Czech University of Life Sciences

Faculty of Environmental Sciences

A multimodal GIS network analysis of Prague cycling routes

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Thesis Supervisor: Vojtěch Barták, Ing

Declaration

I hereby declare that the work presented in this thesis is, to the best of my knowledge, original work, except as cited in the text. I have listed all data sources, literature and publications from which I have acquired information.

Prague 22nd of April, 2015 Larry Daniel Shoemaker

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Department of Applied Geoinformatics and Spatial Planning

Faculty of Environmental Sciences

DIPLOMA THESIS ASSIGNMENT

Larry Daniel Shoemaker

Landscape Planning

Thesis title

A multimodal GIS network analysis of Prague cycling routes

Objectives of thesis

The aim of the thesis is to understand and model the Prague cyclist network service area from various major population and transportation centers, as well as to understand the impact of Metro connectivity on bike route network regional connectivity, including the new Metro A-line extension and planned Metro D line.

Methodology

First a bike route and Metro network dataset will be built, using OpenStreetMaps open-source data, satellite photography digitization, and incorporatating quantitative/qualitative site-visit research data. Then the spatial area reachability will be assessed by time analysis from locations in selected Prague districts. The Analysis will be performed both with and without Metro, including A and D line extensions, and considering hill-speed variation profiles. Use of Network Analyst ArcGIS extension is expected.

The proposed extent of the thesis

40 – 60 pages

Keywords

Cycling Pathways, Urban Traffic Connectivity, Network Analysis, Site Accessibility, Urban Planning

Recommended information sources

Auto*mat- Prahou na kole (2015). Map of Prague Cycle Routes.
Černá, A., Černý, J., Malucelli, F., Nonato, M., Polena, L., & Giovannini, A. (n.d.). Designing Optimal Routes for Cycle-tourists. Transportation Research Procedia.
Milakis, D., & Athanasopoulos, K. (2014). What about people in cycle network planning? applying participative multicriteria GIS analysis in the case of the Athens metropolitan cycle network. Journal of Transport Geography, 35(0), 120–129.
Ortúzar Salas, J. d. D., & Willumsen, L. G. (2011). Modelling transport. Chichester: Wiley.

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Abstract/Keywords

This multimodal transportation network GIS model simulates the spatial reach interactions between two different modes of transportation infrastructure: the bicycle and the Metro. This research begins with the development of a Prague, Czech Republic based GIS multimodal transportation network dataset consisting of type classified cycling routes and heavy-rail subway Metro routes. The model was used to forecast the separate and combined cycling and Metro network service areas reachable in 15 minute increment time-breaks, from key chosen sections of the city. From this service area generation, a cross-tabulation was performed on OpenSourceMaps data to shed light on available amenities within the time frames (such as number of restaurants, banks, or schools within 30 minutes). Furthermore, the research explores the regional impacts of different phases of planned Metro Subway build out, including the recent Metro A-line extension and the planned Metro D line to Southern Prague.

Keywords*: bicycle planning, GIS, ArcGIS, Network Analysis, Mass Transit, OpenSource, transportation networks.*

Acknowledgements:

I would like to thank my advisor Vojtěch Barták, Ing., for his support and guidance in this project.

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Table of Contents

1. Introduction

Over the last decades, the city of Prague, Czech Republic, has invested considerable amounts of resources in developing new cyclist and mass transit infrastructure (Exner, 2009). Both systems of infrastructure development are sustainable, mutually beneficial, and well researched subjects (Schiller, 2010). Investments in these areas have shown to provide many economic, environmental and health benefits to society (Kutz, 2008). It has been shown in Prague that designing and building efficient systems for both transport modes are often complicated, site specific, and slow-moving decisions (Automat, 2014). They require careful planning, implementation, and post-project strategies. With haphazard planning and oversight, they can end up being less than ideal. Going forward, one strategy to avoid this outcome is to ensure that institutions and their decisions are well informed as to the potential outcomes of their actions. This need is filled by multimodal transportation network geographic information system models that allow us to better understand our transportation systems. These models provide new insight on the transportation network's problems, needs, opportunities, and establishment of sustainable solutions. For this research, the transport model allows us to understand how new bike and Metro infrastructure investments in areas will interact with existing modes, landscapes, places, and people. Prague, with the development of new Metro and cycling infrastructure, is a perfect testing ground.

2. The Aims of Thesis

The aims of this research is to spatially assess the areas and amenities of Prague reachable by non-motorized bicycle transport, with and without Metro connectivity, limited to established cycling routes in 15 minute time increments. Furthermore, the research targets to project the spatial-time-extent impacts of additional Metro transportation connectivity provided by the new Metro A-line extension and planned Metro D line.

The thesis contributes new maps, statistics and a prototype intelligent transportation system (ITS) capable of spatial-time-extent accessibility analysis of Prague by bicycle routes under a variety of cycling scenarios and from a number of city-wide locations.

3. Literature Review

3.1 Multimodal Transportation Models

A transportation model is a simplified representation of a transportation reality. Multimodal transportation GIS modelling therefore logically is a model of multiple modes of transportation networks within a geographic information system (GIS). At its basis, the aforementioned model can only predict scenario outcomes based on the quality and depth of information it is made from. As such, it is central to distinguish the perspective of the model and its underlying data (Ortuzar & Dios, 2011). GIS models can provide easily understood, detailed, and sought after information. Some common examples are: maps showing pedestrian-cyclist / car conflict areas, best origin to destination routes, finding gaps in infrastructure, showing current or projected traffic, and-or developing cost/benefit analyses that offer a starting point for discussion and/or targeted actions (Knowles, Shaw, & Docherty, 2008; Milakis, 2014).

A multimodal GIS cyclist transportation model needs accurate, unbiased, information regarding the different transportation networks it aims to represent, as well as how/where the different transportation modes interact. Fundamentally in any transportation network, there is necessity of providing a supply (infrastructure, roads, trains) to match a demand - as people are seldom located in the exact same **place** as their desires or needs are - i.e. goods, services, employment or otherwise. This spatial component of transport networks makes the geographical information system an ideal, logical choice to create transportation model (Knowles, Shaw, & Docherty, 2008). These network user needs and desires, along with the inherent spatial configuration components of transportation infrastructure, necessitate the procurement or creation and interplay of comprehensive and detailed qualitative and quantitative datasets.

Models dealing with more qualitative data, utilize information such as safety, comfort, and convenience factors amongst others (Rybarczyk & Changshan Wu, 2014). This includes trip purposes (work, leisure, or health-related) or other factors such as:

preferred ride difficulty, traffic perceptions, accessibility to activities, attractions, or services, and accessibility to other transit systems (Černá 2014; Milakis, 2014). Dealing with this sort of qualitative data is often inherently abstruse, and more problematic to codify in traditional pure GIS models due to its fixed rather than fuzzy logic systems (Adhikari & Li, 2013).

Quantitative transportation model data usually include: generalized costs of travel, speed-limits, one-way restrictions, segment lengths, origin-destination pairs, spatial details, observed cycling rates, or time-specific information on the general streets, transit lines or cycle paths:(Chowdhury, 2003; Milakis, 2014; Ortuzar & Dios, 2011).

However, involving both sets of data, in a "mixed model" approach is a most common and preferred standard (Creswell, 2003). Many years of development of transportation algorithms, continuous academic research, and public/commercial spatially aware transportation model applications provide modern citizens with a plethora of accessible transportation information and management.

3.1.1 Limitations

However powerful these tools have become, multimodal transport models still have limits in what they can do. They are only one element in a cohesive urban transport planning strategy (Ortuzar & Dios, 2011). A cohesive, effective planning strategy still requires strong administrative and institutional frameworks, broad support, along with consistent on-going communication with decision makers and the public as the plan develops (Lucy, 2003).

Limits of available data are a common problem in the field of transportation planning. It is often unfeasible to collect data for an entire population and its overall movements, therefore making data corollaries based on smaller populations is inevitable, and subject to potential statistical error (Creswell, 2003; Wong & Wong, 2015). Furthermore limiting is the fact that many research models have capabilities that only focus on cross-sectional research. These models have the tendency to focus on a single facet of change without understanding other correlated influences, and may lead to incorrect conclusions. Results may be overstated or oversimplified out of line with reality (Krizek, Barnes, & Thompson, 2009). It is difficult to model every potential network user, their perceptions of travel costs and the combined measures sought to minimize them, be it distance, travel time, or otherwise.

3.2 Bike Planning Essentials

To understand the needs of cyclists, to accurately simulate real-world conditions, and to correctly categorize cycling data for this research requires a basic understanding of some focused cyclist urban planning terminology.

3.2.1 Cycling Speeds

Cycling speeds depend largely on cyclist's ability (strength/exertion), pace, topography, and infrastructure-traffic conditions amongst other factors. On bicycle, there are three primary physical forces to be overcome: rolling resistance, air resistance and gravity (Swain, 1998).

As such, average cyclist speeds are highly variable. For example, speeds on a flat, continuous, lightly trafficked street in Saint Petersburg, Florida, recorded by automatic speed counters showed average speeds between 17-19 kilometers per hour (Hunter, Srinivasan, & Martell, 2009). A flat, 3.6km long, official cycling route in Berkeley, California, with 21 stop signs and one traffic light (31 total intersections) averaged 17km/hr. with moderate physical exertion. However, the same cyclist on a parallel route with only 8 traffic lights, averaged 22km/hr. (Fajans, 2003).

3.2.2 Infrastructure types

Here in Prague and in most western societies, cycling infrastructures are generally categorized into three principle categories.

Class 1: cycle paths, lanes, or zones without motor vehicles.

Class 2: cycle lanes, usually marked lanes – and roadway shared with cars.

Class 3: cycle routes, designated routes for cyclists, in motorized traffic usually without any special markings or infrastructures.

Cyclist Infrastructure Types and Classification (City of Prague, 2014)

Name (Czech)	Name (English)	Class #	Photo
Piktokoridor	Sparrow	3	
Cyklopruh	Cycle Lanes	2	

Buspruh	Traffic Lane for Bus/Bike/Taxi	3	
Cyklojednosměrka	Cyclindg Lane-One Direction	1	
Bezmotorová cesta	Non Motorized Path	1	
Stezka pro chodce a cyklisty společná	Route for pedestrians and cyclists not spatially separated	1	
Stezka pro chodce a cyklisty	A route for pedestrians and cyclists	1	

prostorově oddělená	spatially separated.		
Samostatná cyklostezka	A separate bike path	1	
Přejezd přes silnici, křižovatku	Crossing/ road intersection	1, 2 3	
Pěší zóna s cyklistickou dopravou	Pedestrian zone with bike transport	1	
Obytná zóna	Residential Zone	3	Low Traffic Speeds, Residential areas, no painted lanes.
Cyklotrasa v běžné ulici	Cycle Track in Street	3	

Průjezd zákazem vjezdu-legální	Permitted to ride through a traffic sign that forbids driving through	3	
Cyklisto veď kolo	Dismount & walk- bike	3	
Cyklotrasa na komunikaci s dopravním stresem	Cycle route in stressful traffic	3	
MTB trasa, singletrack	Mountain bike track, single	3	

Chodník s povolením jízdy	Sidewalk, permitted to ride	1	
Chodník	Sidewalk	1	

3.2.2.1 Infrastructure and Usage

Many studies have shown that the number of quality cyclist infrastructure (primarily Class 1 or 2) positively correlates with the percentage of people that use bicycling for commuting purposes (Nelson & Allen, 1997). In Dutch cycling design, considered an international design gold standard, “unbundled” routes, those that run in non-motorized- traffic separated right of ways, reduce cyclists-car collision risks and correspond positively with cycling safety (Schepers, 2013). However, causality cannot be proved from this data (Dill, 2003; Schoner & Levinson, 2014). In addition to having quality bicycle facilities, the network should adequately connect origins and destinations to encourage cycling as an everyday activity.

3.2.3 Ridership Statistics for Prague

According to a compilation/English translation of a Prague City cycling transportation poll conducted 2010 by Auto*Mat:

- Rate of bicycle transport mode share: 1.8% (summer 3.05%, winter 0.55%)
- Regular cyclists: 144 000 (12% of Prague population)
- Average cyclist kilometers travelled/ per person/ per year was: 147 km (→ 500 000 km cycled in Prague every day) (Vratislav Filler, 2014).

Cycling modal share for various kinds of journeys

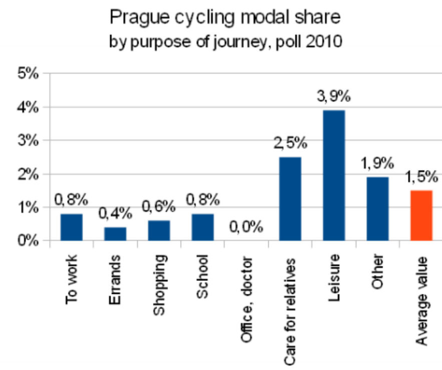


FIGURE 3-1: PURPOSE OF JOURNEY. SOURCE (AUTOMAT, 2012)

3.3 Review of ESRI specific network analyst terminology

To understand the methodological approach to answering the central research question, a review of ESRI terminology and literature is presented.

3.3.1 Dijkstra's algorithm

The network service area analysis is made possible by the computation of the “shortest path algorithm”. Within computer science, it is known as the Dijkstra’s algorithm, named after its creator Edsger W. Dijkstra, published in 1959. According to the ESRI documentation:

“The classic Dijkstra's algorithm solves the single-source, shortest-path problem on a weighted graph. To find a shortest path from a starting location s to a destination location d, Dijkstra's algorithm maintains a set of junctions, S, whose final shortest path from s has already been computed. The algorithm repeatedly finds a junction in the set of junctions that has the minimum shortest-path estimate, adds it to the set of junctions S, and updates the shortest-path estimates of all neighbors of this junction that are not in S. The algorithm continues until the destination junction is added to S (ESRI, 2014)*.”*

3.3.2 Computing the Service Area

A subset of the network analysis functionality is the creation of “network service areas”. It is used to find the area around the accessible network, calculating the amount of area as it varies by travel time and various costs. With this calculated service area, it can be used in conjunction with other datasets to identify other entities such as land use, populations, or anything analogous that is within a neighborhood or region (ESRI, 2014).

After the shortest path is calculated, a service area polygon is created. This is done by generating a triangulated irregular network (TIN) data structure. The TIN uses the network lines calculated accessible by putting the network distance as the height of locations. Locations not accessible are assigned a much greater height value. Then a proprietary ESRI polygon generation routine is used to carve out regions inbetween the break values such as time or distance (ESRI, 2014).

4. Methodology

To spatially assess and compare the different amounts of area and amenities in Prague reachable by bicycle on the transport network(s); a number of datasets needed to be created and organized before analysis could be completed. First was the creation of the base-layer and its organizational data structure. The base layer primarily consists of the high quality satellite orthophotography. Orthophotos are satellite photographs that are geometrically accurate, with a uniform scale, and image shifts generated during acquisition are removed (CUZK, 2014). Second was the creation and codification of the Cycle network dataset from the base layer research, site visits, and other procured public access open sources. Thirdly, phases of Metro connectivity are also defined and placed into the network dataset. Finally, additional cost points (barriers) and variables were coded into the system using elevation profiles and traffic signal data, before ESRI service area analysis outputs were created.

4.1 Creation of Base Layer

In order to perform a network analysis of the Prague cyclist infrastructure, a base layer dataset needed to be created first to correctly cartographically orient the researcher. To create this dataset, a wide range of sources was used. The first was a Czech Republic satellite orthophoto base layer. This was procured via a public access Web Map Service (WMS) into a blank ESRI ArcMap 10.2 document. The WMS imagery layer was provided by the Czech Office for Mapping, Surveying and Cadaster (CUZK, 2014). Then OpenStreetMaps (OSM) project GIS data was added for the entire Czech Republic, from the January 5th 2015 public release. The OSM data provides multiple type transportation lines, building outlines, place names, and points of interest. All OSM data was converted from the open source OSM file format into an ESRI compatible format by the OpenStreetMap consultant company Geofabrik, an active member of the OpenStreetMap Foundation (Geofabrik GmbH Karlsruhe, 2014). The map data was projected from the 1984 World Geodetic Coordinate system to the S-JTSK Krovak East-

North projected-coordinate system, used in the Czech Republic. This was accomplished using the ArcToolbox Data Management toolkit. This allowed for the OSM data to align correctly with the WMS CZUK Czech Republic Orthophotography. A shapefile in the same projected coordinate system containing the administrative boundaries for the Prague City districts was added. For ease of data management and analysis, the OpenStreetMap data was then clipped down, so that it contained no data that resided 10 kilometers outside the city limits.

4.2 Creation of the Cycling Route Network

The underlying baselayer data only contained partial information regarding the official cycling routes in Prague, those of which were tagged as type “cyclepath”. With permission from the non-profit civic organization Auto*Mat and its sister organization Prahou Na Kole, which operates a comprehensive OpenSource Prague cycling map, I proceeded with manual digitization of the majority of remaining routes.

4.2.1 Cycling Route Digitization

This was performed by editing the “cyclepath” tagged OSM shapefile. The resulting core network file was named CycleNetwork, and at the writing of this dissertation was on iteration version 7. It is important to note, that due to time-constraints, the entire system of Prague cycling routes was not digitized into the network dataset. However, upon comparison with official route maps, it contains a sizable majority, and special attention was given to fill in important gaps and regional corridors.

Cyclist route vectorized segments were classified with various attributes as defined in the Literature Review and in Section 4.2.1. These included values such as assumed or observed segment speeds, route name, observed infrastructure types, and one-way direction values. The length of this network set of routes is cumulatively 1023 kilometers, which includes one way segments for the same route. In total, 3747 different polyline segments were created and each represents a unique state of the Prague regional cycling network.

4.2.1 Segment Attribute Values Table

<table>
<tr><th>name</th><th>value</th><th colspan="2">notes</th></tr>
<tr><td>Maxspeed</td><td>km / hr.</td><td>Contains segment Estimated or observed cycling speed.</td><td>
<table>
<tr><th>Infrastructure type</th><th>Average speed</th><th>Total length</th></tr>
<tr><td>Class 1</td><td>12.7 km / hr.</td><td>383km</td></tr>
<tr><td>Class 2</td><td>12.2 km / hr.</td><td>52km</td></tr>
<tr><td>Class 3</td><td>11.6 km / hr.</td><td>430km</td></tr>
</table>
</td></tr>
<tr><td rowspan="3">Type</td><td>Class1</td><td colspan="2">Class1- paved, painted, or surface bike path (no automotive traffic).</td></tr>
<tr><td>Class 2</td><td colspan="2">Class 2- paved, bike path with painted lane.</td></tr>
<tr><td>Class 3</td><td colspan="2">Class 3- cycling route.
Signage as a cycling route, but little to no dedicated infrastructure.</td></tr>
<tr><td>Type 2</td><td colspan="3">Further description of segment: Nolane, sidewalk, pathway, nature, sharrow, bikebox, etc.</td></tr>
<tr><td>route</td><td colspan="3">A-Class: Official Prague routing
X-Class: alternative routing (Automat)
Metro RT: connection lines to Metro Stations.</td></tr>
<tr><td>Street _name</td><td colspan="3">Street Name (if provided)</td></tr>
<tr><td>Name</td><td colspan="3">Place name, if provided</td></tr>
<tr><td>Note</td><td colspan="3">Segment notes</td></tr>
<tr><td>minutes</td><td colspan="3">Calculated per edge (line) segment. This value represents the time cost to move from an individual network segment from start to finish. It is calculated from the fields: [lengthkm]/[maxspeed] *60</td></tr>
</table>

oneway	**FT** **TF**	Connotates one way rules for cyclists. *Dependent on vector shape* digitization (i.e. direction of line drawing of the line in the GIS system) ‘FT’ means travel is allowed in the digitized direction ‘TF’ means travel would be permitted only against the digitized direction
Hill-speed Adjustment	Used to simulate 25% faster downhill speeds and 25% increase in downhill speeds.	

Uphill	km/ hr.	Length [km]
Class 1	10	9.8
Class 2	10.	4.6
Class 3	10	29.6

Downhill	km/hr.	Length [km]
Class 1	17.6	11.6
Class 2	17	5
Class 3	15.7	31

4.3. Metro Connectivity

4.3.1 Configuration of Metro Core

Metro Core refers to the Metro subway infrastructure existing immediately prior to the Metro A-Line Extension opening in April 2015.

Maxspeed values for Metro Core, and its three lines of service A, B, and C, was put at 37km/hr. This speed variable was determined by analyzing departure and arrival timetables. This inherently includes the amount of time that the train stays at each station to load and off-load passengers. It does not model the amount of time it takes to connect to the street from the Metro and re-start your journey outward. It also does not take into account the multiple exits and entrances, but instead uses one centralized point to interact with the cyclist network. However, future iterations of the model can implement these changes to test their effects.

4.3.2 Configuration of the Metro A Line Extension-

The Metro A Line extension was extracted from the OSM transportation-line file. It was edited into its own separate shapefile. Metro station connectivity points remained in the metro core stations shapefile. Max speed was put at 40km/hr. reflecting newer infrastructure.

4.3.3 Configuration of Planned Metro D Line-

An image of the planned extension map provided by MetroProjekt and Dopravní podnik hlavního města Prahy, was georeferenced onto the existing satellite imagery and data-set (Dopravní podnik hlavního města Prahy, 2014). The research then utilized further satellite base layer analysis to determine the placement of logical D-line section subway portals near established population centers. A connecting line was drawn to connect the stations with the C-line transfer station at Pankrác. Maxspeed for Metro D is set at 40km/hr. This is assumed that the newer construction and automation of the extensions would also amount to a modest speed increase. Stations were connected to the nearby regional cycling route networks in short polyline segments and were tagged route "MetroRT".

4.3.4 Metro Lengths and Segment Speeds

	Length (km)	Transversal time (minutes)	Stations #
Metro Core Line A	11.39	18.47	13
Metro A Extension	6	8.9	4
Metro Core Line B	26.19	42.48	24
Metro Core Line C	23.15	37.54	20
Metro D- planned	8.43	12.65	7

TABLE 1: ENTIRE METRO SEGMENT LENGTH& TRAVEL-TIME

4.4 Elevation and Slope Profiles

A fourth generation digital elevation model (DEM) provided by the Czech State Administration of Land Surveying and Cadastre (CUZK, 2014) was imported into the CycleNetwork shapefile attribute table using the ArcMap 3D-Analyst toolbox -> Extract Surface Values function. This digital elevation model was established to allow for analysis of terrain at a regional scale, which made it a fit for transport modelling.

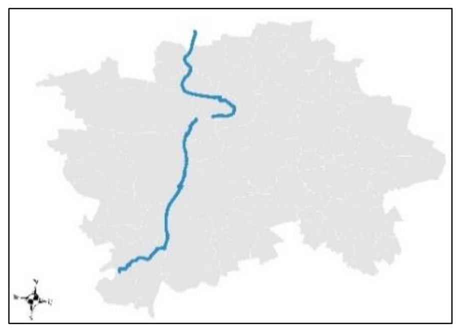
Using the cycling network attribute table, which now contained imported elevations and slopes, cyclist routes with 7% or more average slope increase over a 100-meter distance, were identified. These routes then were separated into separate one-way polylines, tagged with uphill or downhill keys, and assigned baseline maxspeed variables of 10km/hr. uphill, and 16-18km/hr. downhill.

4.5 Site Research

Site Research involved on-foot, or bike reconnaissance of selected segments of the network. In particular, site research included GPS tracked rides along the route using an Android powered smart-phone. This information allowed the researcher to compare estimated travel times and achieved average speeds along a segment. All gathered information was then placed into the model during digitization of the cycling network file (section 4.2).

4.5.1 Route A1

The A1 path follows the western edge of the Vltava River. It is a mixed infrastructure route, running on and off heavily car trafficked streets. Many sections have quality Class 1 or Class 2 type infrastructure facilities, primarily on the northern and southern sections away from the city center.



MAP 1: GENERAL LOCATION A1 ROUTE

The A1 segment of the Network Model size is: 31.7kilometers, with 145 unique network segments, and an overall average speed 12.3km/hr. Digitization accuracy is estimated at 90% complete.

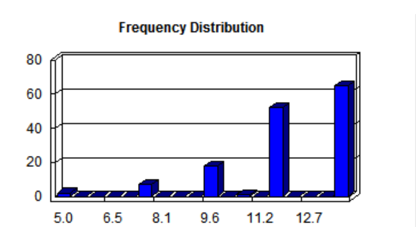


FIGURE 4-1-FREQUENCY DISTRIBUTION OF SEGMENT SPEEDS, ROUTE A1

4.5.2 Route A2

Map 2- General Location of A2 Route

The core A2 route, popular with residents and visitors alike in this model is 32.75 kilometers in cumulative length. The route passes through Praha 1, 2, 4, 7, 8, 12, Praha-Troja and Praha-Zbraslav. It is a mixed infrastructure type, running on and off car trafficked streets, with and without separated facilities. It has an overall average slope 0.28%. End to end travel time on this segment from start to end is calculated to take 158 minutes.

In Prague 1, the city center area, it runs in street and tram traffic (Class 3) before following the riverbank on separate car-free facilities (Class 1). Areas nearest the center are often congested and potential max speeds are not always achieved. Furthermore, areas in this central area, particularly the waterfronts and Praha-Troja areas are also home to large pedestrian crowds during weekends, good weather or special events. In these areas, the model utilizes a slower maxspeed attribute.

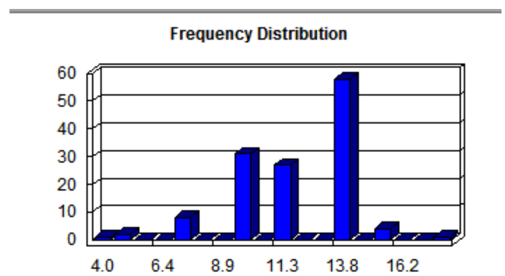
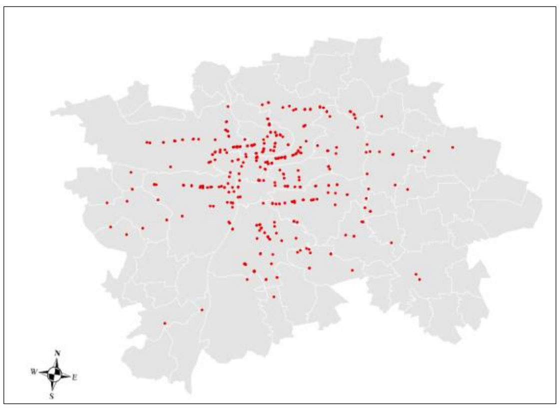


Figure 4-2- Frequency distribution of segment speeds, Route A2

4.6 Added Cost Points (traffic lights and obstacles)

Utilizing the OpenStreetMaps points file, field types tagged “traffic-lights” were extracted into a separate shapefile and manually snapped to the corresponding CycleNetwork polyline segments. They were then loaded into each analysis segment’s network analysis service area layer as an “Added Cost”, and set with a 1-minute time delay. This models a one minute wait time at a traffic light. Of the entire OSM point file, there are 421 traffic lights intersecting the current network build out.

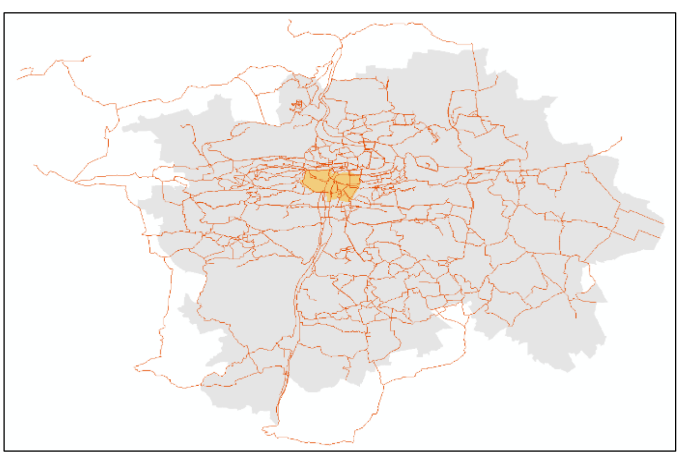


MAP 3- MAP OF TRAFFIC SIGNALS ON BIKE NETWORK

FIGURE 4-3: EXAMPLE OF CYCLING NETWORK OBSTACLE & SIGNAGE

4.7 Study Area

4.7.1 Overall Area



MAP 4: BIKE ROUTES NETWORK MODEL

The general study area is confined primarily to the transport routes within the Prague metropolitan region. It includes a few routes immediately outside of the city boundaries. These non-Prague routes primarily are an incomplete digitization of the ‘8100’ ring route, one route to Southern Kladno area, and the eastern Vltava river routes outside of Prague. In Prague this dataset has cumulative segment length total of 891.5 kilometers.

4.7.2 Model Distribution by District

The following table shows the distribution of the model segment lengths and average speeds by district.

District	sum length (km)	% of Model	Average Speed (km/h)		sum length (km)	% of Prague	Avg Speed (km/h)
Praha 1	31.8	3.5%	10.5	Praha-Dolní Chabry	4.5	0.6%	12.3
Praha 2	17.4	1.8%	11.7	Praha-Dolní Měcholupy	5.5	0.7%	12.5
Praha 3	26.6	2.9%	12.3	Praha-Dolní Pocernice	8.1	1.0%	13.1
Praha 4	62.9	6.8%	12.2	Praha-Dubec	8.3	1.1%	12.7
Praha 5	66.0	7.2%	12.1	Praha-Klánovice	4.3	0.5%	12.4
Praha 6	118.9	12.3%	12.2	Praha-Koloděje	4.1	0.6%	12.2
Praha 7	42.7	4.5%	11.9	Praha-Královice	5.1	0.6%	12.0
Praha 8	66.1	6.9%	12.3	Praha-Křeslice	3.4	0.5%	12.3
Praha 9	25.6	2.7%	12.5	Praha-Kunratice	17.3	1.9%	12.2
Praha 10	41.6	4.6%	11.5	Praha-Libuš	9.6	1.7%	12.9
Praha 11	23.3	2.5%	13.2	Praha-Lipence	4.2	0.4%	12.3
Praha 12	30.5	3.3%	12.5	Praha-Lysolaje	5.1	0.6%	11.6
Praha 13	31.2	3.7%	13.2	Praha-Nebušice	5.2	0.8%	11.8
Praha 14	28.5	3.1%	12.5	Praha-Petrovice	3.8	0.6%	12.0
Praha 15	16.4	1.9%	12.6	Praha-Řeporyje	11.1	1.3%	11.8
Praha 16-Radotín	11.1	1.2%	12.7	Praha-Satalice	2.5	0.3%	12.0
Praha 17-Řepy	8.8	1.1%	11.4	Praha-Šeberov	1.9	0.3%	12.8
Praha 18-Letňany	14.6	2.1%	12.0	Praha-Slivenec	0.8	0.2%	12.7
Praha 19-Kbely	7.0	0.9%	12.5	Praha-Štěrboholy	2.5	0.4%	11.3
Praha 20- Horní Počernice	13.5	1.5%	12.7	Praha-Suchdol	20.2	2.1%	11.5
Praha 21-	9.2	1.0%	12.8	Praha-Troja	14.5	1.8%	12.3

Újezd nad Lesy							
Praha 22	**15.7**	**1.7%**	**12.2**	**Praha-Velká Chuchle**	**2.7**	**0.5%**	**13.6**
Praha-Bechovice	**6.6**	**0.8%**	**12.9**	**Praha-Zbraslav**	**15.9**	**1.9%**	**12.9**
Praha-Čakovice	**8.8**	**0.9%**	**12.0**	**Praha-Zličín**	**6.2**	**0.7%**	**12.2**
Praha-Ďáblice	**0.0**	**0.0%**	**12.0**				

TABLE 2: CROSS TABULATION OF CYCLIST ROUTE NETWORK GIS FILE WITH PRAGUE DISTRICTS.

4.8 Generation of Network Service Area Layers

This section contains the parameters and network location points for the service area solver routine in ESRI's Network Analyst toolkit.

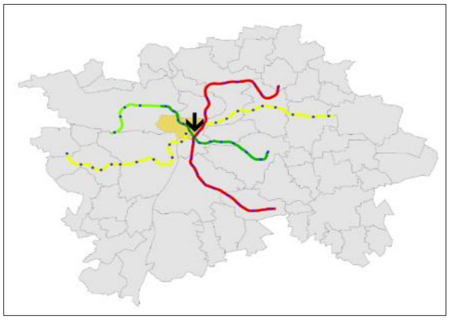
Universal Configuration Values

- Away from Facility (area computed in direction away from Network Location point)
- Detailed Polygons Feature (produces a more accurate result polygon)
- Merge polygons with the same break values (create one polygon per time break)

TABLE 3: TIME IMPEDANCE BREAK VALUES FOR ANALYSIS (MINUTES)

0-5	**30-45**	**75-90**	**120-135**
0-15	**45-60**	**90-105**	**135-150**
15-30	**60-75**	**90-120**	

4.8.1 Prague 1 - Staroměstské náměstí



MAP 5: LOCATION OF PRAGUE 1 - STAROMĚSTSKÉ NÁMĚSTÍ

Staroměstské náměstí plaza was selected foranalysis because of its historic, symbolic, and centrally located properties. It is close to most major transportation corridors, and the overall surrounding central region is home to a large number of employers, services, and cultural institutions. Six service area scenario sets were run from this location.

FIGURE 4-4: ORTHOPHOTO OF STAROMĚSTSKÉ NÁMĚSTÍ. (CUZK, 2014)

Analysis number 1 (code P1-1) provides the basic network service area on baseline segment speeds with ***no traffic signals*** factored in. It is of note that, no following analysis scenarios in the research will use this function, but instead will always take traffic signalization into account. This is done to further increase the accuracy of the model. Analysis number 2 (code P1-2) then factors in 421 city-wide traffic signals that intersect with the cycling network and have impact on travel-times. Analysis 3 (code P1-3) uses analysis 2 speeds and traffic signalization, but introduces multi-modal transport network capabilities with Metro connectivity prior to the Metro A-Line extension. Analysis 4 (code P1-4) includes the Metro-A Line extension. Analysis 5 (P1-5) models the future-slated 2020's era Model D line opening between Pankrác and Depo Písnice. Analysis 6 (code P1-6) then compares this with Metro A extension included.

4.8.1.1 Network Service Area Analysis Parameters

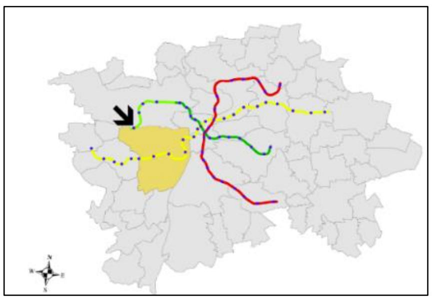
Analysis #	Traffic Lights	Metro Core	Metro A Extension	Metro D	25% hillspeed adjustment
P1-1	N	N	N	N	N
P1-2	Y	N	N	N	N
P1-3	Y	Y	N	N	N
P1-4	Y	Y	Y	N	N
P1-5	Y	Y	Y	Y	N
P1-6	Y	Y	Y	N	Y

4.8.1.2 Amenities Analysis Parameters

Upon running the Service Area analysis, the Prague OpenStreetMap amenities point file was cross-tabulated to the service area outputs to understand the distribution of amenities by time break.

Amenities analysis code #	Input Service Area Network Analysis	Time breaks	Note
P1-OSM-1	P1-2, P1-3	0-60	Compares Amenities reach with and without Metro Core
P1-OSM-2	P1-3, P1-4	0-60	Compares Amenities reach with Metro Core, and Metro A extension

4.8.2 Prague 5 - Nemocnice Motol Station



MAP 6- LOCATION OF NEMOCNICE MOTOL METRO

Nemocnice Motol is the current terminus of the Prague Metro Line A extension, opened April 6th 2015. The new station is located on the northern section of Kukulova Street, near the northern-most entrance to the Motol hospital in Praha 5. It is of note that the area is not home to a large residential population.

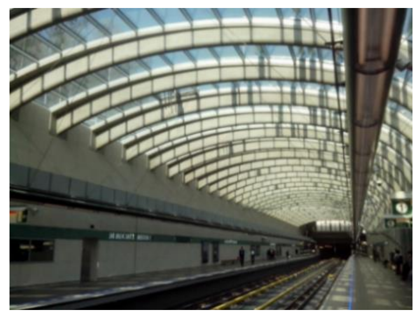
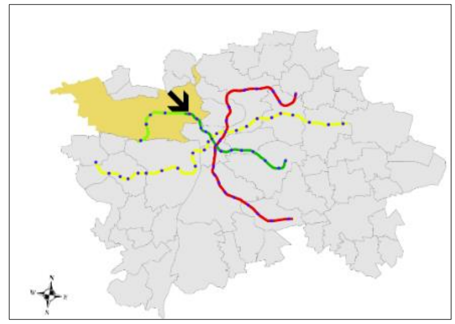


FIGURE 4-5: NEW METRO STATION

Network Service Area Analysis Parameters

Analysis #	Traffic Lights	Metro Core	Metro A Extension	Metro D
P5-1	Y	N	N	N
P5-2	Y	Y	N	N
P5-3	Y	Y	Y	N
P5-4	Y	Y	Y	Y

4.8.3 Prague 6 - Dejvická



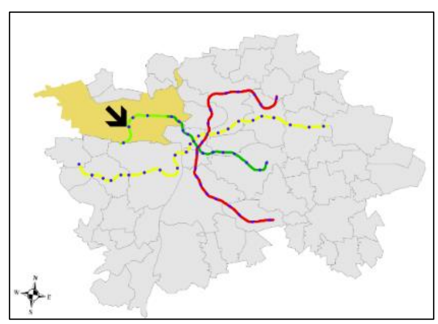
Map 7: Location of Dejvická

The Dejvická Metro station, opened 1978, is in the heart of the Prague 6-Dejvice neighborhood, home to many residents, and important Czech institutions. Significant transport investment has been placed into this area recently via the Tunnel Blanka and Metro-A line extension projects. The central network location point for this analysis was placed near a portal of the Dejvická station. Service area analysis queries 1 (code P6-D-1), 2 & 3 were conceived to compare service area reach via bicycle with and without Metro availability. Metro Analysis 2 (code P6-D-2) & 3 (code P6-D-3) network queries are used to compare the differences between the pre-April 2015 Metro and the latest extension. Analysis 4 (code P6-D-4) analyses the effect of the Metro D line extension.

4.8.3.1 Network Service Area Analysis Parameters

Analysis #	Traffic Lights	Metro Core	Metro A Extension	Metro D
P6-D-1	Y	N	N	N
P6-D-2	Y	Y	N	N
P6-D-3	Y	Y	Y	N
P6-D-4	Y	Y	Y	Y

4.8.4 Prague 6 - Petřiny



Map 8: Location of Petřiny

Petřiny is one of the principle new stops of the Metro A line extension, located in Prague 6. It is located in a highly populated, large scale prefabricated panel housing estate built in the 20th century. Located in the hills west of central Prague near major residential populations and parks, it is of interest to study the station's impact on the regional cycling experience.

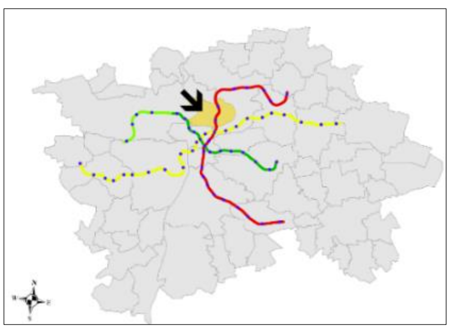
4.8.4.1 Network Service Area Analysis Parameters

Analysis Code	Traffic Lights	Metro Core	Metro A Extension	Metro D
P6-P-1	Y	N	N	N
P6-P-2	Y	Y	N	N
P6-P-3	Y	Y	Y	N
P6-P-4	Y	Y	Y	Y

4.8.4.2 Amenities Analysis Parameters

Amenities analysis code #	Input Service Area Network Analysis	Time breaks	Note
P6-OSM-1	P6-3, P6-4	0-60	Compares Amenities reach with Metro Core, and Metro A extension

4.8.5 Prague 7 - Holešovice Fairgrounds



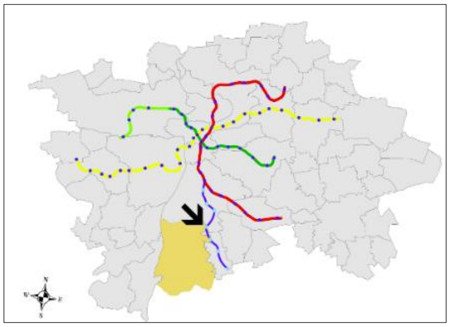
Map 9- Location of Prague Fairgrounds

The Prague fairgrounds in Holešovice are an important meeting place for locals and visitors. It is a major event hub, conveniently located with many major amenities nearby, such as Stromovka Park, the Letná and Holešovice neighborhoods, and multiple transportation modes. It is a starting off point for cyclists travelling along the A1 or A2 routes park, towards the Prague Zoo and other attractions.

4.8.6.1 Network Service Area Network Analysis Parameters

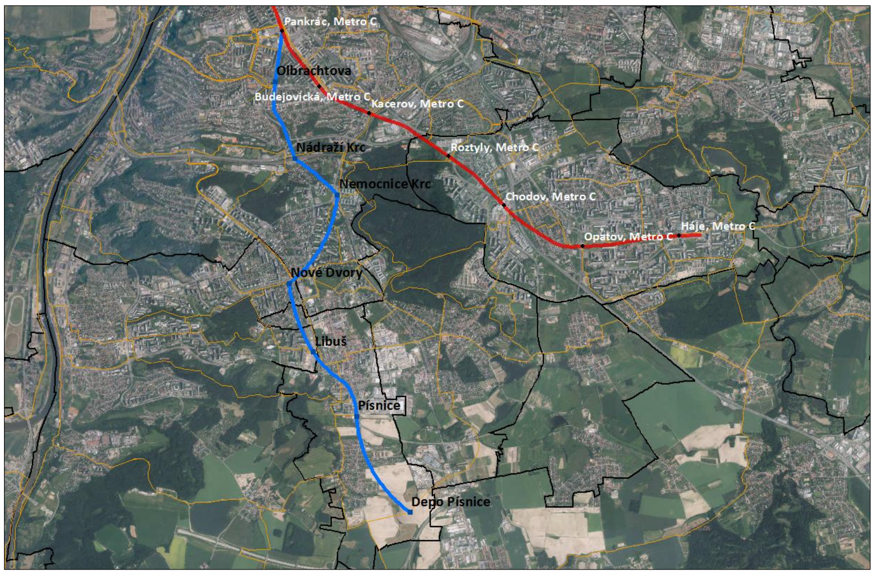
Analysis Code	Traffic Lights	Metro Core	Metro A Extension	Metro D
P7-1	Y	N	N	N
P7-2	Y	Y	N	N
P7-3	Y	Y	Y	N
P7-4	Y	Y	Y	Y

4.8.7 Prague 12 - Nové Dvory Metro Station (Proposed)



Nové Dvory is a proposed station on the Metro D, blue line extension, in southern Prague. The station is located more or less in the center of the proposed line. There is a significant residential population in this area that is underserved by rapid transit.

MAP 10: LOCATION OF NOVÉ DVORY PROPOSED METRO STATION



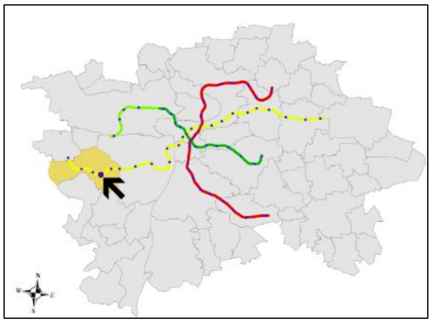
MAP 11: SATELLITE MAP OF PROPOSED METRO EXTENSION, WITH CYCLING NETWORK (CUZK, 2014)

4.8.7.1 Network Service Area Analysis Parameters

Analysis Code	Traffic Lights	Metro Core	Metro A Extension	Metro D
P12-1	Y	N	N	N
P12-2	Y	Y	N	N
P12-3	Y	Y	Y	N
P12-4	Y	Y	Y	N
P12-5	Y	N	Y	Y

4.8.8 Prague 13 - Lužiny Metro

Lužiny Metro is located in a population dense district of a socialism era master-planned panel housing estate built from the 1970-80's in Western district of Prague 13. This particular district is served by five Metro stations (Nové Butovice, Hůrka, Lužiny, Luka and Stodůlky). Along with its towering apartment flats, the area is home to wide pedestrian walkways, and a large central park. The Metro station, where the analysis set is based from, opened in 1994.



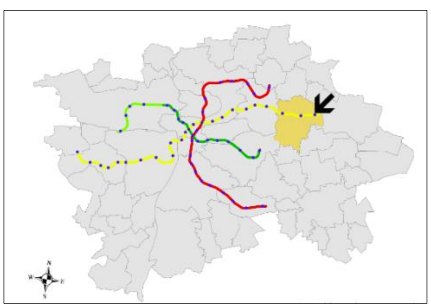
MAP 12: LOCATION OF LUŽINY METRO

4.8.8.1 Network Service Area Analysis Parameters

Analysis code	Traffic Lights	Metro Core	Metro A Extension	Metro D
P13-1	Y	N	N	N
P13-2	Y	Y	N	N
P13-3	Y	Y	Y	N
P13-4	Y	Y	Y	Y

4.8.9 Prague 14 - Černý Most Metro

Černý Most Metro station is the network location point for the analysis. The surrounding area is home to large panel housing estate built during the mid 1970s to 1990's. It is an eastern hub for regional, national, and international bus transport. Recent developments include new residential and shopping centers. The Metro station opened in 1998.



MAP 13: LOCATION OF CERNY MOST

4.8.9.1 Network Service Area Analysis Parameters

Analysis Code	Traffic Lights	Metro Core	Metro A-Extension	Metro D
P14-1	Y	N	N	N
P14-2	Y	Y	N	N
P14-3	Y	Y	Y	N
P14-4	Y	Y	Y	Y

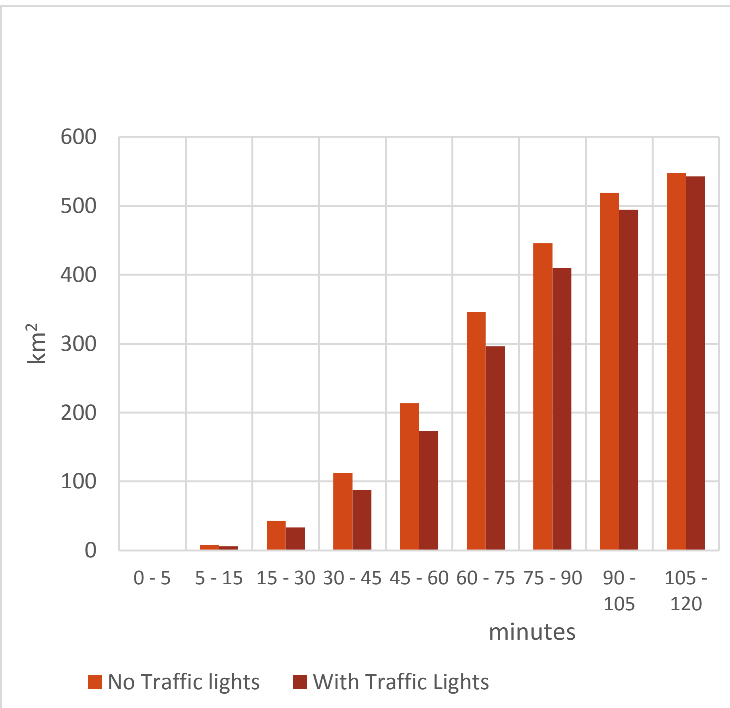
5. Results

Data generated from the Network service area analysis, along with amenities cross tabulation is incorporated into this section. Larger scale maps are available in the Appendix and in interactive form online at *http://www.ecoplans.info*

5.2 Prague 1 - Staroměstské náměstí

5.2.1 Network Service Area with and without Traffic Signals

The service area analysis of the impacts of traffic lights from the Staroměstské náměstí start-point show relatively modest reductions on network service area, however they do cumulatively act to slow down area accessibility, particularly in the 0-60 minute range (Figure 5-1).



Impact of Traffic Lights on Service Area Reach		
minutes	Δ km^2	Δ %
0 - 15	-1.2	-15.4%
15 - 30	-2.3	-5.2%
30 - 45	-24.7	-21.9%
45 - 60	-40.5	-19.0%
60 - 75	-50.1	-14.5%
75 - 90	-36.2	-8.1%
90 - 105	-24.4	-4.7%
105 -120	-4.8	-0.9%

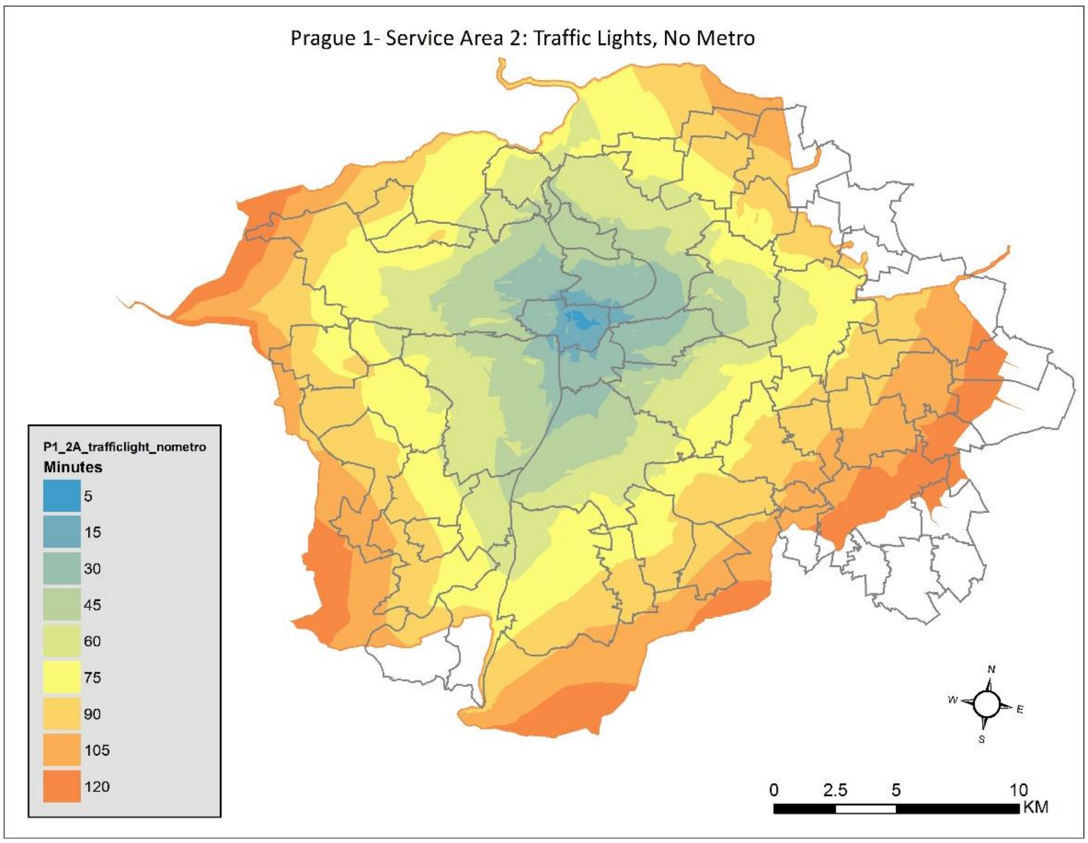
FIGURE 5-1: IMPACT OF TRAFFIC SIGNALS ON AREA ACCESSIBILITY, PRAGUE 1

5.2.2 Network Service Area: No Metro and Metro Core Connectivity

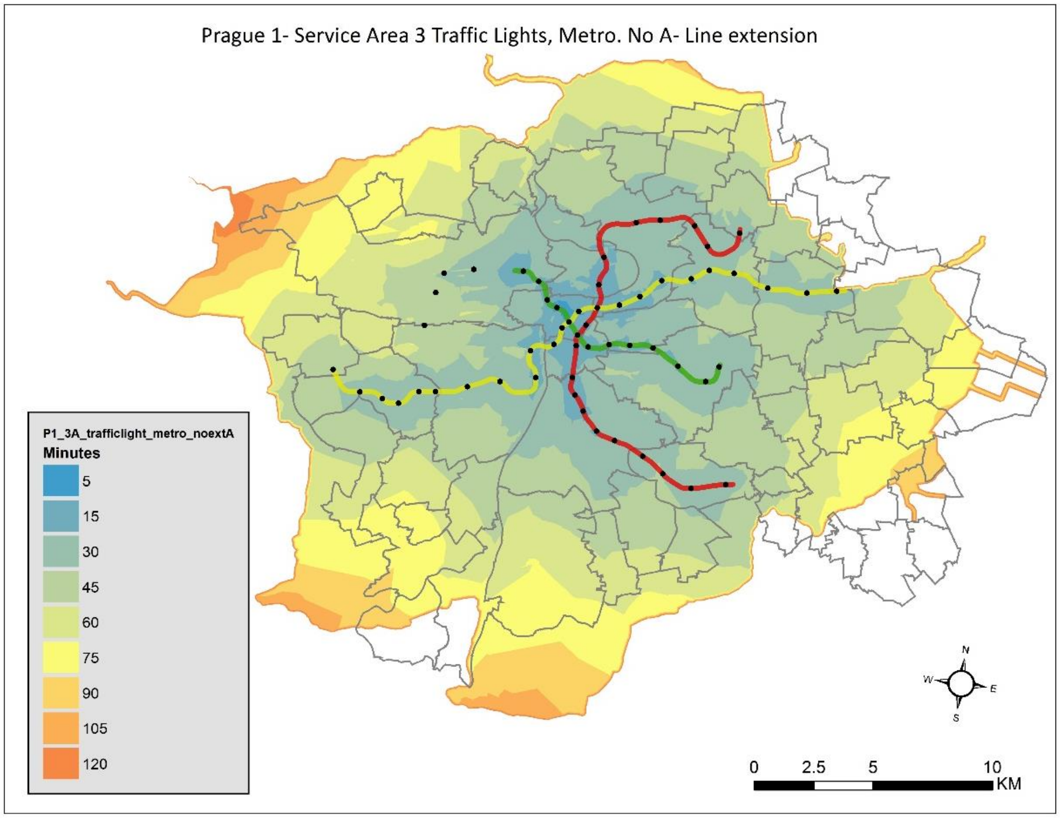
This service area analysis showed that Metro Core connectivity added into the mix of Transportation choices from Staroměstské náměstí significantly increases the amount of area accessible within a given time frame (Map 14, 15). This increase of area is pronounced in the 15-75 minute breaks (Figure 5-2).

minutes	Δ%
0 - 5	88%
0-15	81%
15 - 30	109%
30 - 45	158%
45 - 60	150%
60 - 75	111%
75 - 90	73%
90 - 105	41%
105 - 120	22%

FIGURE 5-2: % AREA CHANGE WITH METRO CORE CONNECTIVITY



MAP 14: SERVICE AREA ANALYSIS, PRAGUE 1, NO METRO



MAP 15: SERVICE AREA ANALYSIS, PRAGUE 1, METRO CORE

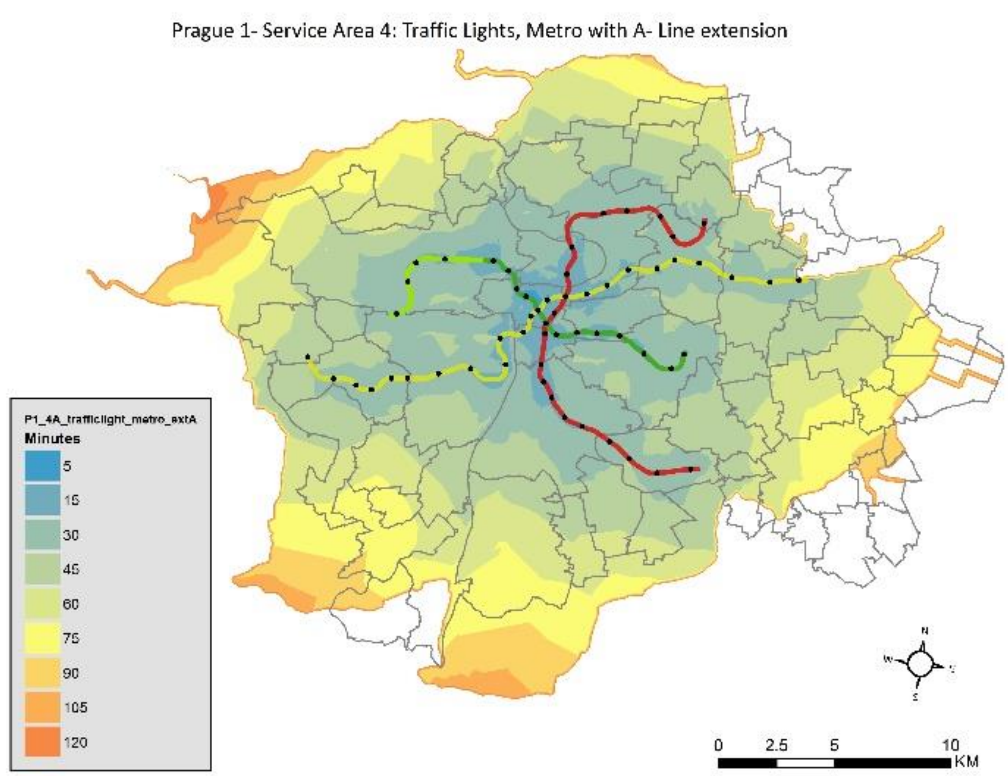
5.2.2.1 Amenities

By taking the bicycle aboard Metro for part of the journey, there is a significant increase in accessibility to amenities in every time bracket. For example, the model predicts there is an additional 140 café/restaurants, 67 bars/pubs/beer gardens, and 17 libraries one can reach within 60 minutes (Figure 5-3).

	No Metro	Metro Core	% Δ	#	#	% Δ	No Metro	Metro Core	% Δ	No Metro	Metro Core	% Δ
minutes	0-15	0-15	%	0-30	0-30	%	0-45	0-45	%	0-60	0-60	%
atm/bank	121	266	*120*	293	486	*66*	393	551	*40*	471	564	*20*
bar, beergarden, pub	63	172	*173*	258	387	*50*	343	475	*38*	426	493	*16*
bicycle parking	51	120	*135*	169	403	*138*	276	571	*107*	372	601	*62*
café/restaurant	425	819	*93*	1133	1460	*29*	1355	1617	*19*	1494	1654	*11*
cinema	8	11	*38*	13	17	*31*	19	21	*11*	20	22	*10*
college/university	5	25	*400*	27	36	*33*	31	39	*26*	31	39	*26*
hospital	2	8	*300*	11	17	*55*	15	27	*80*	21	27	*29*
library	4	22	*450*	29	50	*72*	37	62	*68*	49	66	*35*
school	7	23	*229*	35	64	*83*	50	89	*78*	64	95	*48*
surveillance	231	389	*68*	458	691	*51*	588	828	*41*	665	864	*30*
toilets	5	73	*1360*	21	140	*567*	22	150	*582*	22	150	*582*

FIGURE 5-3: AMENITIES ACCESSIBILITY, NO METRO/ METRO CORE, PRAGUE 1 [CODE: P1-OSM-1]

5.2.3 Network Service Area: Metro A extension connectivity



MAP 16: SERVICE AREA ANALYSIS, PRAGUE 1, METRO A EXTENSION

5.2.3.1 Amenities: Metro Core vs Metro A Extension

minutes	0-15 Metro Core	0-15 Metro A extension	0-15 % Δ	0-30	0-30	0-30 % Δ	0-45	0-45	0-45 % Δ	0-60	0-60	0-60 % Δ
atm/bank	266	281	*6%*	486	495	*2%*	551	557	*1%*	564	578	*2%*
bar, beergarden, pub	172	172	*0%*	387	399	*3%*	475	482	*1%*	493	493	*0%*
bicycle_parking	120	125	*4%*	403	416	*3%*	571	578	*1%*	601	603	*0%*
café/restaurants	819	850	*4%*	1460	1487	*2%*	1617	1631	*1%*	1654	1665	*1%*
Cinema	11	13	*18%*	17	17	*0%*	21	21	*0%*	22	22	*0%*
college/university	25	26	*4%*	36	36	*0%*	39	39	*0%*	39	39	*0%*
hospital	8	8	*0%*	17	17	*0%*	27	27	*0%*	27	27	*0%*
library	22	23	*5%*	50	52	*4%*	62	63	*2%*	66	66	*0%*
school	23	23	*0%*	64	67	*5%*	89	91	*2%*	95	95	*0%*
surveillance	389	410	*5%*	691	707	*2%*	828	840	*1%*	864	864	*0%*
toilets	73	80	*10%*	140	144	*3%*	150	150	*0%*	150	153	*2%*

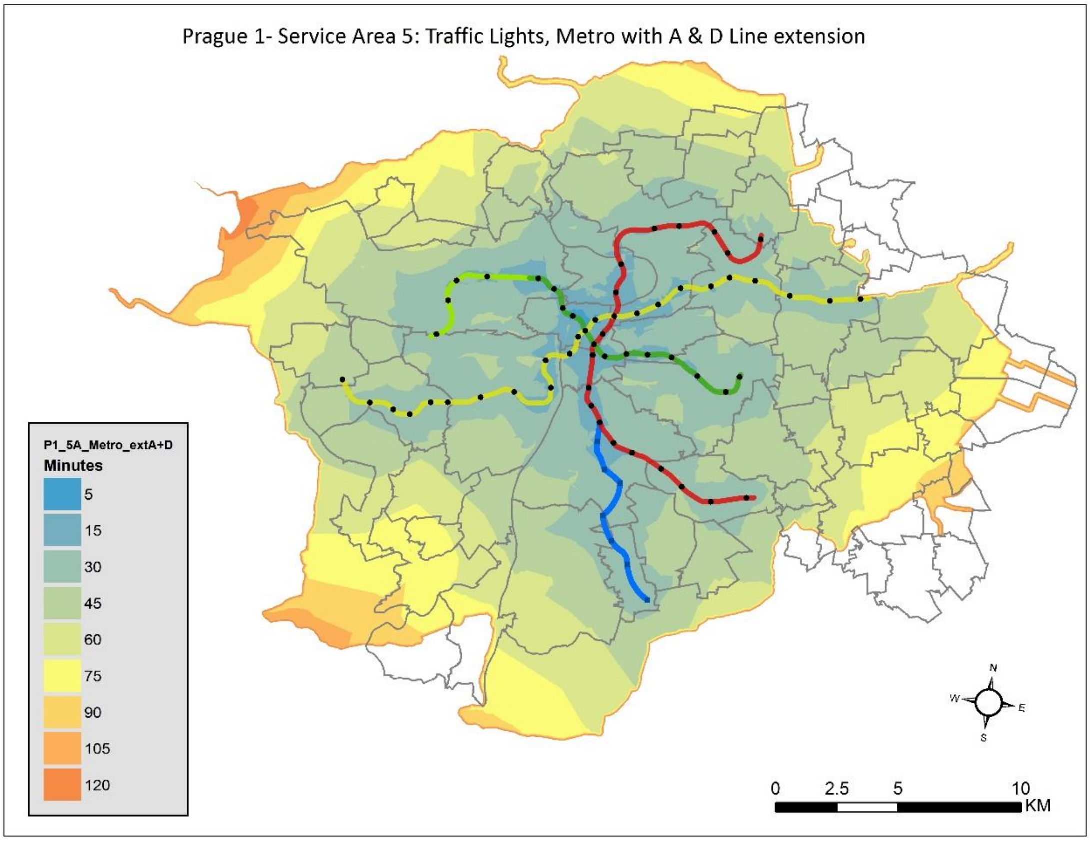
FIGURE 5-4: AMENITIES COMPARASION WITH AND WITHOUT METRO A-LINE EXTENSION

5.2.4 Network Service Area: Metro A Extension and Metro D

As compared to the predicted service area extent of the Metro with the A-line extension (Map 16), the planned D-Line (Map 17) would speed area accessibility, modestly but sizably, and mostly in the 30-75 minute range (Figure 5-5). This is likely due to the fact that getting to the start of the D-line would take at least 30+ minutes from the Staroměstské náměstí area.

minutes)	Metro A Extension km²	Metro D Line km²	Δ vs Metro A extension km²	% increase %
0-5	2.6	2.6	0.0	*0*
5-15	17.8	17.8	0.0	*0*
15-30	85.0	86.8	1.8	*2.1*
30-45	231.5	249.1	17.6	*7.6*
45-60	364.7	385.9	21.2	*5.8*
60-75	465.2	483.1	17.8	*3.8*
75-90	525.8	535.1	9.3	*1.8*
90-105	548.0	549.5	1.5	*0.3*
105-120	557.4	557.8	0.4	*0.1*
120-135	567.0	567.1	0.1	*0*

FIGURE 5-5: METRO D SERVICE AREA IMPACTS FROM PRAGUE 1



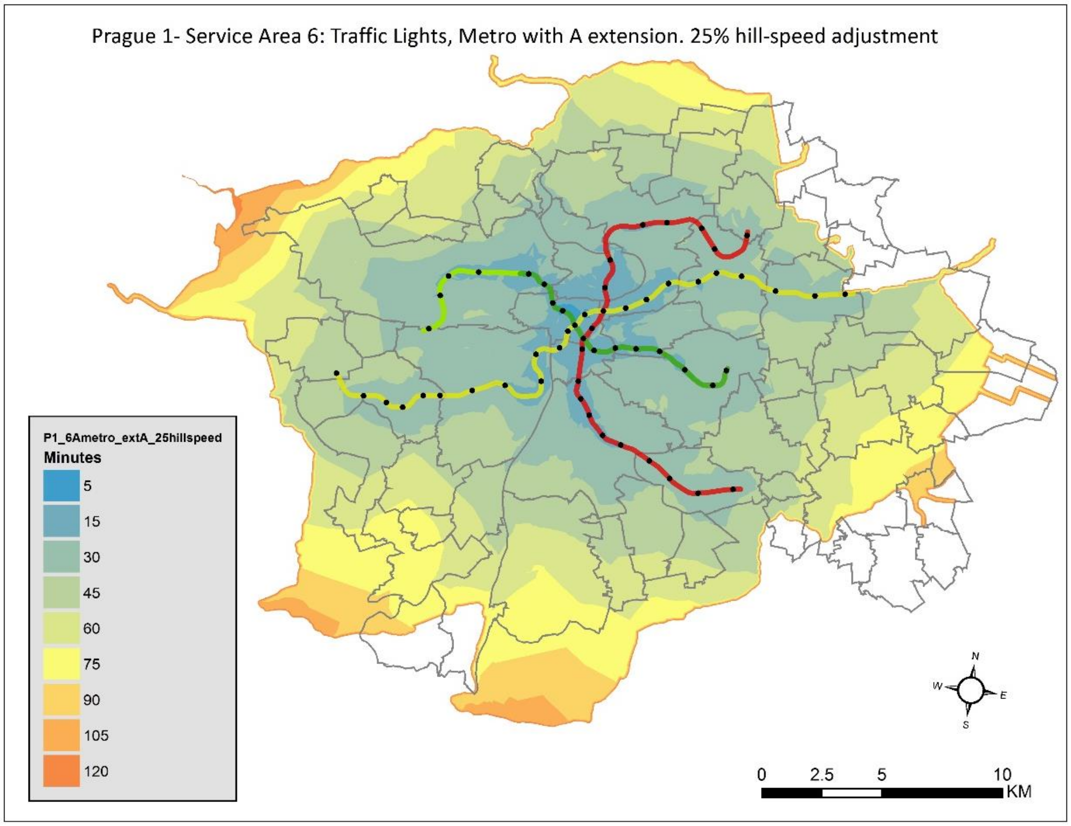
MAP 17: SERVICE AREA ANALYSIS, PRAGUE 1- METRO D

5.2.5 Network Service Area: Metro A-Ext 25% hill-speed adjustment

Factoring in the 25% hill-speed adjustment, while maintaining Metro A extension level connectivity has a noticeable negative but not overwhelming impact on area accessibility, primarily in the first 45 minutes of travel (Figure 5-6)(Map 18).

minutes	km^2 Δ	% Δ
5	-0.1	-17%
15	-6.5	-29%
30	-16.3	-11%
45	-15.0	-5%
60	-12.0	-3%
75	-5.9	-1%
90	-2.3	0%
105	-1.1	0%
120	-0.4	0%

FIGURE 5-6: IMPACT OF HILLSPEED ADJUSTMENT VARIABLE.



MAP 18: SERVICE AREA ANALYSIS, PRAGUE 1, HILLSPEED ADJUSTMENT WITH METRO

5.2.6 Network Service Area Summary

	No Metro	Metro Core	Δ v s. no Metro	% increase	Metro A Extension	Δ vs Metro Core	% increase	Δ vs No Metro	% increase	Metro D Line	Δ vs Metro A extension	% increase
minutes	km²	km²	km²	%	km²	km²	%	km²	%	km²	km²	%
0 - 5	1.4	2.6	1.2	*88.1*	2.6	0.0	*0.0*	1.2	*88.1*	2.6	0.0	*0.0*
5 - 15	9.9	17.8	8.0	*81.0*	17.8	0.0	*0.0*	8.0	*81.0*	17.8	0.0	*0.0*
15 - 30	40.7	85.0	44.3	*108.8*	85.0	0.0	*0.0*	44.3	*108.8*	86.8	1.8	*2.1*
30 - 45	88.4	228.0	139.6	*157.9*	231.5	3.5	*1.5*	143.1	*161*	249.1	17.6	*7.6*
45 - 60	144.9	361.7	216.8	*149.6*	364.7	3.0	*0.8*	219.8	*151.7*	385.9	21.2	*5.8*
60 - 75	219.7	463.4	243.6	*110.9*	465.2	1.9	*0.4*	245.5	*111.7*	483.1	17.8	*3.8*
75 - 90	303.5	525.3	221.8	*73.1*	525.8	0.5	*0.1*	222.2	*73.2*	535.1	9.3	*1.8*
90 - 105	390.1	548.0	157.9	*40.5*	548.0	0.0	*0.0*	157.9	*40.5*	549.5	1.5	*0.3*
105- 120	455.4	557.4	102.0	*22.4*	557.4	0.0	*0.0*	102.0	*22.4*	557.8	0.4	*0.1*
120 -135	507.4	567.0	59.6	*11.7*	567.0	0.0	*0.0*	59.6	*11.7*	567.1	0.1	*0.0*
135 -150	542.1	572.7	30.5	*5.6*	572.7	0.0	*0.0*	30.5	*5.6*	572.7	0.0	*0.0*

SERVICE AREA (km²) VS TIME (MINUTES) VIA TRANSPORT METHOD

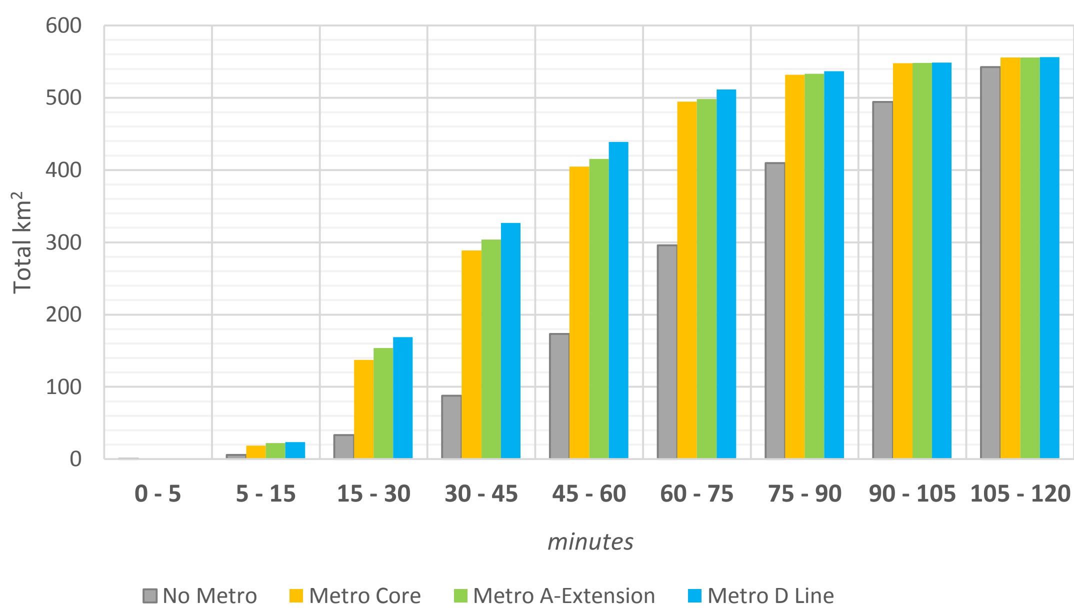


FIGURE 5-7: SERVICE AREA COMPARISON, ALL MODES OF TRANSIT, PRAGUE 1.

5.3 Prague 5 - Nemocnice Motol Metro

The service area accessibility impact of the Metro A-Line extension is evident from this location. Compared to pre-extension Metro connectivity, the A-line extension significantly increases the overall amount of area accessible within the 0-105 minute range (Figure 5-8). Prior, the nearest Metro stations one could transfer to were at least 20-30 minutes away by bicycle. The effects are most pronounced in the 0-60 minute range. Metro D Line extension accessibility benefits take place primarily within the 30-90 minute range (Figure 5-8).

5.3.1 Network Service Area Summary

	No Metro	Metro Core	Δ vs no Metro	% Δ	Metro A-Extension	Δ vs Metro Core	% increase	Metro D Line	Δ vs Metro A extension	% increase
Appendix #	**1**	**2**			**3**			**4**		
minutes	km²	km²	km²	%	km²	km²	%	km²	km²	%
0 - 5	0.6	0.8	0.2	*24*	1.1	0.3	*37.8*	1.1	0.0	*0*
5 - 15	7.5	8.0	0.4	*5.6*	15.0	7.1	*88.7*	15.0	0.0	*0*
15 - 30	38.3	41.3	3.0	*8*	92.8	51.5	*124.7*	95.7	2.8	*3*
30 -45	90.1	103.6	13.5	*15.0*	237.7	134.1	*129.3*	257.5	19.8	*8.3*
45 -60	155.2	222.4	67.3	*43.4*	368.5	146.0	*65.7*	392.7	24.2	*6.6*
60-75	236.5	365.6	129.1	*54.6*	462.2	96.6	*26.4*	483.8	21.7	*4.7*
75 - 90	323.5	462.6	139.2	*43.0*	521.6	59.0	*12.7*	532.2	10.6	*2.0*
90- 105	405.2	523.0	117.8	*29.1*	545.8	22.8	*4.4*	547.7	1.9	*0.4*
105-120	475.1	548.6	73.5	*15.5*	555.0	6.4	*1.2*	555.5	0.5	*0.1*
120- 135	515.4	561.4	46.0	*8.9*	563.1	1.7	*0.3*	563.3	0.2	*0*
135- 150	544.2	572.7	28.5	*5.2*	572.7	0.0	*0*	572.7	0.0	*0*

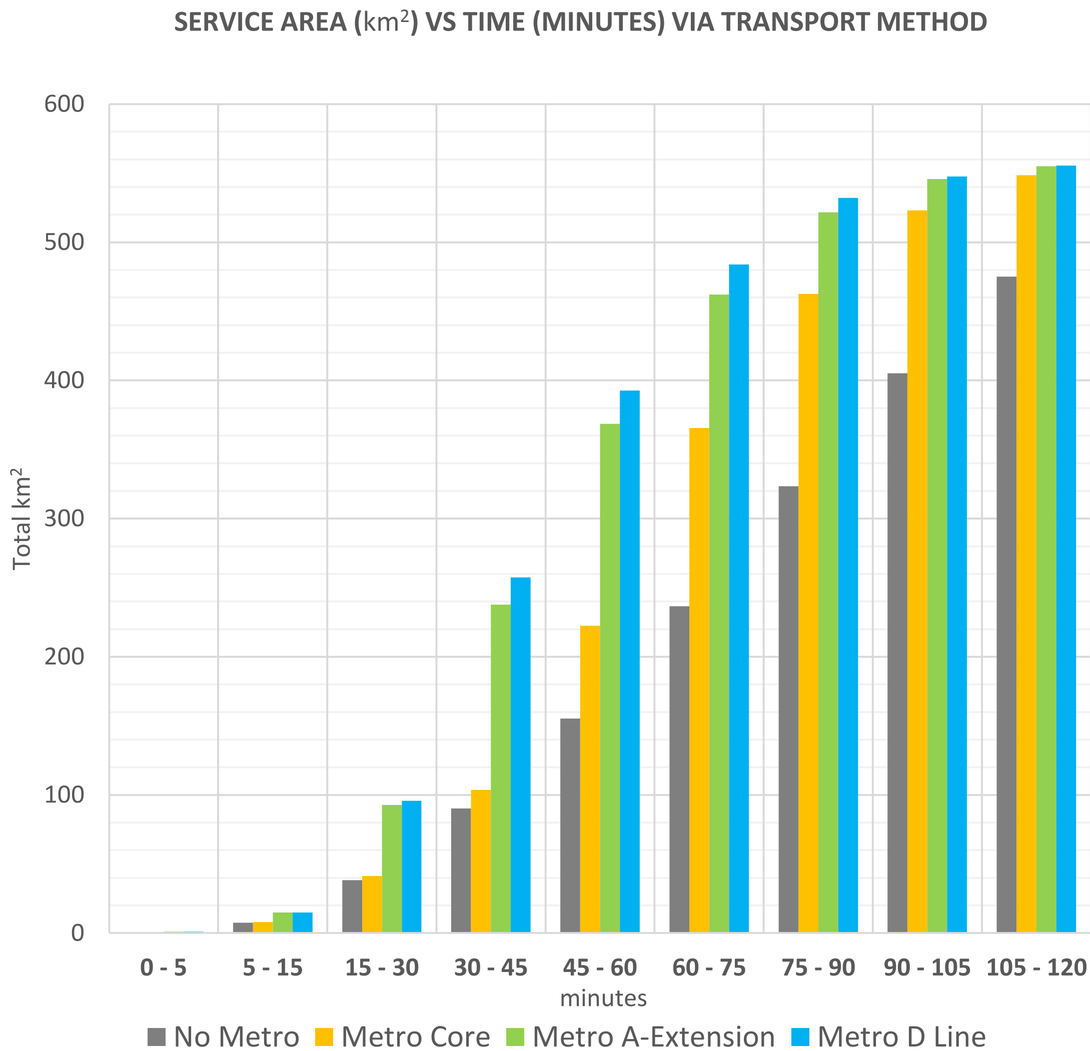


FIGURE 5-8: SERVICE AREA COMPARISON, ALL MODES OF TRANSIT, PRAGUE 5-MOTOL.

5.4 Prague 6 - Dejvická

Results for the Dejvická network service area analysis shows that there is a modest increase in quickly accessible areas thanks to the A-line extension. Added Metro D-Line connectivity also shows modest increases in accessible area (Figure 5-10).

5.4.1 Network Service Area Summary

	No Metro	Metro Core	Δ vs no Metro	% increase	Metro A-Extension	Δ vs Metro Core	% increase	Δ vs No Metro	% increase	Metro D Line	Δ vs Metro A-ext	% increase
Appendix #	5	6			7					8		
minutes	km^2	km^2	km^2	%	km^2	km^2	%	km^2	%	km^2	km^2	%
0 - 5	0.8	0.9	0.1	*19*	1.4	0.4	*48*	0.6	75.2	1.4	0.0	*0*
5 - 15	7.2	16.4	9.2	*127*	24.3	7.9	*48*	17.1	236.5	24.9	0.5	*2.2*
15 - 30	36.5	122.6	86.1	*236*	146.3	23.7	*19*	109.8	300.9	159.0	12.7	*8.7*
30- 45	92.3	281.4	189.2	*205*	305.0	23.5	*8*	212.7	230.5	327.9	23.0	*7.5*
45- 60	182.1	404	221.9	*122*	414.7	10.6	*3*	232.6	127.7	438.4	23.8	*5.7*
60- 75	269.1	489.2	220.1	*82*	496.7	7.4	*2*	227.5	84.5	511.5	14.8	*3.0*
75- 90	368.4	531.7	163.3	*44*	534.5	2.8	*1*	166.1	45.1	539.2	4.6	*0.9*
90-105	451.6	549.6	98.0	*22*	550.2	0.6	*0*	98.5	21.8	550.8	0.6	*0.1*
105-120	515.4	557.3	41.9	*8*	557.4	0.1	*0*	42.0	8.2	557.8	0.4	*0.1*
120-135	556.0	565.6	9.6	*2*	565.5	-0.2	*0*	9.4	1.7	565.6	0.2	*0*
135-150	572.7	572.7	0	*0*	572.7	0.0	*0*	0	0	572.7	0.0	*0*

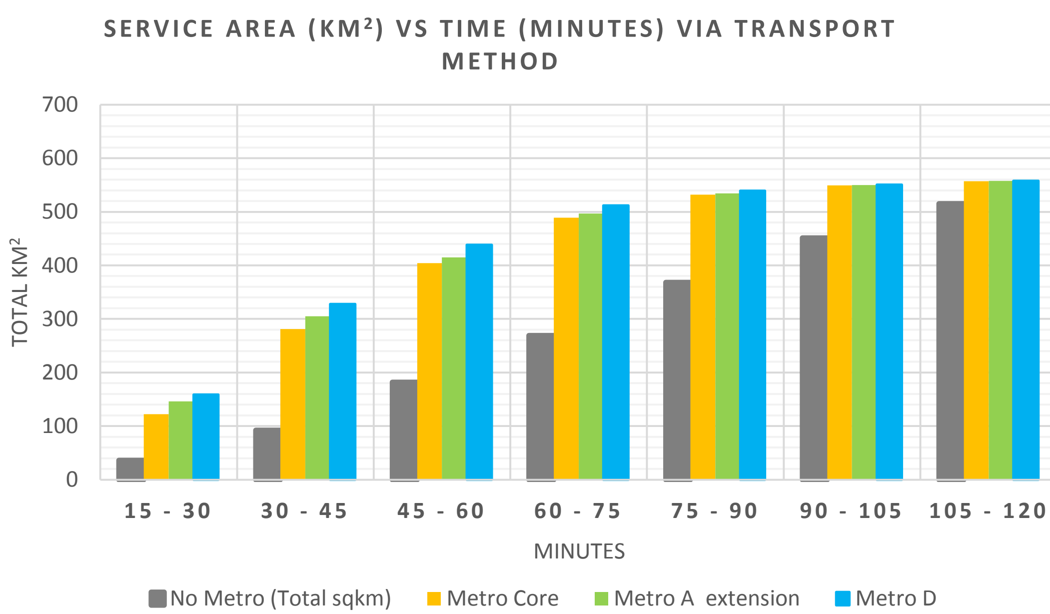


FIGURE 5-9-: SERVICE AREA COMPARISON, ALL MODES OF TRANSIT, PRAGUE 6- DEJVICKA.

5.5 Prague 6 - Petřiny

Results for Petřiny show that pre-extension, the larger regional reach benefits of riding the Metro didn't start until the 30-45 minute range, due to the moderate distance between start point and metro stations (Figure 5-11). The new extension is modelled to create a 57.3% increase in reachable area within a 5-15 minute ride, and a 20.9% increase in the 15-30 minute range. Those cyclists who need quick access in an out of Petřiny for their journeys are well serviced by this extension.

5.5.1 Network Service Area Summary

	No Metro	Metro Core	Δ vs no Metro	% increase	Metro A Extension	Δ vs Metro Core	% increase	Metro D Line	difference vs Metro A-ext	% increase
Appendix #	9	10			11			12		
minutes	km^2	km^2	km^2	%	km^2	km^2	%	km^2	km^2	%
0 - 5	0.5	0.5	0.0	0	0.7	0.2	44.1	0.7	0.0	0
5 - 15	7.5	7.5	0.0	0	11.8	4.3	57.3	11.8	0.0	0
15 - 30	34.7	38.9	4.2	12	47.0	8.1	20.9	47.0	0.0	0
30 - 45	90.9	147.0	56.1	61.8	154.5	7.5	5.1	163.4	8.9	5.8
45 - 60	163.7	295.7	132.0	80.7	303.4	7.7	2.6	326.9	23.5	7.8
60 - 75	244.2	409.6	165.5	67.8	415.9	6.2	1.5	440.4	24.5	5.9
75 - 90	318.6	491.7	173.1	54.3	495.8	4.2	0.8	513.0	17.2	3.5
90 - 105	398.0	535.1	137.0	34.4	536.1	1.0	0.2	543.1	7.0	1.3
105 - 120	456.8	552.7	96.0	21	553.1	0.3	0.1	553.9	0.9	0.2
120 - 135	502.2	562.4	60.3	12	562.5	0.1	0	562.8	0.3	0.1
135 - 150	536.7	572.7	36.0	6.7	572.7	0.0	0	572.7	0.0	0

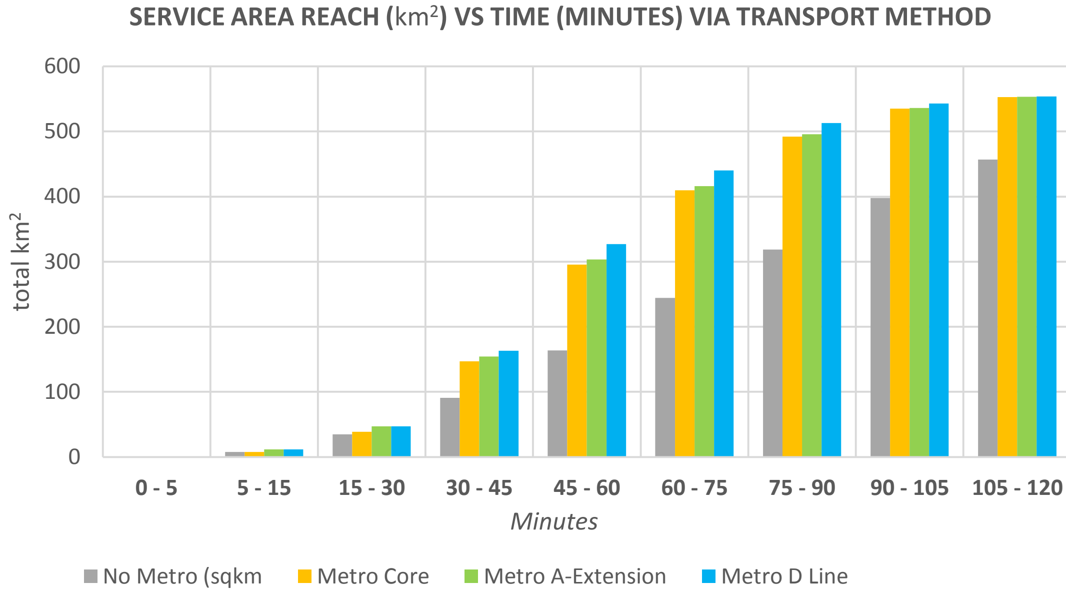


FIGURE 5-10: SERVICE AREA COMPARISON, ALL MODES OF TRANSIT, PRAGUE 6 - PETŘINY.

5.5.1 Amenities

With Metro A-line connectivity modestly increases the number of amenities from Petřiny particularly in the 45-60 minute time bracket (Figure 5-11).

	Metro Core	Metro A Extension	Δ vs Metro Core	Δ % vs metro Core	Metro Core	Metro A Extension	Δ vs Metro Core	Δ % vs metro Core
Minutes	#, 0-45	0-45	#	%	0-60	0-60	*#*	*%*
atm/bank	466	467	1	*0.2%*	560	570	**10**	*1.8%*
bar, beergarden, pub	379	386	7	*1.8%*	469	477	**8**	*1.7%*
bicycle_parking	360	372	12	*3.3%*	559	574	**15**	*2.7%*
café/restaurant	1435	1453	18	*1.3%*	1623	1636	**13**	*0.8%*
cinema	18	18	0	*0.0%*	22	23	**1**	*4.5%*
college/university	33	34	1	*3.0%*	38	39	**1**	*2.6%*
hospital	13	13	0	*0.0%*	26	26	**0**	*0.0%*
library	46	47	1	*2.2%*	61	63	**2**	*3.3%*
school	54	56	2	*3.7%*	80	86	**6**	*7.5%*
surveillance	670	686	16	*2.4%*	812	828	**16**	*2.0%*
toilets	139	139	0	*0.0%*	153	153	**0**	*0.0%*

FIGURE 5-11: AMENITIES ANALYSIS BY NETWORK SERVICE AREA FOR PRAGUE 6 - PETŘINY

5.6 Prague 7- Holešovice Fairgrounds

Results show that utilizing Metro connectivity increases the overall reachable area. Metro A extension shows small increases in overall accessibility, not reaching in excess of 4.6%. Metro D-line extensions show larger gains.

5.6.1 Network Service Area Summary

	No Metro	Metro Core	Δ vs no Metro	% increase	Metro A Extension	Δ vs Metro Core	% increase	Metro D Line	Δ vs Metro A-Extension	% increase
Appendix #	13	14			15			16		
minutes	km²	km²	km²	%	km²	km²	%	km²	km²	%
0 - 5	1.1	1.0	0.0	*-2.6*	1.0	0.0	*-0.9*	1.0	0.0	*0*
5 - 15	7.9	10.1	2.2	*27.6*	10.0	-0.1	*-1.2*	10	0.0	*0*
15 - 30	35.9	90.2	54.3	*151*	93.0	2.8	*3.1*	98.1	5.2	*0.1*
30 - 45	86.5	235.4	149.0	*172*	246.2	10.8	*4.6*	269.0	22.8	*0.1*
45 - 60	173.1	362.5	189.3	*109.4*	373.2	10.7	*3.0*	398.0	24.9	*0.1*
60 - 75	273.5	462.3	188.8	*69*	466.1	3.8	*0.8*	485.0	18.9	*0*
75 - 90	370.2	518.8	148.6	*40.2*	520.3	1.5	*0.3*	529.0	8.7	*0*
90 - 105	461.7	544.8	83.1	*18*	545.0	0.1	*0*	546.1	1.2	*0*
105-120	527.8	554.6	26.7	*5.1*	554.6	0.0	*0*	555	0.5	*0*
120-135	556.1	562.3	6.1	*1.1*	562.3	0.0	*0*	562.5	0.2	*0*
135-150	572.5	572.4	0.0	*0*	572.5	0.0	*0*	572.5	0.0	*0*

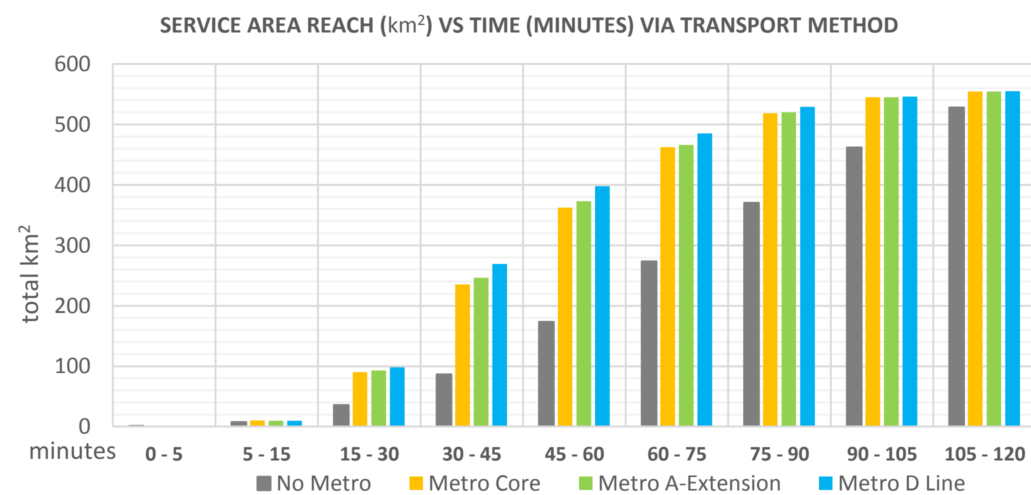


FIGURE 5-12: SERVICE AREA COMPARISON, ALL MODES OF TRANSIT, PRAGUE 7-HOLEŠOVICE

5.7 Prague 12 - Nové Dvory Proposed Metro Station.

The enormous potential accessibility improvements of the planned D line extension are evident in the results of this service area analysis. The D-Line shortens time to reach regional areas considerably. For example areas reachable in the 15-30 minute time range increase 171% over existing Metro 2015 connectivity (Figure 5-13).

5.7.1 Network Service Area Summary

	No Metro	Metro Core	Δ vs no Metro	% increase	Metro A Extension	Δ vs Metro Core	% increase	Metro D Line	Δ vs Metro A Extension	% increase	Δ vs no Metro	% increase
appendix #	17	18			19			20				
minutes	km²	km²	km²	%	km²	km²	%	km²	km²	%	km²	%
0 - 5	1.1	1.1	0.0	*0*	1.08	0.0	*0*	2.35	1.27	*118*	1.27	*118*
5 - 15	9.1	9.1	0.0	*0*	9.08	-0.01	*-0.1*	28.66	19.58	*216*	19.57	*215.4*
15 - 30	40.6	47.2	6.6	*16.2*	47.17	-0.01	*0*	127.93	80.76	*171*	87.32	*215*
30 - 45	99.9	148.4	48.5	*48.6*	148.17	-0.25	*-0.2*	277.36	129.19	*87*	177.46	*177.6*
45 - 60	169.2	292.6	123.4	*73.0*	295.17	2.57	*0.9*	401.97	106.80	*36*	232.81	*137.6*
60 - 75	236.0	411.1	175.1	*74.2*	414.32	3.17	*0.8*	489.71	75.39	*18*	253.70	*107.5*
75 - 90	305.5	494.3	188.8	*61.8*	496.89	2.55	*0.5*	528.37	31.48	*6*	222.87	*73*
90 - 105	385.6	530.2	144.6	*37.5*	530.73	0.50	*0.1*	543.88	13.16	*2*	158.29	*41*
105 - 120	443.5	546.7	103.2	*23.3*	546.86	0.17	*0*	554.58	7.72	*1*	111.09	*25*
120 - 135	474.8	559.2	84.4	*17.8*	559.20	0.00	*0*	561.86	2.66	*0*	87.03	*18.3*
135 - 150	498.1	569.2	71.1	*14.3*	569.16	-0.01	*0*	570.50	1.34	*0*	72.41	*14.5*

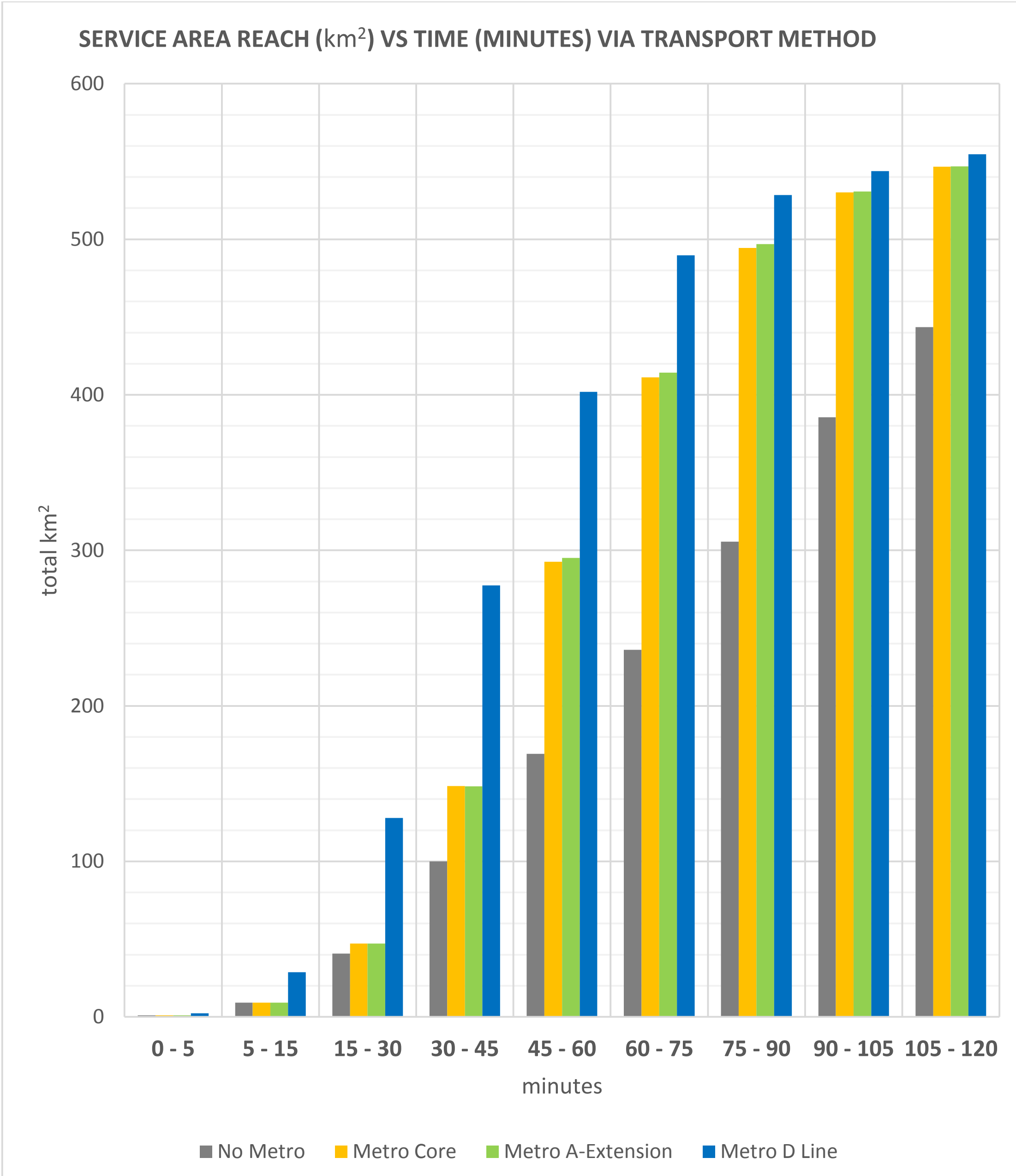


FIGURE 5-13: SERVICE AREA COMPARISON, ALL MODES OF TRANSIT, PRAGUE 12-NOVÉ DVORY

5.8 Prague 13 - Lužiny Metro

The Metro A extension provides very little additional accessibility benefits from this location, with a small 1.5% increase in the 30-45 minute time bracket. Metro D-line extension provides modest, but more sizable accessibility benefits, primarily in the 30-75 minute range (Figure 5-14).

5.8.1 Network Service Area Summary

	No Metro	Metro Core	Δ vs no Metro	% increase	Metro A Extension	Δ vs Metro Core	% increase	Metro D Line	Δ vs Metro A extension	% increase
Appendix #	21	22			23			24		
minutes	km²	km²	km²	%	km²	km²	%	km²	km²	%
0 - 5	1.4	2.6	1.2	*88.1*	2.6	0.0	*0*	2.6	0.0	*0*
5 - 15	9.9	17.8	8.0	*81.0*	17.8	0.0	*0*	17.8	0.0	*0*
15 - 30	40.7	85.0	44.3	*108.8*	85	0.0	*0*	86.8	1.8	*2.1*
30 - 45	88.4	228	139.6	*157.9*	231.5	3.5	*1.5*	249.1	17.6	*7.6*
45 - 60	144.9	361.7	216.8	*149.6*	364.7	3.0	*0.8*	385.9	21.2	*5.8*
60 - 75	219.7	463.4	243.6	*110.9*	465.2	1.9	*0.4*	483.1	17.8	*3.8*
75 - 90	303.5	525.3	221.8	*73.1*	525.8	0.5	*0.1*	535.1	9.3	*1.8*
90 - 105	390.1	548	157.9	*40.5*	548	0.0	*0*	549.5	1.5	*0.3*
105-120	455.4	557.4	102.0	*22.4*	557.4	0.0	*0*	557.8	0.4	*0.1*
120-135	507.4	567	59.6	*11.7*	567	0.0	*0*	567.1	0.1	*0*
135-150	542.1	572.7	30.5	*5.6*	572.7	0.0	*0*	572.7	0	*0*

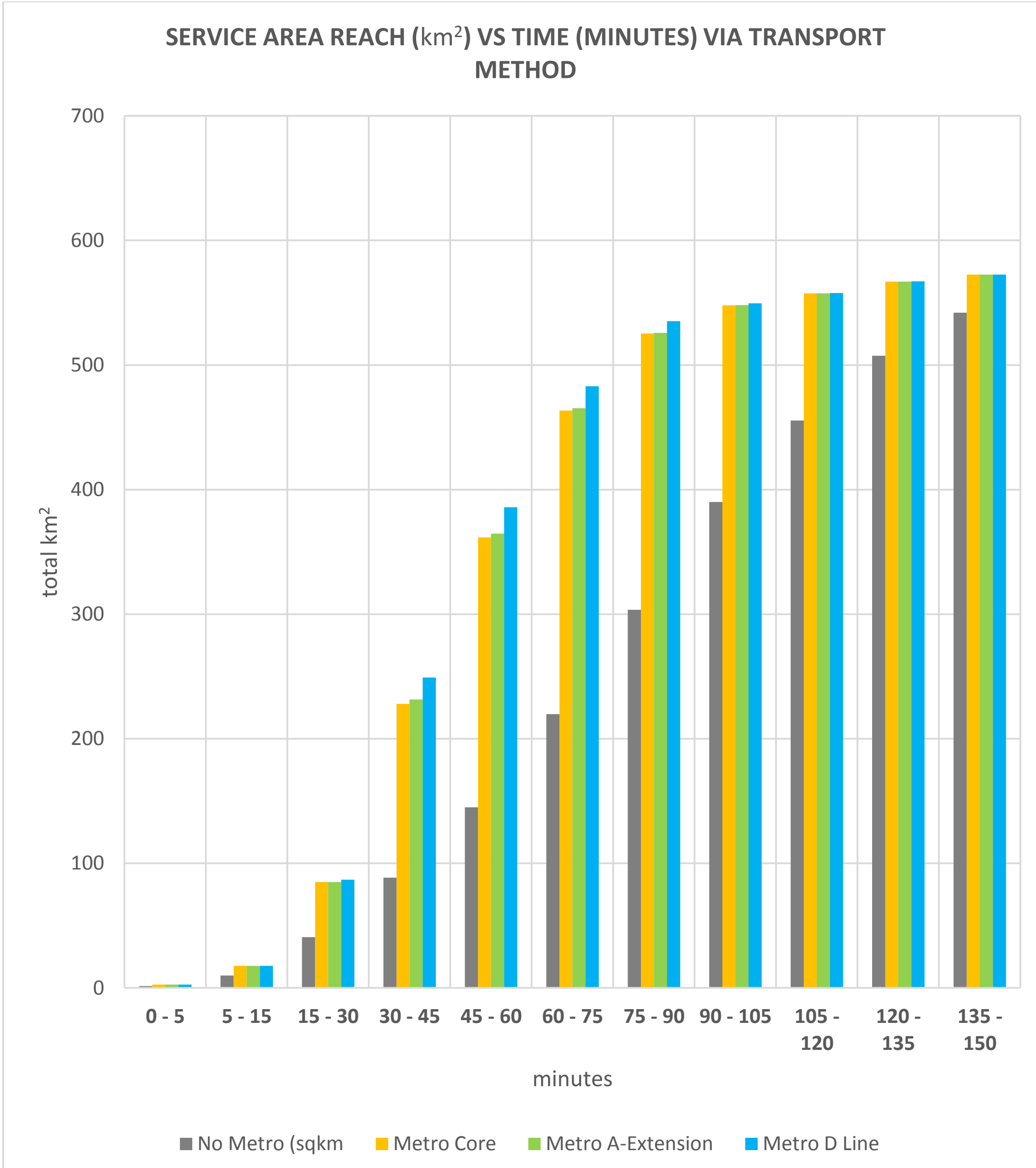


FIGURE 5-14- COMPARISON SERVICE AREA OF ALL MODES OF TRANSIT, PRAGUE 13- LUŽINY METRO

5.9 Prague 14 - Černý Most

Like previous network service area analyses, the impacts of Metro Core connectivity significantly increase area accessibility. Within a two hour time frame, there is 186 square kilometers that are not accessible. However Metro A-extension only slightly increases the speed of accessibility for a modest portion. This is outweighed by Metro D-line extension.

5.9.1 Network Service Area Summary

	No Metro	Metro Core	Δ vs no Metro	% increase	Metro A Extension	Δ vs Metro Core	% increase	Metro D Line	Δ vs Metro A extension	% increase
Appendix	**25**	**26**			**27**			**28**		
minutes	**km²**	**km²**	**km²**	**%**	**km²**	**km²**	**%**	**km²**	**km²**	**%**
0 - 5	0.9	1.3	0.4	39.9	1.3	0	2.5	1.3	0.0	0
5 - 15	9.4	14.3	4.9	52.6	14.4	0.1	0.9	14.4	0.0	0
15 - 30	37.2	67.9	30.8	82.7	68.6	0.7	1	69.6	0.9	1.4
30 - 45	78.7	191.2	112.5	143	203.0	11.8	6.1	217.2	14.2	7
45 - 60	133.0	324.6	191.7	144.1	340.1	15.4	4.8	363.3	23.2	6.8
60 - 75	189.3	418.3	229.0	121	432.0	13.6	3.3	456.1	24.1	5.6
75 - 90	252.2	495.0	242.7	96.2	499.1	4.1	0.8	513.2	14.2	2.8
90 - 105	313.6	533.2	219.5	70.	534.8	1.6	0.3	538.9	4.1	0.8
105 - 120	364.6	551.3	186.7	51.2	551.6	0.3	0.1	552.3	0.6	0.1
120 - 135	396.0	560.9	164.9	41.6	560.9	0	0	561.2	0.3	0.1
135 - 150	426.2	569.8	143.6	33.7	569.8	0	0	569.8	0	0

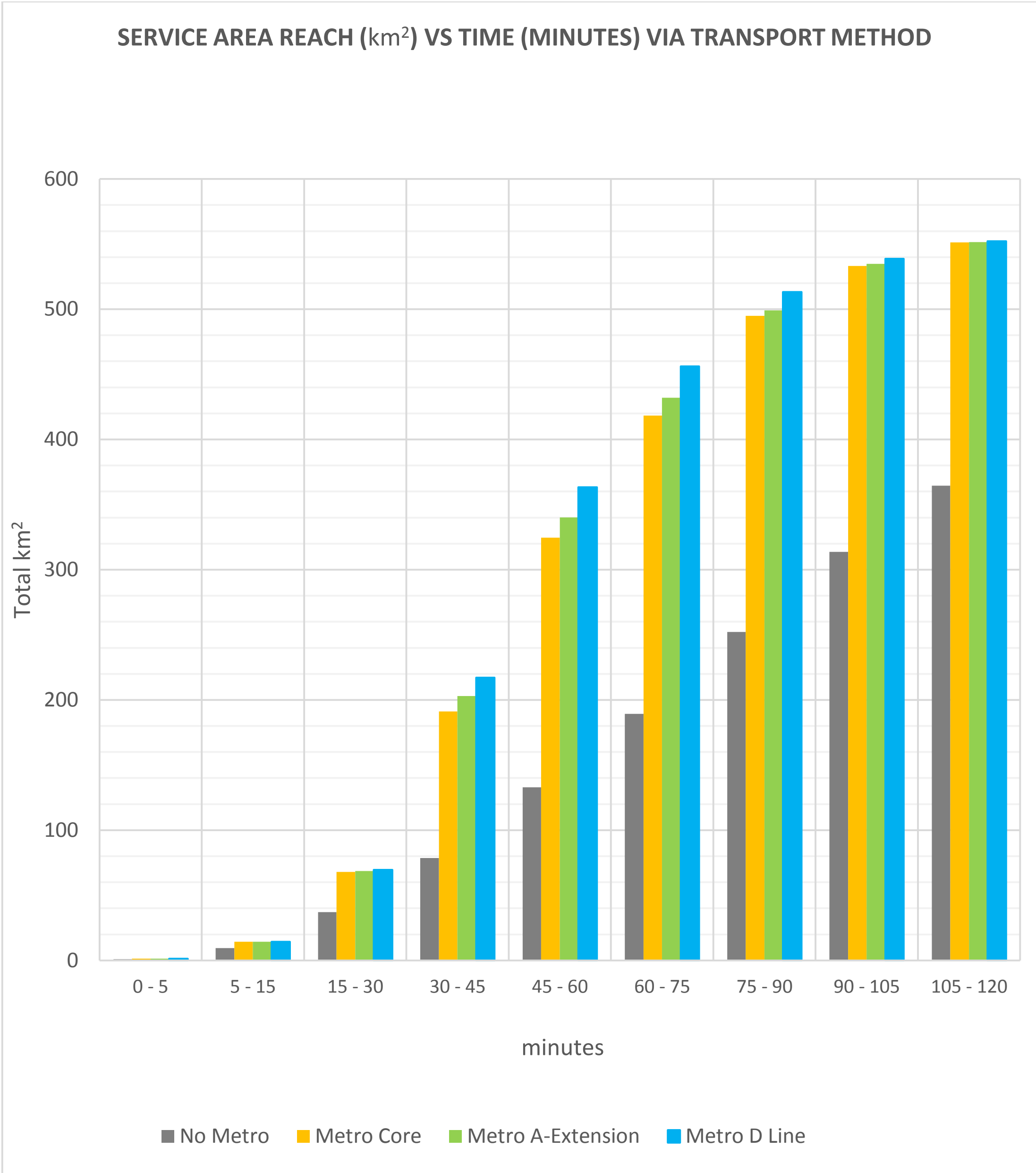
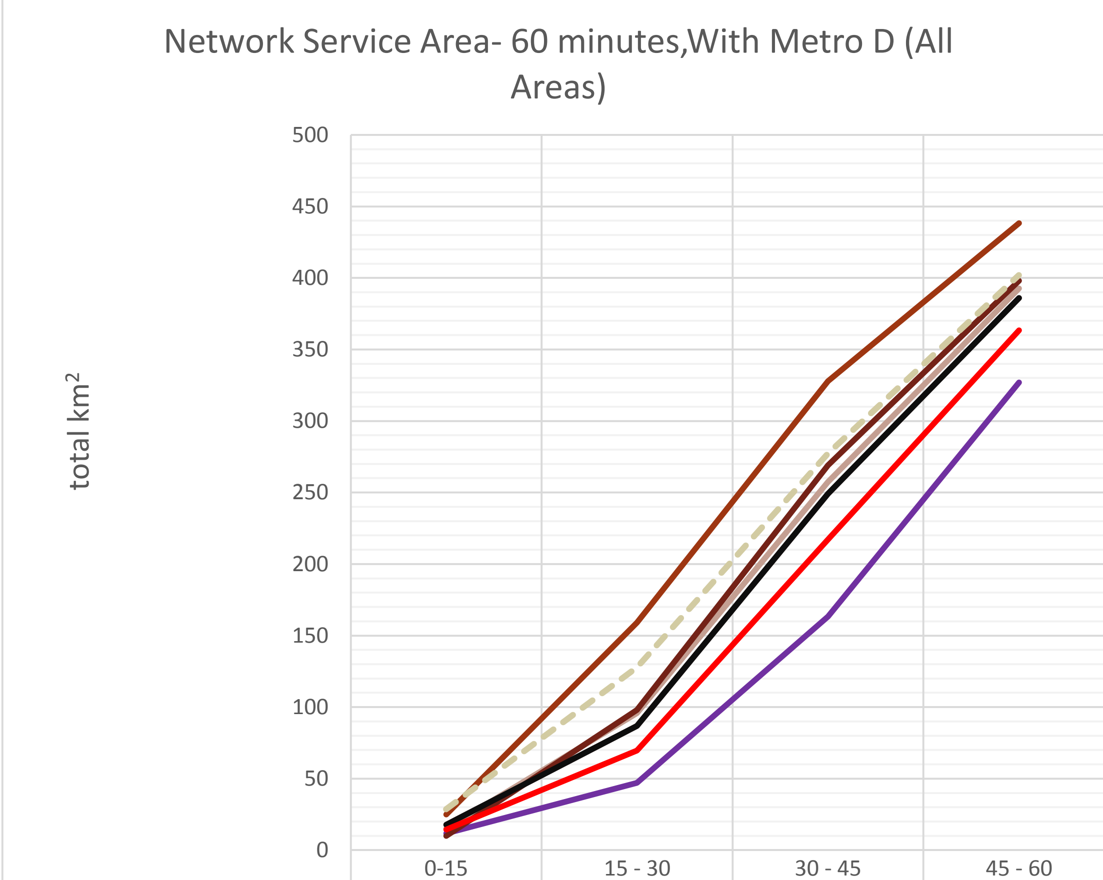


FIGURE 5-15-COMPARISON SERVICE AREA OF ALL MODES OF TRANSIT, PRAGUE 14 - ČERNÝ MOST.

5.10 Metro D Summary – Network Service Area Summary

The following graph compares the network service area of all eight study areas within a 60 minute time frame, with the Metro D line connectivity in place (Figure 5-16).



	0-15	15 - 30	30 - 45	45 - 60
Prague 1	17.8	86.8	249.1	385.9
Prague 5- Motol	15	95.7	257.5	392.7
Prague 6-Dejvicka	24.9	159	327.9	438.4
Prague 6-Petriny	11.8	47	163.4	326.9
Prague 7	10	98.1	269	398
Prague 12-Nove Dvory	28.66	127.93	277.36	401.97
Prague 13- Luziny	17.8	86.8	249.1	385.9
Prague 14- Cerne Most	14.4	69.6	217.2	363.3

FIGURE 5-16- METRO D SERVICE AREA ALL AREAS

6. Discussion

This multimodal GIS transportation network model provides an interesting insight into the accessibility by bicycle to Prague landscapes and amenities without or in conjunction with the heavy rail Metro system.

6.1 Impact of Metro

The Metro significantly increases regional accessibility for all study areas. Logically, taking the bicycle on the much faster and consistent subway system will increase the areas accessible, while taking less time. However, it is also of interest that the beneficial aspects of Metro connectivity considerably decrease in greater time breaks.

6.2 Impact of Metro A-line extension

The short extension of the Metro-A Line does benefit cyclists with significant increases in regional accessibility and time savings for those who travel to, or from, Petřiny, Motol, Dejvická and nearby areas. However it is far less pronounced benefit from other locations studied in the model. From the Lužiny metro location for instance, this model predicts it is not a significant time saver. However, this extension does provide cyclists who are unwilling, or unable to cope with the uphill climb to the areas Petřiny, Motol, and surroundings (such as Divoká Šárka park) an easier alternative for residents Whether this new option entices more cyclist ridership to and from the area remains to be seen, and is a subject of further research.

6.3 Impact of Metro-D Line

The Metro D line shows a significant positive regional accessibility impact for most of the areas studied. These benefits however are particularly evident in the population rich districts it aims to serve, which otherwise have a lack of nearby Metro stations. However, it remains to be seen exactly how fast and how convenient it will be for cyclists to use this planned extension.

6.4 Significant limitations of the Model

This model, while a useful tool to assess accessibility has several limitations as it is currently built. These include:

- The model assumes travel at a constant, uniform speed. At intersections not signalized with a traffic light, the model assumes one does not have to stop. However, this was partially offset during vectorization of routes by giving segments that cross streets a slower speed variable.
- Digitization of the entire Prague bicycle network has not been accomplished due to time constraints.
- Other bicycle friendly modes of transit in Prague have not been included, primarily the S-railway commuter services, and segments of the Prague tram system where bicycles are allowed.
- The amount of time to enter and exit from Metro stations to the street has not been properly quantified.
    - The model also assumes once the cyclist descends to the Metro platform, that there is immediately a train waiting for them.
    - The model also assumes transfers between lines do not incur any additional time costs.
- Not all hills or areas with significant slopes are input into the system.
- Other obstacles or conditions (such as bad quality pavement, complicated intersections, etc.) that were not recognized by satellite imagery route digitization or site visit research have not been included.
- The network build out restricts movement only to officialized bike routes. Therefore, shortcuts, or other more direct routes on other streets, sidewalks, or other routes are not factored into the calculation.

7. Conclusion

This model, despite its drawbacks, offers an enhanced spatially based understanding of how the two modes of transportation work together to offer residents quick and sustainable mobility throughout the region. The ability to easily bring a bike aboard the Metro allows cyclists to access a larger amount of territory and amenities in a shorter time span. A less experienced cyclist can use the Metro for longer trips, and quickly plus immediately carry on their journey when they've arrived at the Metro station nearest their destination. In this multi-modal configuration, there is no need to wait for potentially costly and indirect connector bus or tram services. These factors make the prospect of using a combination of public and pedal transportation even more enticing over private vehicle. Furthermore, the Metro offers a convenient alternative for cyclists when there are problematic topographies, bad weather, or have mechanical issues - making cycling even more approachable.

In conclusion, this model helps illustrate the fact that further investments in building the capacity of both modes will complement each other. As the model results of the planned D-line extension show, the expansion of the metro will considerably increase accessibility to a large portion of highly populated metropolitan Prague. A coordinated approach to creating quality cycling infrastructure to Metro stations, along with the creation of new Metro routes to underserved locations will improve the accessibility and environment for all citizens of Prague.

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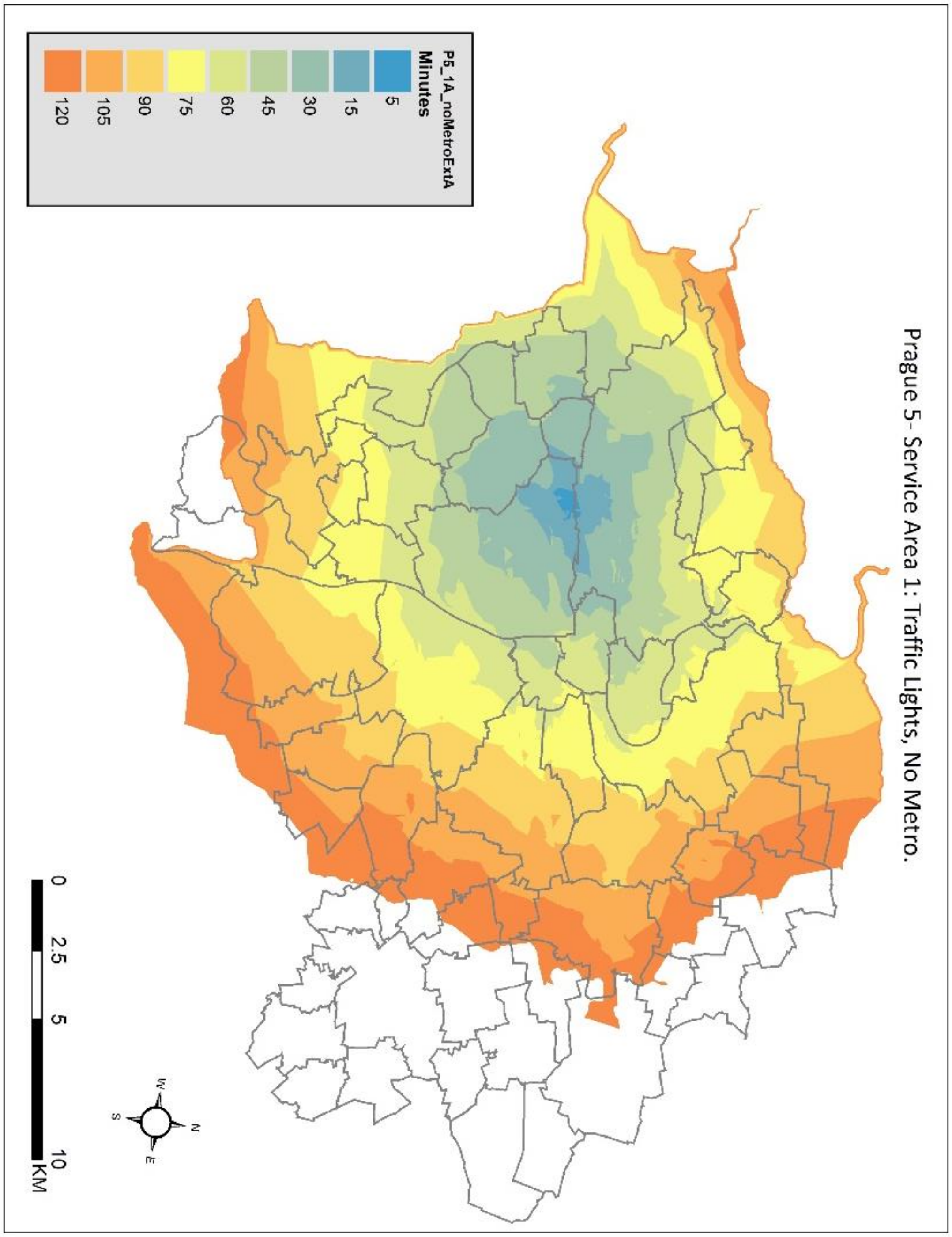
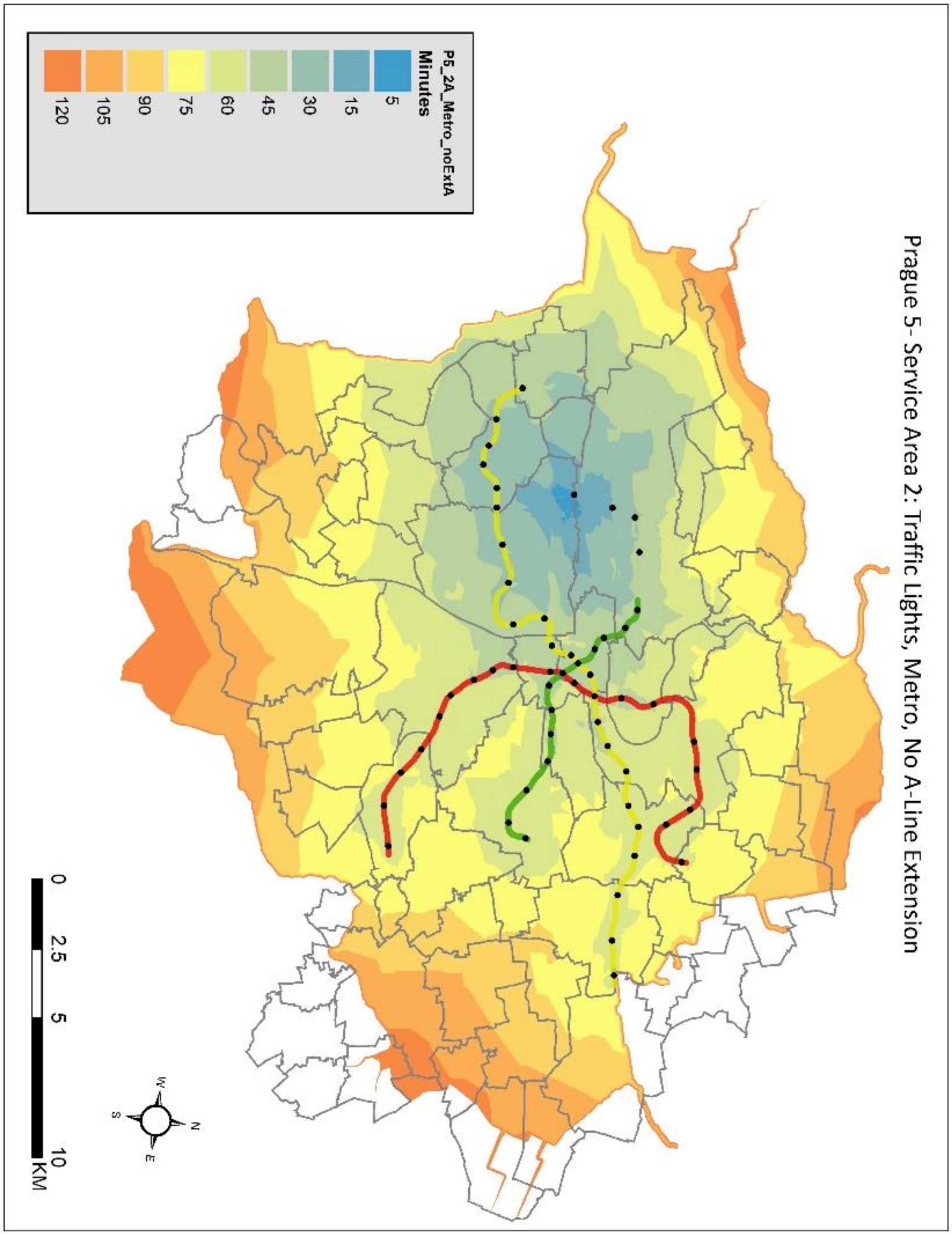
9. Appendix

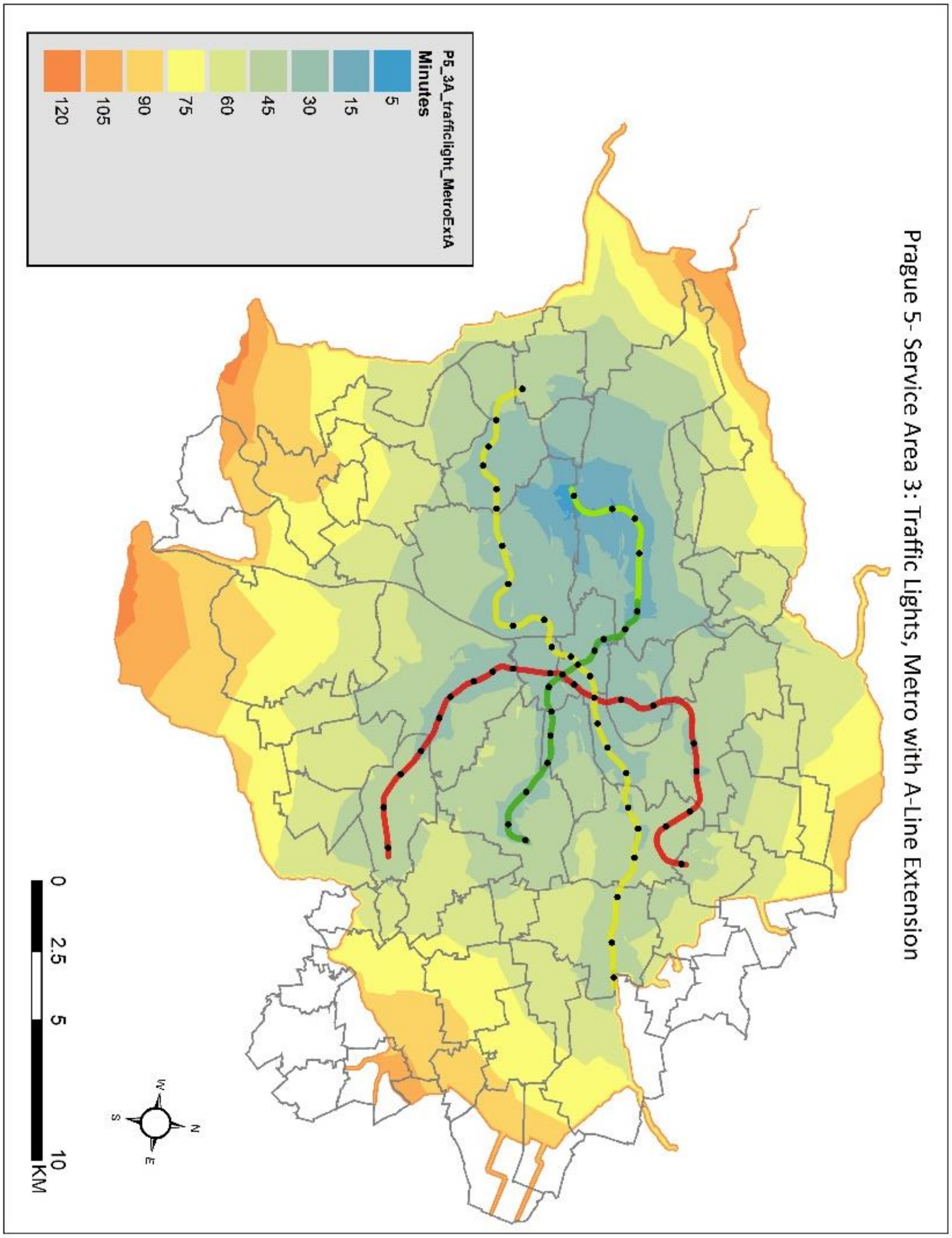
Appendix 1: Network Service Area, Prague 5, Traffic Lights, No Metro



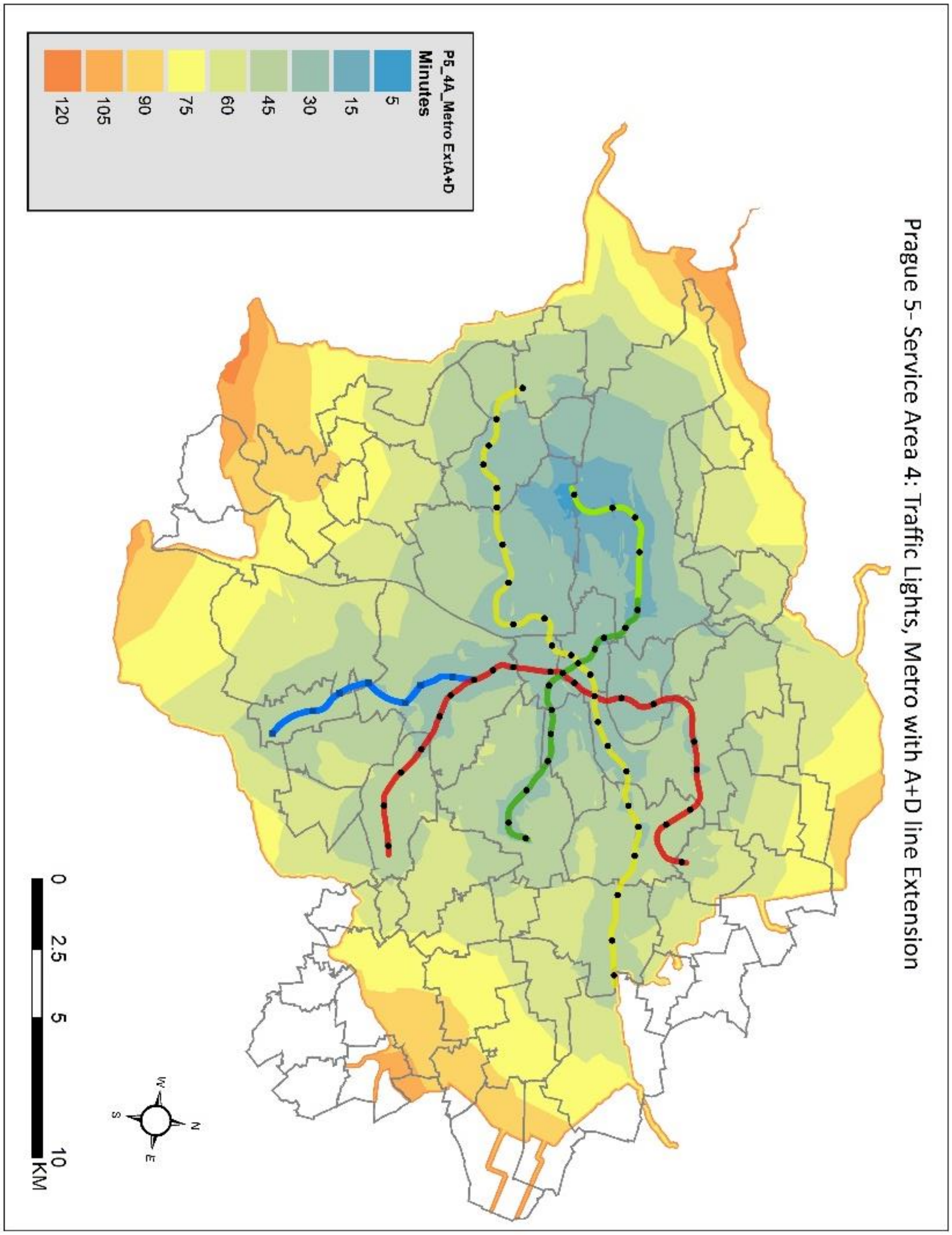
Appendix 2: Network Service Area, Prague 5, Traffic Lights, Metro Core.



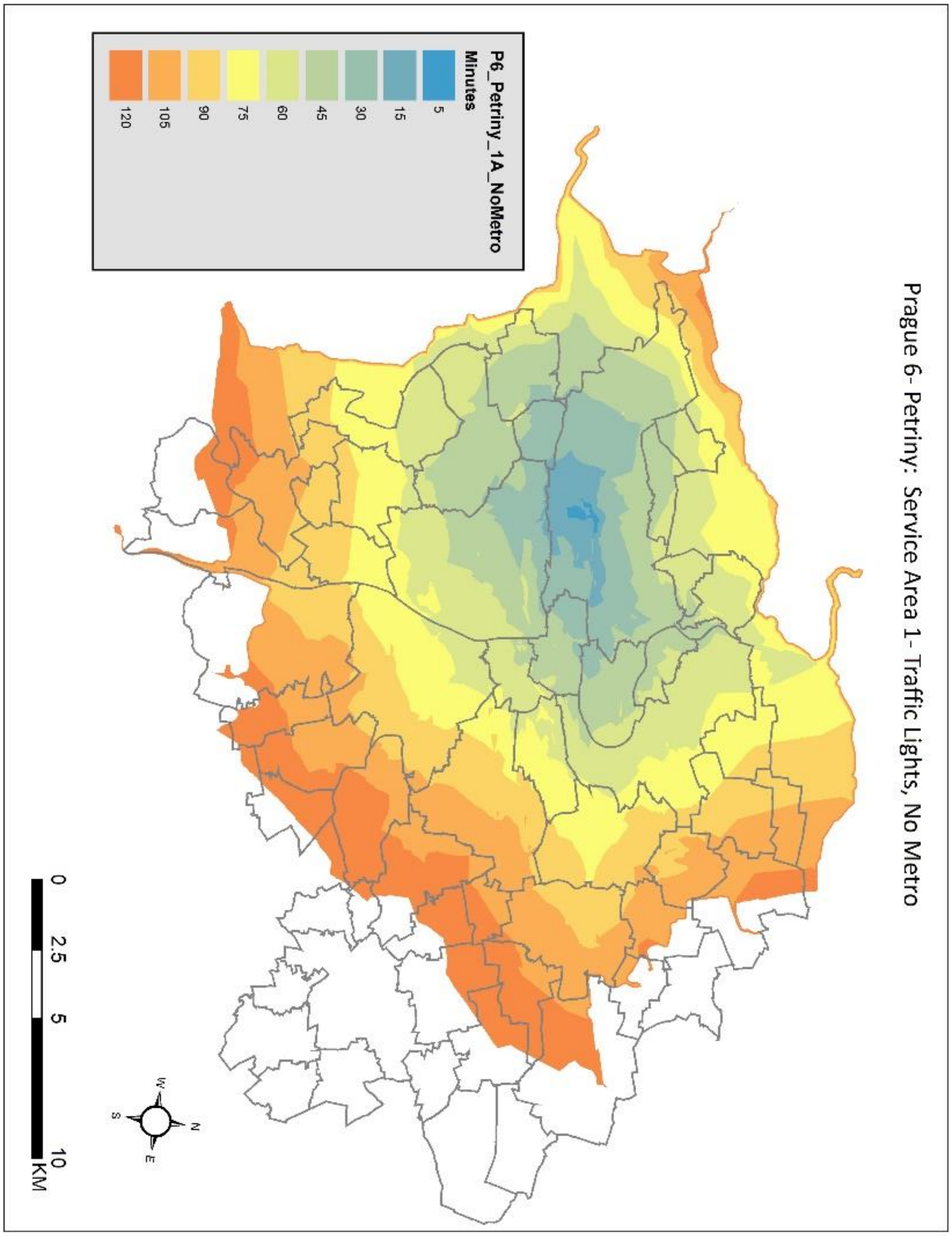
Appendix 3: Network Service Area, Prague 5, Traffic Lights, Metro with A line extension



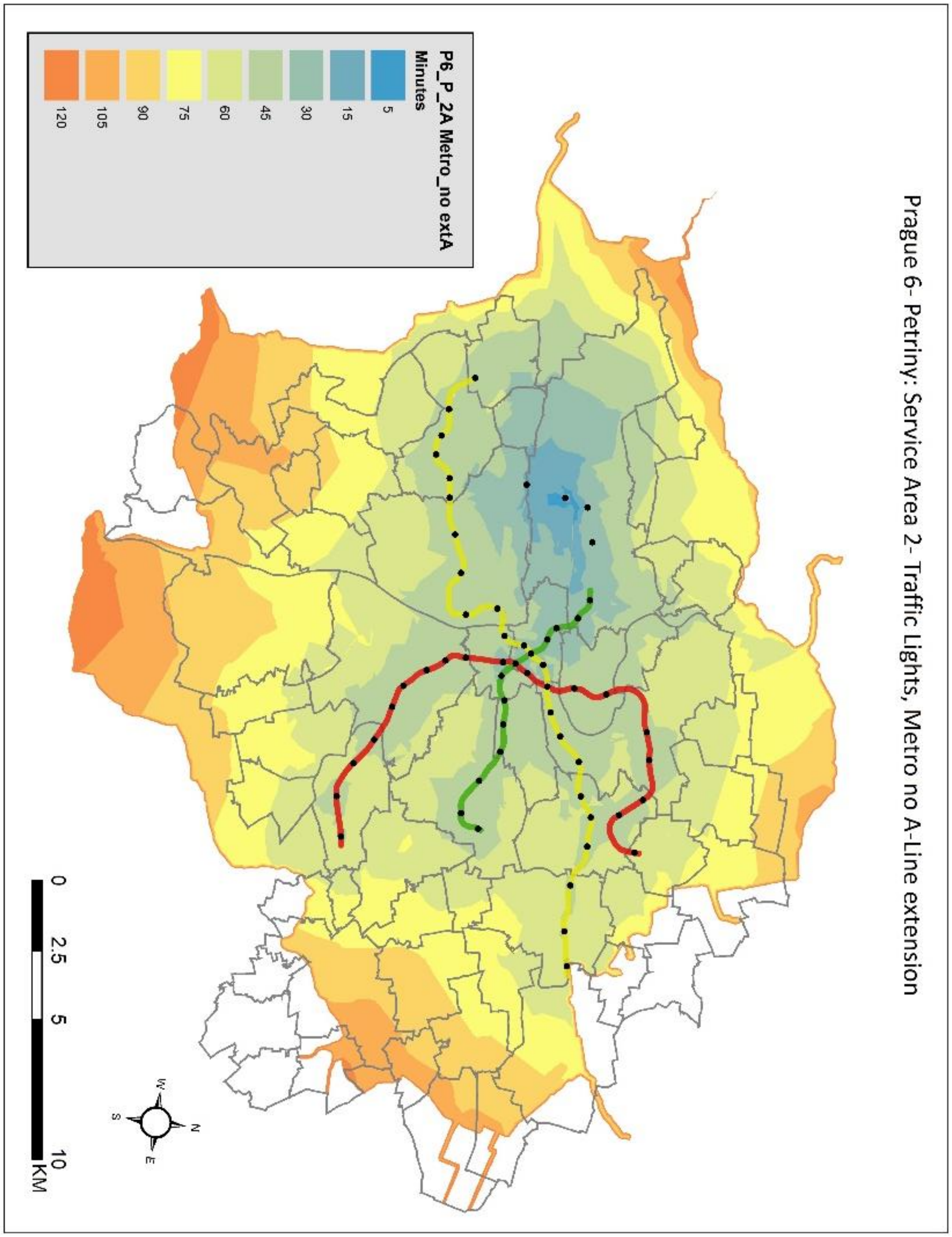
Appendix 4: Network Service Area, Prague 5, Traffic Lights, Metro with A+D line extensions



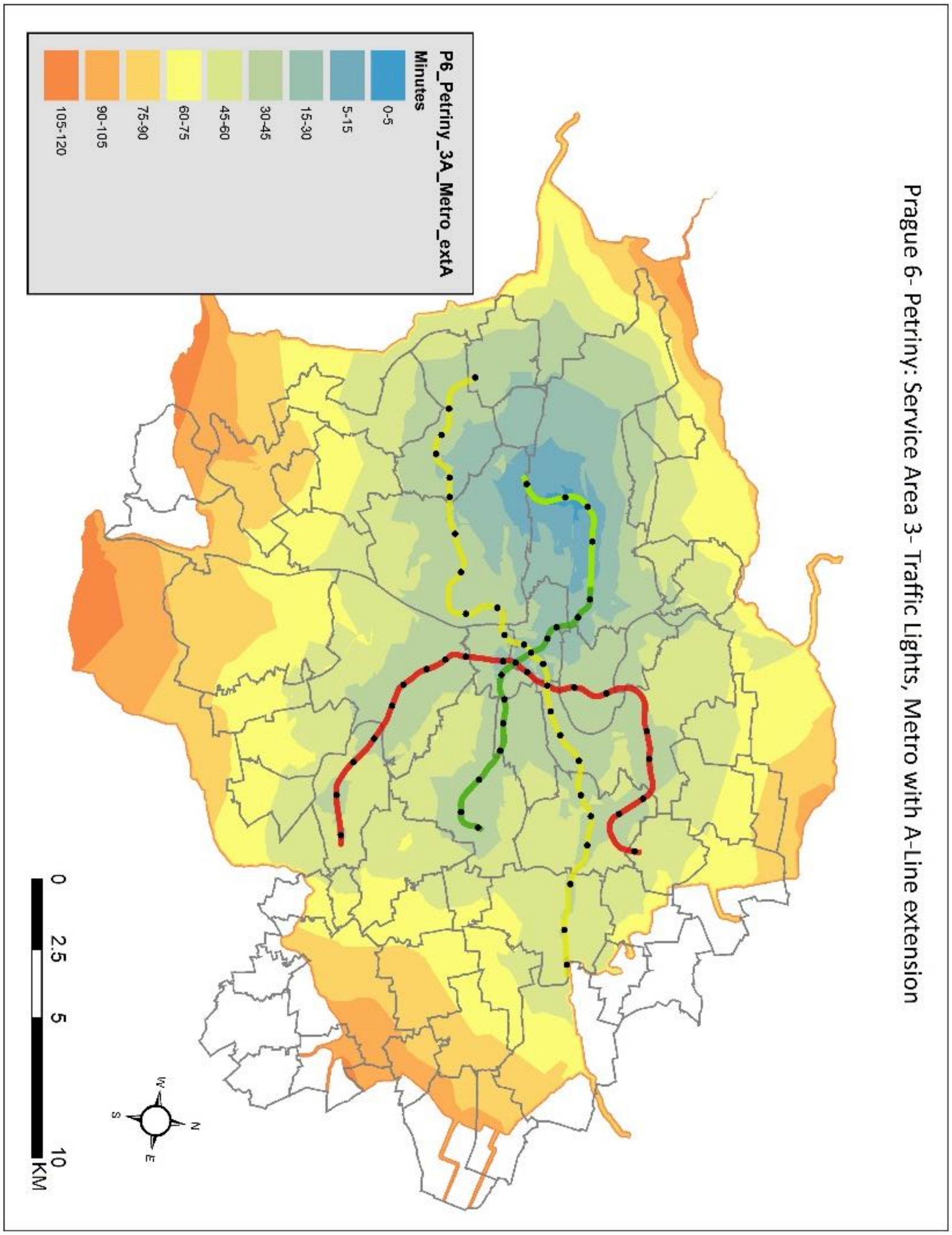
Appendix 5: Network Service Area, Prague 6- Petřiny, Traffic Lights, No Metro



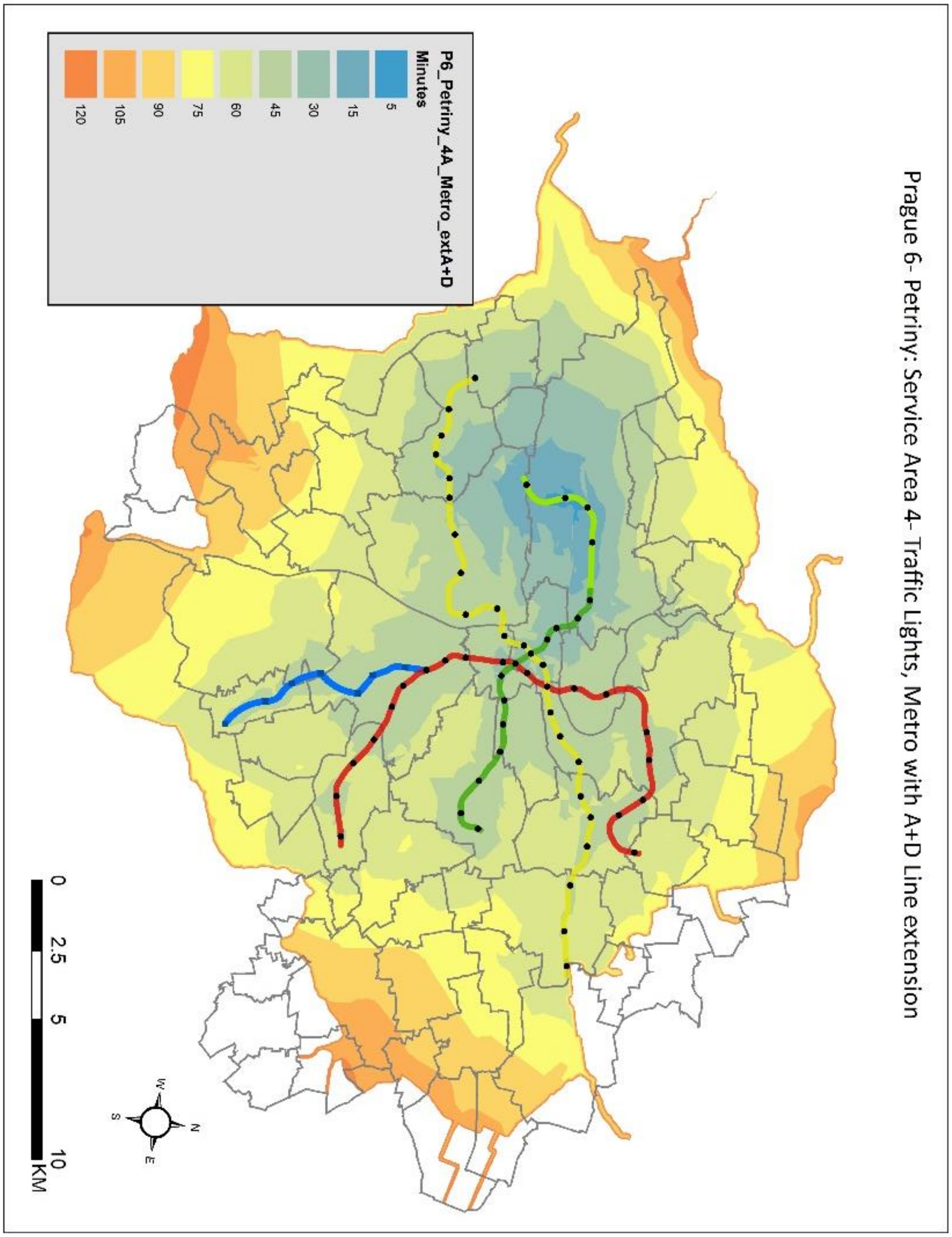
Appendix 6: Network Service Area, Prague 6- Petřiny, Traffic Lights, Metro Core



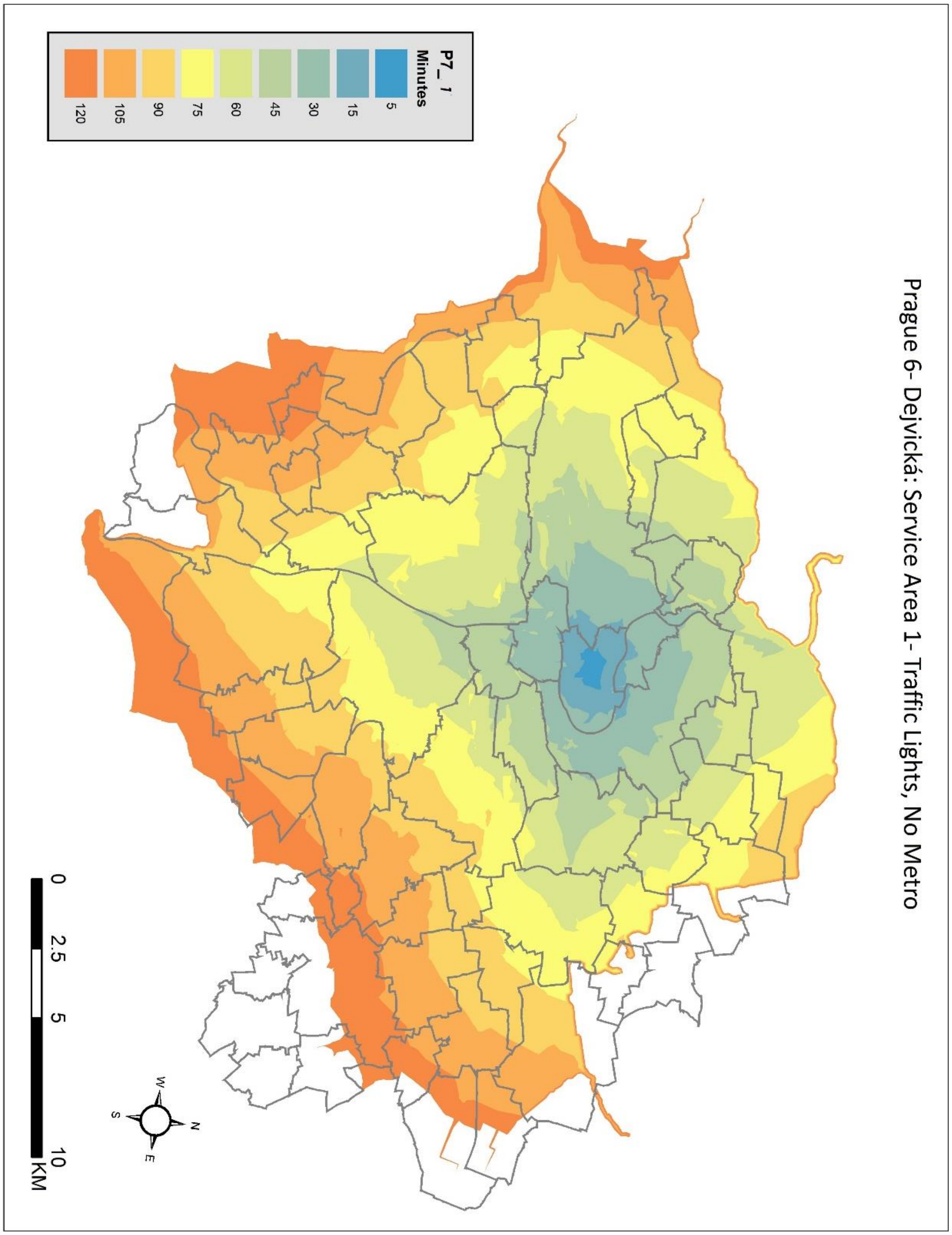
Appendix 7: Network Service Area, Prague 6- Petřiny, Traffic Lights, Metro with A line extension



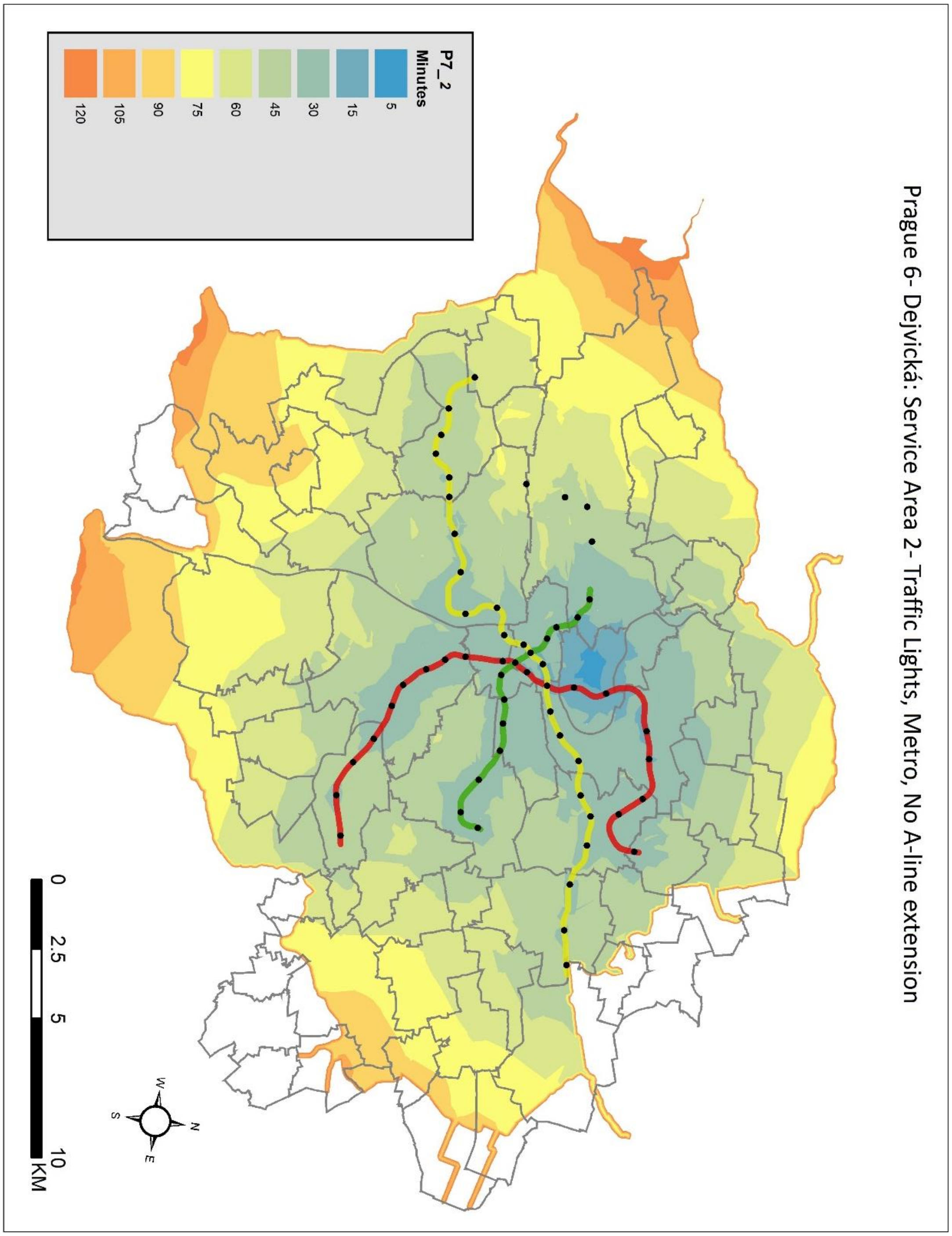
Appendix 8: Network Service Area, Prague 6- Petřiny, Metro with A+D line extension



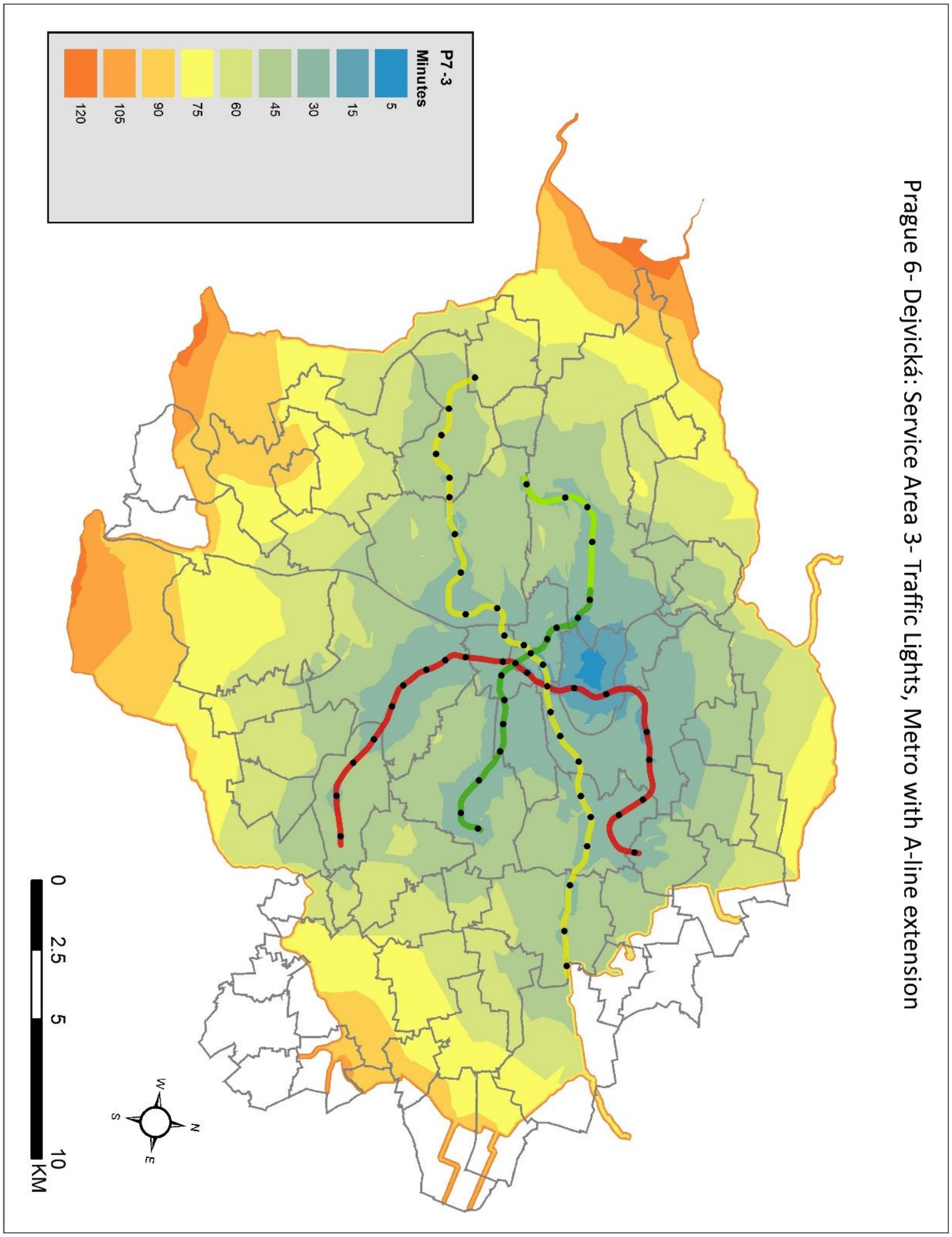
Appendix 9: Network Service Area, Prague 6- Dejvická, Traffic Lights, No Metro



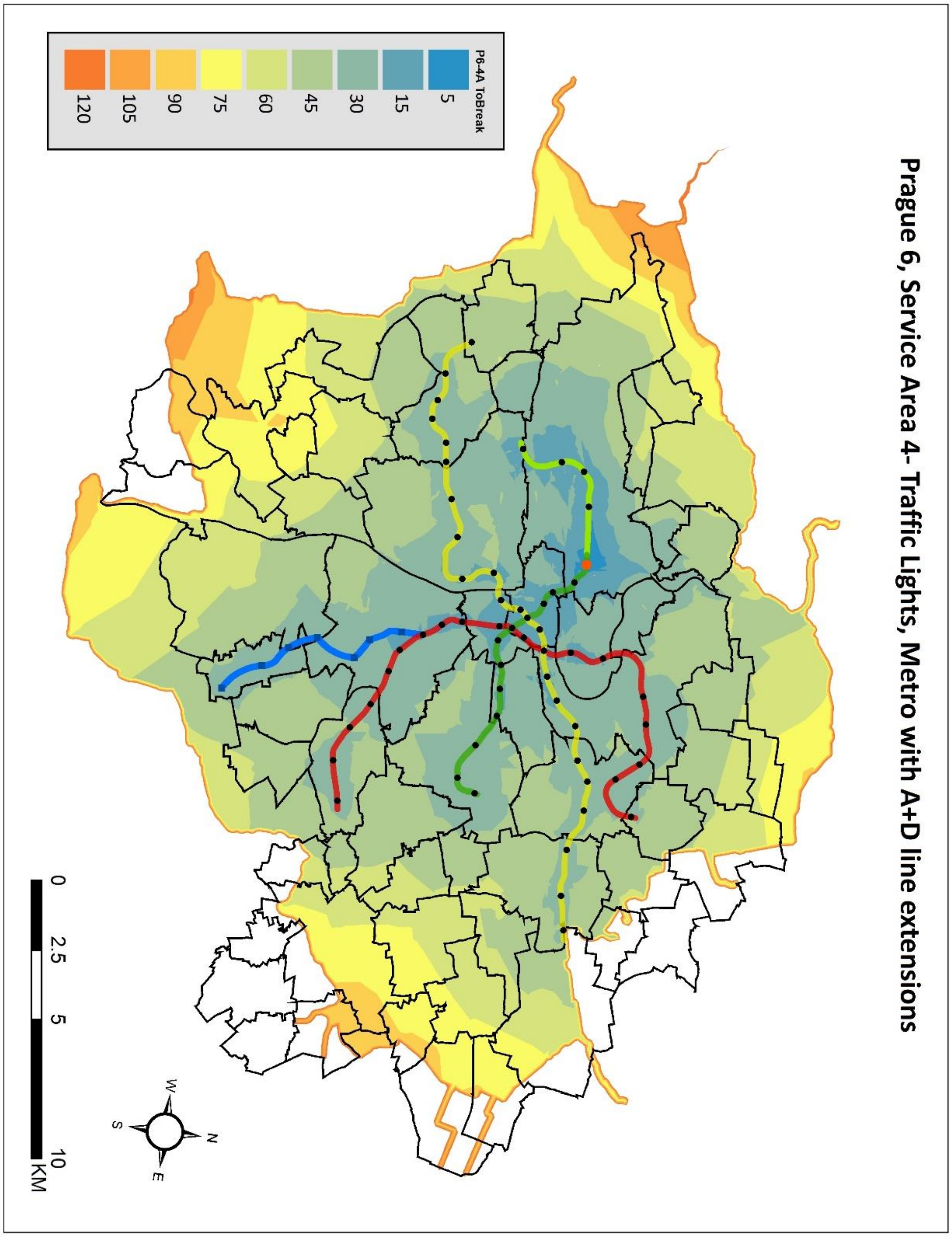
Appendix 10: Network Service Area, Prague 6- Dejvická, Traffic Lights, Metro Core



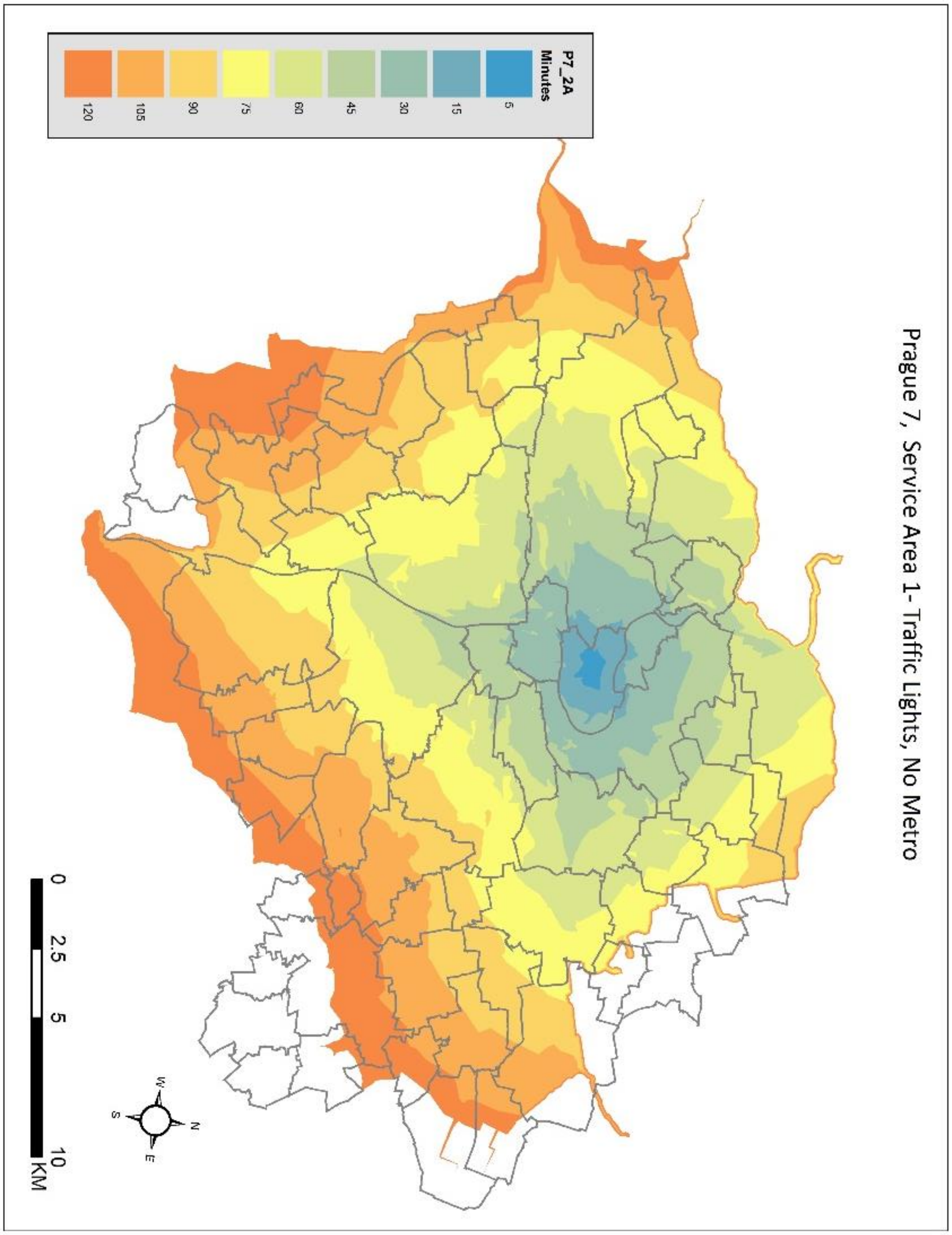
Appendix 11: Network Service Area, Prague 6- Dejvická, Traffic Lights, Metro with A line extension



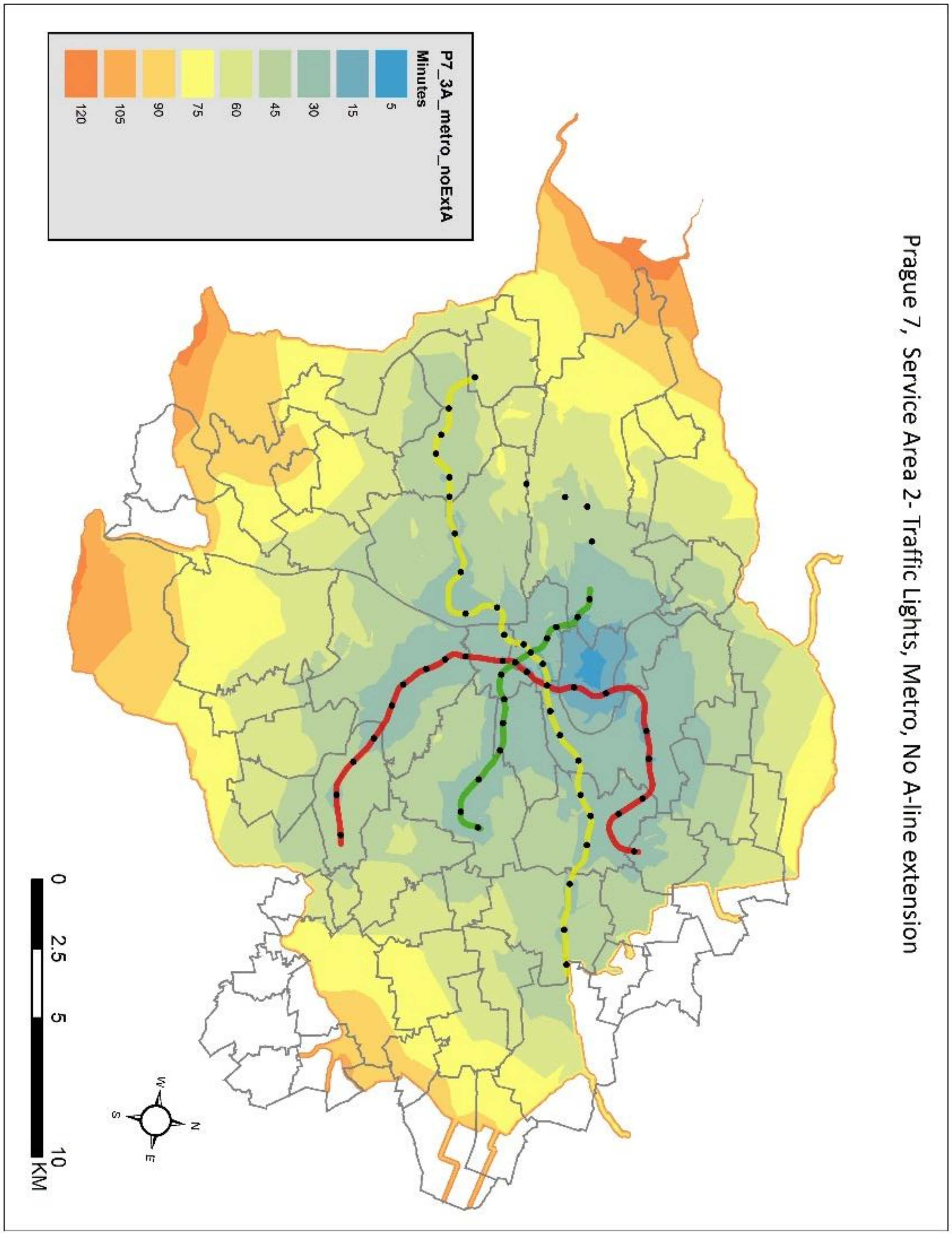
Appendix 12: Network Service Area, Prague 6- Dejvická, Traffic lights, Metro with A+D line extensions



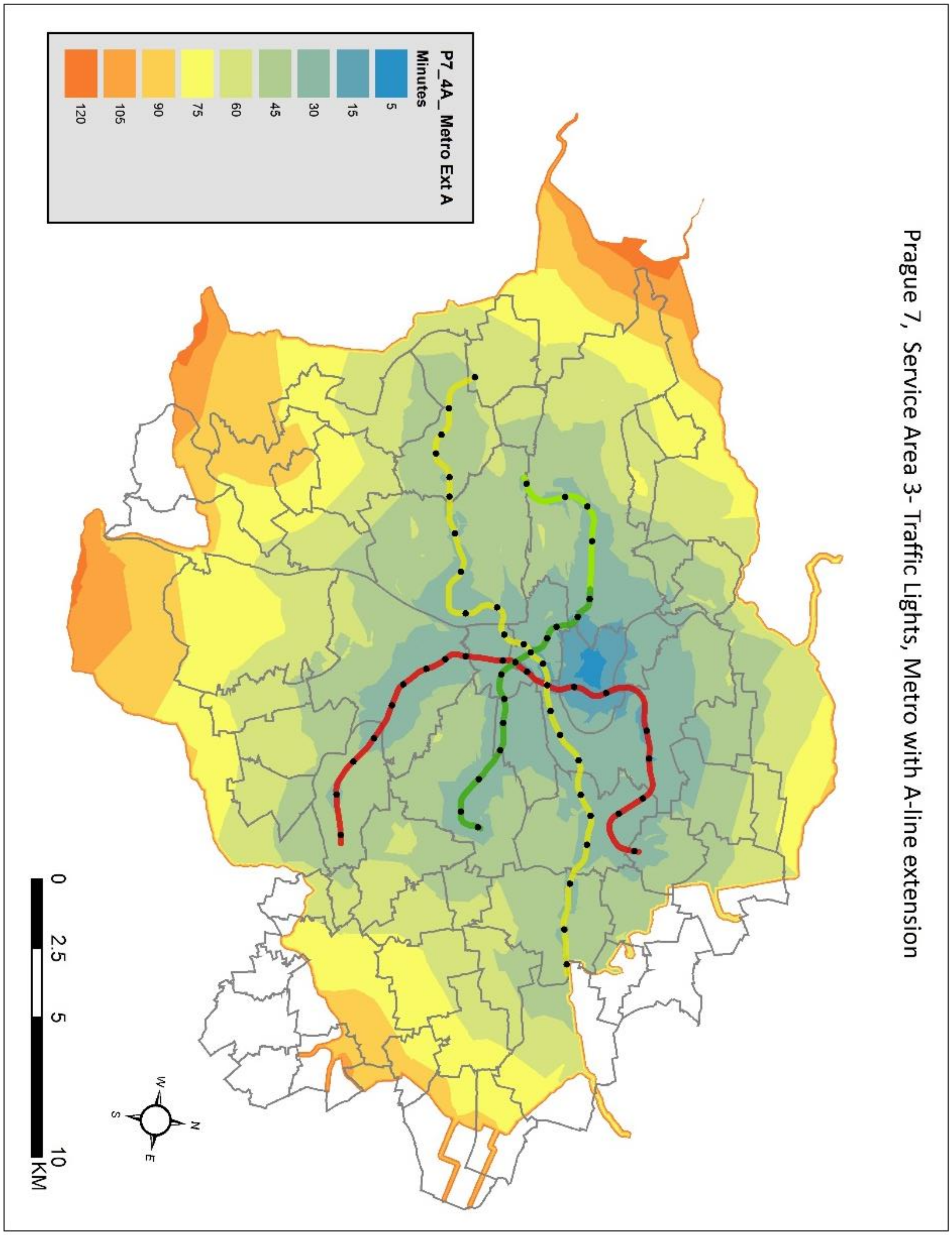
Appendix 13: Network Service Area, Prague 7- Holešovice Fairgrounds,Traffic Lights, Metro Core



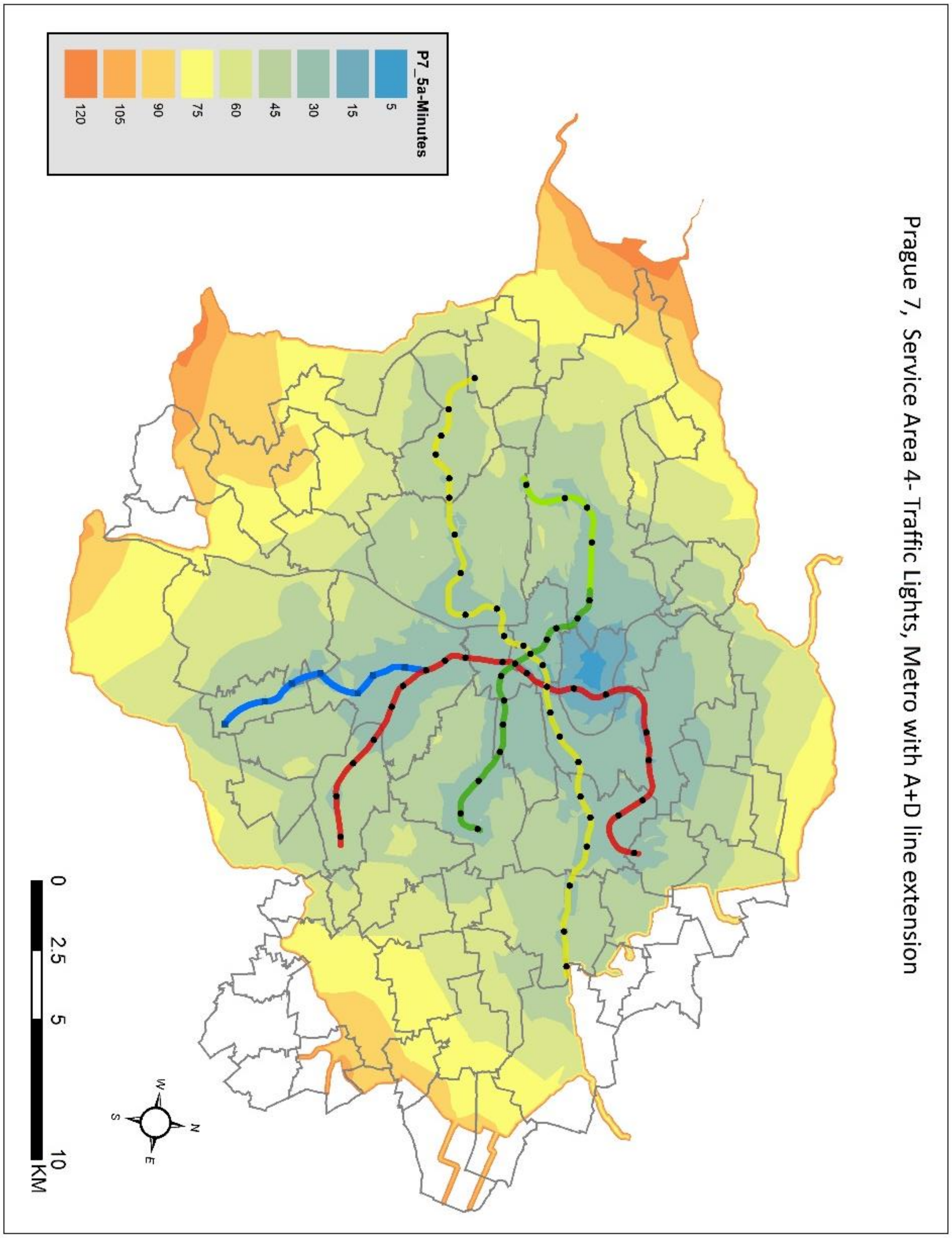
Appendix 14: Network Service Area, Prague 7- Holešovice Fairgrounds, Traffic Lights, Metro Core



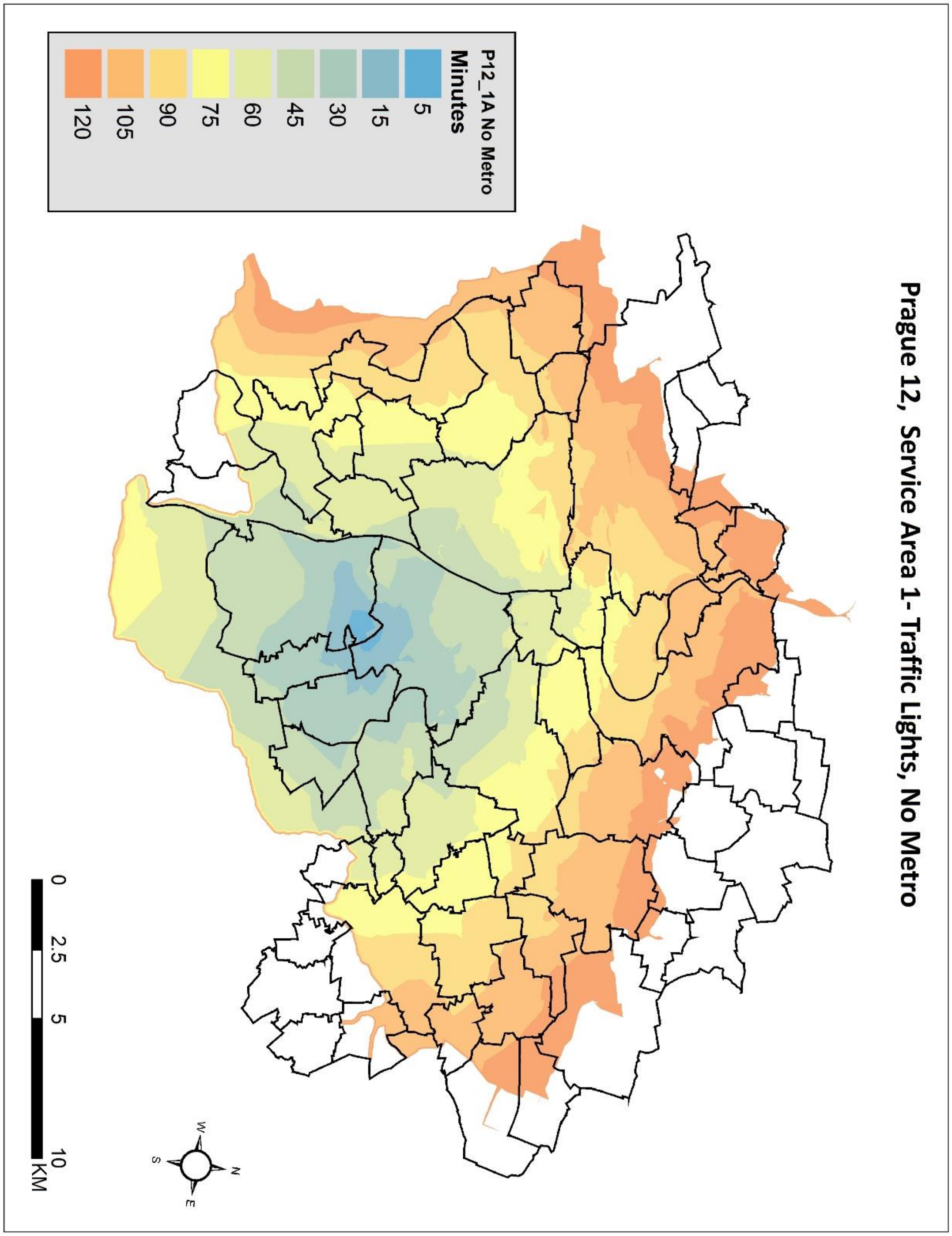
Appendix 15: Network Service Area, Prague 7- Holešovice Fairgrounds, Traffic Lights, Metro with A line extension



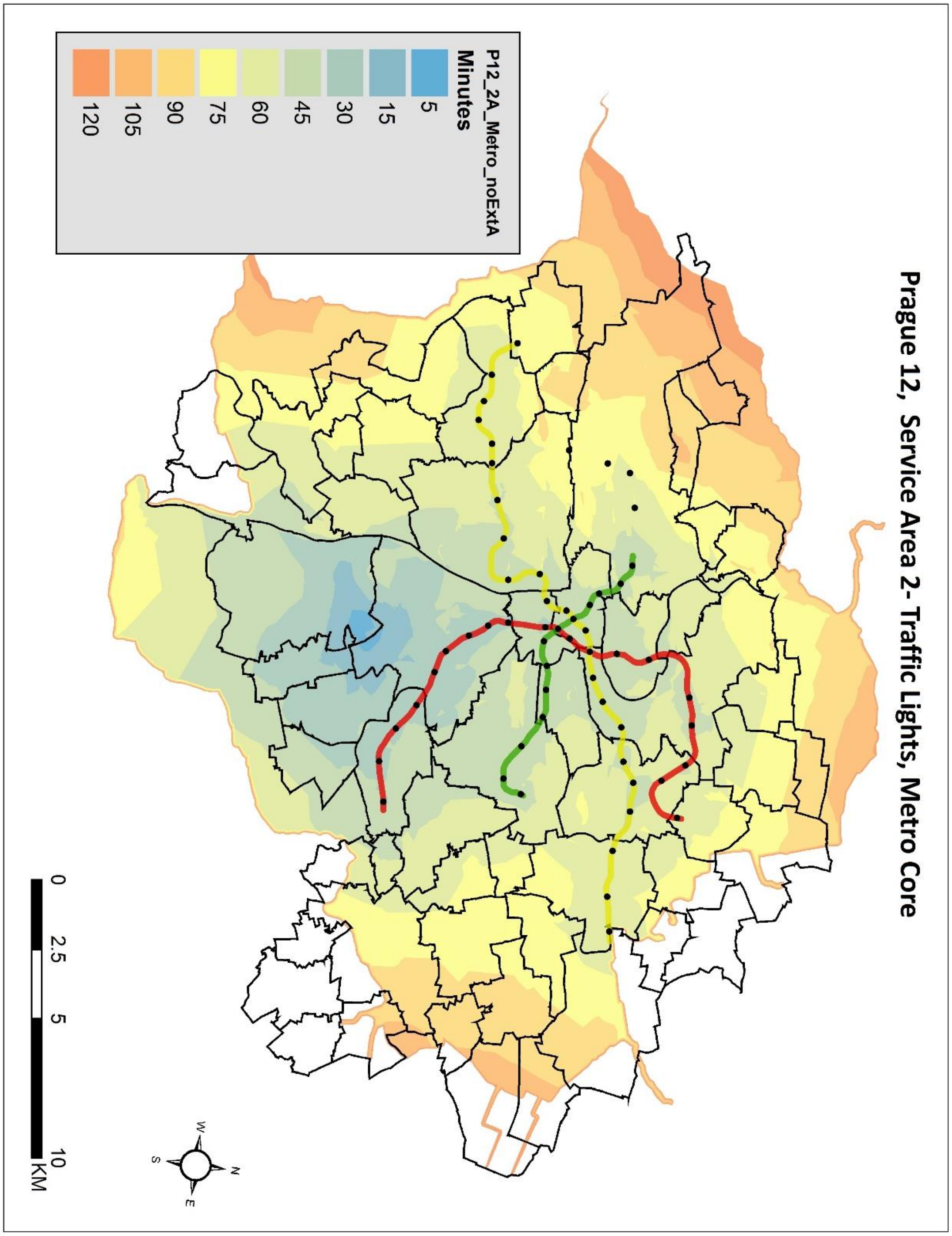
Appendix 16: Network Service Area, Prague 7- Holešovice Fairgrounds, Traffic Lights, Metro with A+D line extensions



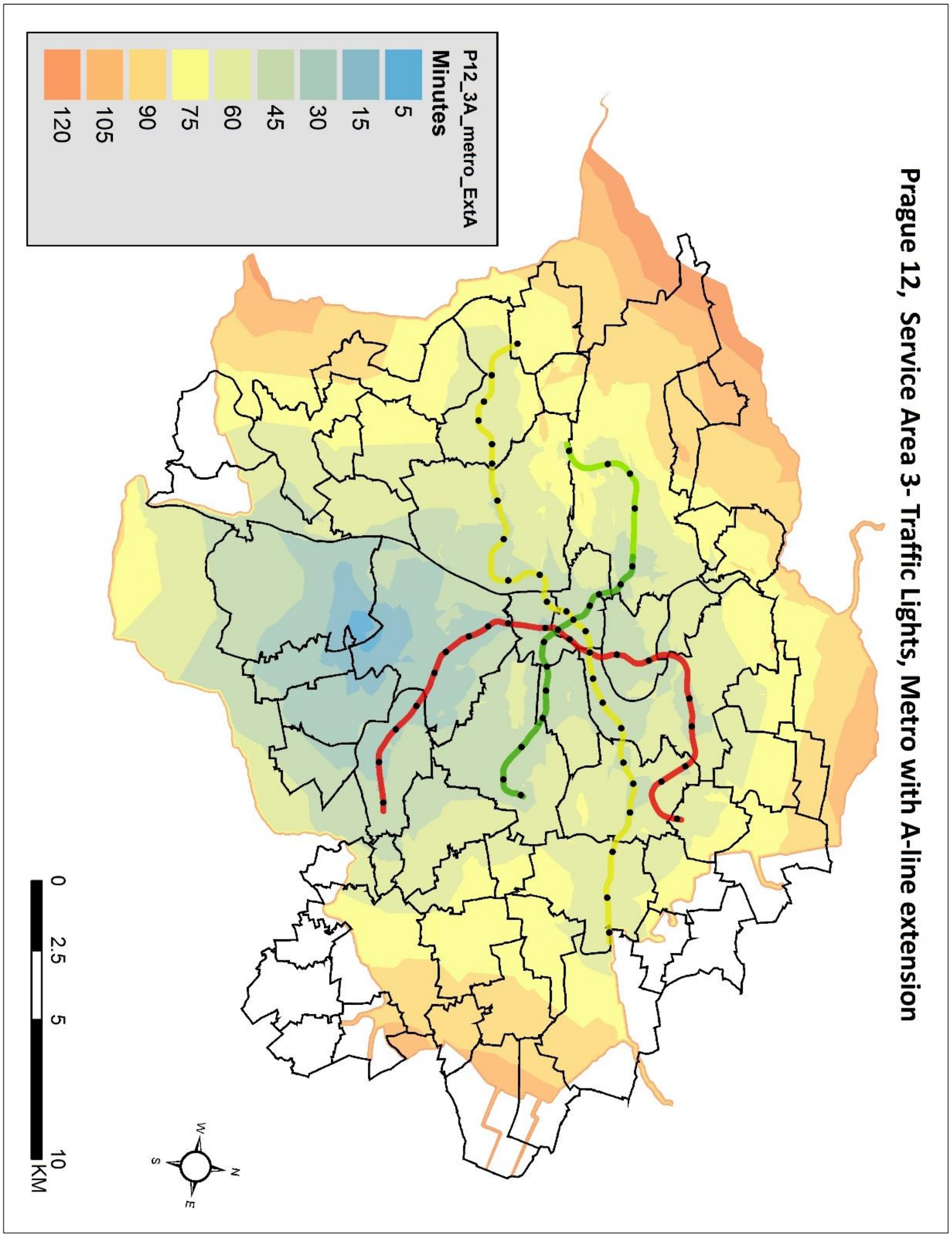
Appendix 17: Network Service Area, Prague 12-Nové Dvory- Traffic Lights, No Metro



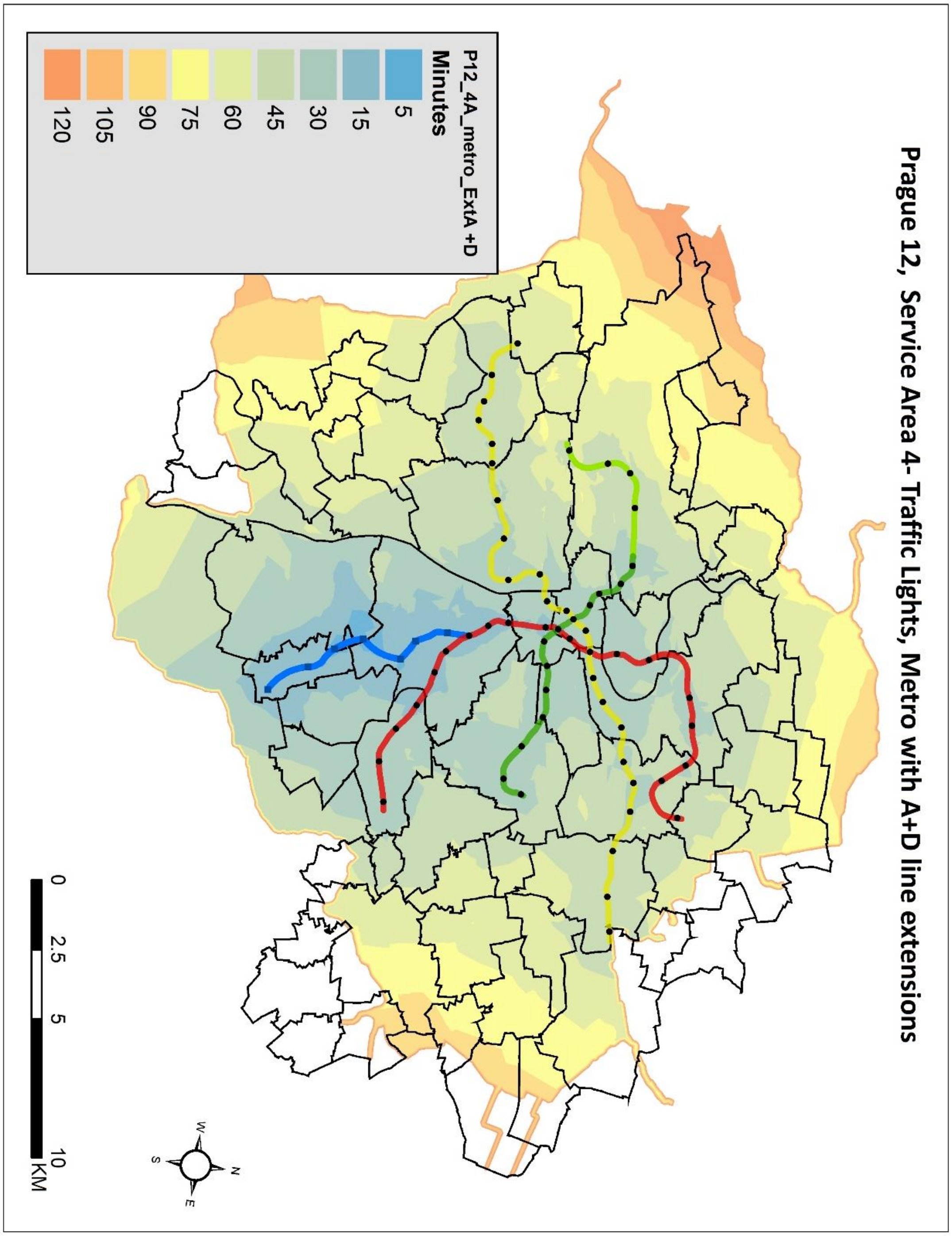
Appendix 18: Network Service Area, Prague 12-Nové Dvory- Traffic Lights, Metro Core



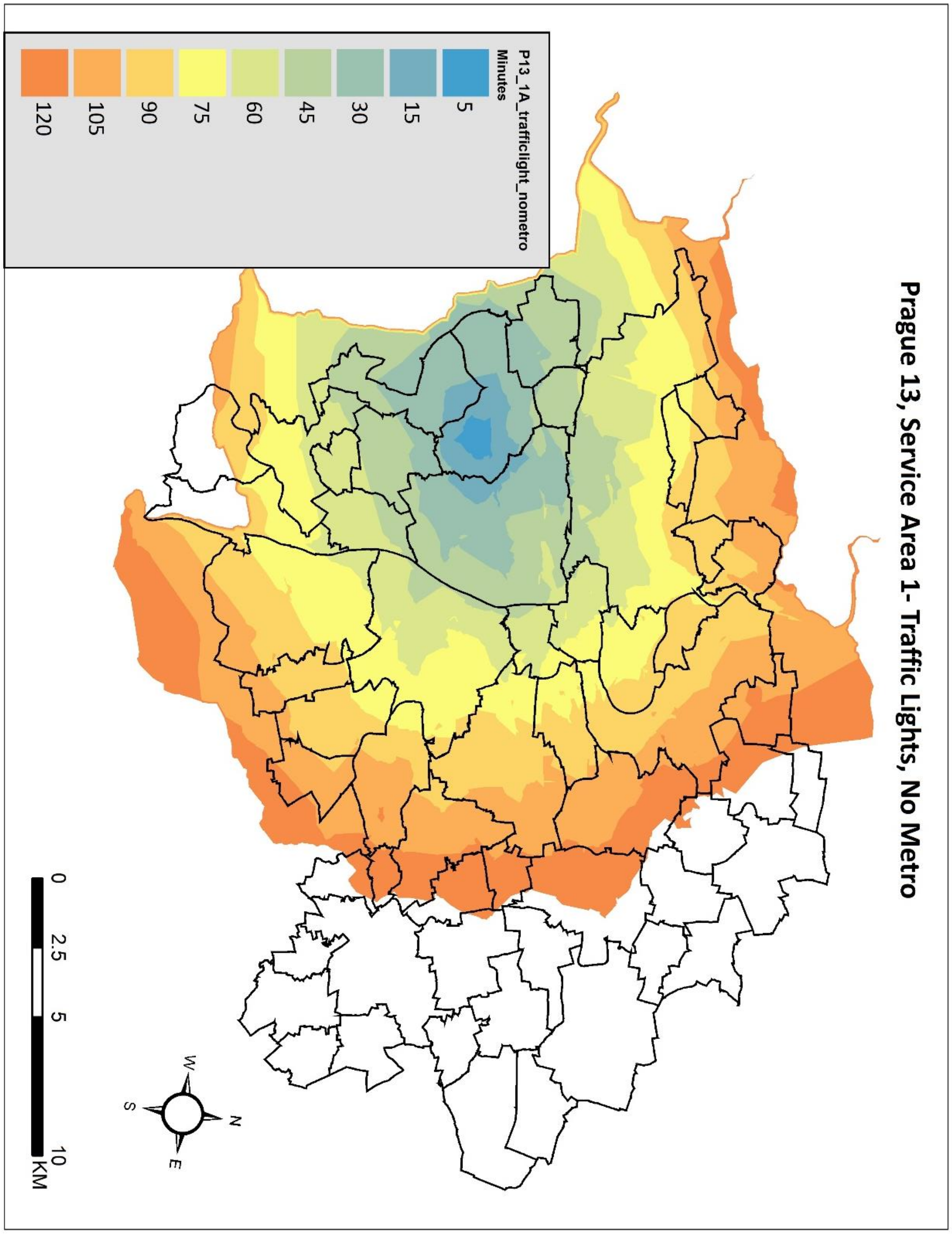
Appendix 19: Network Service Area, Prague 12-Nové Dvory, Traffic Lights, Metro with A line extension



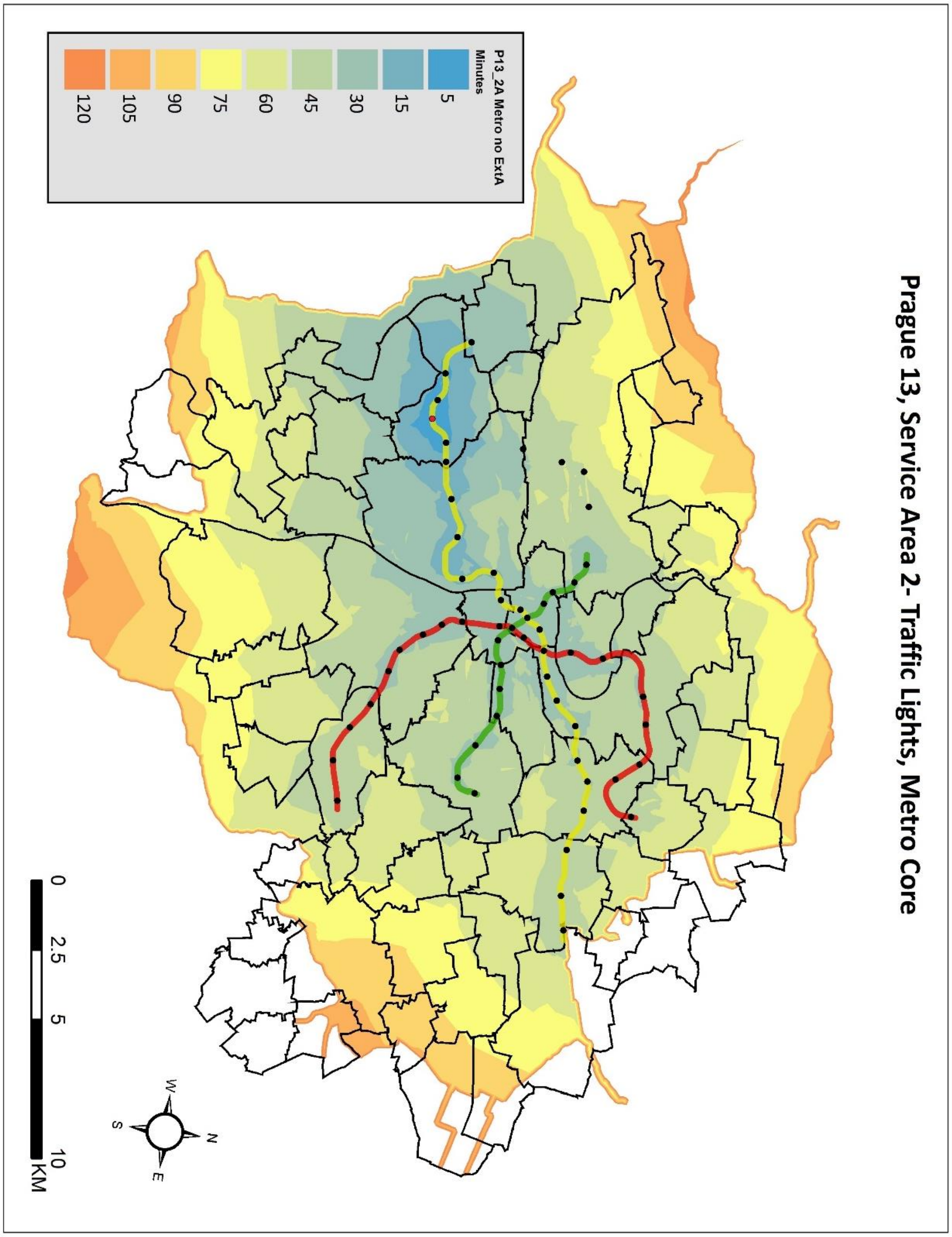
Appendix 20: Network Service Area, Prague 12-Nové Dvory, Traffic Lights, Metro with A+D line extensions



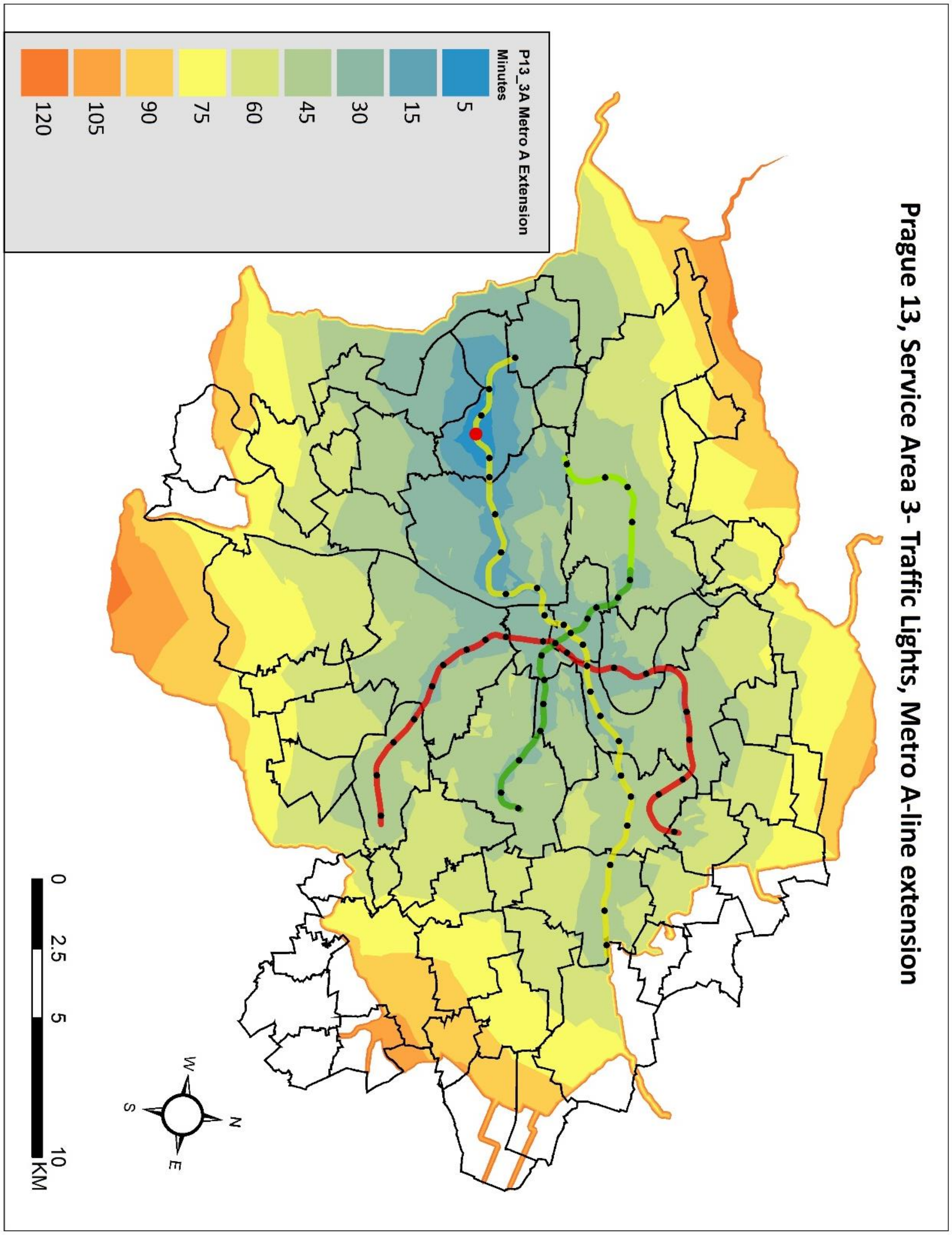
Appendix 21: Network Service Area, Prague 13- Lužiny Metro, Traffic Lights, No Metro



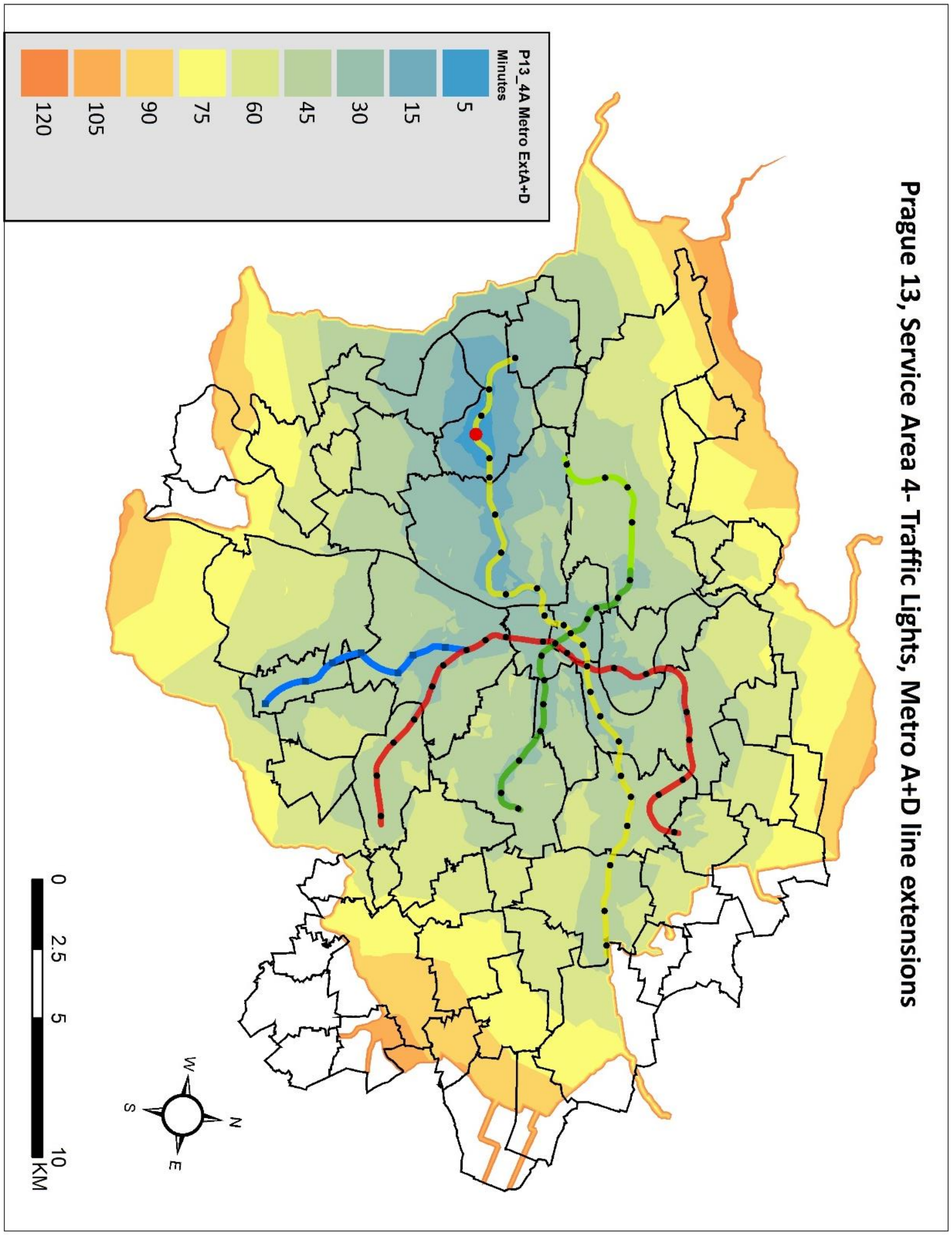
Appendix 22: Network Service Area, Prague 13- Lužiny Metro, Traffic Lights, Metro Core



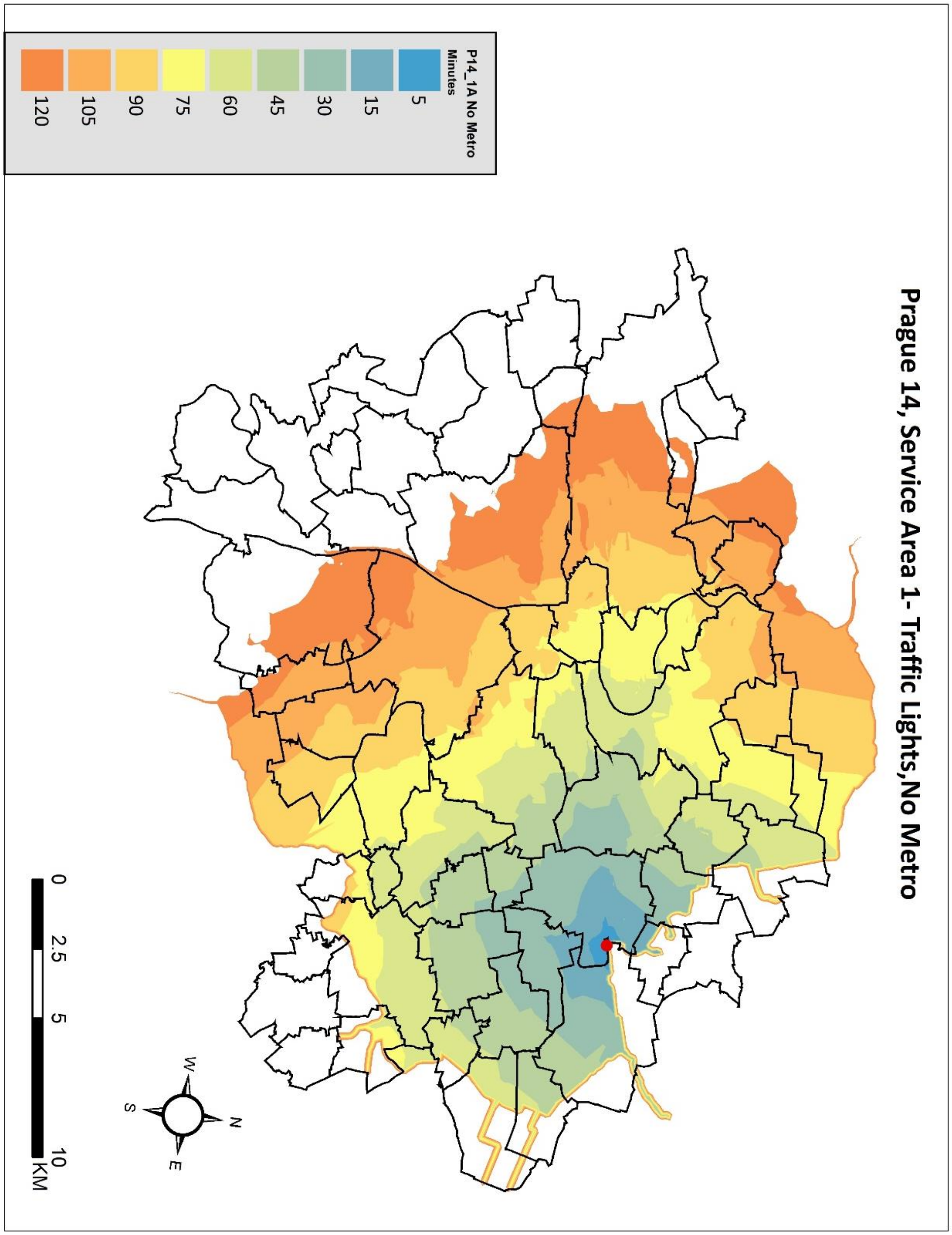
Appendix 23: Network Service Area, Prague 13- Lužiny Metro, Traffic Lights, Metro with A line extension



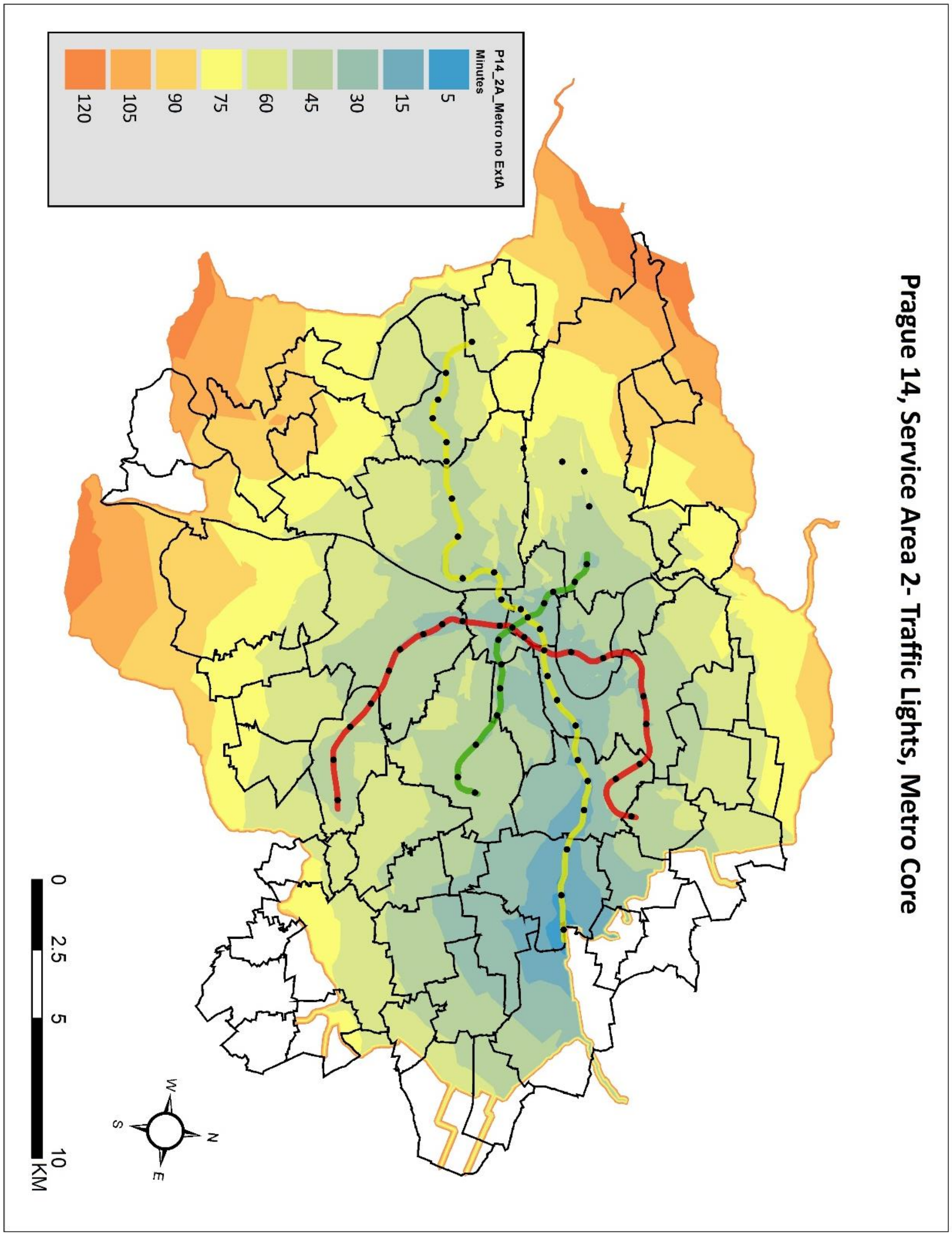
Appendix 24: Network Service Area, Prague 13- Lužiny Metro, Traffic Lights, Metro with A+D line extensions



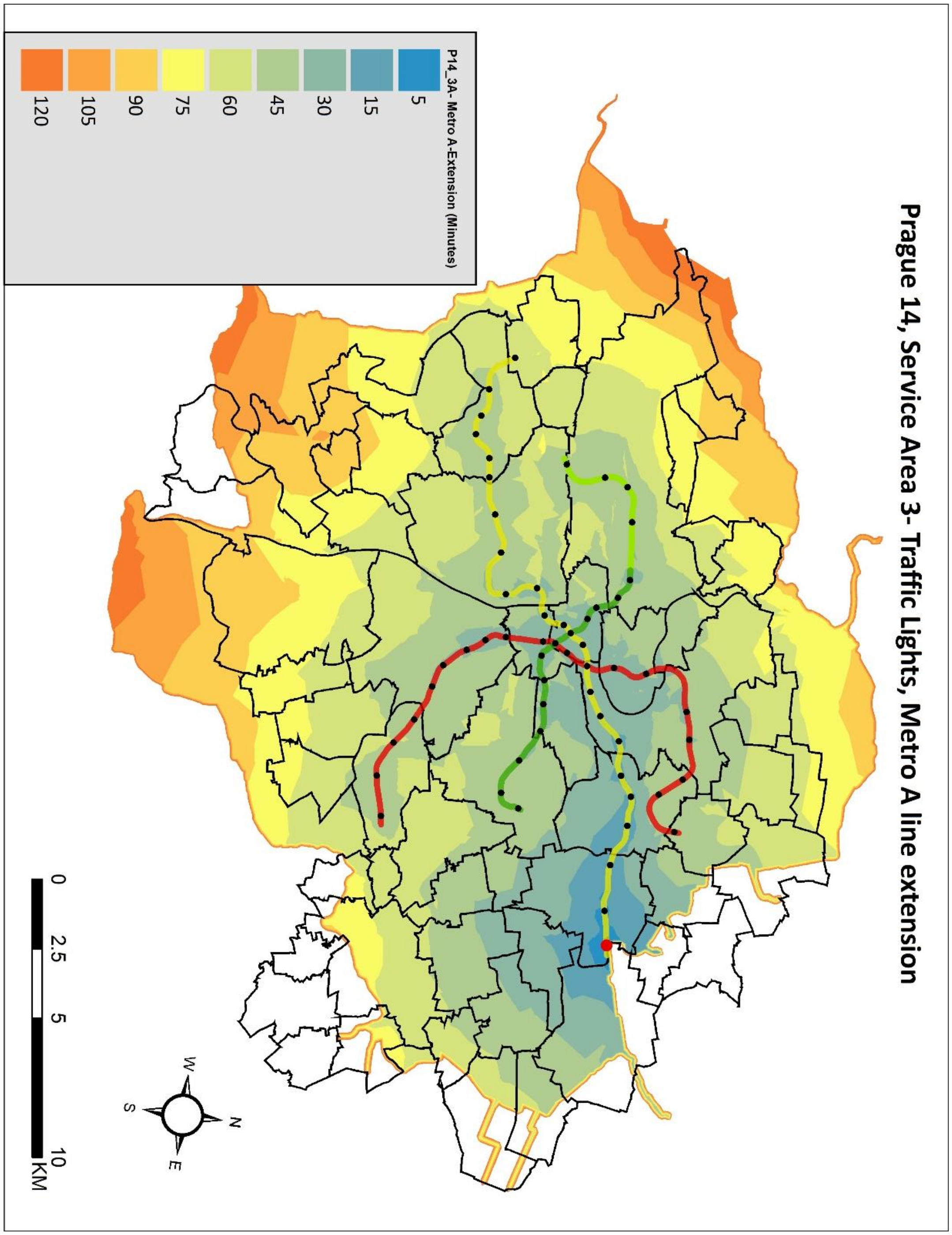
Appendix 25: Network Service Area, Prague 14- Černý Most, Traffic Lights, No Metro



Appendix 26: Network Service Area, Prague 14- Černý Most, Traffic Lights, Metro Core



Appendix 27: Network Service Area, Prague 14- Černý Most, Traffic Lights, Metro with A line extension



Appendix 28: Network Service Area, Prague 14- Černý Most, Traffic Lights, Metro with A+D line extension