Orbital Routes: A Possible Public Transport Answer to Small, Densely Populated Islands

A dissertation submitted in partial fulfilment of the requirements

Degree of Master of Science in Applied GIS

The University of Salford

Noel Seguna

Student ID: 00413194

September 2017

Declaration of Originality

This is to certify that the work is entirely my own and not of any other person, unless explicitly acknowledged (including citation of published and unpublished sources). The work has not previously been submitted in any form to the University of Salford or to any other institution for assessment for any other purpose.

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Date: 9th September 2017

Abstract

Having an oft used public transportation system is very important if the negative effects on the environment by land transport are to be reduced, a more accessibly just society is to be had and if congestion in urban areas is to be reduced. Designing a public transportation system though is a very difficult task. Although operations research (OR) has been very beneficial in designing the frequency of the network, practical route planning of the network itself has been in general ignored by the academic community.

This thesis thus tries to build on Nielsen et al.'s (2005) work and attempts to find out the best network design for small densely populated islands. It thus compares: a radial network, an orbital route-based network, a grid-based network, and two networks that were laid down in the last five years both of which had both radial and dispersed elements. The comparisons were carried out by calculating the modal accessibility gap (MAG) as described in Kwok and Yeh (2004). The results indicate that although the MAG may be used when comparing the car with a public transportation system, this equation is inadequate if the public transportation networks are to be compared with each other. The results also indicate that for small islands an orbital-based network is not desirable.

Acknowledgements

This thesis would not have been completed without the support and encouragement of my family and friends. I would like to thank especially my mother, Dorothy Seguna for her unending encouragement and support without which I would have surely faltered, and my dear friend Sofia Almagro.

I would like to thank my tutor, Dr. James Cheng, for his patience and guidance. I am also very grateful to Ms. Tracy McKenna at UNIGIS for her unending support and initiative. I am indebted to my formal University of Malta lecturer, Ms. Therese Bajada, for introducing me to different GIS fora which were indispensable sources of inspiration from which to troubleshoot the GIS models. I would also like to thank my uncle, Jude Muscat, for proof reading this thesis.

Finally I would like to dedicate this thesis to the Maltese nation in the hope that one day it may also have an attractive public transport system.

Word Count

Number of Words: 12919

Number of pages: 164

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CHAPTER 1

INTRODUCTION

1.1 Background

"I refuse to go downtown by car! I just refuse to go, because it is despairing having to park the car, and it takes too long and the continuous stop and go." 43 year old female public transport user (Beirão and Cabral, 2007:482).

"... we are in our car and suddenly we have an idea to go somewhere and just go." 56 year old female car user (Beirão and Cabral, 2007:484).

"I often get really tired of driving the car, and I would prefer to catch a bus if I had the time." 39 year old female car user (Beirão and Cabral, 2007:485).

A functioning public transport service considerably improves the social, economical and environmental aspects of a society (Fan and Machemehl, 2006; Benenson et al., 2011; Vega, 2011). Despite this, individuals do not automatically use public transportation services simply because they exist. Although various factors such as: information dissemination, urban planning, economics and politics play an important role in influencing public transport ridership (Pucher and Kurt, 1996; Lau, 1997; Hensher, 1998; Cullinane, 2003; Nielsen et al., 2005; Tang and Lo, 2008; Stone, 2009; Mees, 2010; Kim et al., 2016), network design is by far the most important aspect if public transport is to become successful (Murray, 2001; Nielsen et al., 2005; Nielsen et al., 2006; Stone, 2009; Mees, 2010, Stone and Mees, 2010).

Since the conquest of the automobile as the dominant mode of travel, urban planners have argued about the role that public transport should take. Some planners argue that the primary role of public transport is to achieve a more spatially just society while more recent arguments propose that the role of public transport is to go beyond social equity and be a major part of the solution to alleviate traffic congestion in urban areas (Thompson and Matoff, 2003; Nielsen et.al., 2005; Mees, 2010). The mere access to a transportation system is enough to justify social equity whilst much more thought is to be given to network design if it is to compete against the car. The strategy that politicians take is therefore the decisive factor on what kind of network is implemented in a governed area (Nielsen et.al., 2005; Mees, 2010).

1.2 Urban Transport Challenges

Congestion in urban areas is the result of infrastructure not meeting the demand imposed on it. An ever increasing population and its increasing motorisation have not only exasperated congestion in urban areas but have catapulted transport as the largest air and noise pollution source in them (Murray et al., 1998; Murray, 2001, Mees, 2010).

Various approaches could be taken to limit transport-related emissions and congestion. Economists are of the idea that imposing congestion pricing could lessen the problem, even though the evidence for this measure's effectiveness is still disputed (Hodge, 1997) whilst at the same time being very politically risky for politicians (Murray, 2001). The literature has also disproved the idea of increasing the capacity of automobile-related infrastructure as the answer to relieve congestion (Mogridge, 1997; Mees, 2010). Other proposals that offer better solutions to lessen transport-related problems are: to induce a modal shift from the car to public transport and to other soft modes such as walking and cycling (Mees, 2010); to encourage car pooling; and increase the development in ICT and green engines (Murray, 2001).

The most effective of these measures is the induction of a modal shift from public transport to the car. Public transport is able to transport people with greater efficient use of resources (figure 1) because of its greater economy of scale that it is able to achieve (Mees, 2010). In practice, achieving modal shift is much more easily said than done. The car is usually the preferred mode of transport because of practical aspects such as: lower travel time, increased reliability, better convenience, better access, better comfort and better security (Murray et al., 1998; Nielsen et al., 2005; Mees, 2010). Furthermore, psychological aspects such as: personal status, attitudes, perception and habits, all play a role in an individual's mode choice, albeit with different strengths from person to person (Cullinane, 2002; Cullinane and Cullinane, 2003; Anable, 2005; Nielsen et al., 2005; Lämmer et al., 2006; Beirão and Cabral, 2007; Mees, 2010).

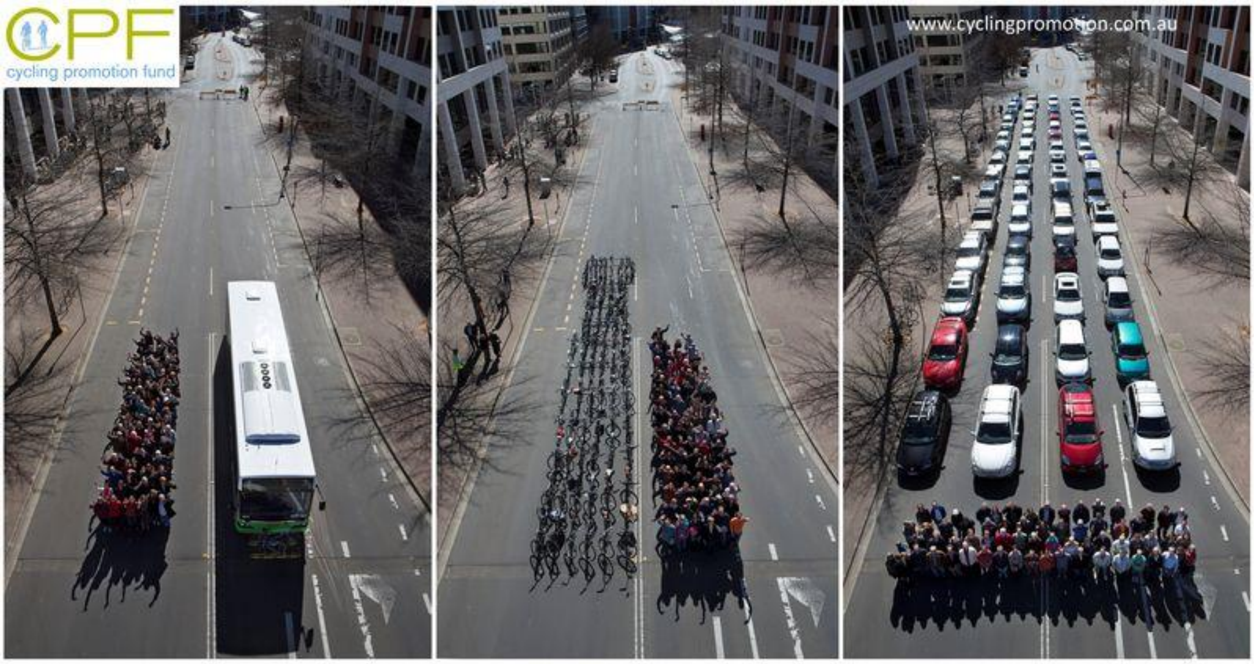

Figure 1: Public Transport Landuse Efficiency (Cell Bikes Mark, 2012: online)

From a practical perspective, travel time and reliability are the most important factors why individuals do not use public transport (Nielsen et al., 2005; Vandebulcke et al., 2009; Lei and Chruch, 2010; Mees, 2010). Thus lowering the travel time as much as possible is an imperative if public transport is to compete with the car. It is hoped that this thesis will be able to increase our understanding of how to create a public transportation network by suggesting a new network design that may be better suited to the hinterlands of small densely populated islands like Malta.

1.3 Study Area

The state of Malta is a small archipelago of seven islands, three of which, Malta, Għawdex (Gozo) and Kemmuna (Comino) are inhabited. The largest island, Malta, will be taken as the case study area because of its diverse geography, familiarity by the author and the congestion problems experienced in it. Malta is divided into five regions corresponding to the INSPIRE's classification level of LAU1: Northern, South Eastern, Western, Northern Harbour and Southern Harbour (figure 2). Furthermore it is subdivided into fifty two local councils (figure 3).

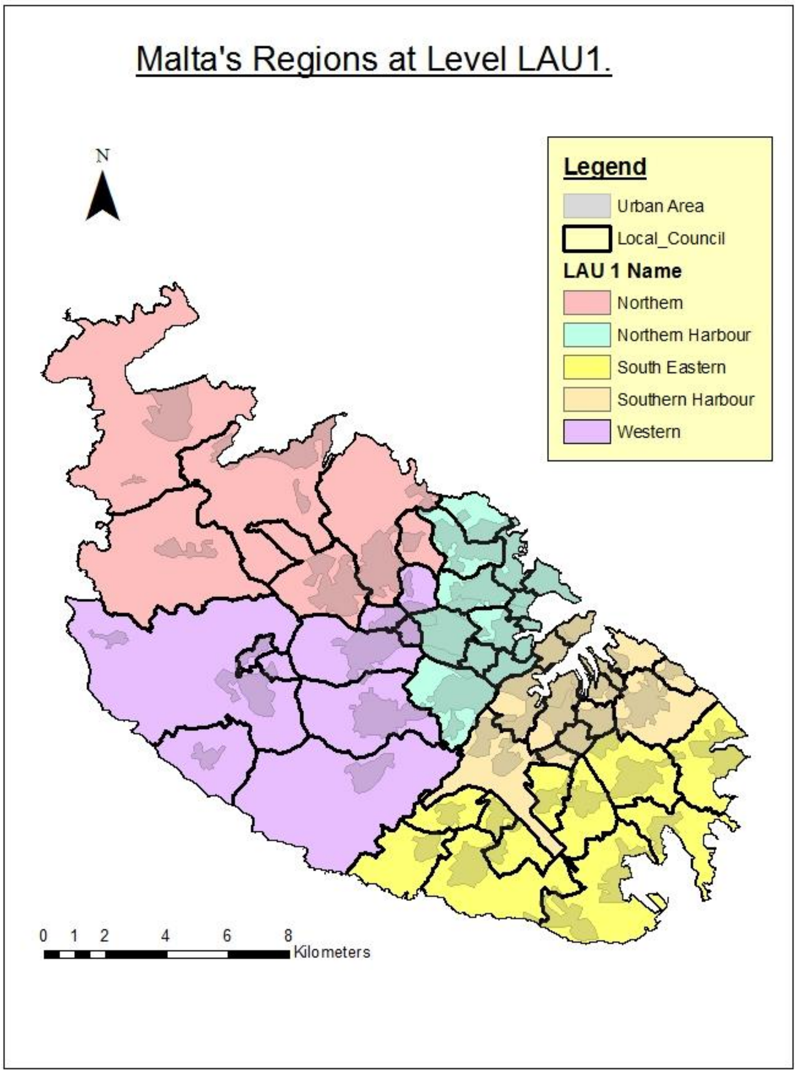

Figure 2: Malta's Regions at Level LAU1.

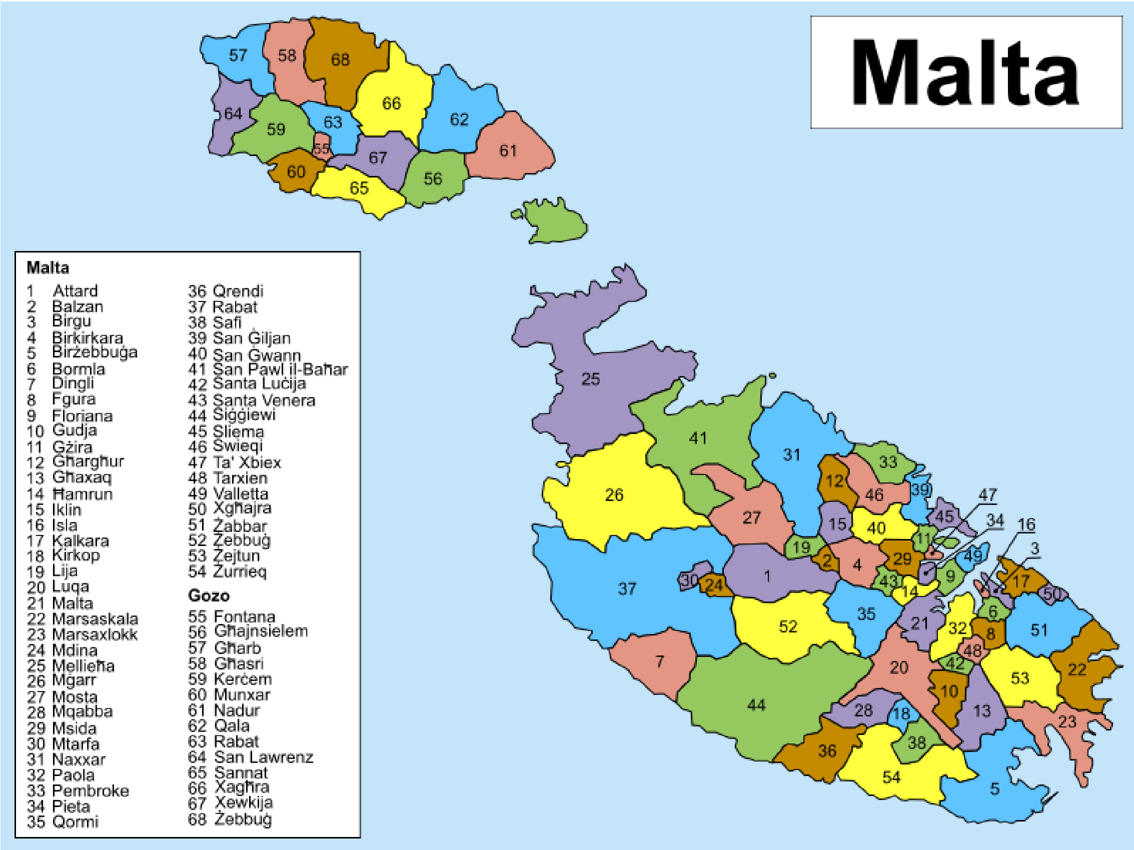

Figure 3: Local Council Areas in Malta (Shazz, 2006: online)

Having a resident population of about 400,000 (Local Councils Act 2014), Malta can be said to be equivalent to a medium-sized city (Nielsen et al.,2005). Malta is one of the most motorised (Fiorello and Zani, 2015) and densely populated countries in the world enjoying a good economic environment and experiencing population growth (Attard et al., 2015). All these factors combined with a lack of land use planning (TM, 2016) have consequently contributed to the state's ever worsening traffic congestion problem ranking it the third worst in the European Union (Attard et al., 2015). Locally, congestion not only negatively effects the economy by increasing the cost of the transportation of goods and reducing the locals' quality of life, it also affects the economy by reducing the tourists' accessibility on whom rests the biggest employment sector in Malta (MITC, 2008). Not immediately noticeable but equally important are also the long term negative impacts on the environment, such as the country's carbon footprint and the presence of respiratory diseases (Childs and Sutton, 2008; Attard et al., 2015).

Despite efforts by various governments to alleviate Malta's congestion problem, for example the introduction of the public transport reform (MITC, 2008) and new traffic management measures such as tidal lanes (Castillo, 2016) and new junctions (Micallef, 2015), traffic congestion still remains one of the country's major problems (TNS–Opinion and Social, 2013; Attard et al., 2015; Illum, 2016). Although the transport reform has managed to reverse the trend of decreasing patronage it is unlikely that this increase is the result of a modal shift (TM, 2016), which in a Maltese context is the most effective way to reduce congestion (Attard et al., 2015).

1.4 Aims and objectives

This thesis tries to build on the work done by Nielsen et al. (2005) by attempting to find the best kind of network design in small, densely populated islands, taking Malta as a case study. Furthermore it proposes a novel network design based on orbital routes and tests its viability.

The aim was achieved by the following objectives:

1) Reviewing the relevant literature on:
    a) How public transport networks are laid.
    b) How public transport networks are measured and assessed.
2) Developing a GIS methodology to assess public networks.

3) Collecting and integrating GIS data.
4) Measuring the accessibility for each network and comparing the results to find the best network design.
5) Critically evaluating the different travel time and accessibility results of the different network models.

1.5 Research Questions

The following research question was formulated to support the aim above:

What is the best network geometry in a small densely populated island state?

Measuring the modal accessibility gap will provide the answer as to which public transport network design is the most suited to compete with the car.

1.6 Thesis Structure

This thesis is divided into five chapters. The first chapter introduces the topic and aim. The second chapter describes in detail the topic to be studied. The third deals with and describes the methodology, while the fourth and the fifth deals with the results, where they are respectively described and discussed. Finally, in the sixth chapter the recommendations are made and conclusions are drawn.

CHAPTER 2

LITERATURE REVIEW

2.1 Public Transport Design

2.1.1. Introduction

Designing a public transport network is an incredibly difficult task (Nielsen et al., 2005; Stone et al., 2010). A planner must not only decide where to lay down the routes themselves but also their mode, frequency, bus stop location and bus stop design (Murray et al., 1998; Nielsen et al., 2005; Mees, 2010; Meng and Qu, 2013; Zhang and Teng, 2013). Furthermore best practice guides on practical network planning are few and far between. The academic community has had more interest in the engineering and economical aspects of public transport networks than its planning aspects (Nielsen et al.,2005; Mees, 2010; Dodson et al., 2011). Although operations research is making advances in public transport network design (Fan and Machemehl, 2006; Desaulniers and Hickman, 2007; Kepaptsoglou and Karlaftis, 2009; Farahani et al., 2013) it still does not considerably aid public transport planners in practice because it does not consider the practical planning principles (Dodson et al., 2011). Despite this, Operations Research has proved its worth in timetabling (Dodson et al., 2011), as experienced, for example, in Zurich's public transport system (Mees, 2010). Furthermore, a public transport planner is surely aided by tools such as SNAMUTS to assess a network (Scheurer and Curtis, 2008) or Remix (Remix, no date) to measure route attributes such as: passenger catchment area, travel time, and operator cost on the fly; making it especially useful during public consultations.

2.1.2. Public Transport Design Hierarchy

Public transport design is divided into three hierarchical levels: strategic, tactical and operational. At the strategic level, the policy of the transport network is set from which the general network design takes shape. At the tactical level, the frequency and the modes of the different lines are set. Finally the rosters and schedules of the personnel and vehicles are set at the operational level (Nielsen et al., 2005; Foletta et al., 2010).

Public transport design is a continuous and circular process. Once a design level is completed does not mean that it is immutable. On the contrary, even after implementation, feedback from the ground should affect all levels of design and these should then be amended accordingly (Nielsen et al., 2005).

2.1.3. Different Designs of Public Transport Networks

Public transport networks are historically laid out in a radial fashion. Radial networks, also known as hub-and-spoke networks, emerge out from urban centres into the hinterland like the spokes of a wheel. A second network typology is the dispersed or multi-destinational network, in which no discernible pattern exists and a “go anywhere to anywhere” approach is taken. The aim of this kind of network is to achieve seamless travel between the different lines, a state called the network effect. The network effect is achieved by conceptualising lines not in isolation but as part of a network in which transfers, although undesirable by travellers are indispensible

(Thompson and Matoff, 2003; Nielsen et al.,2005). Finally, the fish-bone kind of network is something in between the radial and the dispersed network design. It consists of a main trunk through the CBD from which perpendicular lines emerge throughout its length (Liu and Yu, 2012). An example for such a network is Curtiba, in Brazil. Curtiba was designed with public transport in mind and laid out around a main trunk (Mees, 2010).

Although there is no readily available objective statistic by which one can identify whether a public transport network is a radial or dispersed design (Thompson and Matoff, 2003), the dispersed approach is deemed to be more effective, about as efficient and more equitable than the radial approaches (Thompson and Matoff, 2003). By catering mostly to trips from the hinterland to the core, the radial approach manifests a design that requires destinations, other than the CBD, to have highly indirect travel (Thompson and Matoff, 2003) whilst also being highly susceptible to bus bunching (Foletta et al., 2010).

2.1.4. Travel Mode Selection

The two most important factors that affect an individual's decision on mode selection are: the time budget of the individual on one hand and the repercussions of arriving late on the other, hence travel time and travel time reliability. In order for a public transport system to compete with the car it needs to transport people from everywhere to anywhere as fast as possible on time (Lei and Chruch, 2010; Mees, 2010).

This aim has been achieved in Switzerland. The small town of Schaffhausen for example, surpasses even central Brisbane in the sheer number of journeys by public transport per head by about four times (Mees, 2010)! In Zurich, one of the wealthiest cities in the world, public transport does not only have a sizable mode share but has the admirable fact of being one of the few public transport systems in the world that not only has an ever increasing modal share but also enjoys patronage from the wealthier sections of society as well. This enviable result is achieved without imposing moral guilt on the population for not using public transport (Nielsen et al., 2005) and hence Zurich can be regarded as the model city (Mees, 2010).

Although topography may have played a part in Zurich's success, their success is achieved mostly by good planning, specifically by: restrictions on parking, limited supply of road space, prioritisation of public transport vehicles, increased pedestrian areas, good land use density, and urban structure. The result is a public transport system that although comparable with other cities in terms of speed, is not hampered by traffic and thus is able to serve more stops in the same time period as its contemporaries (Nielsen et al., 2005).

The lessons learned from Zurich among other cities has enabled Nielsen et al. (2005) to develop a set of guiding principles to help the public transport planner lay down the routes. After a route network is designed and laid down, its frequency and capacity requirements can then be calculated more precisely using Vuchic's (2005) guidance.

Finally, in public transport literature there is sometimes confusion between the terms "lines" and "route" (Nielsen et al., 2005). In this thesis the definitions by Tarzis and Last (2000 as cited in Nielsen et al., 2005), are adopted. Therefore, lines are defined as the operational element of public transport and route is defined as the physical location through which a vehicle passes.

2.1.5. Principle 1: Low Travel Times.

Travel time is a major consideration when people decide whether to use public transport or not. Therefore every effort must be made to decrease it. To decrease travel time, lines must be as long as possible to avoid transfers even though shorter lines are less susceptible to delays. Longer lines also have the added advantage of being more efficient because they: reduce the total vehicle and driver turnaround times at the end of the lines; lessen the number of lines to administer; and lessen the number of lines to inform the public about. Lines though should be sensitive to market demand and therefore when a demand changes in particular segments of the lines, wherever practical, the vehicle must also be changed (Nielsen et al., 2005).

The total journey time by public transport that a traveller takes is affected by: walking to the bus stop (access time), the number of bus stops on a line until egressing from the vehicle, walking from the bus stop (egress time) and the total journey length. Conversely, the speed of travel of the public transport vehicle itself depends on: the distance between stops; the maximum speed of operation on the lines; the rate of acceleration and the rate of deceleration at the stops. Increasing the operational speed has an added advantage of lowering the number of vehicles required to perform at the same frequency, thereby reducing costs (Nielsen et al., 2005).

In order for operations to be sped up, it is imperative that public transport vehicles have priority treatment**,** not only in road planning but also in traffic management measures such as; priority systems at traffic lights, control of priority lanes and signals; ticketing systems; location and distance between stops; bus stop design and vehicle design. Although infrastructure may need to be adopted to cater for public transport there is usually no need for very expensive infrastructures such as underground systems (Nielsen et al., 2005).

2.1.6. Principle 2: Simple and Stable Design

A public transport network is best designed to remain stable over time so that it may influence land use development around it. It must not be "tailor-made" to specific markets but "ready-to-use" from anywhere to anywhere (figure 4) (Nielsen et al., 2005). The design must also be flexible enough to be able to adapt to the demand. For the system to be as efficient as possible, and thus more competitive, travellers need to be directed onto the main corridors by making use of transfers. The need for efficiency therefore conflicts with the need to provide public transport access everywhere as a social commitment (Nielsen et al., 2005) and the need to reduce access walking time (Kornelsen, 2015). Furthermore transfers are a disincentive for travellers, especially because they have to wait, though in practice a complicated system with direct lines requires much more planning effort and planning time (figure 5) (Nielsen et al., 2005). Hence a public transport system that manages to reduce the discomforts of transfers whilst making use of them is the more desirable one.

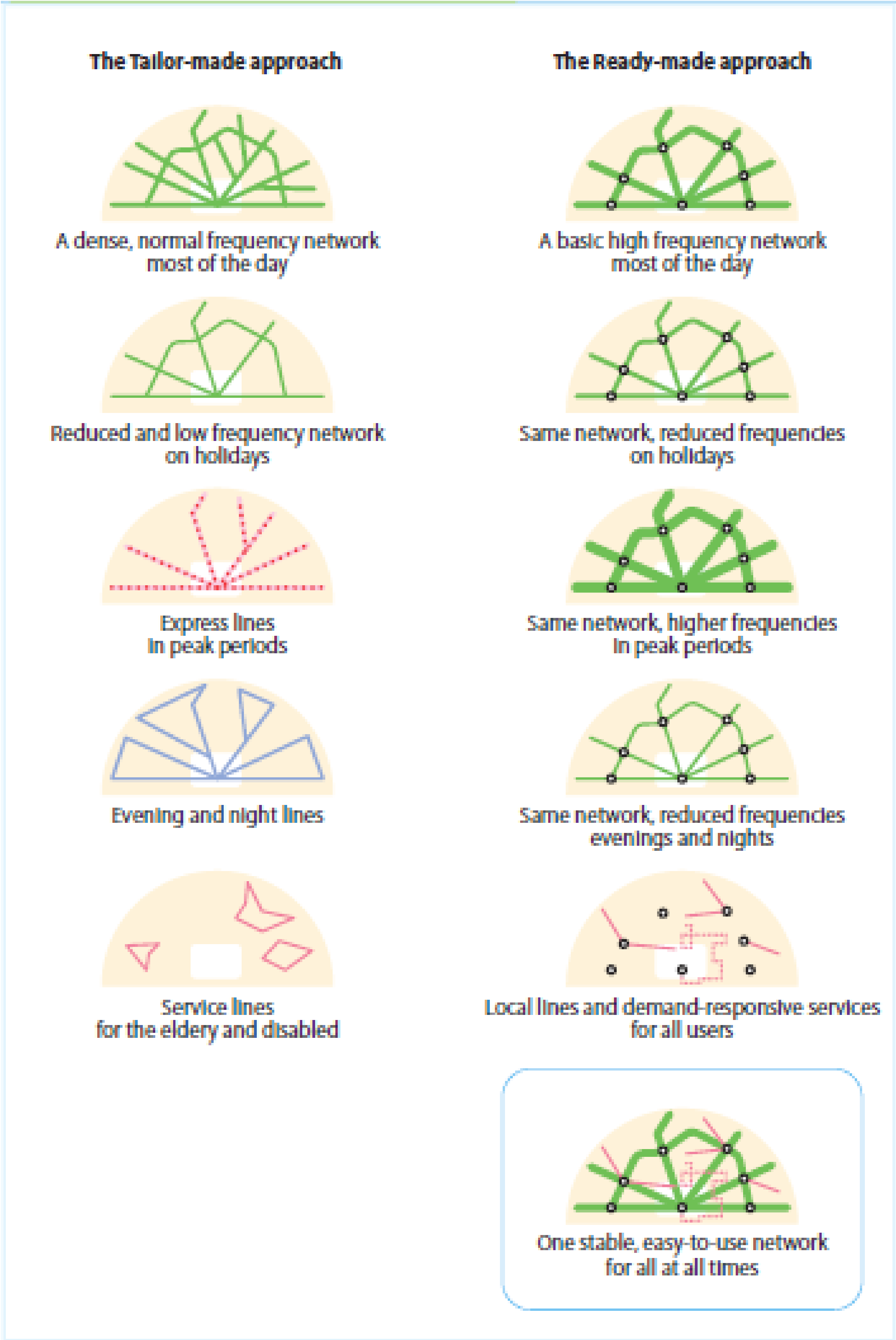

Figure 4: Tailor-made Networks against Ready-made Networks (Nielsen et al., 2005: 35)

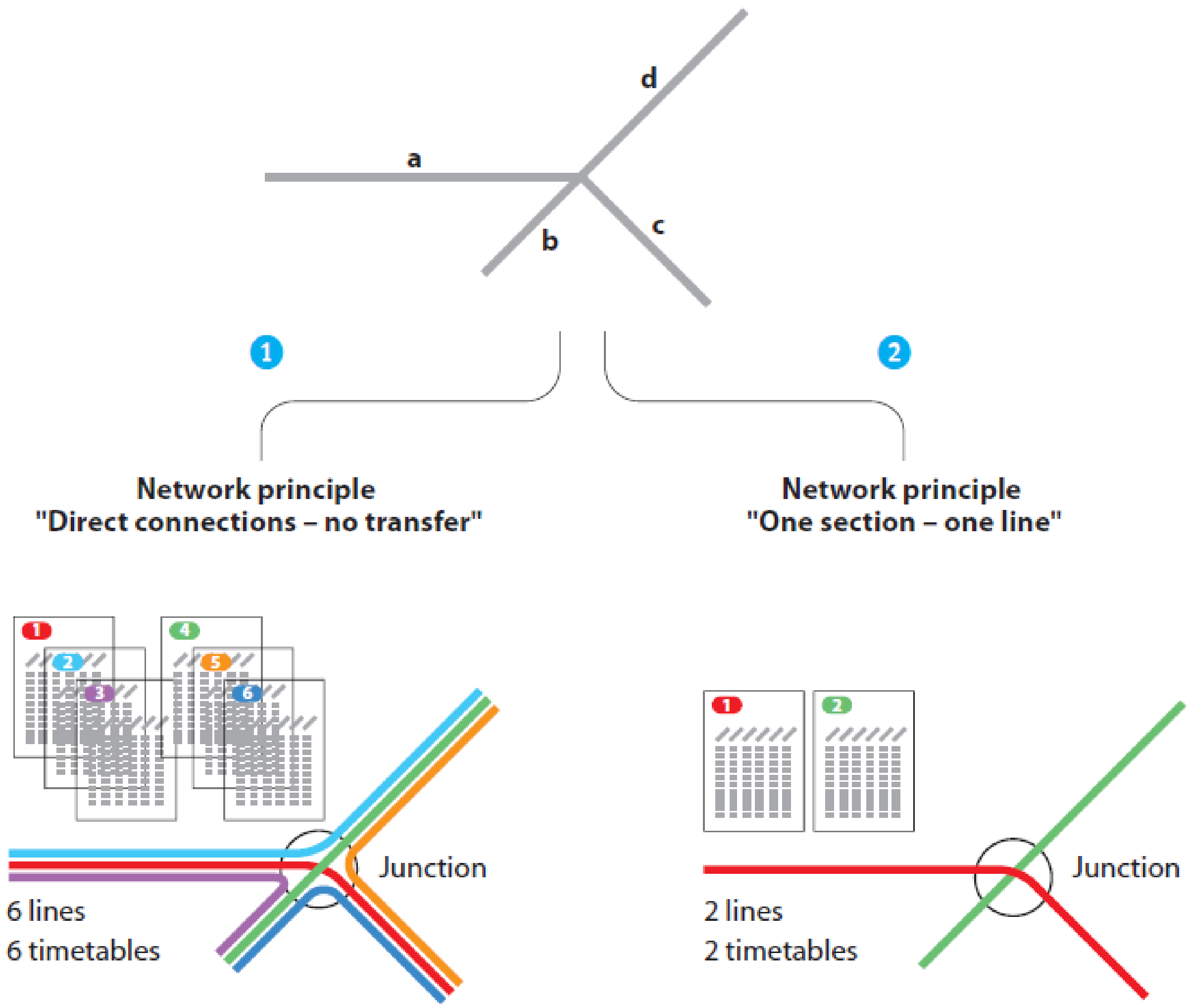

Figure 5: One Section - One Line (Nielsen et al., 2004: 107)

A public transport network should be conceived like a road network, with some parts capable of handling high demand at high speed and others acting as feeders to the main arteries (Nielsen et al., 2005). Stability in the design is achieved when it contains the least number of lines as possible. Having as small number of lines as possible is also desirable because it makes the service easier to market, be remembered and be perceived by the travellers while also simpler to plan and operate by the provider (Nielsen et al., 2005). A stable system reduces the risk of bus bunching or convoying; that is, buses servicing the same line arriving at a bus stop at the same time (Nielsen et al., 2005). Bus bunching increases the risk of congestion (Nielsen et al., 2005; Foletta et al., 2010), delays buses at the bus stops and confuses the traveller on discerning which vehicle he has to board at a bus stop. Stability therefore requires the important principle of the "one section – one line" which demands that as much as possible an area is served by only one line. Flexibility and wide reach are then achieved by the provision of supplementary lines to the main trunk. These supplementary lines may not only consist of scheduled public transport services but also of other modes, such as taxis, demand-responsive services (Nielsen et al., 2005) and bicycles (Martens, 2004; Martens, 2007).

Trunk corridors need to be: simple and with a clear line structure; fast and with direct priority lanes. They need to have simple timetables and reliable operations; high frequency services over most part of the day; real time table information on bus stops and on vehicles; high profile lines through the design of stops and vehicles, information, signs and simple network maps. Furthermore vehicles operating on these lines need to have a high level of comfort, ample capacity and be low floored. In order to increase comfort and reduce stopping time, they need to have simple ticketing systems. Finally the interchanges at the trunk lines need to be both efficient and have a pleasant environment with low levels of air and noise pollution (Nielsen et al., 2005).

Finally, the route alignment can make the difference between the failure and success of a system. Lines must preferably go through the service areas in a direct fashion with no meandering. They should follow the natural direction of travel in the serviced area thereby improving the chance of travel without transfer and avoiding servicing the same catchment areas (figure 6) (Nielsen et al., 2005).

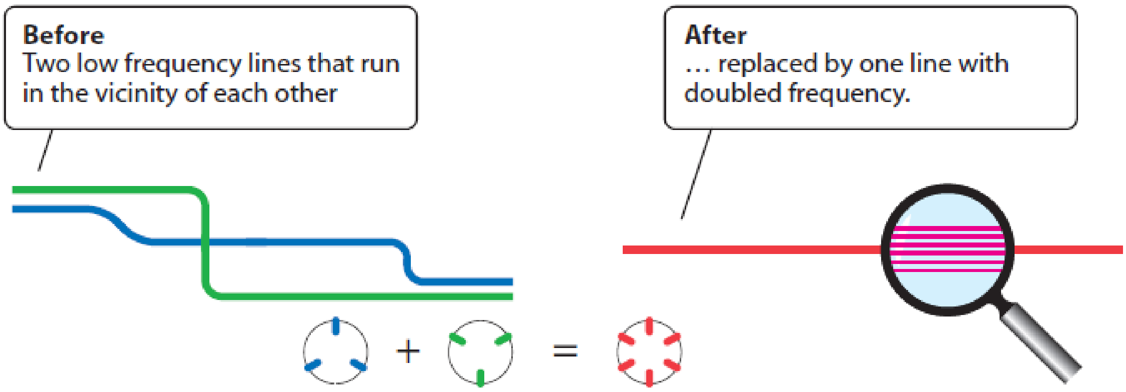

Figure 6: Rationalisation of Lines (Nielsen et al., 2005: 105)

2.1.7. Principle 3. Frequency

Frequency is determined by market analysis and optimised by experience of the daily running of the system. A robust network design implies that the same line would still be used but its frequency may change according to the demand during the time of the day (Nielsen et al., 2005).

Public transport providers are always under pressure to provide higher frequencies even though increasing the frequency does not gather a proportional amount of profits. Furthermore, what frequency is acceptable differs between different locations depending on what the public has been used to. To be competitive with the car, public transport lines need to have lines with at most 15 minute headways. The network effect is reached when all lines are high in frequency. This level of frequency is not economically viable in low density areas, so timetable co-ordination is a crucial alternative if the network effect is to still be achieved there (Nielsen et al., 2005).

2.2. Accessibility

2.2.1. Definitions

Public transport design is best assessed through the concept of accessibility (Neutens et al., 2012). Although accessibility may seem a simple concept, it is in fact a multi-faceted concept (Vandenbulcke et al., 2009; Curl et al., 2011) to which a plethora of definitions have been made (Dong et al., 2006) and which consequently have made it hard for accessibility to be defined (Popper and Hoel, 1976; Geurs and van Vee, 2004; Yigitcanlar et al., 2007; Lei and Chruch, 2010; Liu and Yu, 2012) and therefore confusing to measure (Dong et al., 2006, Vandenbulcke et al., 2009; Curl et al., 2011) and apply in practice (Halden, 2011). Accessibility has been defined as: the ease of reaching a needed or desired activity (Morris et al., 1979; Yigitcanlar et al., 2007; Litman, 2011); the suitability for a public transport network to get individuals from their system entry point to the system exit location in a reasonable amount of time (Murray et al., 1998); or the potential of interaction for opportunities (Hansen, 1979). Accessibility has also been defined as the what and how can be reached from a given point in space (Thériault et al., 2004; Bertolini et al., 2005) after impedances such as travel time or cost have been deducted (Bertolini et al., 2005).

Analysing accessibility from an origin perspective is called origin-based accessibility whereas analysing it from a destination perspective is called destination-based accessibility (Halden, 2011). Areas that are not accessible are deemed to be peripheral (Kotavaara et al., 2012) or remote (Nutley, 2003). This is usually taken at more than 30 minutes of travel time and thus remoteness is dependent more on travel time than distance (Vandebulcke et al., 2009). Hence, a location may be remote by a mode but not by another.

The literature is also plagued by vagueness of the definitions themselves. For example the term “ease” is hard to quantify and likely varies from individual to individual (Dong et al., 2006). Likewise the same problems arise with other terms such as “need”, “choice” and “reasonable” (Halden, 2011). Access and accessibility although used indiscriminately in the literature (Geurs and van Vee, 2004) should be kept as two separate terms, access meaning accessibility from a person perspective whilst accessibility having a location perspective (Geurs and van Vee, 2004).

2.2.2. Interplay of Mobility and Accessibility

Accessibility is not to be confused with mobility either, which is defined as the ease with which one can interact with the environment (Popper and Hoel, 1976) or the ability of individuals to travel (Morris et al., 1979; Farber et al., 2014). Mobility is concerned with the characteristics of the transport system itself (Scheurer and Curtis, 2007) and is measured in terms of car ownership, physical disabilities, vehicle km, vehicle occupancy, passenger km or speed of travel (Litman, 2011). Mobility can thus be said to be the potential for movement, the ability to get from one place to another whereas accessibility is the potential for interaction among the different and distributed urban activities (Handy, 2002, cited in Bonotti et al., 2015)

Maldague et al., (2015) dissect accessibility into three components: the location of origins and destinations, the socio-economic profile of travellers and the impedance needed to be overcome for the trip to be completed. Accessibility is therefore dependent on: the qualities of the transport system; the impedance to reach the destinations; and the quality of destinations offered themselves (Handy and Niemeier, 1997). Hence, accessibility is the marriage between the transport system with the land use pattern (Geurs and van Vee, 2004; Bertolini et al., 2005; Scheurer and Curtis, 2007; Straatmeier, 2008). Accessibility is also described as the performance of the transport system according to individual choices, and therefore requires both a transport and an individual perspective (Liu and Yu, 2012). In practice, the land use system is assessed through functional land use densities and mixes whereas the transport system is assessed mainly through travel time (Bertolini et al., 2005).

The goal of any transport system is therefore not for people to travel per se, (mobility), but for people to access a destination, (accessibility) (O'Sullivan, 2000; Bertolini et al., 2005; Straatmeier, 2008; Benenson et al., 2011; Halden, 2011; Litman, 2011). The realisation therefore that an increase in mobility does not equate to an increase in accessibility (SAMP, 2005, cited in Halden, 2011) has led to a change in transport planning perspective. The aim is no longer to provide vehicular mobility but to provide personal accessibility (Morris et al., 1979; Curtis and Scheurer, 2012). Rather than concentrate solely on the efficiency of automobile-related infrastructure a better perspective is to keep in mind the need for interaction that people have (Straatmeier, 2008).This does not mean that mobility is to be ignored, but rather that it must be kept in context in so far that mobility is the function by which accessibility by physical means, physical accessibility, is achieved (Popper and Hoel, 1976; Halden, 2011; Curl et al., 2011). Thus by making use of ICT, accessibility may still be achieved even though no physical travelling is made by enabling virtual interaction (Shen, 1998; Halden, 2011), hence virtual accessibility.

Virtual accessibility will never entirely replace physical accessibility though because there is always a need for people to interact physically (O' Sullivan, 2000). Finally it must be recognised that a person's accessibility level may be enhanced by social contacts, for example by gaining a lift. This is defined as indirect accessibility (Curtis and Scheurer, 2010).

The concept of accessibility in urban planning therefore emphasises the importance of the transport infrastructure over the spatial separation between origins and destinations, making travel time a more crucial component than physical separation (Gutiérrez et al., 1996). Consequently, physical accessibility is strongly affected by the design of the infrastructure and land use planning (Yigitcanlar et al., 2007), even though land use itself is not of a crucial factor in the success of public transport systems (Thompson and Matoff, 2003)

This change in approach from vehicular mobility to personal mobility has led to the concept of New Urbanism, in which the primary mode of travel is shifted from the car to public transport systems. All urban planning is therefore done in such a way as to induce a modal shift away from the car (Zhang, 2005).

Accessibility is closely related with mobility, economic development, social development and environmental impact (Gutiérrez et al., 2010). The relationship between the transportation system available and locations of origins and destinations is important because it affects a household's decision on: how many cars to own and how many trips to make to how many destinations by which mode (Burns and Golob, 1976). Depending on the function and scope of relationships, different actors want access to different spatially dispersed resources at different geographic scales (Straatmeier, 2008). Consequently urban planning, defined as the planning of the location of services and the transport network itself (Murray et al., 1998) and accessibility planning, defined as the provision of more opportunities with less mobility (Straatmeier,2008) using the same time budget (Bonotti et al., 2015), is immensely important because it increases the quality of life of the inhabitants (Vandebulcke et al., 2009; Karou and Hull, 2014). The concept of sustainable accessibility (Vega, 2011) further emphasises the primacy of the efficient use of resources for the benefit of the economy, the environment and quality of life (Bertolini et al., 2005)

In this thesis accessibility is defined as the ease of interaction between a person and an opportunity by physical means, mobility is defined as the ability of a person to participate in an opportunity whilst access is defined as the ability of a person to enter a vehicle or building.

2.2.3. Geurs and van Vee's (2004) Different Components of Accessibility

Geurs and van Vee (2004) describe accessibility as consisting of four components: transport, land use, time and individual.

The transport component consists of the characteristics of the transportation system, described as the "disutility for an individual to cover the distance between origin and destination using a specific transport mode." (Geurs and van Vee, 2004:128). The transport component takes into consideration that a journey whether for people or for freight, consists of: travel time; monetary costs; and effort expressed as the level of comfort or security among others (Geurs and van Vee, 2004).

The land use component describes the land use system: the amount, quality and spatial distribution of the opportunities, the demand for these opportunities at the point of origin and any competition between consumers of the land use activity that may exist (Geurs and van Vee, 2004).

The temporal component deals with the temporal constraints on the journey. These are the travel budget of a person and the varying availability of opportunities according to the time of day (Geurs and van Vee, 2004).

The final component, the individual component consists of the needs, abilities and opportunities that vary between any given individual in a society according to age, income, gender and physical ability among others (Geurs and van Vee, 2004).

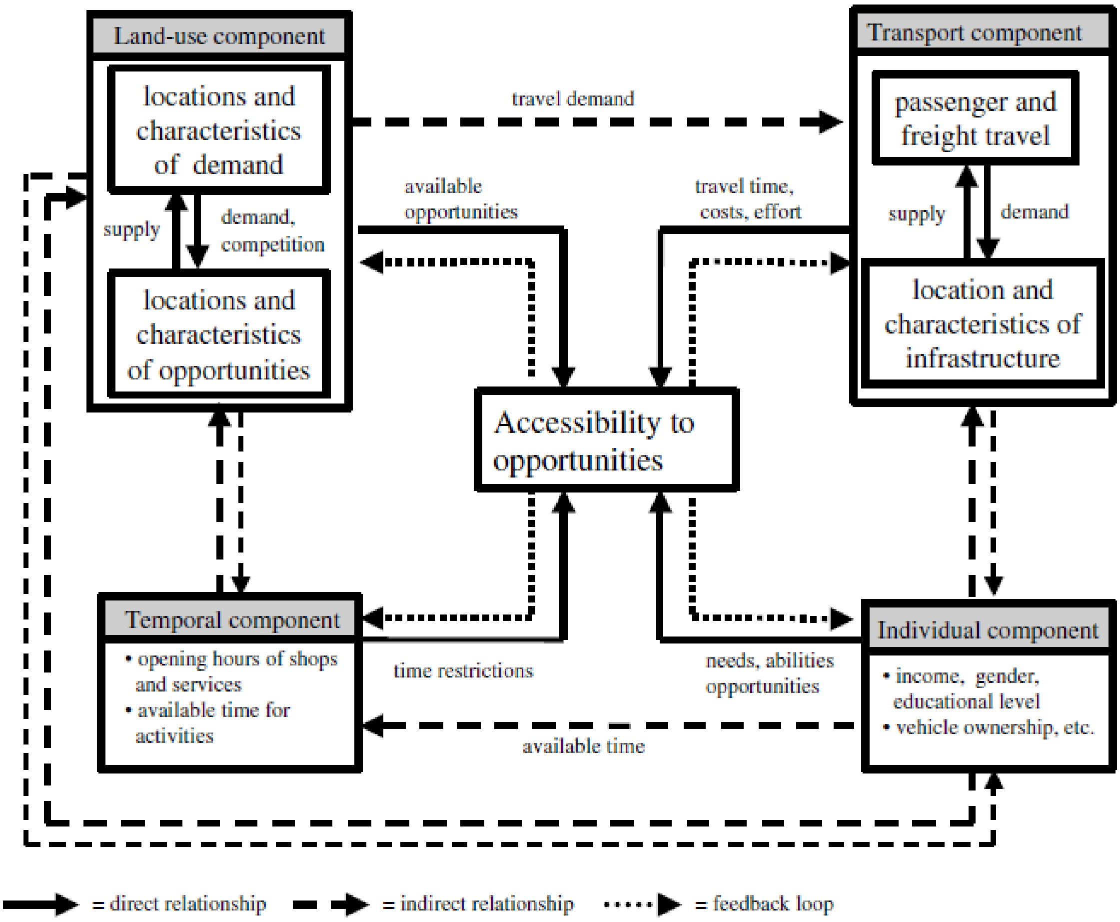

Figure 7: Components of Accessibility (Geurs and van Vee, 2004: 129)

2.2.4. Accessibility Measures

'... you can't manage what you can't measure' (Litman, 2011:2). What data is measured, how the data is measured, and how data is presented influences the problem evaluation process and the problem solution (Litman, 2011). These notions have to be kept in mind whenever accessibility is measured especially since different accessibility measures will give different results according to the definition and perspective of the measure (Van Vee et al., 2001; Vandebulcke et al., 2009). Furthermore results may be effected by the time of day, geographical scale and reliability of the transport system (Hodge, 1997). Moreover, just as accessibility is not a replacement of mobility, accessibility tools do not replace traditional transport models. Accessibility tools are better suited for strategic planning whereas transport tools are better suited for operative and capacity planning of the transport infrastructure (Curtis and Scheurer, 2010; Litman, 2011).

Just like the definition of accessibility there are also many different accessibility measures that assess the feedback effects between the transport system and the modal participation with the land use patterns and the spatial distribution of activities. Some accessibility measures also include behavioural determinants for space and time and the responses of transport users to these physical conditions (Scheurer and Curtis, 2007).

There is currently no single perfect accessibility measurement that is able to measure all the components of accessibility at the same time. On the contrary accessibility measurements usually investigate only a single aspect of accessibility not least because of data limitations (Geurs and van Vee, 2004) and thus the aim of the project determines which measure is to be selected (Handy and Niemeier, 1997). On the other hand, accessibility measures will never be able to measure real life accessibility, no matter how complex the measure is. This is because a model will never be able to capture a person's complex activity patterns and other softer barriers such as, low travel horizons, cognitive mapping abilities and mental mapping abilities. These parameters are by far a more decisive factor on a person's travel mode selection than simple distance or travel time to opportunities. This does not mean that time or distance are irrelevant, they just need to be taken into context (Curtl et al., 2011).

Accessibility measures need to be: meaningful, meaning that they can be used by decision makers (Bertolini et al., 2005); accurate, meaning that they are based on verifiable, easy-to-obtain data; and legible, meaning easy to understand (Curtis and Scheurer, 2010). In practice there is still confusion on what is explicit and what is implicit for each type of measure (Halden, 2011). Although even simple accessibility measures could be useful to support decisions taken by politicians and decision makers (Vandebulcke et al., 2009), accessibility measures have in practice become more complex (Straatmeier, 2008) especially when different modes are taken into consideration (Hodge, 1997).

Many different categories of accessibility measures have been created. Handy and Niemeier (1997) divide accessibility measures into three types: those that measure by isochrones, those that are gravity-based, and those that are utility-based, that is by personal perspective. Lei and Church (2010) divide accessibility measures into six categories ranging from regional to local accessibility, from space-time geography to utility theory and relative accessibility. Geurs and van Vee (2004) build upon their components from which four types of accessibility measures are derived (table 1).

Scheurer and Curtis (2007) elaborate on Geurs and van Vee's (2004) classification, adding three more categories (table 2). In accessibility studies, place-based accessibility measures are overwhelmingly favoured in the literature(Neutens et al., 2012) because they give valuable insights with relatively little data collection; are easy to implement using GIS and are easy to interpret (Geurs and van Vee, 2004). Their limitations though include their disregard for accessibility fluctuations during the day and different mobility patterns that every individual or social group has. The latter can be corrected for though by conducting activity travel diary surveys (Neutens et al., 2012).

Table 1: Accessibility Measure Classification according to Geurs and van Vee (2004)

ACCESSIBILITY MEASURE	MEASUREMENT	USE	PROS AND CONS
Infrastructure-based	Analyze the performance of the infrastructure, eg. average travel speed, level of congestion, etc.	Transport planning	• Very easy to interpret • Disregard land use component
Location-based	Analyze the number of activities that may be reached from a given location. They can be measured by contours or gravity models.	Urban planners and geography studies.	Very easy to interpret Data is easily available Do not take the effect of transport and land use on each other. Do not take into account an individual's different preferences and perceptions Do not take competition effects into account.
Person-based	Analyze the limitations that time imposes on the person. Is	Space-time research	Satisfy all theoretical criteria Hard to collect data

	measured by space-time models.		Hard to interpret the data Applications restricted to a small geographical area and subset of the population in it.
Utility-based	Analyze the economic benefits that an individual gains from accessing a service	Economic evaluations	Satisfy most of the theoretical criteria Difficulty in interpreting the data.

Table 2: Accessibility Measure Classification according to Scheurer and Curtis (2007: 10)

MEASURE	METHODOLOGICAL CATEGORY	APPROACH	PROS AND CONS
Spatial Separation Measures	Spatial Separation Model Infrastructure Measures Travel Cost Approach	Measures travel impedance or resistance between nodes. Eg. Physical (Euclidean) Distance Network Distance (by mode) Travel Time (by mode) Travel Time (by network status – congestion etc.) Travel Cost (variable user cost or total social cost) Service Quality (eg. public transport frequency).	Data is easily available. No consideration of land use patterns and spatial distribution of opportunities.

Contour Measures	Contour Measures Cumulative Opportunity Measures	Defines catchment areas by drawing one of more travel time contours around a node and measures the number of opportunities within each contour (eg. Number of jobs etc).	Incorporates land use and infrastructure constraints by using travel time as indicator of impediment. Definition of contours may be arbitrary and does not differentiate between activities and travel purpose. Methodology cannot capture variation within each contour.
Gravity Measures	Gravity Model Potential Accessibility Measure	Defines catchment areas by measuring travel impediment on a continuous scale.	More accurate representation of accessibility measures than contour measures but tends to be less legible. Does not differentiate between travel purposes and individual drivers for travel.
Competition Measures	Competition Measures Joseph and Bantock Measure Inverse Balancing Factor Model	Incorporates capacity constraints of activities and users. May make use of the preceding three models.	Provides a regional perspective on accessibility.

Time-Space Measures	Time-Space Measures Person-based Measures	Measures opportunities with pre-defined time constraints.	Well suited to examine trip chaining and spatial clustering of activities. Usually requires project specific user surveys, limiting the geographical range and compatibility of data.
Utility Measures	Utility Measures Utility Surplus Approach	Measures individual and societal benefits of accessibility Economic utility (to the individual or community) Social or environmental benefits (eg. social inclusion, greenhouse emissions etc.) Individual motivations of travel (by activity or travel purpose). Option and non-user benefits of transport infrastructure.	The empirical link between infrastructure provision and economic performance is tenuous and contested. The indicator can analyse existing motivations of travel, but cannot anticipate feedback effects between land use and travel patterns, or future travel behaviour patterns of users.

Network Measures	Multiple Centrality Assessment	Measures centrality across entire movement networks. Networks can be represented by the: Primal approach (networks are understood as intersections connected by route segments). Dual approach (networks are understood as route segments connected by intersections).	More intuitive and, and allows for the incorporation of a travel impediment measure in the network analysis. Clearly captures the topological form of a network, and can be used to assess its spatial legibility.

CHAPTER 3

DATA AND METHODS

3.1. GIS in Accessibility Studies

The use of GIS in accessibility planning and modelling has experienced a recent upsurge (Vandebulcke et al., 2009) to become a crucial tool in this field (Lei and Church, 2010; Bonotti et al., 2015). GIS is well suited to investigate accessibility (O' Sullivan, 2000) because it is both interactive and able to perform calculations rapidly (Ford et al., 2015). GIS is also good at combining, analysing and visualising different layers of information (Wu and Hine, 2003 cited in Vandebulcke et al., 2009). Visualisation is important because it can significantly enhance the user's understanding of the results (Curtis and Scheurer, 2010). Accessibility is better measured by a GIS than standalone accessibility tools because it is easier for non-specialists and decision-makers to interact with the data. Furthermore accessibility tools may be integrated with other built-in features of GIS such as geostatistical analysis tools (Ford et al., 2015).

3.2. Limitations in the Field

In accessibility analysis an ubiquitous major methodological challenge is to find the right balance between a measurement which is theoretically sound and one which is sufficiently simple to use and understand (Bertolini et al., 2005; Vandebulcke et al., 2009). Although many models exist, many have not been used by traffic planners in practice because they are too complicated, too simple or too incomprehensible (Karou and Hull, 2014). Data limitations, and the difficulty in modelling people's adaptability and travel scenarios call for measures to be as simple as possible (Benenson et al., 2011). Another challenge is on whether to use correct data or precise data (Litman, 2011). The aim of the project is therefore the deciding factor on how to strike these balances (O' Sullivan, 2000; Halden, 2011).

When deciding on which accessibility measure to consider, it is best to keep in mind four interrelated issues that are to be taken into consideration: degree and type of disaggregation, whether spatial, socio-economic, purpose of trip, or activity are considered; how origins and destinations are defined; the impedance to be considered; and the attractiveness of destinations (Handy and Niemeier, 1997)

The different approaches to accessibility has led to disagreements on how to measure accessibility (Scheurer and Curtis, 2007; Lei and Church, 2010), if real life accessibility can be measured at all (Weber, 2006; Halden, 2011). Although the trend is for more complex measures to be used, complexity increases the difficulty of interpretation. Geurs and van Vee (2014) therefore propose that a scenario should have its accessibility level measured from the different accessibility components in isolation (Litman, 2011), for example the SNAPTA model (Karou and Hull, 2014). Another limitation in accessibility studies is the lack of appreciation of the effects of aggregation of data. There is currently a lack of understanding on how the dependence of scale and accessibility work and the effects of competition within these aggregations (Bertolini et al., 2005). Although aggregation may be used in cases when opportunities cannot be disaggregated (Halden, 2011), whenever possible disaggregation is to be preferred (Vandebulcke et al., 2009) because of both the increase in detail and the less probable a chance of self-potential in the results (Gutiérrez et al., 2010). Finally, trends may seem to be robust at a specific scale but may in fact contain fallacies because of a wrong scale used in the analysis (Kotavaara et al., 2012).

In public transport accessibility analysis there exists a lack of consideration to: the pedsheds, actual geography of pedestrian network (Scheurer and Curtis, 2007); the walking environment itself, especially its topography and design (Yigitcanlar et al., 2007; Maldague et al., 2015). There is also a lack of recognition that desirable higher transit speeds are determined by such factors as: congestion (Maldague et al., 2015), traffic priority, vehicle performance, boarding procedures and alongside stop spacing among others (Scheurer and Curtis, 2007). Finally whilst single origin-destination public transport accessibility has been extensively studied (Morrison and Shearer, 2000 cited in Farber et al., 2014; Lei and Church, 2010, cited in Farber et al., 2014) multiple origins to multiple destinations have been left out (Farber et al., 2014).

When displaying catchment area results there is a tendency for accessibility to be conceptualised in a binary sense. In real life, accessibility is more of a continuum adjusted per individual (Scheurer and Curtis, 2007; Widener et al., 2013) and thus the limits of a result should be considered more as a benchmark to compare the different scenarios rather than a hard-and-fast rule on what individuals will actually decide to do (Bertolini et al., 2005).

Finally there is a need for a broad enough view of all transport and communications options to reflect all aspects of modal choice, telecommunications and quality in terms of speed, cost, prestige, security and comfort to be considered when conducting accessibility analysis (Halden, 2011).

3.2. Data Acquisition

The method is described in the workflow diagram in figure 8. Data availability is a major concern of any project and its acquisition consumes most part of any project (Yigitcanlar et al., 2007). Accurate results depend on the detail and quality of input data (Zhu et al., 2005 as cited in Yigitcanlar et al., 2007) though data that is precise enough is usually hard to come by (Holl, 2007).

For the purpose of this thesis, road data containing speed limit, one way and overpass information was downloaded from Openstreetmap and used directly in ArcGIS 10.2. Unfortunately its attributes were in a format that was not recognised by the ArcGIS Network Wizard and therefore these were manually modified. Openstreetmap has been used in other works for example in Ford et al., (2015) and though it can be well suited to accessibility analysis it may still have to undergo some form of data preparation (Hacklay, 2010; Maldague et al., 2015; Loidl et al., 2016). The analysis was done at two scales. A fine scale was used to calculate the absolute travel time and a coarser scale at local council level was taken to include population data.

The destination data were determined by considering five kinds of destinations: communications, health, industry, leisure and residential (figure 10). The most prevalent were residential areas which were symbolised by parish churches. Parish churches were considered as proxy for residential areas since parishes were in general formed in proportion to the size of a settlement. Thus settlements like Ħal Qormi and Birkirkara had two parishes due to their large size even though they both have a single local council each. Parish churches were also selected as destinations because they were the locations around which settlements

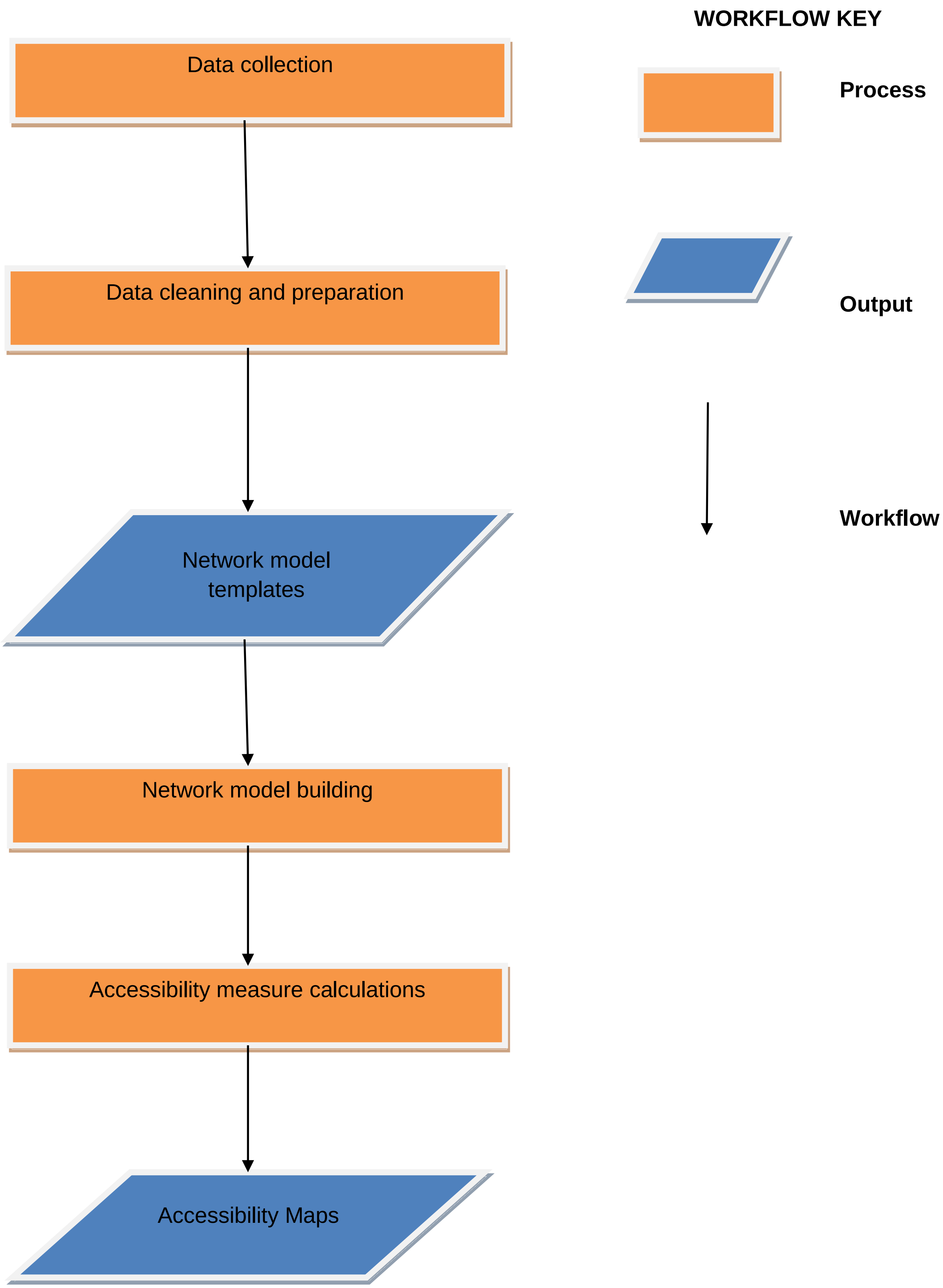

Figure 8: Workflow Diagram

historically grew. Finally parish churches were selected because their large size and shape made them very easy to discern on aerial photographs (figure 9). Although residential areas covered much of the island, other important destinations were deemed not to be represented adequately enough. These destinations such as the national hospital (health), the airport (communications), Ċirkewwa Ferry Terminal (communications) and Ħal Far Industrial Estate (Industrial) were added. The last type of destinations added were locations of purely recreational value, for example Golden Bay and Mellieħa Bay.

Figure 9: Zabbar Parish Church

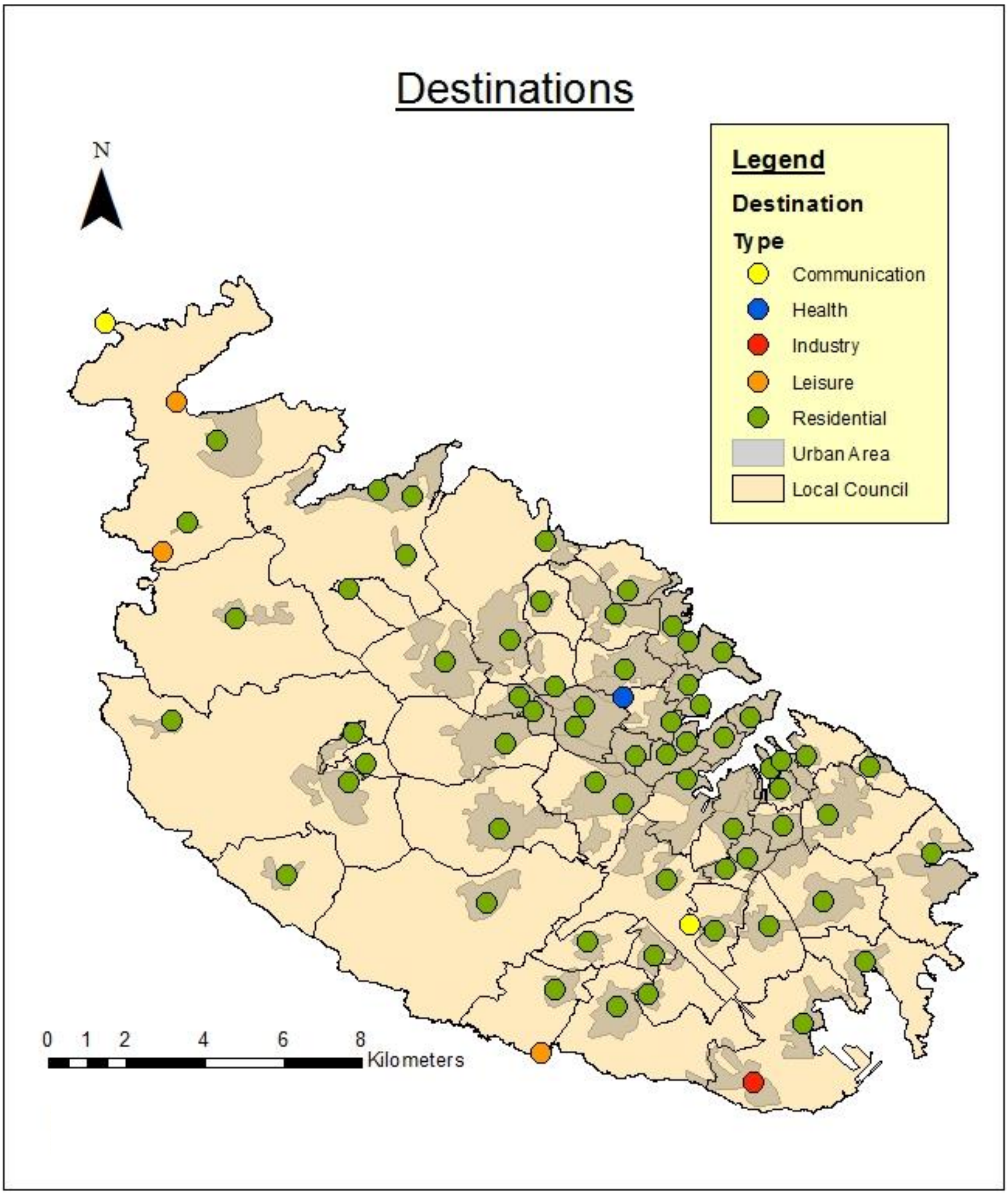

Figure 10: Map of the Selected Destinations

The origin set was made up of two sets (figure 11), an urban set at 250m interval, as found by Salonen and Toivonen (2013) to be a satisfactory compromise between aggregation and data volume, and a rural data set at 1km interval. In rural areas the spatial interval was increased to reduce the table size. The origin points were created by using the Create Fishnet tool in ArcGIS. Origin points on the hospital, university, airport and freeport were deleted except for their entrances. At the local council level, parish churches were used as the points of origin for the same reason that they were used as proxies for destinations at the fine scales.

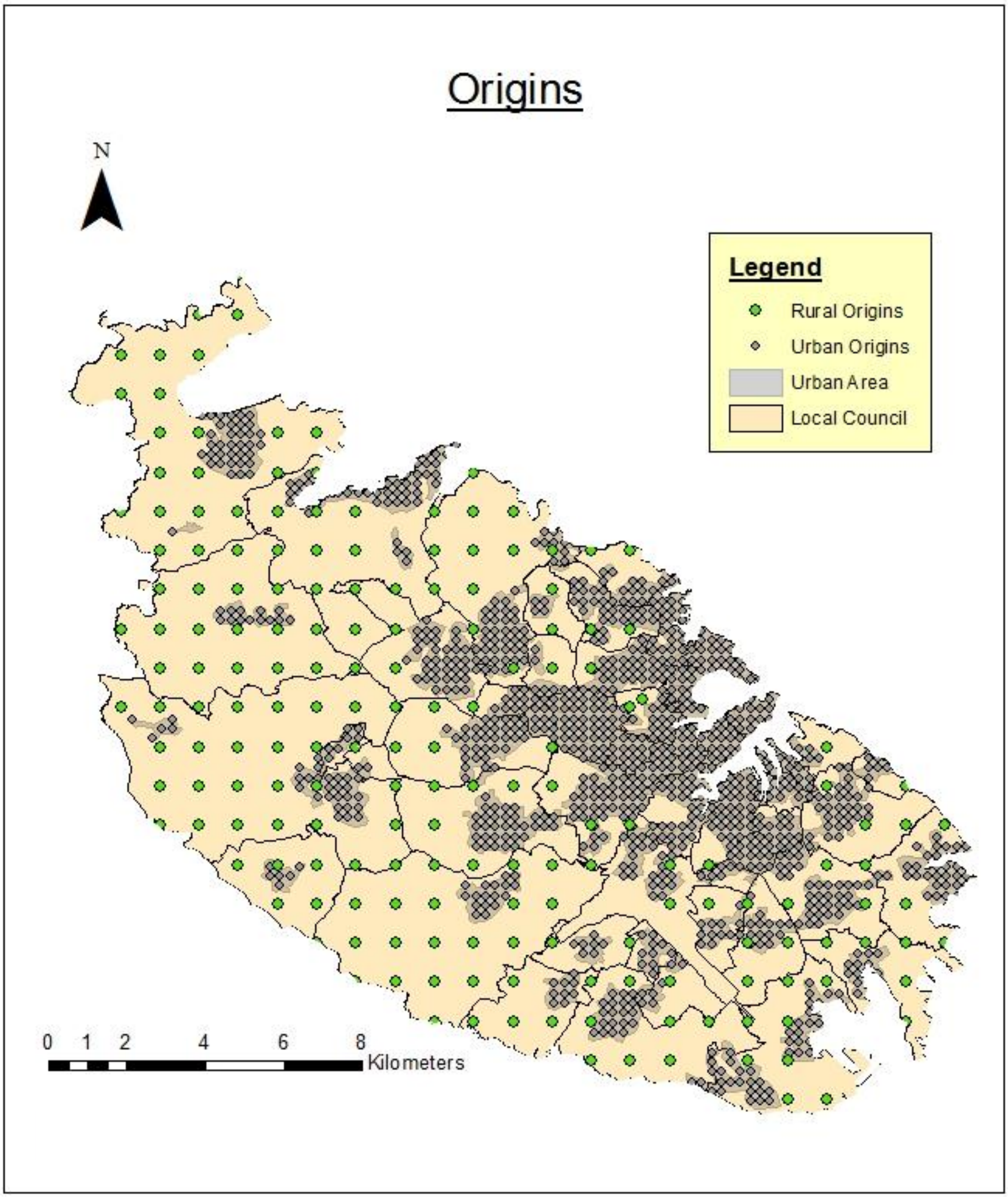

Figure 11: Map of the Selected Origins

Local council jurisdiction and urban areas data were downloaded from the MITA (2017) geoportal to which the two industrial areas of Mrieħel and San Ġwann, the university, hospital, airport and Freeport were all subsequently manually added. The estimated population levels for each local council area were taken from the Local Councils Act 2014. The digitised road data was downloaded from Openstreetmap on October 2016 (table 3).

Table 3: Acquisition of Data

DATASET	DERIVED FROM
Origins at fine scale	ArcGIS Fishnet tool
Origins at local council scale	Digitised
Destinations	Digitised
Local Council Areas	MITA Geoportal
Population per each local council	Local Councils Act 2014
Road Data	Openstreetmap

3.3 Data Preparation

To make the Openstreetmap attribute data recognisable by the ArcGIS Network Analyst Wizard, attribute data containing one way information was modified from “0” and “1” to “F” and “T”. To determine the accuracy of one way information of the data, Google Maps (Google, 2016) were used. The information was inferred from noticing the streets markings on the road and the direction cars were parked at. In dubious cases, the ESRI Streets Basemap and the ESRI Aerial Photograph

Basemap were used to help infer the flow direction of an edge. Although in this exercise, the author tried to get as accurate a representation of reality as possible, it was not deemed a crucial objective since the aim of the thesis is to find the differences between the networks in a given environment rather than to find the best network specifically for Malta. Furthermore one ways do not influence the result of a regional context (Maldague et al., 2015; Ford et al., 2015). Similarly the same exercise was taken to model flyovers and underpasses. The attributes “Tunnel” and “Bridge” were changed to “T_elev” and “F_elev”.

The data set’s speed limit was also checked and manually altered according to the guidelines in TM and MITC (2011). Furthermore all roundabouts and single carriage two way country roads were assigned a value of 30km/h. TM and MITC (2011) also propose the alteration of speed limits and these proposals were used in this thesis’ model. Edges that are traversed only by pedestrians were set to 6km/h.

The travel time t, measured in m/min, was obtained by the following equation (eq. 1):

$$\mathbf{t = (6 * s) / (100 * v)} \qquad \textbf{(eq. 1)}$$

where **s** denotes the distance of the edge and **v** denotes the speed limit that the edge is to be traversed at.

Unwanted edges for example: the islands of Gozo and Comino; airport and Freeport infrastructure; service roads; roads on private land, car parks; and countryside tracks that did not connect higher order roads were deleted.

Figure 12: An Example of Openstreetmap Mistake.

Unfortunately these edges could not be quickly deleted by being selected by their attributes in the attribute table because their category assignment was not accurate enough. These edges, therefore had to be deleted manually as the entire network was being checked for one ways and speed limits. Other errors that were noticed were: streets that were not digitised, streets that were connected but digitised as not connected and streets that were not connected digitised as connected (figure 12).

In creating these models, certain assumptions were made. It was assumed that public transport was accessed from any point on the route and not from dedicated stops as in real life. This decision was taken because of the difficulty of getting bus stop data and the temporal limitations that the author had in assigning bus stops to the two new networks that he created. Other works for example Nielsen et al. (2004); Azar et al. (1994, cited in Lei and Church, 2010); and Nyerges (1995, cited in Lei and Church, 2010) used such an approximation as well.

The different nature of public and private transport on the one hand and data availability on the other implies that there is a risk of bias in the result because of the use of conceptually dissimilar models. Hence whilst the less assumptions are taken, the more precise the result is, the more conceptually similar the models are the more accurate the results are. Data unavailability of congestion penalties, transfer times, waiting times, time to find parking, traffic times and time penalties at compulsory stops all resulted in the decision to use the simplest models in this thesis as proposed by Salonen and Toivonen (2013). Furthermore it was assumed that all vehicles started a journey at the maximum road speed limit and travelled the whole journey at the maximum road speed limit. Thus results of absolute travel time maps have to be viewed with these assumptions in mind and are of any worth only if they are relatively compared with each other (figure 13)..

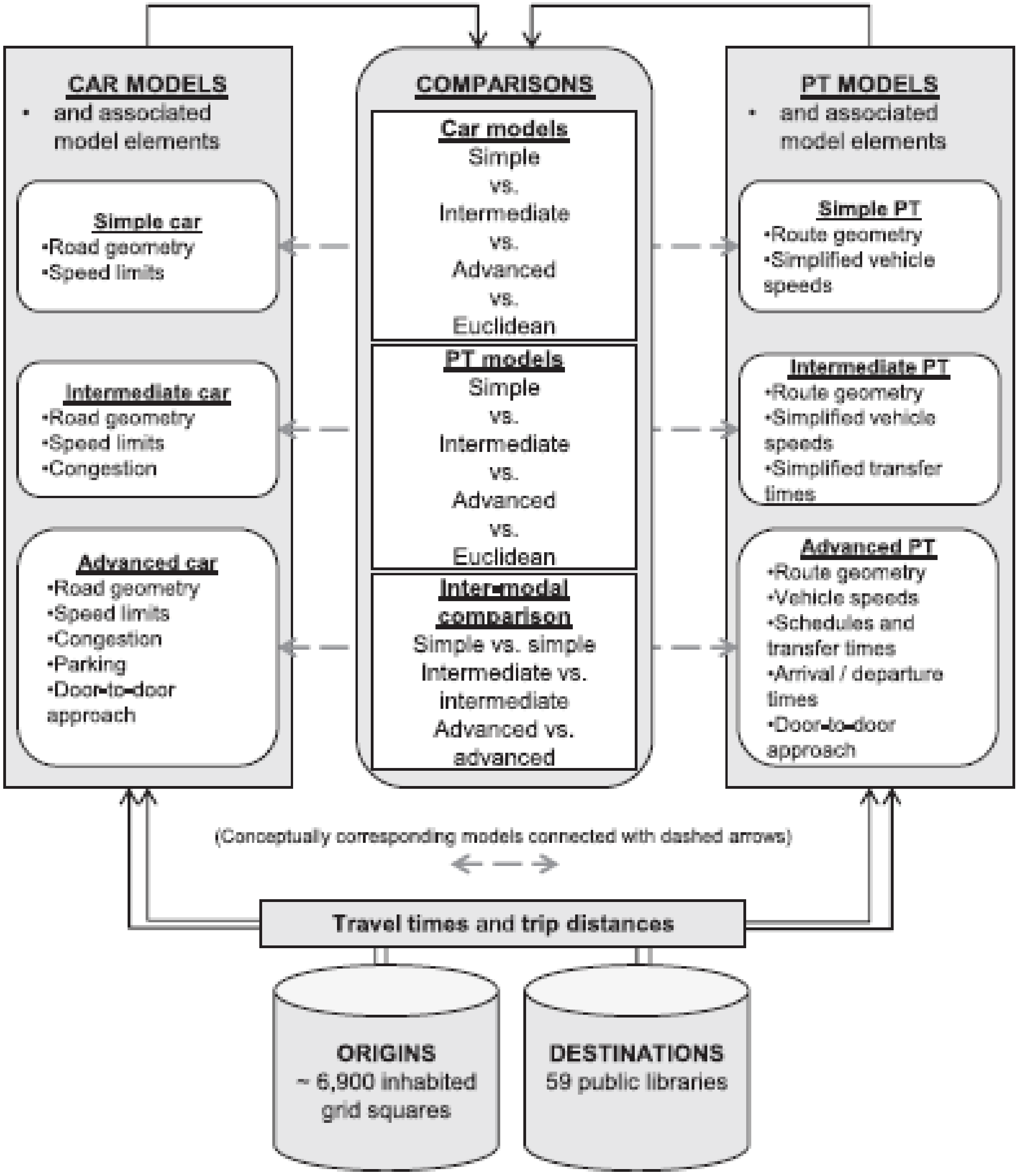

Figure 13: Salonen and Toivonen's (2013) Conceptually Similar Models

3.4. Travel Time in Accessibility Studies

Accessibility may be measured by one of its many attributes, such as: safety, cost, convenience or physical mobility (Curl et al., 2011). The attribute most commonly used in the field though is travel time (Kotavaara et al., 2012). Travel time is an attractive criterion by which to measure accessibility because it is one of the most important determinants that influence mode choice (Nielsen et al., 2005; Vandebulcke et al., 2009; Lei and Church, 2010; Mees, 2010). Furthermore travel time access to public transport is a crucial factor in whether a public transport system is used or not (Murray, 2001; Kimpel et al., 2007).

Travel time results are the easiest to produce and understand (Kotavaara et al., 2012) though it must be kept in mind that a traveller's perceptions of travel time, is what ultimately determines mode choice; which is not the same as the measured travel time (Thériault et al., 2004). Furthermore individuals may have preferences from the destination set offered and thus not necessarily want to choose the closest available destination (Vandebulcke et al., 2009). Finally travel time is a better measurement of accessibility than distance because travel time and cost are rarely proportional to distance (Scheurer and Curtis, 2007; Salonen and Toivonen, 2013) and the fastest path is not necessarily the shortest (figure 14) (Widener et al., 2015).

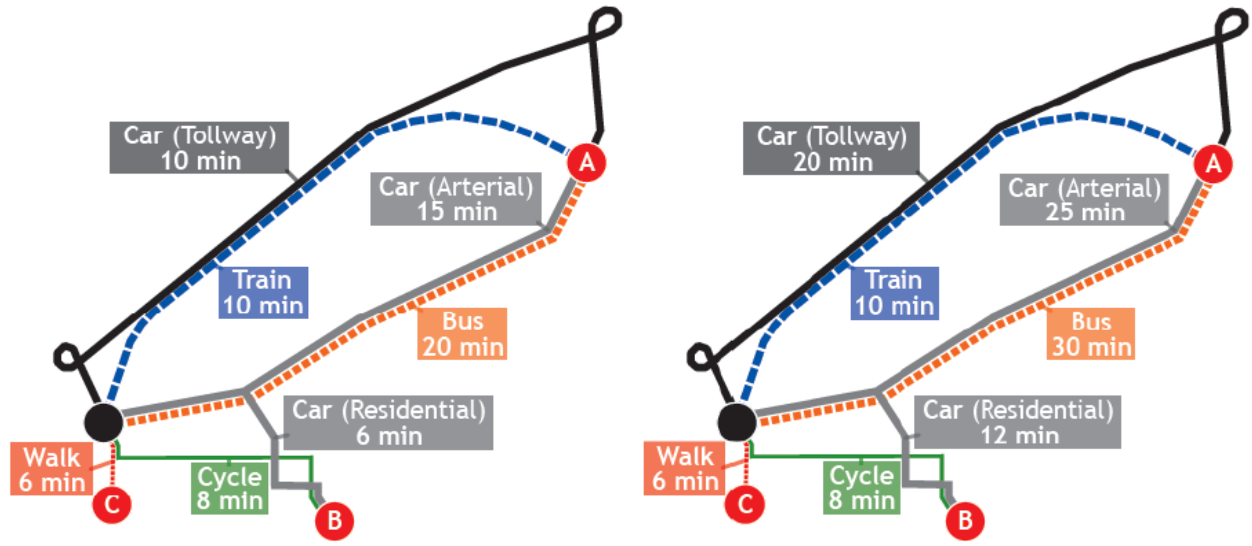

Figure 14: The Relationship between Travel Distance and Travel Time (Scheurer and Curtis, 2007:15)

3.5. Data Set Preparation

From the initial road dataset two datasets were created, a private transport dataset and a public transport dataset. In the former, pedestrian areas such as stairs were deleted to prevent analysis paths from taking pedestrian only edges as short cuts which is unrealistic for private transport. Conversely, these pedestrian edges were left for public transport though, because a traveller may stop at a location, walk a short distance and catch another public transport vehicle.

Public transport networks were than created from this public transport dataset by deleting the edges that were not served by the public transport and then superimposing it on the pedestrian dataset. The result is a network of edges traversable either by a public transport vehicle or on foot. For the purpose of this thesis five network designs were considered, three of which, namely the Radial, MPT and Arriva were implemented in real life while the other two, the Grid and Orbital, were created by the author.

The Radial Network (figure 15) is modelled on a 1996 map of the bus routes in Malta. The map only gives a general idea of where the routes where laid and hence the MPT network was modified to mimic the areas served by the Radial network by deleting certain edges. An exception is line 103 that currently serves the village of Bidnija, but was not served by public transport in 1996. The lines deleted from the MPT network were: 49, 56, 71, 74, 80, 85, 101, 117, 119, 182, 201, 213, 218, 223, X1, X2, X3 and X4. The Malta Public Transport (MPT) Network (figure 16) was copied from the MPT(2016) whilst the Arriva Network (figure 16) was digitised from an unpublished bus network manual that was kindly lent to the author by Transport Malta (Arriva, no date).

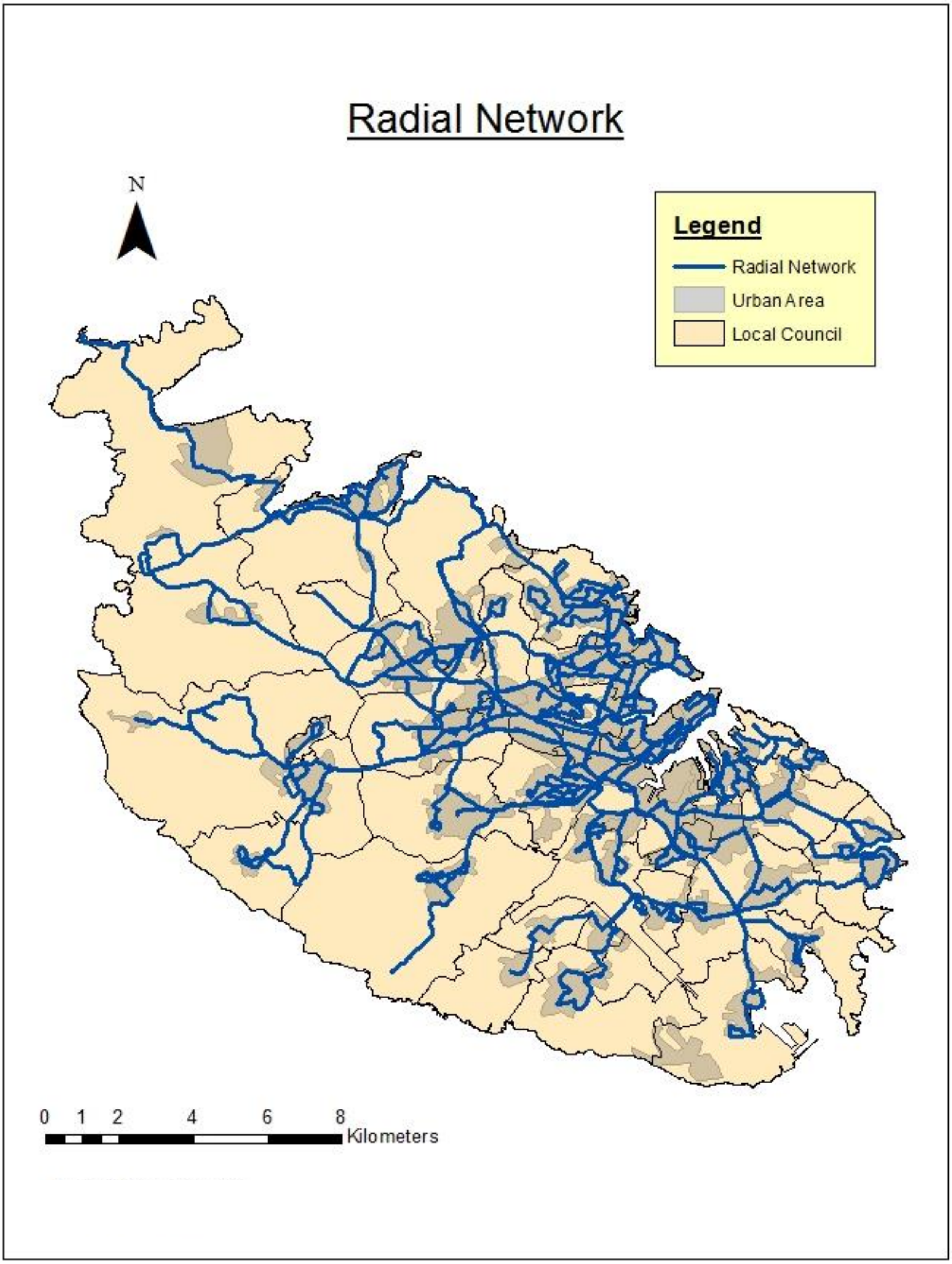

Figure 15: The Radial Network

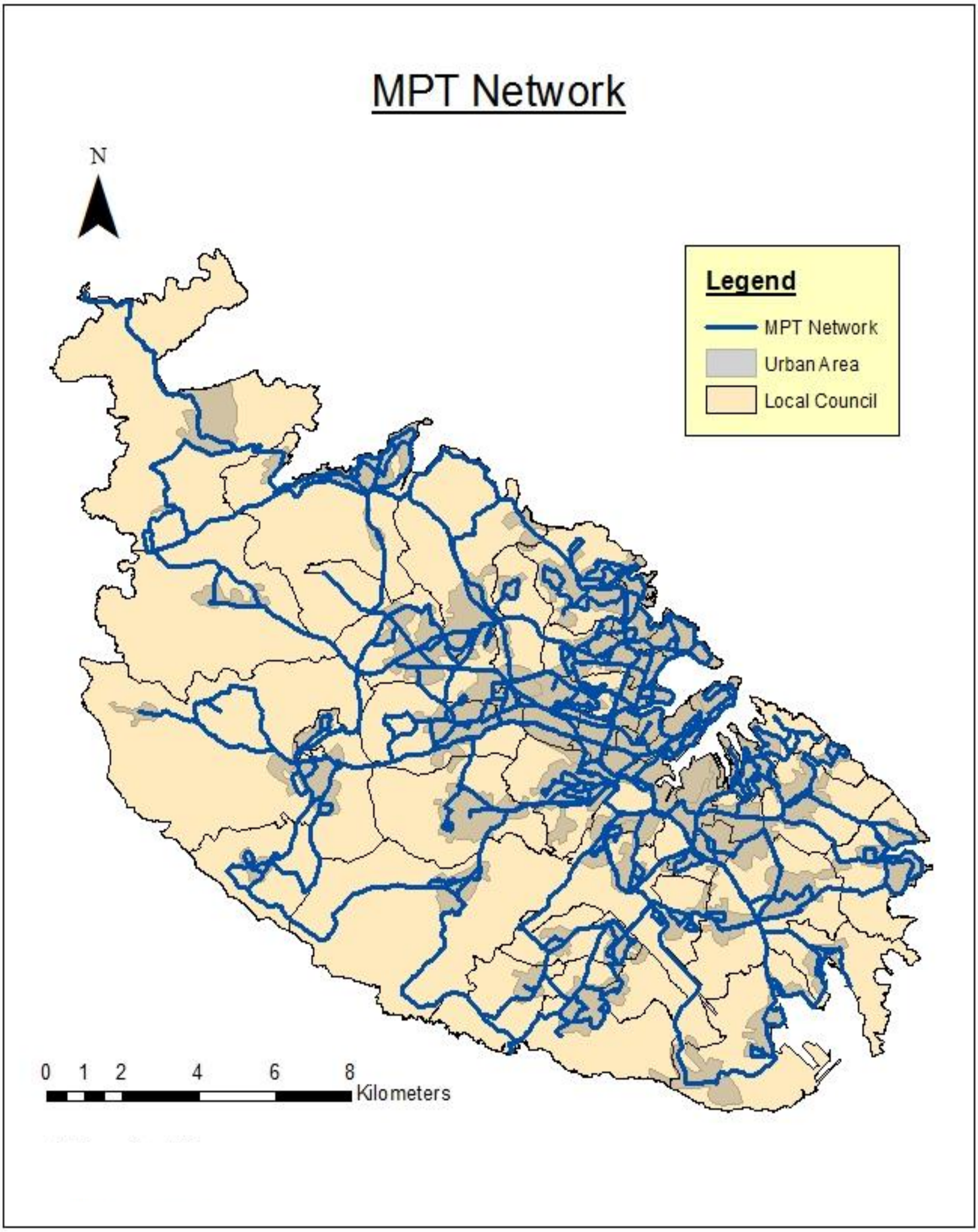

Figure 16: The MPT Network

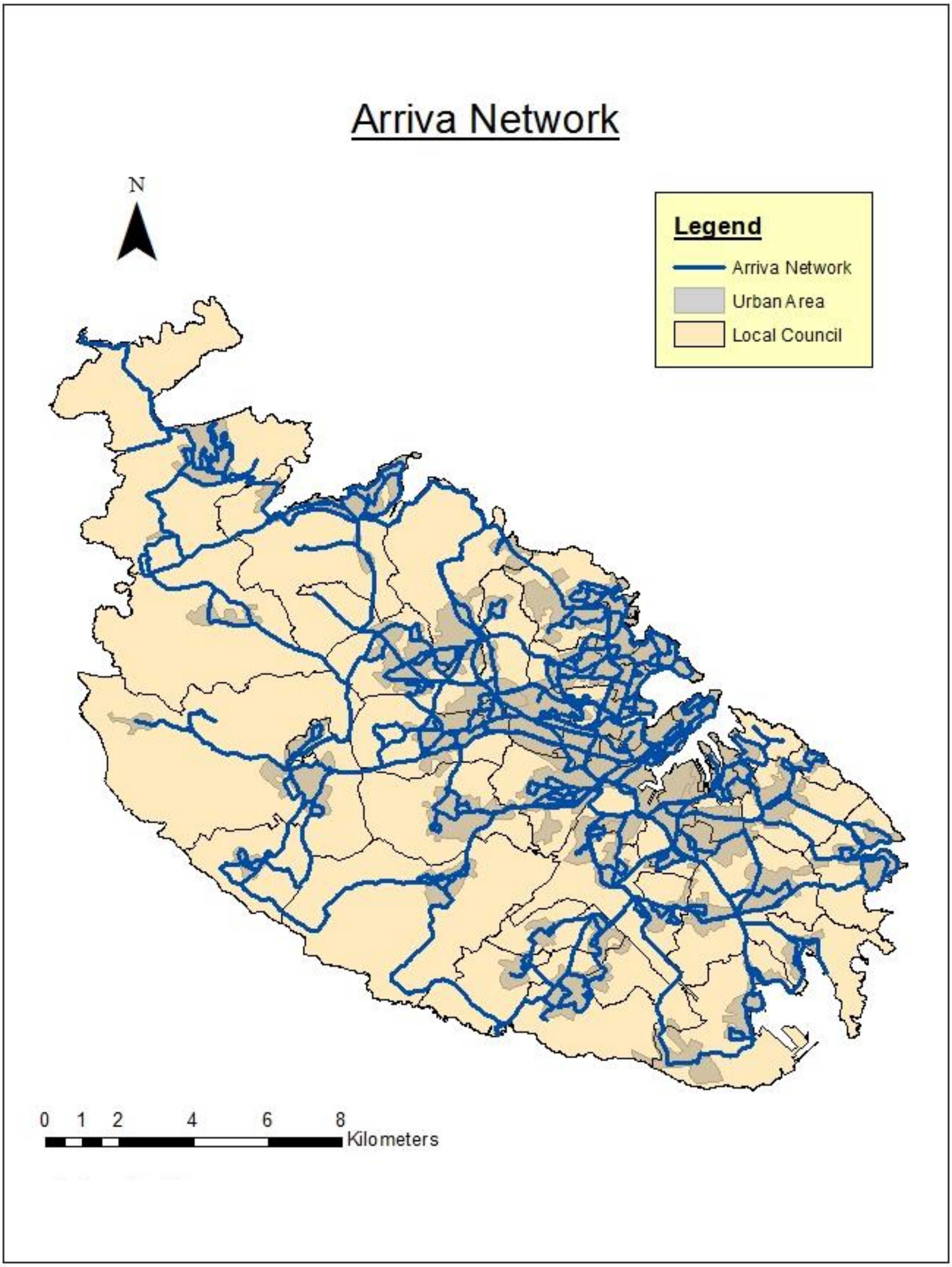

Figure 17: The Arriva Network

3.5.1. Grid design

This design (figure 18) was inspired from the squaresville model described in Nielsen et al., (2005) and conceived as the laying down of a grid-like network structure on the area of interest to be served. In practice as in other real world public transport applications (Daniels, 2012) geography dictated that these parallel lines were forced to cross each other transforming a grid design into X-pairs crossed by horizontal lines.

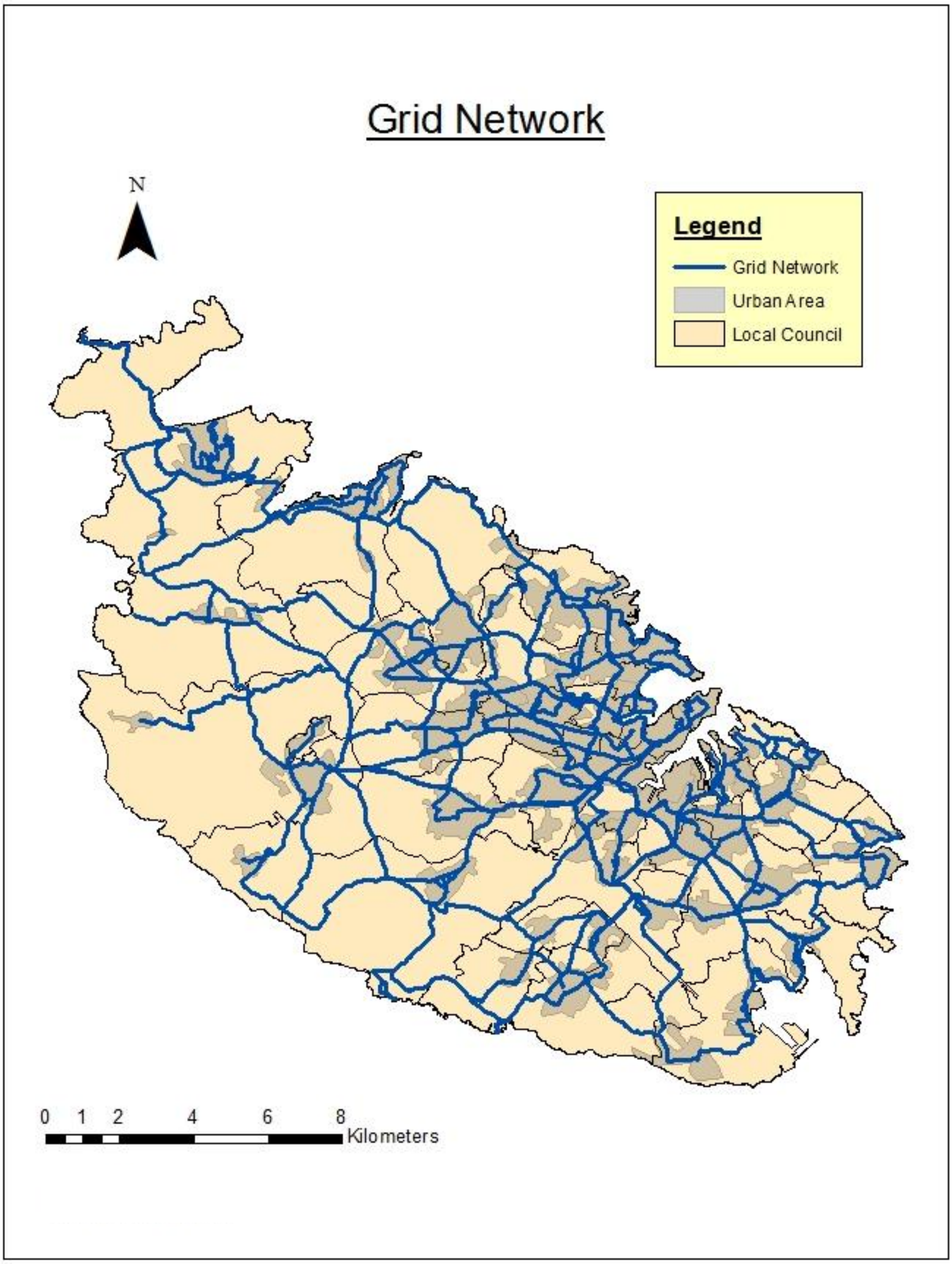

Figure 18: The Grid Network

3.5.2 Orbital design

The idea behind this design (figure 23) is to facilitate cross town travel needs without the need for long circumvented routes (figure 19 and 20). Hence orbital routes are a special kind of dispersed network design.

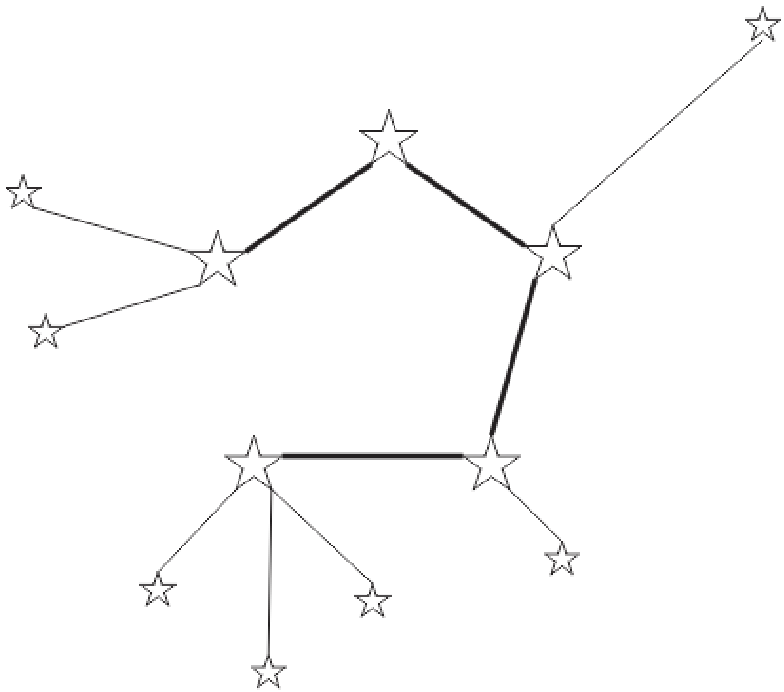

Figure 19: Model of the Radial Bus Network

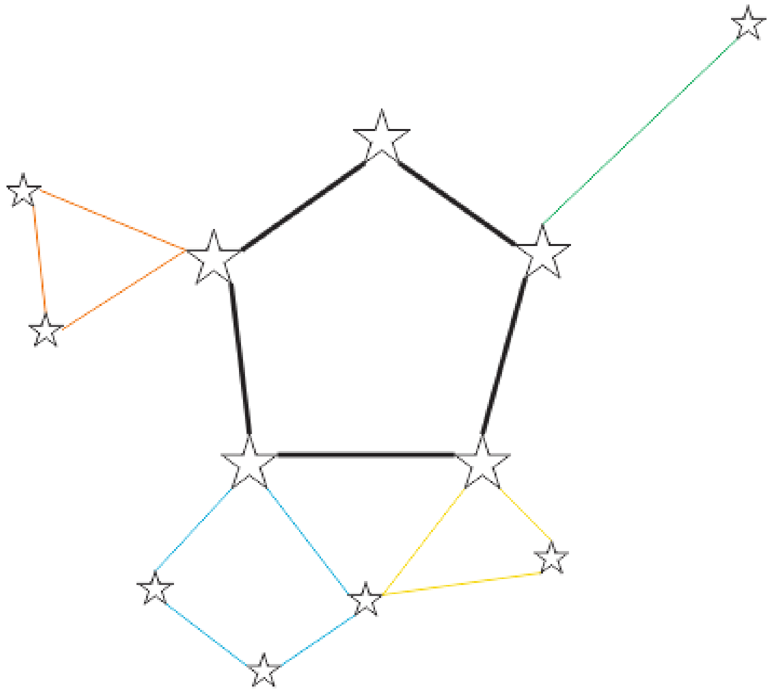

Figure 20: Model of the Proposed Network

Towns and villages were conceptualized as nodes (figure 21) and these were grouped together in clusters. Each cluster is served by an orbital link with two sets of buses running counter to each other. Each orbital link was then connected by the existing interchanges to a faster, higher capacity orbital link that operates on the main roads (figure 22). The decision on which nodes are connected by which links was based on the route distance to each other.

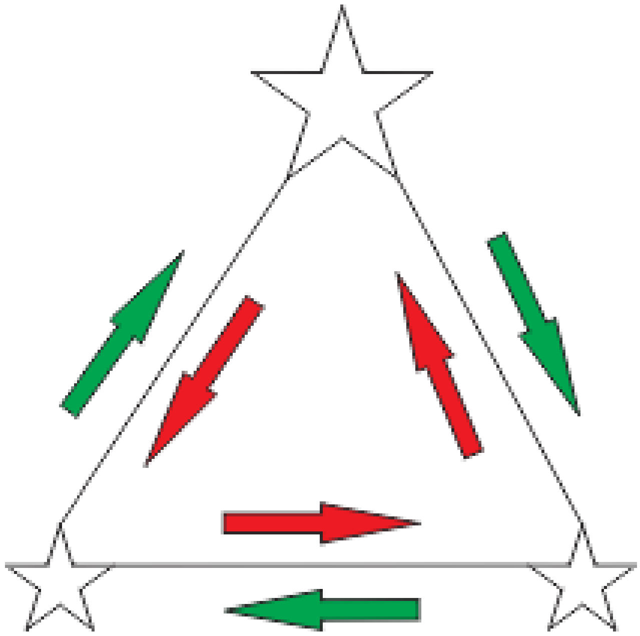

Figure 21: Basic model with the counter-rotating bus routes.

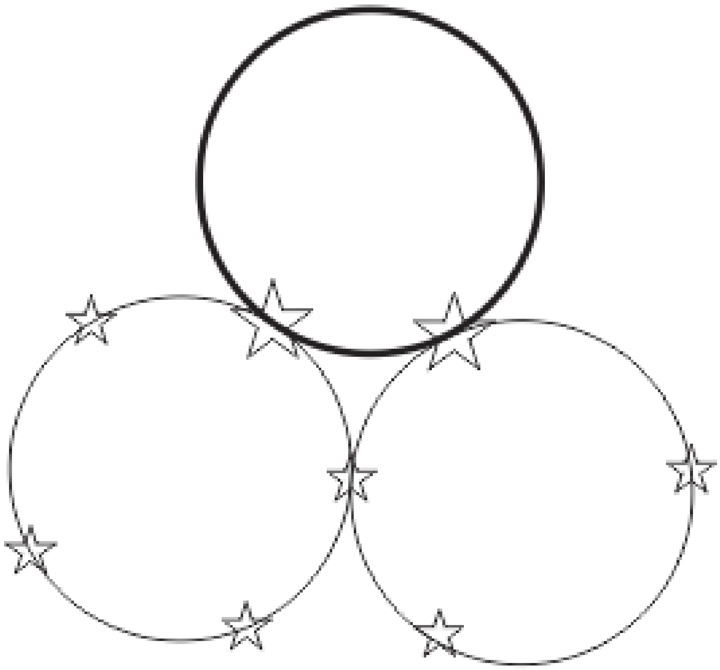

Figure 22: How Radial Links Connect with Each Other

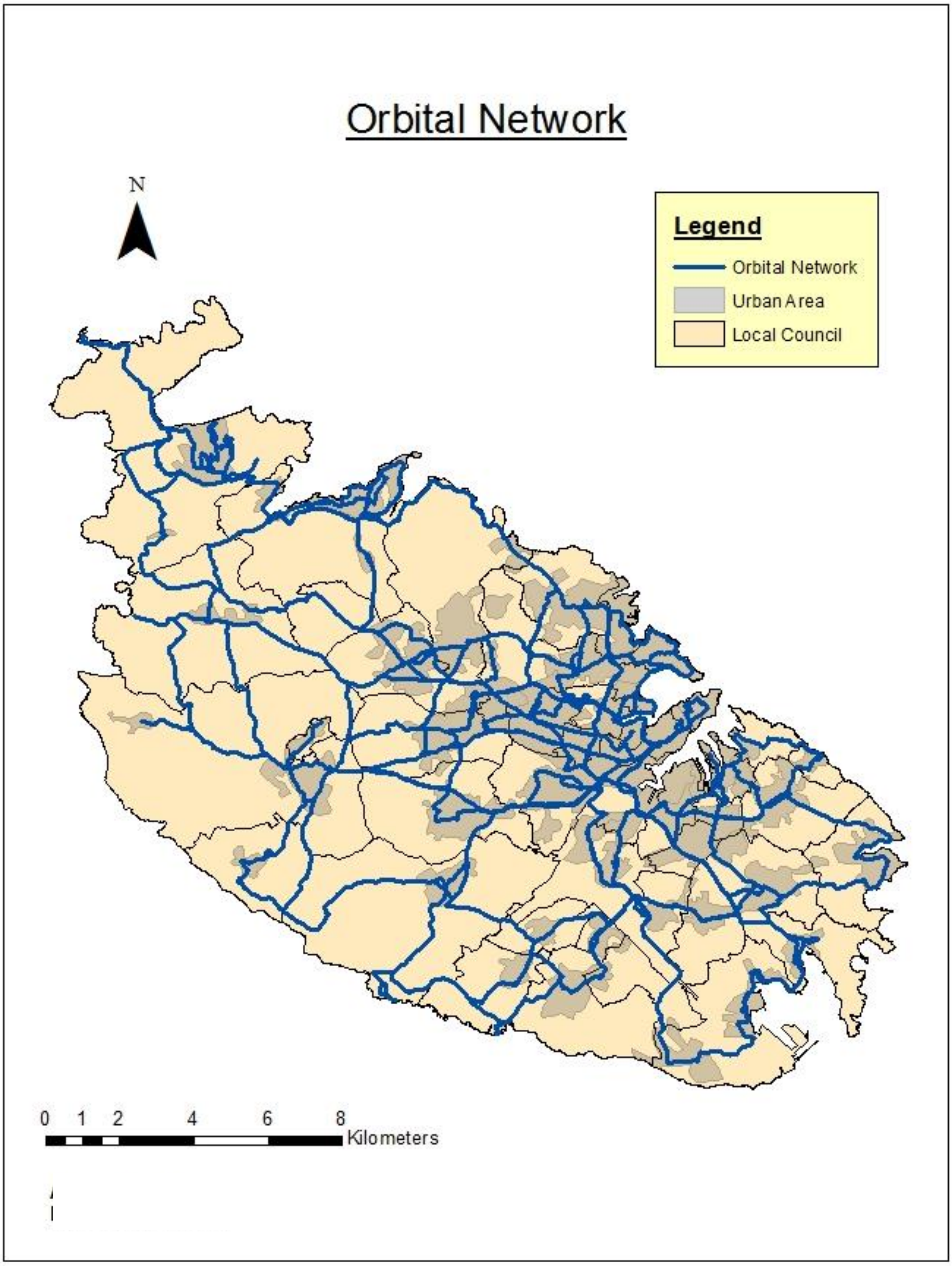

Figure 23: The Orbital Network

3.5.3. Ferry Design

The best public transport network design was then integrated with the Marsamxett Harbour and the Grand Harbour ferries by adding two edges representing each route. Each route was given a cost of 10 minutes, the time that ferries currently take to perform the route. During initial testing by the New Service Area function in ArcGIS it was realised that the ferry models predicted that it was faster to travel from the ferry's point of departure to point of arrival by bus than by ferry (figure 24 and 25), thus this approach was abandoned.

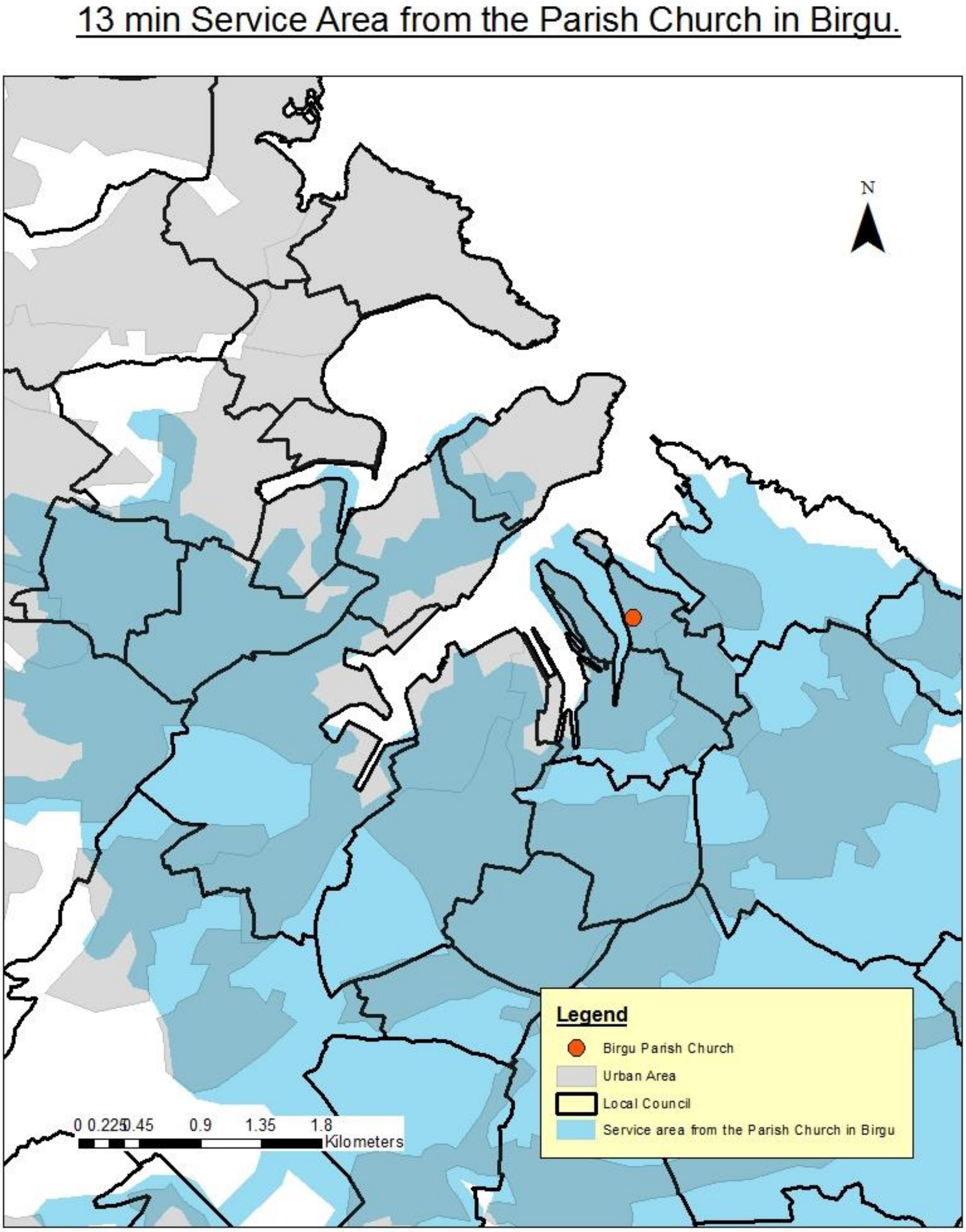

Figure 24: Birgu Service Area

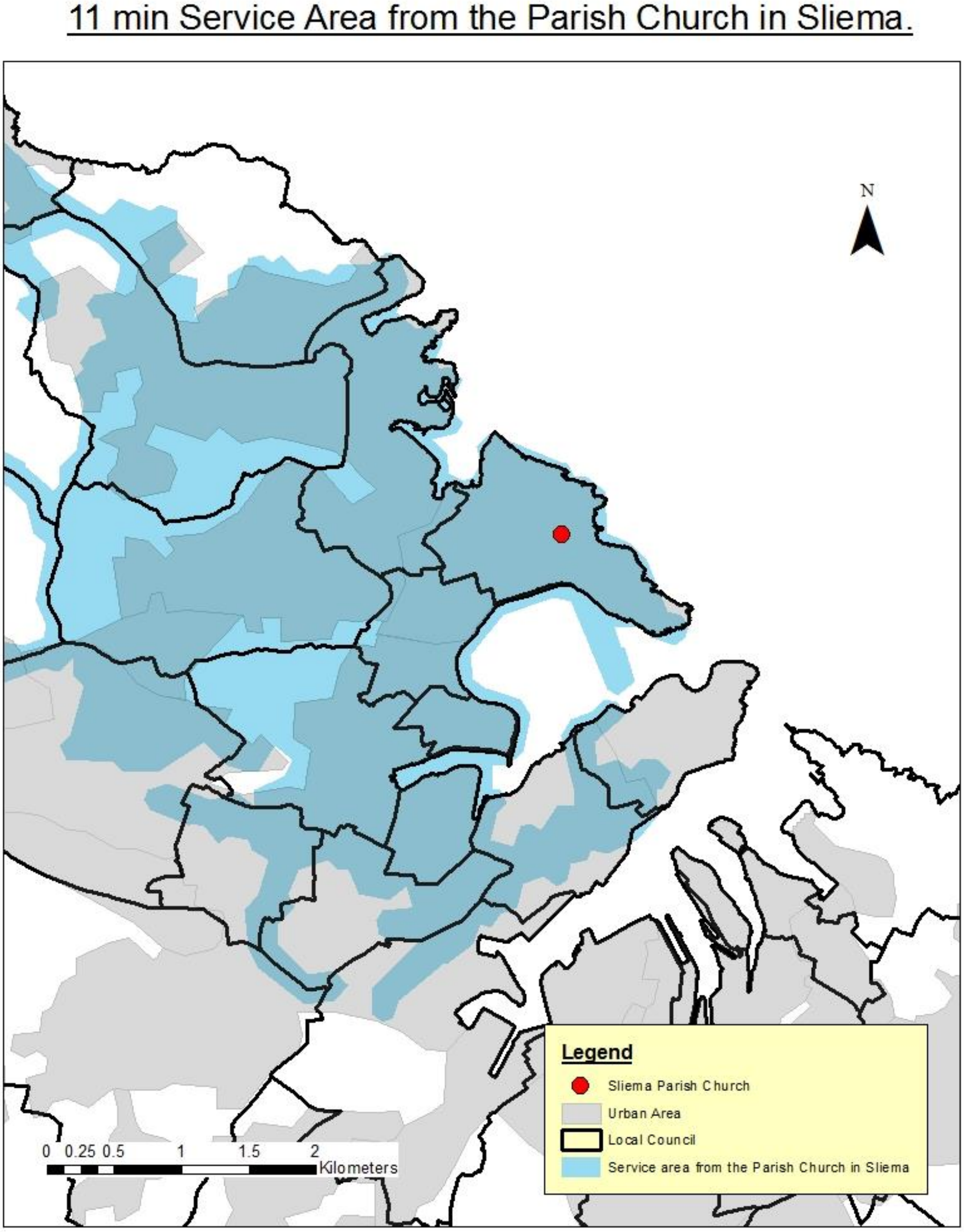

Figure 25: Sliema Service Area

3.5.4. Rail Network

A final perspective was taken at the effect that rail may make on the public transport networks. Work by Grech (2014) was an initial inspiration from which the final design (figure 26) was created according to what the author thought was best in light of Nielsen et al.'s (2005) principles. All lines were designed to be as straight as possible, with stops not closer than 1800m to be able to have a maximum speed of 75km/h. An exception to this rule is between the outskirts of Buġibba area and the centre of Buġibba, which was deemed necessary for the line to be extended to the heart of this important economic area.

Since the aim of this thesis is to test the effect of geometry on travel time while all else is equal, only time was taken into consideration when the rail was designed. Cost, property and geography among other factors which could alter the travel time between railway stations were not considered.

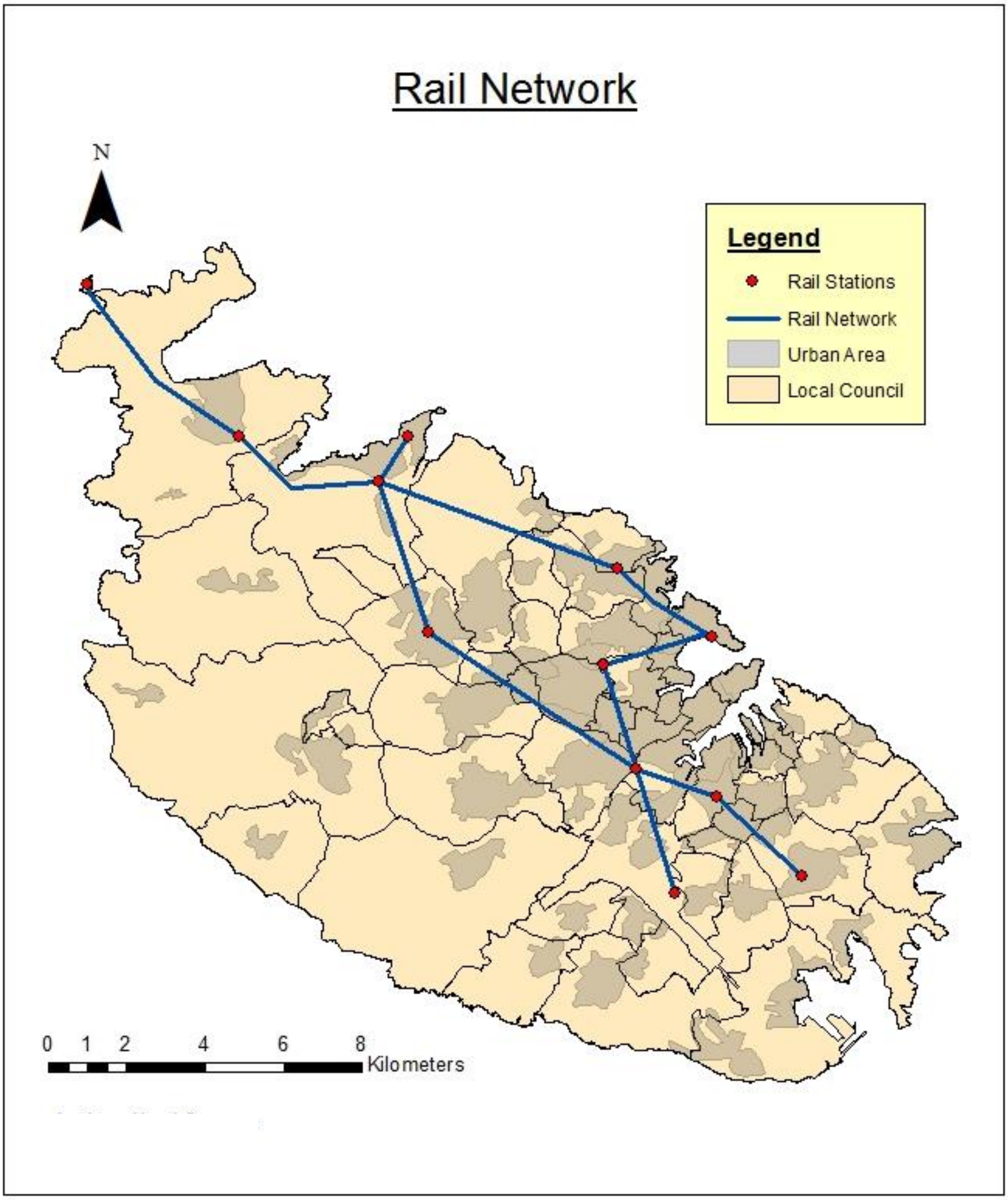

Figure 26: The Rail Network

3.6. Data Set Travel Time Calculation at a Fine Scale

Absolute travel time was calculated for every origin by the New OD Cost Matrix function present in the Network Analyst extension in ArcGIS. The average travel time for every origin was calculated and the average score of all the origins was taken as the score of the network. The work of Kwok and Yeh (2004) inspired the author to similarly compare the networks by using a normalised difference ratio.

The different results were compared by an adaptation of the Modal Accessibility Gap equation in Kwok and Yeh (2004). The travel times of the different models were compared at both the points of origin and on the total average value of the urban area. The best public transport network was the one with the lowest average travel time in the urban area. The calculations at point level show with more precision where networks excel and where they are wanting.

$$\mathbf{MAG} = \frac{\sum t_{pj} - \sum t_{cj}}{\sum t_{pj} + \sum t_{cj}} \qquad \textbf{(eq. 2)}$$

where MAG is the modal accessibility value at the sample point, $\mathbf{t_p}$ is the average absolute travel time value of the public transport network at point j and $\mathbf{t_c}$ is the average absolute travel time value of the car at point j.

The modal accessibility gap of the network was found by summing up the values of all the points in the urban areas of the network as per the equation 3.

$$\mathbf{MAG} = \frac{\sum t_{pu} - \sum t_{cu}}{\sum t_{pu} + \sum t_{cu}} \qquad \textbf{(eq. 3)}$$

where $\sum t_{pu}$ is the sum of the values of the travel times in the urban areas of the public transport and $\sum t_{cu}$ is the sum of the values of the travel times in the urban areas of the car.

3.7. Weighted Travel Time Calculations at Local Council Level

The travel time at local council areas were calculated both in absolute terms and in weighted terms by the New OD Cost Matrix function in ArcGIS Network Analyst extension.

Weighted travel times are useful because they demonstrate the value of each link (Gutiérrez and Urbano, 1996; Gutiérrez et al., 1996) without paying emphasis on the shorter distances (Gutiérrez, 2001). It is measured by the following equation:

$$L_i = \frac{\sum_{j=1}^{n} (T_{ij} \cdot M_j)}{\sum_{j=1}^{n} (M_j)}, \qquad \textbf{(eq. 4)}$$

where $\mathbf{L_i}$ denotes the accessibility value at node i, $\mathbf{T_{ij}}$ denoted the time required to travel from node i to node j and $\mathbf{M_j}$ denotes the population at node j.

Moreover, the same equation can be used to see how well the transport system is enjoyed by the population of the local council relative to the population of the other areas in the study area (Kwok and Yeh, 2004).

3.8. Economic Potential at Local Council Level

Economic Potential measures the accessible volume of economic activity after the impedance of covering the distance is taken into consideration (Dundon-Smith and Gibb, 1994; Vandebulcke et al., 2009). Economic potential is useful because it estimates the potential for regional development (Gutiérrez et al., 2010). It is measured by the following equation:

$$P_i = \sum_{j=1}^{n} \frac{M_j}{T_{ij}^a}, \qquad \textbf{(eq. 5)}$$

where $\mathbf{P_i}$ denotes the economic potential of node i; $\mathbf{M_j}$ denotes the measure of attraction at node j, taken in this case as population instead of GDP (Holl, 2007); and $\mathbf{T_{ij}^a}$ denotes the travel time required to travel from node i to node j. a is an exponential value that describes the importance of distance to the volume of economic activity. Its value has as in most accessibility studies been set to 1 because there was no data to which it could be calibrated (Dundon-Smith and Gibb, 1994; Gutiérrez, 1996).

CHAPTER 4

RESULTS

4.1. Introduction

A look at the results of the OD Cost Matrix tool for every network model (table 4) suggests that in free flow conditions, the car is by far the fastest mode by which to travel. The public transport network that on average was able to transport travellers fastest was the MPT network followed by the similarly designed Arriva network. When performance is analyzed according to whether the land use is urban or rural, the MPT and Arriva networks perform best in the urban areas, whereas the Grid network performs best in rural areas. Of the networks designed by the author the Grid network was the one that performed best. As expected, the Radial network was the worst performer of all the models. The results also demonstrate the potential improvement that rail has on a bus network, in this case saving about 7.74% of the travelling time on a national level and 8% and 6.7% of the urban and rural areas respectively.

These findings can be better compared when the MAG of the urban areas (MAG_u) is calculated. It is worth noting that unlike in the accessibility calculations cited in Kwok and Yeh (2004), lower values are the more desirable and thus Kwok and Yeh’s (2004) guidance on the interpretations of the values have to be inverted. The closer the value is to 1 the less competitive a public transport system is whereas at 0 there is equal performance between the two systems and negative values denote a public transport system that is more advantageous to use than the car.

Table 4: Network Average Absolute Travel Time.

	NETWORK AVERAGE ABSOLUTE TRAVEL TIME (MINUTES)						
	Car	MPT with Rail Network	MPT Network	Arriva Network	Grid Network	Orbital Network	Radial Network
Urban	**11.603**	**15.181**	**16.501**	**16.52**	**16.842**	**17.846**	**18.583**
Rural	16.352	24.367	26.134	26.552	25.135	26.471	29.936
Country-wide	12.357	16.638	18.034	18.112	18.158	19.214	20.384
MAG_U		0.134	0.174	0.175	0.184	0.212	0.231

4.2. Absolute Travel Time at a Local Council Scale

All the maps indicate that from a transport infrastructure perspective the central and eastern local councils are the most accessible areas of the island. The car, by providing a sizeable part of the country with an average of 10 minutes of travel time to access destinations, is the mode that in free flow conditions offers the best accessibility levels. In general, at a local council level the results indicate that public transport penalises the traveller with a 5 minute travel time delay in the central and eastern areas and a 5 to 10 minute travel time delay in the periphery. It is in the peripheries that the strongest differences between the different transport networks manifest themselves.

The MPT and Arriva networks were the only bus based public transport networks to manage to service a local council area with a 5 minute average travel time budget. They also exhibited a better travel time result in the south eastern part of the country. Although it was hoped that the Orbital network would give peripheral towns better accessibility, the results indicate that this is not the case, having actually the worst travel time values of all the public transport networks tested.

The travel time calculations also show the potential that rail has in the lowering of travel time of public transport networks. The rail model serves most of the local councils with a 5 – 10 average minute interval and was the only public transport model to bring down the travel time of Mellieħa Local Council and San Pawl il-Baħar Local Council from 30 minutes to 25, making the accessibility of these councils comparable with the car. On the other hand the rail did not seem to drastically improve the travel time results of the central and eastern areas but was only restricted to the peripheries that it serves.

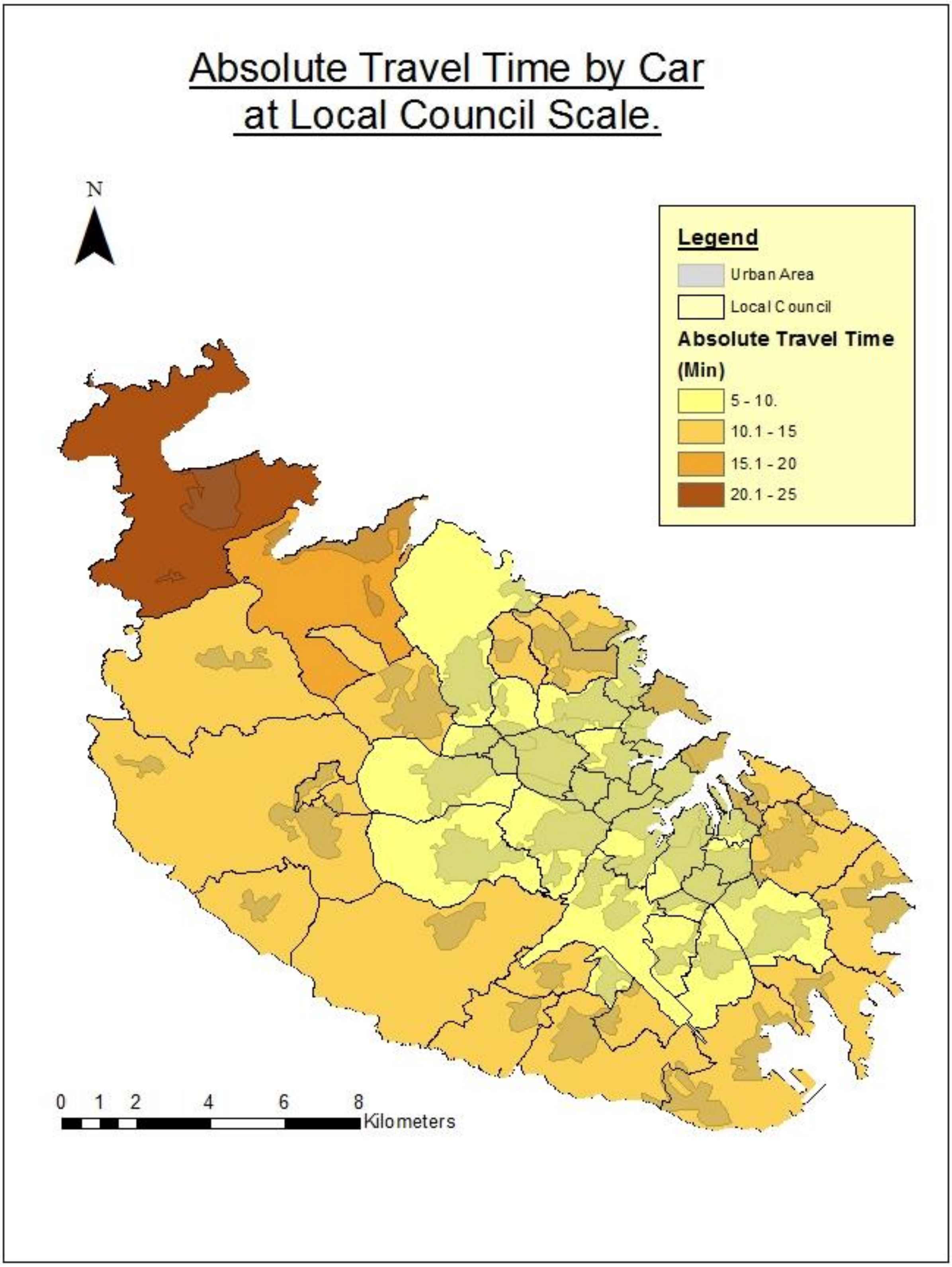

Figure 27: Absolute Travel Time by Car at Local Council Scale

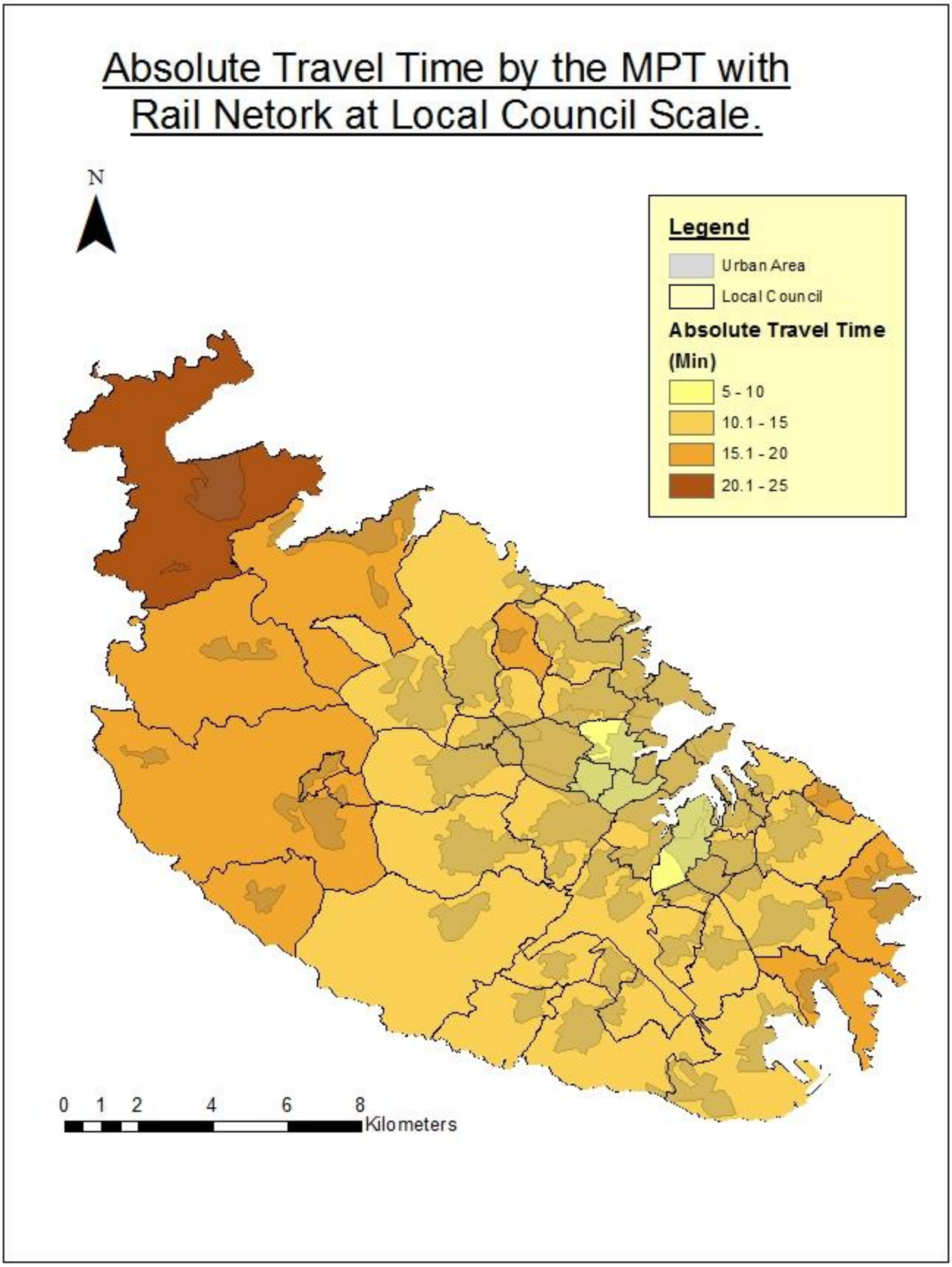

Figure 28: Absolute Travel Time by the MPT with Rail Network at Local Council Scale

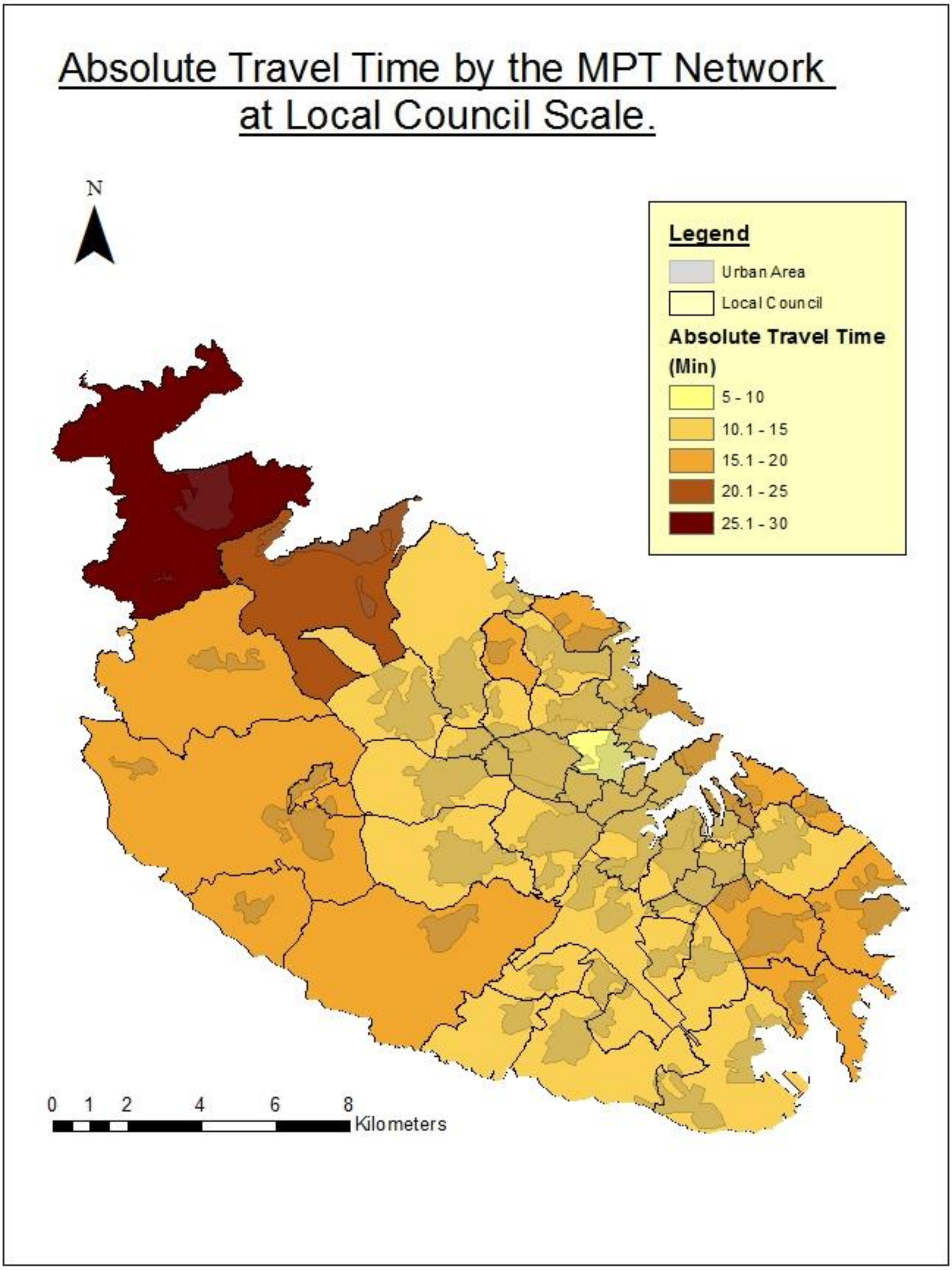

Figure 29: Absolute Travel Time by the MPT Network at Local Council Scale

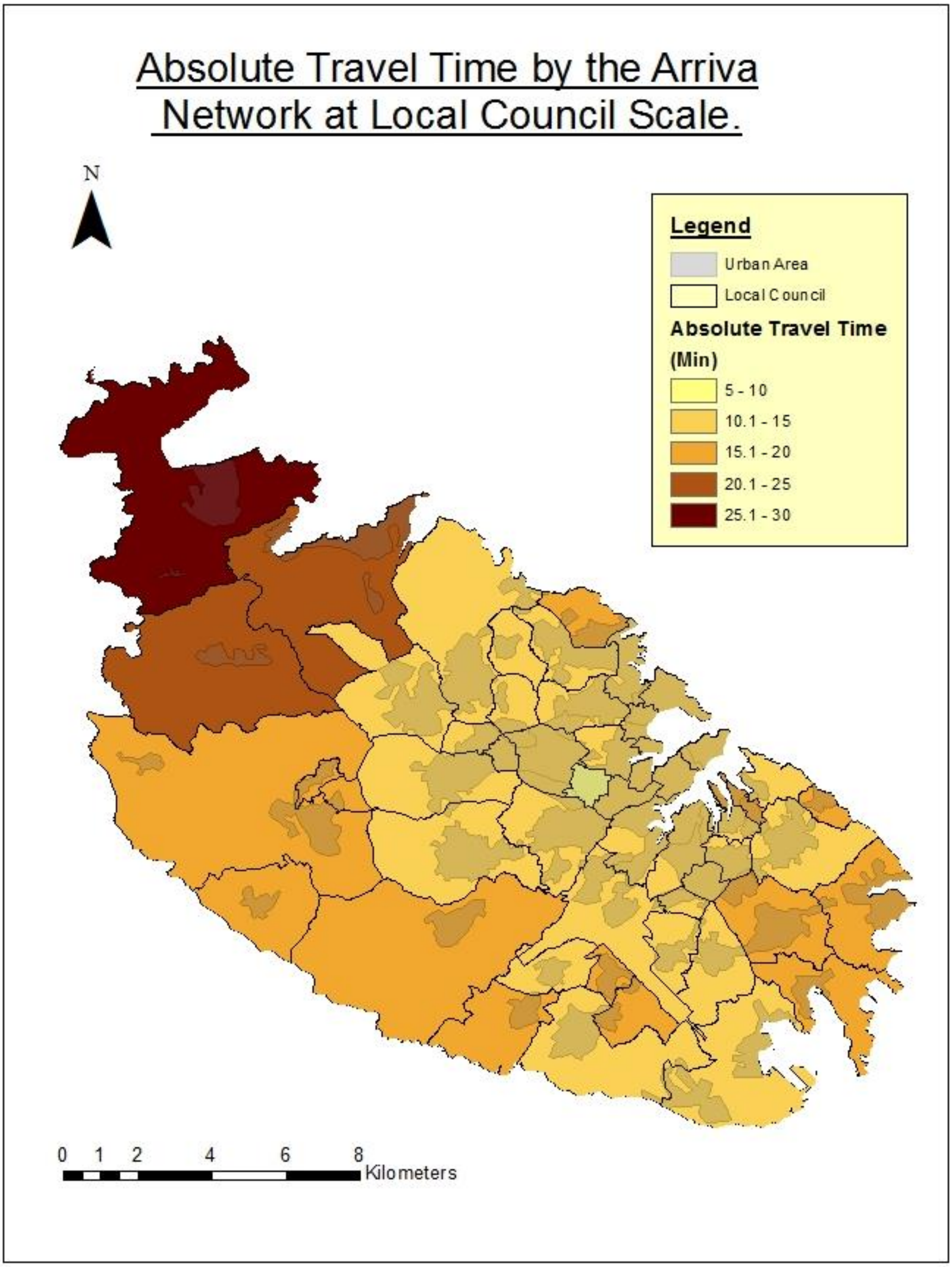

Figure 30: Absolute Travel Time by the Arriva Network at Local Council Scale

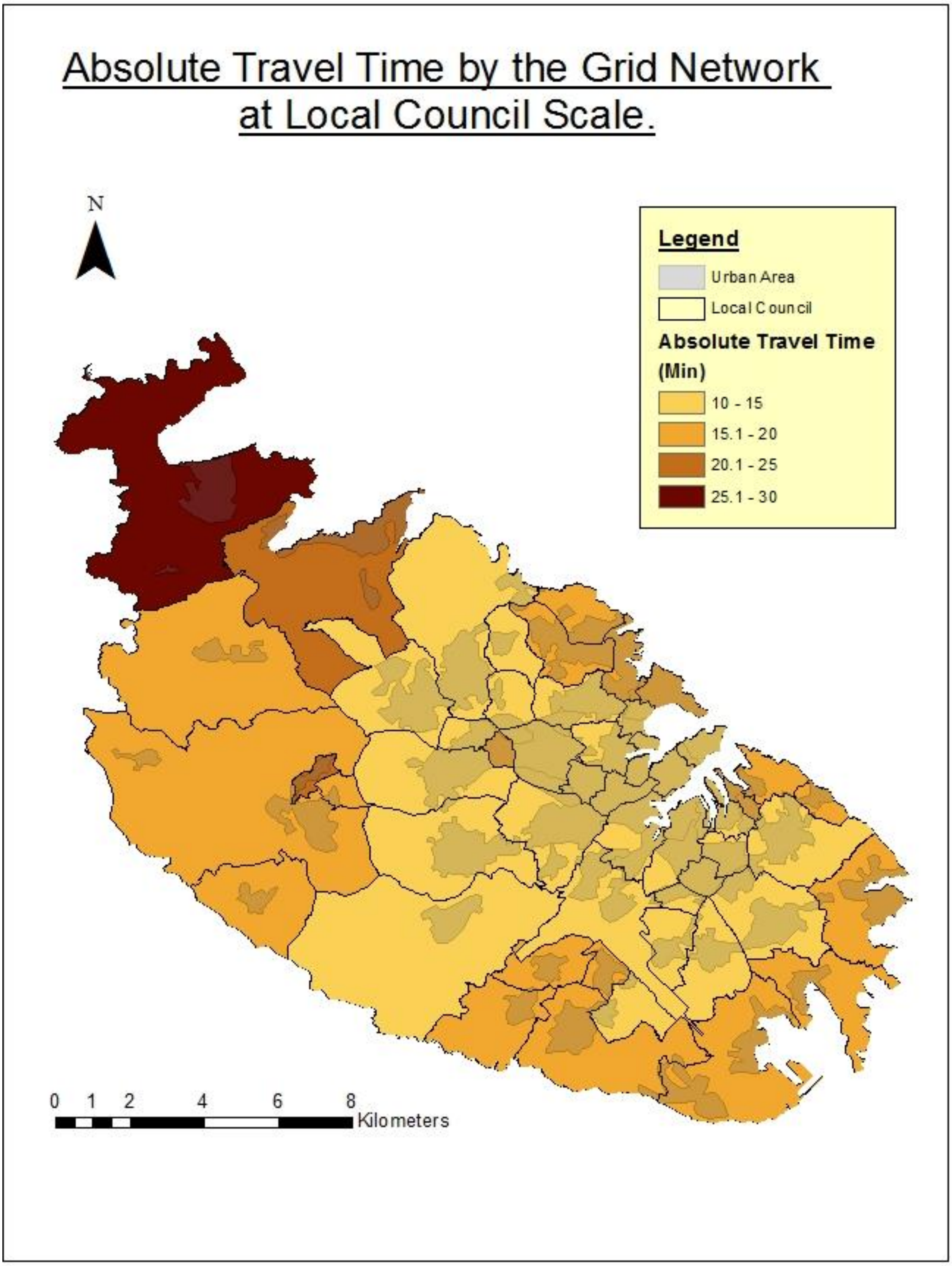

Figure 31: Absolute Travel Time by the Grid Network at Local Council Scale

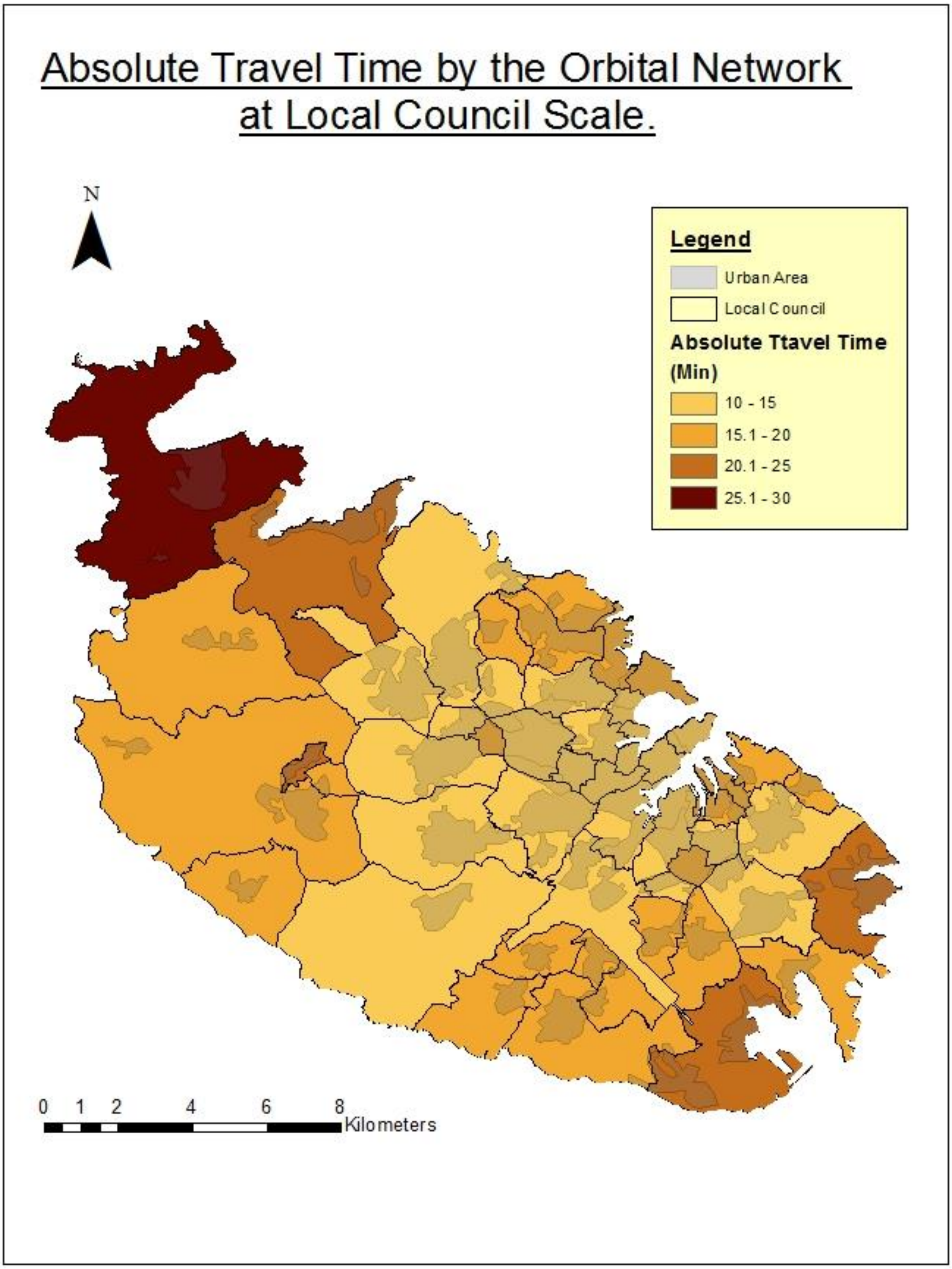

Figure 32: Absolute Travel Time by the Orbital Network at Local Council Scale

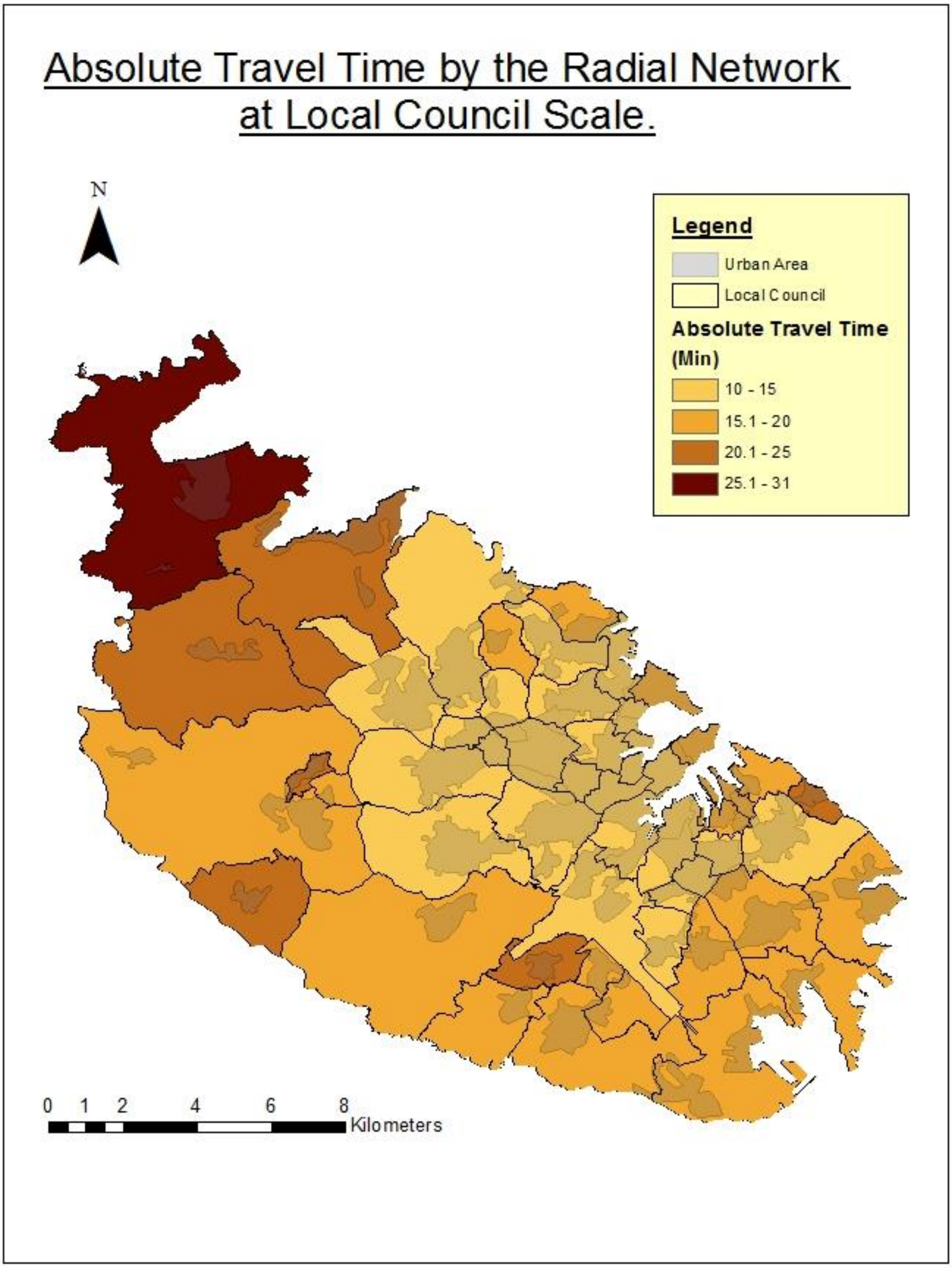

Figure 33: Absolute Travel Time by the Radial Network at Local Council Scale

4.3. MAG of Absolute Travel Time at Local Council Level

The advantage that the rail can bestow on a bus based public transport network is very easily identifiable when the MAG of absolute travel time at local council level is inspected and compared with the MAG of the MPT network. Immediately noticeable is Mellieħa Local Council, to which the rail manages to make public transport even more attractive than the car. The rail model also significantly improves the MAG of most of the country, even those that it does not directly serve, for example in the South, though it is implicit that these indirect benefits are only achievable if the network effect is reached.

The MAG exhibited by the different bus based public transport networks on the other hand exhibit a very dissimilar pattern save that a public transport networks suffer from disadvantage to the car in Rabat Local Council and Marsa Local Council. Another interesting finding is that the Grid and Orbital networks, more than the other networks seem to suffer especially in the Northern Harbour Area. In general the peripheral local councils are best served by the Grid network whereas the Harbour areas are best served by the MPT network. Another common theme is the relatively low result for Mellieħa Local Council which implies that if the public transport infrastructure is developed well enough, peripheral areas of the country are better able to compete with the car than the more centrally located ones. The reason behind this may be due to the proportion of walking time to the whole travel time journey that is devoted to access and egress of the vehicle; a proportion which is less in longer journeys than in shorter ones.

Another interesting result emerges when the MAG of the MPT network and the Grid network are observed. Whilst the MPT network is characterised by local councils that either have low or high MAG values, the Grid network seems to have a more stable MAG value across the country. The increased effort to decentralise and offer a truly multi-destinational set of opportunities therefore seems to have worked.

Finally both the Radial network and the Orbital network seem to offer the worst potential for competition against the car.

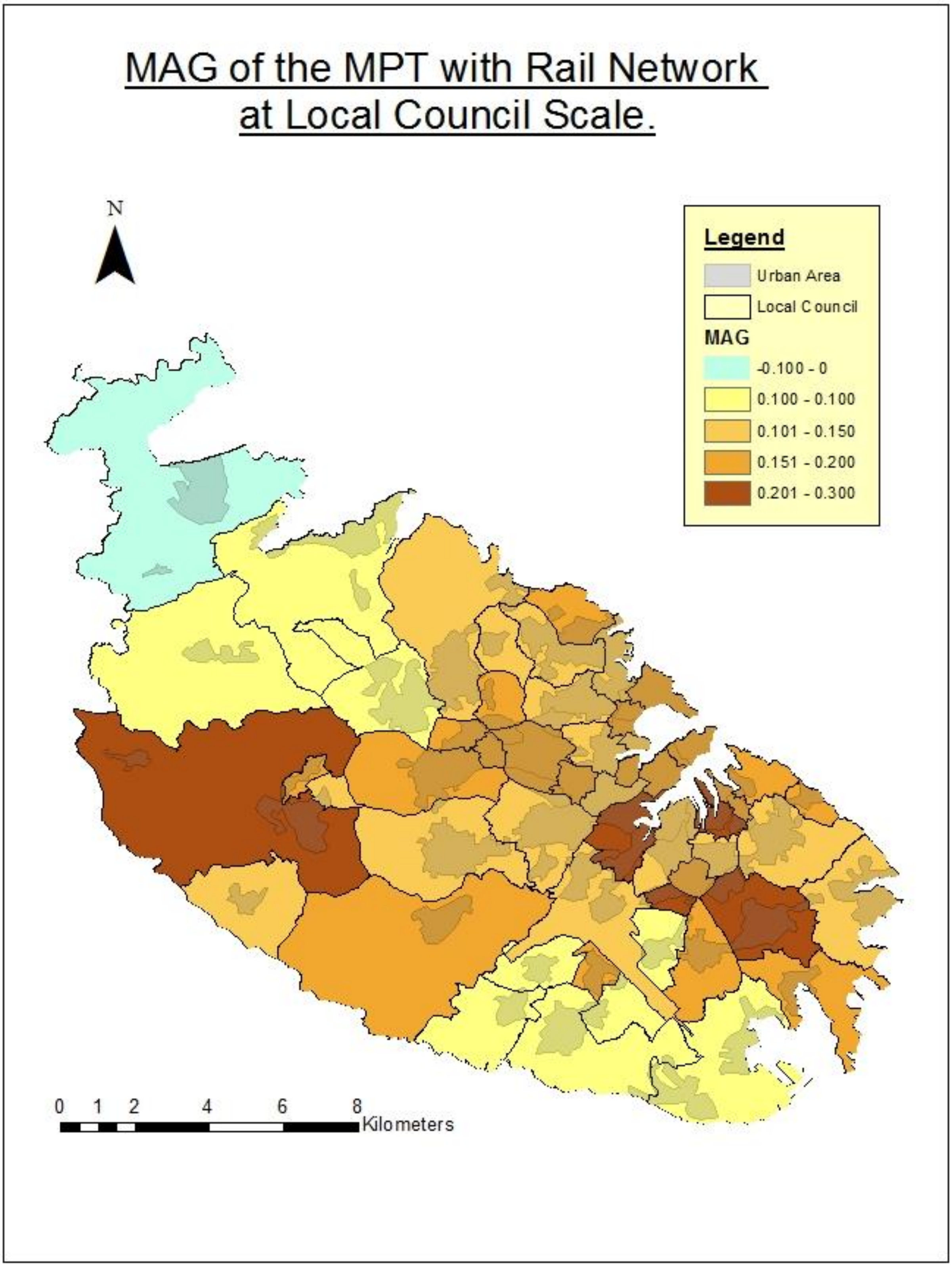

Figure 34: MAG of the MPT with Rail Network at Local Council Scale

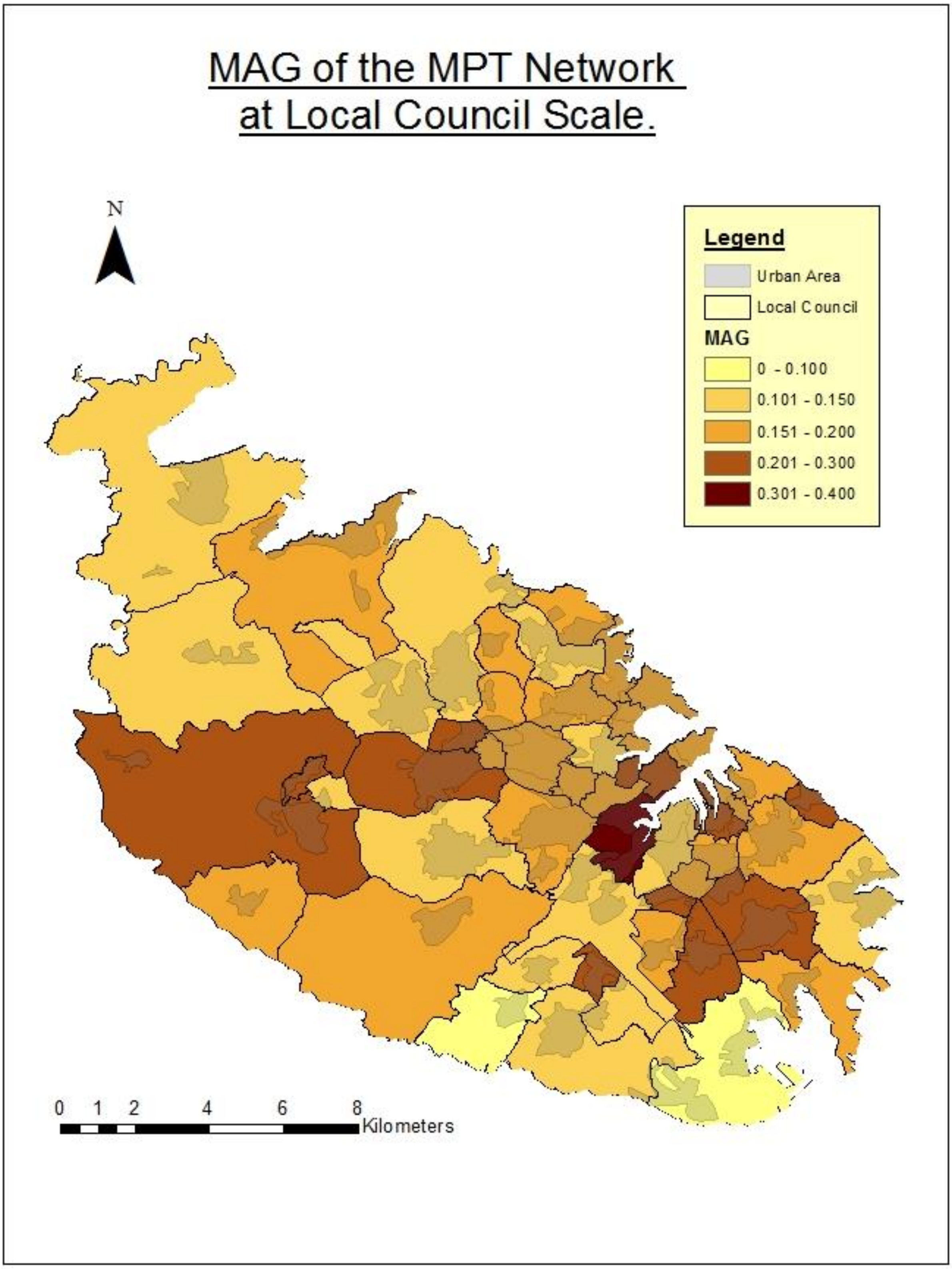

Figure 35: MAG of the MPT Network at Local Council Scale

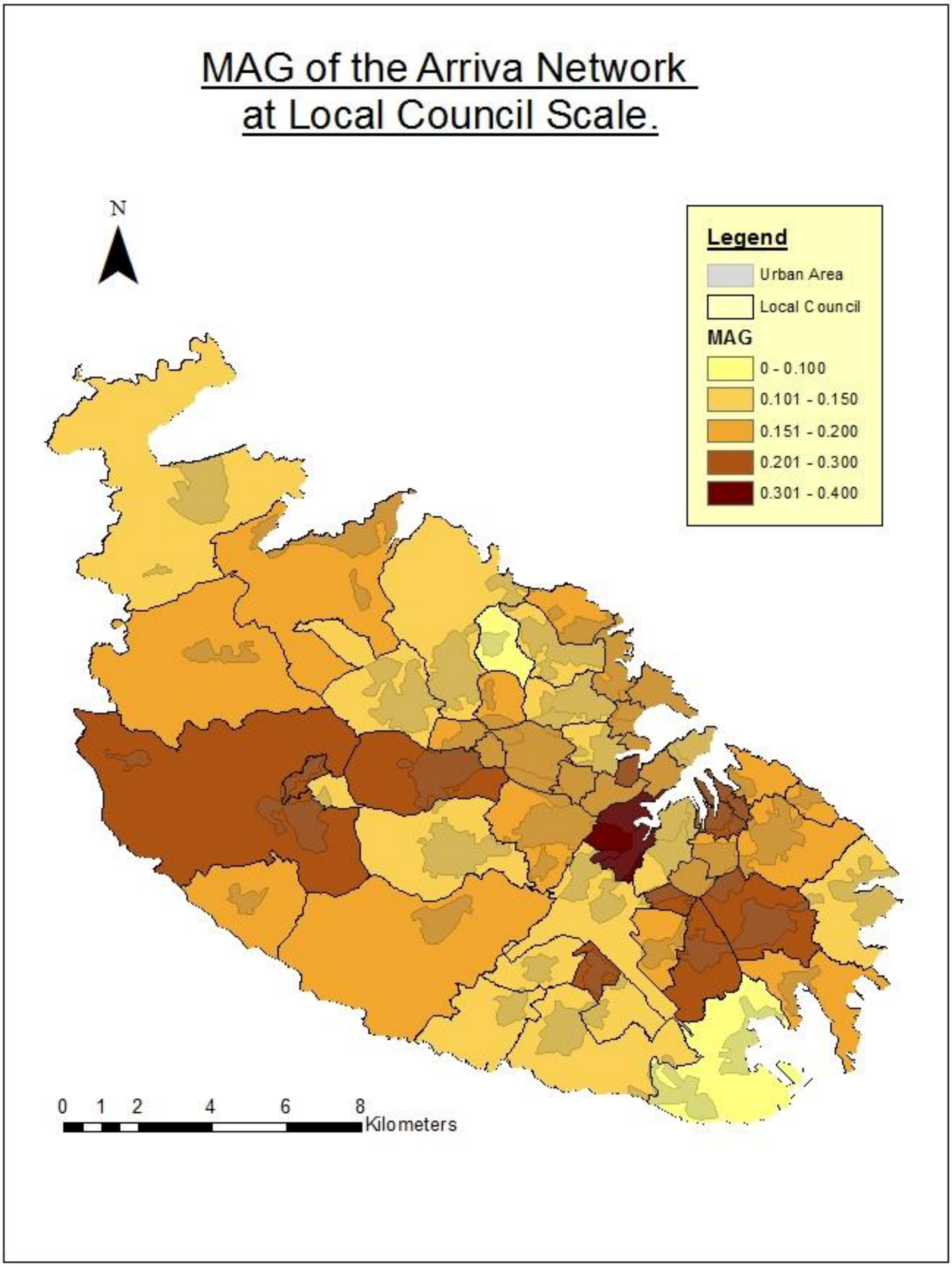

Figure 36: MAG of the Arriva Network at Local Council Scale

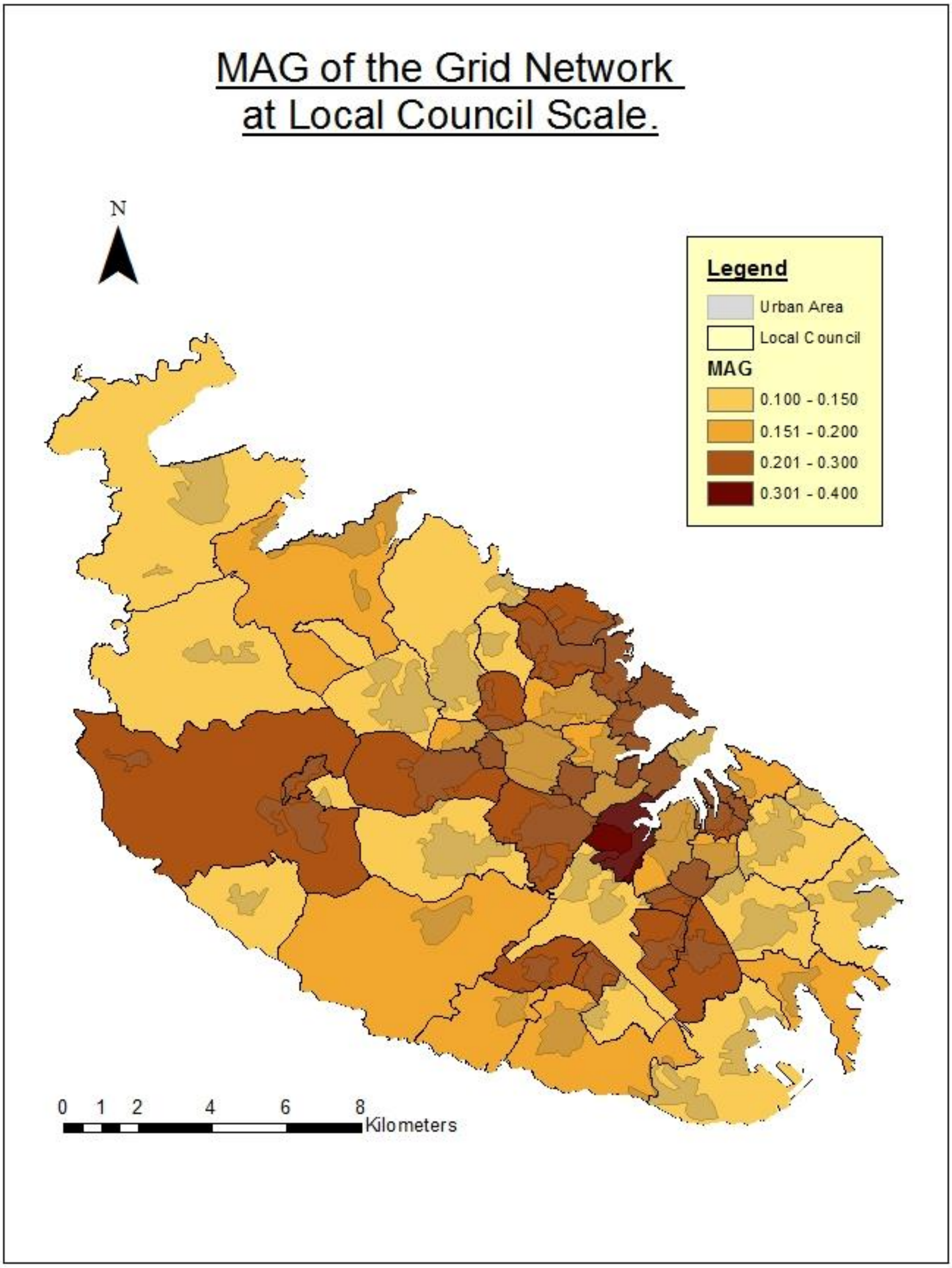

Figure 37: MAG of the Grid Network at Local Council Scale

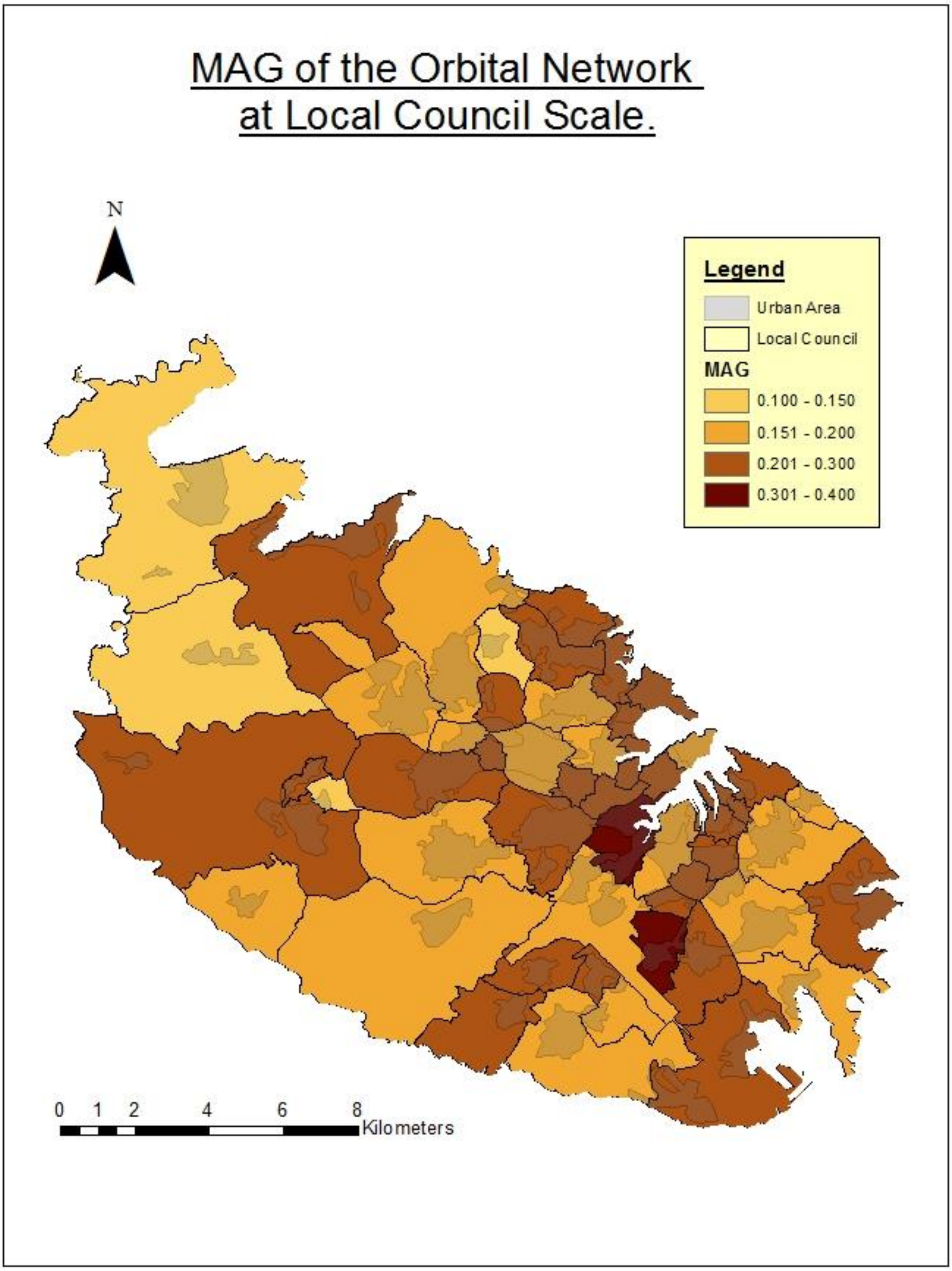

Figure 38: Mag of the Orbital Network at Local Council Scale

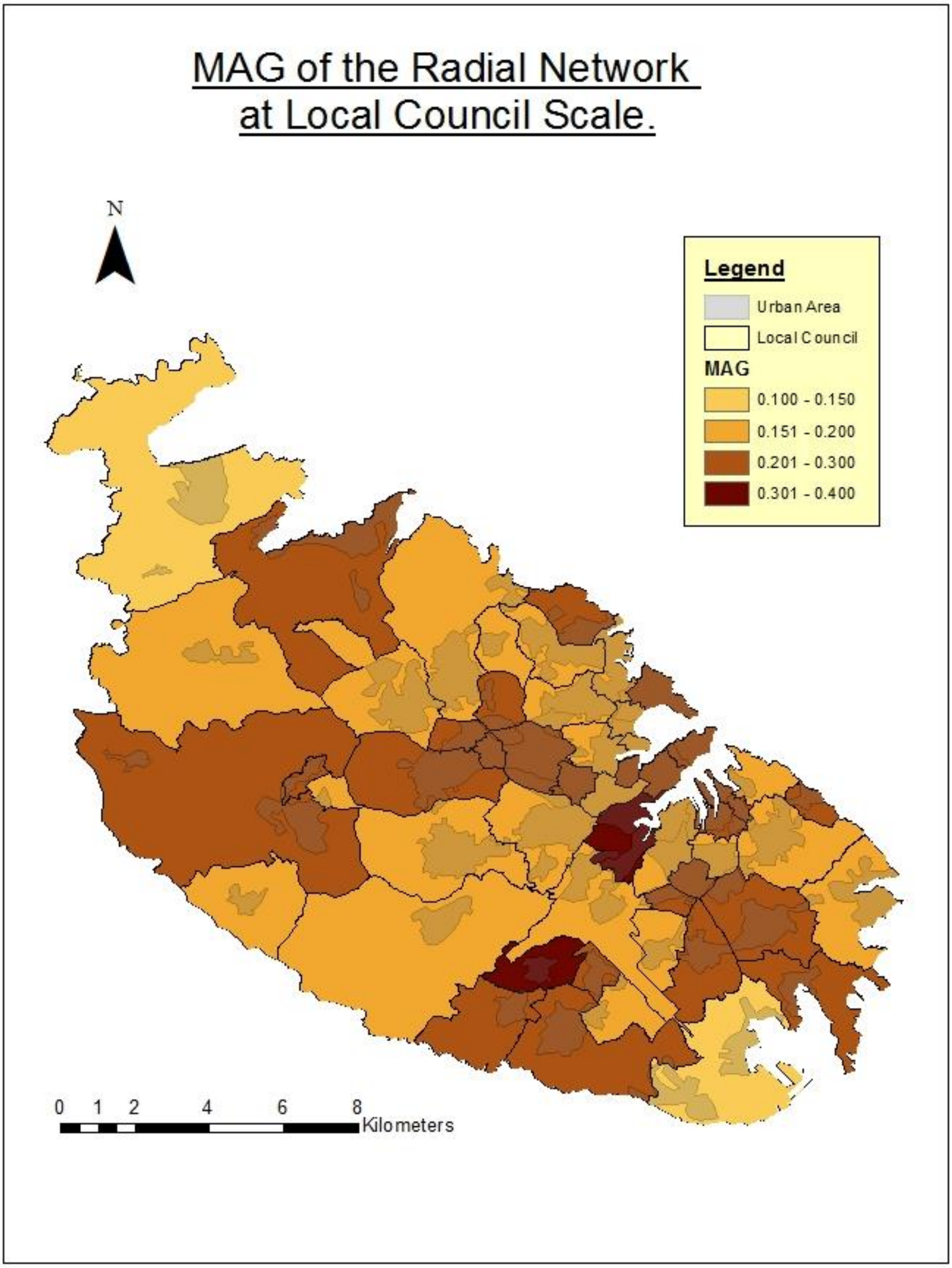

Figure 39: MAG of the Radial Network at Local Council Scale

4.4. Absolute Travel Time at a Fine Scale

The thesis delved deeper in the capabilities of the different networks and to determine whether trends that were observed at the local council level are more distorted at the fine spatial scale. For example, the large spatial extent of the increased attractiveness that the rail seems to offer at the Mellieħa at a local council level shrinks drastically to only half the town when measurements are taken at a larger scale. Although providing areas of accessibility that are more attractive than the car, is still an impressive result, the potential advantage that the rail offers is in fact much more conservative. Conversely, the fine spatial scale has also made it possible for the identification of localised clusters that would otherwise be unnoticed; for example the superior attraction of the rail near the train station in the Qawra neighbourhood of San Pawl il-Baħar Local Council over the car.

When the fine spatial scale maps are observed it is evident that the car has by far the best accessibility level. A sizable area of the country has an average of 10 minute travel time requirement for a traveller to reach a destination in free flow conditions. Furthermore, most of the origins on the island can reach destinations within a 20 minute drive whereas the remotest parts can reach destinations in less than 30 minutes drive. By contrast except for the Orbital and Radial networks, all of the public transport systems excluding their peripheries in the northwest exhibit a 5 minute delay to the car, as was exhibited at the local council level. On the other hand, the 5 minute delay in the Orbital and Radial networks is restricted to the central area of the island with much larger delays at the peripheries.

At the fine spatial scale, by taking into consideration points located in the rural areas, which have a higher probability of not to be well served by public transport and therefore needing much more time to access the desired destinations, have resulted in the increase of the possible range of travel time. Thus, the maximum limit of the range of travel time values for public transport was increased by 50 minutes, from a maximum of 30 minutes to a maximum of 80 minute. Conversely, the car's maximum was only increased by 15 minutes, from a maximum average travel time of 25 minutes to a maximum of 40 minutes.

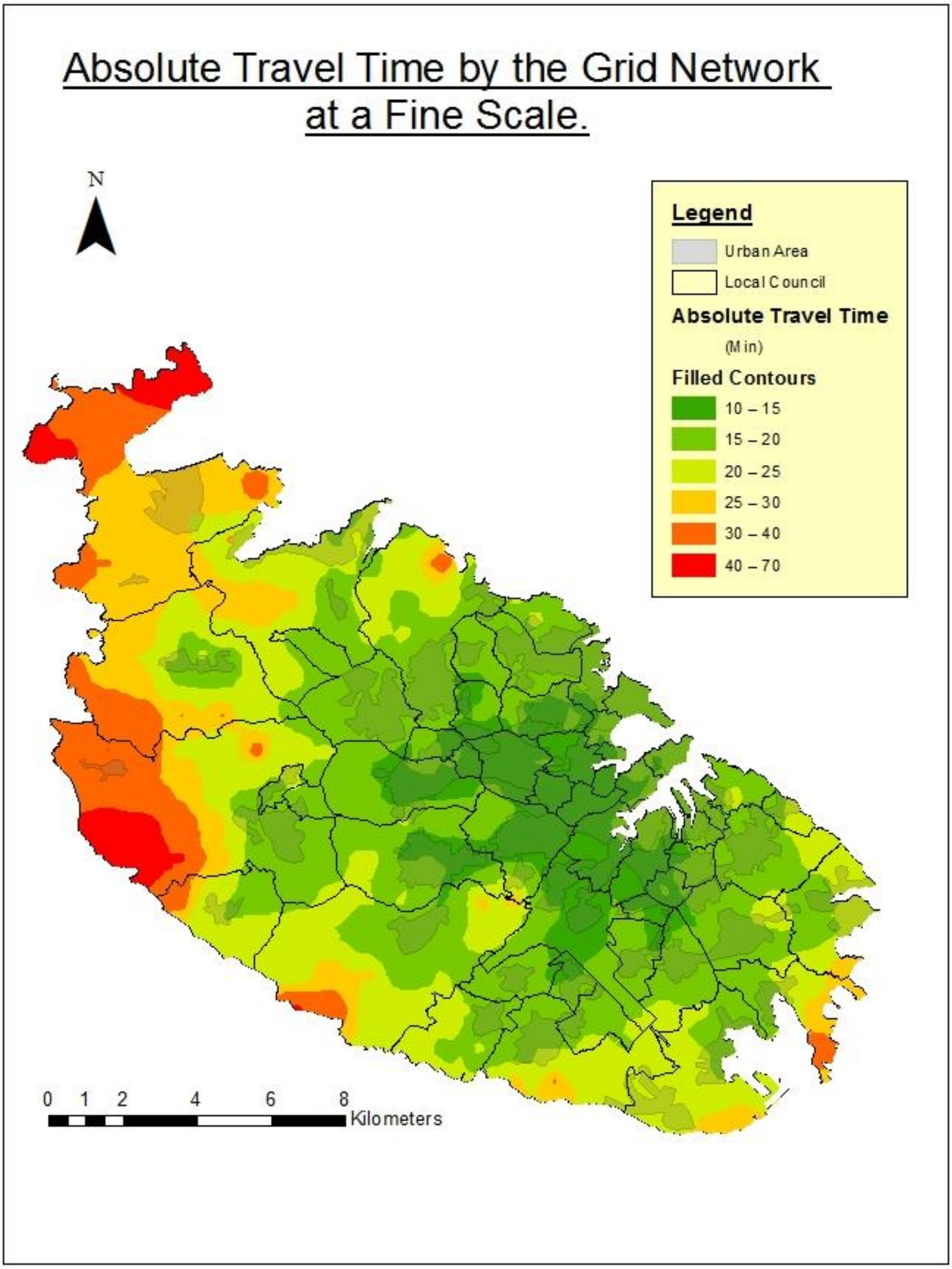

Figure 40: Absolute Travel Time by the Grid Network at a Fine Scale

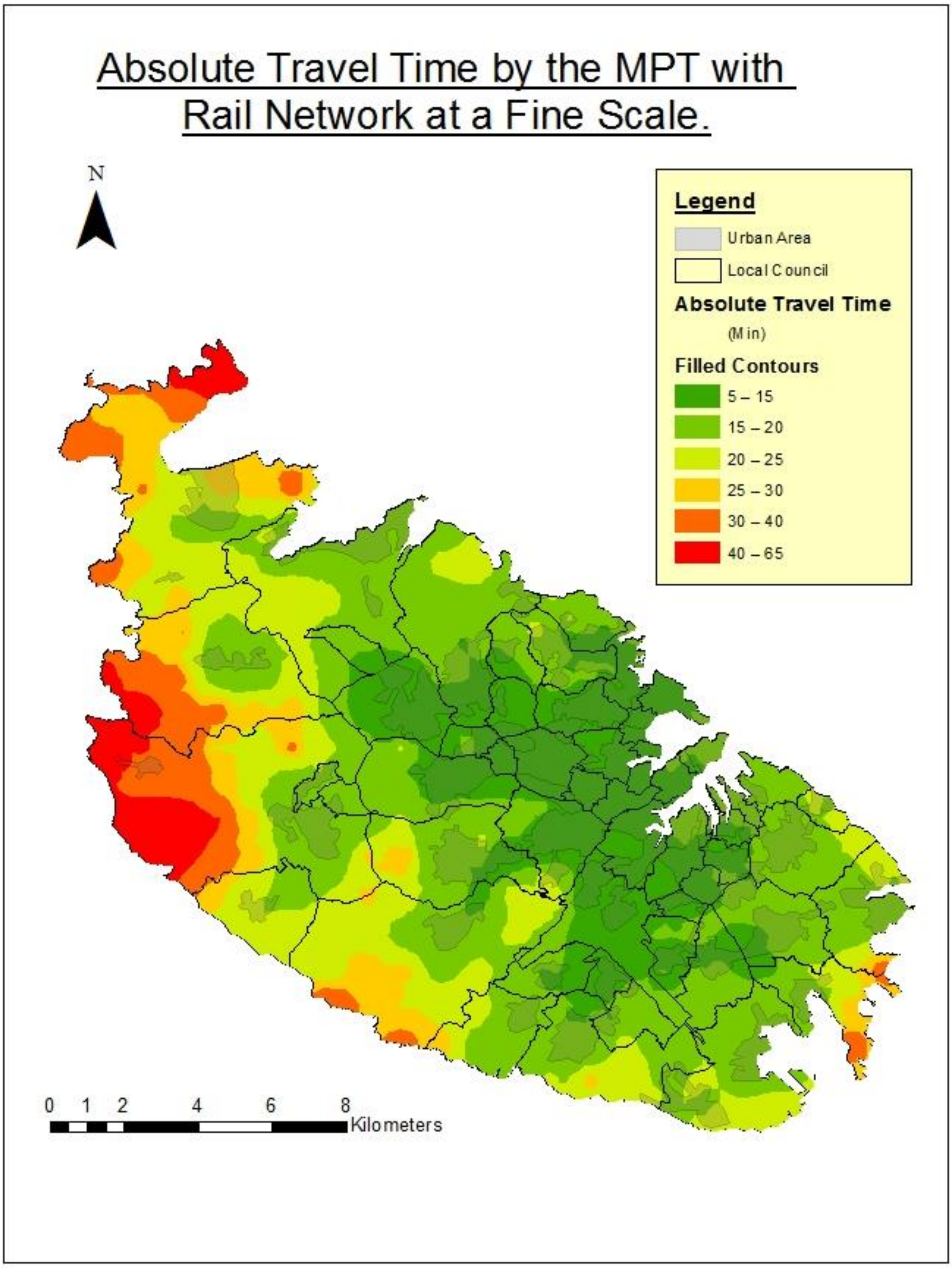

Figure 41: Absolute Travel Time by the MPT with Rail Network at a Fine Scale

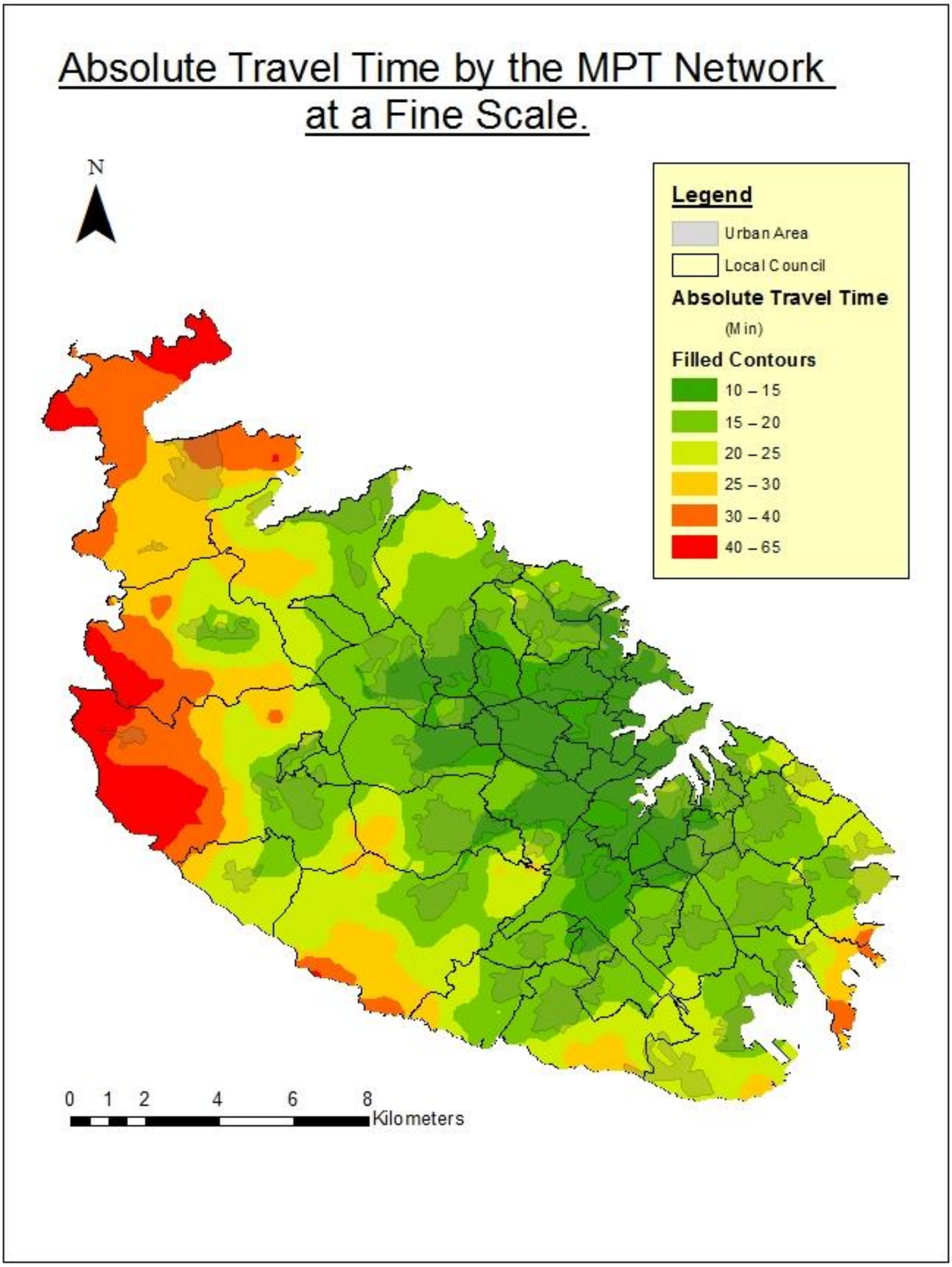

Figure 42: Absolute Travel Time by the MPT Network at a Fine Scale

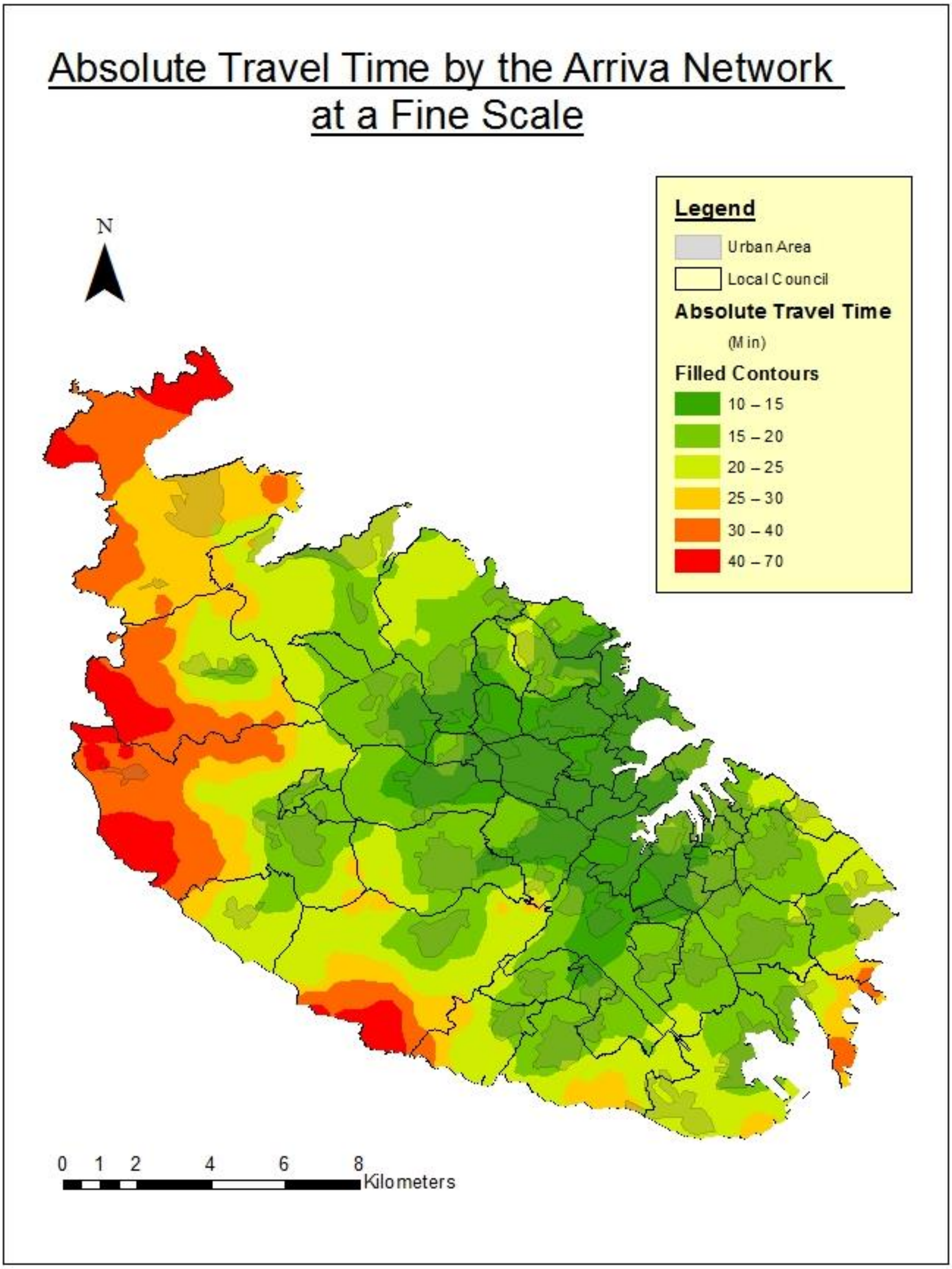

Figure 43: Absolute Travel Time by the Arriva Network at a Fine Scale

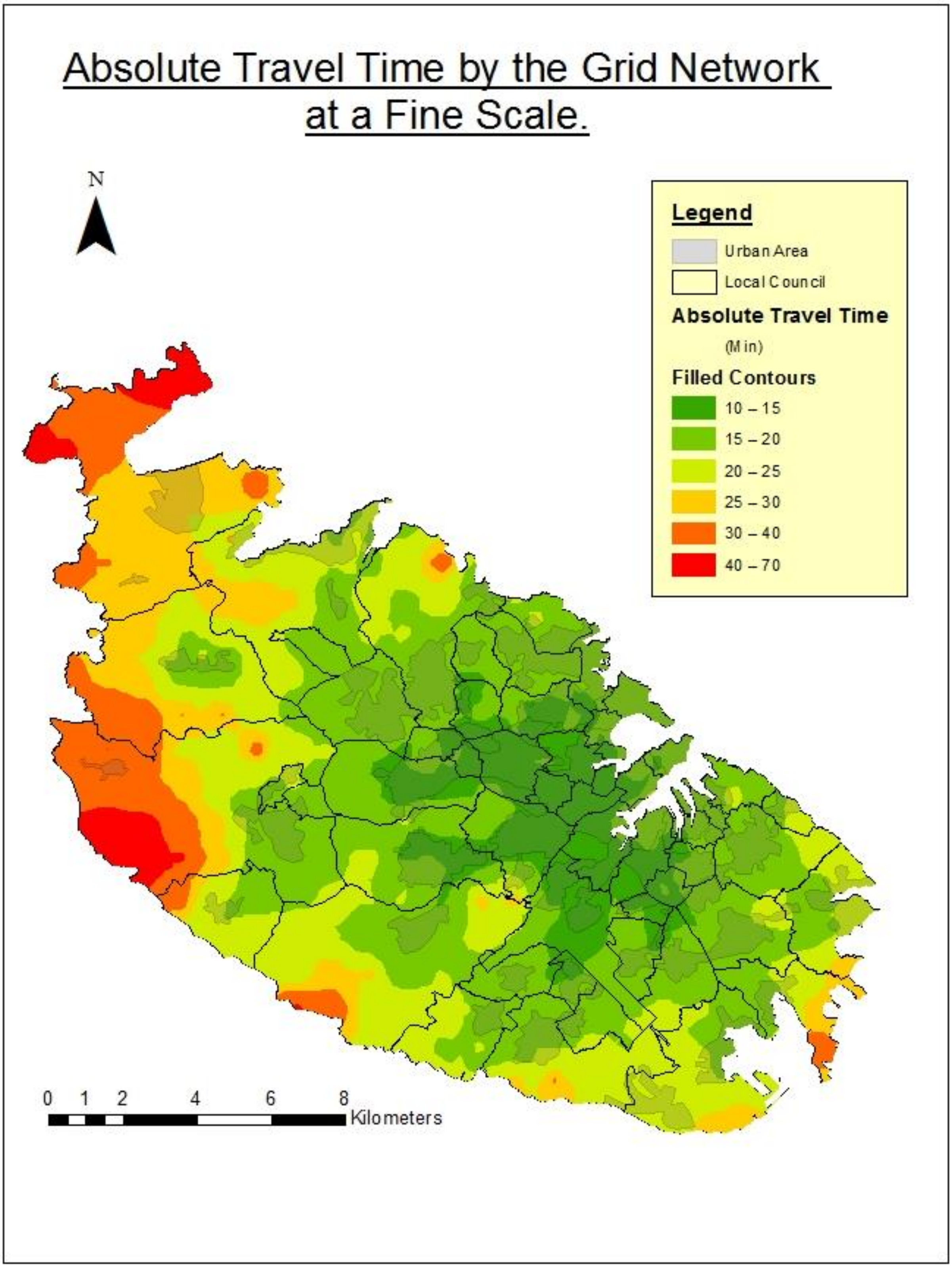

Figure 44: Absolute Travel Time by the Grid Network at a Fine Scale

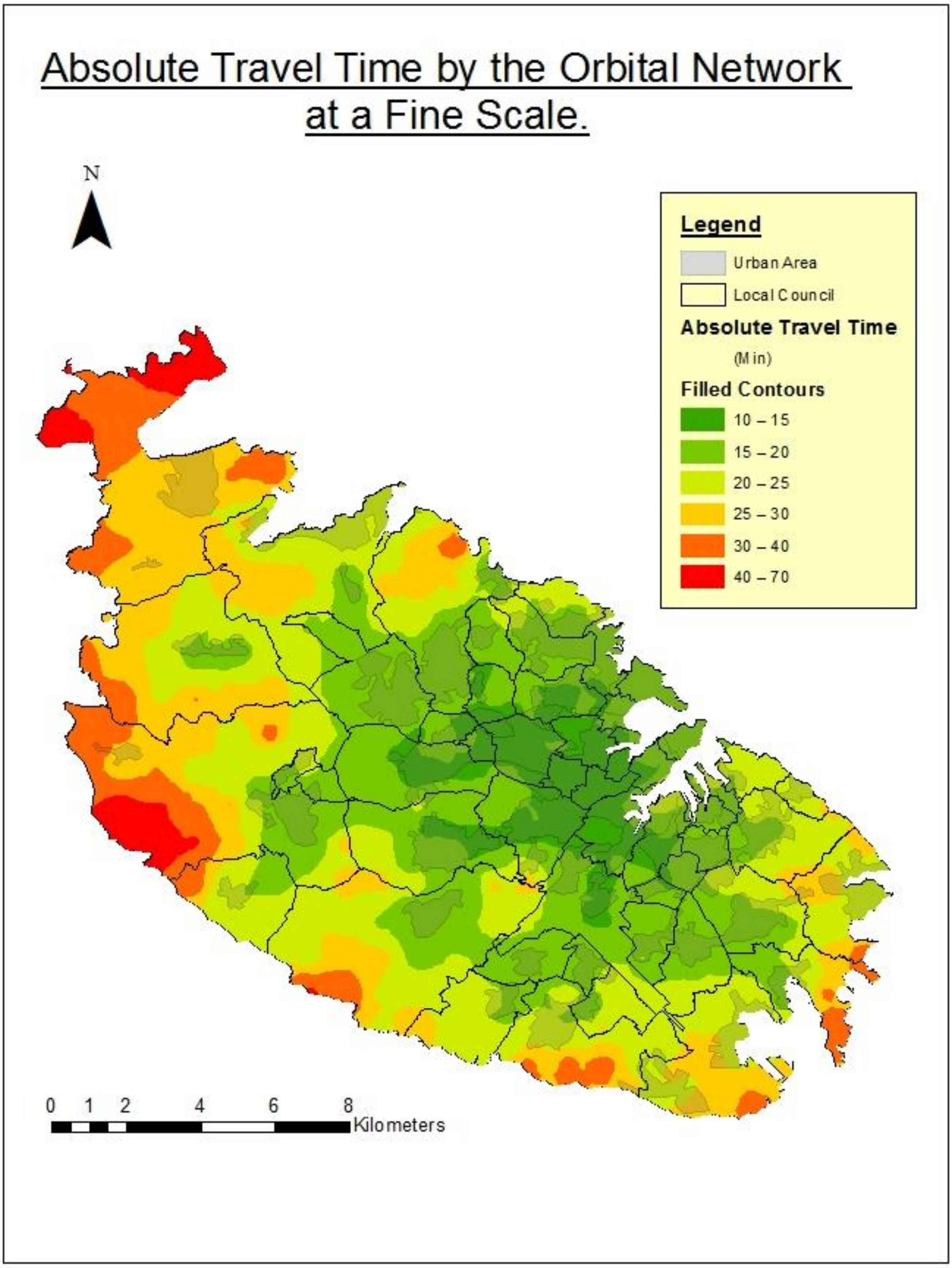

Figure 45: Absolute Travel Time by the Orbital Network at a Fine Scale

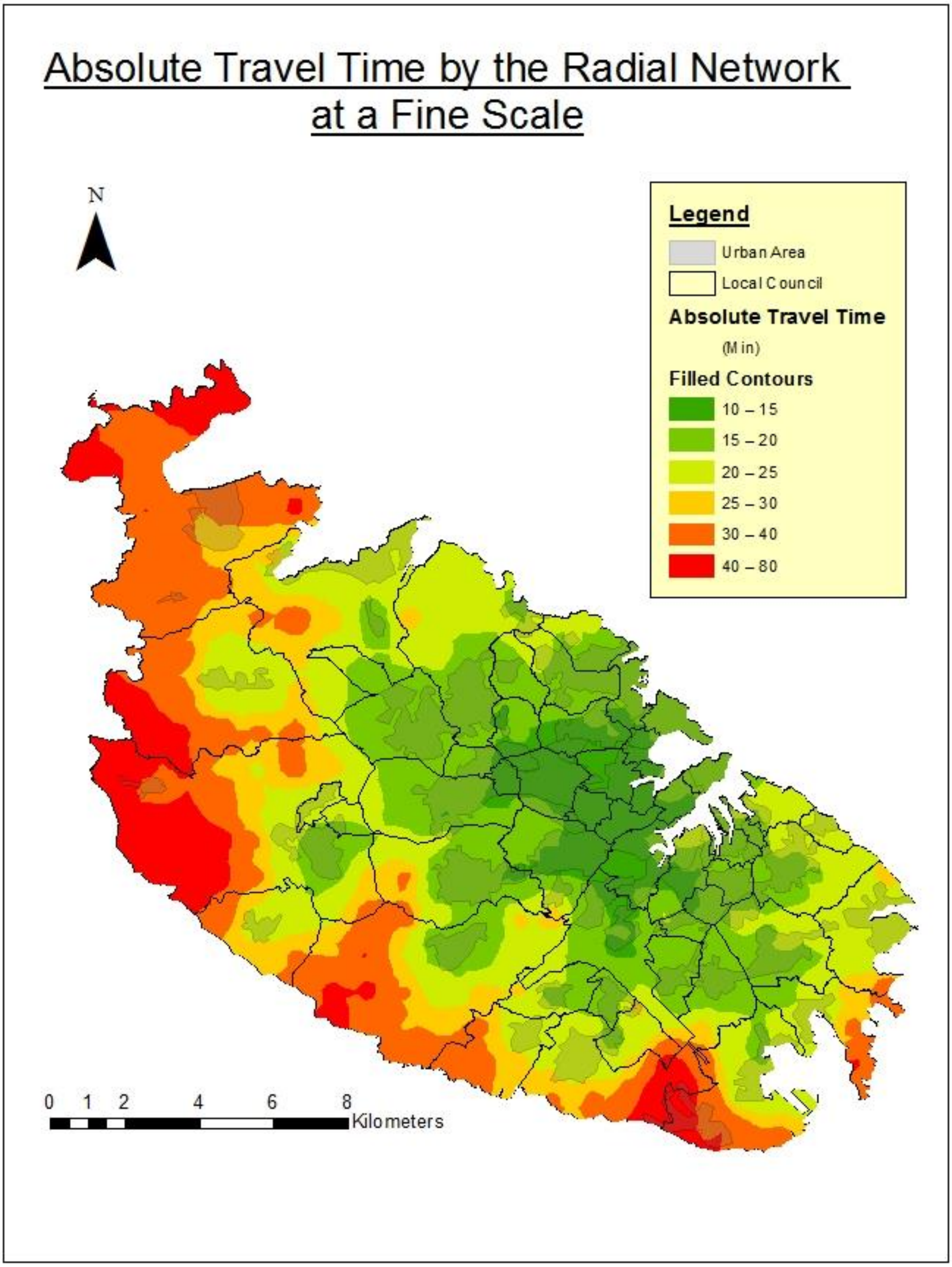

Figure 46: Absolute Travel Time by the Radial Network at a Fine Scale

4.5. MAG of Absolute Travel Time at a Fine Scale

The results at the fine spatial scale also reveal that whereas the Arriva and MPT networks provide a large area with 10 minute accessibility level, outside of this area, the level of accessibility drops much more steeply than the Grid network. The Grid network can thus be said to be able to offer a more balanced accessibility level across the whole country than the Arriva and Grid networks which favour the harbour areas. The Orbital network also seems to exhibit a fairly balance accessibility level across the whole country though by a factor of 0.1

The shortcomings of the Radial network are especially evident in the fine spatial scale, in which large swaths of public transport disadvantage are present in the peripheral areas.

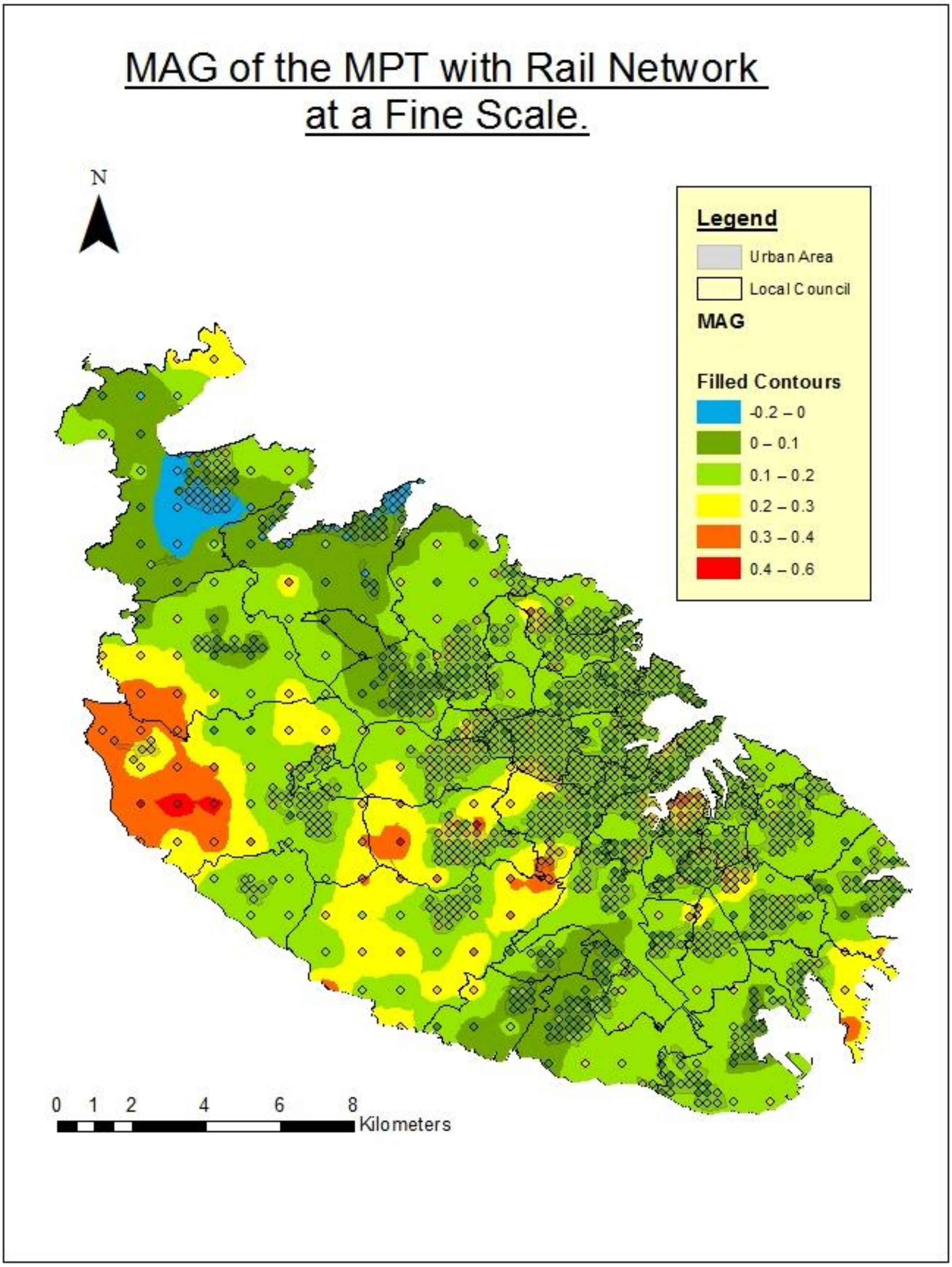

Figure 47: MAG of the MPT with Rail Network at a Fine Scale

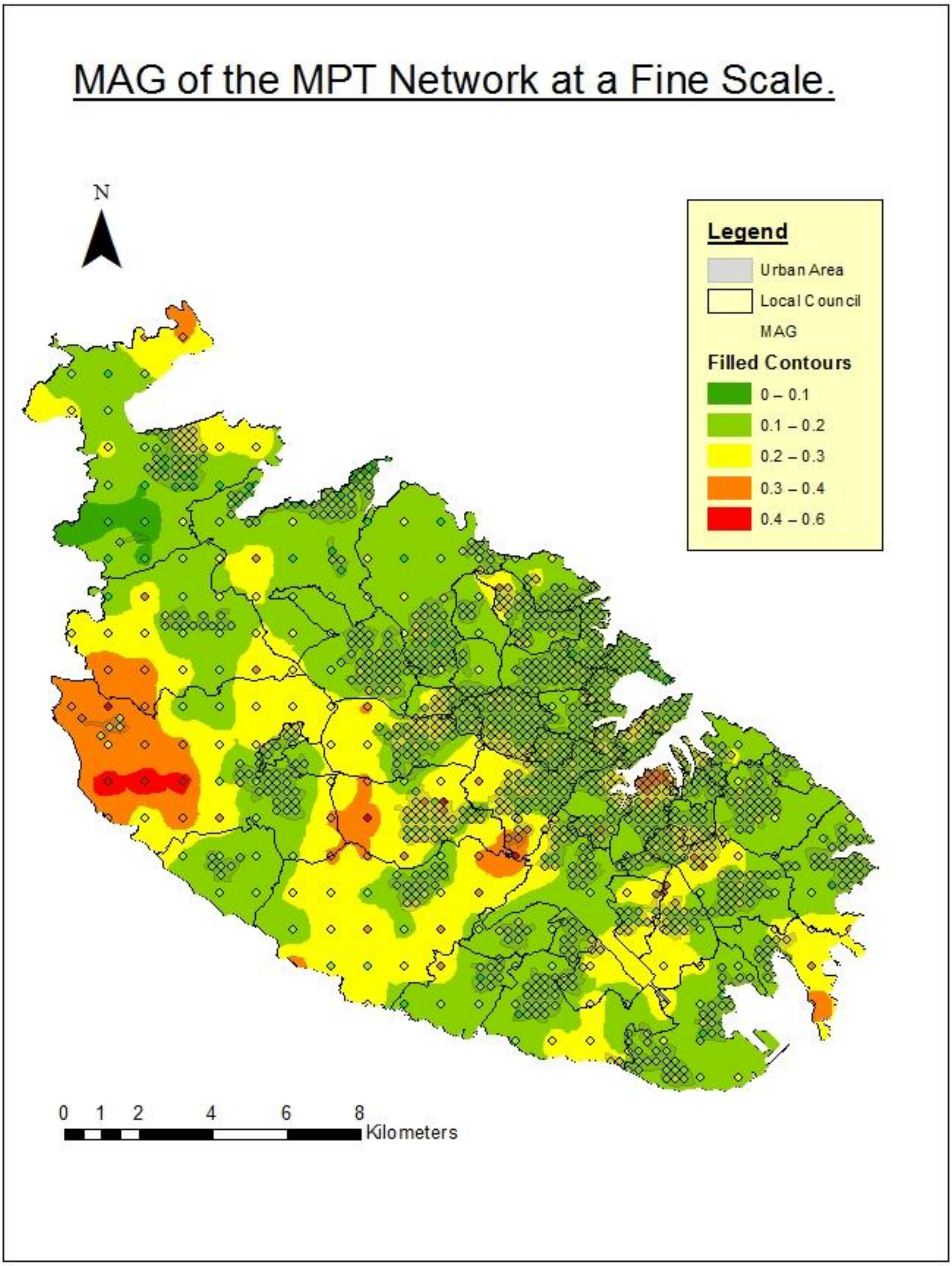

Figure 48: MAG of the MPT Network at a Fine Scale

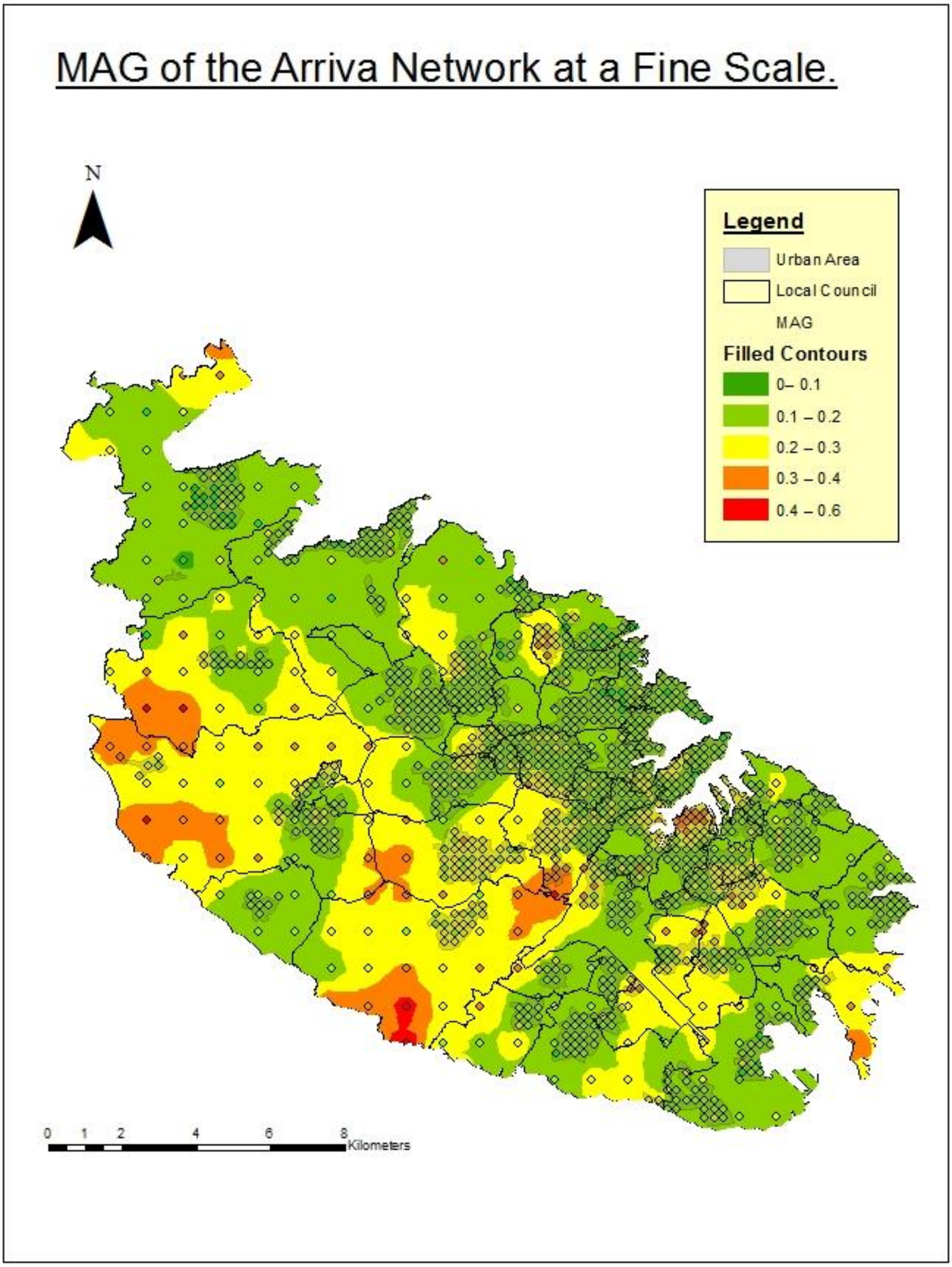

Figure 49: MAG of the Arriva Network at a Fine Scale

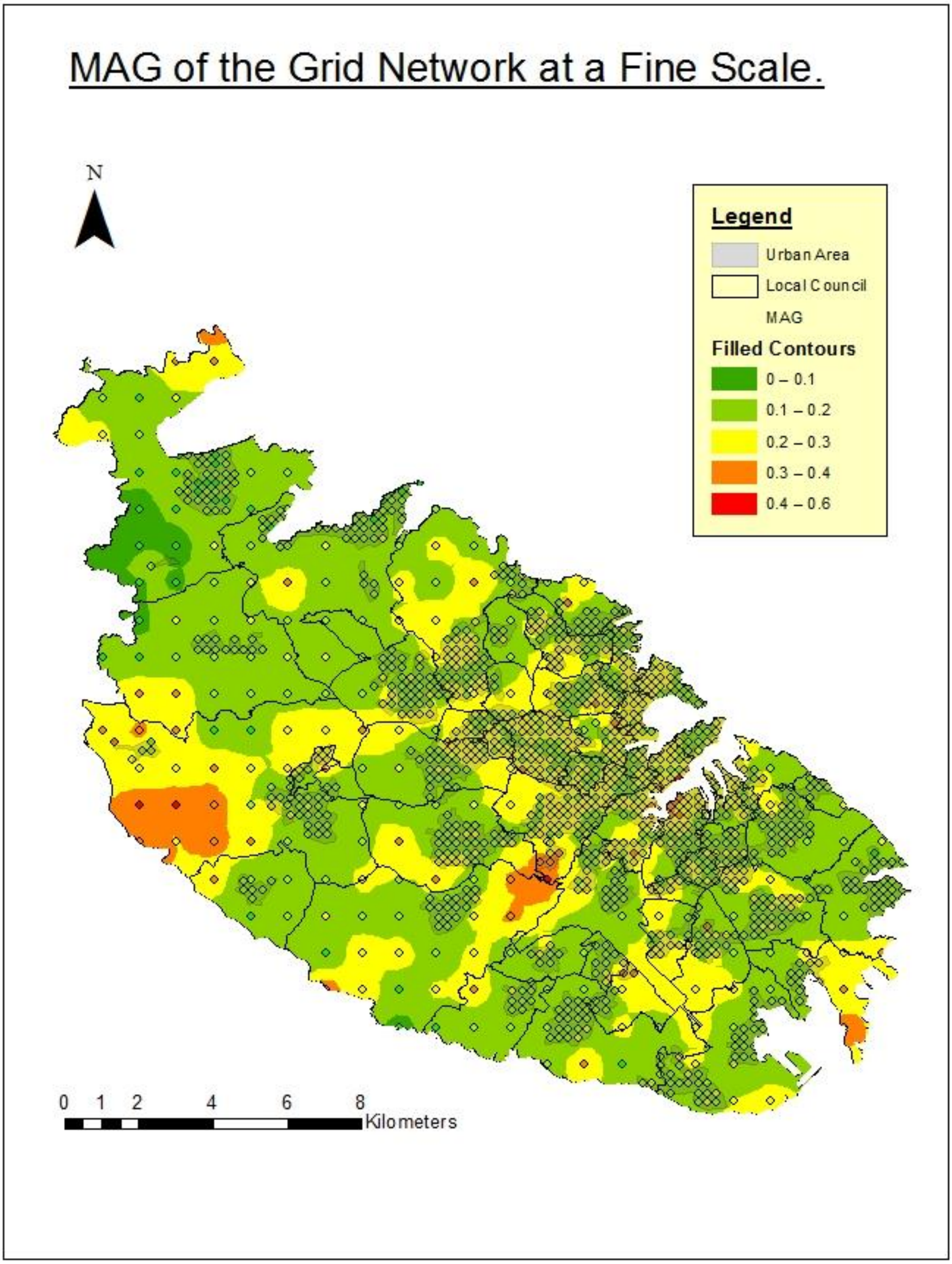

Figure 50: MAG of the Grid Network at a Fine Scale

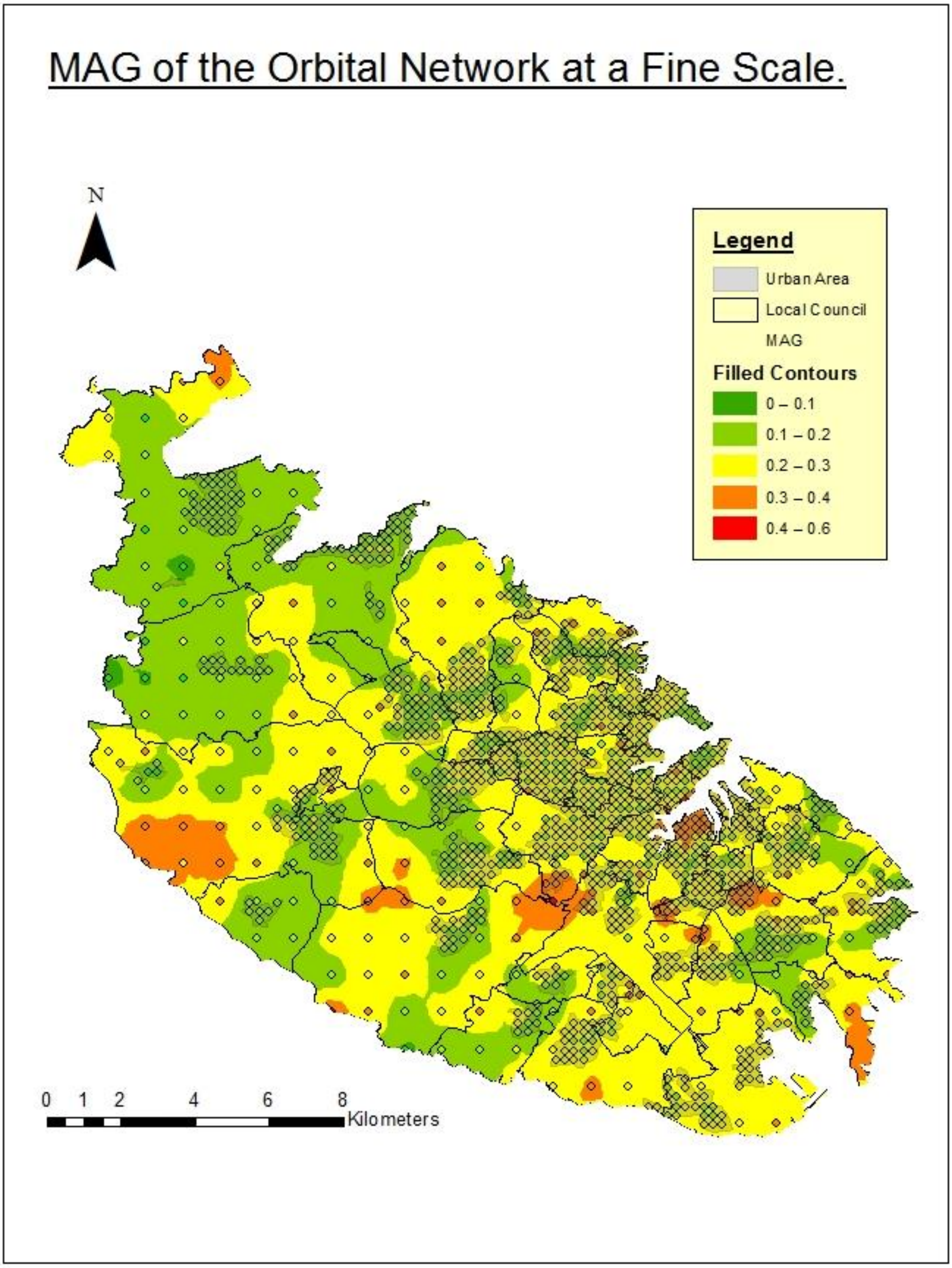

Figure 51: MAG of the Orbital Network at a Fine Scale

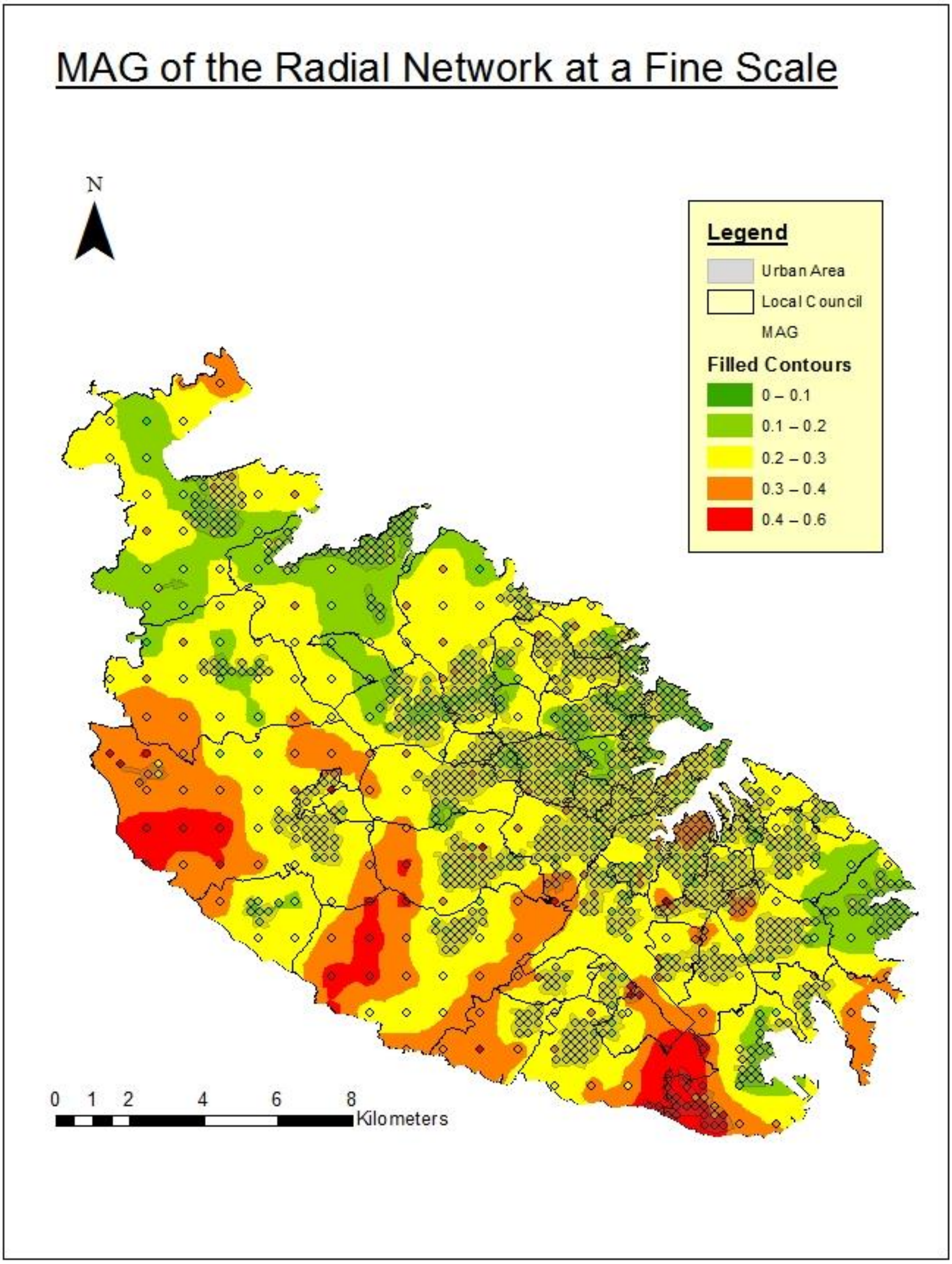

Figure 52: MAG of the Radial Network at a Fine Scale

4.6. Weighted Travel Time

All the maps exhibit the same trend in the importance of the central and eastern areas of the islands. The results indicate that the proportion of travellers able to enjoy the transport infrastructure is by far that of the car users. In all public transport networks Mellieħa Local Council is the local council in which its residents are the least able to enjoy the transport system and the least link to be of importance.

Of the public transport networks, only the MPT and Arriva are able to service local councils with a weighted travel time of less than 10 minutes. On the other hand, the Grid network demonstrates that in general a larger extent of 15 minute weighted travel time and apart from Mellieħa Local Council, all other council areas have a value of 20 minutes weighted travel time. The Orbital network is the network with the most local councils that are relatively less able to enjoy the transport system, especially in the periphery.

Finally the rail has a positive effect in improving the links of both the Mellieħa Local Council and the local councils in the south of the island. The results also show a modest increase in the local council areas in the centre of the island that have a better enjoyment of the transport system if a rail was added to the MPT network.

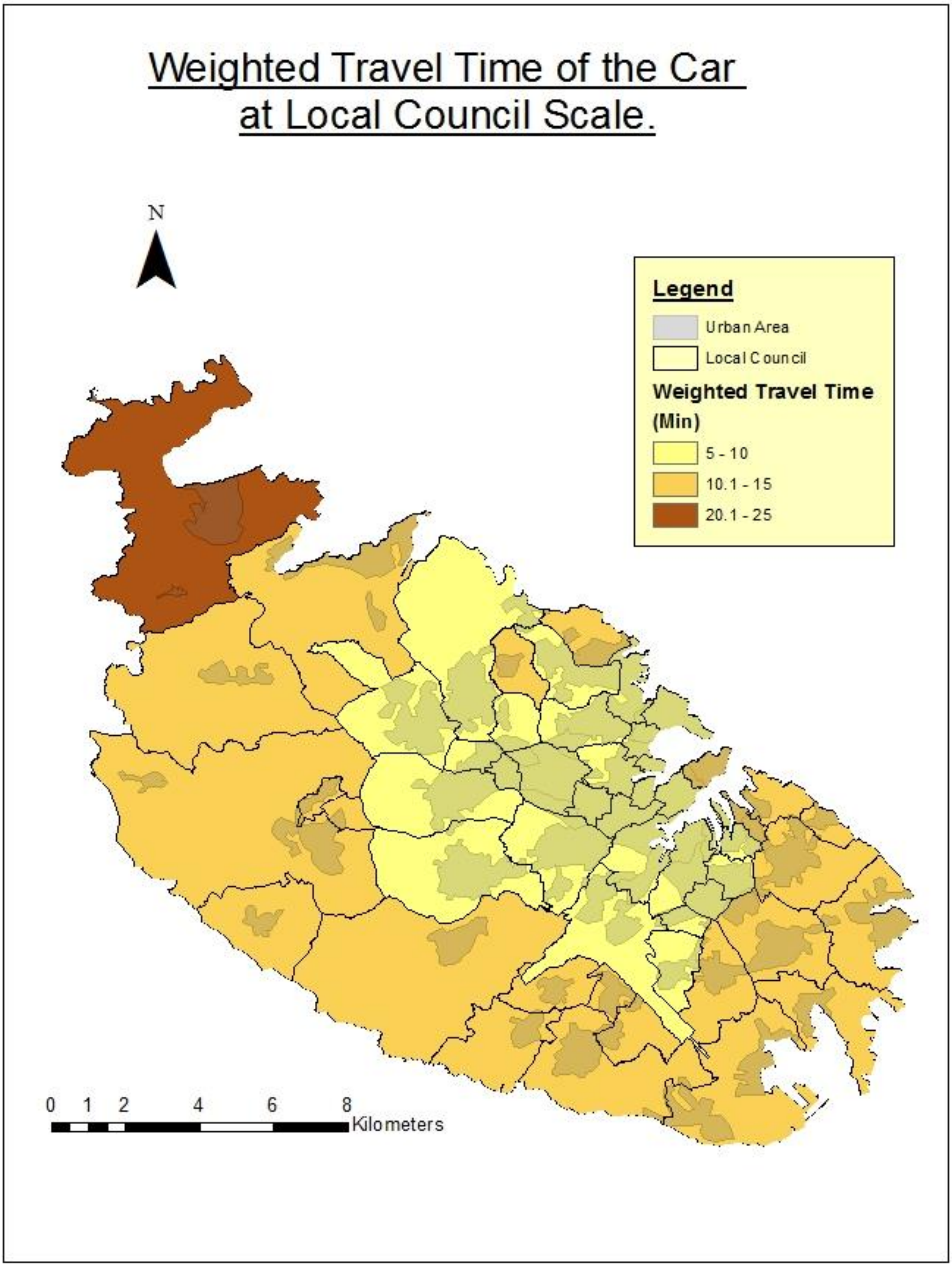

Figure 53: Weighted Travel Time of the Car at Local Council Scale

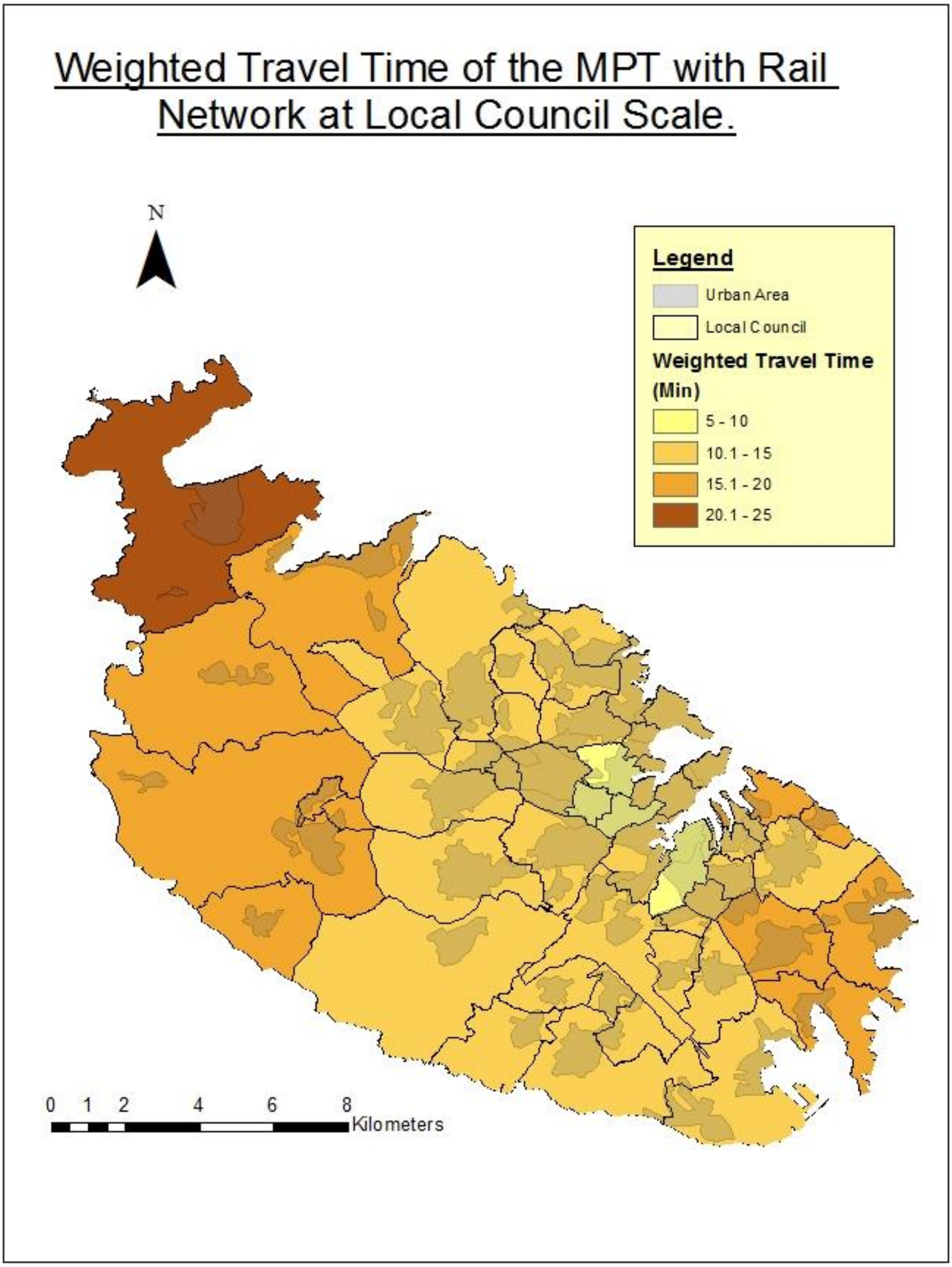

Figure 54: Weighted Travel Time of the MPT with Rail Network at Local Council Scale

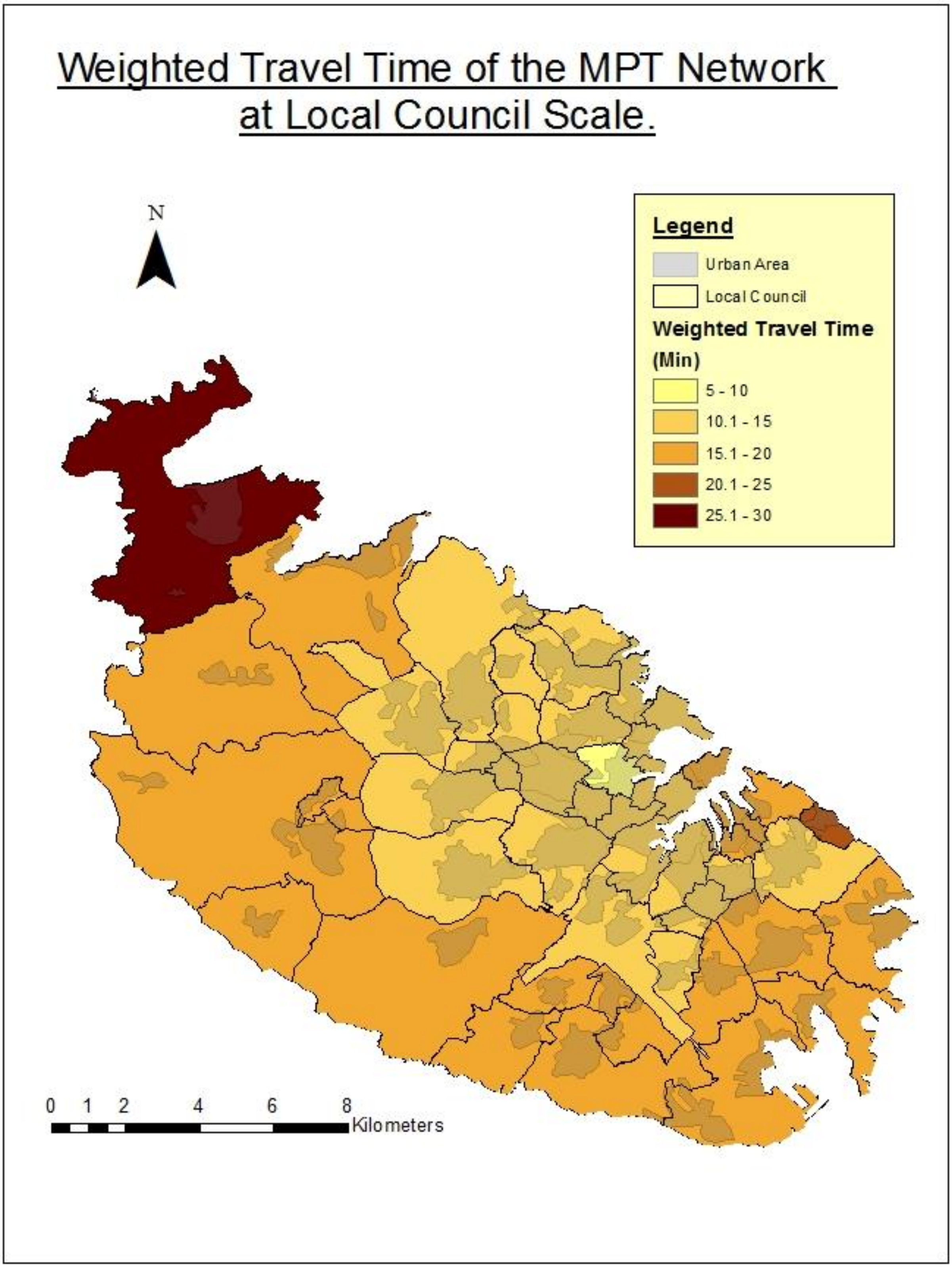

Figure 55: Weighted Travel Time of the MPT Network at Local Council Scale

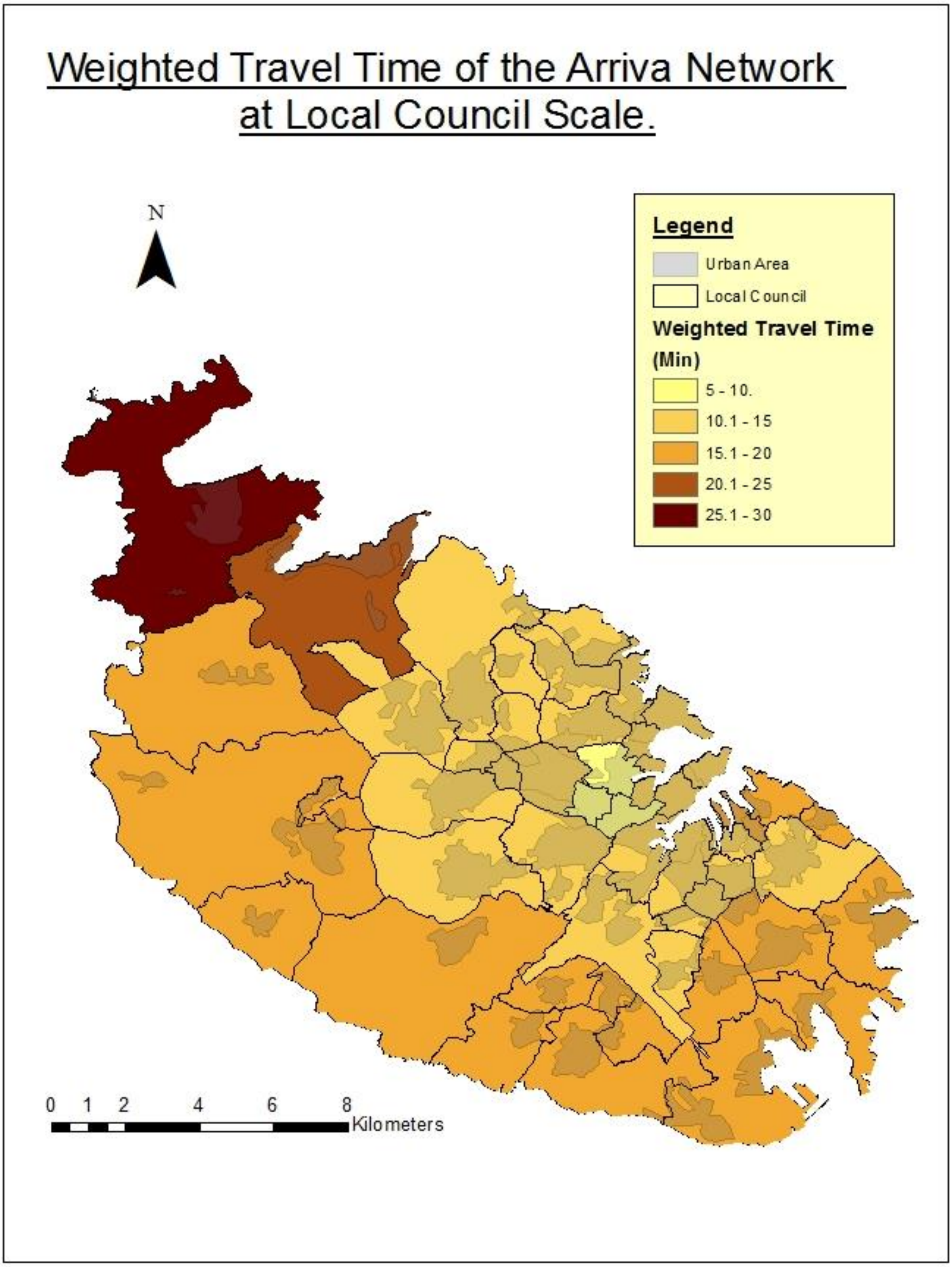

Figure 56: Weighted Travel Time of the Arriva Network at Local Council Scale

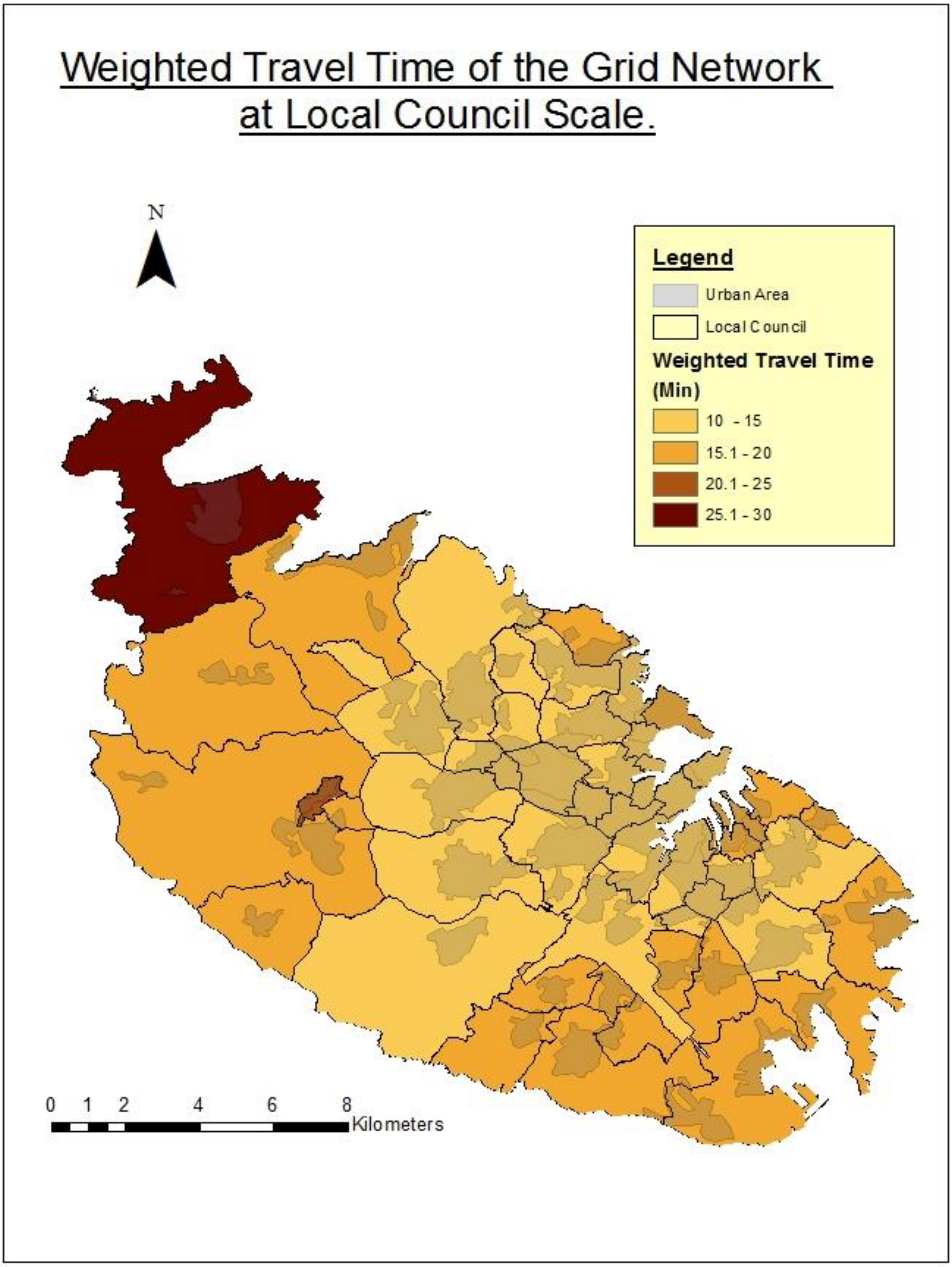

Figure 57: Weighted Travel Time of the Grid Network at Local Council Scale

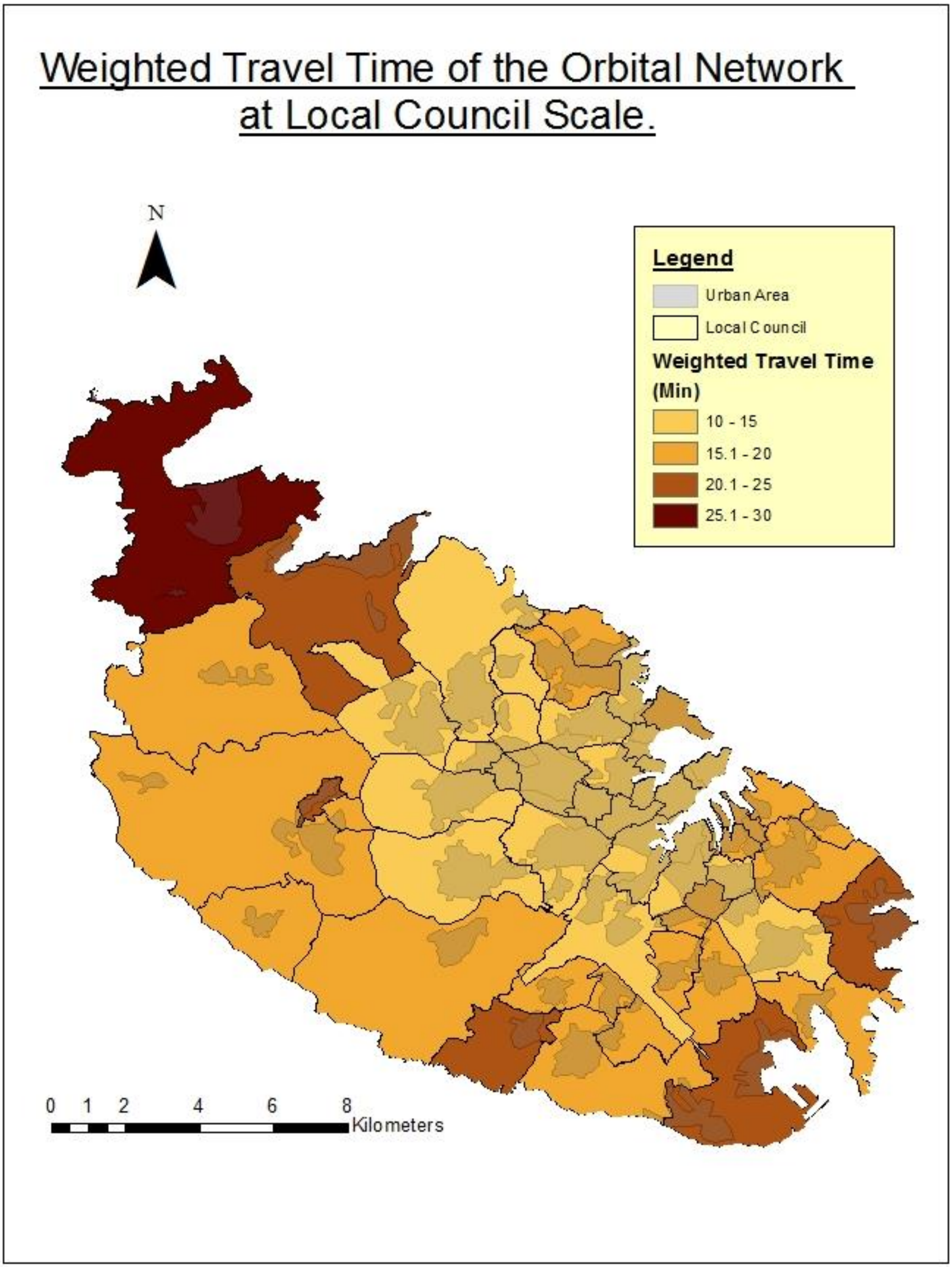

Figure 58: Weighted Travel Time of the Orbital Network at Local Council Scale

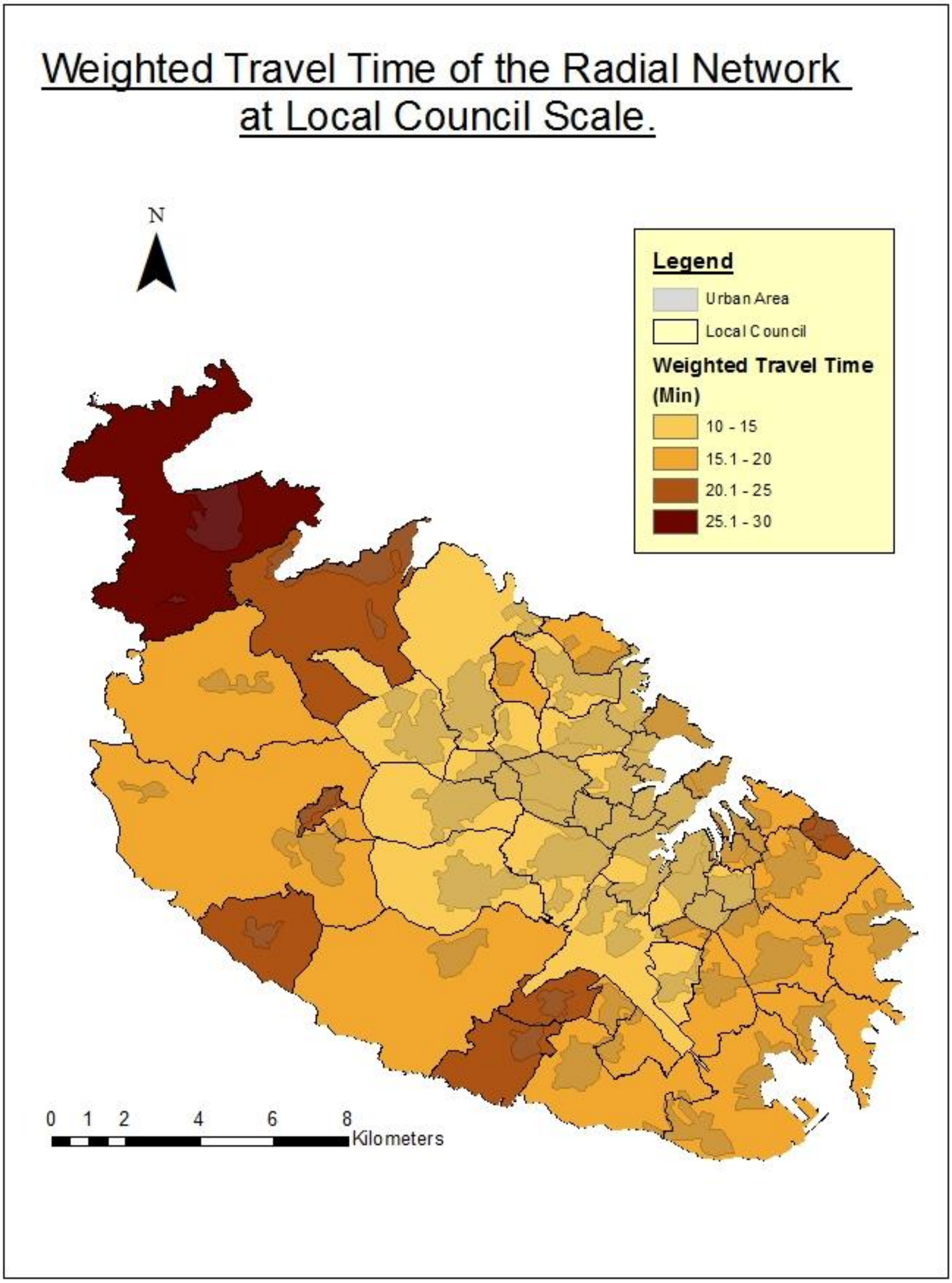

Figure 59: Weighted Travel Time of the Radial Network at Local Council Scale

4.7. Economic Potential

The results point to the car as the mode that by far has the greatest potential to drive the economy, especially in the central and eastern areas. The MPT and the Grid network have surprisingly the same economic potential, whilst the Arriva network offers an inferior economic potential to the Grid network. The Orbital and the Radial networks are the designs that offer the least potential for economic activity. Whilst the Orbital network offers better potential for economic activity in the Northern Harbour Area, both exhibit a local council in the south that has a low potential for economic activity.

All public transport networks offer the Mellieħa Local Council with the least economic potential. This means that network design has no effect on the economic potential of this local council. Economic potential is only improved when a rail network is added to the MPT model. The rail also improves the economic potential of a number of other centrally located local councils, though the economic potential that the car can offer is never reached.

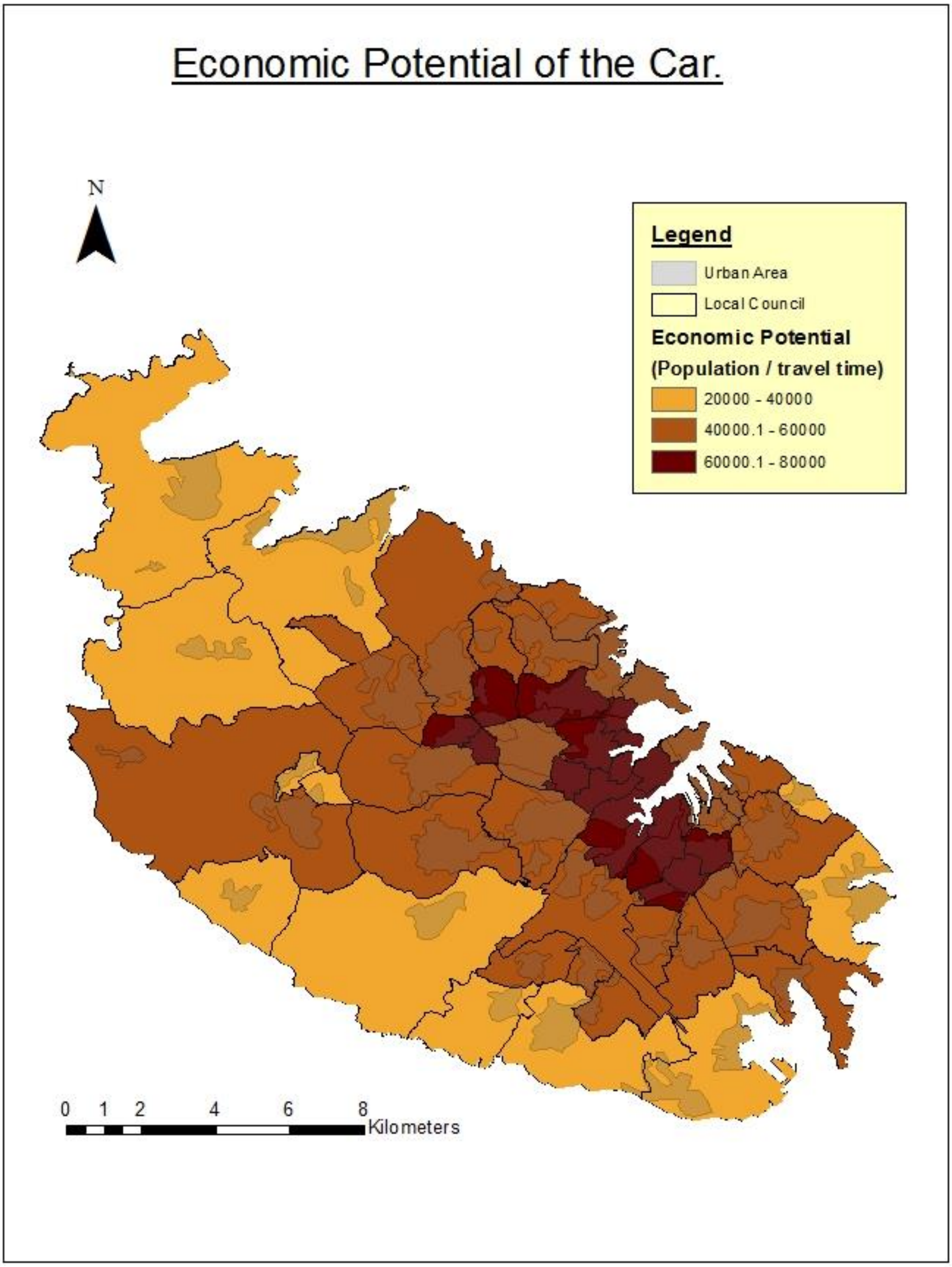

Figure 60: Economic Potential of the Car

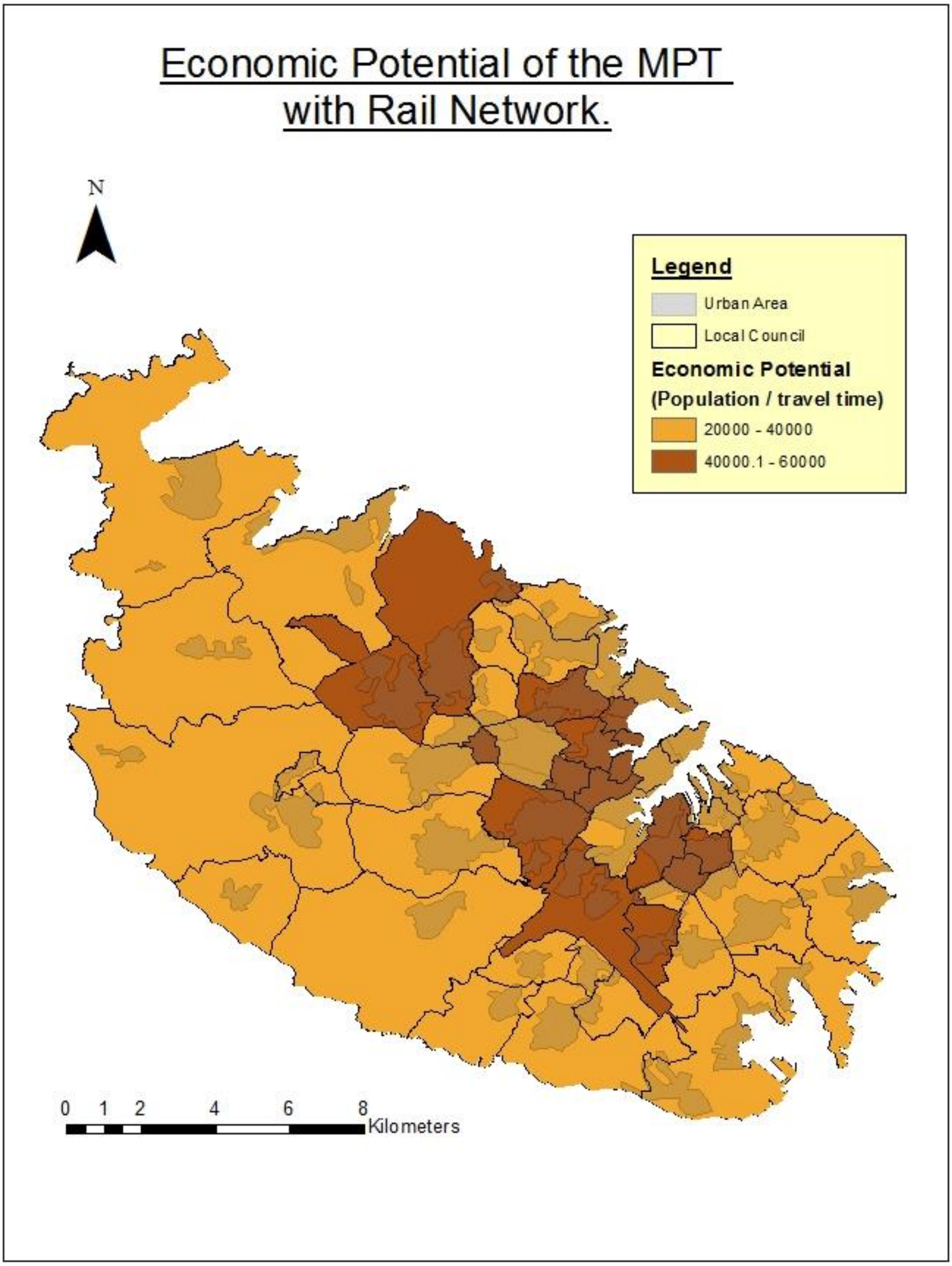

Figure 61: Economic Potential of the MPT with Rail Network

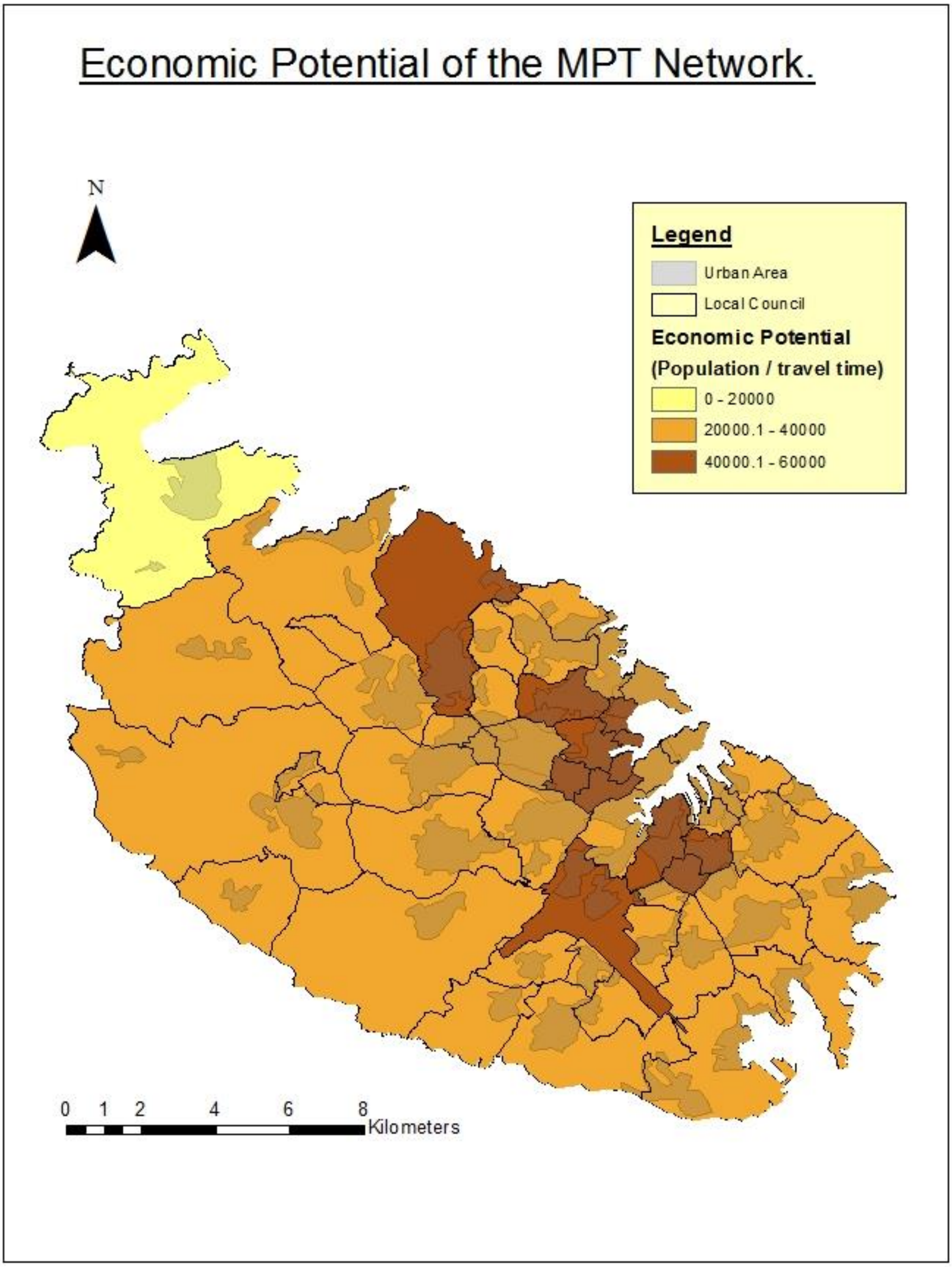

Figure 62: Economic Potential of the MPT Network

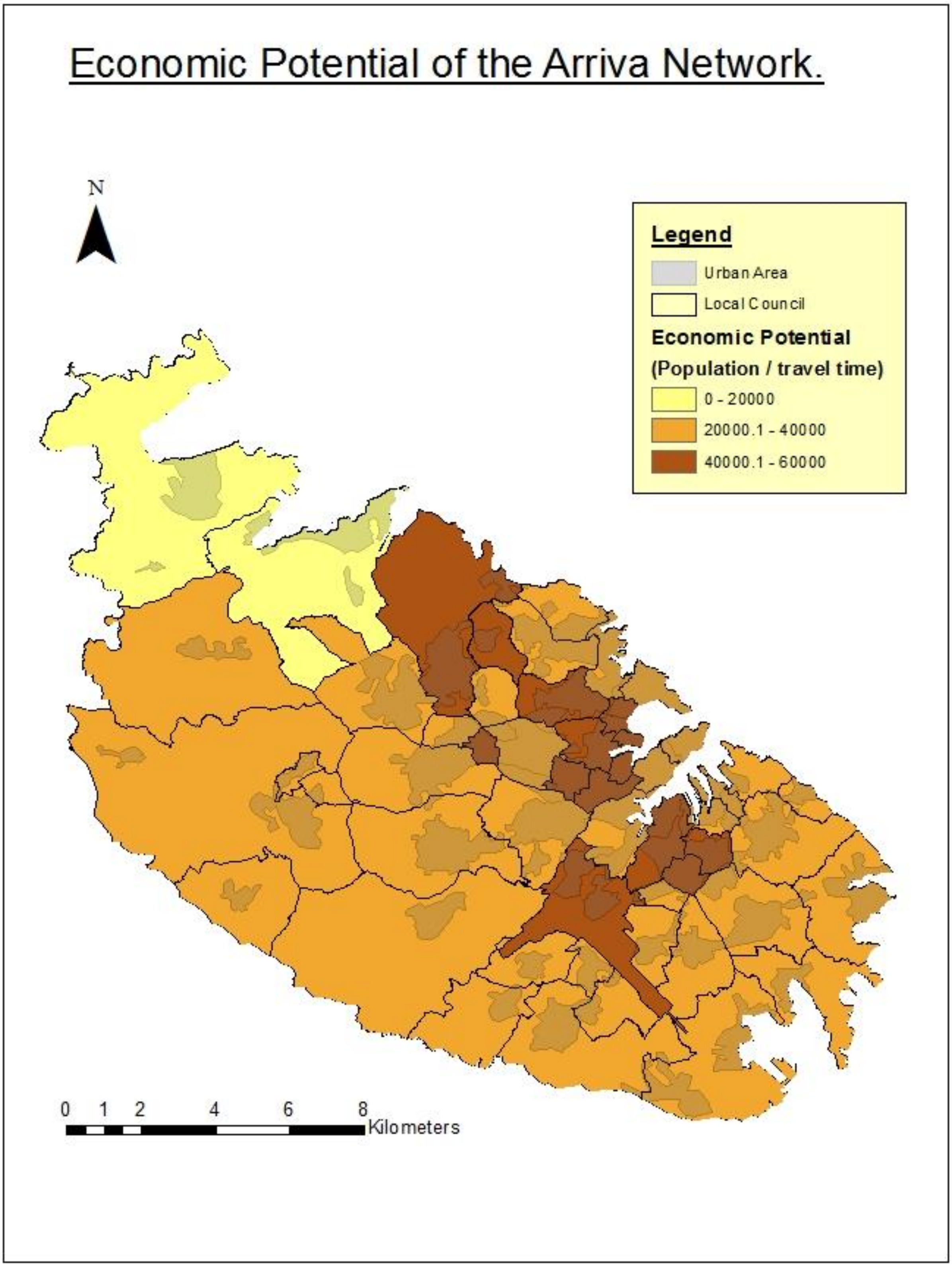

Figure 63: Economic Potential of the Arriva Network

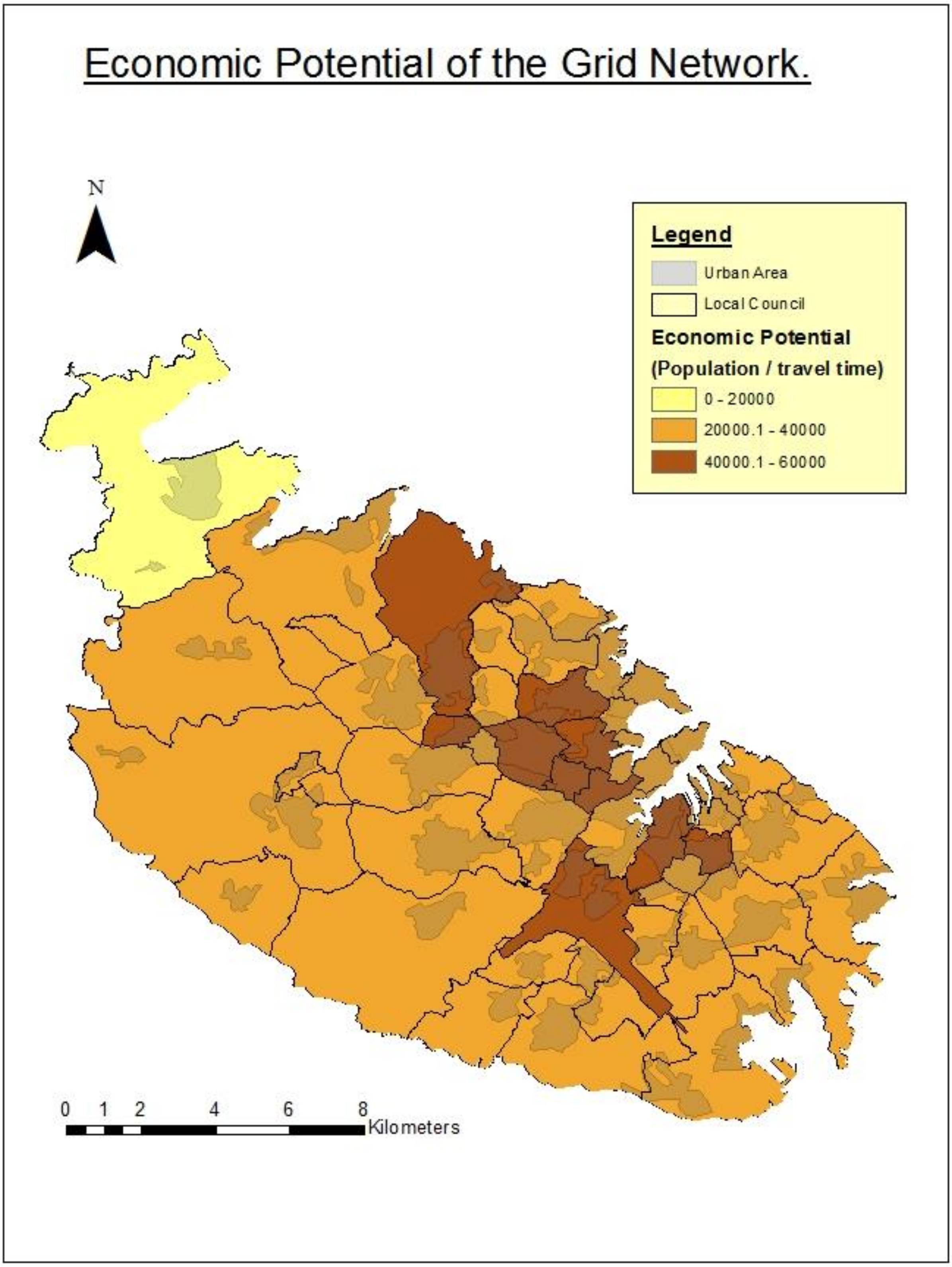

Figure 64; Economic Potential of the Grid Network

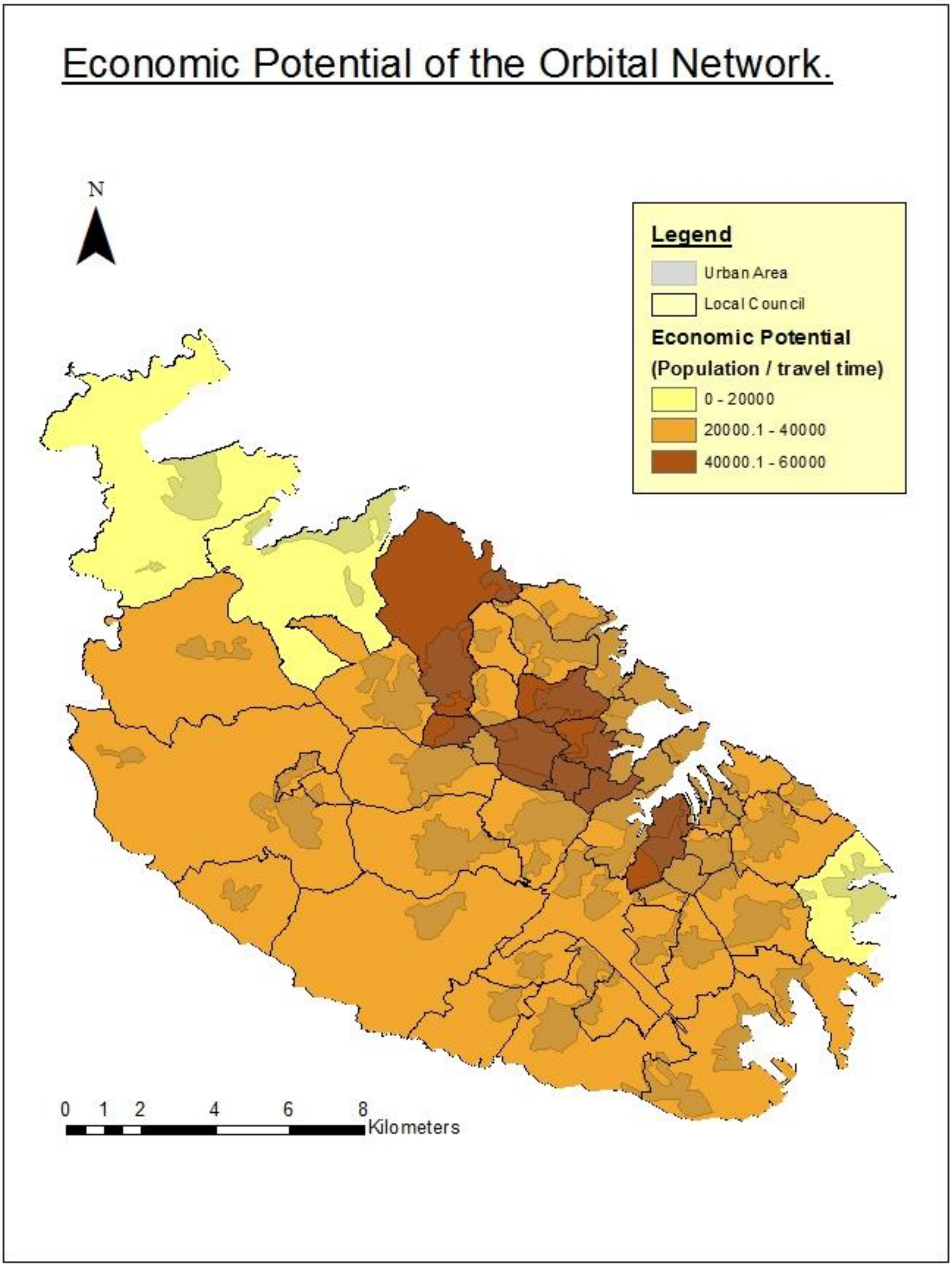

Figure 65: Economic Potential of the Orbital Network

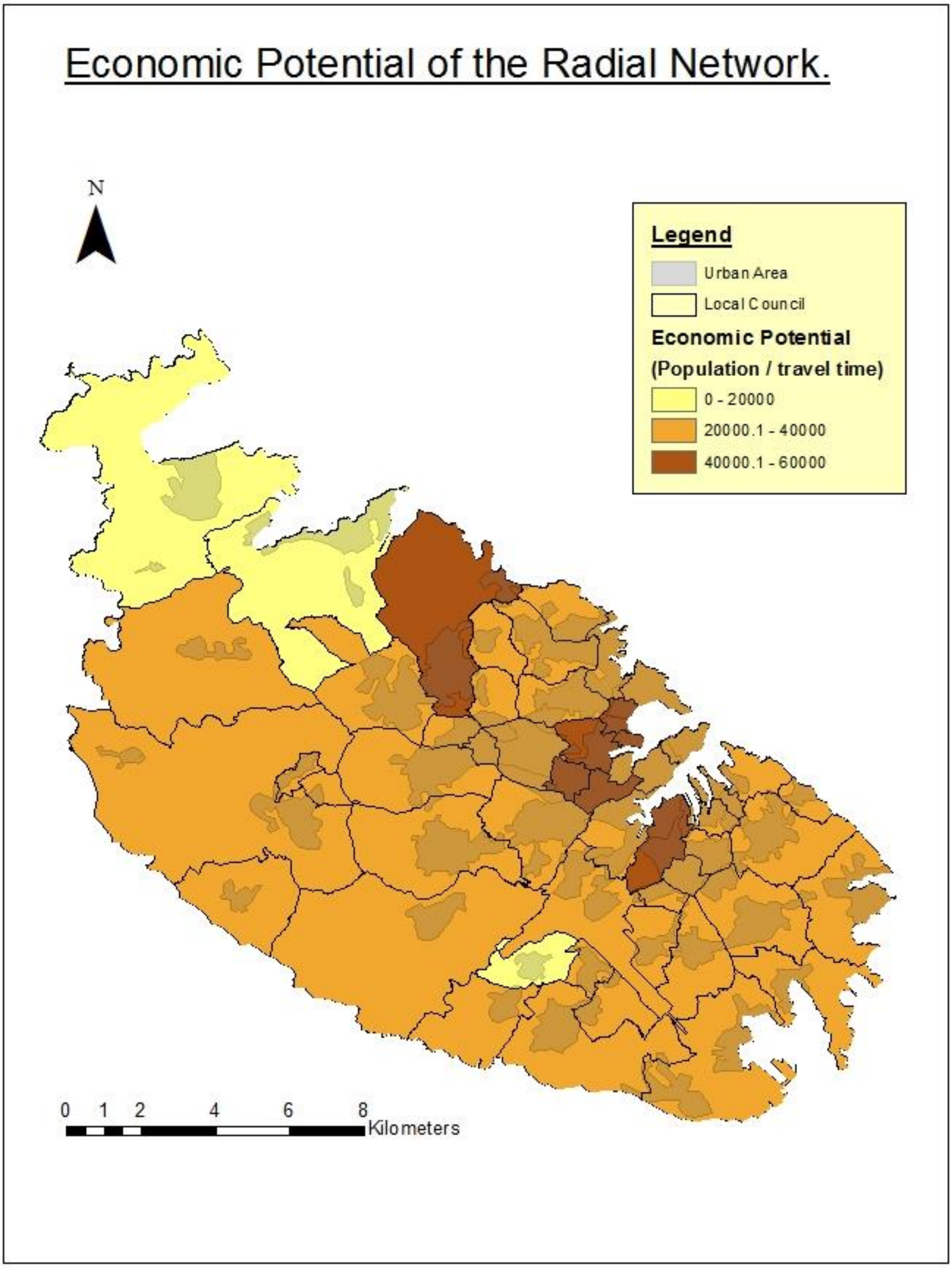

Figure 66: Economic Potential of the Radial Network

CHAPTER 5

DISCUSSION

5.1. Introduction

All of the results show that the car is by far the transport mode that is able to provide the best accessibility levels and economic benefits to the prospective travellers. The public transport network design with the best average absolute travel time results is the MPT design. Conversely, the Orbital network although outperforming the Radial network was drastically outperformed by the Grid network which better adhered to Nielsen et al.'s (2005) principles. It is safe to conclude therefore that a network design based on orbital networks is in general, not the best network design to make a competitive public transportation system within small islands.

5.2. Grid versus MPT

In general, the results seem to suggest that urban areas are best serviced by the MPT network whereas the rural areas are best served by the Grid network. The network design best suited for Malta therefore is the MPT network because it is able to serve better a larger segment of the population. The result is unexpected because in practice the Grid was designed to adhere to Nielsen et al.'s (2005) principles. The unexpected result may have been caused by: either the assessment method not being adequate or Nielsen et al.'s (2005) principles do not apply for geographies that are similar to Malta's. To try to better understand the reason for such an unexpected outcome equation 2 was used again, this time substituting travel time by car (t_{cj}) with travel time by the MPT network (t_{MPTj}) and travel time by public transport (t_{cj}) with travel time by the Grid Network (t_{GRDj}). The final equation therefore is:

$$\mathbf{MAG} = \frac{\sum t_{GRDj} - \sum t_{MPTj}}{\sum t_{GRDj} + \sum t_{MPTj}} \qquad \textbf{(eq. 7)}$$

where $\mathbf{t_{MPTj}}$ denotes the average absolute travel time of the MPT network at point j and $\mathbf{t_{GRDj}}$ denotes absolute travel time of the Grid network at point j.

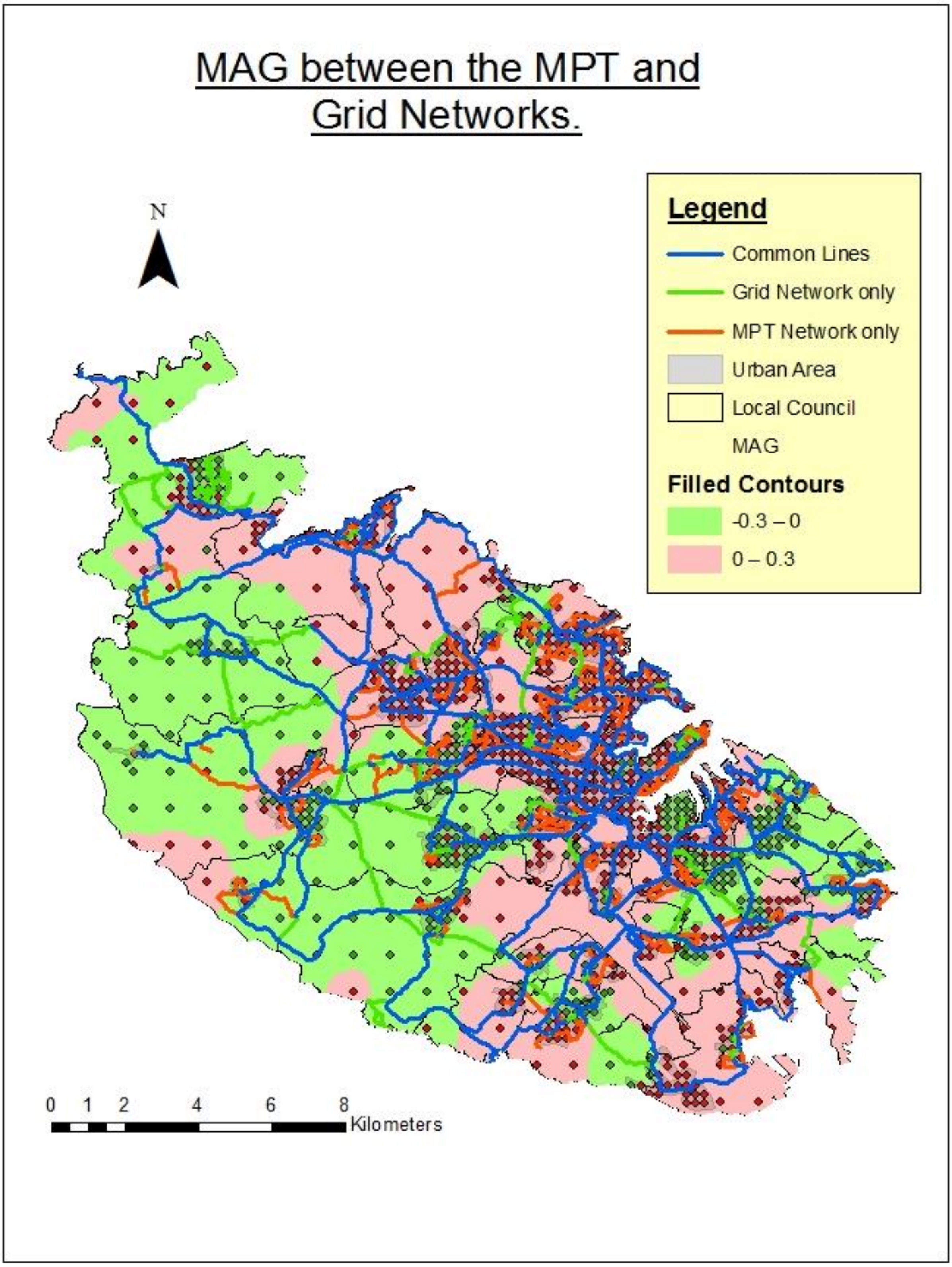

Figure 67: MAG between the MPT and Grid Networks

The map (figure 67) reaffirms the previous results that urban areas are better served by the MPT network than the Grid network. The better service provided by the Grid network, symbolised as the green corridor in Żabbar Local Council, Fgura Local Council, Tarxien Local Council and Żejtun Local Council to the east of the country; and the green area in Mġarr Local Council and the village of Baħrija to the west of the country may be attributed to the more dispersed design of the Grid network whilst the dominance of the MPT network in the Northern Harbour Area can be attributed to the peninsular geography of the country which favours a more radial design.

If the geographical claim is to be pursued however than the conclusion that is derived from the results is that in a planar geographical area a grid-like network is desirable whereas in peninsular areas such as near the coast, for example in the Northern Harbour Area, a radial design is preferred. Upon further inspection of the map however it is clear that although there are areas in which preference for a particular network is dominant, it does not hold true for all origins, for example in Rabat Local Council area (figure 68) and in Paola – Tarxien – Fgura local council area (figure 69). The phenomenon at play here that seems to have an important role in the determination of the final accessibility value is access time.

Access time on its own though does not explain the entire possibilities of such outlier results. There are outlier origins, for example in Santa Luċija Local Council and Gudja Local Council that although they may have a longer access time than the other dominant origins in the area they would still exhibit a preference for the network with the longer access time. This result may be explained because the MPT network does not adhere to Nielsen et al.'s (2005) principle of servicing an area through its middle, servicing it instead by circuitous routes within them. The effort to reduce access time has resulted in longer travel times for these outlier origins that are located at the beginning of the loop with the result that from such origins it is, in general, quicker to walk to the network with the longer access time than to walk a short distance and then ride the whole circuit.

The results of this thesis therefore suggest that there are two dominant factors at play that affect public transport travel time: the geography of the land on a small scale, and access time at a larger scale. The results also show that network design influences design at both a large and a small scale. The results from the fine scale models of this thesis also lay bare how spatially dynamic accessibility really is, even when the change in distance is small. The results indicate that if tastes and perceptions are assumed to be constant, then accessibility can change even in the same street. A street may contain different levels of accessibility in its different parts. This rate of change is not constant and may even be reversed along its length. The results of this thesis hence further support the view that accessibility studies should be conducted at a large a scale as possible.

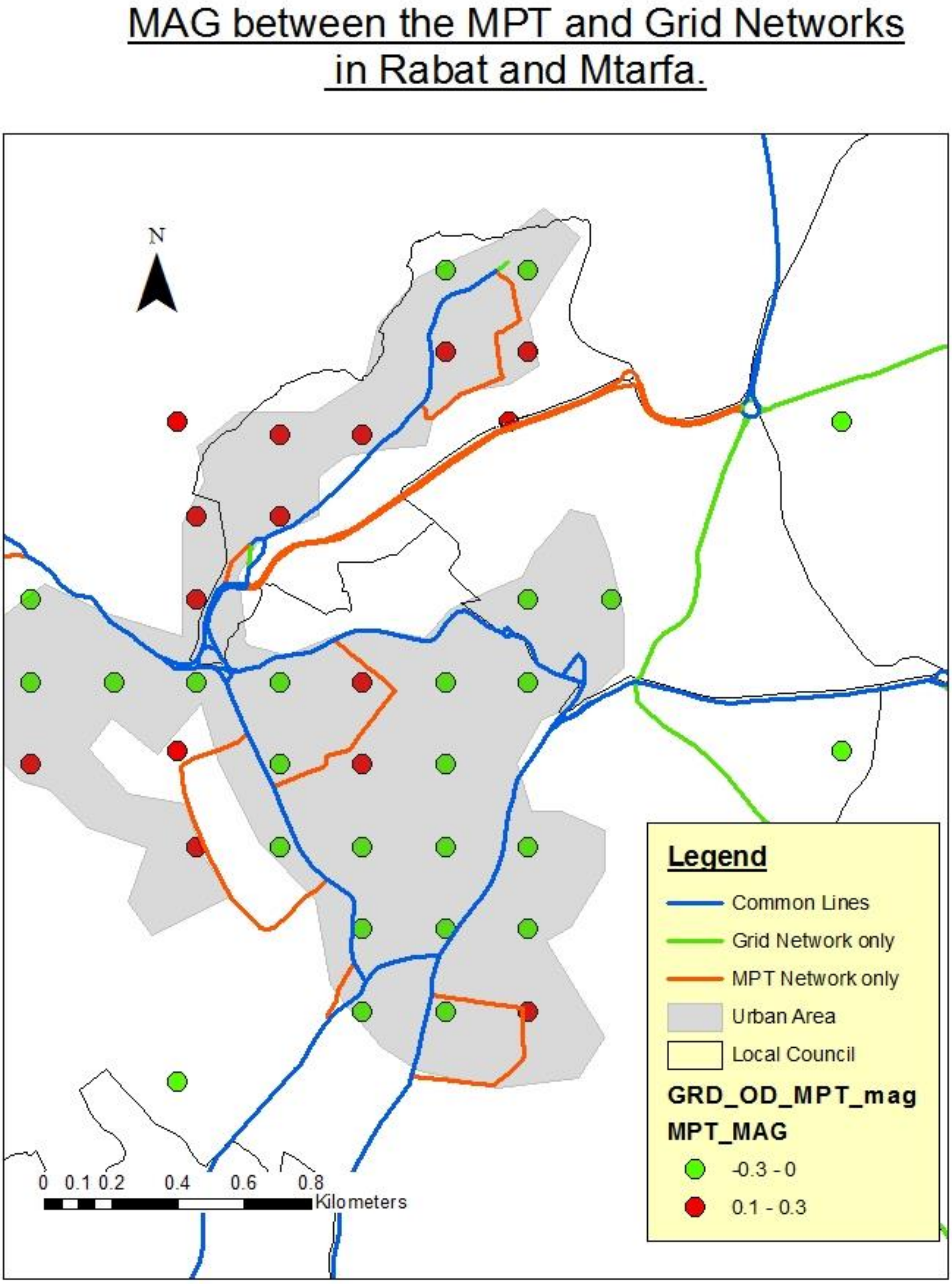

Figure 68: MAG between MPT and Grid Networks in Rabat and Mtarfa

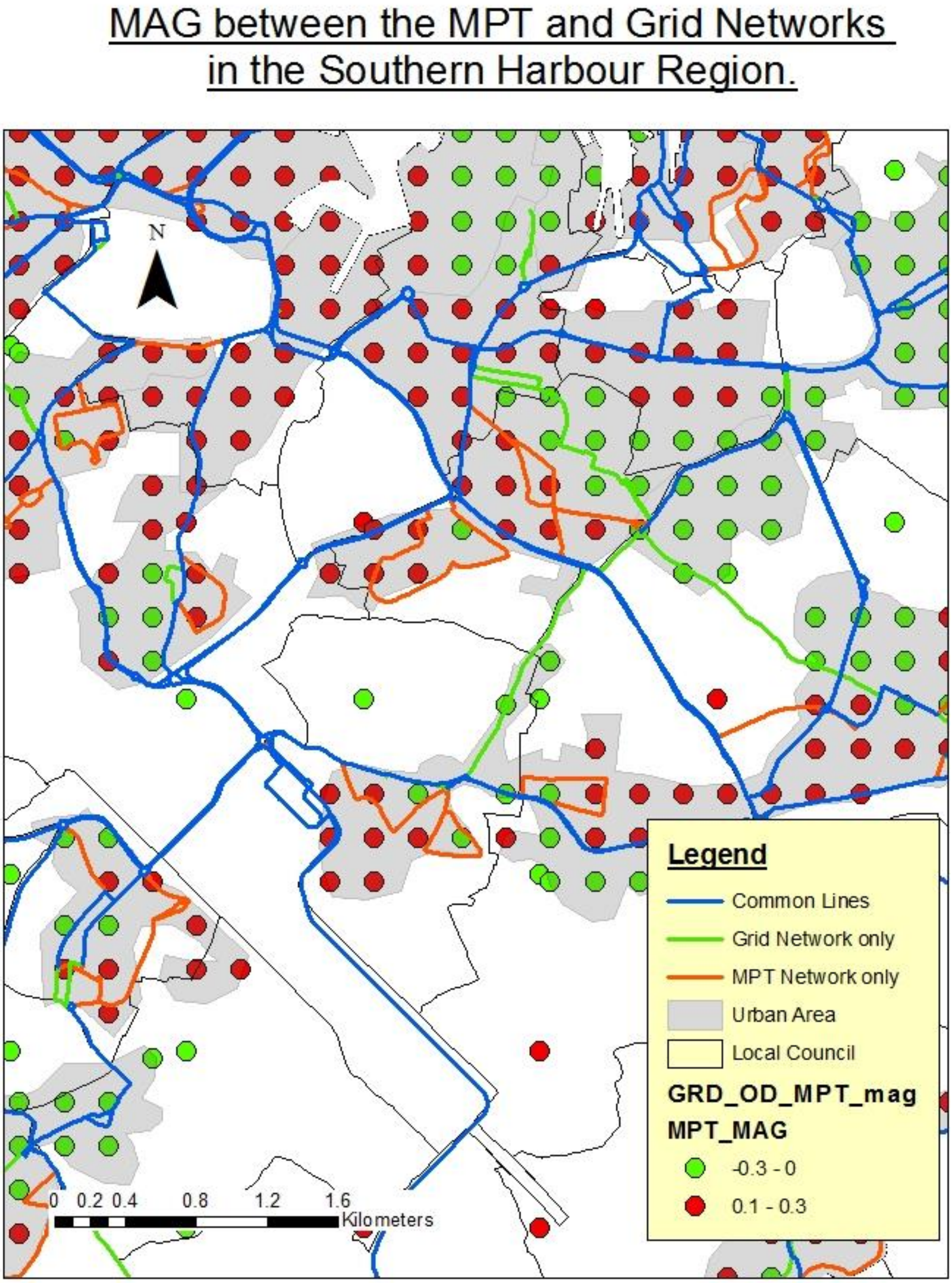

Figure 69: MAG between the MPT and Grid Networks in the Southern Harbour Region

Upon further reflection on the results, the author has realised that an inefficient public transport network design may have favourable travel time results if access time is sufficiently reduced. From a traveller's perspective, the ideal public transport system is that which mimics the car, in the sense that it enables the person to catch a vehicle with minimal walking effort, the extreme case being a door-to-door service. From a public transport planning perspective though this is obviously both impractical and runs counter to the advantages of the economies of scale that a public transport system provides (Nielsen et al., 2005). The case therefore seems to be that although the MPT network seems at first to provide the best accessibility levels, it does so at the cost of efficiency because of a less than 600m distance between the lines (figure 70). Reducing the access and egress times by having parallel lines at a distance of less than 600m results in inefficiencies by having overlapping catchment areas, violating one of Nielsen et al.'s (2005) principles in the process.

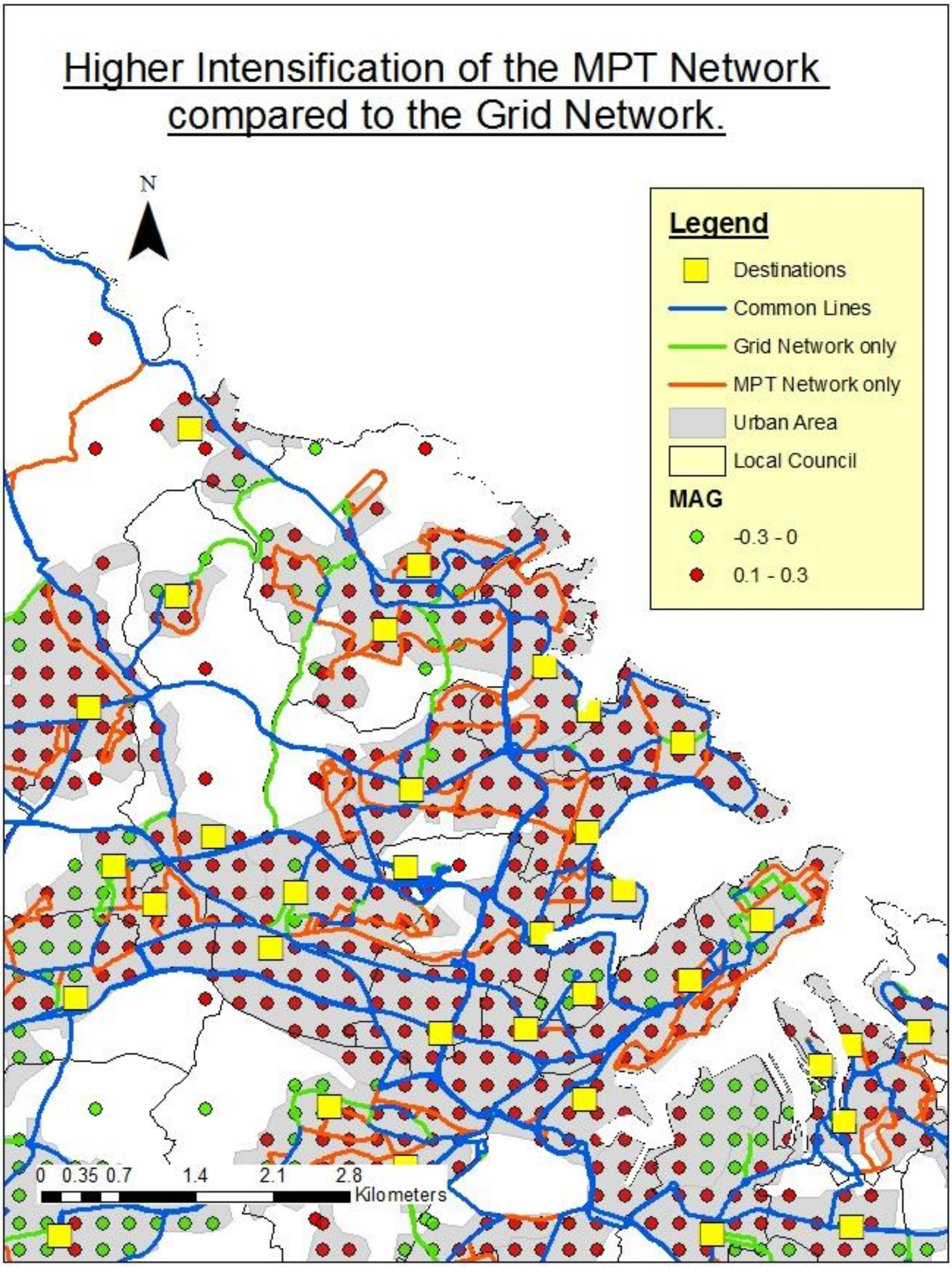

Figure 70: Higher Intensification of the MPT Network compared to the Grid Network

To account for the problem of networks that reduce the access times by intensifying the catchment area with different lines, the models may be calculated without the access and egress time, but ignoring access and egress time is erroneous because as the results suggest, access and egress time have a considerable influence on the whole travel time journey, especially over short distances (Kornelsen, 2015). This argument is further demonstrated in figure 71. If the whole network is to be reduced to a simple small line, the model would predict a superior accessibility level to other more extensive transport networks if access and egress times are ignored. In practice such a result does not reflect reality though because of the 400m walking benchmark beyond which people are deemed to not consider making use of buses (Bertolini et al., 2005; Nielsen et al., 2005). A better comparison method of different public transport network designs would therefore entail the use of the calculation of travel time with a weight that calculates the rate of overlap of the catchment area. Weighting travel time by catchment areas would help the analyst find the better network from the perspective of the travel time budget. It is hoped that such a measure manages to strike the balance between the need to minimise access and egress times and the need to have an efficient design. Thus the conclusion proposed is that whereas Kwok and Yeh's (2004) equation is adequate if a public transport network is to be solely compared with the car, the percentage of catchment area overlap is to be added if public transport networks are to be compared more accurately with each other.

Pedestrian catchment areas are also greatly influenced by topography (Nielsen et al., 2005; Daniels, 2012). Hence, identifying the topography of the area that a public transport network services is therefore of paramount importance if an accurate calculation of overlap is to be made. Gathering topographical data also has the added advantage of aiding the calculations of the catchment areas of commuters that decide to access the transport system with their bicycle, a green mode which can potentially drastically increase the catchment areas of a public transport system (Martens, 2004; Martens, 2007) though less so when egress times are considered (Martens, 2007).

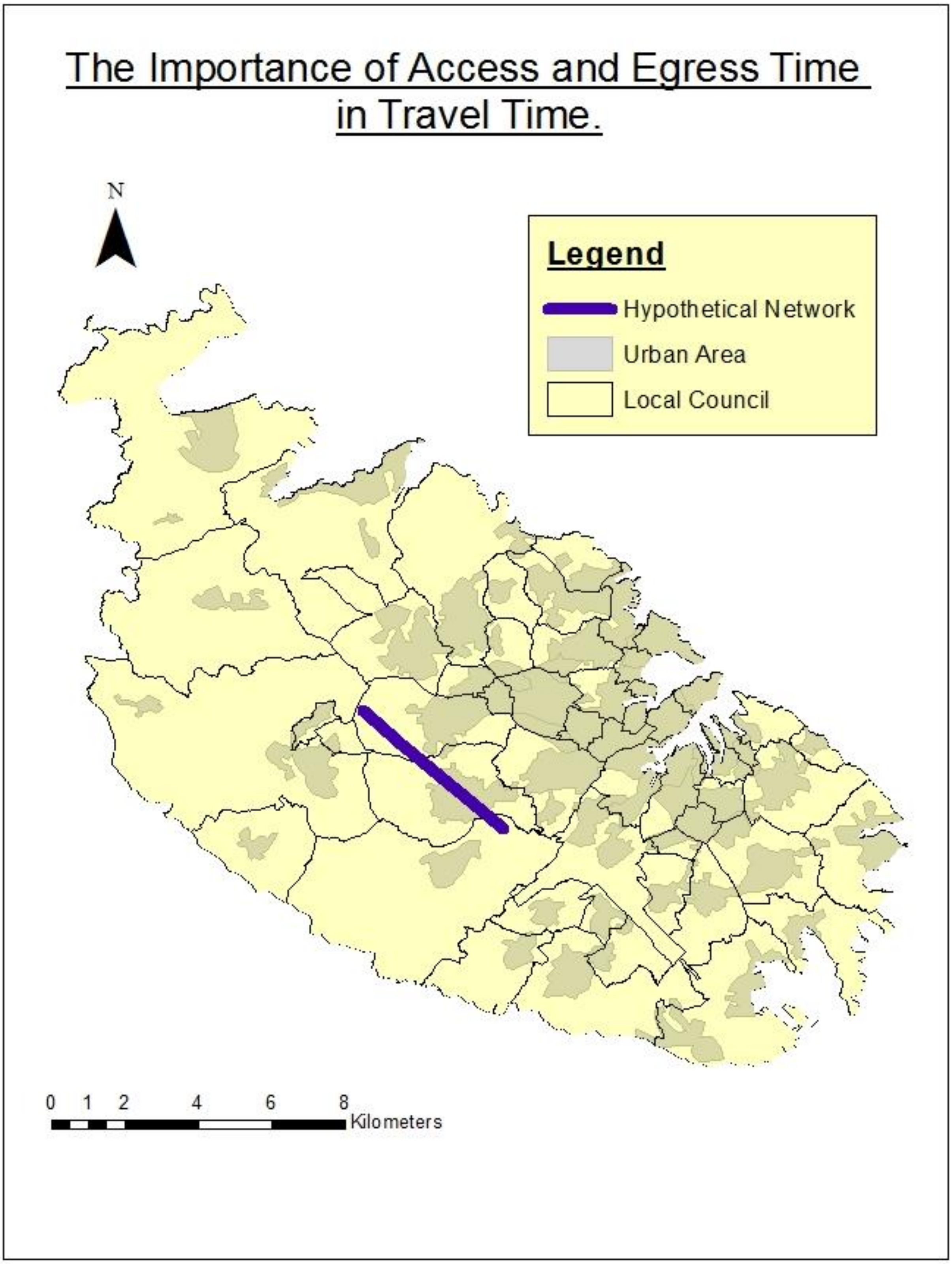

Figure 71: The Importance of Access and Egress Time in Travel Time

5.3. Effect of the Rail on a Bus Based Public Transport System

Apart from investigating how network design influences travel time, this thesis also explored the idea of how the integration of rail and ferry affect a bus based public transportation system's overall travel time results in small islands. The results support the idea that in such a geography, a rail network capable of reaching a 75km/h speed will greatly enhance the competitivety of the public transport system, in some cases even surpassing the car. The case is especially strongest over the longer distances because of the smaller proportion of walking time to the entire journey time.

The results also show that locally, in free flow conditions, the bus is actually faster than the ferry. This is of course an under estimation of the bus travel time because of factors such as: traffic lights and stop servicing all of which contribute to an increased travel time whereas the ferry has in general no such limitations. Adhering to the concept of conceptually similar models would therefore not allow the simple model proposed by Salonen and Toivonen (2013) to be used in Malta to compare the bus to the ferry with.

Although the assumptions made in this thesis were enough to satisfy the aim, in practice a transport planner needs to delve deeper than this thesis did in order to be able to come up with results that are sufficiently accurate to justify changes of a real public transport system. To plan for local needs, both congestion and topography are crucial parameters that cannot be ignored. Furthermore, other factors such as, transfers, traffic lights, intersections and time of day among others, all influence the operational performance of a public transport system.

5.5. Weighted Travel Time

The weighted travel time results suggest that the majority of car users are the section of the population that are able to enjoy the current infrastructure the most. They also show that if the rail is introduced than public transport users are able to enjoy a better portion of the infrastructure. Finally whereas the MPT network seems to have sharp areas of enjoyment and deprivation, the Grid network seems to have a more balanced level of enjoyment across the whole of the country.

5.6. Economic Potential

The results indicate that the car is the mode that has the most potential for economic development. The trend seems to be that the economic potential between the different public transport systems does not radically differ between each other. Economic potential is improved when the rail is added to the bus based network.

5.7. Malta

The results of this thesis suggest that in general the accessibility provided by public transport networks in Malta is better off now than either in 1996 or 2011. These optimistic results though need to be dampened because although they imply that the MPT network was the best performing network it must be borne in mind that the aim of this thesis was not to determine the performance of the established public transport networks in real life but to the determine the performance of the general network design without taking into consideration how the lines are set and thus the transfers between them. Another serious limitation between the models and real life is the effect on congestion, especially since in most part public transport shares the same road space with private transport. These limitations all help in under-estimating public transport travel time and would have been unacceptable if a real-life accessibility study of the networks is to be done.

The results of this thesis also imply that developing a rail network integrated with the bus has the potential to finally make the much anticipated modal shift to public transport a reality, at least for the residents of Mellieħa and Qawra. Furthermore although not directly served by the rail, residents in the south of the country are expected to greatly benefit in terms of travel time if such a project is under-taken. Finally it must be borne in mind though that simply establishing a rail network will not induce modal shift (Edwards and Mackett, 1996). For modal shift to occur a holistic approach needs to be taken (Paulley et al., 2006), from land use planning (OPPI, 2011), to ticketing, to integration of the rail, bus and ferry (Pucher and Kurth, 1996; Frémont and Franc, 2010), whilst at the same time discouraging car use by not increasing the supply of road and parking capacities whilst altering policies that encourage more mixed land use (Bonnel, 1995; Kentworthy and Laube, 1996; Nielsen et al., 2004). Furthermore there must be more bicycle related infrastructure which over the shorter distances can better compete with the car than public transport (Mees, 2010) whilst increasing the public transport's reach (Daniels, 2004; Daniels, 2007).

Finally, policy should focus more on providing accessibility than mobility. In practice it should heed more Mees' (2010) recommendation to use congestion as the inducer of modal shift away from the car than to try to increase auto-mobile related supply. It should reduce the travel time of public transport at the expense of the car and enforce measures already in place with this aim in mind (figure 72 and 73).

Figure 72: Buses emerging from Valletta Terminus Waiting for Traffic

Figure 73: Irrelevance of Bus Lanes

A further consideration when interpreting these results is that in the Maltese specific context, travel time by car is in general over-estimated in free flow conditions because Maltese drivers do not heed the speed limit (TM and MITC, 2011). The car is therefore in practice more attractive than the models are able to predict.

CHAPTER 6

CONCLUSION

When interpreting the results of this thesis care must be taken not to interpret them as real life values, even when they are designated as absolute because of the many assumptions that were made. It must be kept in mind that in this thesis the aim was to compare the networks with each other and not to predict the real-life travel time of a traveller. Thus whereas absolute results in this thesis are inaccurate, relative measurements are acceptable as long as the models used are conceptually comparable. Furthermore it must be acknowledged that this thesis considered only an aspect of accessibility; how the geometry of a network reduces the travel time by which a traveller rationally decides on which mode to travel by, assuming that the one with the lowest travel time is the most desirable. Hence other factors such as reliability, frequency, attitudes and perception among others, all of which influence the final decision of the mode choice of every individual were not considered. In particular population and frequency were not considered because these parameters should be considered at a later stage, after the laying down of the lines themselves.

As described earlier different circumstances require different tools. Though simple tools are always desired to complex ones, they may not always have the accuracy that is needed to answer the aim. It is up to the planner to identify which tools are best suited to the task at hand and up to the academia to instruct and research the applicability of these tools. This thesis thus has helped in this regard by suggesting that:

- Kwok and Yeh's (2004) equations are used strictly when calculating the MAG between public transport and the car. When public transport systems are compared with each other travel time needs to be weighted by the catchment area overlap.
- Topography has to be accounted for when comparing different public transport networks because of the potential for change in the extent of the catchment area and hence in the route alignment.
- Public transport networks based on orbital routes are not the most efficient public transport network designs for small densely populated islands.
- Accessibility levels based solely on travel time are very spatially dynamic.
- In small islands the farther apart that destinations are, the more cost effective the investment is because of the better competition that a public transport network can offer relative to the car.
- In islands, purely radial networks are undesirable, adopting instead a purely dispersed or a dispersed - radial network.

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