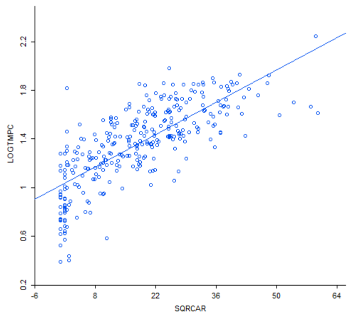

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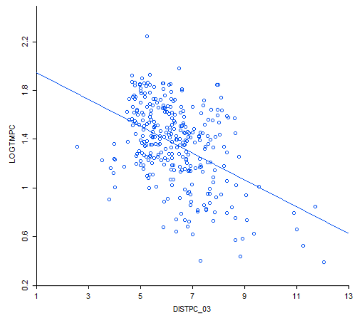

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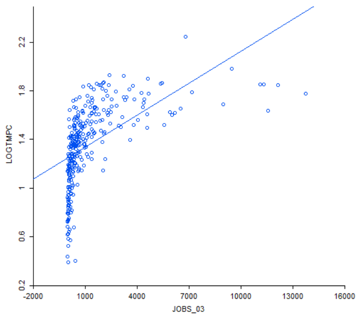

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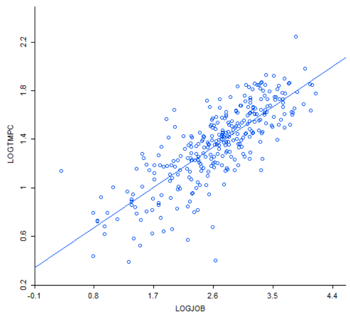

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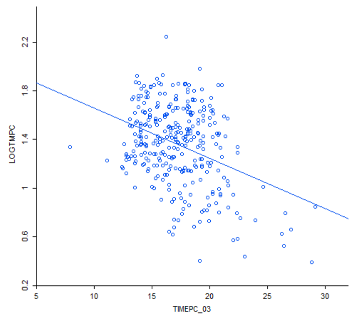

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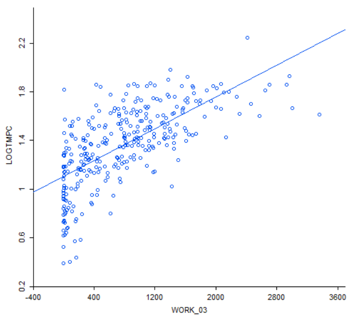

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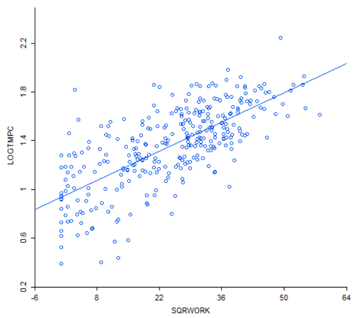

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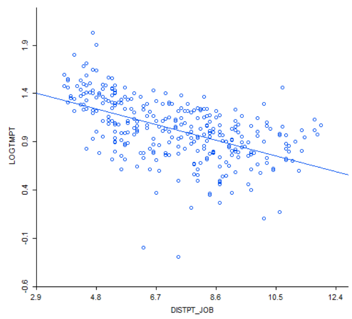

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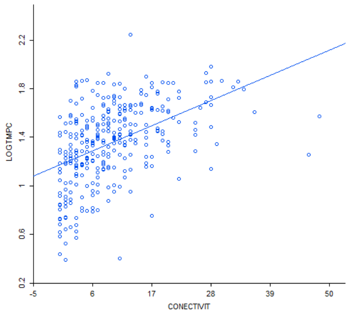

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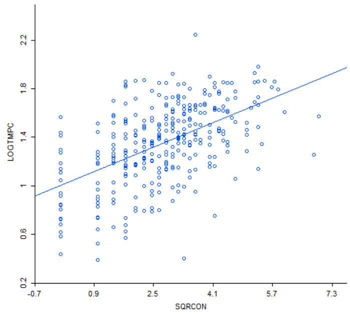

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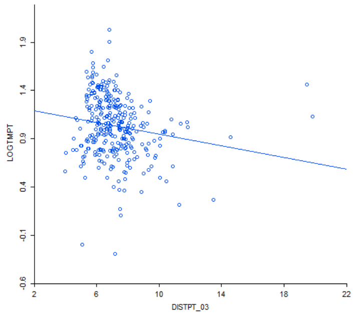

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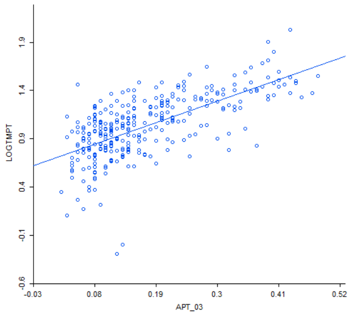

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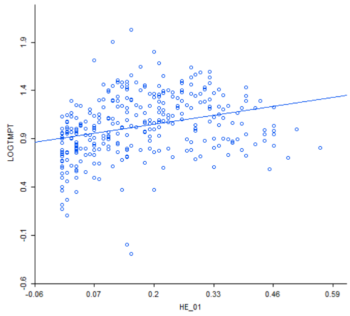

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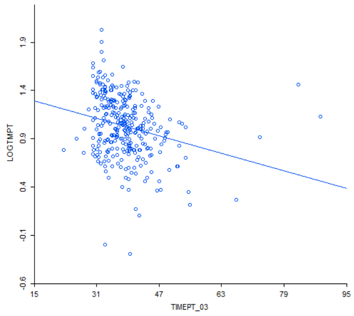

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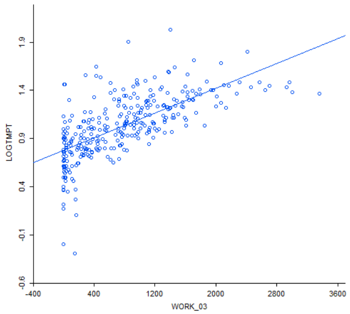

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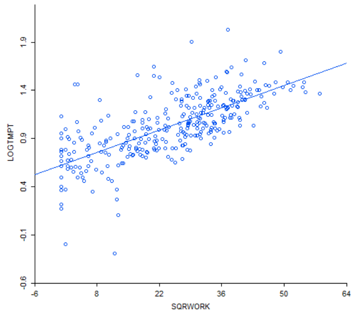

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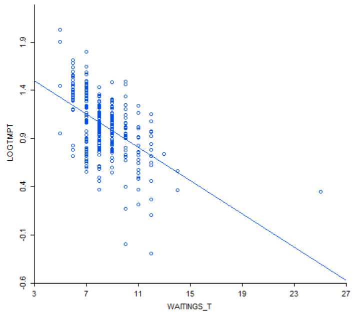

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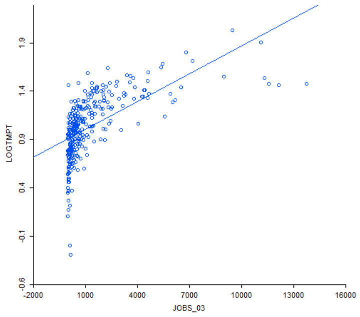

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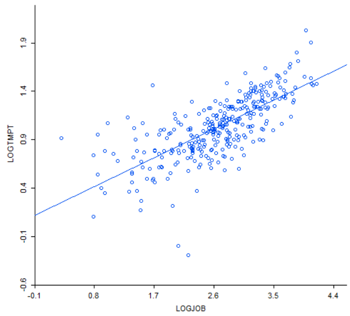

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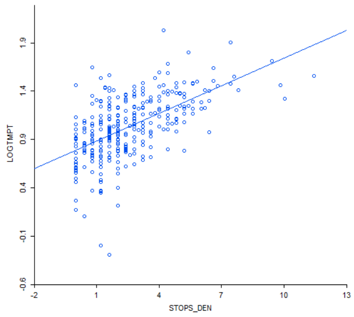

Annex 2

	logTMPC	logTMPT	APC_03	APT_03	ARATIO_03	HE_01	sqrcCAR	sqrWKRS	logJOBS_03	JDPC_03	JDPT_03	DTPC_03	DTPC_03	TIMEPC_03	TIMEPT_03	WAIT_03	STOP_03	sqrCON_03
logTMPC	1	,809**	,621**	,544**	,382**	,449**	,756**	,725**	,796**	-,539**	-,535**	-,517**	-,264**	-,453**	-,321**	-,513**	,550**	,569**
logTMPT	,809**	1	,680**	,575**	,428**	,310**	,701**	,707**	,724**	-,555**	-,569**	-,429**	-,221**	-,322**	-,290**	-,525**	,584**	,542**
APC_03	,544**	,575**	,840**	1	.049	,149**	,302**	,409**	,527**	-,912**	-,910**	-,614**	-,577**	-,546**	-,533**	-,456**	,437**	,363**
APT_03	,621**	,680**	1	,840**	,531**	,358**	,359**	,412**	,648**	-,819**	-,843**	-,560**	-,517**	-,421**	-,606**	-,614**	,536**	,481**
ARATIO_03	,382**	,428**	,531**	.049	1	,438**	,245**	,195**	,366**	-,157**	-,219**	-,188**	-,149**	-.064	-,371**	-,483**	,326**	,369**
HE_01	,449**	,310**	,358**	,149**	,438**	1	,340**	,281**	,494**	-,211**	-,227**	-,225**	-,187**	-,192**	-,252**	-,295**	,212**	,346**
sqrcCAR	,756**	,701**	,359**	,302**	,245**	,340**	1	,895**	,608**	-,346**	-,339**	-,228**	-,138*	-,148**	-,153**	-,279**	,491**	,522**
sqrWKRS	,725**	,707**	,412**	,409**	,195**	,281**	,895**	1	,574**	-,456**	-,438**	-,318**	-,221**	-,219**	-,220**	-,259**	,508**	,545**
logJOBS_03	,796**	,724**	,648**	,527**	,366**	,494**	,608**	,574**	1	-,497**	-,517**	-,310**	-,280**	-,221**	-,342**	-,519**	,538**	,556**
JDPC_03	-,539**	-,555**	-,819**	-,912**	-,157**	-,211**	-,346**	-,456**	-,497**	1	,953**	,727**	,652**	,603**	,593**	,404**	-,408**	-,387**
JDPT_03	-,535**	-,569**	-,843**	-,910**	-,219**	-,227**	-,339**	-,438**	-,517**	,953**	1	,675**	,666**	,559**	,597**	,460**	-,416**	-,399**
DTPC_03	-,517**	-,429**	-,560**	-,614**	-,188**	-,225**	-,228**	-,318**	-,310**	,727**	,675**	1	,625**	,939**	,603**	,371**	-,245**	-,297**
DTPC_03	-,264**	-,221**	-,517**	-,577**	-,149**	-,187**	-,138*	-,221**	-,280**	,652**	,666**	,625**	1	,598**	,920**	,292**	-,202**	-,219**
TIMEPC_03	-,453**	-,322**	-,421**	-,546**	-.064	-,192**	-,148**	-,219**	-,221**	,603**	,559**	,939**	,598**	1	,563**	,326**	-,159**	-,176**
TIMEPT_03	-,321**	-,290**	-,606**	-,533**	-,371**	-,252**	-,153**	-,220**	-,342**	,593**	,597**	,603**	,920**	,563**	1	,430**	-,304**	-,264**
WAIT_03	-,513**	-,525**	-,614**	-,456**	-,483**	-,295**	-,279**	-,259**	-,519**	,404**	,460**	,371**	,292**	,326**	,430**	1	-,352**	-,327**
STOP_03	,550**	,584**	,536**	,437**	,326**	,212**	,491**	,508**	,538**	-,408**	-,416**	-,245**	-,202**	-,159**	-,304**	-,352**	1	,479**
sqrCON_03	,569**	,542**	,481**	,363**	,369**	,346**	,522**	,545**	,556**	-,387**	-,399**	-,297**	-,219**	-,176**	-,264**	-,327**	,479**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Annex 3

SPSS and GEODA Models outputs

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	VIF
1	(Constant)	,935	,037		25,401	,000		
	apc_03	1,098	,092	,544	11,899	,000	1,000	1,000

a. Dependent Variable: logtmpc

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	VIF
1	(Constant)	,645	,025		25,722	,000		
	apt_03	2,181	,128	,680	16,983	,000	1,000	1,000

a. Dependent Variable: logtmpt

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	VIF
1	(Constant)	,381	,043		8,790	,000		
	logjob	,368	,016	,796	23,377	,000	1,000	1,000
2	(Constant)	,508	,037		13,581	,000		
	logjob	,248	,016	,535	15,062	,000	,630	1,587
	sqrcar	,011	,001	,429	12,060	,000	,630	1,587
3	(Constant)	,501	,036		13,873	,000		
	logjob	,205	,018	,444	11,400	,000	,488	2,047
	sqrcar	,011	,001	,441	12,832	,000	,627	1,596
	apc_03	,308	,062	,159	4,960	,000	,718	1,392
4	(Constant)	,513	,036		14,160	,000		
	logjob	,186	,020	,401	9,373	,000	,399	2,507
	sqrcar	,011	,001	,439	12,868	,000	,626	1,596
	apc_03	,335	,063	,173	5,341	,000	,694	1,442
	he_01	,186	,080	,074	2,334	,020	,729	1,371

a. Dependent Variable: logtmpc

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	VIF
1	(Constant)	,149	,049		3,045	,003		
	logjob	,332	,018	,724	18,645	,000	1,000	1,000
2	(Constant)	,196	,043		4,563	,000		
	logjob	,223	,019	,486	11,757	,000	,671	1,491
	sqrwork	,010	,001	,414	10,000	,000	,671	1,491
3	(Constant)	,285	,040		7,073	,000		
	logjob	,123	,021	,268	5,879	,000	,452	2,214
	sqrwork	,010	,001	,414	11,041	,000	,671	1,491
	apt_03	1,030	,123	,336	8,350	,000	,581	1,722
4	(Constant)	,521	,086		6,088	,000		
	logjob	,108	,021	,235	5,080	,000	,428	2,339
	sqrwork	,010	,001	,426	11,460	,000	,663	1,508
	apt_03	,854	,134	,279	6,362	,000	,477	2,095
	waitings_t	-,021	,007	-,122	-3,112	,002	,595	1,681
5	(Constant)	,537	,085		6,295	,000		
	logjob	,099	,021	,217	4,647	,000	,415	2,408
	sqrwork	,010	,001	,403	10,552	,000	,619	1,615
	apt_03	,770	,138	,251	5,578	,000	,445	2,247
	waitings_t	-,021	,007	-,124	-3,189	,002	,594	1,682
	stops_den	,015	,006	,090	2,338	,020	,615	1,627

a. Dependent Variable: logtmpt

```
UMMARY OF OUTPUT: SPATIAL ERROR MODEL - MAXIMUM LIKELIHOOD ESTIMATION
Data set             : GRID_2003_SA_318
Spatial Weight       : Grid_2003_318_queen.gal
Dependent Variable   :     LOGTMPC  Number of Observations:  318
Mean dependent var   :    1.360670  Number of Variables   :    4
S.D. dependent var   :    0.326824  Degrees of Freedom    :  314
Lag coeff. (Lambda)  :    0.561606

R-squared            :    0.819160  R-squared (BUSE)      : -
Sq. Correlation      : -            Log likelihood        :  166.913369
Sigma-square         :   0.0193163  Akaike info criterion :    -325.827
S.E of regression    :    0.138983  Schwarz criterion     :    -310.779

-----------------------------------------------------------------------
    Variable   Coefficient     Std.Error       z-value    Probability
-----------------------------------------------------------------------
    CONSTANT     0.5032246    0.04758228      10.57588     0.00000
      APC_03     0.3944486     0.1036699      3.804853     0.00014
      SQRCAR    0.01134186  0.0008666358      13.08723     0.00000
      LOGJOB     0.1894705    0.01828284       10.3633     0.00000
      LAMBDA     0.5616061    0.06601573      8.507156     0.00000
-----------------------------------------------------------------------

REGRESSION DIAGNOSTICS
DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS
TEST                                     DF      VALUE        PROB
Breusch-Pagan test                       3        45.0716     0.00000

DIAGNOSTICS FOR SPATIAL DEPENDENCE
SPATIAL ERROR DEPENDENCE FOR WEIGHT MATRIX : Grid_2003_318_queen.gal
TEST                                     DF      VALUE        PROB
Likelihood Ratio Test                    1        60.9982     0.00000
```

```
SUMMARY OF OUTPUT: SPATIAL ERROR MODEL - MAXIMUM LIKELIHOOD ESTIMATION
Data set             : GRID_2003_SA_318
Spatial Weight       : Grid_2003_318_queen.gal
Dependent Variable   :     LOGTMPT  Number of Observations:  318
Mean dependent var   :    1.030503  Number of Variables   :    6
S.D. dependent var   :    0.323476  Degrees of Freedom    :  312
Lag coeff. (Lambda)  :    0.445761

R-squared            :    0.749095  R-squared (BUSE)      : -
Sq. Correlation      : -            Log likelihood        :  121.976102
Sigma-square         :   0.0262538  Akaike info criterion :    -231.952
S.E of regression    :     0.16203  Schwarz criterion     :     -209.38

-----------------------------------------------------------------------
    Variable   Coefficient     Std.Error       z-value    Probability
-----------------------------------------------------------------------
    CONSTANT     0.4402081    0.09100714      4.837072     0.00000
      APT_03     0.7678347     0.1785807      4.299652     0.00002
     SQRWORK    0.00954661  0.0009805734      9.735742     0.00000
      LOGJOB     0.1270074     0.0215025      5.906632     0.00000
  WAITINGS_T   -0.01678668   0.007173306      -2.34016     0.01928
   STOPS_DEN    0.01178418   0.006009846      1.960812     0.04990
      LAMBDA     0.4457612    0.07580653      5.880249     0.00000
-----------------------------------------------------------------------

REGRESSION DIAGNOSTICS
DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS
TEST                                     DF      VALUE        PROB
Breusch-Pagan test                       5        79.3976     0.00000

DIAGNOSTICS FOR SPATIAL DEPENDENCE
SPATIAL ERROR DEPENDENCE FOR WEIGHT MATRIX : Grid_2003_318_queen.gal
TEST                                     DF      VALUE        PROB
Likelihood Ratio Test                    1        25.9919     0.00000
```

```
SUMMARY OF OUTPUT: SPATIAL LAG MODEL - MAXIMUM LIKELIHOOD ESTIMATION
Data set             : Grid_2011_SA-318
Spatial Weight       : Grid_2011_SA-318_queen.gal
Dependent Variable   :  LOGTMPC_11  Number of Observations:  318
Mean dependent var   :     1.38622  Number of Variables   :    5
S.D. dependent var   :    0.308305  Degrees of Freedom    :  313
Lag coeff.   (Rho)   :    0.329847

R-squared            :    0.729904  Log likelihood        :     128.202
Sq. Correlation      : -            Akaike info criterion :    -246.403
Sigma-square         :   0.0256732  Schwarz criterion     :    -227.593
S.E of regression    :    0.160229

-----------------------------------------------------------------------
    Variable   Coefficient     Std.Error       z-value    Probability
-----------------------------------------------------------------------
W_LOGTMPC_11     0.3298475    0.05996577      5.500596     0.00000
    CONSTANT     0.1991211    0.06184629      3.219613     0.00128
      APC_11     0.3023718    0.09045151      3.342915     0.00083
   SQRCAR_11   0.005665949  0.0007114571      7.963866     0.00000
   LOGJOB_11     0.1831995    0.01814298      10.09754     0.00000
-----------------------------------------------------------------------

REGRESSION DIAGNOSTICS
DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS
TEST                                     DF      VALUE        PROB
Breusch-Pagan test                       3         8.4128     0.03821

DIAGNOSTICS FOR SPATIAL DEPENDENCE
SPATIAL LAG DEPENDENCE FOR WEIGHT MATRIX : Grid_2011_SA-318_queen.gal
TEST                                     DF      VALUE        PROB
Likelihood Ratio Test                    1        26.4611     0.00000
```

```
SUMMARY OF OUTPUT: SPATIAL ERROR MODEL - MAXIMUM LIKELIHOOD ESTIMATION
Data set             : Grid_2011_SA-318
Spatial Weight       : Grid_2011_SA-318_queen.gal
Dependent Variable   :  LOGTMPT_11  Number of Observations:  318
Mean dependent var   :    0.972920  Number of Variables   :    6
S.D. dependent var   :    0.378689  Degrees of Freedom    :  312
Lag coeff. (Lambda)  :    0.263228

R-squared            :    0.779977  R-squared (BUSE)      : -
Sq. Correlation      : -            Log likelihood        :   96.510266
Sigma-square         :   0.0315524  Akaike info criterion :    -181.021
S.E of regression    :     0.17763  Schwarz criterion     :    -158.448

-----------------------------------------------------------------------
    Variable   Coefficient     Std.Error       z-value    Probability
-----------------------------------------------------------------------
    CONSTANT     0.1771493    0.09577634      1.849615     0.06437
      APT_11      1.187908     0.1973981      6.017829     0.00000
  SQRWORK_11    0.01052786   0.001267714      8.304605     0.00000
   LOGJOB_11     0.1646335    0.02494181      6.600702     0.00000
  WAITS_TIME   -0.01638693    0.00644672     -2.541903     0.01103
   STOP_DENS    0.02657789   0.006471562      4.106875     0.00004
      LAMBDA     0.2632278    0.08840631      2.977477     0.00291
-----------------------------------------------------------------------

REGRESSION DIAGNOSTICS
DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS
TEST                                     DF      VALUE        PROB
Breusch-Pagan test                       5        67.1661     0.00000

DIAGNOSTICS FOR SPATIAL DEPENDENCE
SPATIAL ERROR DEPENDENCE FOR WEIGHT MATRIX : Grid_2011_SA-318_queen.gal
TEST                                     DF      VALUE        PROB
Likelihood Ratio Test                    1         6.7910     0.00916
```