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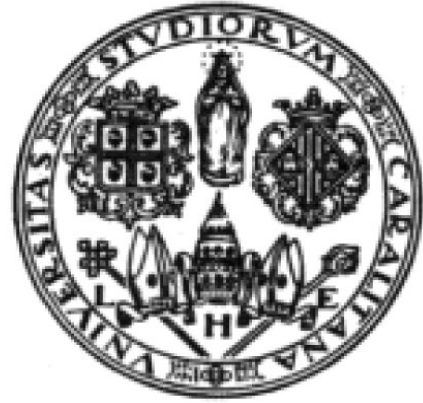**University**
of Lisbon

University
of Cagliari

Parameters for the Choice of Propagation and Traffic Models for Cell Planning in UMTS

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"Do not try to bite off more than you can chew."

My father.

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Abstract

Having been pointed out the need for the construction of a tool for the automatic selection of propagation and traffic models for cell planning in UMTS, in the European project MOMENTUM (MOdels and SiMulations for NEtwork PlaNning and ConTrol of UMTS), an innovative approach for its achievement is addressed in this report. The parameters that are available in digital terrain models, as well as parameters that can be used for the selection of propagation models like COST 231- Hata, COST 231- Walfisch-Ikegami and 3GPP, and for the classification of the different areas for traffic distributions are identified, analysed in detail, and all the thresholds for the automatic choice are set according to simulation results. A software implementation, using an object oriented programming language (C++), for the construction of the tool is done. A set of cities, according to the MOMENTUM choice, are identified, and some results of the tool, based on cell planning simulations, are presented, and visualised with a GIS tool, with grids with a resolution of 100 m, for the cities of Lisbon, Porto, Berlin and The Hague.

Keywords

UMTS, Propagation Models, Traffic Distributions, GIS, Grids.

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List of Acronyms

1G	1st Generation
2G	2nd Generation
3G	3rd Generation
3GPP	Third Generation Partnership Project
AMPS	Advanced Mobile Phone System
BER	Bit Error Rate
CDMA	Code Division Multiple Access
CLPC	Closed Loop Power Control
CN	Core Network
CT	Cordless Telephone
DRNC	Drift Radio Network Controller
DTMs	Digital Terrain Models
EDGE	Enhanced Data for Global Evolution
EIRP	Equivalent Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
GERAN	GSM/EDGE Radio Access Network
GIS	Geographic Information System
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
IMT2000	International Mobile Telecommunications 2000
IP	Internet Protocol
IS	Interim Standard
ITU	International Telecommunication Union
LoS	Line of Sight
MCL	Minimum Coupling Loss
ME	Mobile Equipment
MID	MapInfo® Interchange Data
MIF	MapInfo® Interchange Format

MOMENTUM	MOdels and SiMulations for NEtwork PlaNning and ConTrol of UMTS
MSS	Mobile Satellite Systems
MT	Mobile Terminal
NLoS	Non Line of Sight
NMT	Nordic Mobile Telephone
OLPC	Open Loop Power Control
OVSF	Orthogonal Variable Spreading Factor
PCS	Personal Communications System
PDC	Personal Digital Communications
PMR	Private Mobile Radio
QoS	Quality of Service
RNC	Radio Network Controller
RSN	Radio Sub Network
RTT	Radio Transmission Technology
SF	Spreading Factor
SIR	Signal to Interference Ratio
SMS	Short Messages Service
SRNC	Serving Radio Network Controller
SGSN	Serving GPRS Support Node
TACS	Total Access Communications System
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TD-SCDMA	Time Division – Synchronous Code Division Multiple Access
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
USIM	UMTS Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
WAP	Wireless Application Protocol
WCDMA	Wideband Code Division Multiple Access
WLL	Wireless Local Loop
WP	Work Package

List of Symbols

α_j	Ortoghonality of channel for user j
η_{DL}	Downlink load factor
η_{UL}	Uplink load factor
φ	Road orientation with respect to the direct radio path
λ	Wavelength
μ_X	Mean value of x in a ΔS-type pixel
σ_X	Standard deviation of x_n values in a ΔS-type pixel
τ	Call duration
ΔL	Original grid pixel side size
ΔS	Sampling grid pixel side size
a	Antenna height
b	Building separation
BH_MV	Building height mean value
BH_STDEV	Building height standard deviation
BI	Building index
c	Function of the angle of the street crossing
C_m	Correction factor
d	Distance between the transmitter and the receiver
D_{hb}	Base station antenna height (measured from the average rooftop level)
d_n	"Illusory distance"
d_{sh}	Shortest physical geographical distance from the transmitter and the receiver
E_b	Received energy per information bit
f	Carrier frequency
F	Receiver noise figure
F_{FM}	Fast fading margin
F_M	Fading margin
F_N	Noise factor
F_{SM}	Slow fading margin

G_{Rx}	Receiver antenna gain
G_{SH}	Soft handover gain
G_{Tx}	Transmitter antenna gain
h_{BS}	Base Station antenna height
h_{MT}	Mobile Terminal antenna height
h_{Roof}	Buildings height
i_j	Ratio of other cell to own cell Base Station power, received by user j
I_0	Interference power
I_m	Interference margin
IR	Information Rate
I_Y	Land use class Y index in a ΔS-type pixel
j	Total effective noise plus interference density
K	Rice factor
k	Normalization parameter
K_a	Increase of the power loss for Base Station antenna
K_d	Multi-screen diffraction ratio (loss versus distance)
K_f	Multi-screen diffraction ratio (loss versus radio frequency)
K_{rur}	Rice factor for rural area
K_{sub}	Rice factor for suburban area
L_{msd}	Multiple screen diffraction loss
L_o	Free-space loss
L_{Ori}	Empirical correction factor
L_{Other}	Other additional attenuations
L_p	Path loss
L_{pmax}	Maximum propagation loss allowed for a given service
$L_{p,macro}^{50\%}$	Median path loss for macro-cell
$L_{p,micro}^{50\%}$	Median path loss for micro-cell
L_{rst}	Rooftop to street diffraction and scatter
L_{UB}	Body loss additional attenuations
L_x	Additional attenuations
L_c	Cable loss additional attenuations
$M(p)$	Path loss or intermediate result evaluated at the transition region
MCL	Minimum Couple Loss

$M_H(p)$	Path loss or intermediate result valid for high values of parameter p
$M_L(p)$	Path loss or intermediate result valid for low values of parameter p
n	Number of straight street segments between Base Station and Mobile Terminal (along the shortest path)
N	Thermal Noise Density
N_0	Total effective noise
N_c	Number of connections per cell
N_u	Number of users per cell
OAI	Open areas index
p	General parameter for evaluation of a scenario
P_r	Received antenna input power
P_t	Transmitted antenna output power
P_{Rx}	Receiving signal power
P_{Tx}	Transmitting signal power
R_b	Bit Rate
R_N	Receiver interference power
R_{No}	Receiver noise density
R_{Smin}	Receiver sensitivity for a given service bearer
s_{n-1}	Length of the last segment
SF	Spreading factor
SI	Street index
SW_MV	Street width mean value
SW_STDEV	Street width standard deviation
T	Offered traffic
TH_MV	Terrain height mean value
TH_STDEV	Terrain height standard deviation
VI	Vegetation index
w	Width of road
W	W-CDMA chip rate
WI	Water index
x_n	Layer value in ΔL-type pixel n
X	Layer value being calculated
Y	Land use class

1 Introduction

1.1 Focus on Mobile Phone

Nowadays, a mobile phone belongs to a strict whole of things that are the most efficient and useful for every day's life. A mobile telephone is designed to give maximum freedom of movement to the user, even though today it can be considered as something more than a simple device used for wireless voice speech. It is a symbol of fashion, a precious tool enssuring many basic services.

Everyone can personalise a mobile phone in design (model, cover…) and in its functionalities (operator choice, ring tone…), and keep private notions on it (address book, diary, received sms…), thus, since the purchase, the user reaches a special interaction with his mobile, which day by day becomes an inseparable "travel-mate".

Customers require a mobile phone that meets their needs, ensuring a lot of services, which must be not only simple and efficient, but most of all reliable. That is why the number of these services increased, reducing their costs while improving themselves in quality.

For all these reasons, mobile phones are developed from First Generation (1G) to the Third one (3G). In this last generation, the top level of services and functionalities is represented, for instance in Europe, by UMTS (Universal Mobile Telecommunications Systems), where data, text images, audio and video can be transmitted. 3G is designed for multimedia communications, allowing users to have a combined camera, video camera, computer, stereo and radio, all included in one terminal.

Rich-media information and entertainment will be at everyone's fingerprints whenever wanted, in any place where there is a wireless network. In fact, a wireless network does not mean just services and functionalities, but, most of all, it is required to provide efficient and reliable network coverage in any kind of environment: a very difficult target to be reached.

1.2 Short history of mobile phones

When Guglielmo Marconi developed, with his experiments in 1895, the way to produce a device capable of making electromagnetic waves travel through the air, giving birth to wireless communications, he certain could not think that thanks to his discovery the telephone would become one of the most useful and essential objects for XX century's mankind. Although electromagnetic waves were first discovered as a communications means at the end of the XIX century, it was the necessary to wait until the late 1940s to see the first system offering mobile telephone services (car phone).

Those early single cell systems were severely constrained by restricted mobility, low capacity, limited service, and poor speech quality; the equipment was heavy, bulky, expensive, and susceptible to interference. Because of those limitations, less than one million subscribers were registered worldwide by the early 1980s. These cellular systems, called First Generation (1G), still transmit only analogue voice information, the most prominent being Advanced Mobile Phone System (AMPS), Nordic Mobile Telephone (NMT), and Total Access Communication System (TACS) [IECP02].

The need to improve transmission quality, system capacity, and coverage, drove to the birth of the Second Generation cellular systems (2G); further advances in semiconductor technology and microwave devices brought digital transmission to mobile communications. At the same time, the demands for fax, short message, and data transmissions were growing rapidly. 2G includes Global System for Mobile communications (GSM), Digital AMPS (D-AMPS), Code Division Multiple Access (CDMA), and Personal Digital Communication (PDC) [IECP02].

Today, multiple 1G and 2G standards are used in worldwide mobile communications. The European market is controlled by GSM, supporting some 250 million of the world's 450 million cellular subscribers with international roaming, in approximately 140 countries and 400 networks [IECP02]. It uses TDMA (Time Division Multiple Access) as its radio transmission technology. Network operators in most of the world use the original GSM spectrum allocation at 900 MHz, while additional spectrum at 1800 MHz is used for GSM in many countries. In many areas of the United States, there are GSM systems operating in the 1900 MHz PCS (Personal Communication Systems) frequency band [Intro02].

Considering the many available options, dual-band GSM phones are quite commonplace now. Circuit-switched voice calls are still the most commonly used services in

GSM networks, although users start using also data services. Current data services over GSM generally allow to transfer files or data and to send faxes at 9.6 kbit/s, in a circuit switched operation.

The spreading of Internet and its services lead to the Wireless Application Protocol (WAP). WAP is an open, global specification, which gives mobile users the opportunity to access and interact easily with information and services. It is a collection of languages and tools, and an infrastructure for implementing services for mobile phones, similar to the World Wide Web. Unlike marketers claim, WAP does not bring the existing content of the Internet directly to the phone, since there are too many technical and other problems for this to work properly. WAP is advertised as bringing "the web" onto the mobile phone, but in reality, the bottom line is that WAP is not "the web" on the mobile phone, but something a lot less. WAP can be used to build many mobile phone specific services and to give very limited web access from mobile phones.

The transition from 2G to 3G is technically extremely challenging (requiring the development of new transmission technologies), and highly expensive (requiring vast capital outlay on new infrastructure). For both of these reasons, it makes sense to move to 3G via intermediate 2.5G standards, Figure 1-1.
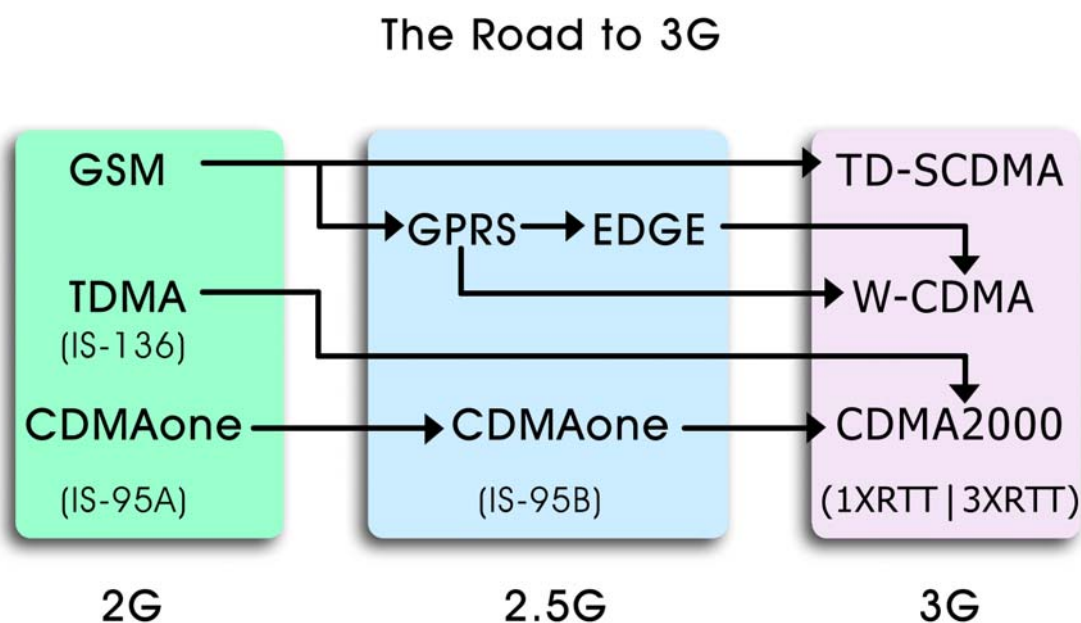
Figure 1-1 - From 2G to 3G (adapted from [GNET02]).

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2.5G radio transmission technologies are different from 2G technologies, because they use packet switching. GPRS (General Packet Radio Service) is the European 2.5G standard, the upgrade from GSM; GPRS overlays a packet-switched architecture onto the GSM circuit-switched one, and data transfer rates will reach on average 50 kbit/s. EDGE (Enhanced Data for Global Evolution) is another 2.5G upgrade path from GSM, its data rates being three times faster than GPRS ones; realistically, the maximum rate that EDGE it will be able to achieve will be 150 kbit/s.

The 2.5G upgrade from CDMA-one (Interim Standard-95a) is CDMA-one (IS-95b), which adds packet-switched capability (data rates up to 115 kbit/s), arriving to the 3G CDMA 2000 deployed into its two phases through 1XRTT and 3XRTT (data rates up to 614 kbit/s and 2 Mbit/s respectively), where 1X and 3X are spectrum migration technologies for the existing IS-95 bands and systems, and RTT stands for Radio Transmission Technology, Figure 1-1, [IECP02].

Moreover, today, it is possible to speak about 3G mobiles, and 4G is actually object of study among researchers.

1.3 General aspects of UMTS

UMTS is the European vision of a 3G mobile communication systems. The goal of UMTS is to provide lots of services boosting the current ones, but above all, offering global radio coverage and worldwide roaming. In order to reach this goal, a series of networks must be built, allowing consumers to use their phone anytime, anywhere. But all this is far from becoming a reality, since across the world operators and vendors did not seem to agree on a single air interface, so, to make this happen, the wireless community has focused its attention on developing multimode systems that can support CDMA, TDMA, GSM, GPRS, wideband CDMA (W-CDMA), and a host of other air interfaces in the same box, in spite of having a lot of standards different in target group, mobility, service area, etc., Figure 1-2.

In order to be possible to go anywhere in the world secure that the mobile phone is compatible with the local system, a scenario known, as "global roaming" is needed. Unfortunately, the process of unifying the numerous international standards has proved to be extremely difficult and time consuming. International Telecommunication Union (ITU) started the process of defining the standard for 3G systems, referred to as International Mobile Telecommunications 2000 (IMT-2000).

In Europe, European Telecommunications Standards Institute (ETSI) is working to develop technical standards for UMTS, and it is responsible for the UMTS standardisation process.
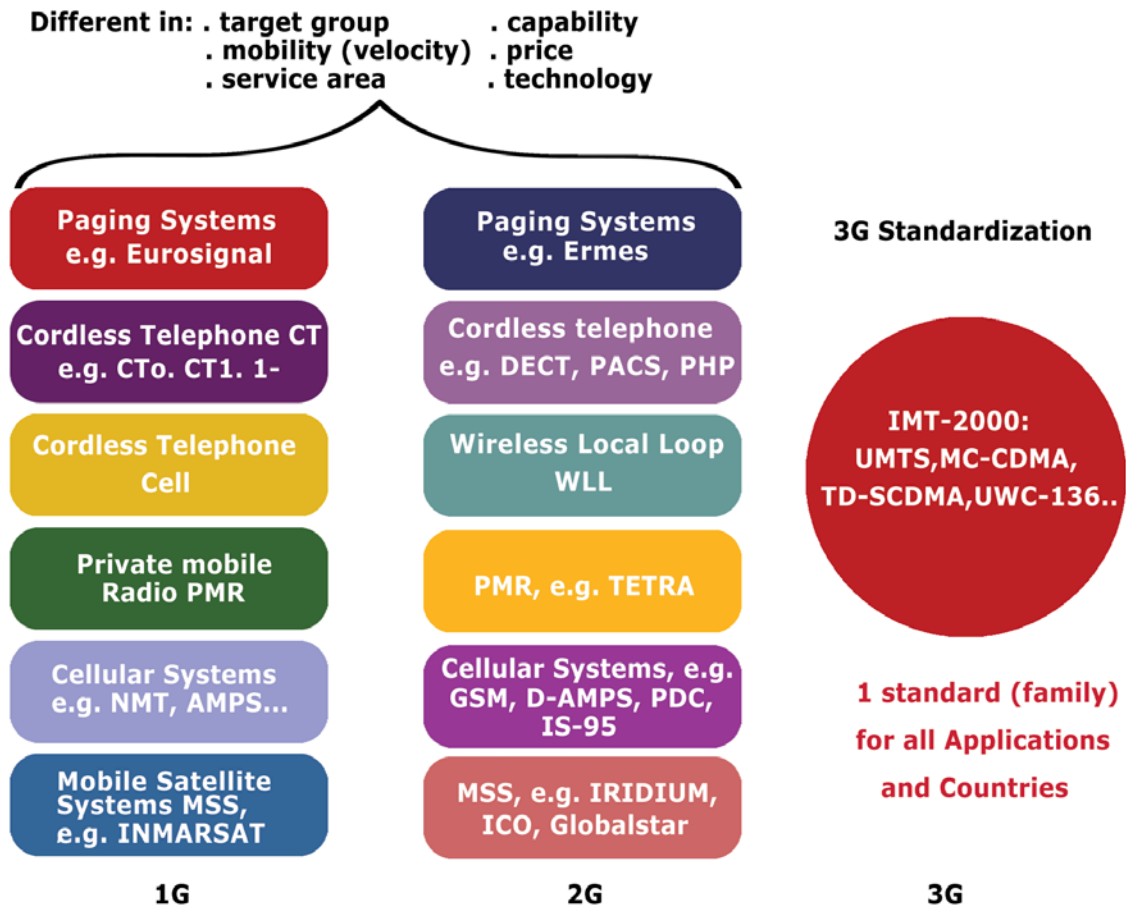
Figure 1-2 - Multiple Standards from 1G to 3G (adapted from [IECP02]).

It is expected that with IMT-2000 phones using all these different standards will be able to move without problems among all networks, thus, providing global roaming. In 1998, Third Generation Partnership Project (3GPP) was formed to work with international standards bodies, and to make technical specifications for UMTS and 3G mobile telephony. 3GPP has five main UMTS standardisation areas: Radio Access Network, Core Network, Terminals, Services and System Aspects, and GERAN (GSM/EDGE Radio Access Network). Each area is responsible for all the technical aspects and specifications of the system, so that any part is standardised and analysed in all its details.

The main UMTS innovations are ([Corr02a]):
- Bit rates up to 2 Mbit/s

- Variable bit rate to offer bandwidth on demand
- Multiplexing of services with different quality requirements on a single connection, e.g., speech, video and packet data
- Delay requirements from delay-sensitive real time traffic to flexible best effort packet data
- Different quality requirements associated to different services
- Coexistence of second and third generation systems and inter-systems handovers for coverage enhancements and load balancing
- Support of asymmetric uplink and downlink traffic (e.g., web browsing causes more load in downlink than in uplink)
- High spectrum efficiency
- Coexistence of FDD and TDD modes

In addition, the shape and the design of mobile phones have to satisfy the innovation of services. In Figure 1-3, examples of new UMTS models are shown, where it is evident the great display relevance and the addition of a micro web-cam for multimedia application, like videoconference.

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Figure 1-3 - Examples of UMTS mobiles (adapted from [NOKI03]).

1.4 Motivations

There are many planning tools these days for cellular planning purposes, within which propagation models play an important role, for either coverage or interference estimation.

Nevertheless, in these tools, the user still has a key part, in choosing in which areas a specific propagation model should be used, since no automatic choice is performed by the tool. Reasons for the applications of different propagation models, within a large planning area have to do with the enormous variety of different requirements to the prediction model in the various propagation environments. Although propagation models are an area of intensive research, a universal propagation model applicable to all possible propagation situations is not available. The same problem occurs for the use of traffic models, since in fact the classification of the different traffic distribution scenarios is many times defined without any heuristic method but just according to the user opinion. Furthermore, both propagation and traffic models require Digital Terrain Models (DTMs) with different content, granularity and resolutions, so that the work complexity to perform a correct cell planning, in an automatic way, increases.

Nowadays, the need of a tool for the automatic choice of propagation and traffic models for cell planning in UMTS, is really an interesting topic, and it holds a great importance for mobile communications; some steps have already moved in this direction and some first frameworks have already been presented to reach this goal, nevertheless, a lot of work still needs to be done, for the complete achievement of this tool. It seems clear that to carry out such task, above all, a key issue is the identification of the parameters that can be used to perform an automatic selection without the intervention of the tool user; since tools are being based on DTMs, it is also necessary, that these parameters can be obtained from DTMs, which implies that parameters associated to DTMs need to be identified as well. The selection parameters that will be used as criteria for selection of a propagation and traffic models have to be based on the available data in the tool and parameters for cell selection.

This work proposes an innovative approach to achieve the construction of a first version of a tool for the automatic choice of propagation and traffic models, implementing a code that applies the propagation and traffic theories of mobile communications in cell planning, combining the object oriented programming powerful flexibility, with the great GIS tools graphical utilities.

MOMENTUM is the acronym of Models and Simulations for Network Planning and Control of UMTS [MOME01], which is an European Commission Fifth Framework project, started in August 2001, and working on the performance assessment of relative mature UMTS radio networks and on the optimisation of their design.

The project aims at a long lasting impact on the development of UMTS planning tools, and focuses on two key aspects in UMTS network planning: the expected time and location

variant demand distribution for mobile users, and how this can be satisfied by a given network configuration. MOMENTUM addresses the first aspect by defining flexible discrete and probabilistic models for the resource demand of various service types, together with expected user mobility patterns, a great flexibility being needed to ensure the possibility to adapt and tune the results to the circumstances that may change in time. The second aspect is treated at three levels, the first one dealing with the most accurate performance evaluation that is reached by means of a dynamic real-time system-level simulator to be developed; this simulator will supersede previous simulators by being capable of handling relative large-scale networks (order of magnitude: 100) and by taking most dynamic aspects of UMTS into account, including radio resource management and users' behaviour (mobility, bursty tele-traffic); to achieve this goal, the simulator is specifically designed to run on massive parallel super-computers and workstation clusters. In the second one, for every-day planning purposes, a fast snapshot-based simulation method and a simulation prototype will be designed and tuned in order to fit the results of dynamic simulations the best way as possible, focus being on packet-oriented, i.e., highly bursty, traffic; the networks simulated in this way will have - in practice - an order of magnitude of 1000-10000. In the third one, during automatic planning, tens of thousands of configurations need to be considered, and an even faster evaluation with heuristic rules is required in this context where such rules are identified. The main project is divided in six different work packages:

- WP-0 Project Management;
- WP-1 Traffic Estimation and Service Characterisation;
- WP-2 Traffic Modelling and Simulations for radio Resource Management;
- WP-3 Dynamic Simulations for radio Resource Management;
- WP-4 Automatic Planning of Large-Scale Networks;
- WP-5 Assessment and Evaluation;
- WP-6 Dissemination and Implementation.

This work deals with the WP-4 work as part of the overall objective to develop flexible mathematical models and algorithmic methods that allow an automatic planning and optimisation of the RF configuration of large-scale UMTS networks.

In order to create a tool with the capability of the automatic selection of an appropriate propagation model, in an independent way, for a given environment, a good description of the propagation scenario is needed. The aim of this tool is to eliminate the user interaction in choosing in which areas a specific propagation model should be used, so that the selection

will not be pre-assigned to a scenario, and will be completely based on scenario descriptive layers as shown in Figure 1-4.
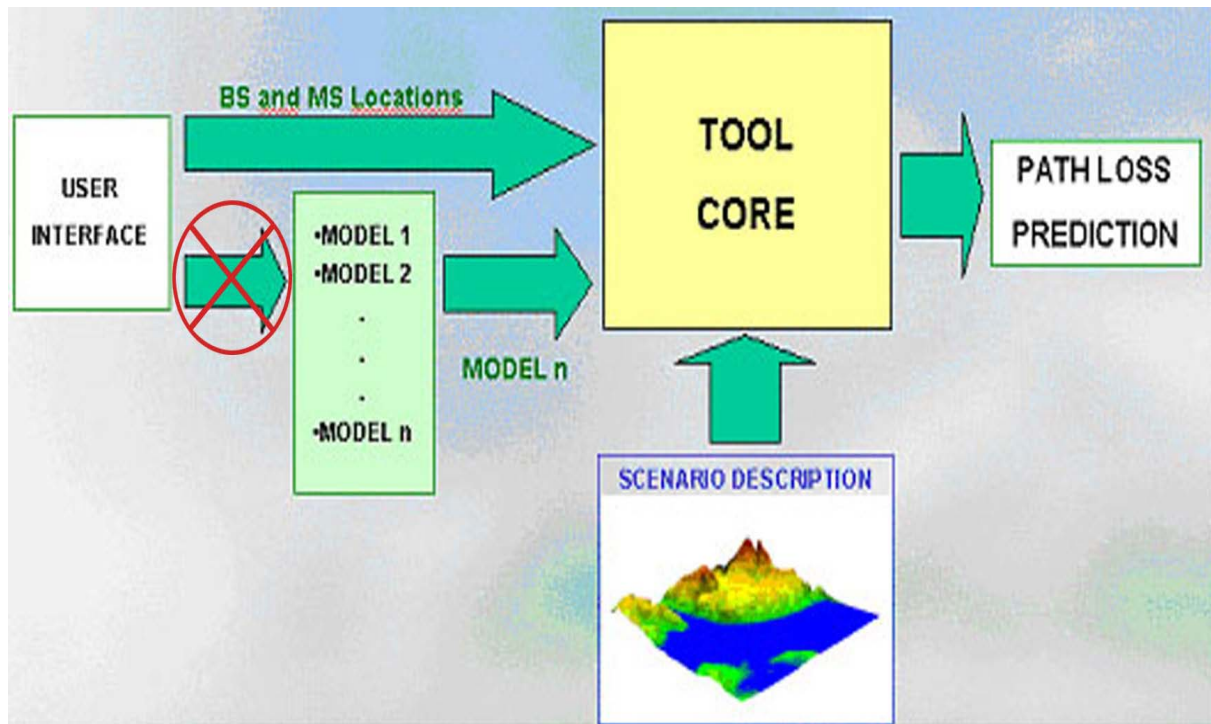
Figure 1-4 - Perspective of automatic model selection tool (adapted from [CoVe02]).

The report is divided in six Chapters and two Annexes. In Chapter 1 a short history of mobile communications from first to third generation is presented, analysing the main standard and performances of each generation and the reasons that lead to the UMTS standard. Then the UMTS general aspects addressing its main innovations, and the motivations for this work, including a short description of MOMENTUM project are shown. In Chapter 2 a general technical overview on UMTS descriptions dealing with spectrum allocation, network architecture, WCDMA, services and applications, capacity and interference is addressed. Chapter 3 deals with propagation models (COST 231 Hata, COST 231 Walfisch-Ikegami, and 3GPP models) and with traffic distributions main properties, and the parameters dealing with typical UMTS cell planning and link budget are described as well. In Chapter 4 the methods for the choice of the parameters, their definition, and the thresholds to allow an automatic selection of both propagation and traffic models are shown as well as the algorithm, which stands at the base of the automatic tool, development and detailed description. Chapter 5 presents the main results obtained in this works with the relative comments and explanations. In Chapter 6 the conclusions of this works are drawn and

some suggestions and ideas for future works are presented. The two Annexes show the complete collections of histograms and maps respectively. These layouts are based on the input data for the 100 m resolution grids, for the cities of Lisbon, Porto, Berlin and The Hague, and represent the layers chosen and used in this work for characterizing scenarios and making the automatic selection of the models.

2 A Brief UMTS Description

2.1 Generic Technical Aspects

UMTS brings together two powerful forces into one environment: wideband radio with its high-speed radio access communications, and IP based services. The step towards IP is very important, and it should be considerate vital; in fact IP is a packet-based system that enables a very fast and efficient access by its connection nature. Due to the higher data rates up to 2 Mbit/s, the bandwidth of the radio channels is larger (5 MHz instead of 200 kHz with GSM). In Figure 2-1 the spectrum allocation for the main types of systems for major world countries is illustrated.
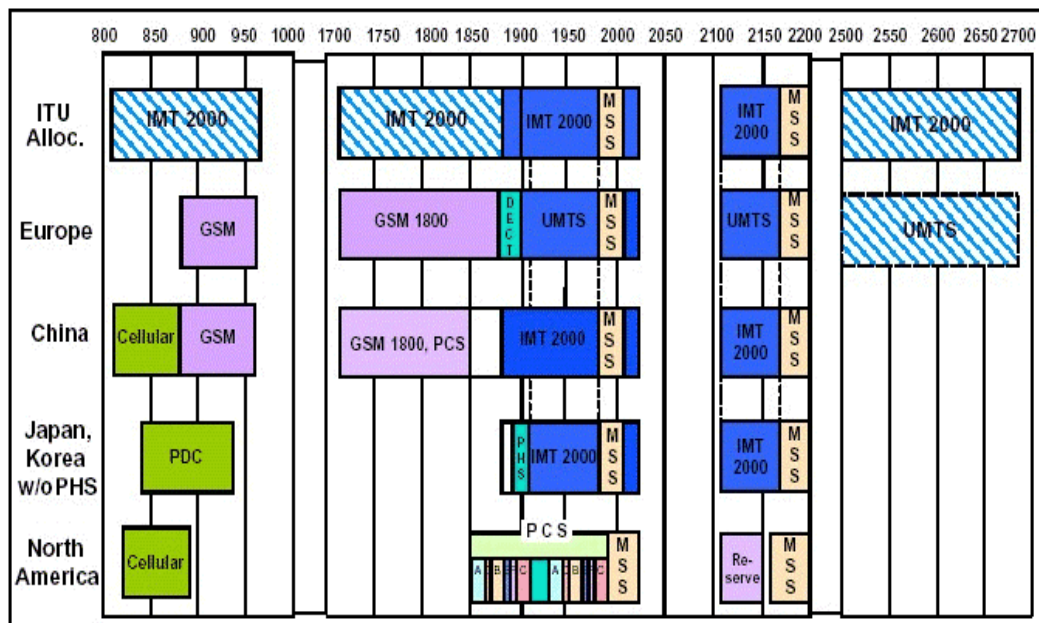
Figure 2-1 - Spectrum allocation (extracted from [UMTS00]).

The spectrum for UMTS in Europe lies between 1900 MHz and 2170 MHz. For the satellite service, a subband in the UMTS spectrum is reserved (uplink 1980 MHz to 2010 MHz, and downlink 2170 MHz to 2200 MHz). The remaining spectrum for terrestrial use is divided between two modes of operation.

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In the FDD (Frequency Division Duplex) mode, there are two equal bands (paired) for the uplink (1920 MHz to 1980 MHz) and for the downlink (2110 MHz to 2170 MHz). In the TDD (Time Division Duplex) mode, unpaired bands are used (1900 MHz to 1920 MHz and 2010 MHz to 2025 MHz), for both up- and downlinks, [UMTS98], [HoTo00].

The following paragraphs describe just the main UMTS aspects concerning network architecture, WCDMA, services and applications, and power budget, interference, and capacity.

2.2 UMTS Network Architecture

A UMTS network is characterised by the coexistence of two different sub networks that on the one hand carry the user traffic and on the other assure the management and control of the traffic. A third sub network, called User Equipment (UE), can be added to complete the architecture and to interface with user and the radio interface allowing access to UMTS services; hence, a UMTS network consists of three interacting domains [HoTo00]:

- Core Network (CN)
- UMTS Terrestrial Radio Access Network (UTRAN)
- User Equipment (UE)

The main function of the CN is to provide switching, routing and transit for user traffic; it also contains the databases and network management functions. The basic Core Network architecture for UMTS is based on GSM network with GPRS (constituted by SGSN -Serving GPRS Support Node, and MSC – Message Service Centre); nevertheless, all equipment has to be modified for UMTS operations and services.

The UTRAN provides the air interface access to the UE. The access to the network is composed by a group of Radio Sub-Network (RSN) and Base Station (BS), referred as Node-B, while its control equipment is called Radio Network Controller (RNC). Each Node-B manages a group of different cells (usually 3 to a maximum of 6) using one or two of basic modes of operation (FDD and TDD), depending on the cell where it is working, Figure 2-2.

The TDD mode does not allow long-range transmission (the delays incurred would cause interference between the up- and the downlink); for this reason, it can only be used in environments where the propagation delay is small (pico-cells).

An air interface, called Uu, supports the link between users and the network; it transmits the user data and all the information used for the management of mobility, radio resources, and network control, while the other interfaces Iu, Iur, and Iub provide the other UMTS network architecture blocks linkage.
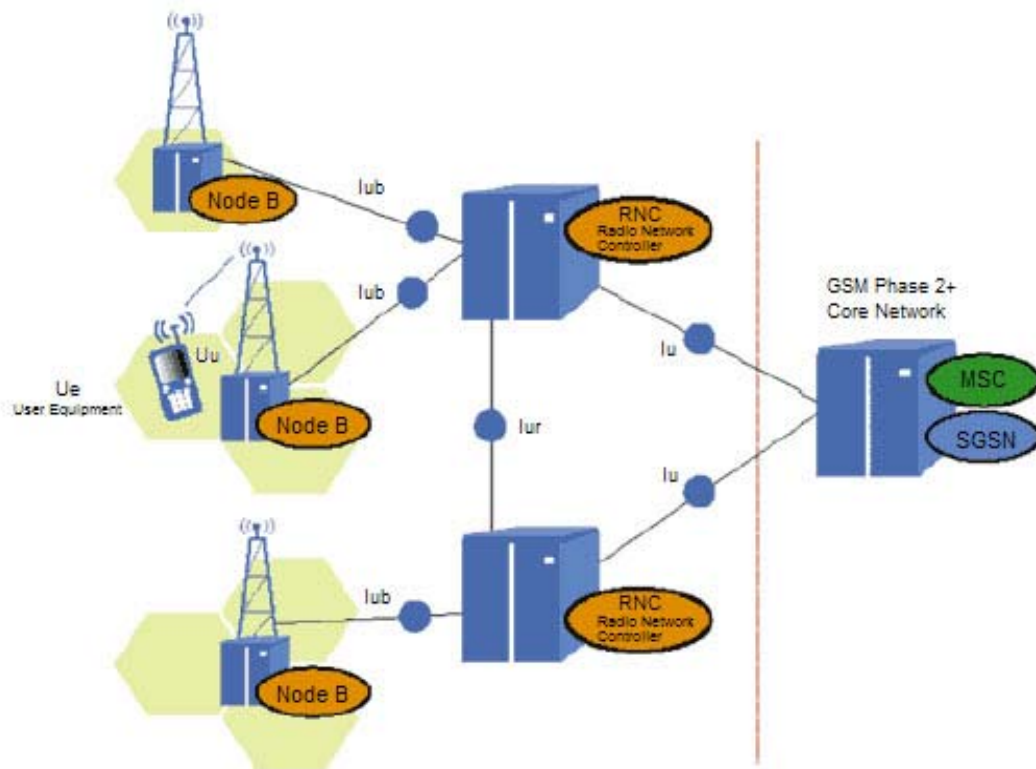
Figure 2-2 - UTRAN structure (adapted from [IECP02]).

RNS is linked to CN by Iu interfaces supporting both packet-switching (Iu-PS) and circuit switching (Iu-CS), so that the architecture of the CN may change when new services and features are introduced according to the service in use [3GPP99]. RNC manages the amount of functionalities of the radio interface among users, and allows the transport of services toward the CN in a transparent manner. In this way, the UTRAN can control user mobility and handover functionalities, while the CN is very distinguished from all the transport of the service functions. RNC works in two different modes: "Serving" (SRNC) or "Drift" (DRNC), SRNC controls and manages all the user resources, whereas DRNC just readdresses all the signals from Node-B to the SRNC by allocating the previous chanalisation codes. Through handover procedures applied to this process, the user is able to receive data from an RNC different from the one of the original call, Figure 2-3.
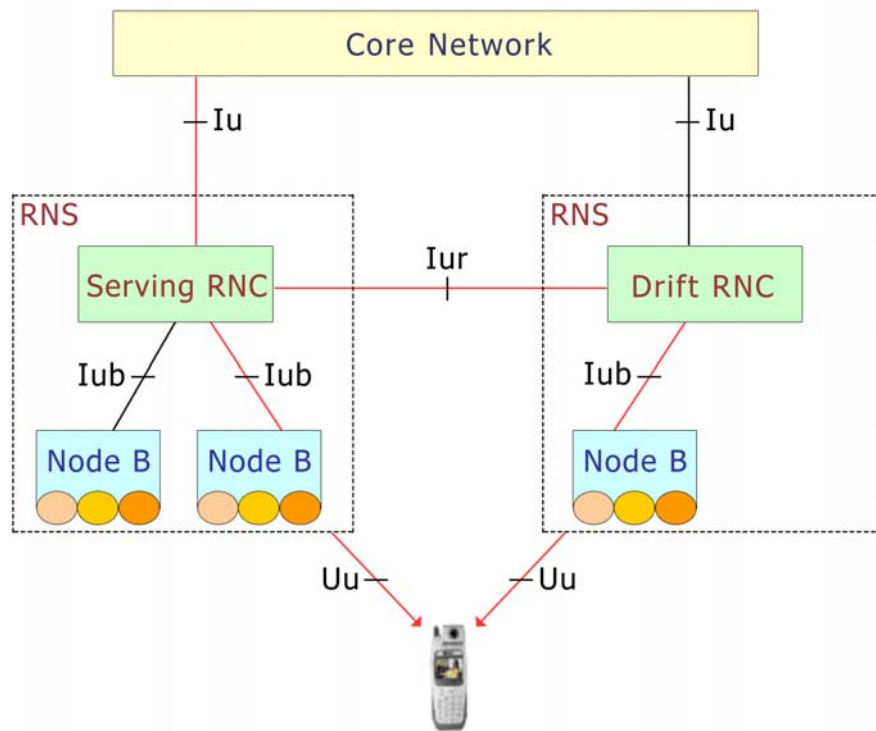
Figure 2-3 - RNC structure (adapted from [Info02]).

The UMTS standard does not restrict the functionality of the UE in any way, and Mobile Terminals (MTs) work as an air interface counter part for Node-B and have many different types of identities; most of these UMTS identity types are taken directly from GSM specifications. The 3G-network terminal is constituted by the UE, which is sub-divided into the Mobile Equipment (ME) Domain, and the User Services Identity Module (USIM) Domain; ME is used for radio communications, while USIM consists of a smart card containing all data and security procedures [HoTo00].

2.3   Wideband Code Division Multiple Access

Wideband Code Division Multiple Access (W-CDMA) is a Direct Sequence CDMA system, where user data is multiplied with quasi-random bits derived from W-CDMA

Spreading codes. By W-CDMA, all the users are able to use all the bandwidth at the same time; besides simplifying the management of a large number of users, UMTS splits the original band into sub-bands of 5 MHz. One code (called chanalisation code) is associated to each user, allowing decoding of the signal in a simple manner, so that all the other codes are, for the receiver, just interference; the codes must be orthogonal to each other, and keep this ortoghonality if they are shifted. In order to assure the ortoghonality of the codes, the OVSF method is used, Figure 2-4.
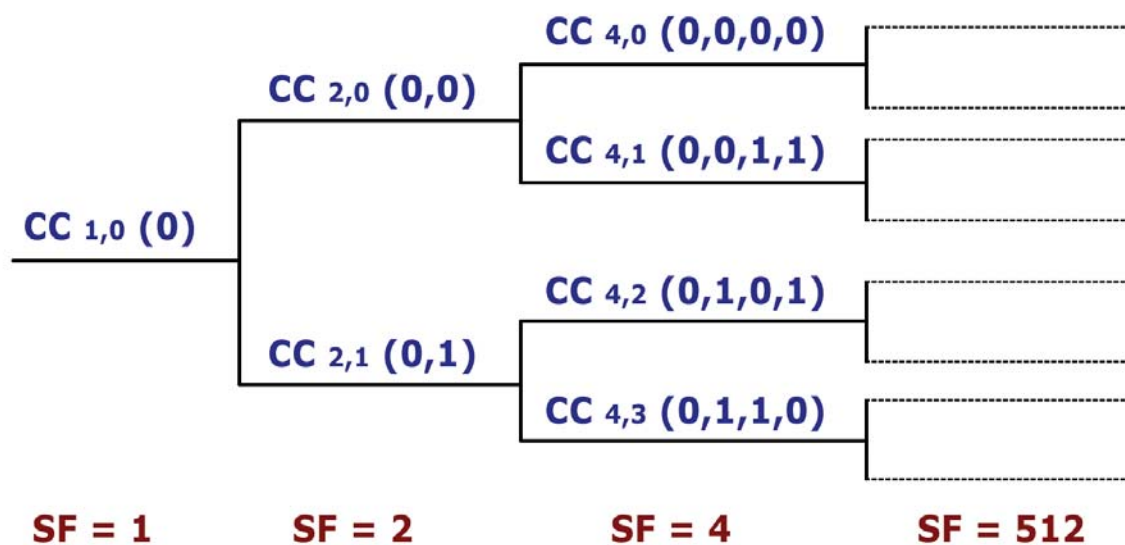
Figure 2-4 - OVSF method (adapted from [3GPP00b])

WCDMA supports both FDD and TDD modes, the main difference being that with the first mode separate sub-band are used for up- and downlinks respectively, whereas in the second, only one sub-band is shared between the up- and downlinks. W-CDMA does not fix a standard value of power, but it just works with a variable minimum one depending on the demanded service; moreover, W-CDMA has a variable Spreading Factor (SF), with a chip rate of 3.84 Mchip/s, so that highly variable user data rates are well supported.

The code domain is articulated in two phases: the coding of each symbol (Spreading), and the decoding at the destination (Despreading). In the Spreading process, the chanalisation code is added, to each data symbol, but before it is sent to the air interface, an additional operation of Scrambling occurs. Scrambling makes the signals from different sources separable from each other, but it does not change the signal bandwidth and its symbol rate, (Figure 2-5).

In Despreading, the reverse process is applied, but the right chanalisation code acknowledgement is necessary for a correct decoding of the original data. Frames of 10ms duration are used, and data rate is kept constant in each frame, but data capacity can change frame to frame, so that a different SF can be associated to the same user [HoTo00].
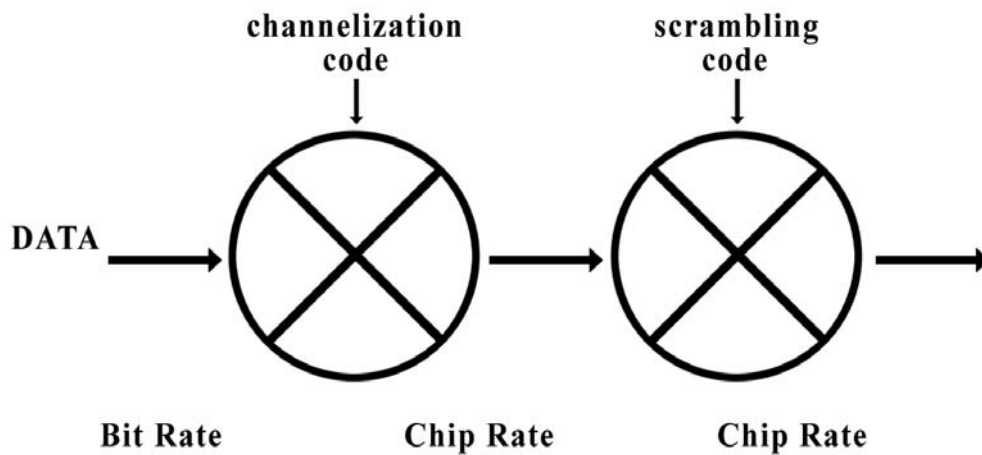
Figure 2-5 - Relation between spreading and scrambling (adapted from [HoTo00]).

2.4 UMTS Services and Applications

UMTS offers applications (like speech or SMS) and bearer services, which provide the capability for information transfer among end terminals. It is possible to negotiate the characteristics of a bearer service at a session establishment, and during on going sessions. Both connections oriented and connectionless services are offered for Point-to-Point and Point-to-Multipoint communication.

An End-to-End Service may have certain bearer services with different Quality of Service (QoS) parameters for maximum transfer delay, delay variation and bit error rate; it may be the user that decides whether he is satisfied with the provided QoS or not. Offered data rate targets are [HoTo00]:

- 144 kbit/s in rural outdoor
- 384 kbit/s in urban outdoor
- 2048 kbit/s in indoor and low range outdoor

UMTS services have different QoS characteristics for four types of traffic classes [3GPP02]:

- Conversational

- Streaming

- Interactive

- Background

Table 2-1 shows how they are classified, and what are their fundamental characteristics.

Table 2-1- QoS classes (adapted from [HoTo00]).

Traffic class	Conversational	Streaming	Interactive	Background
Type of service	Real Time	Real Time	Best Effort	Best Effort
Fundamental characteristics	Preserve time relation (variation between information entities of the stream Conversational pattern (stringent and low delay)	Preserve time relation (variation) between information entities of the stream	Request response pattern Preserve payload content	Destination is not expecting the data within a certain time Preserve payload content
Example of the application	Voice	Streaming video	Web browsing	Emails

Conversational is the most important class, and it includes all the speech service over circuit-switched bearers, being characterised by real time. For this reason, it is the only class of the four where the required QoS characteristics are strictly dependent on human perception, and the end-to end delay has to be less than 200 ms; if this limit is not respected, the quality of transmission will result very unacceptable. Streaming involves all types of asymmetric streaming applications, like web broadcast and video streaming on demand; for this reason, more delay is allowed than the conversational class, and jitter can be more tolerated in transmission by using buffering procedures. Interactive concerns all services on demand with response, so that round-trip delay time has relevance, and the content of the pack must be transparently transferred with a low BER (Bit Error Rate); classical examples of services are the location-based ones, like messages sent on mobile with local information, localisation of emergency calls, or the location of the nearest gas station, hotels and so on. Finally, Background includes all services like sms, e-mail, etc, where the delay can be seconds or even minutes without any problems.

2.5 Cell Coverage

The 3G network may be divided in a hierarchical way, Figure 2-6:
- Macro-cell - the area of largest coverage, e.g., an entire city.
- Micro-cell - the area of intermediate coverage, e.g., a city centre.
- Pico-cell - the area of smallest coverage, e.g., a hotel or airport.

There is this sub-division of regions because smaller regions (shorter ranges) allow higher user density and faster transmission rates.
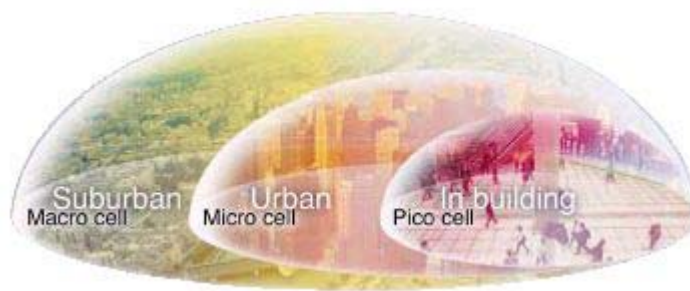
Figure 2-6 - UMTS cells (extracted from [GNET02]).

Because all users in W-CDMA may transmit on the same frequency, internal interference generated by the system is the most significant factor in determining system capacity and quality of service. The transmit power for each user must be reduced to limit interference, however, the power should be enough to maintain the required signal to noise ratio, for a satisfactory call quality, E_b/N_o, where E_b is the received energy per information bit and N_0 is the total effective noise, including the interference power needed. Maximum capacity is achieved when E_b / N_o of every user is at the minimum level needed for the acceptable link performance. As the MT moves around, the radio environment continuously changes due to fast and slow fading, external interference, shadowing, and other factors.

UMTS cells have variable dimensions depending on the number of users and noise value, so that the cell radius depends on these factors (cell breathing effect), Figure 2-7. E_b/N_o depends on factors such as: bit rate, service, multipath profile, mobile speed, receiver algorithms and BS antenna structure. Power control is used to limit transmitted power on both links, while maintaining link quality under all conditions. In GSM, power is a function of the real peak received level, while in UMTS a target SIR (Signal-Interference-Ratio) value is

monitored at 1.5 kHz by the BS. In UMTS, two different procedures of power control are defined:

- Open Loop Power Control (OLPC)
- Closed Loop Power Control (CLPC)
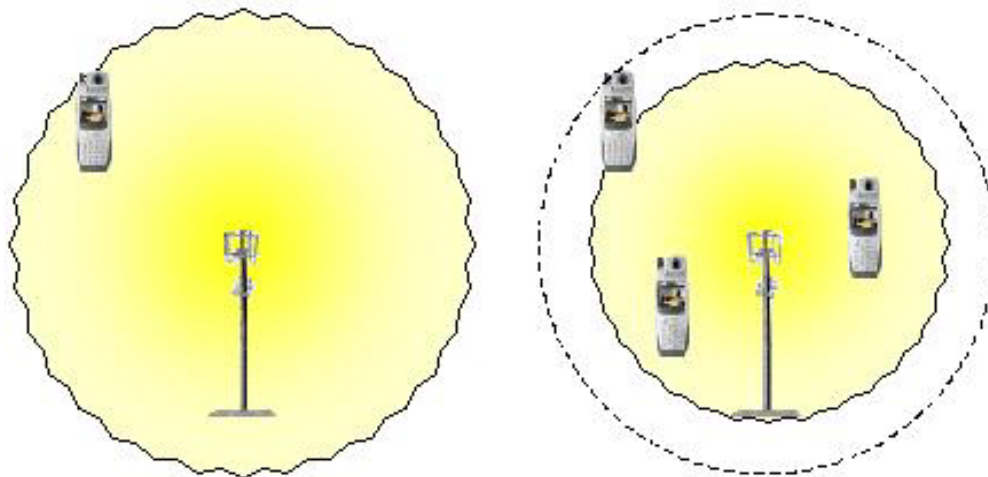
Figure 2-7 - Cell breathing effect (extracted from [Info02]).

Uplink common channels use OLPC. This type of power control is used when the MT is in standby mode; the Node-B transmits on a common channel its sent power level, so that the MT is able to estimate the received power and calculate the power loss. When the MT sends a request for transmission, it uses a power level 10 dB lower than the last received one, and may increase this level until the maximum one in case of interference problems.

CLPC is used in a dedicated channel, and it can be divided in Inner loop e Outer loop control. The former is also called Fast Power Control, and its task is to respond to propagation variations during a connection mode; in fact, Node-B and UE repeatedly measure the received SIR and compare it with the optimum SIR (SIR target). Outer loop control is the procedure made by RNC to determinate the SIR target that should be used for the connection.

Handover occurs when a call has to be passed from one cell to another as the user moves between cells. In a traditional "hard" handover, the connection to the current cell is broken, and then the connection to the new cell is made, which is also known as a "break-before-make" handover. Since all cells in W-CDMA use the same frequency, it is possible to make the connection to the new cell before leaving the current cell, which is also called as a "make-before-break" or "soft" handover. Soft handovers require less power, which reduces interference and increases capacity, and mobiles can be connected with more than two BS.

"Softer" handover is a special case of soft handover, where the cells to which the MT is connected belong to the same Node B, so that each UMTS user can be served by more than one cell simultaneously.

2.6 Capacity and Interference

In the W-CDMA system, all users share the same resources (in the air interface), therefore, each user can not be analysed independently, since he is influencing all the other users in the cell, causing a change of their transmission power and consequently of its own, so a new specific parameter in the link budget called interference margin is needed.

The coverage efficiency of W-CDMA system is defined by the average coverage area per site, in km^2/site, for a predefined reference propagation environment and supported traffic density, thus, the amount of supported traffic per BS, the amount of interference, and the delivered cell capacity must be estimated.

The load in the cell, expressed by load factors, affects coverage in different ways; for coverage-limited cases, a smaller interference margin is suggested, while in capacity-limited cases a larger one is suggested. Two load factors are calculated, one for the uplink (2.1) and the other for the downlink (2.2), [HoTo00]:

$$\eta_{UL} = (1+i)\cdot \sum_{j=1}^{N} \frac{1}{1+\dfrac{W}{(E_b/N_0)_j \cdot R_j \cdot v_j}} \qquad (2.1)$$

where:

- N : number of users per *ce*ll;
- i : other cell to own cell interference ratio seen by the base receiver;
- W : W-CDMA chip rate;
- R_j : Bit rate of user j;
- v_j : Activity factor of user j at physical layer;

while the downlink load factor can be expressed as:

$$\eta_{DL} = \sum_{j=1}^{N_c} v_j \cdot \frac{(E_b/N_0)_j}{W/R_j} \cdot \left[\left(1 - \alpha_j \right) + i_j \right]$$ (2.2)

where:

- N_c : number of connections per cell = number of users per cell (N) multiplied for (1+soft handover overhead);
- i_j : Ratio of other cell to own cell base station power, received by user j;
- α_j : Ortoghonality of channel of user j;

The main consequence is that the load in the air interface affects coverage in up- and downlinks in different ways. In fact, in the former, the transmission power depends on the number of users, while in the latter, it is always the same and it is shared between the downlink users, whereas the coverage decreases as function of the number of users. The maximum BS transmission power is set at 43 dBm for macro-cells and 33 dBm for micro-cells; if in the power control loop of each snapshot the overall transmission power of each BS is higher than the maximum power allowed, an attenuation is applied to set the output power equal to its maximum level, this process being quite similar to an analogue mechanism used to protect the power amplifier. In Table 2-2 the typical transmission power is shown, both for BS and mobile terminals MT.

Table 2-2 – Maximum transmitted power for BSs and MTs (adapted from [3GPPa]).

Cell Structure		Macro	Micro	Pico
TDD mode	MT	30 dBm	21 dBm	21 dBm
	BS	36 dBm	27 dBm	27 dBm
FDD mode	MT	21 dBm	14 dBm	14 dBm
	BS	27 dBm	20 dBm	20 dBm

These values are used in 3GPP simulation according to TDD and FDD transmission modes and different cell structures, [3GPPa].

The splitting of the downlink power between two or many carriers is an efficient approach to increase the downlink capacity, and it requires the operator's frequency allocation to allow the use of more than one carrier. Other useful approaches are the increase of the

number of sectors (from three to six), the deployment TDD cells (micro-cells), or a cell splitting technique.

3 Models

3.1 Propagation Models

In order to perform a good radio network planning, among other things, it is essential to estimate the propagation loss between the transmitter and the receiver. The physical phenomena, which influence the path-loss, can generally be described by four basic mechanisms: reflection, penetration, diffraction and scattering. For this reason, the propagation loss is significantly dependent of a given scenario (indoor, outdoor, rural, etc.), and on its environment characteristics (presence of buildings, terrain variations, etc.). Combining the output of one of these models (Path Loss), with the link budget, it is possible to estimate the cell coverage and the number of cells, in a given area. Obviously, these models, have some validity limitations and specific assumptions of applicability, one of the most used choice criteria being the propagation environment or cell type (dimensions): the COST 231-Hata-model [DaCo99] is more dedicated to macro-cells and urban and suburban environments; the COST 231-Walfisch-Ikekami model [DaCo99] is for dense urban scenarios and to micro-cells; the 3GPP model [3GPP00a] is more dedicated to micro-cells in a city with a Manhattan like urban structure, and for particular macro-cells cases, like urban and suburban areas outside the urban core, where buildings are of nearly uniform height.

3.1.1 COST 231 – Hata model

The Hata model [Hata80] is an empirical formulation of the graphical path loss data provided by Okumura et al. [OOKF68], and is valid from 150 MHz to 1500 MHz. Hata presented the urban area propagation loss as a standard formula and supplied correction factors for application to other situations. Although Hata's model does not have any of the path-specific corrections that are available in Okumura's model, the expressions of Hata have significant practical value. The predictions of the Hata model is closely related to the original Okumura model, as long as distance exceeds 1 km, therefore, this model is well suited for large cells (it provides good results only for distance larger than 5 km).

Within the COST-231 project, an extended version of the Hata model was developed to the frequency band [1500, 2000] MHz, by analysing Okumura's propagation curves in the upper frequency band, and creating a new one called COST 231-Hata [DaCO99]. It is restricted to large and small macro-cells, i.e., BS antenna heights above roof top levels adjacent to the BS, and it should not be used in micro-cells.

The proposed model for path-loss is:

$$L_{p[dB]} = 46.3 + 33.9 \log\left(f_{[MHz]}\right) - 13.82 \ \log\left(h_{BS[m]}\right) - a\left(h_{MT[m]}\right) + \left(44.9 - 6.55 \log\left(h_{BS[m]}\right)\right) \cdot$$
$$\log\left(d_{[km]}\right) + C_{m[dB]}$$

(3.1)

where:

- h_{BS} : height of BS;
- h_{MT} : height of MT;
- C_m : correction factor;
- a : MT antenna height correction function;
- d : distance from BS and MT;

The parameter C_m is an additional correction factor that depends on the type of environment, and it can be expressed as:

$$C_{m[dB]} = \begin{cases} 0 & \text{for medium sized city and suburban centres with medium trees density} \\ 3 & \text{for metropolitan centres} \end{cases}$$

(3.2)

The function $a(h_{MT})$ is a correction factor for effective MT antenna height, which depends on the size of the coverage area and it can be expressed as:

$$a\left(h_{MT}\right) = \left(1.1 \ \log \ f_{[MHz]} - 0.7\right) \cdot h_{MT[m]} - \left(1.56 \ \log \ f_{[MHz]} - 0.8\right) - 15$$

(3.3)

The COST-Hata-model ranges of parameters restrictions are described in Table 3-1.

Table 3-1 – COST 231-Hata model ranges

Frequency (f) [MHz]	1500...2000
Distance BS-MT (d) [km]	1...20
BS antenna height (h_BS) [m]	30...200
MT antenna height (h_MT) [m]	1...10

It is important to note that the validity range of this model is [1500, 2000] MHz, while UMTS works in [1900, 2170] MHz, hence, for the upper band of UMTS it can be assumed, that the model is also valid in the frequency band [2000, 2200] MHz.

In this particular model, the estimation of the path-loss depends on the specific scenario. Equation (3.1) is valid only for urban environment. For sub-urban and rural environment, some factors depending on the working frequency have to be added to that equation. In the sub-urban case, one needs to add - K_{sub}, where K_{sub} is an additional factor that can be expressed as:

$$K_{sub[dB]} = 2 \cdot \log^2 \left(f_{[MHz]} / 28 \right) + 5.4 \tag{3.4}$$

while in the rural case, one adds - K_{rur}, where K_{rur} is an additional factor that can be expressed as:

$$K_{rur[dB]} = 4.78 \cdot \log^2 \left(f_{[MHz]} \right) - 18.33 \cdot \log \left(f_{[MHz]} \right) + 35.9 \tag{3.5}$$

A general scheme describing the input/output parameters of the COST 231-Hata model is shown in Figure 3-1.

3.1.2   COST 231-Walfisch-Ikegami model

The well-know semi-empirical Walfisch and Bertoni [WaBe88] and Ikegami [IkYU84] propagation models, were adapted by COST 231 based on measurements performed in Europe, in a new one, called COST 231-Walfisch-Ikegami model [DaCo99]. This model is dedicated to dense urban (European type) scenarios and to micro-cells.
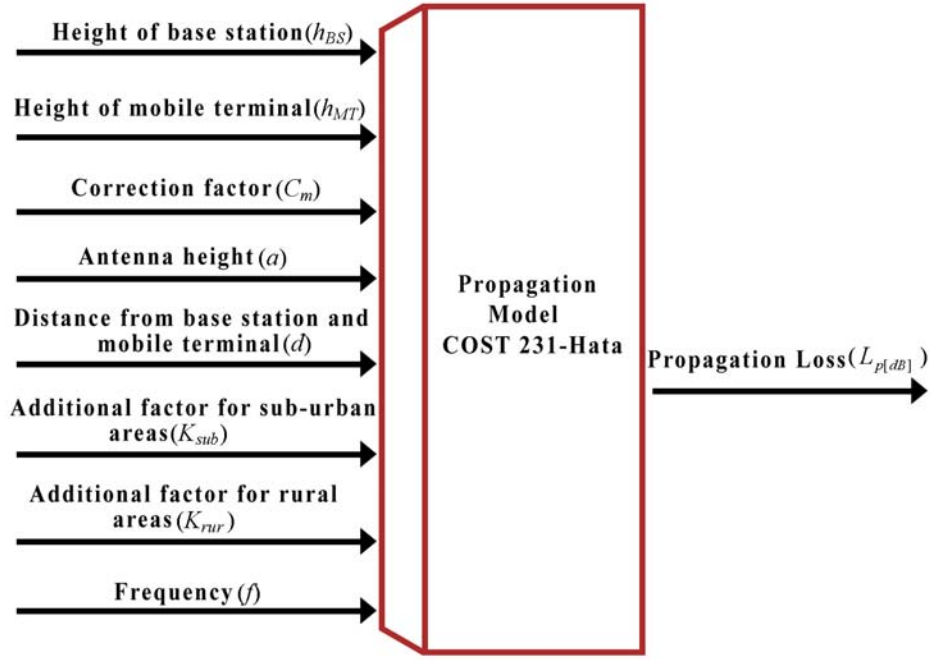
Figure 3-1 - COST 231-Hata-Model input /output parameters.

In fact, this model allows improving the estimation of the path loss in an urban environment by considering additional environment data, namely:

- h_{Roof} : height of buildings;
- w : width of roads;
- b : building separation;
- φ : road orientation with respect to the direct radio path.

In Figure 3-2 a graphical description of this environment data used by the model, is shown [Town03].

The model has some constrains on frequency band, BS height and distance. For example, the validity range of this model in frequency is [800, 2000] MHz, while UMTS, as already mentioned, works in [1900, 2170] MHz, hence, for all the applications for frequency up to 2000 MHz, this does not imply a large error, as explained before, since the difference in frequency is not large.

Additionally, it distinguishes between Line of Sight (LoS) and Non Line of Sight (NLoS) conditions. For the LoS case, within a street canyon, the path loss is evaluated from:

$$L_{p[dB]} = 42.6 + 26\log\left(d_{[km]}\right) + 20\log\left(f_{[MHz]}\right) \qquad \text{for } d \geq 20 \text{ m} \qquad (3.6)$$

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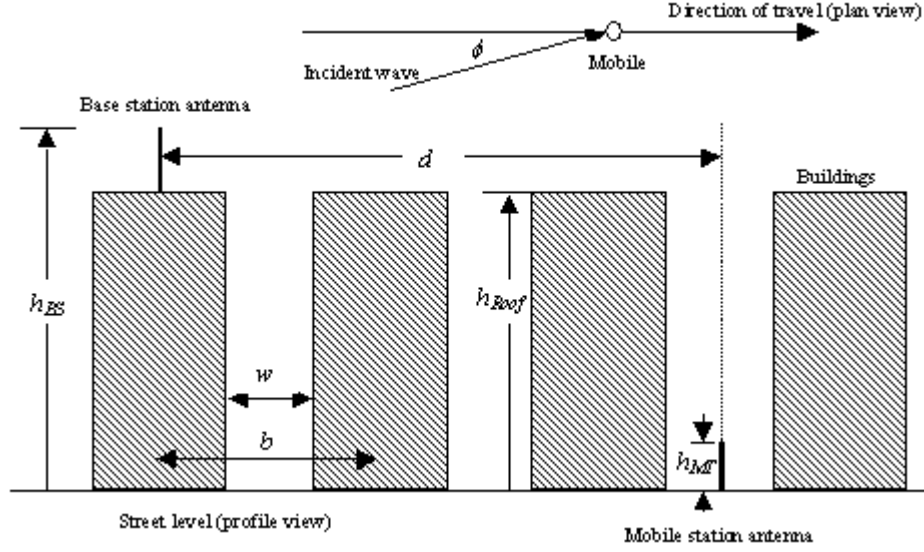
Figure 3-2 - Description of Walfish Ikegami parameters (extracted from [Town03]).

For the NLoS case, the formula of path loss is a sum of three terms:

$$
L_{p\,[dB]} = \begin{cases} L_0 + L_{rts} + L_{msd} & \text{for } L_{rts} + L_{msd} \geq 0 \\[2ex] L_0 & \text{for } L_{rts} + L_{msd} \leq 0 \end{cases} \tag{3.7}
$$

where:

- L_0: free space loss;
- L_{msd}: multiple screen diffraction loss;
- L_{rts}: coupling of the wave propagating along the multiple-screen path into the street where the mobile station is located;

L_0 can be written as:

$$
L_{0[dB]} = 32.44 + 20\log\left(d_{[km]}\right) + 20\log\left(f_{[MHz]}\right) \tag{3.8}
$$

L_{rts} can be written as:

$$
L_{rts[dB]} = -16.9 - 10\log\left(w_{[m]}\right) + 20\log\left(f_{[MHz]}\right) + 20\log\left(\Delta h_{MT[m]}\right) + L_{Ori[dB]} \tag{3.9}
$$

where L_{Ori} is an empirical correction factor, obtained from a few experimental measurements expressed as:

$$L_{Ori} = \begin{cases} -10 + 0.354\,\varphi_{[°]} & \text{for } 0° \leq \varphi < 35° \\[2em] 2.5 - 0.075\left(\varphi_{[°]} - 35\right) & \text{for } 35° \leq \varphi < 55° \\[2em] 4.0 - 0.114\left(\varphi_{[°]} - 55\right) & \text{for } 55° \leq \varphi < 90° \end{cases} \qquad (3.10)$$

and

$$\Delta h_{MT\,[m]} = h_{Roof\,[m]} - h_{MT\,[m]} \qquad (3.11)$$

$$\Delta h_{BS\,[m]} = h_{BS\,[m]} - h_{Roof\,[m]} \qquad (3.12)$$

The multiple screen diffraction loss, L_{msd}, is defined as:

$$L_{msd\,[dB]} = L_{bsh} + k_a + k_d \cdot \log\left(d_{[km]}\right) + k_f \cdot \log\left(f_{[MHz]}\right) - 9\log\left(b_{[m]}\right) \qquad (3.13)$$

where

$$L_{bsh\,[dB]} = \begin{cases} -18\log\left(1 + \Delta h_{MT\,[m]}\right) & \text{for } h_{BS} > h_{Roof} \\[2em] 0 & \text{for } h_{BS} \leq h_{Roof} \end{cases} \qquad (3.14)$$

$$k_a = \begin{cases} 54 & \text{for } h_{BS} > h_{Roof} \\[1.5em] 54 - 0.8\,\Delta h_{BS\,[m]} & \text{for } d \geq 0.5\,km \ \ and \ \ h_{BS} \leq h_{Roof} \\[1.5em] 54 - 0.8\,\Delta h_{BS\,[m]}\,\dfrac{d_{[km]}}{0.5} & \text{for } d < 0.5\,km \ \ and \ \ h_{BS} \leq h_{Roof} \end{cases} \qquad (3.15)$$

$$k_d = \begin{cases} 18 & \text{for } h_{BS} > h_{Roof} \\[1.5em] 18 - 15\,\dfrac{\Delta h_{BS\,[m]}}{h_{Roof\,[m]}} & \text{for } h_{BS} \leq h_{Roof} \end{cases} \qquad (3.16)$$

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$$k_f = -4 + \begin{cases} 0.7\left(\dfrac{f_{[MHz]}}{925}\right) - 1 & \text{for medium sized city and suburban centres} \\ & \text{with medium tree density} \\ 1.5\left(\dfrac{f_{[MHz]}}{925}\right) - 1 & \text{for metropolitan centres} \end{cases} \qquad (3.17)$$

The parameter k_a represents the increase of the path loss for BS antennas below the rooftops of the adjacent buildings; k_d and k_f controls the dependence of the multi-screen diffraction loss versus distance and frequency. When buildings and roads data are unknown, default values are recommended:

$$h_{Roof\,[m]} = 3 \times \{\text{number of floors}\} + \text{roof-height} \qquad (3.18)$$

with

$$\text{roof-height}_{[m]} = \begin{cases} 3 & \text{pitched} \\ 0 & \text{flat} \end{cases} \qquad (3.19)$$

Typical default values and range of applications of the models are described in Table 3-2:

Table 3-2 – COST 231-W.I. ranges and default values

Distance LoS (d) [km]	0.02…0.2
Distance NLoS (d) [km]	0.2…5
BS antenna height (h_{BS}) [m]	4…50
MS antenna height (h_{MT}) [m]	1…3
Building Separation (b) [default] [m]	20…50
Road width (w) [default] [m]	b / 2
Road orientation …(φ) [default] [°]	90

The estimation of path loss agrees rather well with the measurements for BS antenna heights above rooftop level. The mean error is in the range of +3 dB and the standard

deviation is about 4 to 8 dB [DaCo99]. In brief, a scheme of the input parameter of this model is given in Figure 3-3.
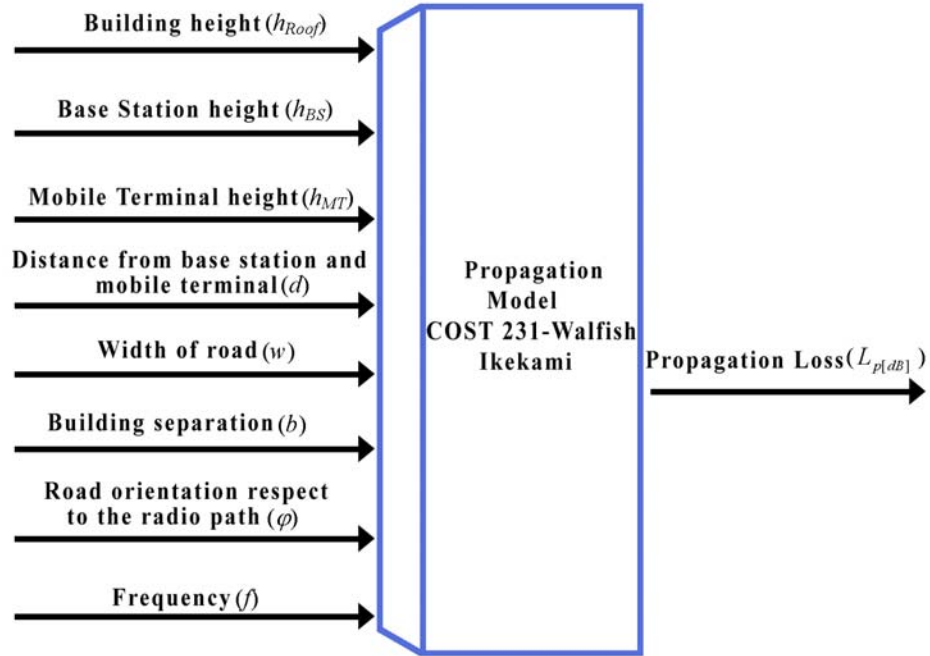
Figure 3-3 – COST 231-W.I. input /output parameters.

However, the prediction error becomes large for $h_{Base} \approx h_{Roof}$ compared to situations where $h_{Base} >> h_{Roof}$. Furthermore, the performance of the model is poor for $h_{Base} << h_{Roof}$. Parameters b, w and φ are not considered in a physically meaningful way for micro-cells, therefore, the prediction error for micro-cells may be quite large. The model does not consider multipath propagation, and the reliability of path-loss estimation decreases if terrain is not flat or the land cover is inhomogeneous.

3.1.3 3GPP Propagations Models

In 3GPP, for each environment (urban, suburban…), a different formulation is used to evaluate the path loss, and an important parameter to be defined is the Minimum Coupling Loss (MCL), i.e., the minimum loss including antenna gain measured between antenna connectors. In [3GPP00a], the MCL of 70 dB is assumed for the macro-cellular environment and 53 dB for the micro-cellular one. With the above definition, the received power, in downlink or uplink, can be expressed for the macro-cellular environments as:

$$P_{Rx[\text{dB}]} = P_{Tx[\text{dB}]} - \max\ \left(L_{p,macro[\text{dB}]} - G_{Tx[\text{dB}]} - G_{Rx[\text{dB}]}, MCL_{[\text{dB}]} \right) \qquad (3.20)$$

and for the micro-cellular as:

$$P_{Rx[\text{dB}]} = P_{Tx[\text{dB}]} - \max\ \left(L_{p,micro[\text{dB}]} - G_{Tx[\text{dB}]} - G_{Rx[\text{dB}]}, MCL_{[\text{dB}]} \right) \qquad (3.21)$$

where :

- P_{Tx} : transmitted signal power;
- P_{Rx} : received signal power;
- G_{Tx} : transmitter antenna gain;
- G_{Rx} : received antenna gain;
- $L_{p,\ macro}$, $L_{p,\ micro}$: output of the propagation model;

Typical antenna gain values are 11 dBi (including cable losses) in the BS and 0 dBi in the MT.

The 3GPP macro-cell propagation model is applicable for the test scenarios in urban and suburban areas outside the urban core, where buildings are of nearly uniform height. The micro-cell model is based on one proposed in [ETSI98], and it is to be used for spectrum efficiency evaluations in urban environments, through a Manhattan-like structure, in order to properly evaluate the performance in micro-cell situations that will be common in European cities at the time of UMTS deployment. The proposed model is a recursive one, which calculates path loss as a sum of LoS and NLoS segments. The shortest path along streets between the BS and the MT has to be found within the Manhattan environment.

The macro cell model is:

$$L_{p,macro[\text{dB}]}^{50\%} = 40 \cdot \left(1 - 4 \cdot 10^{-3} \cdot D_{hb[\text{m}]} \right) \cdot \log\ \left(d_{[\text{km}]} \right) - 18\ \log\ \left(D_{hb[\text{m}]} \right) + 21 \log\ \left(f_{[\text{MHz}]} \right) + 80 \qquad (3.22)$$

where:

- D_{hb} : base station antenna height, measured from the average rooftop level, (default value is 15 m);
- $L_{p,macro}^{50\%}$: median path loss;

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After $L_{p,macro}^{50\%}$ is calculated, log-normally distributed shadowing, $Log\ F$, with standard deviation of 10 dB should be added, so that the resulting path loss for macro cell model is:

$$L_{p,macro[dB]} = L_{p,macro[dB]}^{50\%} + Log\ F_{[dB]}$$

(3.23)

with the constrains that $L_{p,macro}^{50\%}$ should not be less than free space loss in any circumstances. This model is designated mainly for distances from few hundreds meters to kilometres, and it is not very accurate for short distances; moreover, the validation of the model is for a D_{hb} range from 0 to 50 m.

The micro-cell model path loss can be expressed as:

$$L_{p,micro[dB]}^{50\%} = 20\log\left(\frac{4\pi d_n}{\lambda}\right)$$

(3.24)

where:

-   d_n : "illusory" distance;
-   λ : wavelength;
-   n : number of straight street segments between base and mobile station (along the shortest path);

The illusory distance is the sum of these street segments, and it can be obtained by a recursively formula, using:

$$k_n = k_{n-1} + d_{n-1} \cdot c$$

(3.25)

and

$$d_{n[m]} = k_n \cdot s_{n-1[m]} + d_{n-1[m]}$$

(3.26)

where:

-   c : is a function of the angle of the street crossing, and should be set to 0.5 for 90° street crossing;
-   s_{n-1} : length of the last segment.

The initial values are set as: $k_0 = 1$ and $d_0 = 0$

The illusory distance is obtained as the final d_n, when the last segment has been added. Furthermore, the model is extended to cover the micro-cell dual slope behaviour, by modifying the expression to:

$$L^{50\%}_{p,micro[dB]} = 20 \cdot \log \left(\frac{4\pi d_n}{\lambda} \cdot D(d) \cdot \left(\sum_{j=1}^{n} s_{j-1} \right) \right)$$ (3.27)

where:

$$D\ (d) = \begin{cases} 1 & d \leq x_{br} \\ \dfrac{d_{[m]}}{x_{br[m]}} & d > x_{br} \end{cases}$$ (3.28)

Before the break point $x_{br,}$ the slope is 2, after the break point it increases to 4; the break point x_{br} is set to 300 m. To take effects of propagation going above rooftops into account, it is also needed to calculate the path loss according to the shortest geographical distance. This is done by using the COST Walfish-Ikekami model, with antennas below rooftops:

$$L^{50\%}_{p,micro[dB]} = 24 + 45 \cdot \log \left(d_{sh[m]} + 20 \right)$$ (3.29)

where :

- d_{sh} : shortest physical geographical distance from the transmitter and the receiver;

Finally, the final path loss value can be expressed as the minimum between the path loss value from the propagation through streets and the path loss based on the shortest geographical distance, plus the log-normally distributed shadowing, *Log F* (with standard deviation of 10 dB):

$$L_{p,micro[dB]} = min \ \left(L^{50\%}_{p,micro[dB]} \ , \ L_{p,macro[dB]} \right) + Log\ F_{[dB]}$$ (3.30)

3.2 Traffic Distributions

When dimensioning and planning a mobile commmunications system, one should describe the offered traffic load as accurately as possible, so that it is possible to satisfy the relationships between demand, capacity and performance of the system. Defining the call generation λ, which gives call attempts per time unit [call/s], and taking the mean call duration $\bar{\tau}$ into account, the offered traffic can be defined as

$$T_{\left[\text{Erlang/km}^2 \right]} = \lambda \cdot \bar{\tau} \tag{3.31}$$

The system is assumed to have a finite number of channels, so, since the maximum supported traffic can be smaller than the offered traffic, it is possible that the systems fails to assign channels, when a user attempts to get a service. The probability of this failure is called blocking, and it is an important parameter to be taken into account for a correct capacity planning. Besides, each user can generate one or more simultaneous flows belonging to different service classes, and performance requirements within a service class may differ depending on the user's mobility, propagation environment, and terminal type. Therefore, a user profile is described by a set of parameters that define the attempted service type with its associated QoS requirements, the user equipment (e.g., laptop, palmtop, mobile phone), and the related environment (e.g., to allow considerations for mobile speed, propagation condition, etc.).

In other words, the studied environment is split in different areas, and for each one of these areas a busy hour is calculated, according to the various services, type of users and their different types of mobility. For these reasons a scenario classification is a very important topic and a cause for the great complexity related to all these variables; many different approaches were developed, but in this work mainly the theoretical aspects and the related conclusions, analysed and suggested in [VaCa02] and [AlQu98], are taken into account.

In [VaCa02], only an urban scenario is analysed, a city being classified in six different areas:

- High density population;
- Mixed buildings;
- Tertiary sector buildings;

- Low density population;
- Industry buildings;
- Streets and green;

This classification is given by analysing demographic input variables (residential population, number of households, statistics such as gender and age distribution), business database (number of employees at the location, average business revenue, average telephone bills, available office area, etc.), road traffic, and morphology database (type of land-cover at each location, such as water, vegetation, suburban and urban areas, etc.). Three input parameters for each area are considered:

- Number of users;
- Type of service required;
- Location of each potential active user;

The number of active users for each area can be represented by a Poisson distribution.

In [AlQu98], another traffic distribution approach is suggested, so that six different areas classification are used:

- Urban centre;
- Urban Centre with roads;
- Residential area;
- Residential area with roads;
- Suburban area;
- Suburban with roads;

Urban centre is referred to an area with a large amount of services and very low presence of residential buildings, residential area includes classical residential buildings but also commercial areas and suburban areas are the ones with very low buildings and very few streets. The word with roads means that extra cell coverage is needed for main streets and high mobility users. The parameters related to the traffic distribution in each cell are, as already seen before, strictly depending on user number, user grade of activity (type of demanded service), and user mobility.

The main problem, for this kind of approach, is that these kinds of classifications are too generically. In fact, they are used just to set a model for the general forecast of the traffic estimation. In this work, the classification for the various areas classes (urban, mean-urban, dense-urban, buildings…), and road types, delivered by Telecel [Tele02] for Portugal is considered.

Table 3-3 – Classification of typical communication routes (adapted from [CoVe02]).

Communication Route Classification	Description
Highway	3*2 roadways of 3.25 m each +central rail + margins, typical default width is 20 m.
Railway	2 lines plus platforms route, typical default width is 10 m.
Road	2*2 roadways of 3 m each + margins, typical default width is 15 m.
Street	2 roadways of 3 m each + central rail + sidewalks, typical default width is 12 m.

3.3 Cell Structure

In order to perform a good cellular planning, given a certain area, many parameters must be analysed, among which are urban and demographic characteristics in the area, traffic density of each different service in use, propagation coverage. In the previous sections, some of these aspects have been already discussed, while in this section a more detailed description, concerning cell structure, is addressed.

A typical UMTS network is composed by cells, with a hierarchical structure that can be represented in three different layers of cells (macro, micro, pico), allowing higher user density and faster transmission rates according to the FDD or TDD mode.
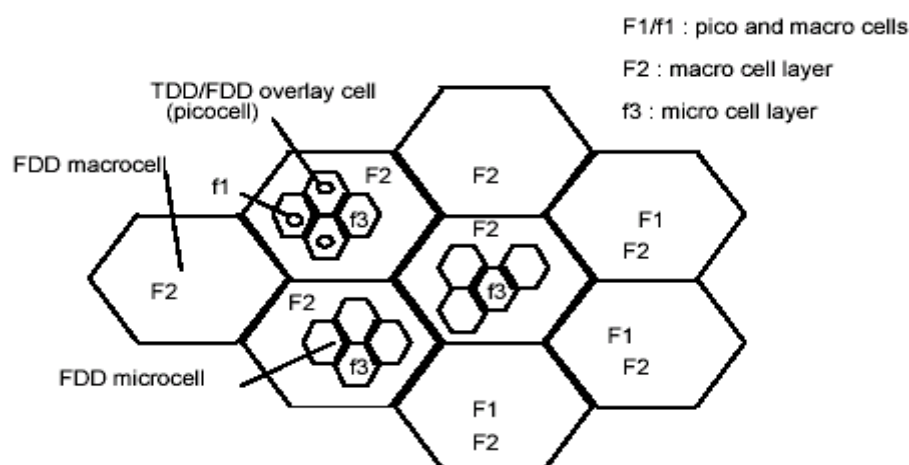

Figure 3-4 – UMTS Hierarchical Cell Structure (extracted from [UMTS98a]).

In cell planning, an optimisation of cost requires a good location of BSs for the different cells, leading to a UMTS network that is not under or over designed. This choice, in a particular scenario, is linked to the traffic demand, i.e., the number of users for each different service. Macro-cells provide wide area coverage with low traffic, in a FDD mode; it is used for optimisation issues, like carrying fast users (high-speed mobiles), or traffic management, being located in suburban and rural areas or along motorways. For urban outdoor scenarios, where traffic is generated mainly by pedestrian and vehicle users, micro-cells are deployed, at street level for outdoor coverage, and in general they provide an extra capacity in all the cases where macro-cells can not cope with. Micro-cells have typically a canyon-like shape, which reflects the topography of the streets, with a distance between 200 and 400 m. Pico-cells are usually employed in great demand traffic areas, also called hot-spot areas, like airports, exhibition areas, office buildings, shopping centres, etc, where high bit-rate data is request, such as laptops networking or multimedia conferencing, by using the TDD mode data rate up to 2 Mbit/s. Pico-cells have a short coverage area, and the way, which they are deployed, will depend on their maximum range in given environments (indoor and outdoor), which will be about 75 m.

Parameters like cell radius, cell area and sectors per BS are very important, and also the possibility to split each cell in different sectors allows for cells with variable dimensions, as it is shown in Table 3-4 for different operational environments [Serr02].

Table 3-4 – Cell Dimensions per Operating Environment (adapted from [Serr02]).

Operational environments	Sectors per base	Cell radium[*] [km]	Sectored Hexagon Cell Area[*] [km^2]
Urban (building)	3	0.075	0.005
Suburban (building / street)	3	3	7.79
Home (building)	1	0.02	0.001
Urban (pedestrian)	3	0.7	0.424
Urban (vehicular)	3	0.7	0.424
Rural in - & out – door	3	8	55.43
[*]: traffic forecast for 2005			

3.4 Link Budget

Radio network planning includes, among other things, radio link budget and coverage analysis. The major aspects of cell coverage analysis and traffic estimation parameters were previously discussed, so that in this section, link budget aspects will be analysed. Above all, WCDMA presents some new specific parameters in the link budget that are not used in a TDMA-based radio access system such a GSM, like interference margin and soft handover gain.

The interference margin is needed in the link budget because the load of the cell, the load factor, affects coverage as already seen in Section 2.6; the more load is allowed in the system, the larger is the interference margin needed in the uplink, and the smaller is the coverage area [HoTo00]. For coverage-limited cases, a smaller interference margin is suggested, the cell size is limited by the maximum allowed path loss in the link budget, and the maximum air interference capacity of the BS site is not used. Typical values for the interference margin in the coverage-limited cases are 1–3 dB, corresponding to 20-50 % loading; 3 dB interference margin, is typically reserved for the uplink noise rise.

The Fast fading margin is the headroom needed in the transmission power for maintaining adequate closed loop fast power control. In fact, especially in slow-moving pedestrian users, the fast power control is able to effectively compensate the fast fading, and a typical fast fading margin value of 2-5 dB is used.

Soft handover gain is needed for giving an additional macro diversity gain against fast fading by reducing the required E_b / N_0 relative to a single radio link; typical values are set as 2-3 dB.

Reference [HoTo00] presents the link budget algorithm, which enables the estimation of the allowed maximum propagation loss L_{pmax}, expressed as:

$$L_{pmax[dB]} = P_{Tx[dBm]} + G_{Tx[dBi]} + G_{Rx[dBi]} + G_{SH[dB]} - R_{S\,min[dBm]} + \sum L_{x[dB]} + \sum F_{m[dB]} \qquad (3.32)$$

where:
- L_{pmax} : maximum propagation loss allowed for a given service;
- P_{Tx} : transmitted signal power (delivered to the antenna);
- G_{tx} : transmitter antenna gain;
- G_{rx} : receiver antenna gain;

- G_{SH} : soft handover gain;
- R_{Smin} : receiver sensitivity for a given service bearer;
- L_x : additional attenuations in a link; user body loss L_{UB}, and others (car loss) L_{Other};
- F_M : fading margin, i.e., fast fading margin F_{FM}, and slow fading margin F_{SM};

Another important parameter, the Equivalent Isotropic Radiated Power (EIRP), defined as follows:

$$EIRP_{[dBm]} = P_{t[dbm]} + G_{tx[dBi]} \tag{3.33}$$

where the antenna transmitted output power P_t is defined as:

$$P_{t[dBm]} = P_{Tx[dBm]} - L_{c[dB]} \tag{3.34}$$

where:

- L_c : cable loss;

and the received antenna input power P_r is defined as:

$$P_{r[dBm]} = P_{Rx[dBm]} - L_{c[dB]} \tag{3.35}$$

where P_{Rx} is the received signal power.

The most important parameter in radio network planning is the receiver sensitivity R_{Smin}, which depends on the service type (energy of bit over noise and bit rate), therefore, different L_{Pmax} and cell radius are expected for each service, as already seen in traffic distribution, and it can be expressed as:

$$R_{Smin[dBm]} = \left(\frac{E_b}{N_0} \right)_{[dB]} - G_{P[dB]} + N_{[dBm]} \tag{3.35}$$

where:

- G_P : processing gain, which depends on the relation between chip rate and bit rate;
- N : the total effective noise plus interference power;

In addition, this last parameter can be expressed as:

$$N_{[dBm]} = 10 \ \log \left(10^{R_{N[dBm]}/10} + 10^{R_{I[dBm]}/10} \right)$$

(3.36)

where the receiver interference power R_N is given by:

$$R_{N[dBm]} = R_{NO[dBm/Hz]} + 10 \ \log \left(W_{[cps]} \right)$$

(3.37)

and the receiver interference power R_I is given by:

$$R_{I[dBm]} = 10 \ \log \left(10^{\left(R_{N[dBm]} + I_{m[dBm]} \right)/10} - 10^{R_{N[dBm]}/10} \right)$$

(3.38)

where:

-   I_m : interference margin;
-   R_{NO} : receiver noise density;

The interference margin I_m can be expressed as:

$$I_m = -10 \ \log \left(1 - \eta \right)$$

(3.39)

where η is the load factor, so that the interference margin depends on it (increases with it); as already seen in Section 2.5, if the load increases, the cell coverage decreases proportionally of the traffic distribution (cell breathing).

The receiver noise density, R_{NO}, depends on the thermal noise N_0 and on the noise factor, F_N:

$$R_{NO[dBm/Hz]} = N_{0[dBm/Hz]} + F_{N[dB]}$$

(3.40)

The interference load in a given cell can be easily estimated by using the upper link budget algorithm joined with an appropriate propagation model. The amount of interference is a parameter of great relevance to calculate the amount of supported traffic (capacity), for each

BS, because UMTS uses a frequency reuse factor of 1, therefore it is strongly interference-limited by the air interface.

4 Methods for the Choice of Parameters

4.1 Definition of parameters

A model for characterising scenarios was already proposed [Corr02b], where several layers were identified in order to obtain grids as a basis for future developments on dynamic selection of propagation models. Eleven parameters were set by using a Geographic Information System (GIS) tool, to be calculated for various DTMs: terrain height statistics (average and standard deviation), building height statistics (average and standard deviation), street width statistics (average and standard deviation), vegetation index, water index, street index, open areas index, building index:

- BH_MV- building height mean value.
- BH_STDEV- building height standard deviation.
- BI- building index
- OAI- open areas index
- SI- street index
- SW_MV- street width mean value.
- SW_STDEV- street width standard deviation.
- TH_MV- terrain height mean value.
- TH_STDEV- terrain height standard deviation.
- VI- vegetation index
- WI- water index

DTMs are put into raster information, arranged in pixel grids, the dimensions of each pixel being $\Delta L \times \Delta L$, and upon those grids, a sampling resolution ΔS is chosen, which should verify $\Delta S \geq \Delta L$. Three different uniform grids with a $\Delta S \times \Delta S$ resolution of 50, 100, and 200 m was considered in MOMENTUM, Figure 4-1.

Statistical parameters, (mean value and standard deviation) and indexes are defined as:

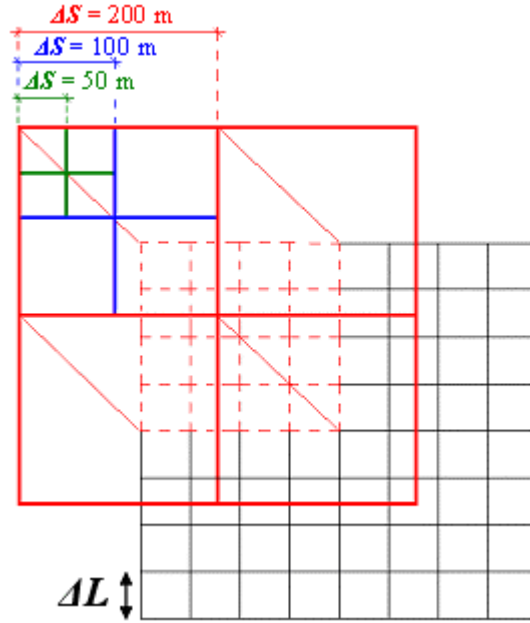$$\mu_X = \frac{\sum_{n=1}^{N} x_n}{N} \tag{4.1}$$

Figure 4-1 - Original grid (*ΔL*) and sampling grid (*ΔS*) (adapted from [CoVe02]).

$$\sigma_X = \sqrt{\frac{\sum\limits_{n=1}^{N}(x_n - \mu_X)^2}{N-1}} \qquad\qquad (4.2)$$

$$I_Y = \frac{P_Y}{N} \qquad\qquad (4.3)$$

where:

- I_Y = land use class *Y* index in a *ΔS*-type pixel;
- N = total number of *ΔL*-type pixels in a *ΔS*-type pixel;
- n = *ΔL*-type pixel number;
- P_Y = number of *Y* *ΔL*-type pixels in a *ΔS*-type pixel;
- X = layer value being calculated (e.g., building height);
- x_n = value of *X* in *ΔL*-type pixel *n;*
- Y = land use class (e.g., vegetation);
- μ_X = mean value of *X*;
- σ_X = standard deviation of x_n values in a *ΔS*-type pixel;

The choice of a particular scenario, and model, is not a strictly binary one, and a transition mechanism is needed for all areas in which a mixture of models is more appropriate rather than one or the other. In fact, since the selection of a given propagation model will have

a direct dependence on scenario's characteristics described by layers, some thresholds still have to be stated, delimiting ranges for models application. Hence, in transition regions, a transition function weighting predictions of two different propagation models should fit the purposes better than a binary choice. In [Corr02], a transition function called the trigonometric transition function was proposed in terms of a given parameter p:

$$M(p) = \frac{M_H(p)[1 + \arctan(p/k)] + M_L(p)[1 - \arctan(p/k)]}{2}$$ (4.4)

where:

- k = normalisation parameter;
- $M(p)$ = path loss or intermediate result evaluated at the transition region;
- $M_H(p)$ = path loss or intermediate result valid for high values of parameter p;
- $M_L(p)$ = path loss or intermediate result valid for low values of parameter p;
- p = general parameter for evaluation of a scenario.

A different, simpler (linear) approach is also possible, [Kürn02b]:

$$M(p) = M_H(p)[w(p)] + M_L(p)[1 - w(p)]$$ (4.5)

where:

$$w(p) = \begin{cases} 1, & \text{for } p \geq p_{\max} \\ 0, & \text{for } p \leq p_{\min} \\ \dfrac{p - p_{\min}}{p_{\max} - p_{\min}}, & \text{else} \end{cases}$$ (4.6)

It is important to note that the interval $[p_{\min}, p_{\max}]$ defines the transition region.

In this work, starting from all the results and conclusions developed by [Corr02b] and [CoVe02], a correlation between all the layers mentioned above and the propagation models analysed in Chapter 3 (COST 231 Hata, COST 231 Walfisch Ikegami, and 3GPP models), and all the input parameters for classification areas used by traffic models, is proposed. The main target is to correlate each parameter to each different propagation model in terms of input parameters and related to traffic distribution for the areas classification of the examined

environment. The goal is to achieve a heuristic approach that will serve as basis for the automatic tool's choice. The selection of models will be based on an evaluation of the terrain characteristics and distance performed in real-time processing. For example, if BS and MT are placed in a vegetation area, say with a vegetation index of 70 %, it turns obvious that using the COST 321 Okumura-Hata model for predictions will probably be wiser than using COST 231 Walfisch-Ikegami. On the other hand, if the street width mean value of the pixel where the MT is placed is 15 m and the distance is of a very few kilometres, COST 231 Walfisch-Ikegami should probably be the better choice, and so on. The models will also use the layers' values for predicting the path loss, [CoVe02].

In Table 4-1, the key parameters, for each propagation model, and traffic distribution selection, according to the different parameters layers, are given, analysing the table in detail, it is possible to see that all the layers dealing with a height like the TH_MV, TH_STDEV, BH_MV, BH_STDEV, have influence on both the COST 231-Hata and COST 231-Walfisch Ikegami propagation models for the parameters like BS and MT heights (h_{BS} h_{MT}). In addition, for COST 231-Walfisch Ikegami layers BH_MV, BH_STDEV have influence on the building height parameter (h_{Roof}) and all the various parameters (k) for the calculation of the multiple screen diffraction loss (L_{msd}); in fact, the building height allows the selection of: the values for the different k, and the environment choice. For 3GPP models, they influence the BS antenna height upon rooftop (D_{hb}).

All the others layers (SW_MV, SW_STDEV, VI, WI, SI, OAI, BI) have also influence: in COST 231-Hata model, in both the Correction factor $(C_m.)$ and the additional factor (K) for suburban and rural environment (K_{Sub}, K_{Rur}); in COST 231-Walfisch Ikegami as already mentioned, for the different k calculations, and it is important to stress the influence of SW_MV and SW_STDEV, on the parameters concerning the street width (w), and the building separation (b), because in many cases it is possible to assign to the street width range the building separation one; in 3GPP models, for an environment classification to establish the models applicability (urban, suburban environment). By the BH_STDEV layer, the selection of the 3GPP macro-cell model is possible, since a low value for this layer means a uniform building height, which is one of the assumptions of the model.

Nevertheless, all the layers explained above are not sufficient to adopt a particular propagation model selection, and it is necessary to include others parameters: the distance (d), between the BS and the MT locations; the MT antenna height (a) for the COST 231-Hata model; and a distinction between LoS and NLoS for the COST 231-Walfisch Ikegami model. So a classification for these parameters is needed, as explained in Table 4-2, for the distance.

Table 4-1 – Layer correlations

	Propagation Models			Traffic Distribution
Parameters Layers	*COST 231 - HATA*	*COST 231 - W.I.*	*3GPP - Models*	
TH_MV- terrain height mean value	h_{MT}, h_{BS}	h_{MT}, h_{BS}	D_{hb}	-
TH_STDEV- terrain height standard deviation	h_{MT}, h_{BS}	h_{MT}, h_{BS}	D_{hb}	-
BH_MV – building height mean value	h_{MT}, h_{BS}	h_{Roof}, h_{MT}, h_{BS}, k	D_{hb}, environment classification for model applicability	Building classification
BH_STDEV – building height standard deviation	h_{MT}, h_{BS}	h_{Roof}, h_{MT}, h_{BS}, k	D_{hb}, Macro-cell applicability	Building classification
SW_MV- street width mean value	K, C_m	k, w, b	Environment classification for model applicability	Street classification
SW_STDEV- street width standard deviation	K, C_m	k, w, b	Environment classification for model applicability	Street classification
VI – vegetation index	K, C_m	k	Environment classification for model applicability	Area classification
WI – water index	K, C_m	k	Environment classification for model applicability	Area classification
SI – street index	K, C_m	k	Environment classification for model applicability	Area classification
OAI – open areas index	K, C_m	k	Environment classification for model applicability	Area classification
BI – building index	K, C_m	k	Environment classification for model applicability	Area classification

Table 4-2 – Other parameters correlation for propagation models.

	Distance (*d*) [km]	Antenna height (*a*) [m]
COST 231-Walfisch Ikegami (LoS)	$0.02 \leq \ \leq 0.2$	Not used
COST 231- Walfisch Ikegami (NloS)	$0.2 \leq \ < 1$	Not used
3GPP – Models	$1 \leq \ < 5$	Not used
COST 231-Hata	$5 \leq \ \leq 20$	Defined by user

Some explanations have to be given for the 3GPP models range. In fact a cause of the absence of precise declaration in the definition for these models (it just says that both the micro-cell and macro-cell models are designated mainly for distances from few hundreds meters to kilometres, and that they are not very accurate for short distances), the range from 1 to 5 km (5 excluded) is chosen for this work.

4.2 GIS

Geographic Information Systems (GIS) refers to computer software that deals with digital spatial databases, meaning a computerised system designed to dealing with the collection, storage, manipulation, analysis, visualisation and displaying of geographic information [GIST03]. GIS is a tool to perform the spatial analysis that will put insight to the activities and phenomena carrying out everyday. In general, typical functions of a GIS tool are: creation and visualisation of spatial data, spatial search, data overlay, buffer operation and network analysis, 3-dimensional analysis, geocoding (conversion of an address into the longitude and latitude co-ordinates).

The most important motivation for GIS use is because it is easily possible to visualise digital maps; in fact, if one has only paper maps, it is time-consuming to integrate several maps into one map by manual tracing. In spatial analysis, it is possible to visualise spatial data repeatedly in various ways and at various scales, consequently, visualisation of spatial data can be done easily and rapidly. The need to do calculations in spatial analysis, is another reason why GIS is necessary; in fact, by using a GIS tool one may count the total number of points, calculate the average population, or measure the length of line segments. The third reason is that spatial data are often provided in a digital format that is suitable for a GIS use,

which assures that sophisticated spatial analysis can be done immediately in a computerised environment if one obtains spatial data; moreover, it is possible to save these data converting them from an analogue format including paper maps and hardcopies of figures, tables, and manuscripts, into a digital one. In general, typical GIS applications are urban planning, real estate, facility management, marketing analysis, environmental management, geo-statistics, and operation research.

Many GIS data formats consist of vectored information rather than raster image data: vector data represents the locations of the discrete objectives by points, lines and areas; raster data are continuous numeric values, such as elevation, and continuous categories, such as vegetation types, and they are represented using the raster model that divides the entire study area into a regular grid of cells in specific sequence, each cell has a unique value representing different types. In this work, the Professional 6.0 version of the well known GIS tool MapInfo® [MapI01a] is used; the great power of this software is given by an easy manipulation and processing of grids, one or more grids being saved in one file table (*.tab) by which it is possible to have a combination of vectored and raster data, Figure 4-2.
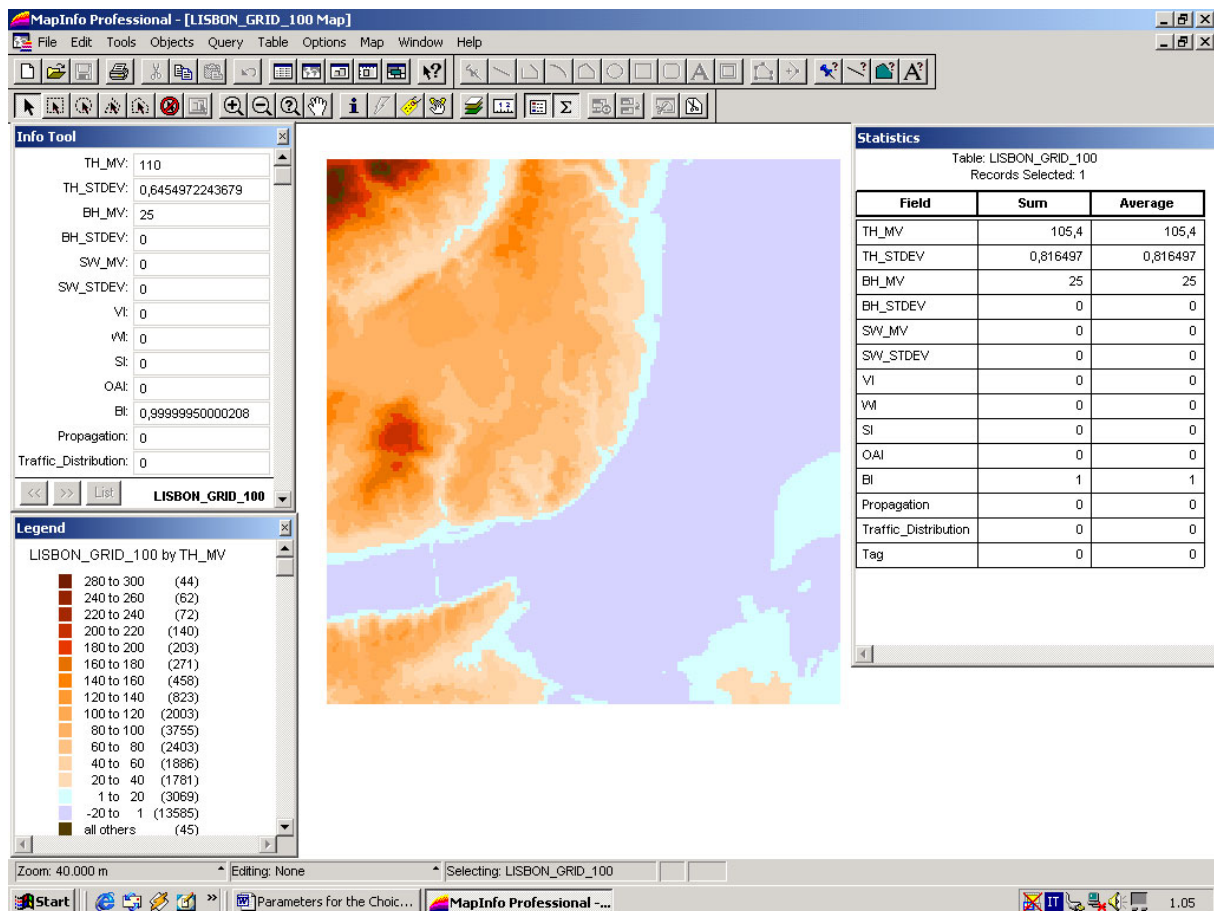
Figure 4-2 – Example of MapInfo® Professional 6.0.

MapInfo data is in two files, the graphics reside in a .MIF (MapInfo Interchange Format) file, and the text data is contained in a .MID file. The MIF file has two areas, the file header and the data section, [MapI01b]; information on how to create MapInfo® tables is in the header, the graphical object definitions are in the data section, meaning as graphical object definitions the border co-ordinates of each object, the centroid co-ordinates (by which is possible to catch the grid resolution), the pen style, the colour, etc. The MID file contains data, one record of data per row, delimited by the character specified in the MIF delimiter statement (the default delimiter is Tab); each row in the MID file is associated with a corresponding object in the MIF file: first row with first object, second row with second object, and so on, starting with respect to the north east quadrant of the grid, and proceeding like in a raster scan mode. This means that the reading of the two files is done at the same time by the software, one pixel for time, and it is also important to say that the software can import external MIF files and can read the corresponding MID ones (with the only assumption of having the same name and that they are both located in the same directory),

The MID file is an optional file, hence, when if there is no one, all fields in the grids are blank meaning the complete absence of values, [MapI01b]. It is important to note that even it is quite simple to create and read a MID file, it is quite complicated to create and most of all to read a MIF file from an external software, the reason for this being the both the presence of the co-ordinates and the need of processing data whose values are stored in the MID file. For this reason, in this work a software is built that allows to read, process, write and to create completely new MIF files in a completely dynamic way, and with a very fast processing time even with very large grids of more than 480000 objects.

4.3 Parameters thresholds

In this work, starting from the results of [CoVe02] that suggests the choice of 100 m resolution grids as input for the tool for the automatic choice of propagation model and area for traffic distribution selection, and due to the easiness on obtaining data from MOMENTUM partners, a set of complete grids of 100 m resolution for seven cities is taken and analysed for simulations: Berlin, Hanover, and Karlsruhe in Germany, Bilthoven, and The Hague in the Netherlands, Lisbon, an Porto in Portugal.

The goal of the tool is reached through a few elementary steps: processing by a GIS tool (MapInfo® Professional 6.0.) of the grids for the eleven well known layers, combining the great relevance of these layers with the great visualisation power of the GIS tool to show all the main environment characteristics and properties of these cities, and assessing all the cities properties by the construction of histograms representing the percentage of pixels' occurrences for each layer, so that a complete visualisation of the results using different outputs is given.

By analysing accurately both these two layouts to choose and set the thresholds for the classification of the different areas, by combining these thresholds with the range of the propagation models ones, and by adding other selection criteria with the appropriate thresholds, the selection of a particular propagation model for a selected area is achieved.

It seems clear that a great advantage to carry out all this work is given by the opportunity of working with well know environments, like the cities of Lisbon and Porto. Also, due to the fact that both these cities present variable properties with all the types of terrain characteristics (Lisbon in particular has got a great variably in terrain height), a great presence of water (they are both crossed by a river, and Porto is also washed by the ocean), and various urban and suburban scenarios, with a combination of old areas (with close old buildings of uniform height and very small streets), with modern ones (for Lisbon one can just take into account all the Expo 98 area). Due to all these characteristics, it is possible to construct an algorithm and to assess it by running simulations, and then apply the results to all the other cities.

The input data for all the cities mentioned above, are stored into grids composed by a variable number of objects (pixels), each pixel represented by its geographical coordinates, with a square of 100 m × 100 m, and by a set of float values, one for each layer. In Table 4-3, the minimum and maximum value for both X and Y coordinates, and the total number of pixels of all the cities grids, are presented.

In order to create a new grid representing just one layer, for a particular city under study, it is necessary to make a sort of quantisation of the input data, transforming these amount of values in a restricted new one; in this way, it is allowed a graphical representation with a GIS tool (e.g. MapInfo® Professional 6.0.), or to process it with a spread-sheet (e.g. Microsoft™ Excel 2000), e.g. graphing histograms, etc. All the layers concerning standard deviation (TH_STDEV, BH_STDEV, SW_STDEV) are not represented into grids or

histograms, given the fact that one cannot get very useful information from the graphical representations of these layers.

Table 4-3 – Grids coordinates and dimensions (adapted from [CoVe02].

	Xmin	Xmax	Ymin	Ymax	# of pixels
Berlin	4 592 500	4 600 000	5 817 500	5 825 000	5 625
Hannover	4 349 000	4 352 000	5 800 000	5 803 000	900
Karlsruhe	4 222 000	4 280 000	5 400 000	5 480 000	480 000
Lisbon	481 000	498 000	4 278 000	4 296 000	36 000
Porto	522 000	538 000	4 548 000	4 564 000	25 600
Bilthoven	130 000	150 000	458 000	470 000	24 000
The Hague	75 000	90 000	450 000	460 000	15 000

An important aspect that needs to be underlined deals with the selection of the quantisation step for the different layers; whereas it is quite reasonable to choose a decimal step for all the layers expressed with an index with values from 0 to 1 (VI, WI, SI, OAI, BI), the choice is not simple at all for all the others layers (TH_MV, BH_MV, SW_MV).

The following criteria is adopted in this work: a step of 20 m is set for the TH_MV, since quantisation steps of 5, 10, 15, 25 m were processed and it was realised that the 20 m step fits the terrain variations in a best way; a step of 3 m is selected for the BH_MV due to the fact that it is equal to a typical floor height; moreover a 4 m step is chosen for the SW_MV, since the width of a communication route (based on some research on national urban technical documentation) is about 3,5 m and because there are many kinds of streets (e.g.: with or without central separator, with large or small sidewalks, with 2 or 4 roadways, etc) it is reasonable to select 4 m width as a one way street. It is also very important to say that for all the index layers the value zero is recognised and separated from the other ones, which is to define the total absence of the layer in the grid (useful for instances for VI, WI layers); for TH_MV it is also necessary to include a negative value, due to the presence of the Dutch cities that have some areas located under the sea level. In Table 4-4 the comparison of the input values for all the layers for the cities of Lisbon, Porto, Berlin and The Hague, is presented, concerning minimum and maximum, mean, and standard deviation values. One can observe by analysing this simple table that it is possible to get precious information from it, understanding some of the cities properties and differences, turning on the great powerful of these layers.

The second step is to establish an universal environment classification for all the cities, creating a way to make the automatic selection just by using the layers' values.

Table 4-4 – Layer values (min, max, mean, st. deviation).

Layers	Min				Max				Mean				St. deviation			
	LISBON	PORTO	BERLIN	HAGUE	LISBON	PORTO	BERLIN	HAGUE	LISBON	PORTO	BERLIN	HAGUE	LISBON	PORTO	BERLIN	HAGUE
TH_MV	0	0	23.94	-5	311	241.8	83.47	22.5	40.67	2.63	39.99	0.61	5.17	51.32	6.85	2.85
TH_STDEV	0	0	0	0	28.46	25.96	11.04	4.69	1.29	4.18	0.77	0.11	1.99	2.04	0.79	0.36
BH_MV	0	0	0	0	60	60	67.48	25	6.88	61.71	15.58	7.13	9.75	7.85	8.79	8.26
BH_STDEV	0	0	0	0	103.41	124.09	85.95	14.14	1.33	40.42	2.21	2.23	6.01	6.35	2.38	3.61
SW_MV	0	0	0	0	20	20	15	20	2.36	21.83	9.77	8.24	5.07	4.67	5.62	6.36
SW_STDEV	0	0	0	0	4.88	5.13	2.74	5.27	0.02	0.03	0.34	0.37	0.19	0.18	0.63	0.82
VI	0	0	0	0	1	1	1	1	0.05	0.01	0.19	0.12	0.18	0.10	0.19	0.28
WI	0	0	0	0	1	1	1	1	0.45	0.20	0.01	0.1	0.49	0.45	0.08	0.3
SI	0	0	0	0	1	0.96	0.22	0.61	0.06	0.01	0.05	0.09	0.14	0.13	0.04	0.09
OAI	0	0	0	0	1	1	1	1	0.23	0.01	0.58	0.37	0.36	0.41	0.18	0.41
BI	0	0	0	0	1	1	0.99	0.65	0.28	0.15	0.23	0.07	0.40	0.39	0.16	0.11

Layers Values' Comparison for Lisbon, Porto, Berlin, and The Hague

This goal is one of the innovations presented in this work. Others approaches were already proposed, like [Corr02c], based on the [Kafa89] classification that classify the scenarios in:

- Rural: (flat, undulating, mountains)
- Suburban: (residential with open area, residential without open area, residential dense)
- Urban: (commercial, services, industrial)

A first environment classification using some of the layers value (BI, BH_MV, BH_STDEV, VI), and just for the urban and suburban area, is presented in Table 4-5, [Corr02a]. In this table just the BI, BH_MV, BH_STDEV, and VI layers are considered and it is easy to see that the area selection is not unique and there are also values of these layers not involved in the classification (e.g., < 0.12 for BI, or $0.2 < \ < 0.25$ for VI, etc.).

In [CoVe02], extensions from the tables describing the land use classes per operator (E-Plus, Telecel, and KPN) in [Kürn02], with the addition of two more columns, one describing to which layers the class was associated and the other containing the numerical value for the calculation purposes, were presented,

Table 4-6 to Table 4-7. In these tables an environment classification considering only some precise values of the BI, BH_MV, OAI, and VI layers, is made, but the complete absence of bounds for these layers renders the classification too much selective and of difficult application. Nevertheless by these tables it is possible to get the great relevance of layers as BI, BH_MV, OAI, and VI, because by them one can make a primary classification of a certain area combining the amount of build area expressed by the BI and also the type of buildings basing on the height value given by the BH_MV with the eventually surrounded area not build described by the OAI and VI layer. It seems almost obvious that it is not possible to make an automatic selection using just these few layers described above, and with these multitude and almost quite chaotic different area classifications: hence, a new one, simpler and more rational, is proposed, containing the following environment classifications:

- Urban light
- Urban dense
- Suburban light
- Suburban dense
- Rural
- Water
- Green
- Open

Table 4-5 – Area Classification based on [Kafa89], (adapted from [Corr02c]).

Area Classification		BI [%]	BH_MV [m]	BH_STDEV [m]	VI [%]
Suburban	Residential with open area	0.12 – 0.2	6	3	0.25 ≤
	Residential without open area	0.2 – 0.3	6 – 9	3	< 0.5
	Dense	0.12 ≤	12 ≤	3	≤ 0.2
Urban	Commercial	0.45 ≤	12 ≤	3	0
	Services	0.3 – 0.4	9	3	0
	Industrial	0.35 – 0.45	6 – 9	3	≤ 1

Table 4-6 - Classification of E-Plus' land use classes (extracted from [CoVe02]).

Name	Description	Layer	Taken Values
Dense urban	Areas with buildings of more than five floors, closed alignment, big buildings, no or only few vegetation; this class does not exist in villages or small towns	BH BI	24 m 0.6
Urban	Built-up areas up to five floors; interrupted alignments and higher portion of vegetation possible	BH BI	15 m 0.4
Suburban	Built-up areas with small buildings up to two floors, high portion of vegetation	BH BI	6 m 0.2
Industrial areas	Big industrial areas (e.g., chemical industry, refineries, docks, etc.); open areas within these industrial areas are classified separately; minimum diameter of an industrial area is 500 m	None	-
Sealed areas	Streets, roads, airfields, etc	OAI	1.0
Coniferous forest	Closed areas with coniferous trees	VI	1.0
Deciduous forest	Closed areas with deciduous trees	VI	1.0
Diversified open areas	Fruit-and-wine-growing areas with single trees, very small forests, cemeteries	OAI	1.0
Agricultural areas including fallow	Open field, fallow, meadow	OAI	1.0
Marsh	Marsh, bog, wet meadow	OAI	1.0
Fresh water	Inland water, lakes, rivers	WI	1.0
Sea water	Sea	WI	1.0
Open-cast areas	Open-cast areas, dumps, quarries, etc	OAI	1.0
Rocks	Mountainous areas without vegetation	OAI	1.0
Sand	Dunes and beaches without vegetation	OAI	1.0
Undefined	All other areas	None	-

Table 4-7 - Classification of Telecel land use classes, (extracted from [CoVe02]).

Name	Description	Layer	Taken Values
Unclassified	Area where no data is available	None	-
Open	Area with little or no vegetation	OAI	1.0
Sea	Ocean and sea	WI	1.0
Inland water	Lakes, rivers or canals	WI	1.0
Residential	Houses in suburban environment. Suburban density typically involves laid out street patterns in which streets are visible. Lots may be as small as 30 m by 30 m, but are typically larger and include vegetation cover. Average height is below 15 m.	BH BI	10 m 1.0
Mean urban	Areas within urban perimeter. The mean urban should have mean street density with no pattern, the major streets are visible, and the built-up features appear distinct from each other. Some small vegetation could be included. Average height is below 40m.	BH BI	25 m 1.0
Dense urban	Areas within urban perimeter. This includes dense urban areas where built-up features do not appear distinct from each other. It also includes built-up features of the downtown district with heights below 40 m.	BH BI	30 m 1.0
Buildings	Cluster of high towers or skyscrapers higher than 40 m.	BH BI	60 m 1.0
Villages	Small built-up area in rural surrounding.	BH BI	10 m 1.0
Industrial	Areas including buildings with larger footprints (greater than or equal to 20 m by 40 m) with heights below 20 m, separated by streets wider than 20m.	BH BI	15 m 1.0
Open_in_urban	Small open land area with no vegetation surrounded by mean urban, dense urban, or residential.	OAI	1.0
Forest	Forested lands with closed tree canopy. No distinction is made between deciduous and coniferous.	VI	1.0
Parks	Any vegetation land in any urban environment. Golf courses, municipal parks, extensive cemeteries are included in this category.	VI	1.0
Block buildings	Scattered buildings group. These buildings have a large footprint and can be separated from each other by visible streets or open land.	BH BI	10 m 1.0
Dense block build	Blocks of densely grouped buildings which may be parallel to one another or not.	BH BI	10 m 1.0

Table 4-8 - Classification of KPN's land use classes, (extracted from [CoVe02]).

Name	Description	Layer	Taken Value
Open	Open areas	OAI	1.000
Wood	Forest areas	VI	1.000
Water 1	Sea water	WI	1.000
Water 2	Fresh water	WI	1.000
Built-up 1	Building height 0-10m	BH	5 m
	Building density 0-15%	BI	0.075
Built-up 2	Building height 0-10m	BH	5 m
	Building density 15-30%	BI	0.225
Built-up 3	Building height 0-10m	BH	5 m
	Building density >30%	BI	0.650
Built-up 4	Building height 10-20m	BH	15 m
	Building density 0-15%	BI	0.075
Built-up 5	Building height 10-20m	BH	15 m
	Building density 15-30%	BI	0.225
Built-up 6	Building height 10-20m	BH	15 m
	Building density >30%	BI	0.650
Built-up 7	Building height >20m	BH	25 m
	Building density 0-15%	BI	0.075
Built-up 8	Building height >20m	BH	25 m
	Building density 15-30%	BI	0.225
Built-up 9	Building height >20m	BH	25 m
	Building density >30%	BI	0.650
Built-up 10	Metallic areas, like oil tank	None	-

The last three area classifications are included to emphasize respectively: particular areas like river, sea etc., or large park and forest, or big squares and large wide-open area. According to this classification, a complete set of new tables, is presented, Table 4-9 to Table 4-14, for both the traffic distributions and the propagations models according to the 3 model range classes.

The values in the tables come from an analysis of the input data grids for the cities of Lisbon and Porto, and are based on the histograms results for the different layers; they are not the definitive thresholds to make the automatic choice of the models, but just a first approach to the problem, trying to get the complex problem of catching the key layers and their possible bounds of ranges that will determinate the definitive thresholds with the running of the simulations through the algorithm assessment. In this way, for example, a dense urban area with close buildings of 8-10 floors of nearly uniform height, can be expressed combining a very high BI value up to 0.8 and a BH_MV values up to 25 m, and also a very low BH_MV value lower than 6 m, with a very low SW_MV value lower than 12 m, while the VI and WI value will be almost 0.

One can see that a great relevance to the BI layer is given for the area classification and consequently for the propagation models selection; the following primary thresholds are assigned: the value that indicates the strict classification between an urban-suburban environment from a rural one is set to 0.3, then the values between 0.3 and 0.6 are assigned to a suburban light area, the values between 0.6 to 1 to a suburban dense, while for an urban light the bounds are between 0.7 to 1 excluded because this value is assigned to a urban dense area. The presence of little vegetation inside an urban core is expressed by a VI value less than 0.2 while different thresholds are set to the OAI, less than 0.3 and 0.4 for a urban and suburban dense respectively, less than 0.5 for an urban light area. For an urban dense area, a maximum SW_MV value of 12 m is established and the WI and VI are set to a 0. The following BH_MV values are established: up to 2 and 3 floors for a suburban light and dense area respectively, while up to 5 floors for an urban light and up to 8 floors for an urban dense scenarios. Any particular threshold for both the SW_STDEV and SI is assigned because it is very difficult to give a priori a particular area classification using these layers' values; while the values for the BH_STDEV are set according to the Table 4-5. For the classification of Green, Open, and Water the following criteria is adopted, for the Water areas just a WI superior to 0.6 with all the others layers equal to 0, for the Green a VI value up to 0.9 is set but a little presence of buildings (BI less than 0.1), and water (WI less than 0.6), is allowed in order to describe the eventually presence of parks with little lakes and some buildings; at least for the Open a OAI value up to 0.9 is set and the presence of some buildings (BI less than 0.1), vegetation or streets (V,ISI, SW_MV,and SW_STDEV up to 0) is allowed, according to the fact that this type of area may represents large squares or wide-open area.

Moreover, for the propagation model tables, the following reasoning is adopted: for the 3GPP models for macro-cells a BH_STDEV value less than 3 m is chosen, meaning an uniform building height; both the 3GPP and COST 231–Walfisch Ikegami models are not applicable in case of presence of rural, water, green, open areas, and the COST 231–Walfisch Ikegami model in particular, in the transition range is just applicable in regions characterised by a SW_MV less than 8 m and a SW_STDEV less than 4 m (absence of wide streets), a OAI less than 0.3 (absence of large open areas), and a VI less than 0.2 (very few presence of vegetation). As one can observe from these tables, a first step on giving a direct relationship between the propagation models and the DTMs layers values is adopted following a acceptable method.

Table 4-9 – Layer values for traffic distribution area selection.

	Traffic Distribution Area Classification							
	SUBURBAN LIGHT	SUBURBAN DENSE	URBAN LIGHT	URBAN DENSE	RURAL	WATER	GREEN	OPEN
BH_MV	$6 \leq$	$12 \leq$	$15 \leq$	$25 \leq$	< 25	0	$0 \leq$	$0 \leq$
BH_STDEV	$6 \leq$	$3 \leq$	$3 \leq$	$3 \leq$	$0 \leq$	0	0	0
BI	$0.3 < \ <0.6$	$0.6 \leq \ \leq 1$	$0.7 \leq \ < 1$	1	≤ 0.3	0	≤ 0.1	≤ 0.1
VI	≤ 1	< 0.2	< 0.2	0	$0 \leq$	0	≤ 0.9	$0 \leq$
SW_MV	≤ 20	≤ 20	≤ 20	≤ 12	≤ 20	0	0	$0 \leq$
SW_STDEV	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	0	0	0
OAI	< 0.9	< 0.5	< 0.5	< 0.3	≤ 1	0	< 0.9	≤ 0.9
WI	< 0.6	< 0.2	< 0.2	0	< 0.6	≤ 0.6	< 0.6	0
SI	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	0	0	$0 \leq$

Table 4-10 - Layer values for COST 231-Walfisch Ikegami model selection.

	SUBURBAN LIGHT	SUBURBAN DENSE	URBAN LIGHT	URBAN DENSE	RURAL	WATER	GREEN	OPEN
COST 231-Walfisch Ikegami **in range 0.2 km $\leq d <$ 1 km**								
BH_MV	$6 \leq$	$12 \leq$	$15 \leq$	$25 \leq$				
BH_STDEV	$3 \leq$	$3 \leq$	$3 \leq$	$3 \leq$				
BI	$0.3 < \ < 0.6$	$0.6 \leq \ \leq 1$	$0.7 \leq \ < 1$	1				
VI	≤ 1	< 0.2	< 0.2	0	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.
SW_MV	≤ 20	≤ 20	≤ 20	≤ 12				
SW_STDEV	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$				
OAI	< 0.9	< 0.5	< 0.5	< 0.3				
WI	< 0.6	< 0.2	< 0.2	0				
SI	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$				

Table 4-11 - Layer values for 3GPP model for macro cell selection.

	SUBURBAN LIGHT	SUBURBAN DENSE	URBAN LIGHT	URBAN DENSE	RURAL	WATER	GREEN	OPEN
3GPP Model for Macro-cell **in range 1 km $\leq d \leq$ 5 km**								
BH_MV	$6 \leq$	$12 \leq$	$15 \leq$	$25 \leq$	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.
BH_STDEV	< 3	< 3	< 3	< 3				
BI	$0.3 < \ <0.6$	$0.6 \leq \ \leq 1$	$0.7 \leq \ < 1$	1				
VI	≤ 1	< 0.2	< 0.2	0				
SW_MV	≤ 20	≤ 20	≤ 20	≤ 12				
SW_STDEV	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$				
OAI	< 0.9	< 0.5	< 0.5	< 0.3				
WI	< 0.6	< 0.2	< 0.2	0				
SI	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$				

Table 4-12 - Layer values for COST 231-Walfisch Ikegami model selection.

	SUBURBAN LIGHT	SUBURBAN DENSE	URBAN LIGHT	URBAN DENSE	RURAL	WATER	GREEN	OPEN
COST 231-Walfisch Ikegami **in range 1 km $\leq d \leq$ 5 km**								
BH_MV	$6 \leq$	$12 \leq$	$15 \leq$	$25 \leq$	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.
BH_STDEV	$3 \leq$	$3 \leq$	$3 \leq$	$3 \leq$				
BI	$0.3 < \ <0.6$	$0.6 \leq \ \leq 1$	$0.7 \leq \ , 1$	1				
VI	< 0.2	< 0.2	< 0.2	0				
SW_MV	≤ 8	≤ 8	≤ 8	≤ 8				
SW_STDEV	≤ 4	≤ 4	≤ 4	≤ 4				
OAI	< 0.3	< 0.3	< 0.3	< 0.3				
WI	< 0.6	< 0.2	< 0.2	0				
SI	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$				

Table 4-13 - Layer values for COST 231- Hata model selection.

	SUBURBAN LIGHT	SUBURBAN DENSE	URBAN LIGHT	URBAN DENSE	RURAL	WATER	GREEN	OPEN
COST 231-Hata Model in range 1 km $\leq d \leq$ 5 km								
BH_MV	$6 \leq$	$12 \leq$	$15 \leq$	$25 \leq$	< 25	0	$0 \leq$	$0 \leq$
BH_STDEV	$3 \leq$	$3 \leq$	$3 \leq$	$3 \leq$	≥ 0	0	0	0
BI	$0.3 < \ <0.6$	$0.6 \leq \ \leq 1$	$0.7 \leq \ < 1$	1	≤ 0.3	0	≤ 0.1	≤ 0.1
VI	≤ 1	< 0.2	< 0.2	0	$0 \leq$	0	$0.9 \leq$	$0 \leq$
SW_MV	$8 <$	$8 <$	$8 <$	$8 <$	≤ 20	0	0	$0 \leq$
SW_STDEV	$4 <$	$4 <$	$4 <$	$4 <$	$0 \leq$	0	0	0
OAI	$0.3 \leq$	$0.3 \leq$	$0.3 \leq$	$0.3 \leq$	≤ 1	0	$0.9 \leq$	$0.9 \leq$
WI	< 0.6	< 0.2	< 0.2	0	< 0.6	$0.6 \leq$	$0.6 <$	0
SI	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	0	0	$0 \leq$

Table 4-14 - Layer values for COST 231- Hata model selection.

	SUBURBAN LIGHT	SUBURBAN DENSE	URBAN LIGHT	URBAN DENSE	RURAL	WATER	GREEN	OPEN
COST 231-Hata Model in range 5 km $\leq d \leq$ 20 km								
BH_MV	$6 \leq$	$12 \leq$	$15 \leq$	$25 \leq$	< 25	0	$0 \leq$	$0 \leq$
BH_STDEV	$6 \leq$	$3 \leq$	$3 \leq$	$3 \leq$	$0 \leq$	0	0	0
BI	$0.3 < \; <0.6$	$0.6 \leq \; \leq 1$	$0.7 \leq \; < 1$	1	≤ 0.3	0	≤ 0.1	≤ 0.1
VI	≤ 1	< 0.2	< 0.2	0	$0 \leq$	0	$0.9 \leq$	$0 \leq$
SW_MV	≤ 20	≤ 20	≤ 20	≤ 12	≤ 20	0	0	$0 \leq$
SW_STDEV	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	0	0	0
OAI	< 0.9	< 0.5	< 0.5	< 0.3	≤ 1	0	< 0.9	$0.9 \leq$
WI	< 0.6	< 0.2	< 0.2	0	< 0.6	$0.6 \leq$	< 0.6	0
SI	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	0	0	$0 \leq$

4.4 Algorithm Development

The achievement of a tool for the automatic choice of propagation and traffic models cannot exclude the use of the great graphical power of MapInfo® Professional 6.0 in mapping grids and maps as previously mentioned. For this reason, in this work, it is chosen to construct an algorithm that is able to read, write, edit and manipulate data of the two MapInfo input files the MID and the MIF file, reducing to the minimal all the user interaction on doing these things. Moreover, as these two types of files are processed at the same time and they are linked to each other, and due of the fact the number of objects can reach hundreds of thousands (480000 for Karlshure), the choice for an object oriented language of programming as the C++ is recommended, for a minimal memory allocation and due to its very dynamic management of the data to be processed.

Using a linked list class, it is so possible to allocate just the needed memory for the requested application, and most of all to clear step by step all the data already processed or the useless information, hence, freeing memory and giving the assurance of a very fast and reliable time of execution: about 30 sec running the code with a notebook ASUS A-1350 with an Intel Celeron 800 processor, and 128 MB of RAM, under a Windows 2000 environment.

Before explaining all the algorithm properties and its flowcharts, it is important to mention all assumptions that this work takes for the construction of the automatic tool. As consequence of the scarce information available, no 3GPP models for micro-cells are taken into account, and the simplification of not using the LoS formulation of COST 231-Walfisch Ikegami propagation model is adopted, so that the models applicability both for the propagation and the traffic ones start over a distance of more than 200 m from the BS, creating a ring of 200 m from the central pixel where BS is located within which model selection is done. For these reasons the tool is not indicated for pico cell planning and for indoor applications and it assumes circular omni directional antennas.

In Figure 4-3, the algorithm flowchart following the international standard of representation is graphed; as one can observe it shows the algorithm properties underlining its great simplicity in spite of the fact the real great complexity of the code implementation. By analysing the algorithm flowchart, it is possible to catch the main algorithm properties and the way by which it is functioning, it is possible to assert that: it asks for both the MID/MIF names, being able to read the files, allocating memory in a complete dynamic way to storage all the data; it catches the grids dimension, the resolution, all the bounds that are kept in the
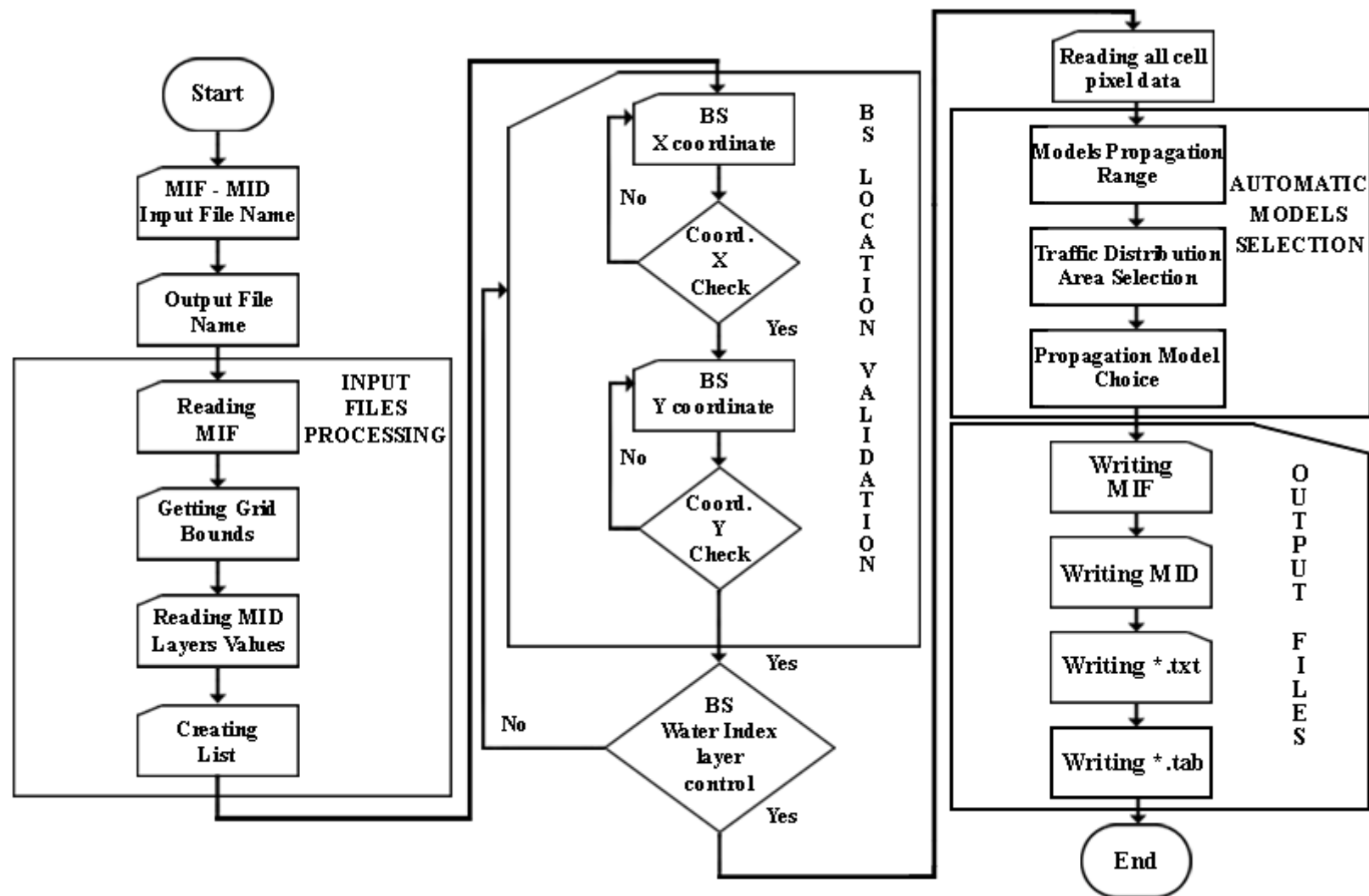
Figure 4-3 –Algorithm Flowcharts

MIF file, it asks the user for the BS coordinates location and it check and recognises this coordinates in the map, checking also if the chosen location is suitable to put a BS into it. This checking is done by controlling if in the related pixel some layers for the presence of excessive values (more than 90%): trees and vegetation in general (by VI), wide open area without building (by OAI), and water (by WI), giving a warning statement with the relative reason, and it forces the user for another BS location just in the case of the excessive presence of water (more than 60%). It also puts in an automatic way the BS above the rooftop of the highest building of the selected pixel and it informs the user about the antenna location from the ground level asking if the user wants to put an extra pole for increasing the BS height (useful especially in the case of complete absence of buildings in the pixel chosen for the BS location). After that, it asks for radius dimension, giving the minimum and maximum bounds according to the current BS location and grid dimensions, (it gets this values from the input MIF files, which is able to read and to catch all the grids properties), refusing any radius value out of these bounds.

After this step it marks a circular shape cell (due to the fact that it is working with omni-directional antennas), creating a new list class and memorising just the data of the pixels inside that cell, and deleting all the other ones. The algorithm is now able to process all these data in a totally dynamic way, without the user interaction, making any kind of operations just by a simple function calls, as calculating the distance from the coordinate of the centre of each pixel to the BS ones, or calculating the free path loss in each pixel etc. Any kind of further implementation required by the user for extra operations is possible just by adding few lines of code and creating a new external function.

At the moment, for this version of the programme, the following functions are implemented:

- Calculation of the 2D distance, between the BS location and each pixel in the cell
- Calculation of the 3D distance between the BS and the MT in each pixel considering the worst case, (BS max height and MT min one);
- Free Path Loss Calculation for each pixel in the cell:
- Effective antenna height with respect to the MT location, useful for propagation model range of applicability for this parameter, and to check the eventual presence of regions inside the pixel where the model is not applicable;
- Classification of each pixel in the cell according to propagation model range;
- Classification of each pixel in the cell according to the traffic distribution areas;
- Classification of each pixel in the cell according to the propagation models classes;

- Creation of a MIF file with the addition of 4 columns for the layers: Propagation Choice, Traffic Distribution, Model Range, Antenna Height;

- Creation of a MID file with the addition of 4 columns for the layers: Propagation Choice, Traffic Distribution, Model Range, Antenna Height, and their respective values;

- Creation of a text file with a detailed report of the simulation done and all the Warnings with the correspondent reasons.

- Creation of a tab file with a table with all the values of all the old input layers and the new ones for an easy Spreadsheet processing;

The algorithm starts by first checking and classifying all the pixels inside the cell according to the ranges for the applicability of the different propagation models, then classifying each pixel in one of the area classification already mentioned above, and at last choosing the propagation model suitable for this type of pixel. It is important to say that for this level of the work, no calculation of the path loss for the selected model is given, while just to have a better reading of the output results, the code gives a sub classification for the COST 231-Hata model in:

- Hata Urban

- Hata Sub-Urban

- Hata Rural

In other words, this sub classification is in accordance with the pixel traffic distribution classification, and it just gives the user more information about the area where the model is being applied.

Some words must be spend on the method for choice of the algorithm. In fact, for this kind of implementation, it seems to be clear that the classification of the areas must be univocal, which is a very hard working. If one observes carefully all the values in the set of tables presented in the previous paragraph, one can notice that they seem to be almost perfect from a logical point of view, but on the other hand they do not make a selective area classification. For this reason, a new set of values is necessary and a new set of tables were build up, establishing logical correlations among the different layers and setting the values step by step, running a lot of different simulations, thank to the fact that, as already mentioned before, it is possible to know in advance the expected results from the good knowledge of the studied environment (Lisbon and Porto). The revisited tables with all the thresholds values for the automatic choice of both propagation models and traffic distribution area selection adopted by the tool are presented in Table 4-15 to Table 4-20.

Table 4-15 – Layers value for traffic distribution area selection adopted by the tool.

	Traffic Distribution Area Classification							
	SUBURBAN LIGHT	SUBURBAN DENSE	URBAN LIGHT	URBAN DENSE	RURAL	WATER	GREEN	OPEN
BH_MV	$10 \leq$	$10 \leq$	$10 \leq$	≥ 10	$0 \leq$	0	$0 \leq$	$0 \leq$
BH_STDEV	$0 \leq$	$0 \leq$	$0 \leq$	≥ 0	$0 \leq$	0	$0 \leq$	$0 \leq$
BI	$0.3 \leq\ < 0.6$	$0.6 \leq\ \leq 1$	$0.3 <\ \leq 0.9$	$0.9 <\ \leq 1$	< 0.3	0	$0 \leq$	$0 \leq$
VI	$0.2 \leq$	$0.2 \leq$	$0 \leq$	≥ 0	< 0.9	0	$0.9 \leq$	$0 \leq$
SW_MV	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	0	$0 \leq$	$0 \leq$
SW_STDEV	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	0	$0 \leq$	$0 \leq$
OAI	$0.5 <$	$0.5 <$	$0 \leq$	$0 \leq$	< 0.9	0	$0 \leq$	$0.9 \leq$
WI	< 0.6	< 0.6	$0 \leq$	$0 \leq$	< 0.6	$0.6 \leq$	$0 \leq$	$0 \leq$
SI	$0.5 <$	$0.5 <$	$0.5 \leq$	$0.5 \leq$	$0 <$	0	$0 \leq$	$0 \leq$

Table 4-16 - Layers value for COST 231-Walfisch Ikegami model selection adopted by the tool.

	SUBURBAN LIGHT	SUBURBAN DENSE	URBAN LIGHT	URBAN DENSE	RURAL	WATER	GREEN	OPEN
COST 231-Walfisch Ikegami **in range 0.2 km $\leq$ d < 1 km**								
BH_MV	10 $\leq$	10 $\leq$	10 $\leq$	10 $\leq$	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.
BH_STDEV	0 $\leq$	0 $\leq$	0 $\leq$	0 $\leq$				
BI	0.3 $\leq$ < 0.6	0.6 $\leq$ $\leq$ 1	0.3 < $\leq$ 0.9	0.9< $\leq$ 1				
VI	0.2 $\leq$	0.2 $\leq$	0 $\leq$	0 $\leq$				
SW_MV	0 $\leq$	0 $\leq$	0 $\leq$	0 $\leq$				
SW_STDEV	0 $\leq$	0 $\leq$	0 $\leq$	0 $\leq$				
OAI	0.5 <	0.5 <	0 $\leq$	0 $\leq$				
WI	< 0.6	< 0.6	0 $\leq$	0 $\leq$				
SI	0.5 <	0.5 <	$\leq$ 0.5	$\leq$ 0.5				

Table 4-17 - Layers value for 3GPP model for macro-cell selection adopted by the tool.

					3GPP Model for Macro-cell **in range 1 km ≤ d ≤ 5 km**			
	SUBURBAN LIGHT	**SUBURBAN DENSE**	**URBAN LIGHT**	**URBAN DENSE**	**RURAL**	**WATER**	**GREEN**	**OPEN**
BH_MV	10 ≤	10 ≤	10 ≤	10 ≤	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.
BH_STDEV	≤ 3	≤ 3	≤ 3	≤ 3				
BI	0.3 ≤ < 0.6	0.6 ≤ ≤ 1	0.3 < ≤ 0.9	0.9< ≤ 1				
VI	0.2 ≤	0.2 ≤	0 ≤	0 ≤				
SW_MV	0 ≤	0 ≤	0 ≤	0 ≤				
SW_STDEV	0 ≤	0 ≤	0 ≤	0 ≤				
OAI	0.5 <	0.5 <	0 ≤	0 ≤				
WI	0 < < 0.6	0 < < 0.6	0 ≤	0 ≤				
SI	0.5 <	0.5 <	≤ 0.5	≤ 0.5				

Table 4-18 - Layers value for COST 231-Walfisch Ikegami model selection adopted by the tool.

	SUBURBAN LIGHT	SUBURBAN DENSE	URBAN LIGHT	URBAN DENSE	RURAL	WATER	GREEN	OPEN
COST 231-Walfisch Ikegami in range 1 km $\leq d \leq$ 5 km								
BH_MV	$10 \leq$	$10 \leq$	$10 \leq$	$10 \leq$	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.	WARNING!!! The model is not applicable here.
BH_STDEV	$3 \leq$	$3 \leq$	$3 \leq$	$3 \leq$				
BI	$0.3 \leq\ < 0.6$	$0.6 \leq\ \leq 1$	$0.3 <\ \leq 0.9$	$0.9 <\ \leq 1$				
VI	$0.2 \leq$	$0.2 \leq$	$0 \leq$	$0 \leq$				
SW_MV	≤ 15	≤ 15	≤ 15	≤ 15				
SW_STDEV	≤ 4	≤ 4	≤ 4	≤ 4				
OAI	$0.5 <$	$0.5 <$	$0 \leq$	$0 \leq$				
WI	$0 <\ < 0.6$	$0 <\ < 0.6$	$0 \leq$	$0 \leq$				
SI	$0.5 <$	$0.5 <$	≤ 0.5	≤ 0.5				

Table 4-19- Layers value for COST 231-Hata model selection adopted by the tool.

	COST 231-Hata in range 1 km ≤ *d* ≤ 5 km							
	SUBURBAN LIGHT	**SUBURBAN DENSE**	**URBAN LIGHT**	**URBAN DENSE**	**RURAL**	**WATER**	**GREEN**	**OPEN**
BH_MV	10 ≤	10 ≤	10 ≤	10 ≤	0 ≤	0	0 ≤	0 ≤
BH_STDEV	3 ≤	3 ≤	3 ≤	3 ≤	0 ≤	0	0 ≤	0 ≤
BI	0.3 ≤ < 0.6	0.6 ≤ ≤ 1	0.3 < ≤ 0.9	0.9< ≤ 1	< 0.3	0	0 ≤	0 ≤
VI	0.2 ≤	0.2 ≤	0 ≤	0 ≤	< 0.9	0	0.9 ≤	0 ≤
SW_MV	15 <	15 <	15 <	15 <	0 ≤	0	0 ≤	0 ≤
SW_STDEV	4 <	4 <	4 <	4 <	0 ≤	0	0 ≤	0 ≤
OAI	0.5 <	0.5 <	0 ≤	0 ≤	< 0.9	0	0 ≤	0.9 ≤
WI	0 < < 0.6	0 < < 0.6	0 ≤	0 ≤	< 0.6	0.6 ≤	0 ≤	0 ≤
SI	0.5 <	0.5 <	≤ 0.5	≤ 0.5	0 <	0	0 ≤	0 ≤

Table 4-20 - Layers value for COST 231-Hata model selection adopted by the tool.

	SUBURBAN LIGHT	SUBURBAN DENSE	URBAN LIGHT	URBAN DENSE	RURAL	WATER	GREEN	OPEN
COST 231-Hata Model **in range 5 km $\leq d \leq$ 20 km**								
BH_MV	$10 \leq$	$10 \leq$	$10 \leq$	≥ 10	$0 \leq$	0	$0 \leq$	$0 \leq$
BH_STDEV	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	0	$0 \leq$	$0 \leq$
BI	$0.3 \leq\ < 0.6$	$0.6 \leq\ \leq 1$	$0.3 <\ \leq 0.9$	$0.9 <\ \leq 1$	< 0.3	0	$0 \leq$	$0 \leq$
VI	$0.2 \leq$	$0.2 \leq$	$0 \leq$	$0 \leq$	< 0.9	0	$0.9 \leq$	$0 \leq$
SW_MV	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	0	$0 \leq$	$0 \leq$
SW_STDEV	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	$0 \leq$	0	$0 \leq$	$0 \leq$
OAI	$0.5 <$	$0.5 <$	$0 \leq$	$0 \leq$	< 0.9	0	$0 \leq$	$0.9 \leq$
WI	$0 <\ < 0.6$	$0 <\ < 0.6$	$0 \leq$	$0 \leq$	< 0.6	$0.6 \leq$	$0 \leq$	$0 \leq$
SI	$0.5 <$	$0.5 <$	≤ 0.5	≤ 0.5	$0 <$	0	$0 \leq$	$0 \leq$

As one can see in these tables some corrections and simplifications respect to the Table 4-9 to Table 4-14 are made. For the traffic distributions classification, the BH_MV thresholds are set up or equal to 10 m for both the suburban and urban environments, these values are adopted because according to the Lisbon and Porto input data, a 10 m value for building height is the minimal one used to characterised a constructed area. The BI thresholds are more or less the same but a correction according to the simulations results for the upper bound of the urban light class is made changing the previous 0.7 value to an higher one of 0.9, as consequence the range for an urban dense area classification is shifted between 0.9 to 1. Others corrections adopted due to the simulations results are for the OAI thresholds, which are set for a value up to 0.5 for both the suburban light and dense areas while for the SI a value up to 0.3 establishes the selection between a suburban from a urban scenario. For all the others values it is possible to see that more grades of freedom are given, in order to not have too many areas where it is not possible to make a classification a cause of the presence of a mixture of layers values.

For the propagation models selection the SW_MV threshold is fixed to 15 m and the SW_STDEV to 4 m and the BH_STDEV is confirmed to 3 m, with the addition of these values to the traffic distribution area selection ones it is so possible to make the selection between the propagation models in the range between 1 km to 5 km, these thresholds in fact stand for a urban-suburban environment with open areas and building of almost the same height that are, as already seen, the basic assumptions to select a model from another one.

5   Analysis of Results

In this chapter, some of the main results obtained in this work are presented. Starting from some few examples of MapInfo® maps, for the cities of Lisbon, Porto, Berlin and The Hague, with the layers representations for a 100 m resolution grid, followed by the same input data processed and shown in histograms with Microsoft Excel 2000, then some pictures with the typical outputs and layouts of the tool, the output files (MIF, MID, TXT, TAB), written by the programme for a complete and detailed report of the simulation, and some results of the simulations (with the automatic choice for the propagation models and traffic distribution classification), presented by MapInfo®maps. Moreover, some simulations results obtained for the cities of Berlin and The Hague, are also shown related with an extra analysis to describe the problems occurred in processing the input data. The complete results on the histograms and the visualisations by grids for all the layers, for the cities of Lisbon, Porto, Berlin and the Hague are separately presented in Annex A and Annex B, respectively.

In Figure 5-4 to 5- 3, some typical maps representing the layer of the TH_MV for the cities of Lisbon, Porto and Berlin, are shown, where it is easy to catch just by a quick view the main terrain properties for these three cities: a very diversified environment with water and a lot of different terrain height levels for both Portuguese cities (from 1 m to 300 m for Lisbon, and to 1m to 210 m for Porto) and a quite flat distribution for the German one (from 20 m to 80 m).

The same input data of these three cities for the TH_MV layer, was then processed with the Microsoft Excel 2000, and the histograms representing the percentage of pixels' occurrences in the map for each quantisation step is shown in Figure 5-4 to 5-6. From this representation it is possible to get more in detail all the terrain properties, i.e., the great variety of terrain levels for both Lisbon and Porto especially for the values between 40 m and 100 m, and just the two levels between 20 m and 60 m for Berlin). It is also important to note, the relevance of the quantisation step, including the zero value, which is 10, 27, and 0% for Lisbon, Porto, and Berlin respectively, standing for the different terrain areas that are at the level of the sea (in others words water, i.e., the river and the ocean), as both Portuguese cities present them in a huge quantity.

Figure 5-1 –TH_MV for Lisbon.
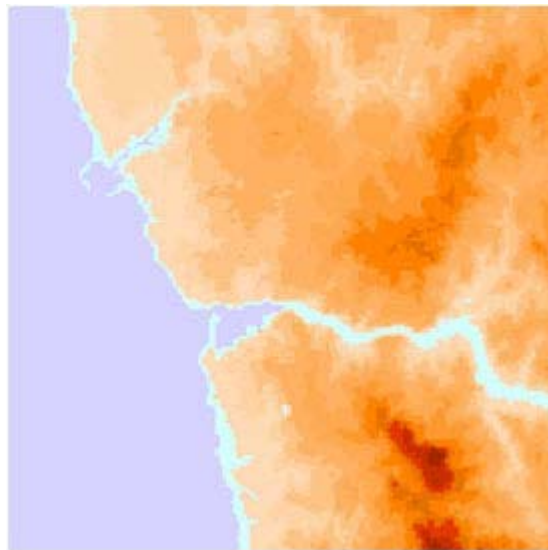
Figure 5-2 –TH_MV for Porto.

Figure 5-3 –TH_MV for Berlin.
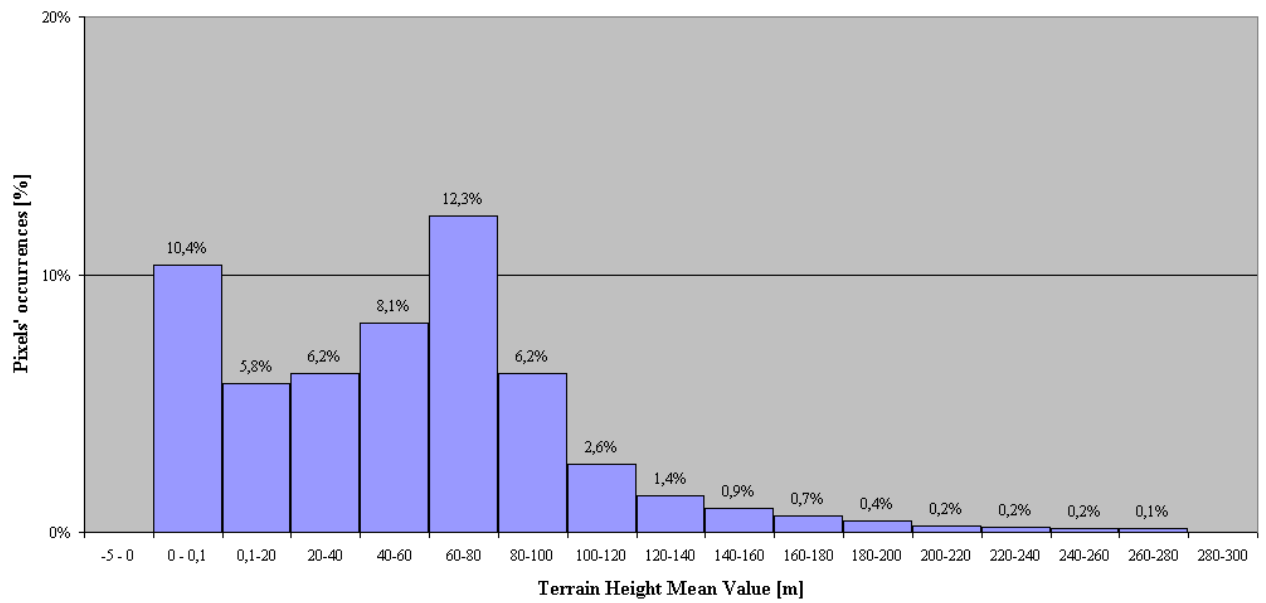
Figure 5-4 – Histograms of TH_MV for Lisbon.
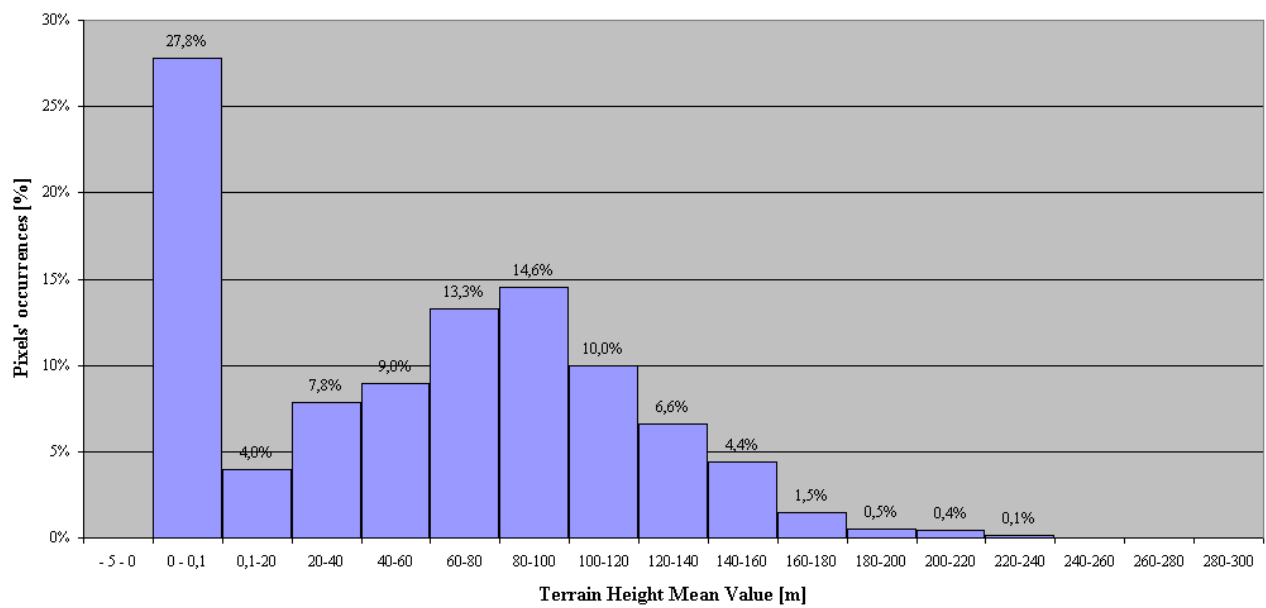
Figure 5-5 - Histograms of TH_MV for Porto.

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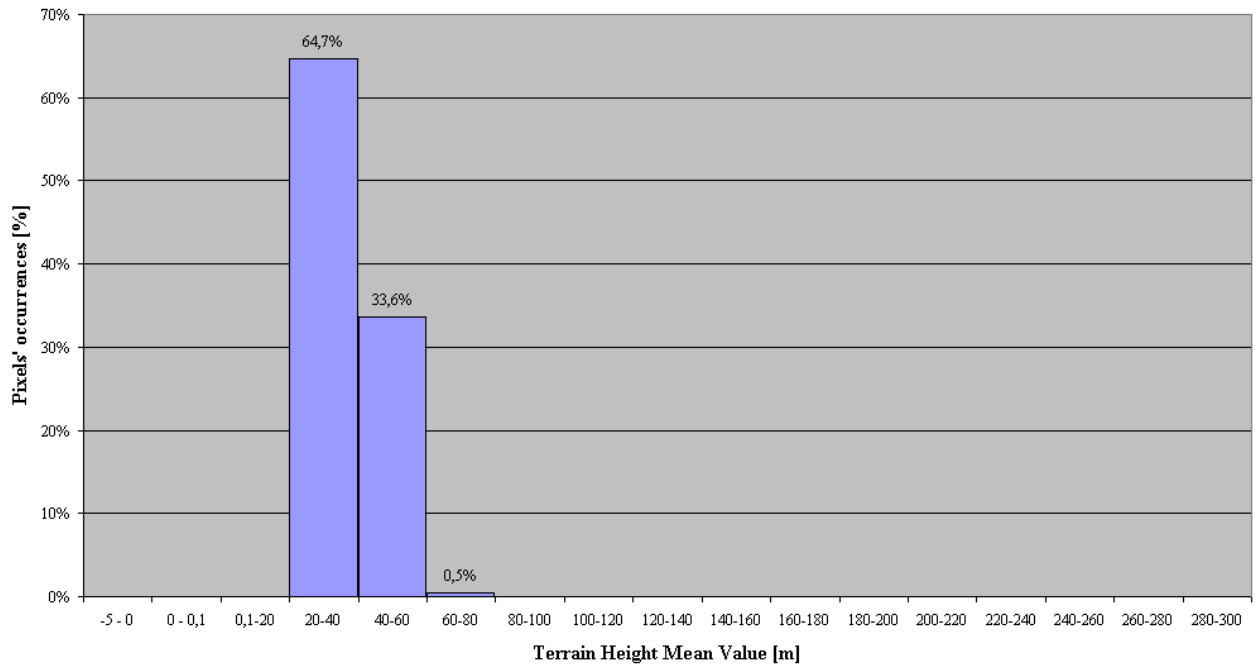
Figure 5-6 - Histograms of TH_MV for Berlin.

Another layer comparison, this time for the cities of Lisbon, Porto and The Hague can be done for the BI, and it is shown in Figure 5-7 to Figure 5-9. This layer, as already seen in the previous chapter, is one of the key parameters for the choice of both propagation and traffic models, due to the fact that it allows to trace the portion of land occupied by buildings, so that the cities morphology can be understood. The grids are matched, as usual, with the relative histograms representations, Figure 5-10 to Figure 5-12.

More words must be spend in this last case. In fact, as one can observe comparing with the representations of Lisbon and Porto, the results shown in the histogram of The Hague are almost strange and anomalous, since for this city the maximum value for the BI layer is just 0.7! To understand the reason for this it is necessary to go back to the input data generation, as already seen in Table 4-6, 4-8 and 4.-9, the areas classification delivered by Telecel, E-Plus and KPN takes a completely different approach, because they are generated by completely different raster data (see the [CoVe02] for more details in raster grids generation), producing for this reason lot of problems in the tool results if the simulations are extended to cities whose input data are generated with standards that differ from Telecels approach on raster grid generation. A future further implementation of the tool proposed in this work is needed, to a completely wide spread the applications of this tool to other European cities, just creating a simple "translator" of input data into the Telecel standard, so that this tool is set and it properly works.

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Figure 5-7 – BI for Lisbon.
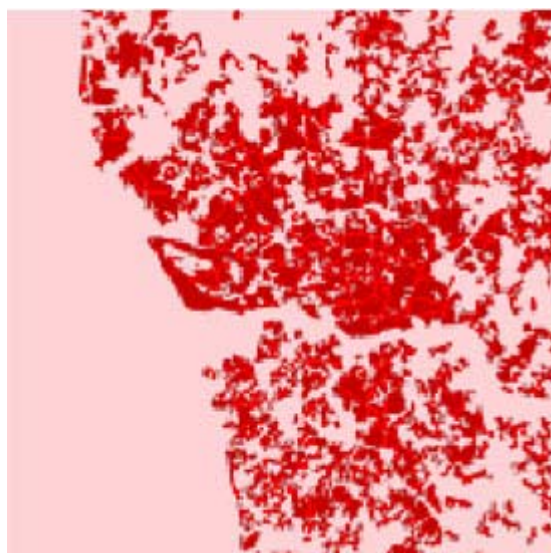
Figure 5-8 – BI for Porto.

Figure 5-9 – BI for The Hague.
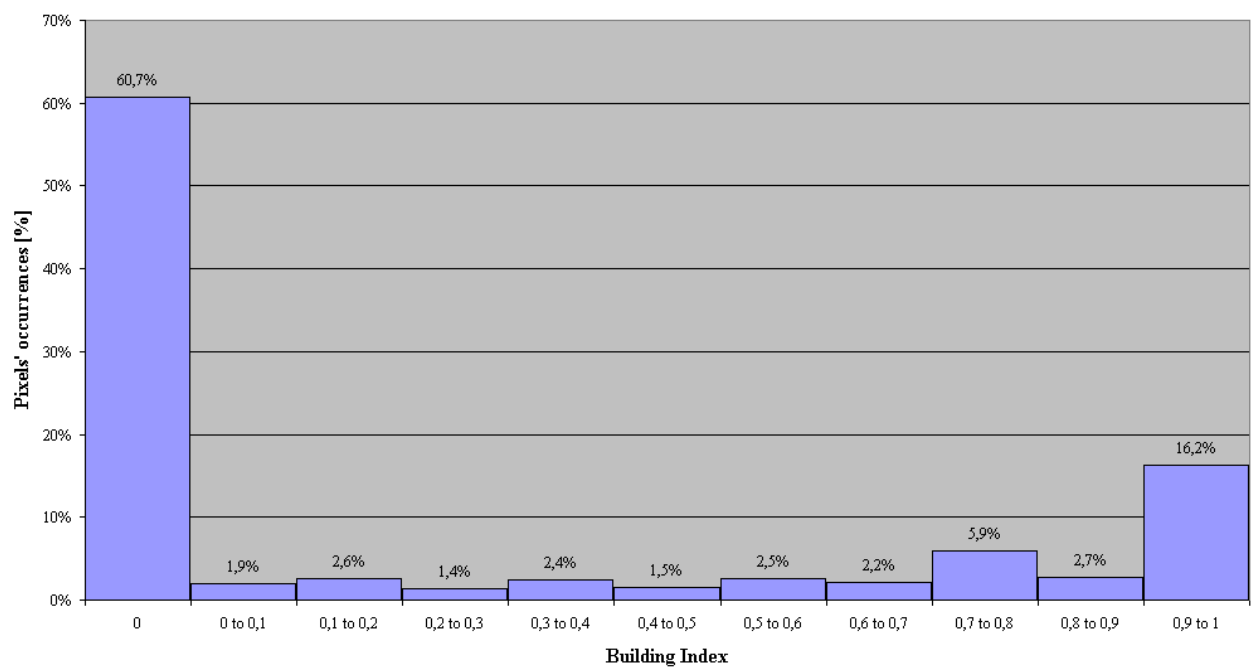
Figure 5-10 - Histograms of BI for Lisbon.
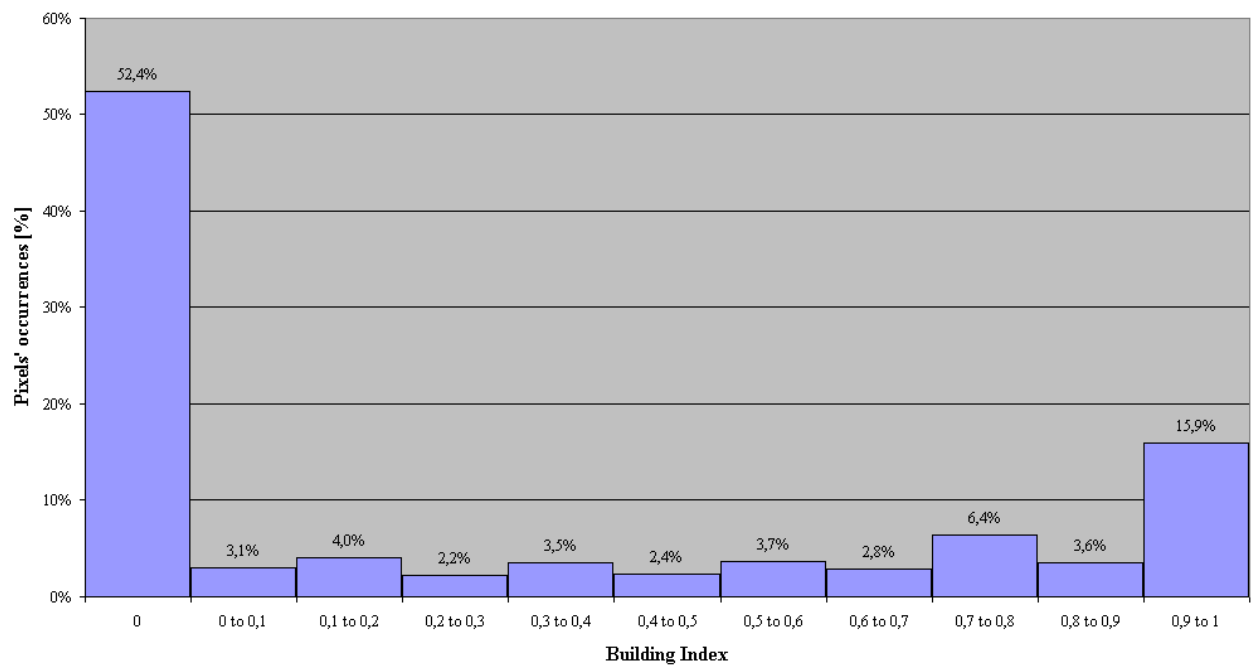
Figure 5-11 - Histograms of BI for Porto.
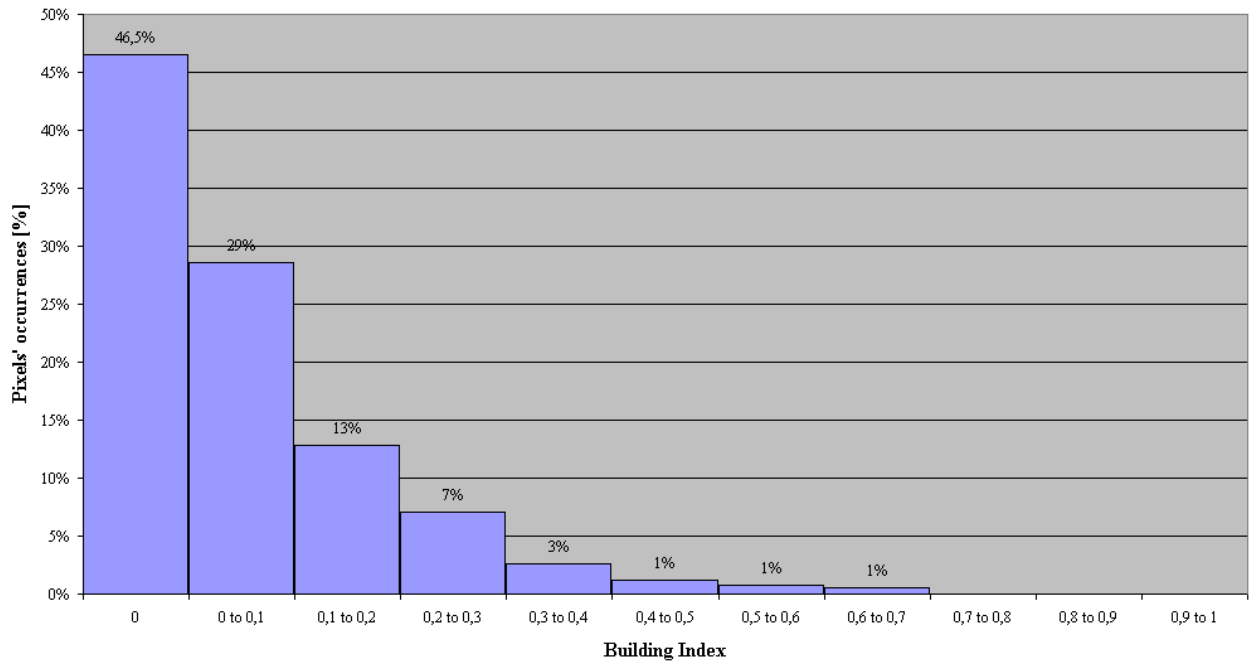
Figure 5-12 – Histograms of BI for The Hague

After the presentation of the typical possible applications, in Figure 5-13 the typical tool layout window, during the running of a simulation is introduced.

Figure 5-13 – Example of the Tool layout.

As one can note, the user interaction is reduced to the minimum, in the sense that just the name of the input and output files, the BS location, the cell radius, and the antenna height, are asked, while all the other tasks are performed by the tool in a total automatic way. In Figure 5 −14, it is shown an example of one of the tool output files, the text file, where a complete report of the simulation is presented, i.e., the BS location with the relative warnings, the radius dimension, the number of pixels in the cell, the antenna height, and the eventually presence of mixed regions, (pixels that is not possible to classify into one of the class of the area classification, or no models applicable regions (pixels where is no possible to apply one of the available models).

Figure 5-14 − Example of the text file layout.

Some examples of the maps, representing the cell planning simulations made by the tool, are shown. These maps are created by MapInfo processing the input MID and MIF file, written by the tool and containing all the results of the simulation concerning both the propagation models choice and the traffic distribution classification. In Figure 5-15 and Figure 5 -16 two maps for the city of Lisbon and Porto, are represented respectively, with the results of two different cell planning simulations, both using a very large radius (larger than 6 km), for the construction of macro-cell; the automatic selection of area for the traffic distribution performed by the tool is shown, and a carefully reading of these two pictures

shows the great reliable of the tool results, with the recognition of the morphology of the city with its structure and its urban, suburban, and rural environment. In Figure 5 –15, it is easy to recognise i.e., the green area of the park of Monsanto, surrounded by a mixture of urban light and suburban light-dense areas, or the huge airport area in the top of the picture, or the EXPO 98 area in the top of right river bank, and all the dock areas near the shores, but most of all the little red urban dense spots standing for the different high dense quarters of Lisbon, while the great relevance of the yellow urban light areas in the map represents all the areas characterised by quite uniform height buildings separated by roads and open areas. Another important thing that one can see both in Figure 5 –15 and Figure 5 -16 is how the pixel are almost grouped in little spot and just a few isolated pixels are presented, this due to the fact of the great reliable of the tool thresholds. Moreover, in Figure 5 -16 it is possible to notice the more chaotic distribution of the build areas of Porto meaning a more modern city which is still growing up without a defined urban plan, something completely opposite if compared with the old city of Lisbon.
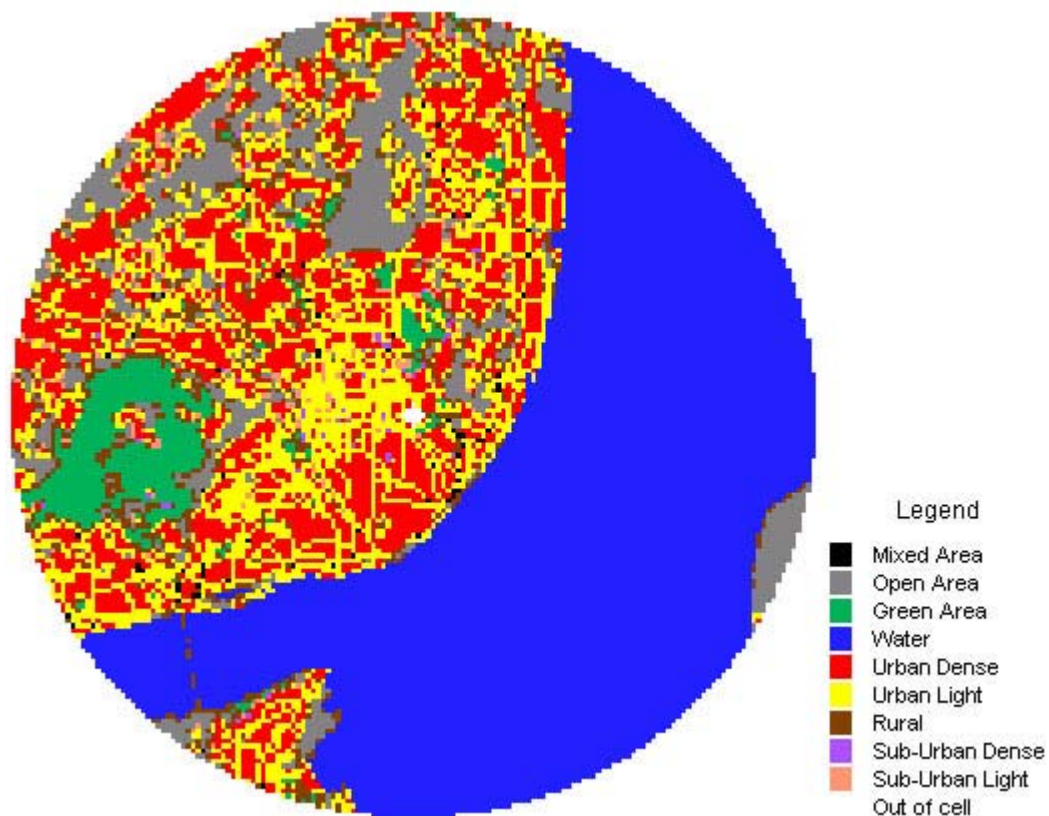
Figure 5-15 – Results of the automatic tool area selection for Lisbon.
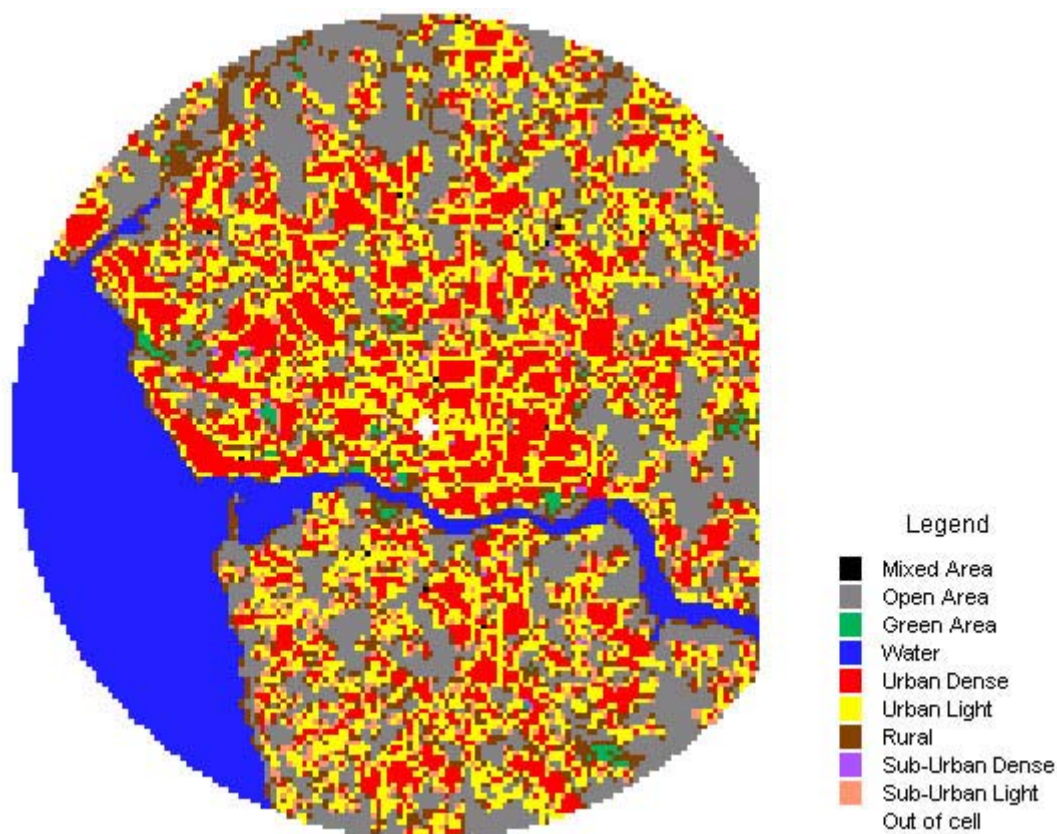
Figure 5-16 - Results of the automatic tool area selection for Porto.

In Figure 5-17 and Figure 5-18, the results of the same simulations are presented for the automatic choice of the propagation models made by the tool, where it is possible to get the model range applicability, constituted by three concentric different circles, the great predominance of the COST 231-Walfisch Ikegami in the urban environment, and the large use of the 3GPP macro-cell model in the transition range, due to the fact of the presence of uniform building height areas. It is also possible to see the few black blocks in the map corresponding to a group of pixels where there is not applicability of any of the available models due to the fact that for example the related pixels belong to a mixed area, or most of all there are rural areas in the COST 231-Walfisch-Ikegami range (0.2 km to 1 km). Another thing that needs to be marked is that thanks to the classification of the COST 231-Hata model in urban, suburban, and rural is possible to understand the cities structure also by these pictures, a very useful aspect to check the reliable of the automatic selection made by the tool. In Figure 5-19 to 5-22, the results of the simulations, made in the cities of Berlin and The Hague, for the area selection for the traffic distribution and the automatic choice of the propagation models are even presented. As one can easy understand, the results are not correct because of the different approach in building the grid generations.
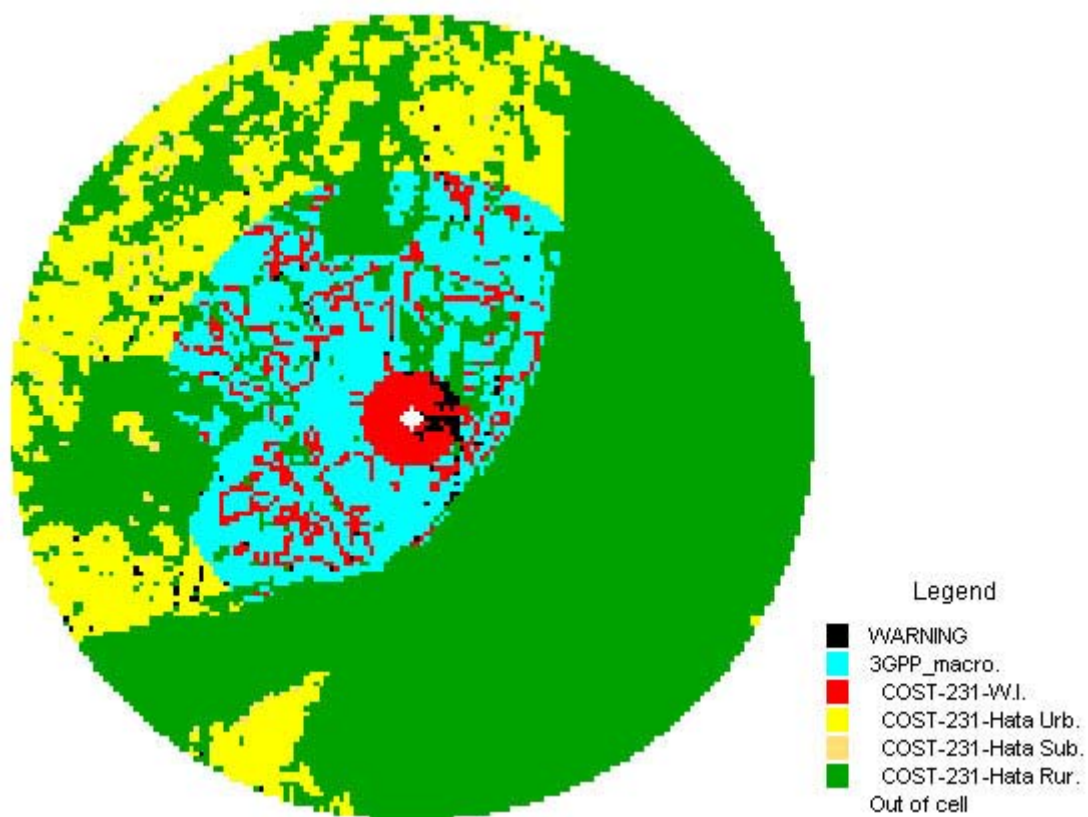
Figure 5-17 – Results of the automatic tool choice of propagation models for Lisbon.
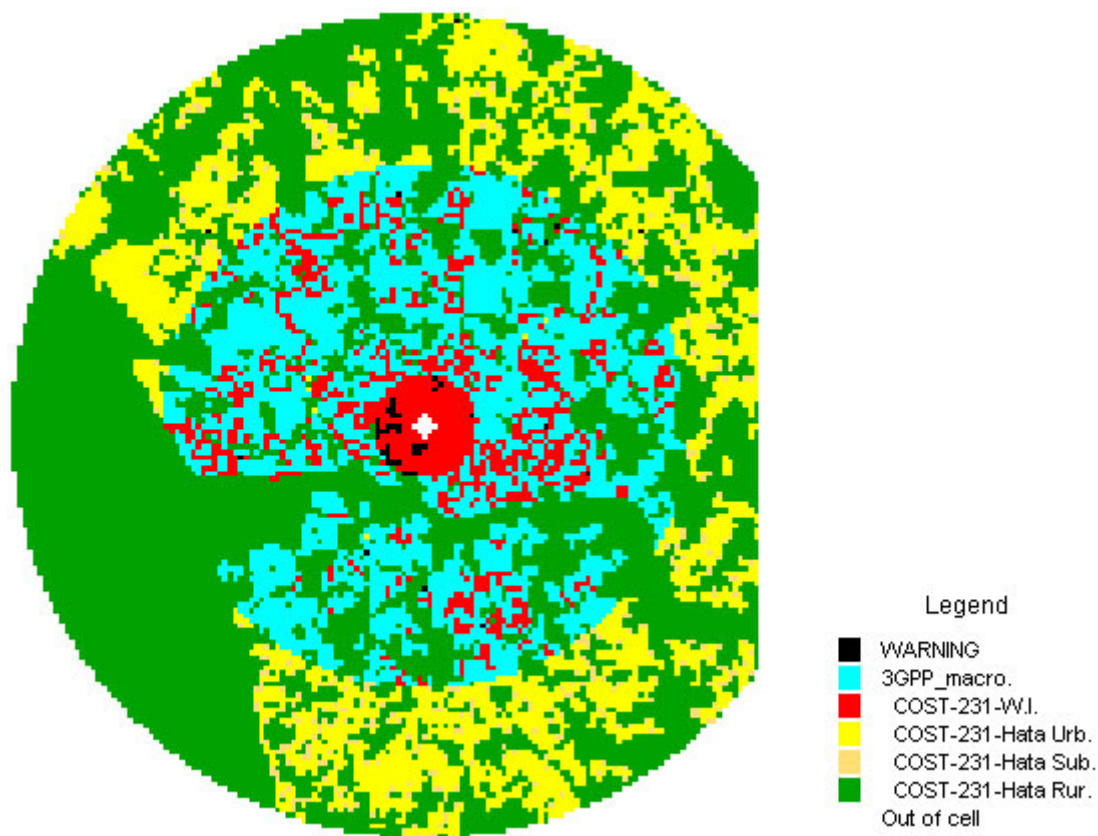
Figure 5-18 - Results of the automatic tool choice of propagation models for Porto.
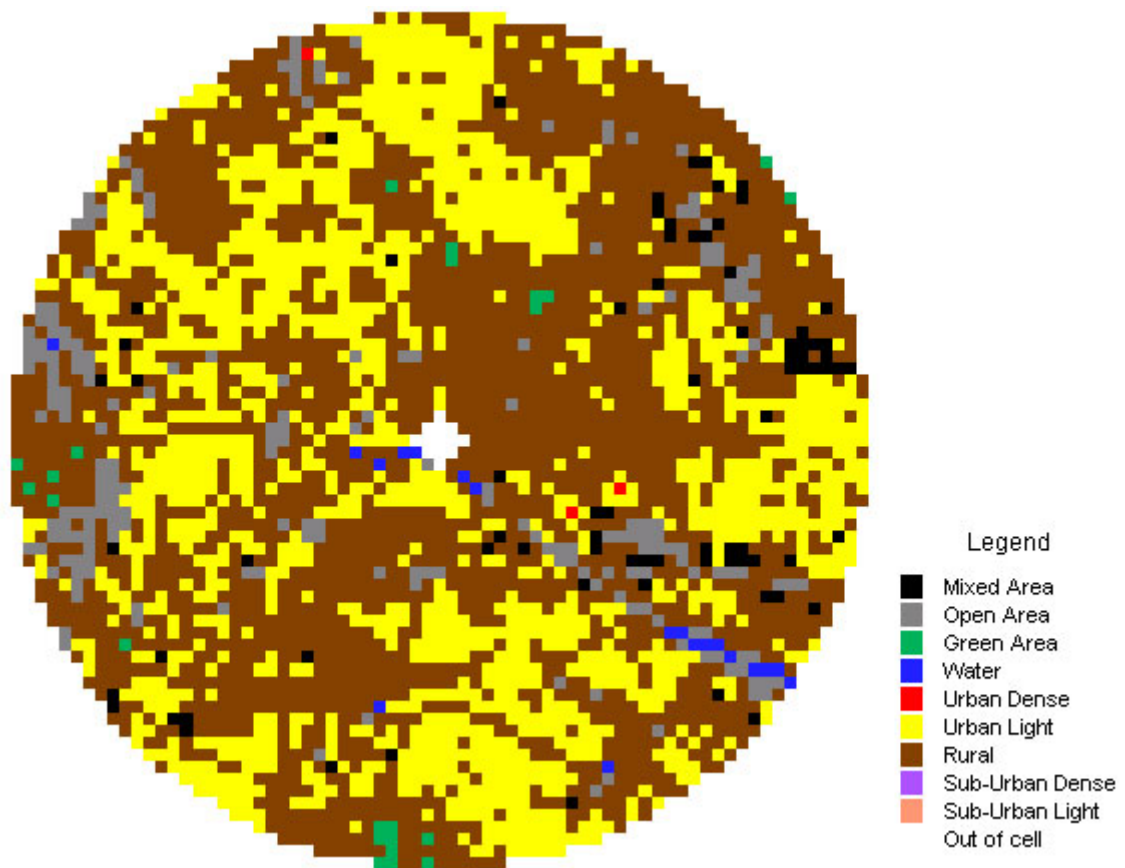
Figure 5-19 - Results of the automatic tool area selection for Berlin.
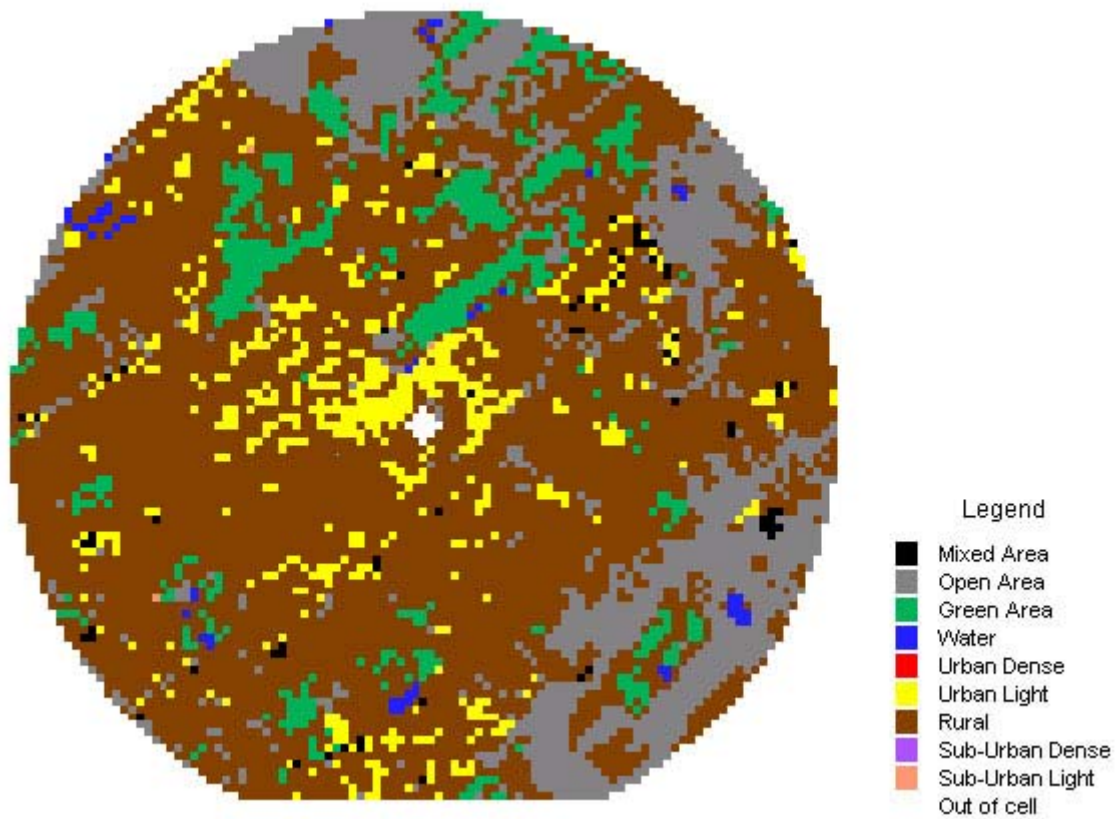
Figure 5-20 - Results of the automatic tool area selection for The Hague.
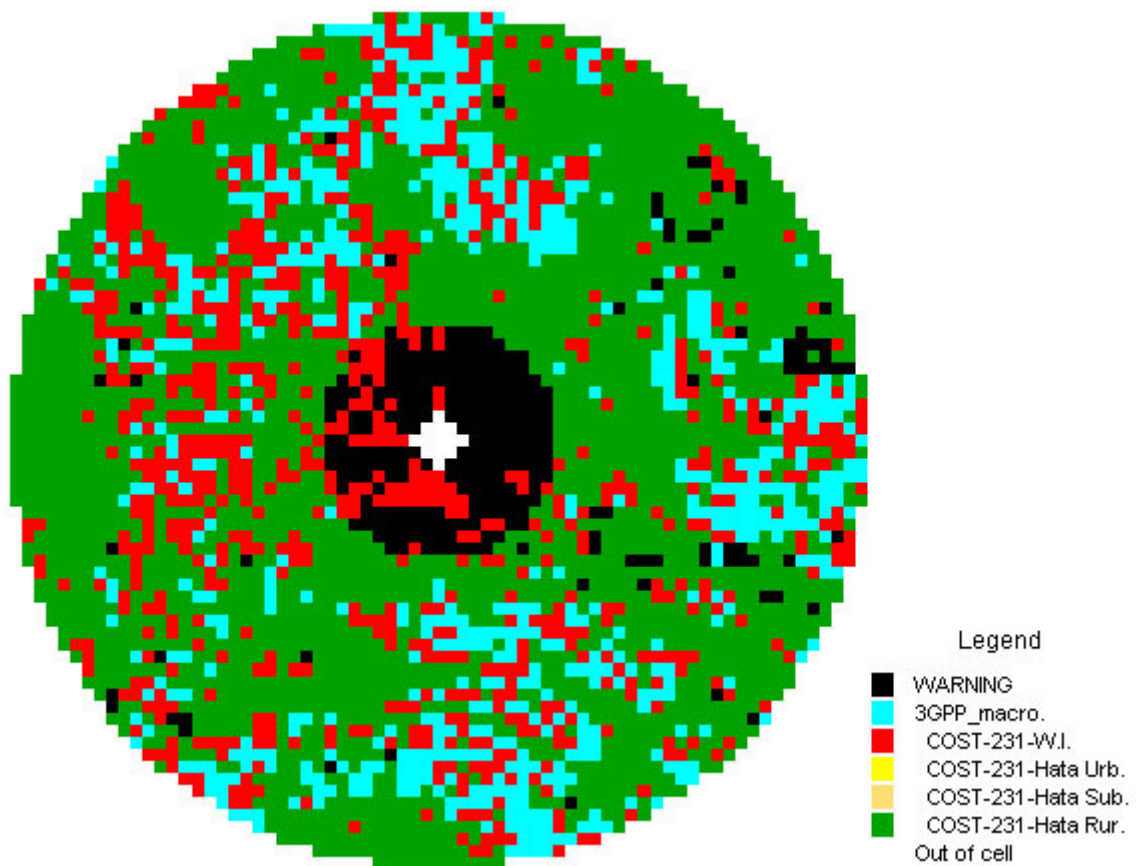
Figure 5-21 - Results of the automatic tool choice of propagation models for Berlin.
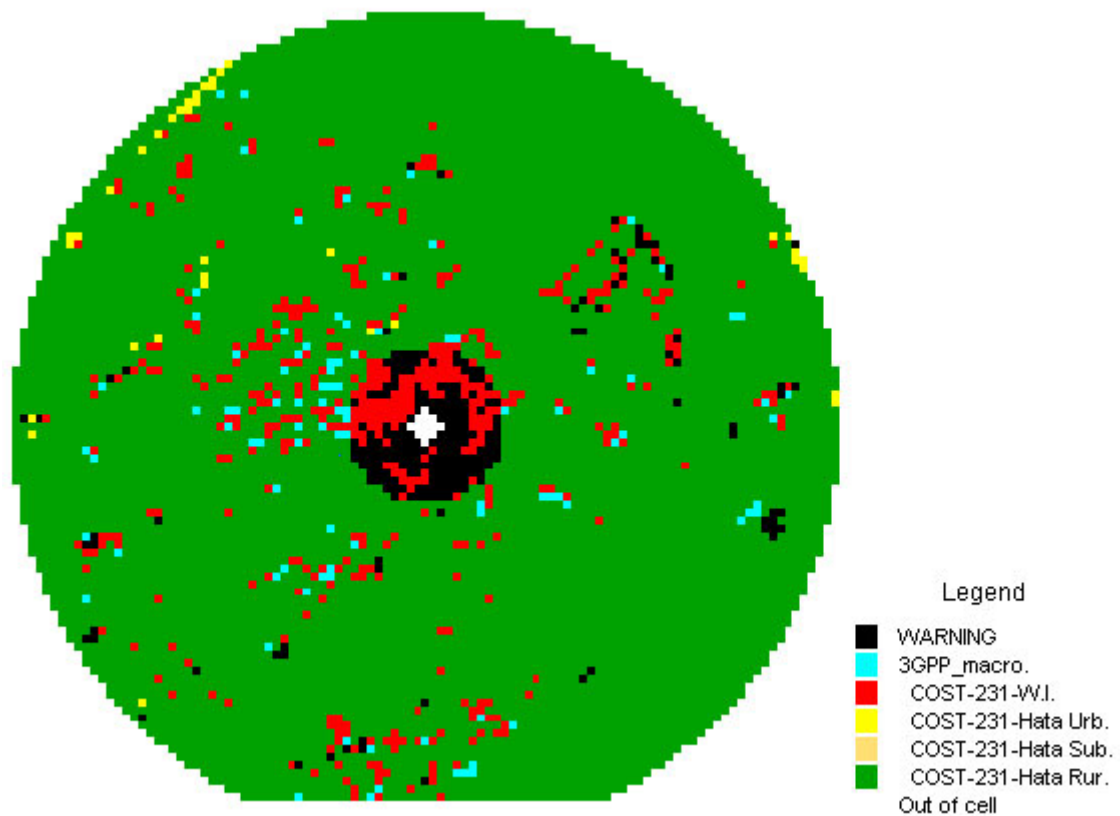
Figure 5-22 - Results of the automatic tool choice of propagation models for The Hague.

In fact, as one can see in Annex A, the histograms representing the BI for these two cities show that the great percentage of pixels' occurences have got values between 0.1 to 0.4 for Berlin and between 0.1 to 0.3 for The Hague, so that according to the tool thresholds all the pixels with these values are classified as rural area, meaning a great amount of brown pixels in both the automatic tool area selection maps, and the propagation choice maps are almost completely green standing for the COST 231-Hata rural model, and it is also present a black circle in the COST 231-Walfisch-Ikegami range, meaning obviously, that it is not allowed to apply this model in a rural area. Both the water and open areas are correctly classified, and the few areas with the highest BI values are classified as Urban Light. Then one can also observe that in the maps for the area classification of Berlin there are almost not any Suburbuan ligh-dense pixels due to the very low SI value of this city (between 0 to 0.3), and as already mentioned in the previous Section this layer allows the selection between a urban from a suburban scenario by a threshold value up than 0.3.

6 Conclusions

This report presents an approach to a preliminary construction of a tool for the automatic selection of propagation and traffic models for cell planning in UMTS. The need for a new software tools capable of taking real-time decisions, without any user interaction in choosing in which areas a specific model should be used, has motivated the proposed work.

A general overview on mobile communications is presented in Chapter 1 and Chapter 2, and particular attention is given to UMTS, analysing the main properties and performance of this standard both in a simple and discursive way, than in a more technical one, dealing with spectrum allocation, network architecture, WCDMA, services and applications, capacity and interference.

A brief description of COST 231- Hata and Walfisch-Ikegami and 3GPP propagation models is given in Chapter 3, focusing the attentions on the input parameters used by these model, i.e., ranges of applicability, bounds, and general assumptions conditions. The main concepts dealing with traffic distribution and area classification are analysed and some examples of typical approaches for area classification are presented. The parameters dealing with typical UMTS cell planning and link budget are shown and described.

In Chapter 4, the main results of previous preliminary stages on generation of grids containing statistical data layers describing the land-use and the main terrain properties are presented and taken as input data for the achievement of the tool. In addition, the transition and switching mechanisms for use in a mixture of two model predictions rather than applying a binary choice are presented and discussed. The graphical applications for displaying maps and grids of the GIS tools are shown, explaining how these tools are able to combine easily vectorial with raster data. Eleven parameters dealing with terrain height statistics (TH_MV and TH_STDEV), building height statistics (BH_MV and BH_STDEV), street width statistics (SW_MV and SW_STDEV), environment general properties represented by index values (VI, WI, OAI, SI, and OAI), that can be used to perform the automatic selection of propagation and traffic models are identified. They are processed using MapInfo$^®$ and Excel, resulting in representations by grids and by histograms for a set of seven cities; the results of a complete set of grids for the cities of Lisbon, Porto, The Hague, and Berlin are presented in the Annex A and Annex B. Moreover, by an accurately analyses of both these representations, the ranges and the bounds for each layer are established, then combining these data with the land use

classes classification delivered by E-Plus, KPN, and Telecel a primary set of tables with the possible thresholds to make an automatic selection of propagation models and area classification, are presented. A new, simple and more rational area classification in Urban (light and dense), Suburban (light and dense), Rural area is adopted with the addition of more three classes, Water, Green, and Open, to emphasize particular areas like river, sea, large park, airports etc.

A code using an object oriented programming (C++) is implemented, this code is able to read and write the typical GIS input files (MIF/MID) and to carry out a cell planning simulation making a completely automatic choice of both propagation models and areas selection according to a traffic distribution classification. By running simulations for the cities of Lisbon and Porto, a new set of tables with the definitive layer's thresholds values used by the code to perform the automatic selection are shown. In these tables is possible to get the great relevance of the layers as BI, SI, BH_MV, and OAI in making the automatic choice of the models, while only few restrictions for the others layers are adopted. Some grade of freedom for the layers values, in comparison of the first tables are taken due to the presence of all that pixel that present a mixture of properties where it is not possible to classify them in one class, so that in this way the number of unclassified regions is reduced to the minimum one.

In Chapter 5, some of the main results obtained in this works are presented. Some examples of layer comparisons among different cities combining both the maps and the histograms are shown, underling the great power of this approach to get, only by a quick view, the cities properties and differences. Then the maps with the simulations results for the cities of Lisbon, Porto, The Hague, and Berlin for a macro cell planning are presented. The results seem to be very acceptable both for the propagation choice and the areas classification for the cities of Lisbon and Porto, proving a first step to the achievement of a tool for the automatic selection of propagation and traffic models as carried out in this work. While for the other cities, due to the fact that their raster input data are generated according to very different approaches in comparison to those of the Portuguese ones, expecially for the key layers like BI, SI, and OAI.

To give to the tool an univeral applicability, an extra implementation is needed, in terms of an input data conversion to the Telecel standards. Moreover a complete set of propagation and traffic models, with the possibility to allocate more than one BS, considering more than one cell planning at the same time, can be added to the tool; and all the calculations of the models propagation loss, and traffic factors can be done; it is important to underline, as

already expressed in the algorithm description, that the code written for this work allows any extra implementation just adding new external functions, so that all these new applications can be easily carried out. In conclusion, this work can be considered an important primary first step to the achievement of a complete realisation of a tool for the automatic choice of propagation and traffic models for cell planning in UMTS.

Annex A – Histograms Results

Annex A contains the histograms, ordered by layer, based on the input data for the 100 m resolution grids, for the cities of Lisbon, Porto, Berlin, and The Hague. Figures A-1 to A-32 show the histograms results for the layers TH_MV, BH_MV, SW_MV, VI, WI, SI, OAI, and BI, drawn with Microsoft Excel 2000; the layers concerning standard deviation like TH_STDEV, BH_STDEV, and SW_STDEV, are not shown. One can observe that the horizontal axis scale of the layout is equal for all the cities, which is to enable the comparison among the cities in a best way, while the vertical axis represents the percentage of pixels' occurrences according to the input grid dimensions (variable for each city), it is important to stress that the sum of these percentages may be different from 100 %, this because some values may be not shown in the picture, as for example, the value 0, that takes the great part of pixels' occurrences, in some of the SW_MV histograms.
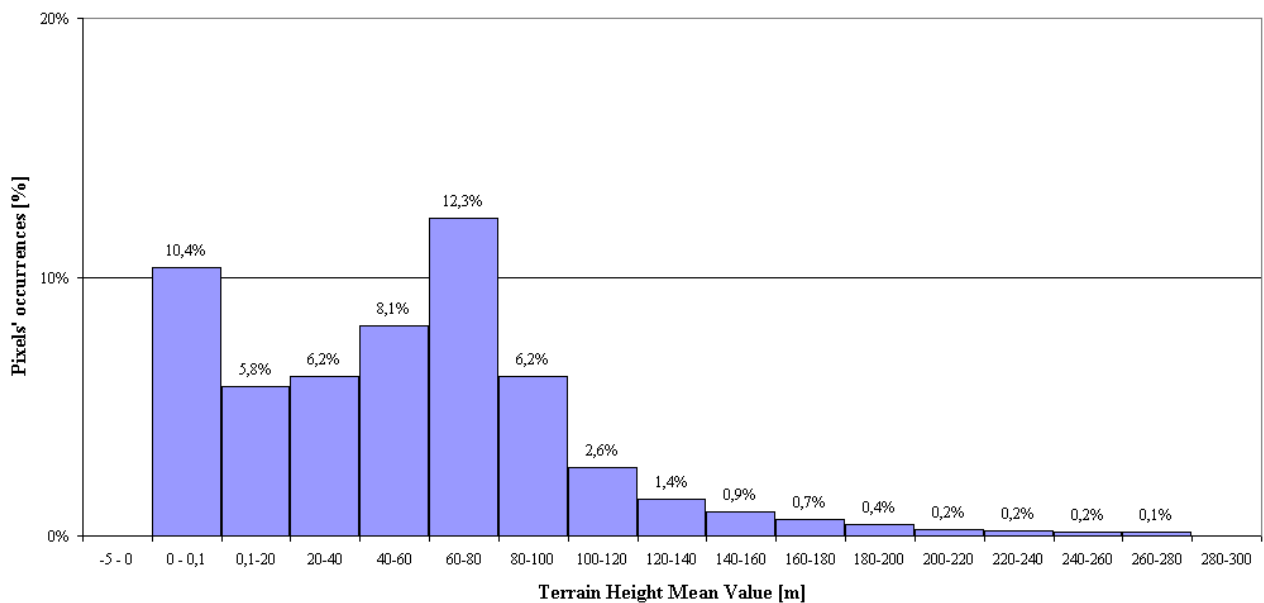
Figure A-1 – Terrain Height Mean Value for Lisbon.
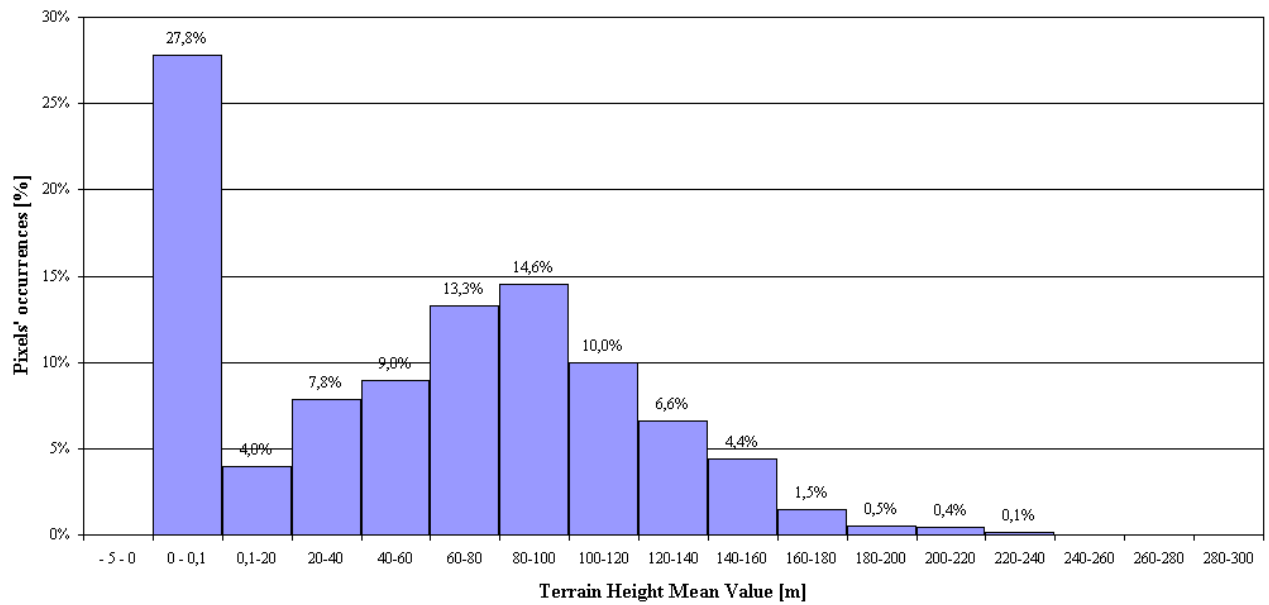
Figure A-2 – Terrain Height Mean Value for Porto.
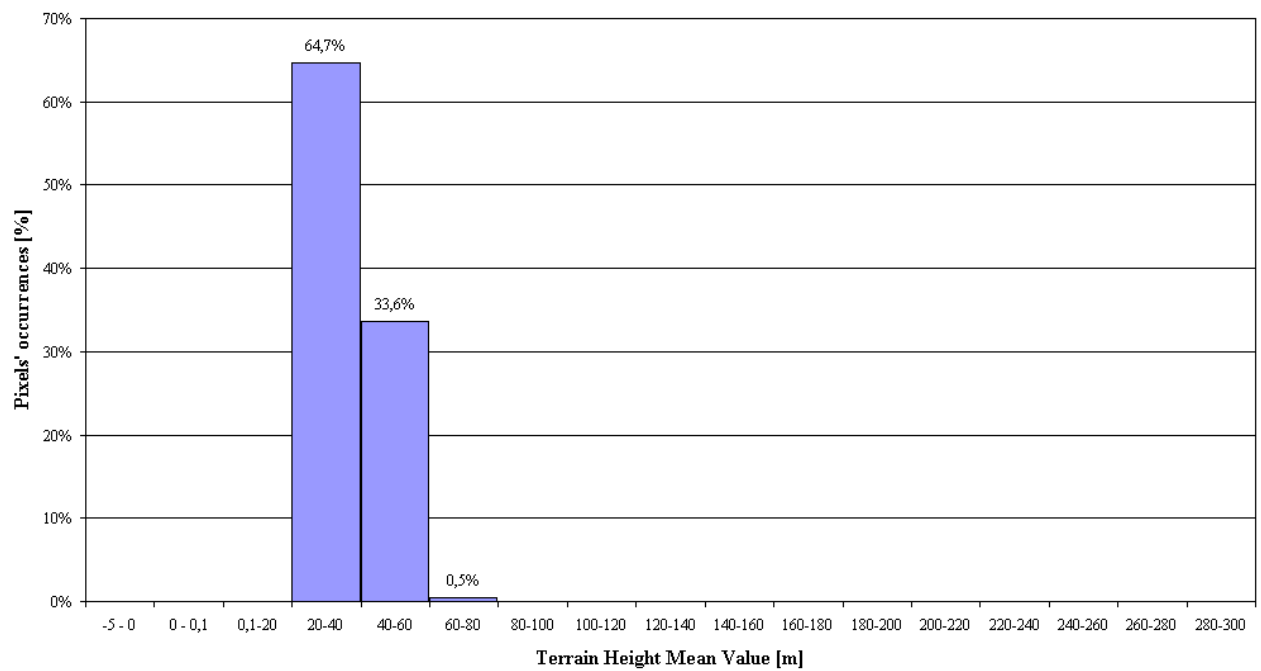
Figure A-3 - Terrain Height Mean Value for Berlin.

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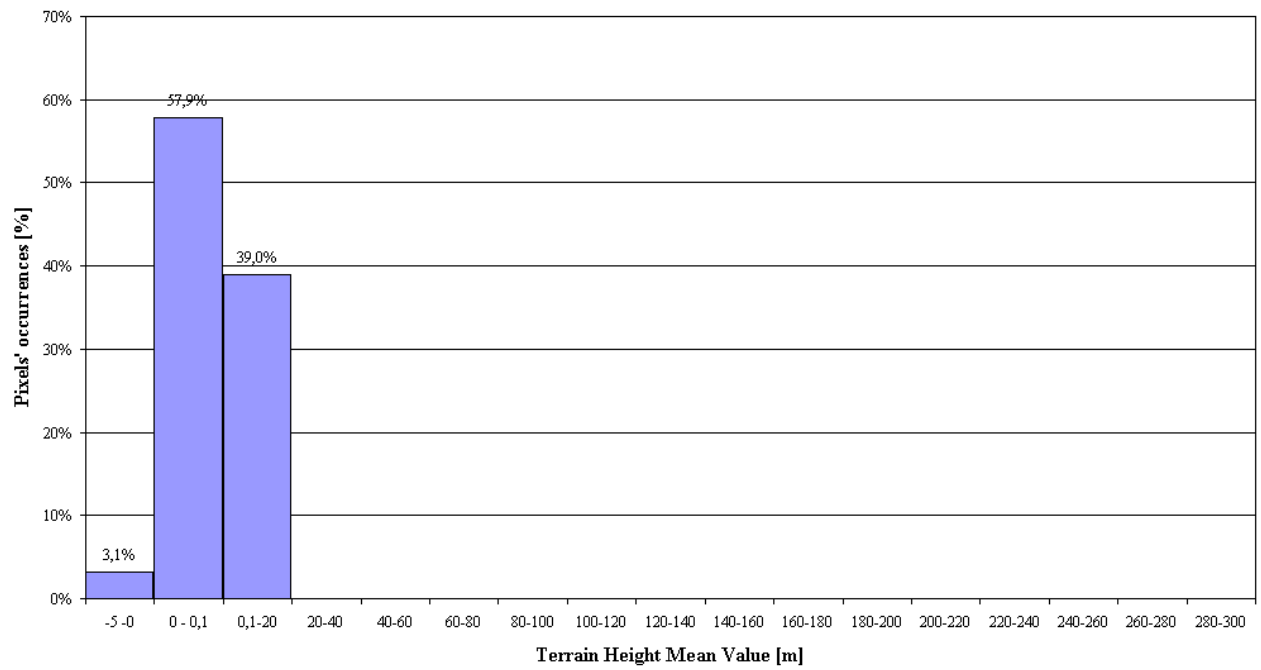
Figure A-4 – Terrain Height Mean Value for The Hague.
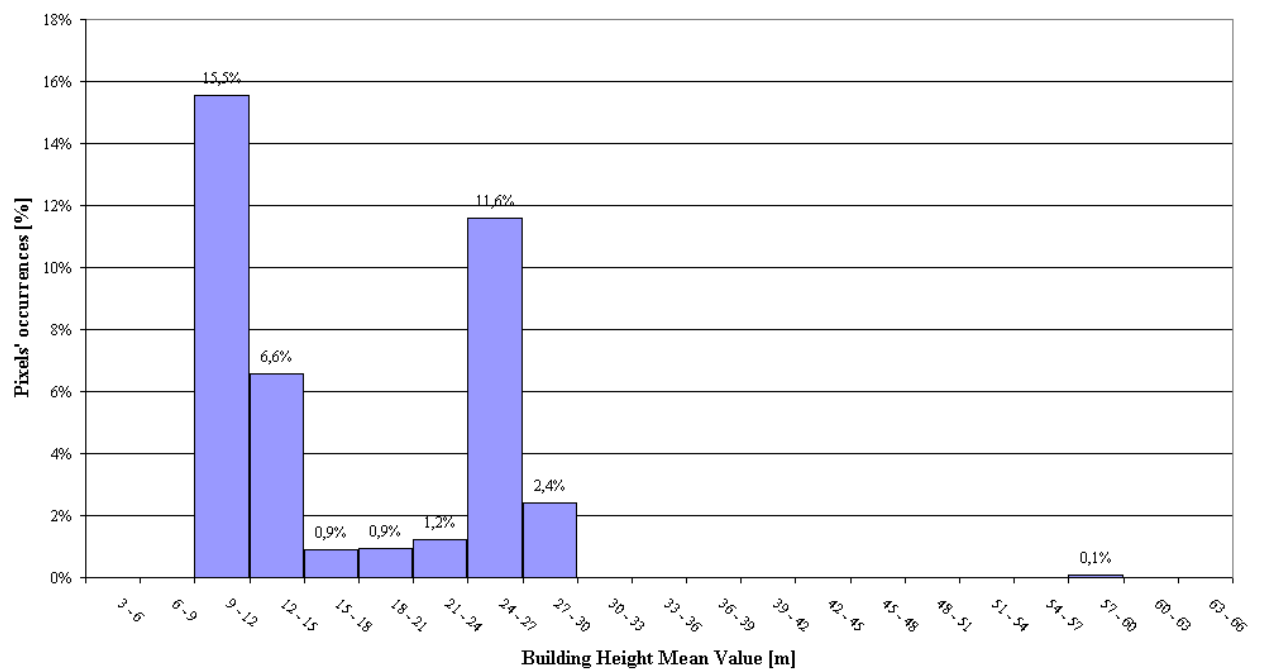
Figure A-5 – Building Height Mean Value for Lisbon.
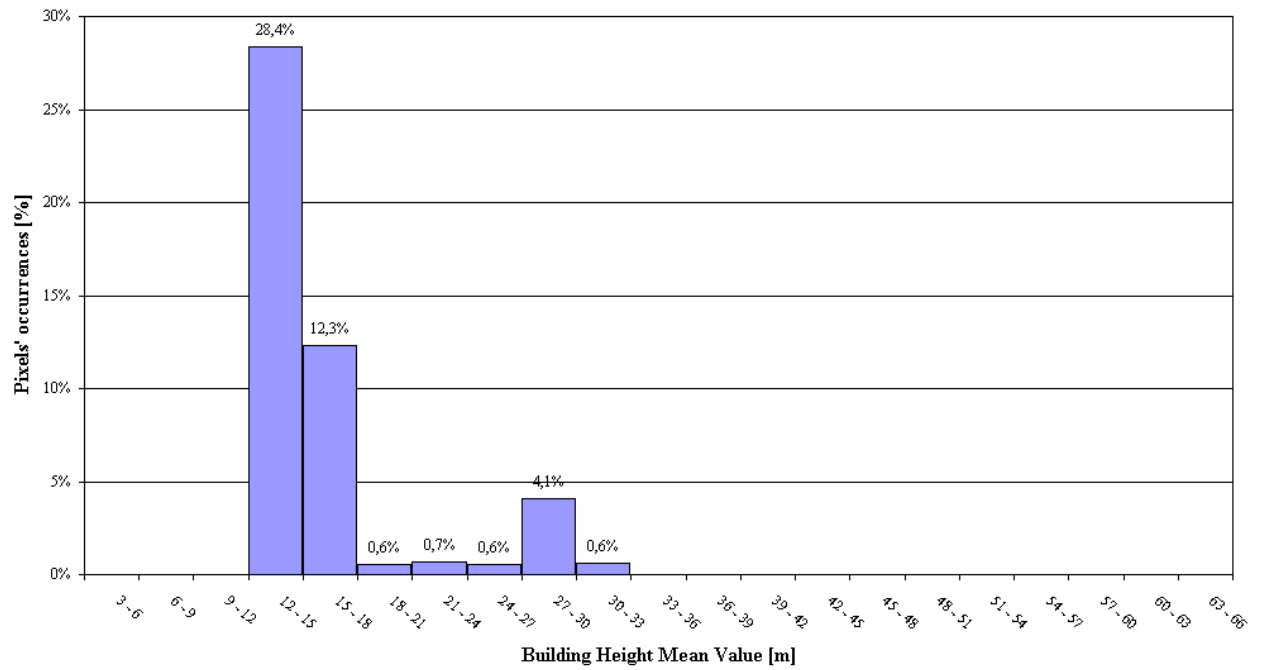
Figure A-6 – Building Height Mean Value for Porto.
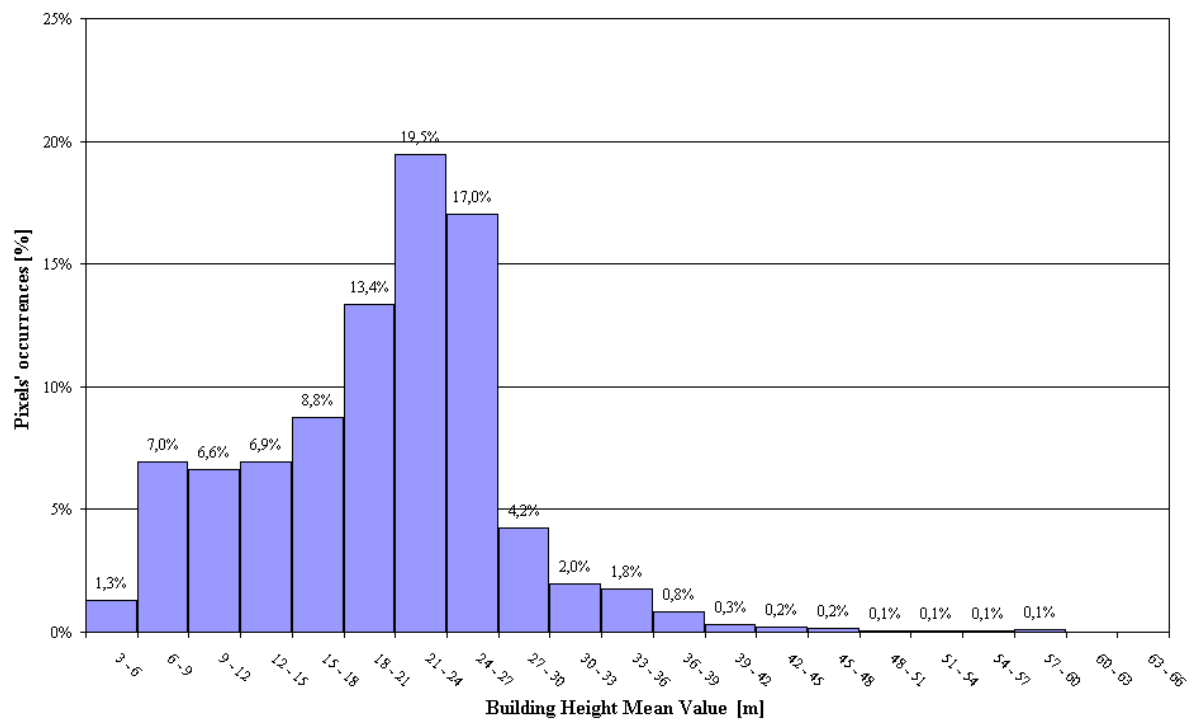
Figure A-7 – Building Height Mean Value for Berlin.
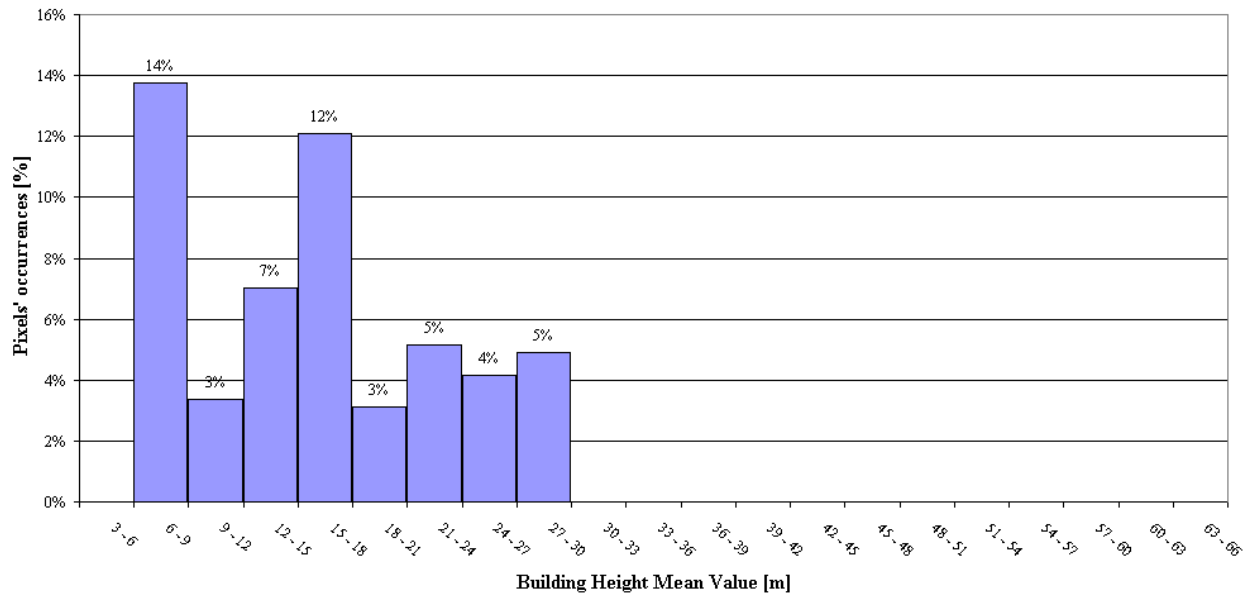
Figure A-8 – Building Height Mean Value for The Hague.

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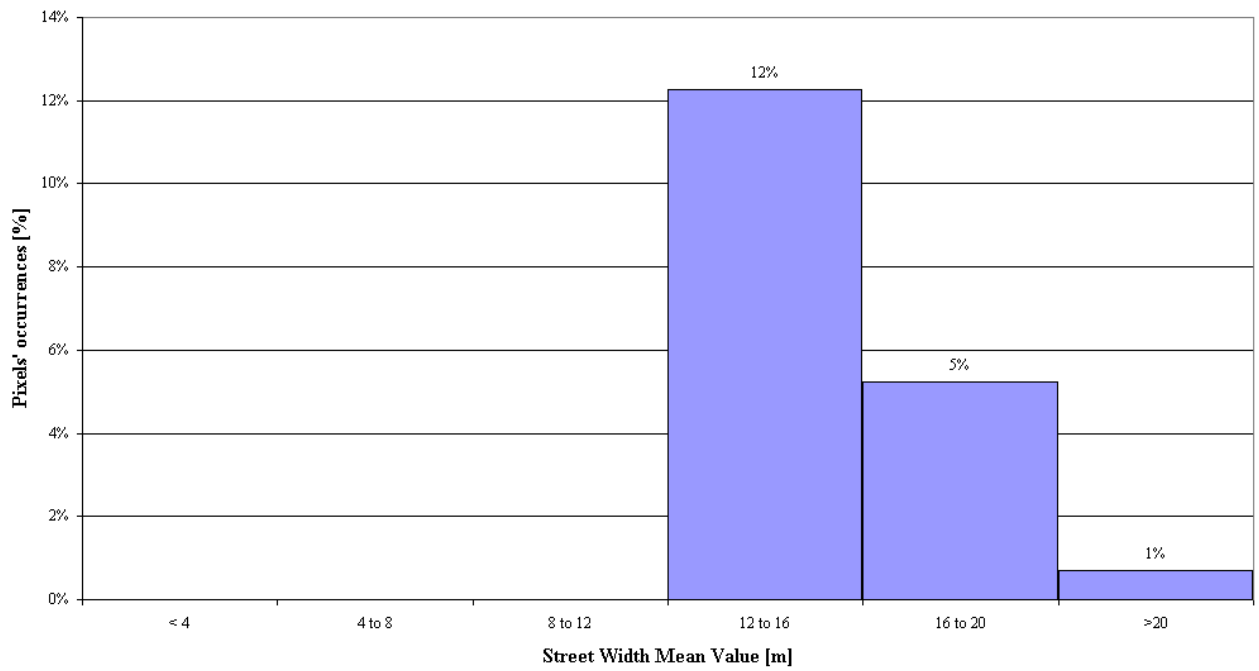
Figure A-9 – Street Width Mean Value for Lisbon.
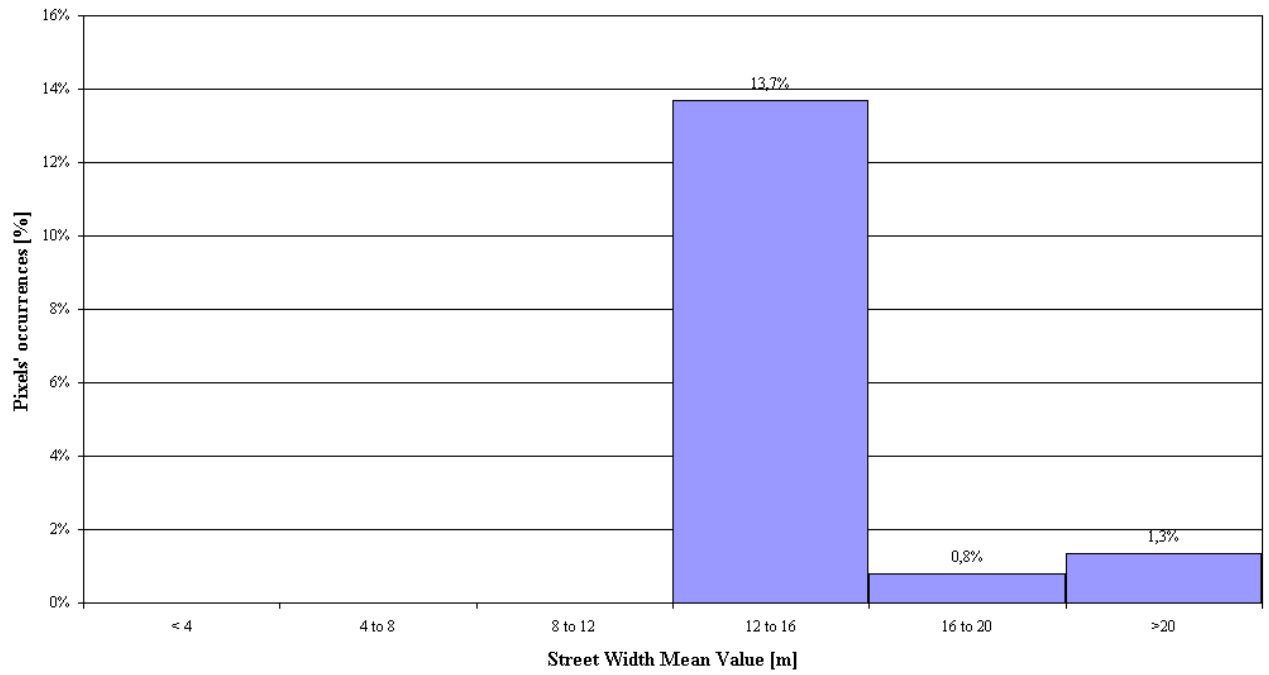
Figure A-10 – Street Width Mean Value for Porto.
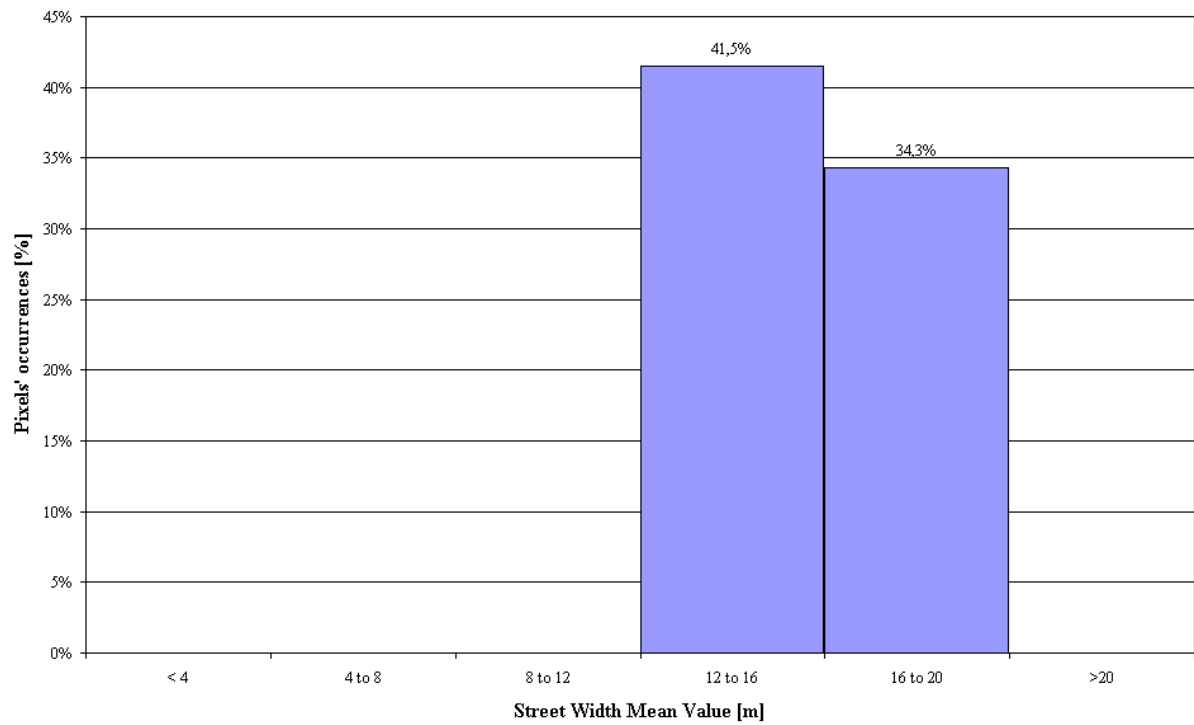
Figure A-11 - Street Width Mean Value for Berlin.
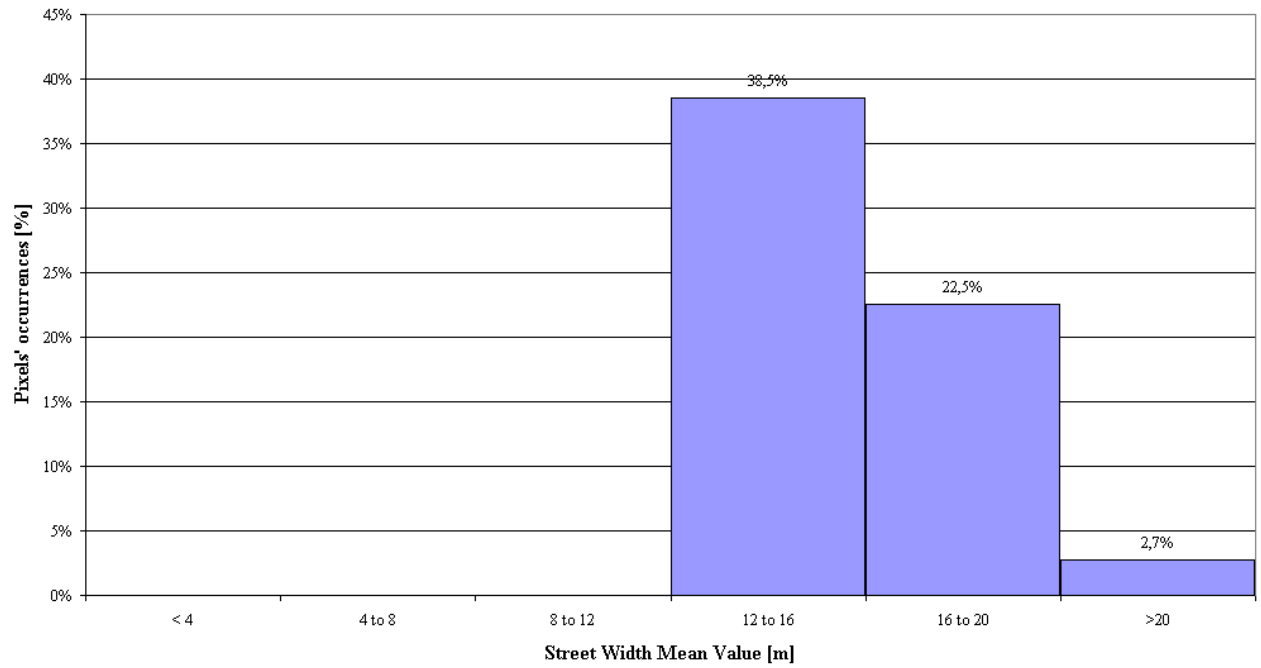
Figure A-12 - Street Width Mean Value for The Hague.
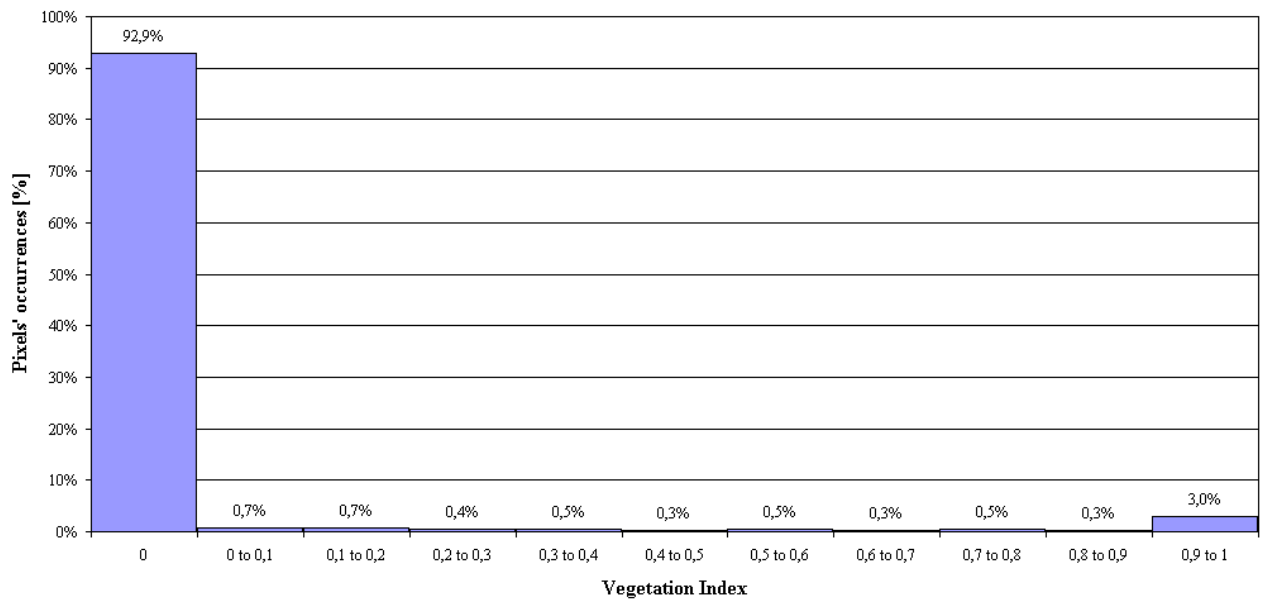
Figure A-13 –Vegetation Index for Lisbon.
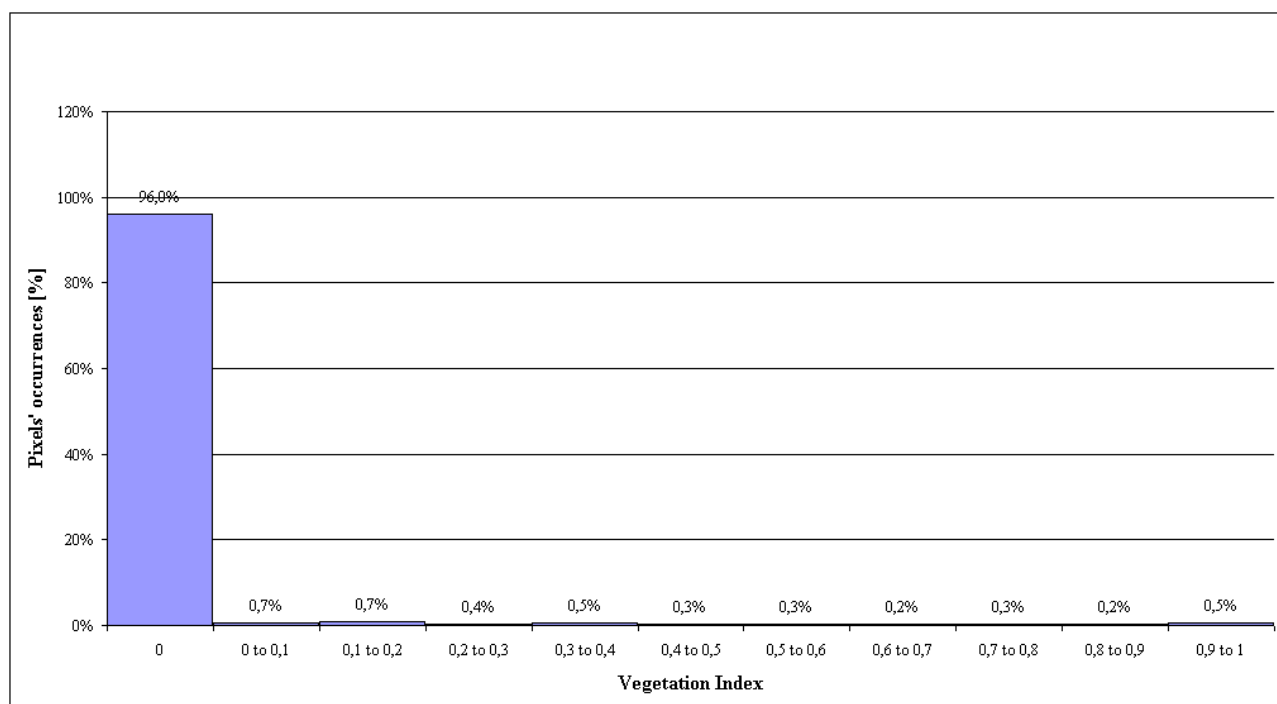
Figure A-14 – Vegetation Index for Porto.
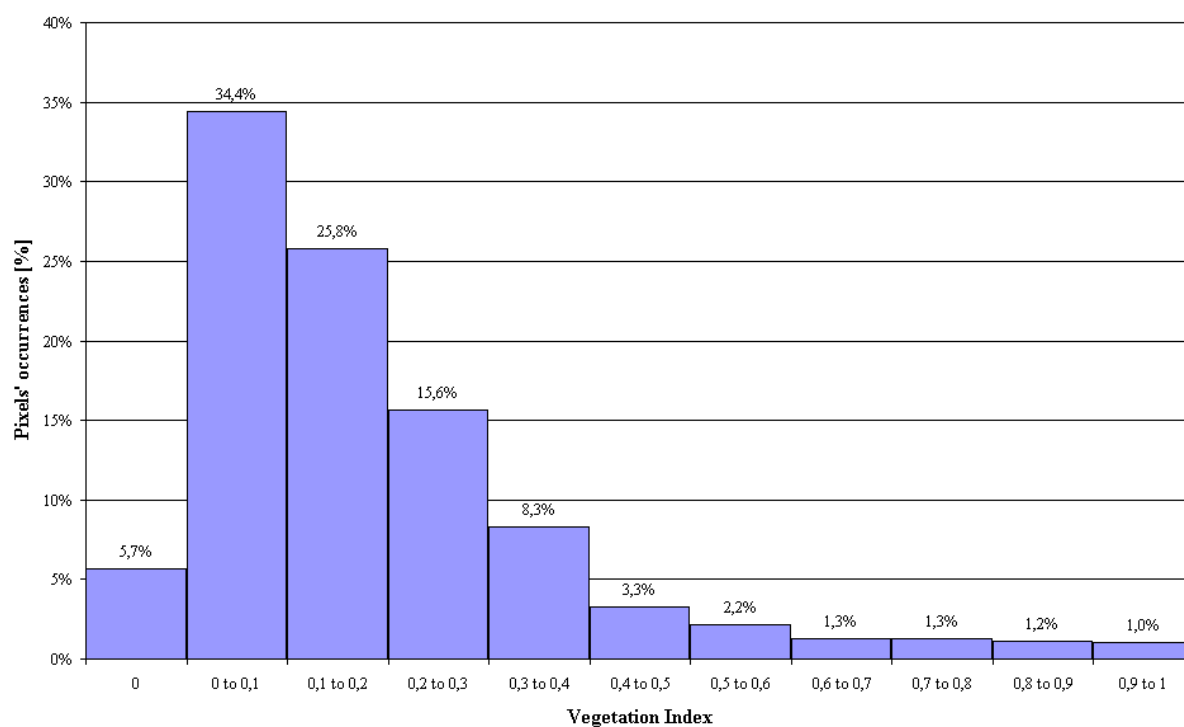
Figure A-15 – Vegetation Index for Berlin.
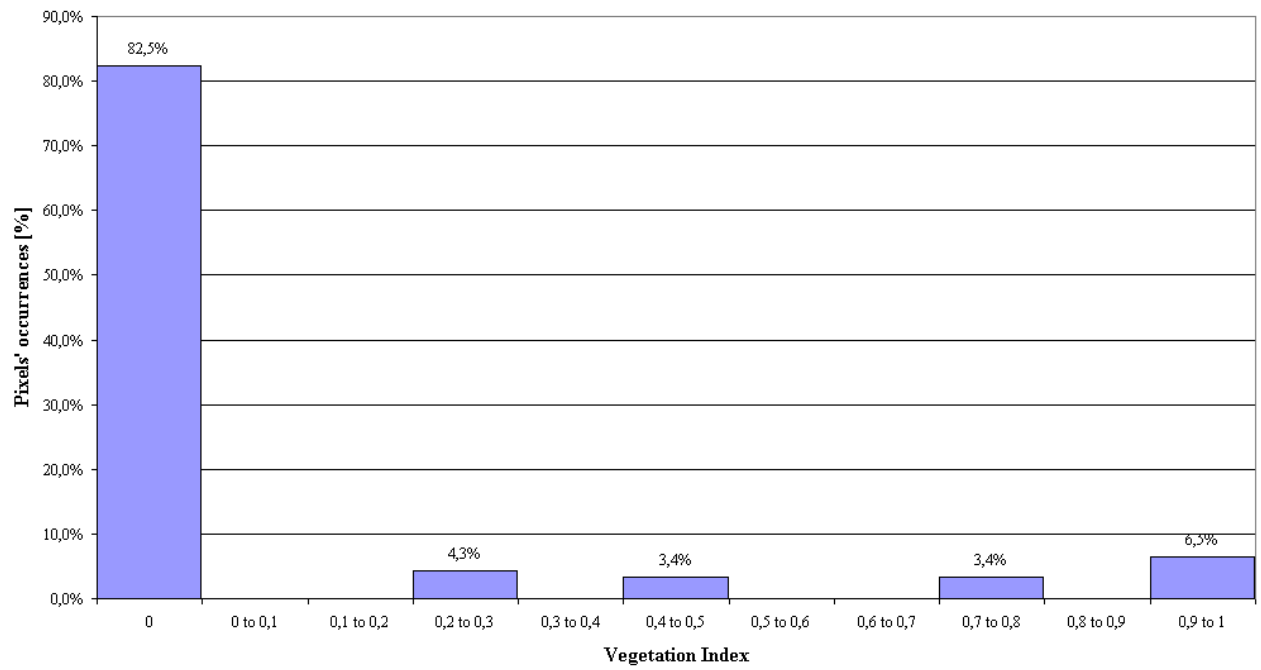
Figure A-16 – Vegetation Index for The Hague.
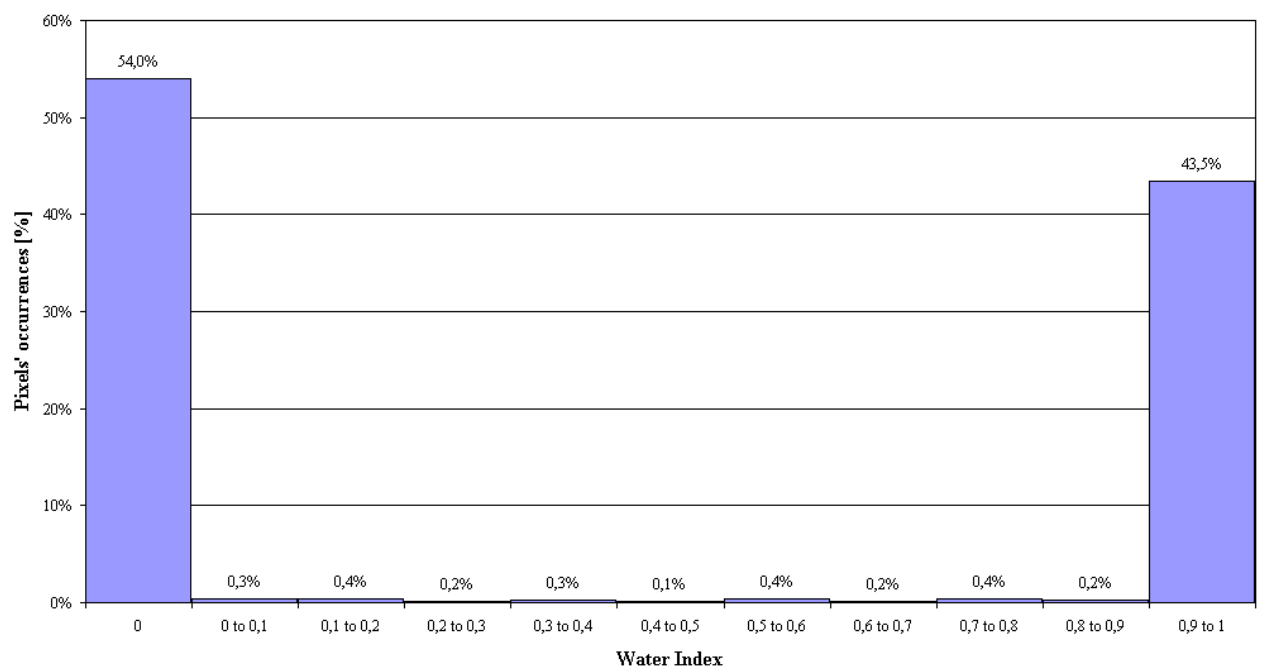
Figure A-17 – Water Index for Lisbon.
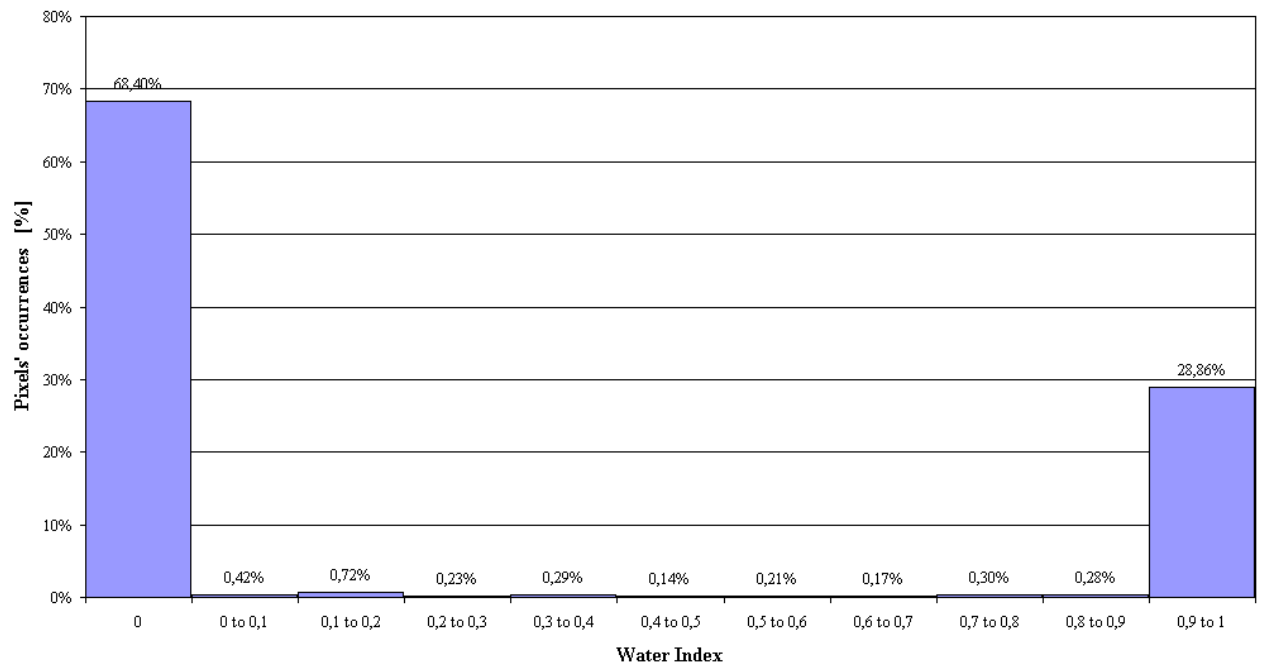
Figure A-18 – Water Index for Porto.
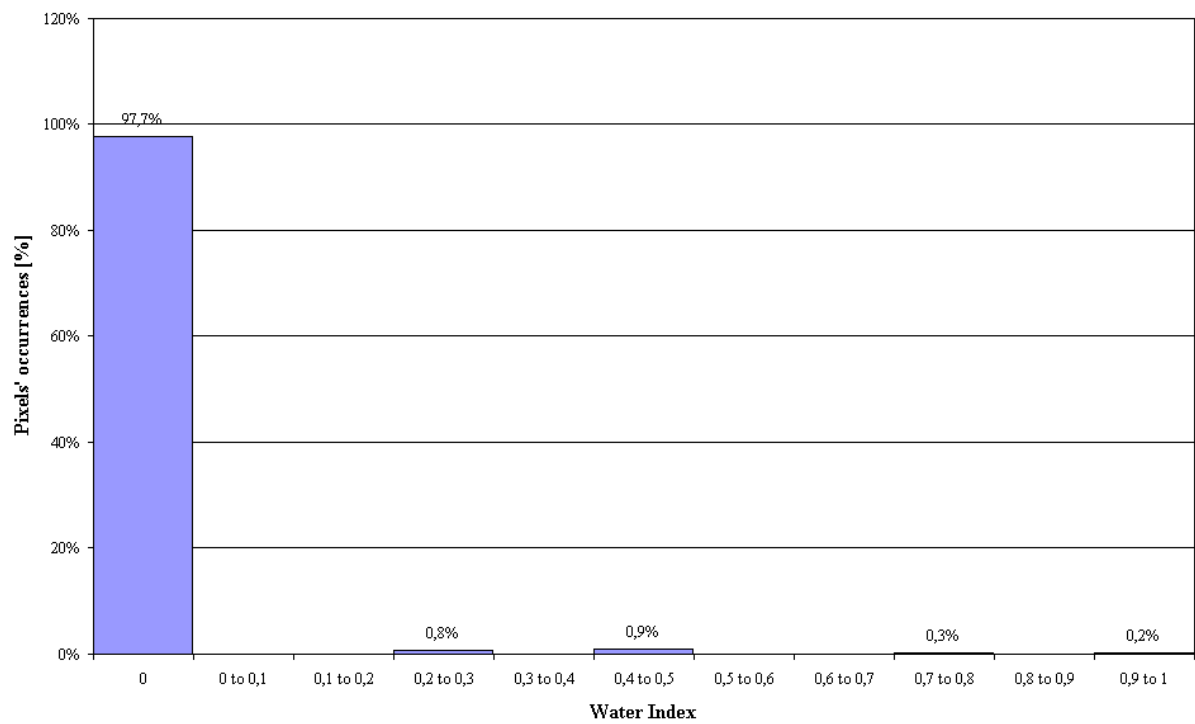
Figure A-19 - Water Index for Berlin.

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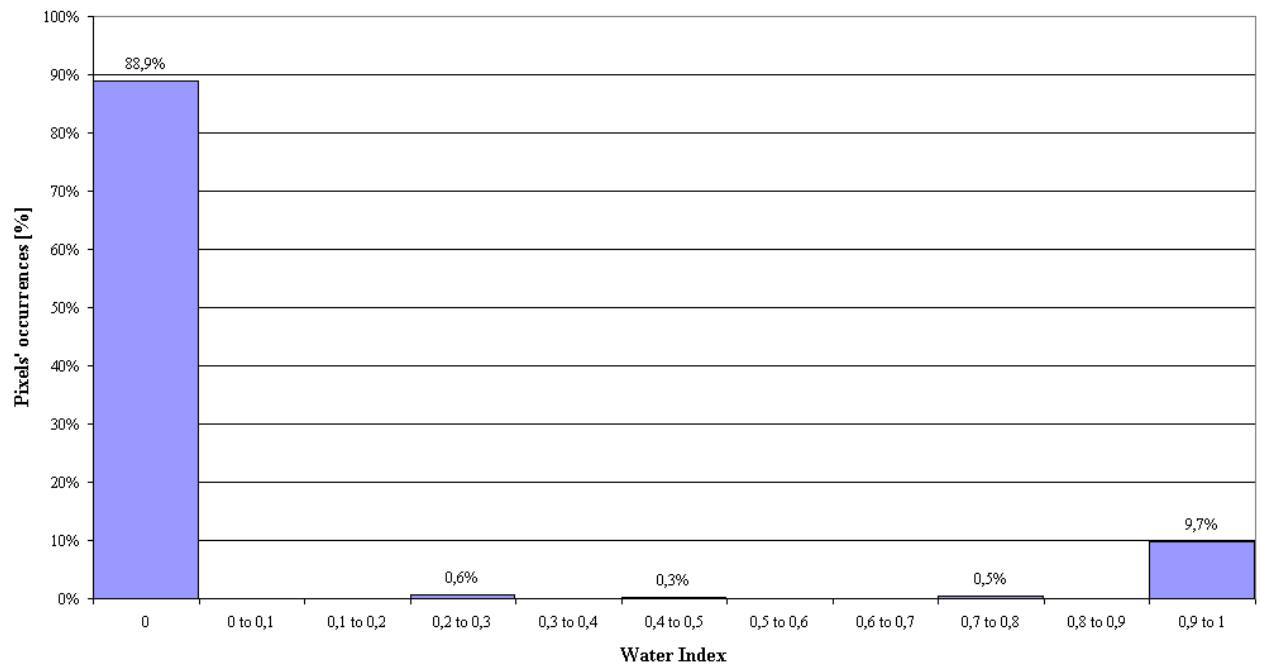
Figure A-20 – Water Index for The Hague.
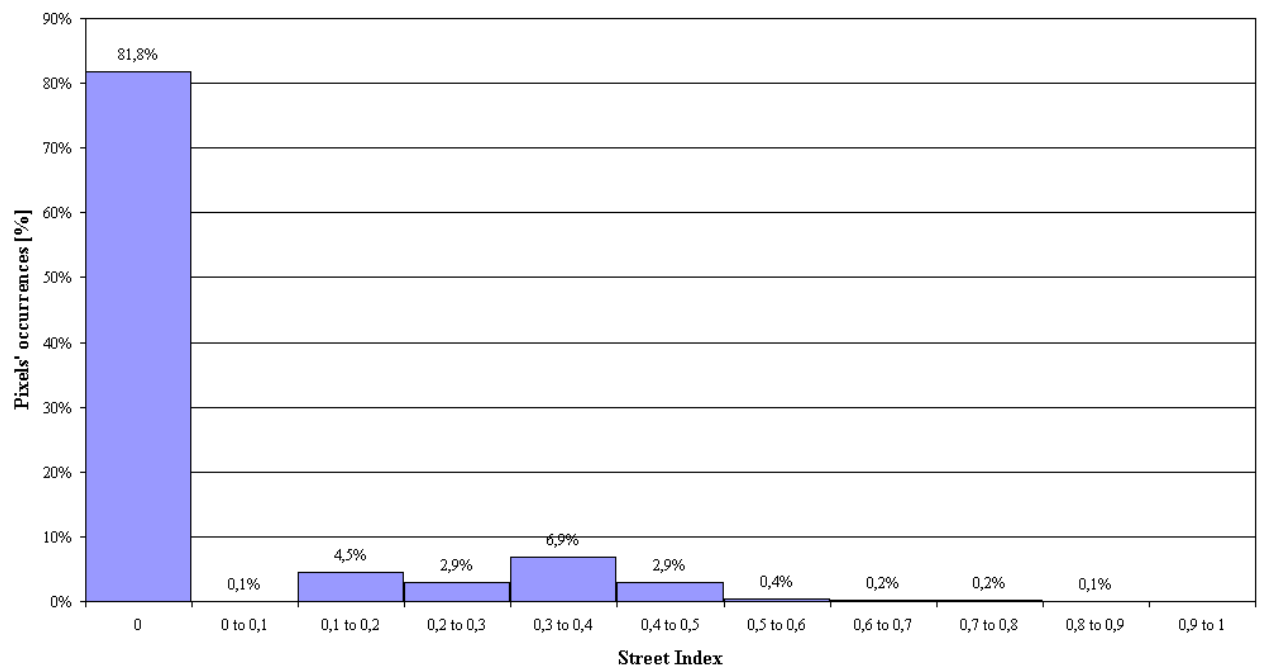
Figure A-21 – Street Index for Lisbon.
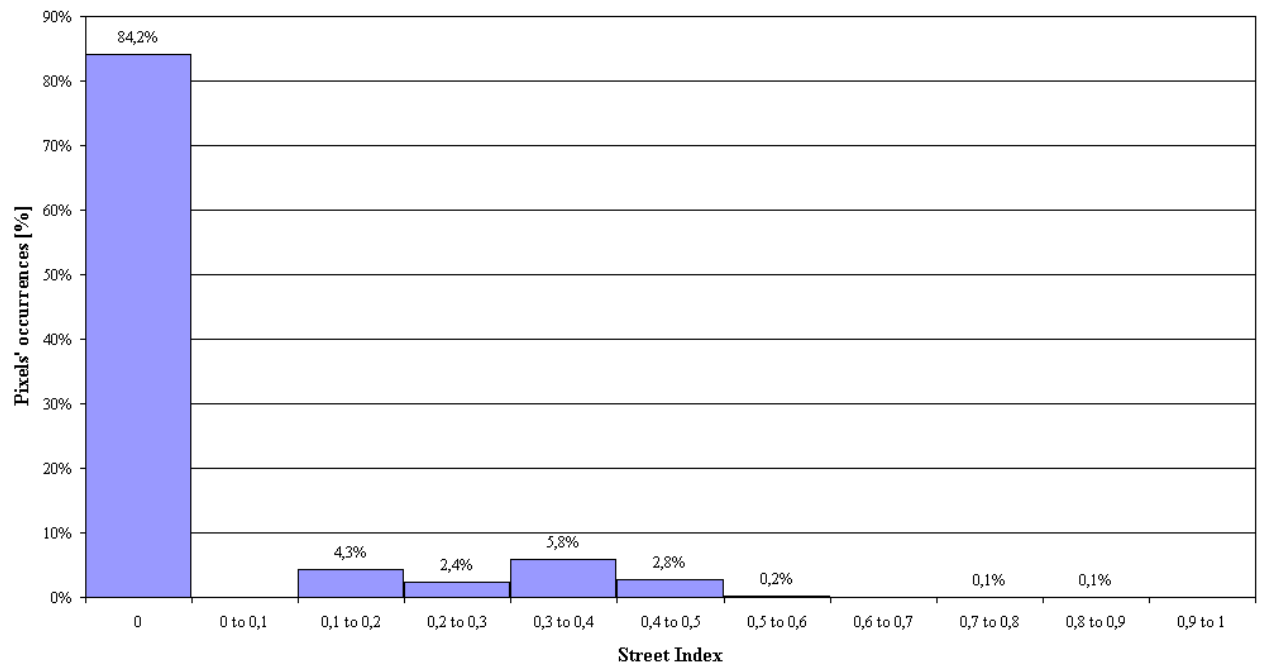
Figure A-22 – Street Index for Porto.
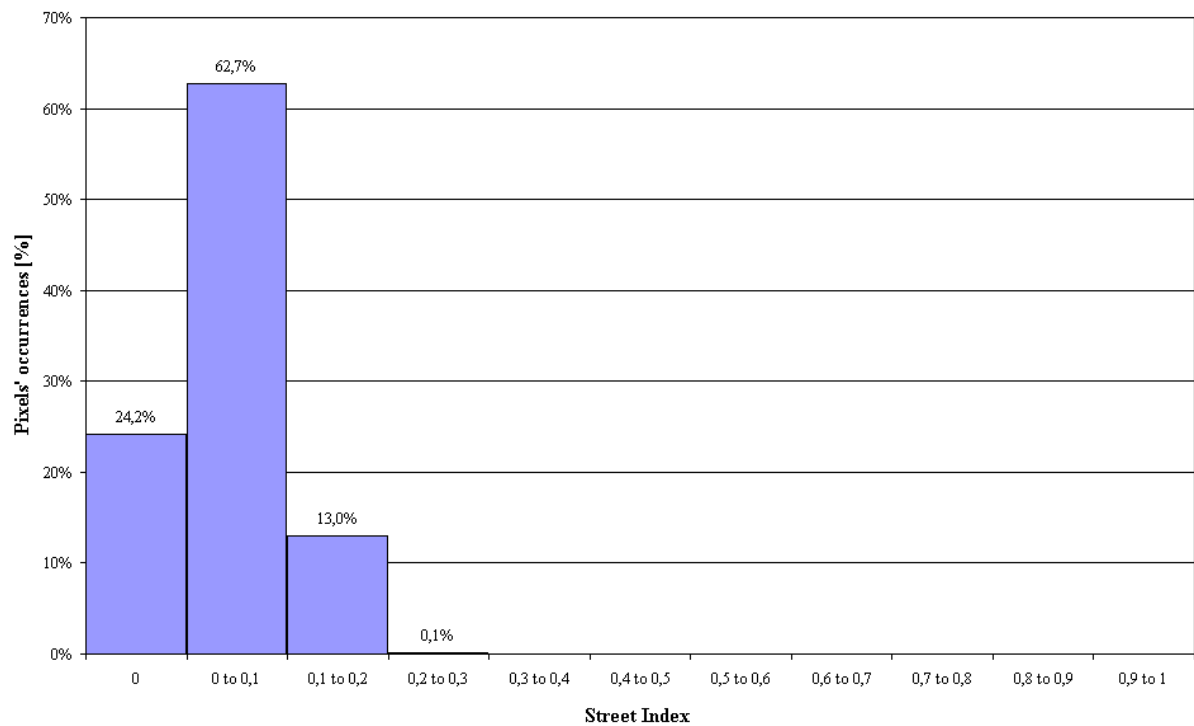
Figure A-23 – Street Index for Berlin.
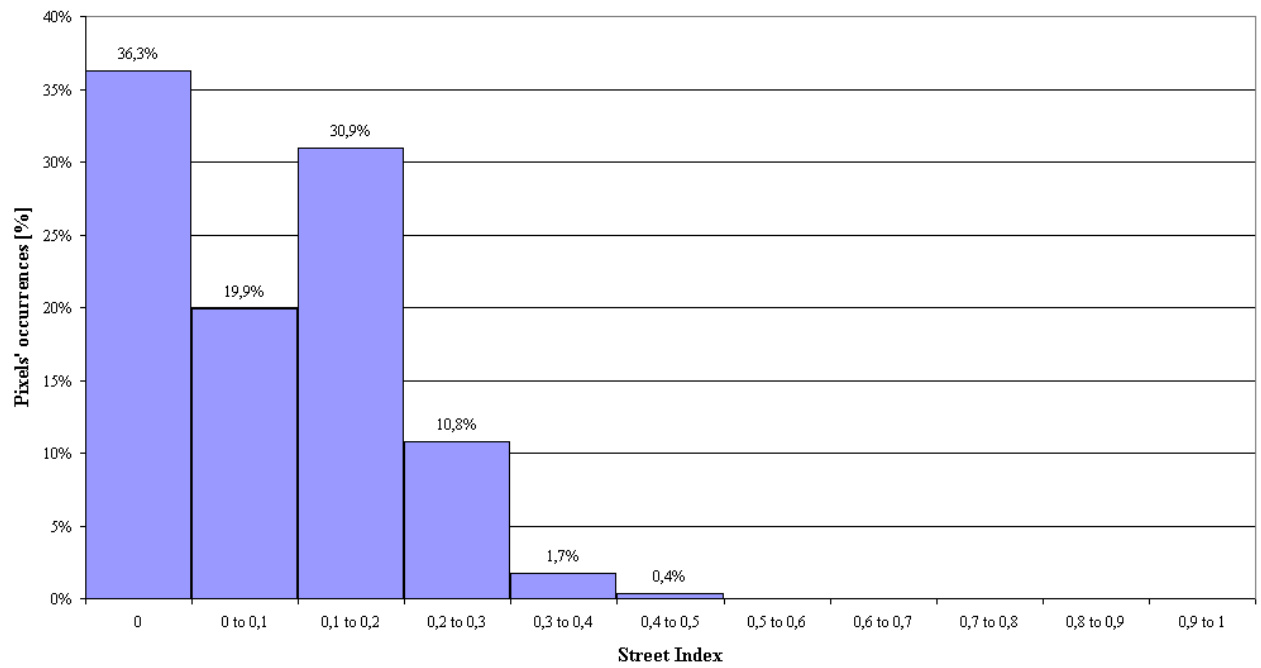
Figure A-24 – Street Index for The Hague.
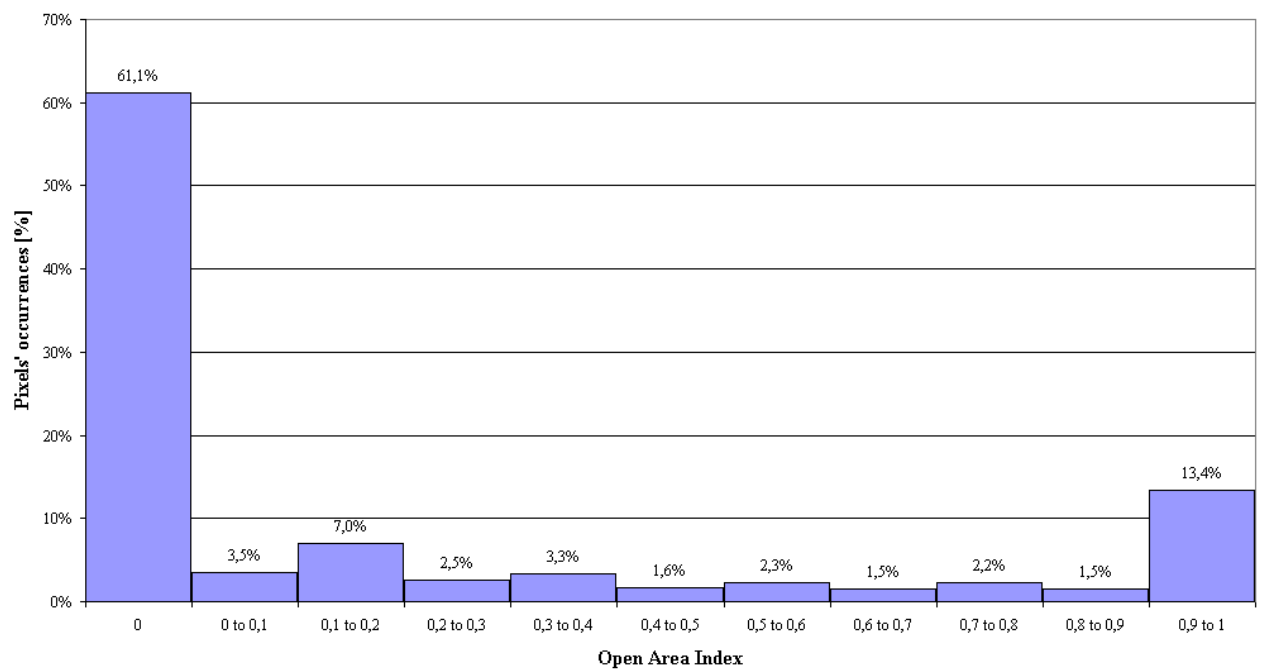
Figure A-25 – Open Area Index for Lisbon.
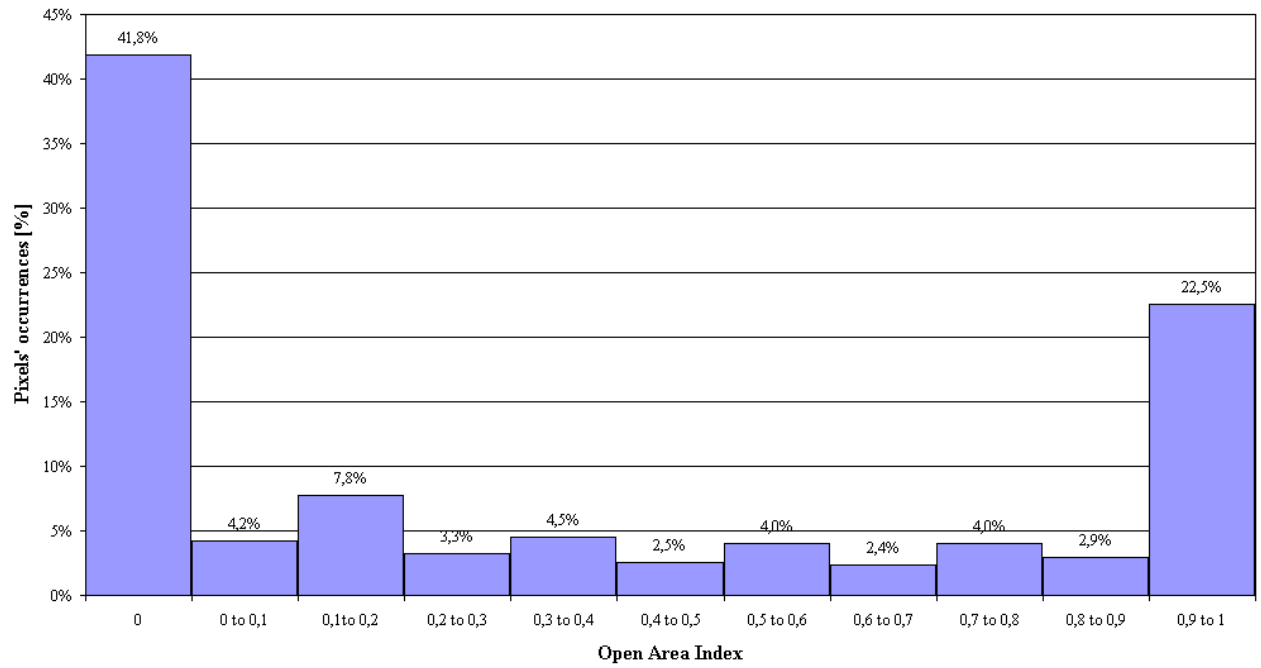
Figure A-26 – Open Area Index for Porto.
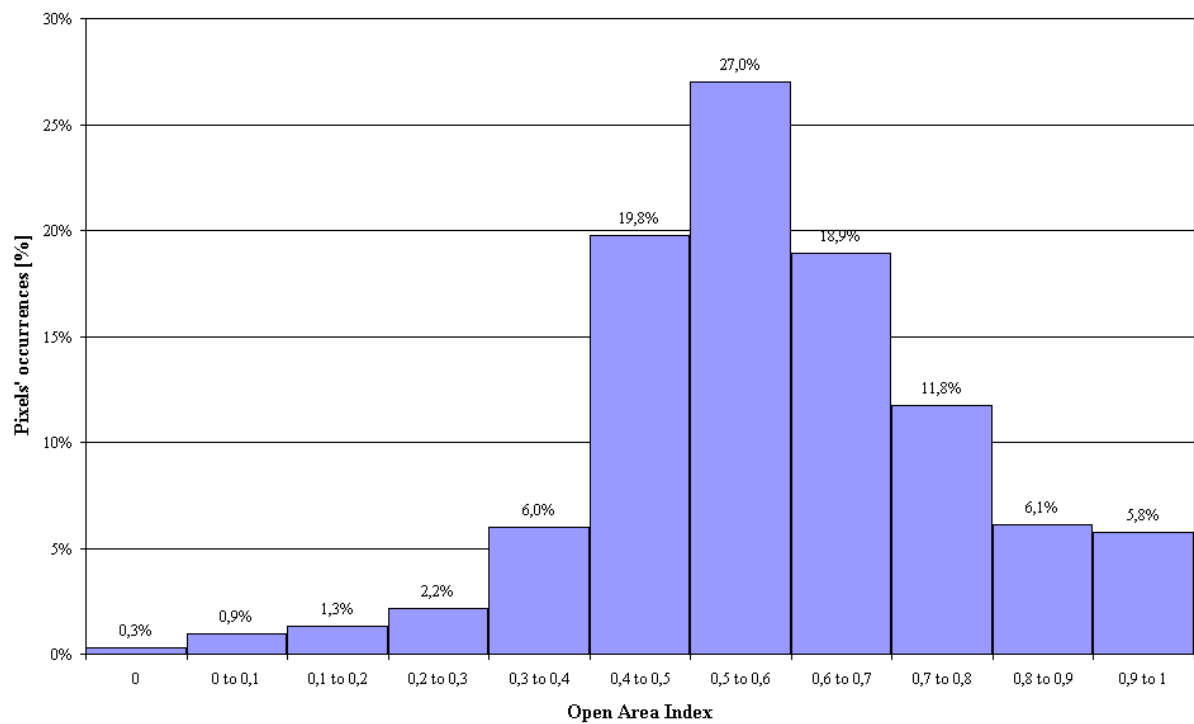
Figure A-27 - Open Area Index for Berlin.
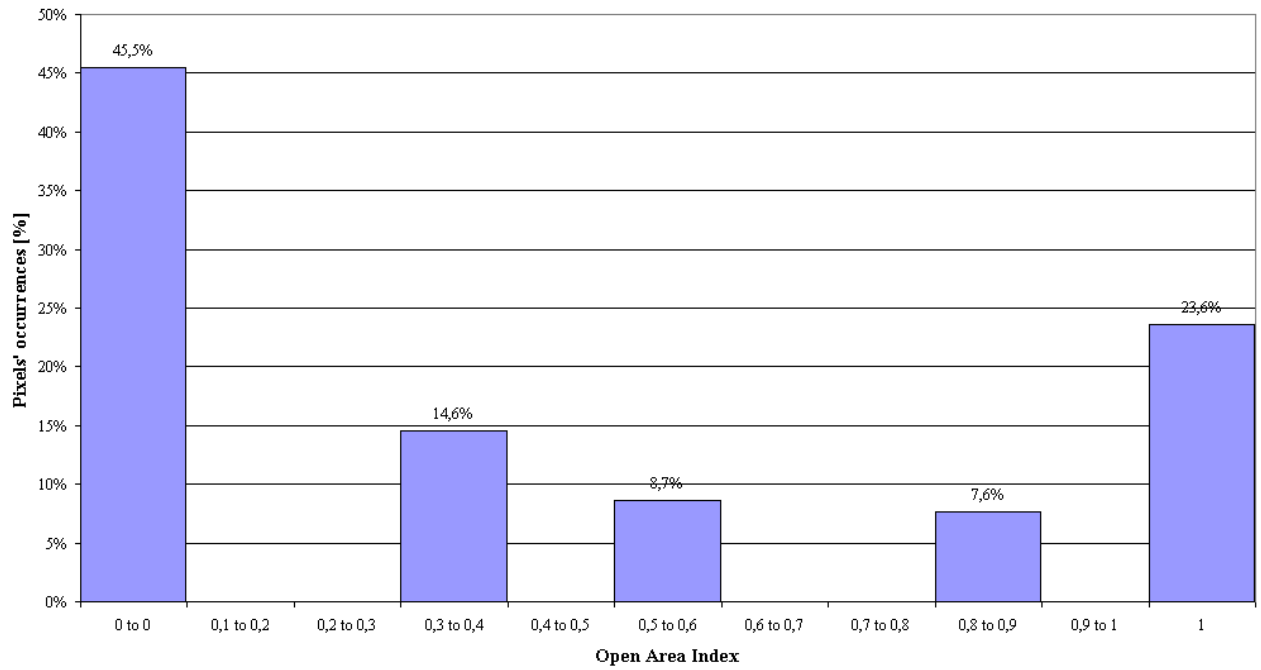
Figure A-28 – Open Area Index for The Hague.
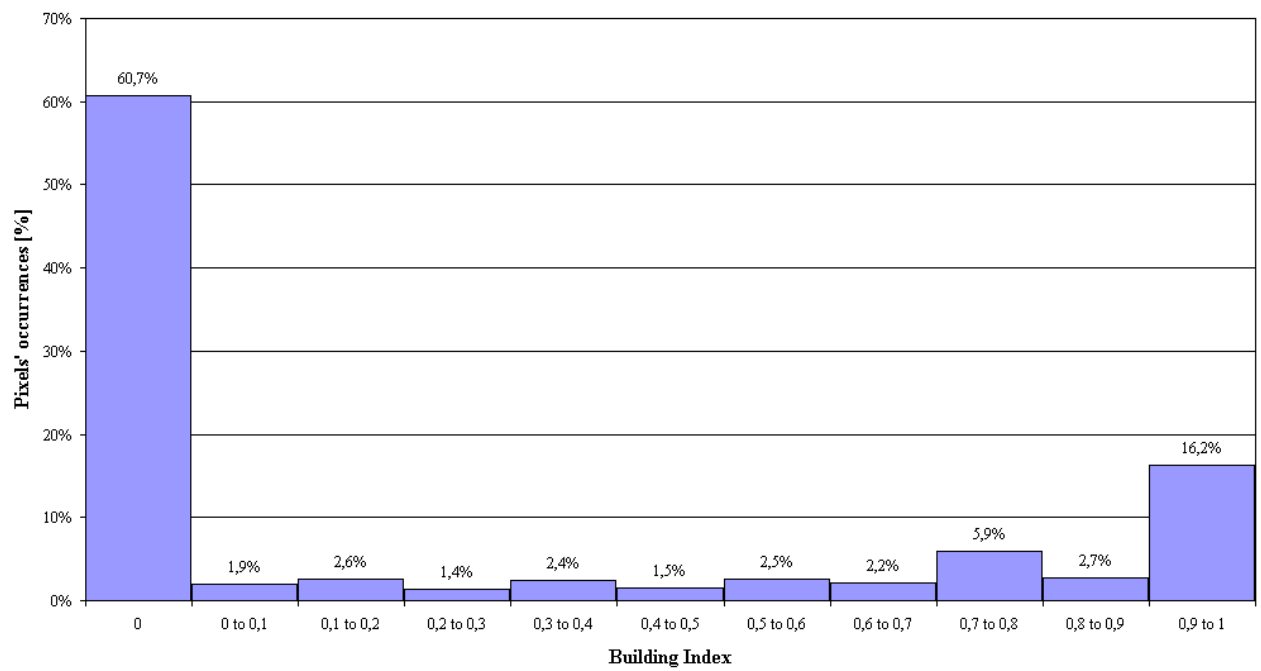
Figure A-29 – Building Index for Lisbon.
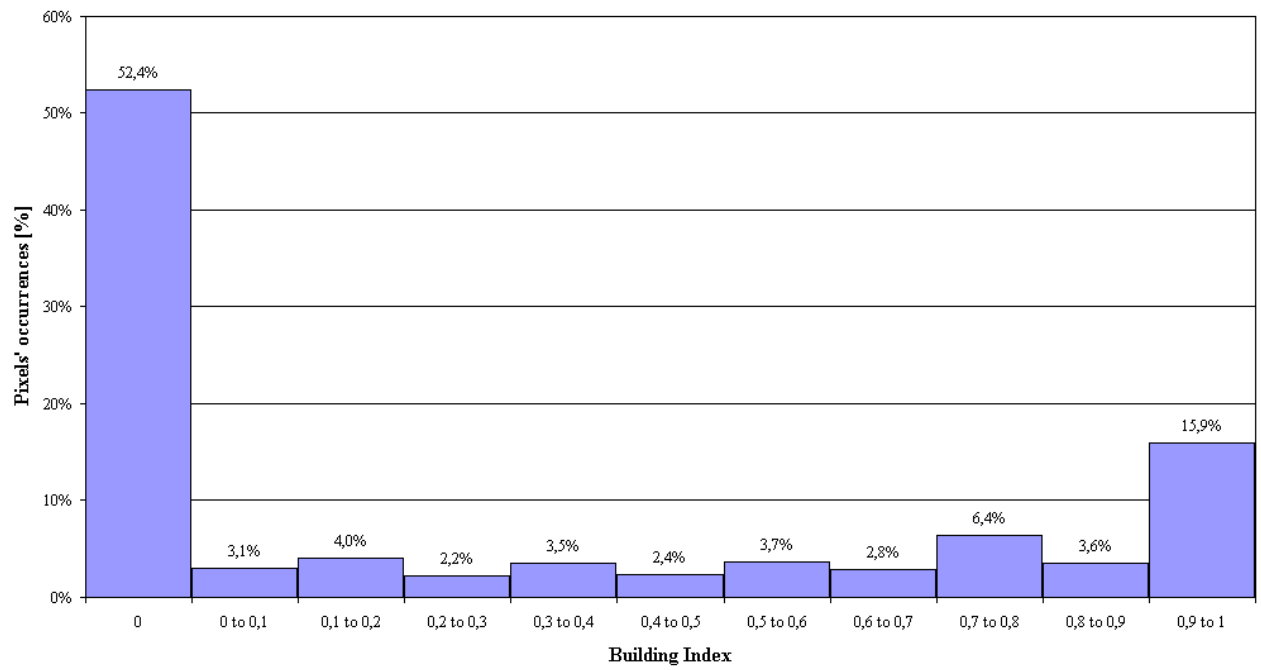
Figure A-30 – Building Index for Porto.
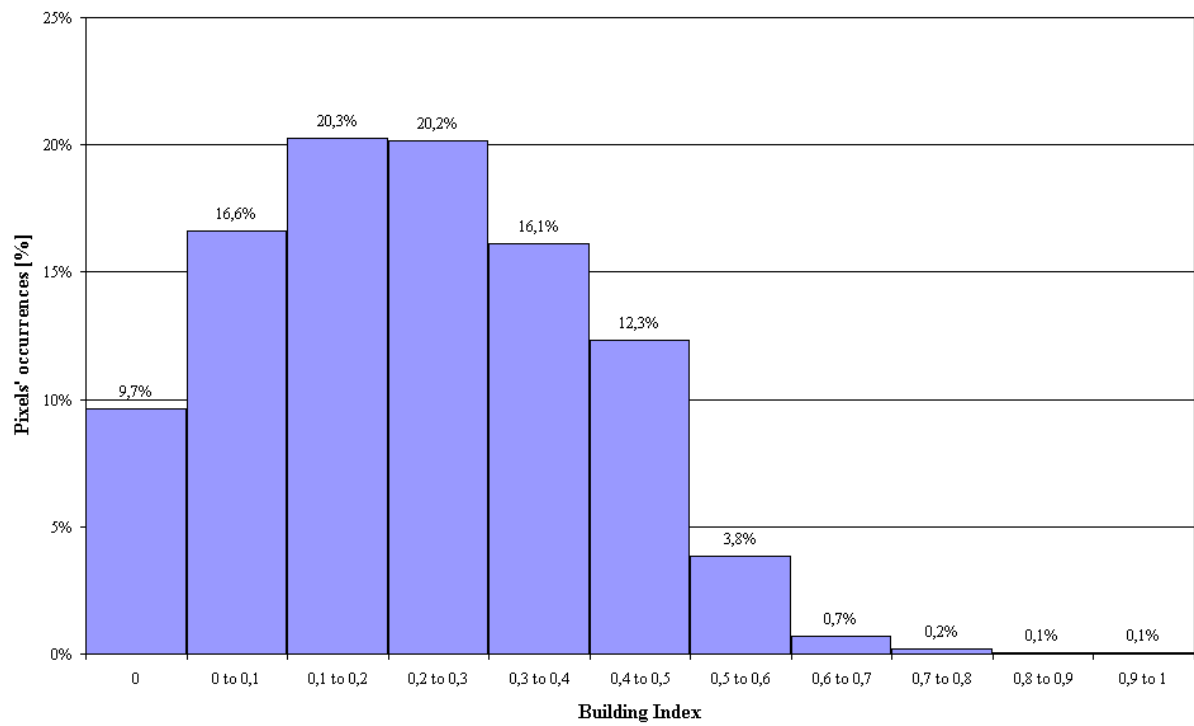
Figure A-31 – Building Index for Berlin.
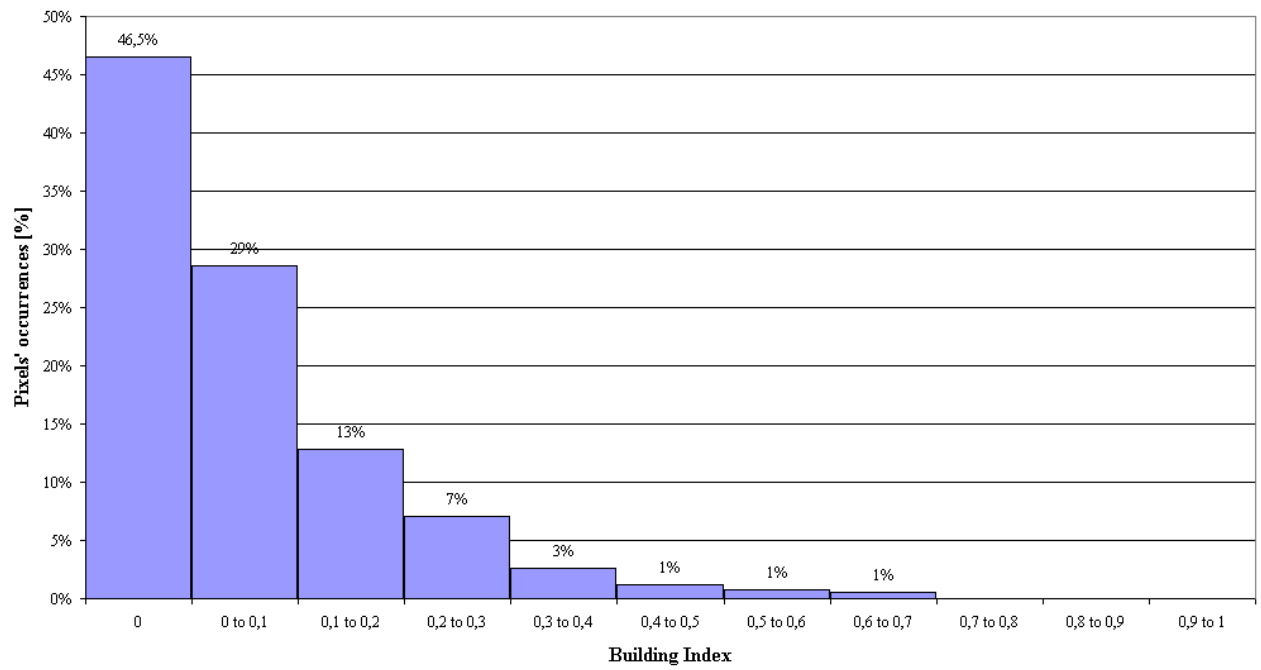
Figure A-32 – Building Index for The Hague.

Annex B - MapInfo Layers Representations

Annex B contains the maps, based on the 100 m resolution grids, for the cities of Lisbon, Porto, Berlin, and The Hague, Figs. B-1 to B- 32 show the graphical results on maps for the layers TH_MV, BH_MV, SW_MV, VI, WI, SI, OAI, and BI, drawn with MapInfo® Professional 6.0; the layers concerning standard deviation like TH_STDEV, BH_STDEV, and SW_STDEV, are not shown. A choice of the colours in order to obtain the best layout results and to give to the reader an easy and quick reading of the maps has been done. The maps are order by layers for an easier comparison among the cities and for each map, an appropriate legend with just the colours presented in the picture is shown.
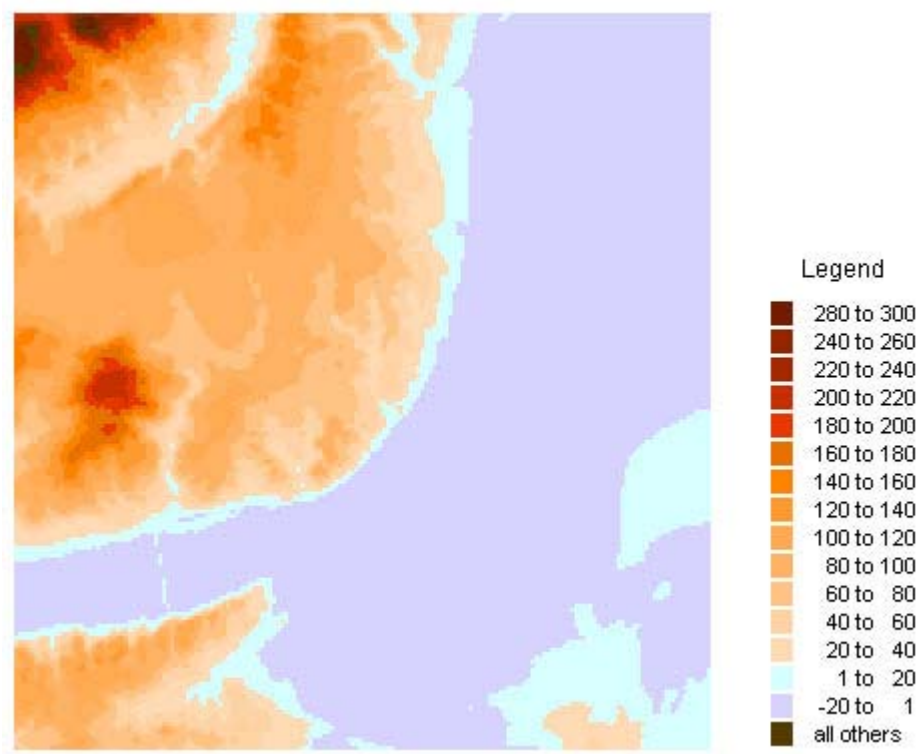
Figure B-1-TH_MV for Lisbon.
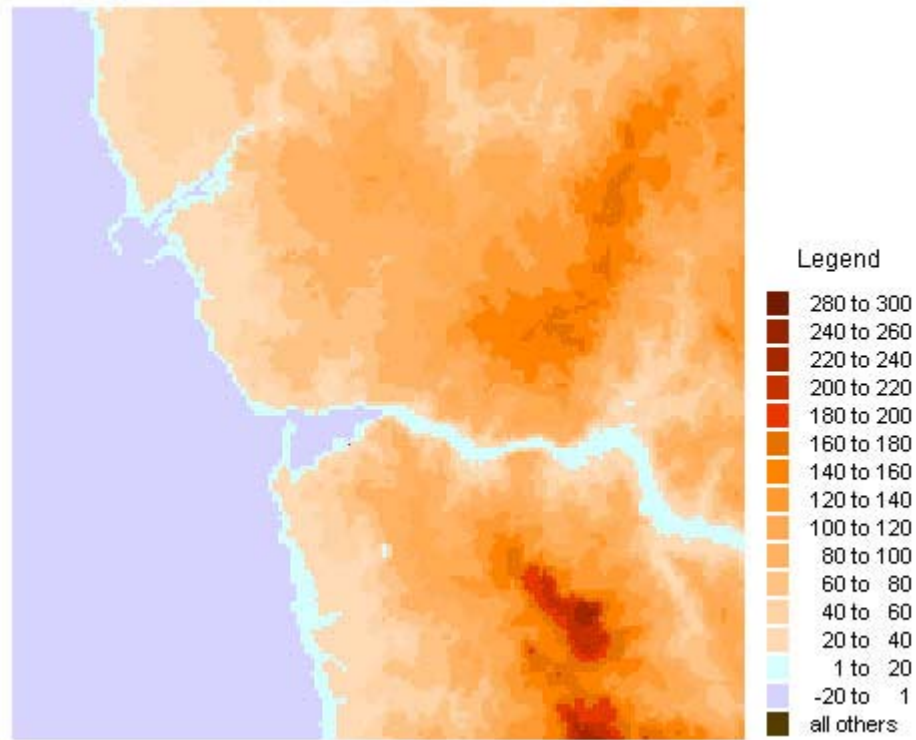
Figure B-2 – TH_MV for Porto.
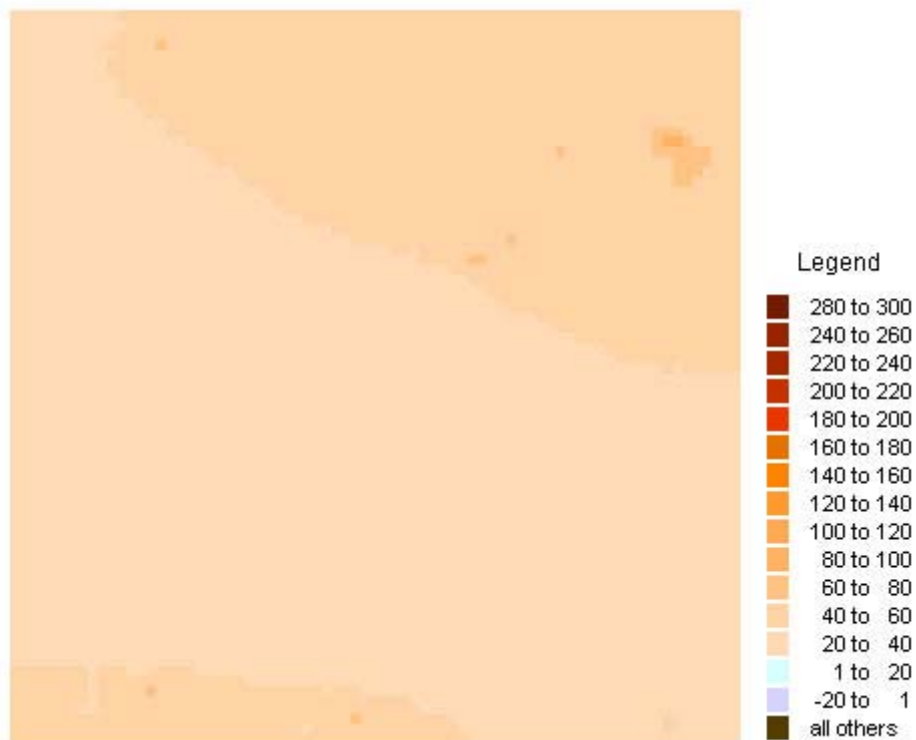
Figure B-3 – TH_MV for Berlin.
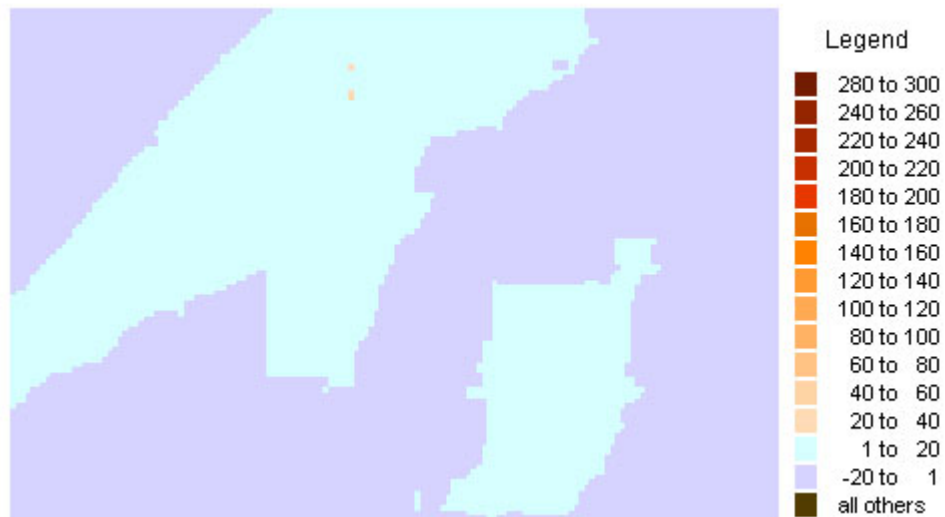
Figure B-4 – TH_MV for The Hague.
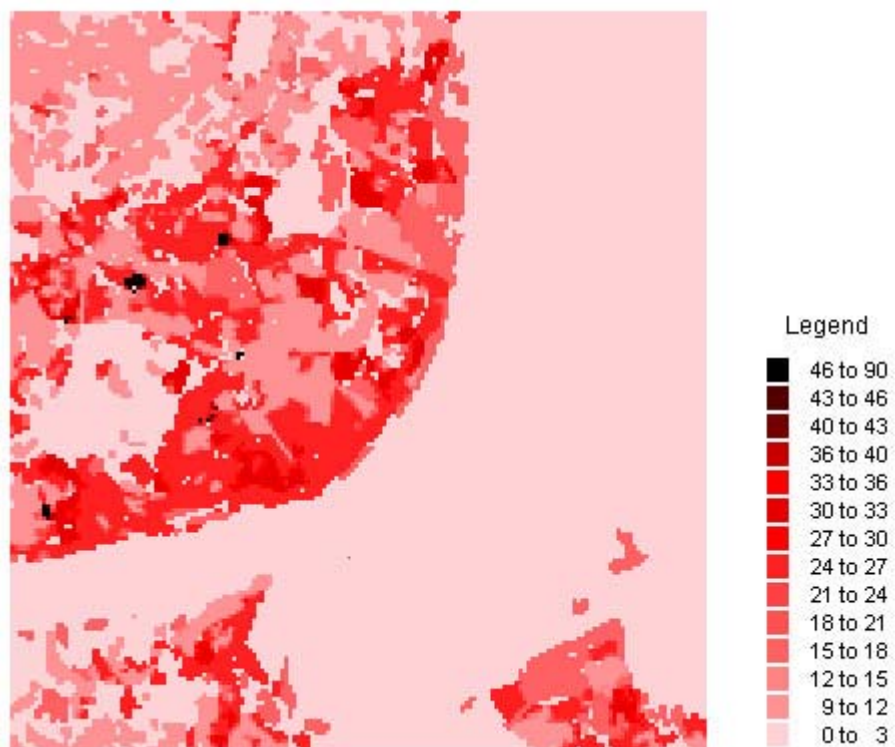
Figure B-5 – BH-MV for Lisbon.
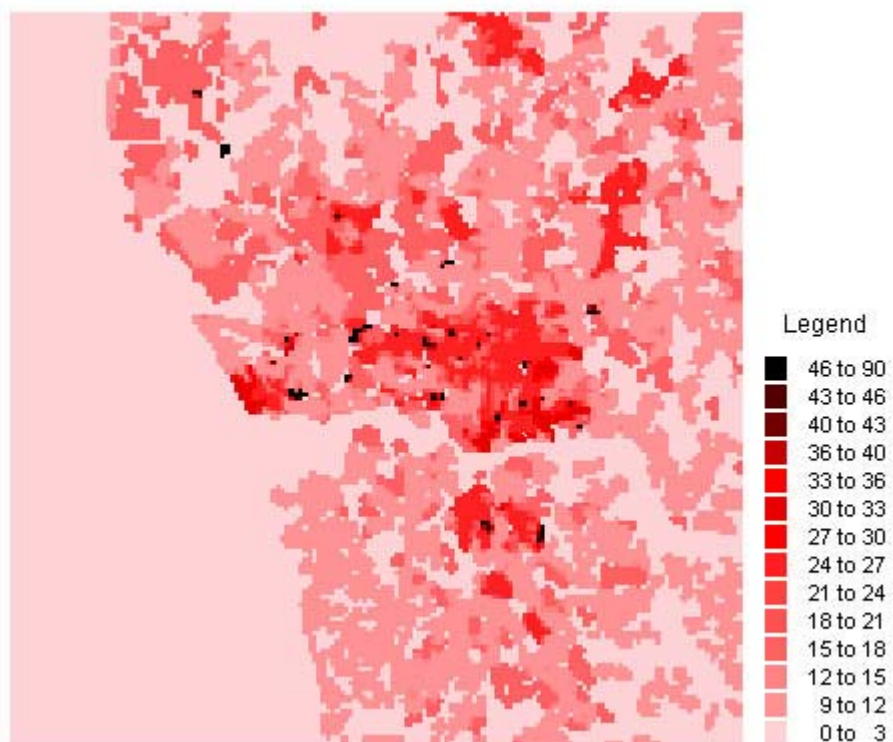
Figure B-6 – BH-MV for Porto.
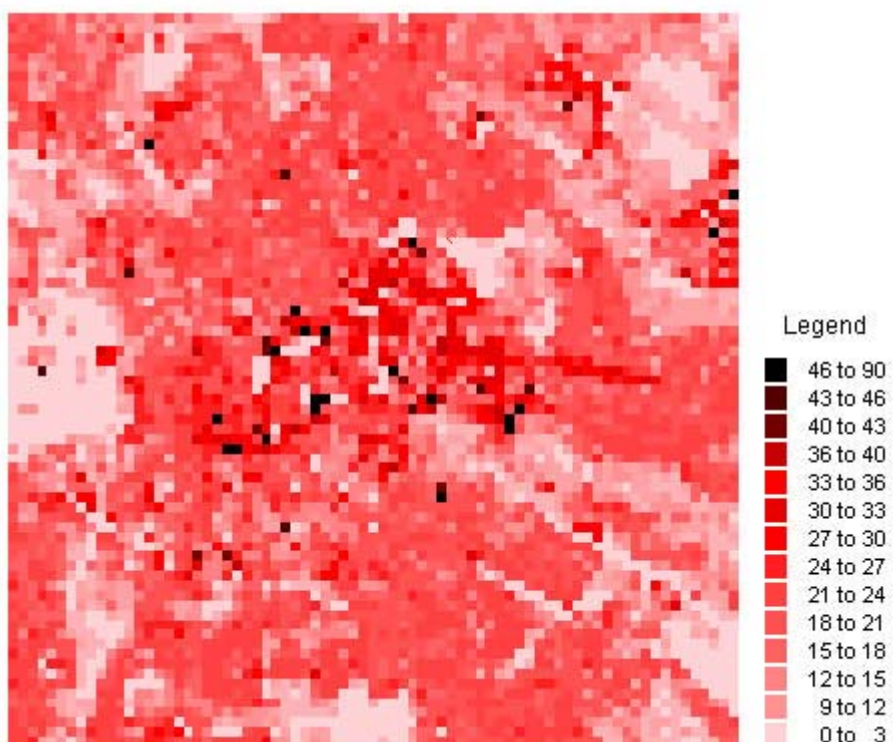
Figure B-7 – BH-MV for Berlin.

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Figure B-8 – BH-MV for The Hague.
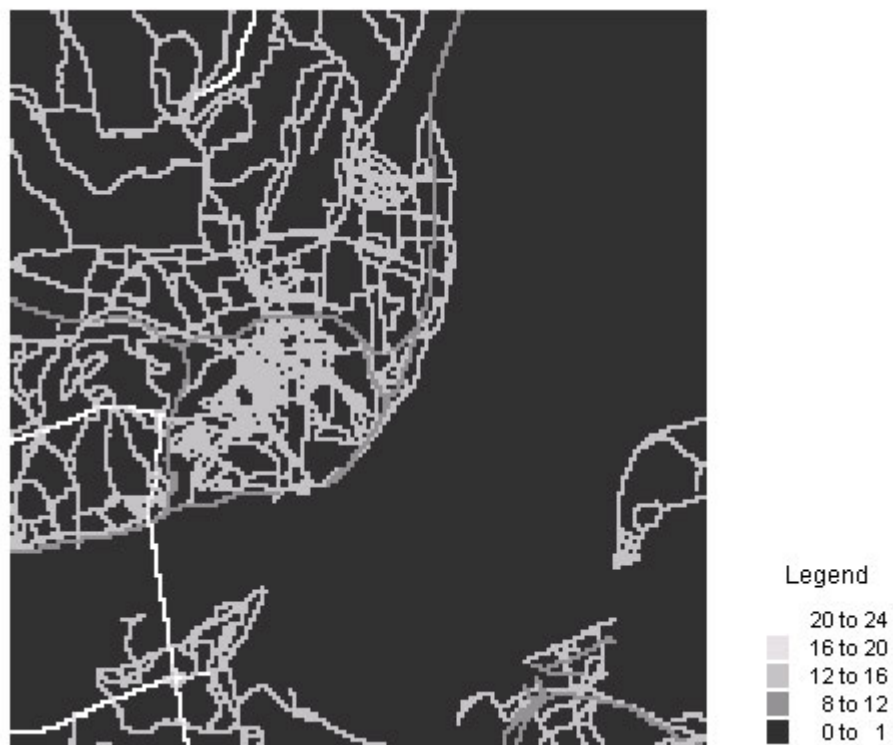
Figure B-9- SW_MV for Lisbon.
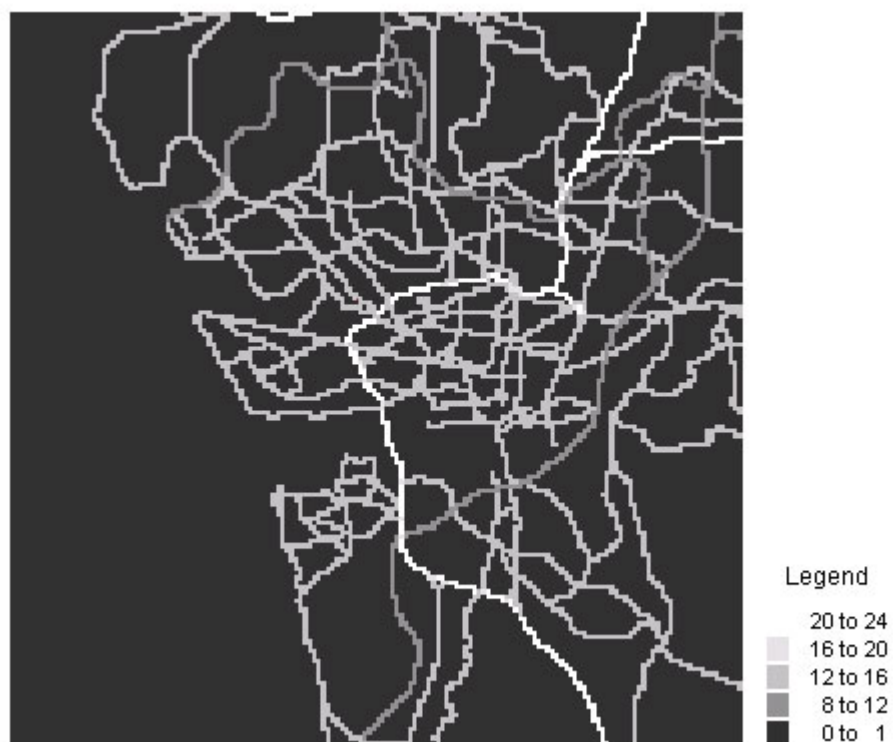
Figure B-10 – SW_MV for Porto.
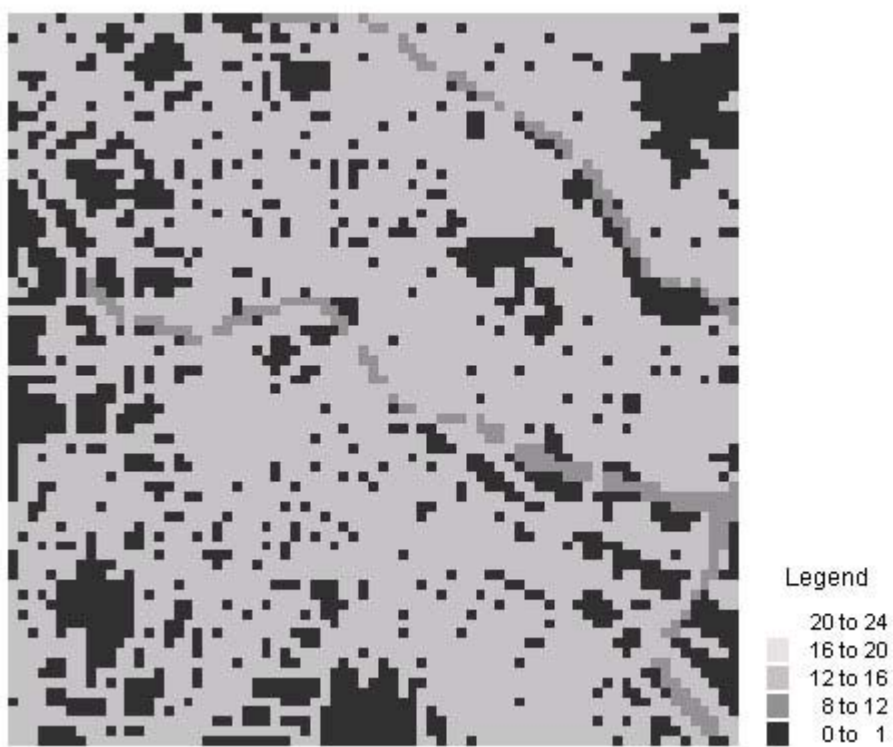
Figure B-11 – SW_MV for Berlin.
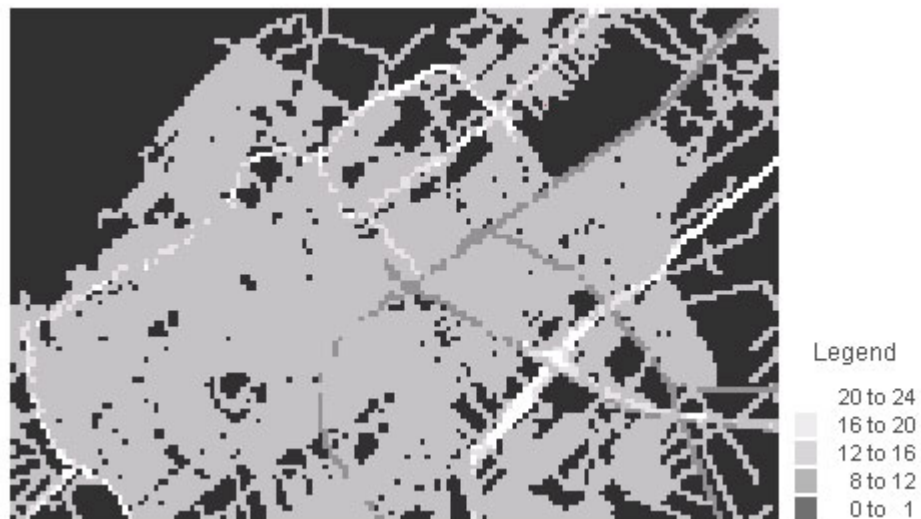
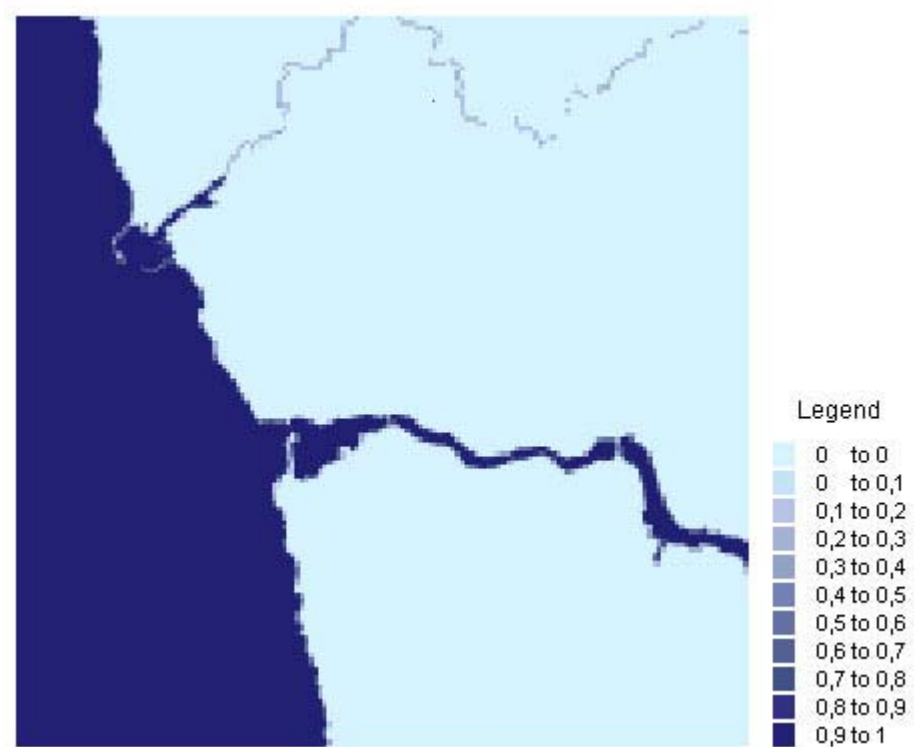Figure B-12 – SW_MV for The Hague.

Figure B-13 – VI for Lisbon.

Legend

■ 0,9 to 1
■ 0,8 to 0,9
■ 0,7 to 0,8
■ 0,6 to 0,7
■ 0,5 to 0,6
■ 0,4 to 0,5
■ 0,3 to 0,4
■ 0,2 to 0,3
■ 0,1 to 0,2
■ 0 to 0,1
■ 0 to 0

Figure B-14 – VI for Porto.

Legend

■ 0,9 to 1
■ 0,8 to 0,9
■ 0,7 to 0,8
■ 0,6 to 0,7
■ 0,5 to 0,6
■ 0,4 to 0,5
■ 0,3 to 0,4
■ 0,2 to 0,3
■ 0,1 to 0,2
■ 0 to 0,1
■ 0 to 0
  all others
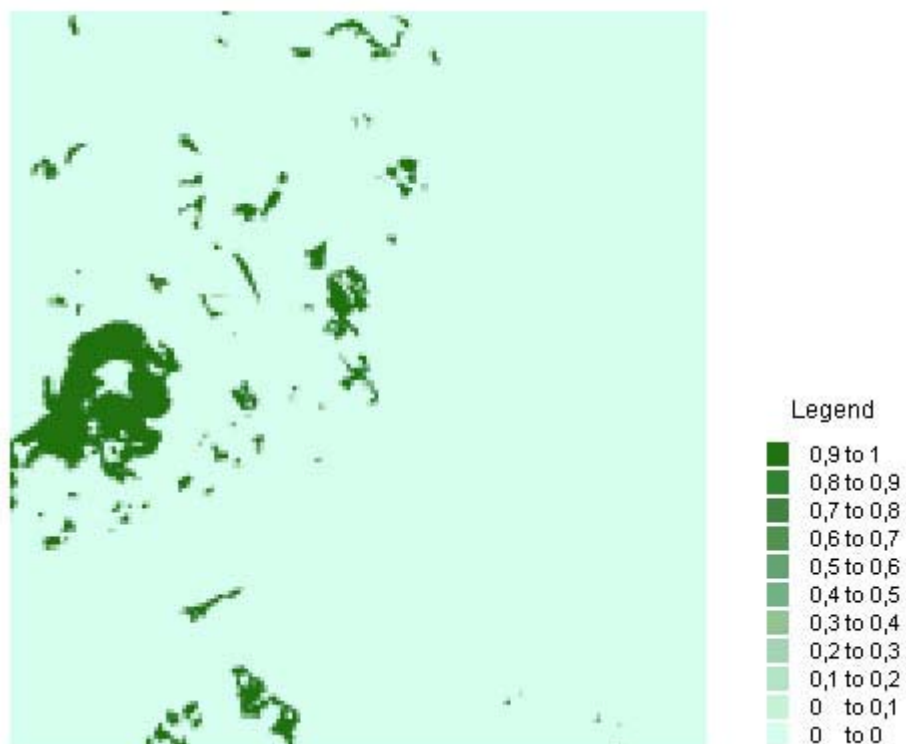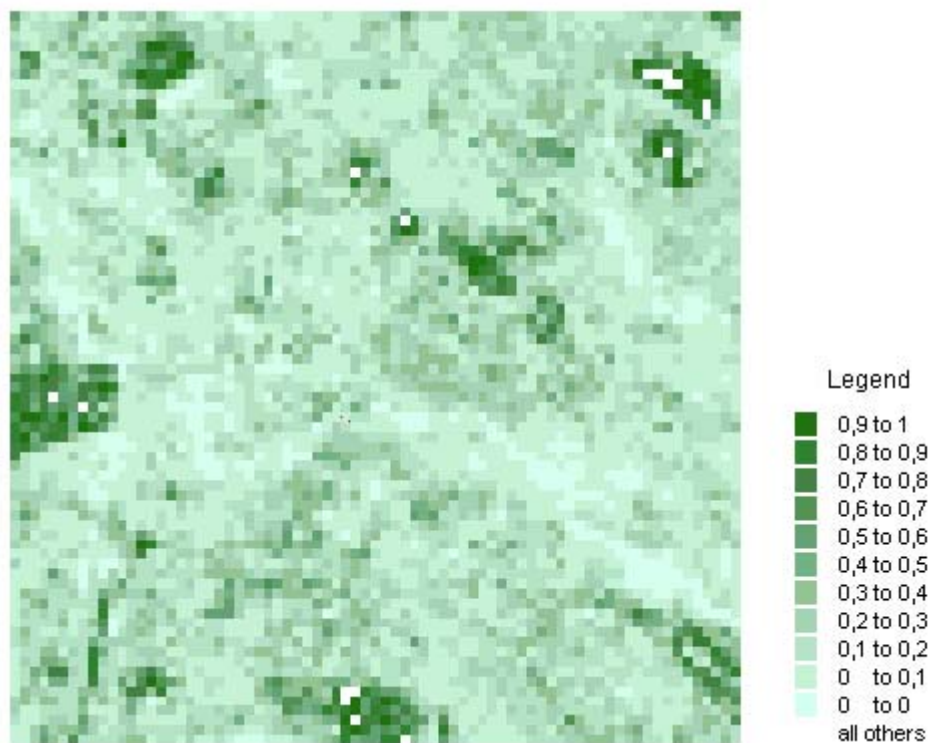
Figure B-15 – VI for Berlin.
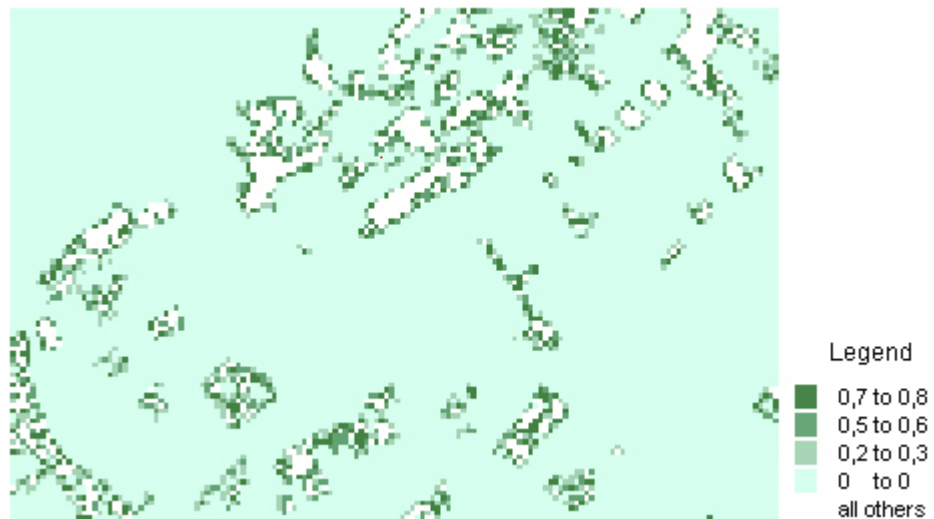
Figure B-16 – VI for The Hague.
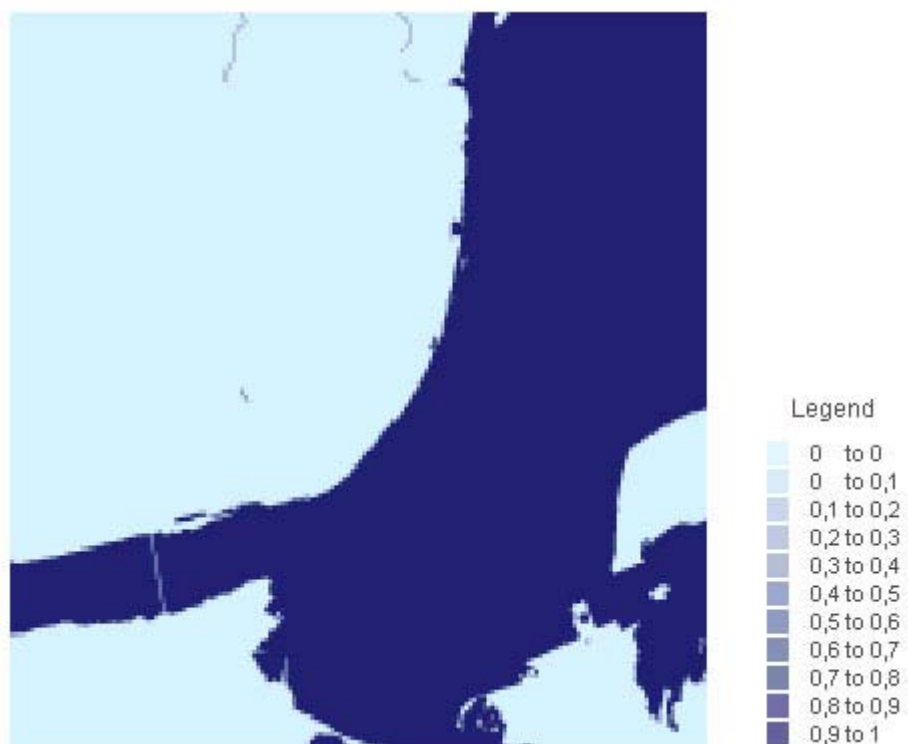
Figure B-17 – WI for Lisbon.

Figure B-18 – WI for Porto.
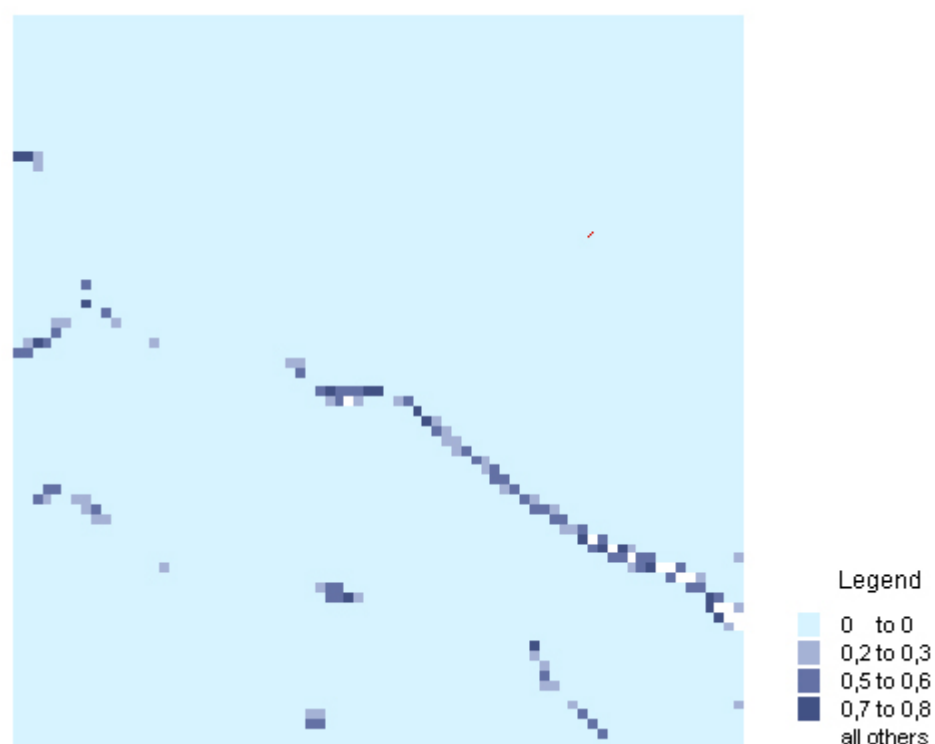
Figure B-19 – WI for Berlin.

Figure B-20 – WI for The Hague.
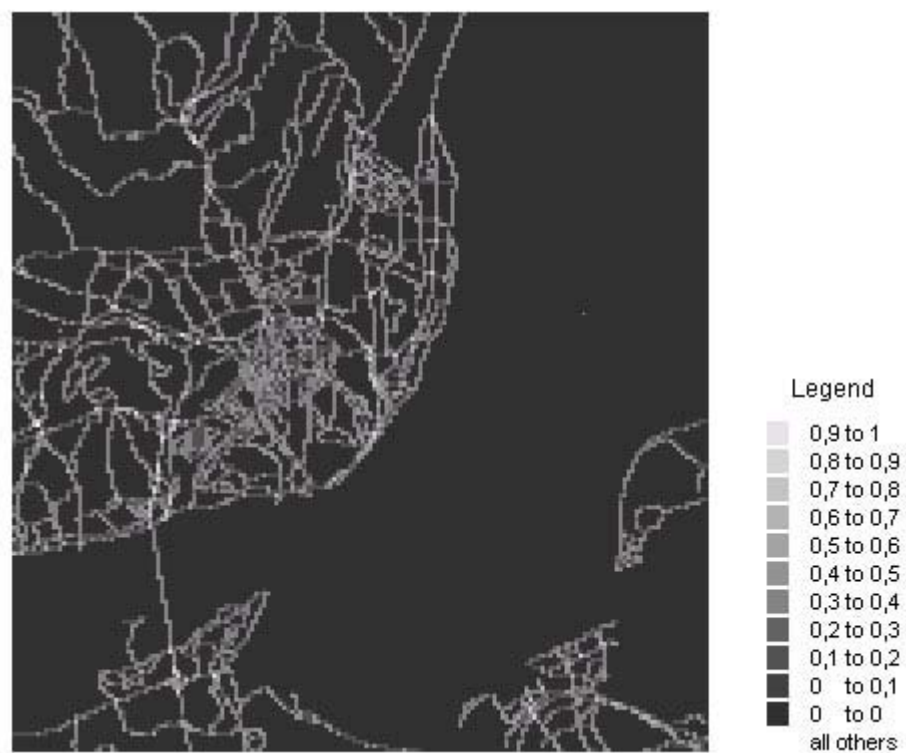
Figure B-21 – SI for Lisbon.
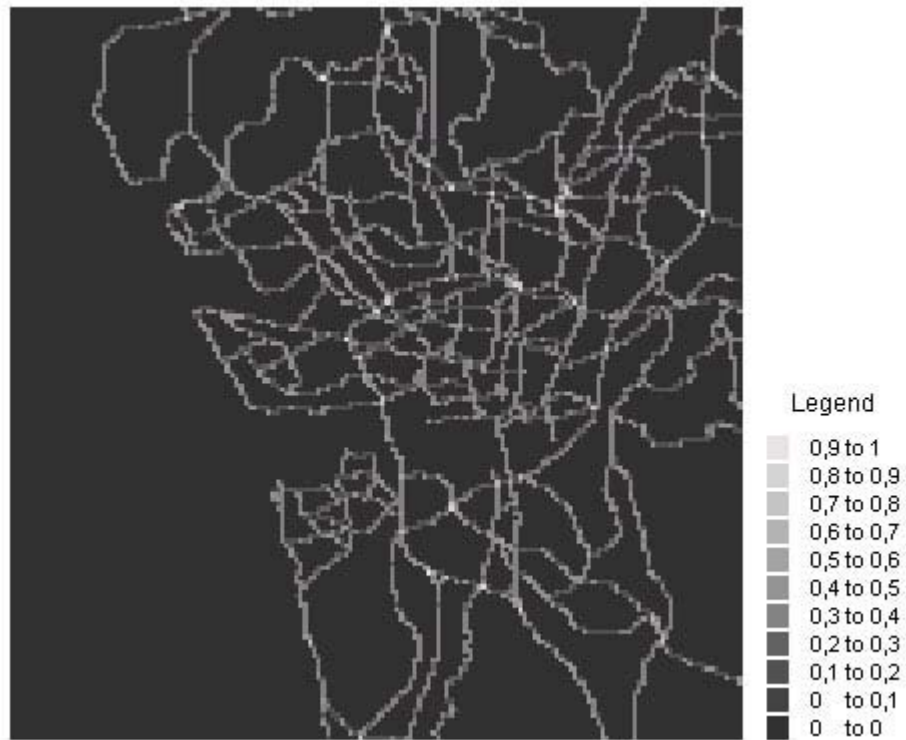
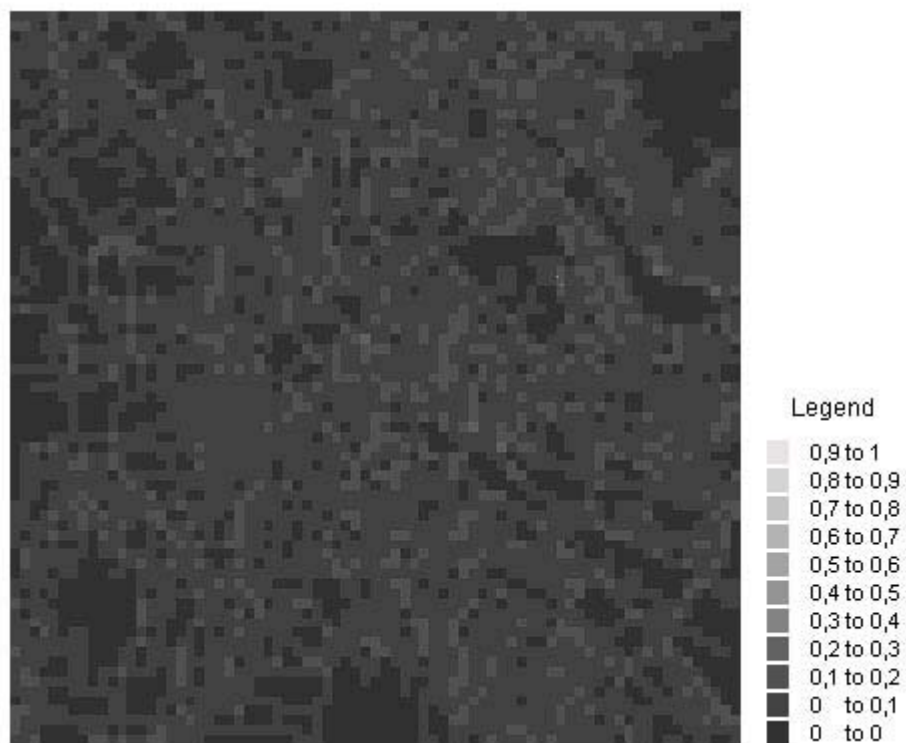Figure B-22 – SI for Porto.

Figure B-23 – SI for Berlin.

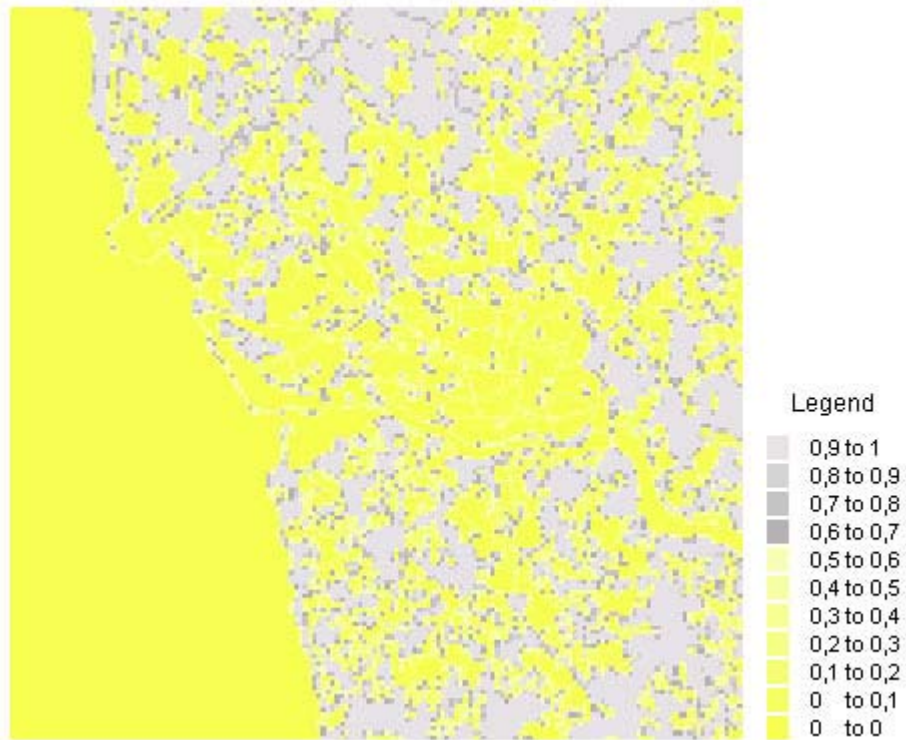Figure B-24 – SI for The Hague.

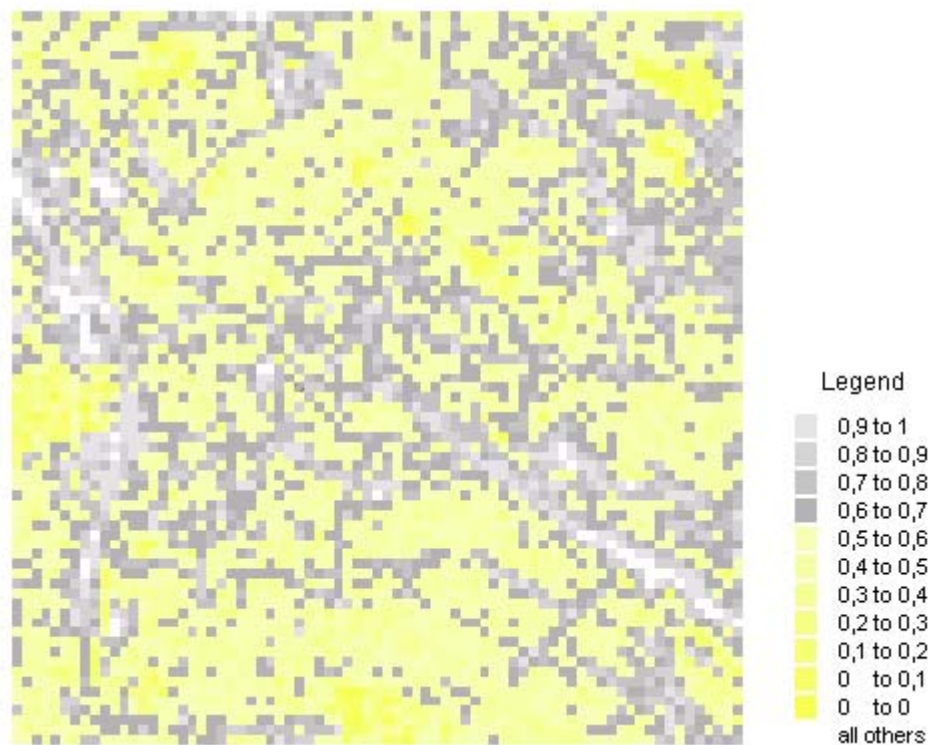Figure B-25 – OAI for Lisbon.

Figure B-26 – OAI for Porto.

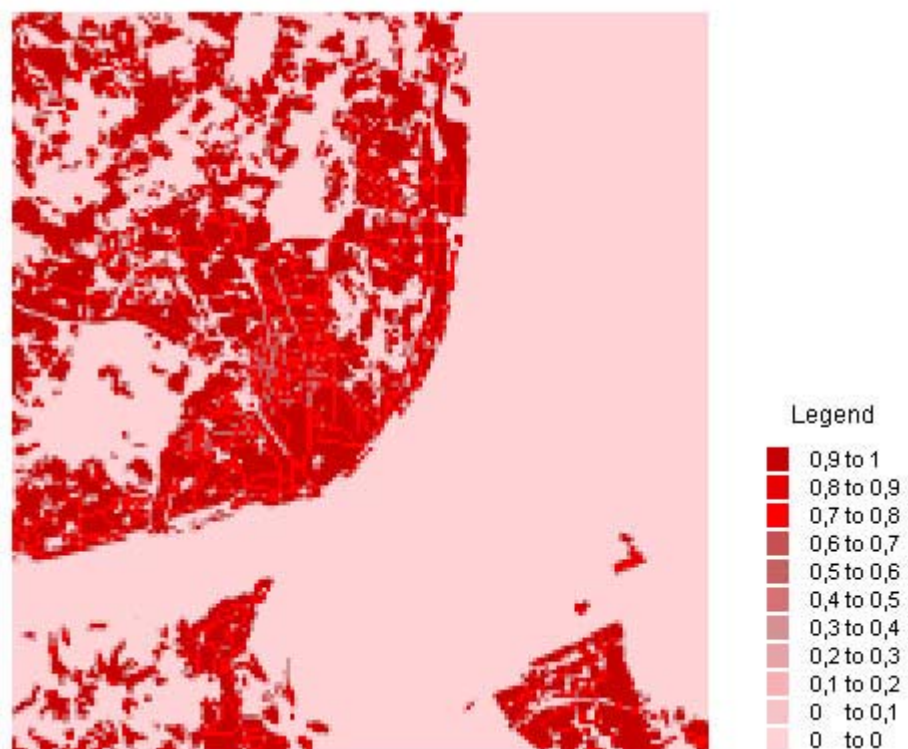Figure B-27 – OAI for Berlin.

Figure B-28 – OAI for The Hague.
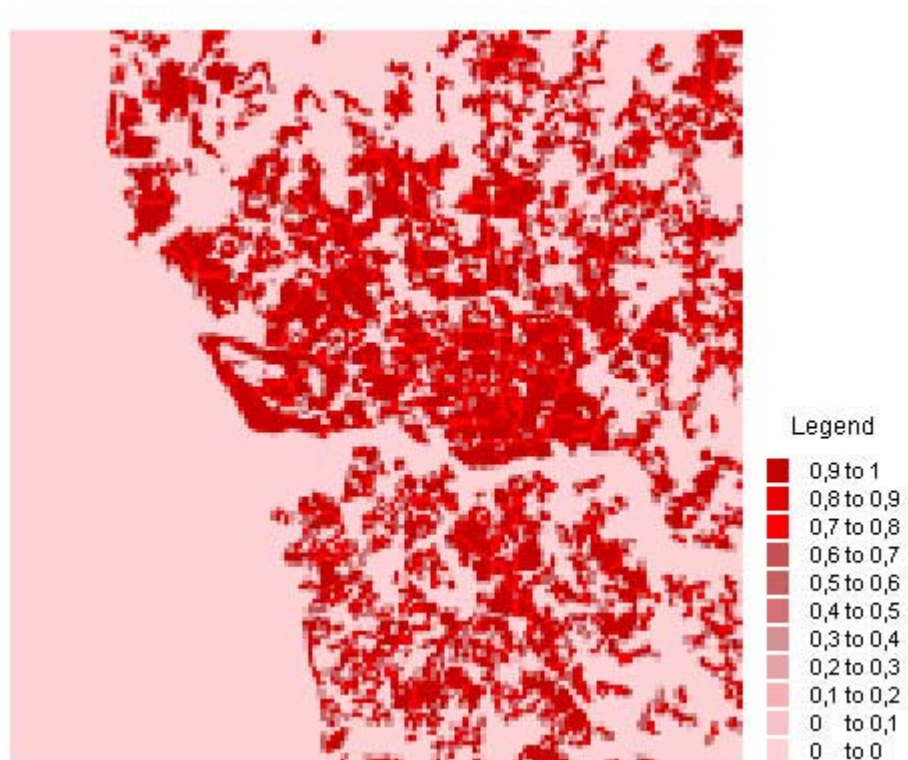

Figure B-29 – BI for Lisbon.
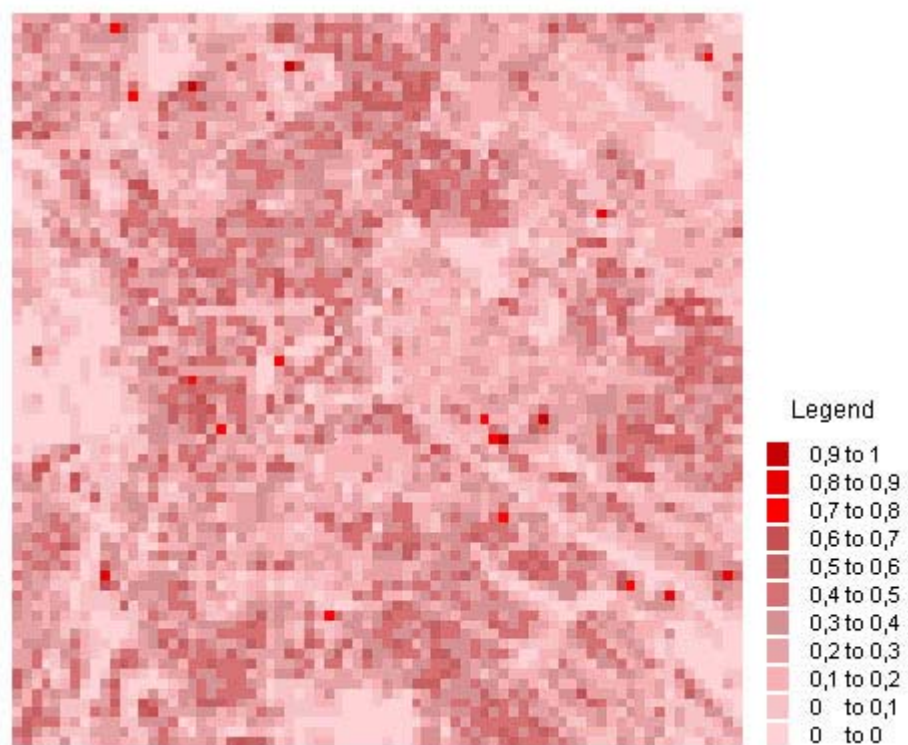
Figure B-30 – BI for Porto.
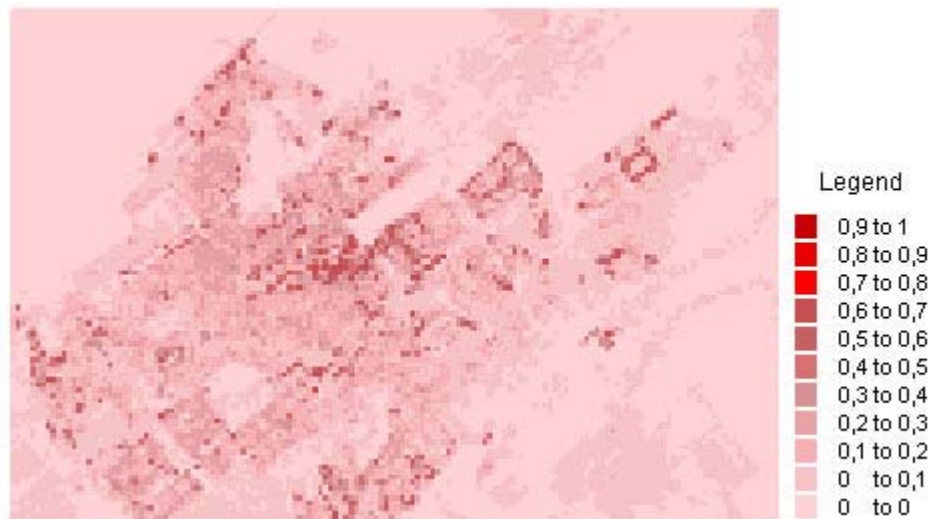

Figure B-31 – BI for Berlin.

Figure B-32 – BI for The Hague.

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