ARTIGOS

INSIGHTS TO THE BRAZILIAN CENTER NORTH ACHIEVES THE SDG 11 GOALS*

Thiago José Arruda de Oliveira[1], Waldecy Rodrigues[2],
Joel Isaac Hernandez Lanza[3]

Abstract: the article used as main hypothesis that the high interaction level among Brazilian Center North (BCN) cities and also with Brazilian territory could be a crucial factor to this region on achieving the Sustainable Development Goals (SDG) n° 11 goals. The polycentrism concept, Gravitational Model and flow of people by bus itinerary were used as research methodology. The results of estimators suggested that the BCN has monocentric functional linkage, a framework that restricts the community cohesion and consequently, the capacity of this region to accomplish the SDG n°11 goals. In a conclusion, the Sub-regional centers A are strong candidates to boost the spatial interaction into BCN due to their social and economic relevance in this scenario.

Keywords: Urban systems. Polycentrism. Brazilian Center North.
Spatial interactions.

CONSIDERAÇÕES PARA QUE O CENTRO NORTE BRASILEIRO EFETIVE AS METAS DA ODS 11

Resumo: o artigo utilizou-se como principal hipótese de que um alto nível de interação entre as cidades do CNB é um fator crucial para que essa região atinja os parâmetros traçados pelo Objetivos do Desenvolvimento Sustentável (ODS) n° 11. O conceito de policentrismo, o Modelo Gravitacional e a quantidade de pessoas por viagem de ônibus foram empregados como ferramentas metodológicas. Os resultados dos estimadores sugerem que o Centro Norte brasileiro tem função monocêntrico, uma estrutura que restringe a coesão interna e consequentemente, a capacidade da região para alcançar os objetivos do ODS n°11. Em conclusão, os

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1, 2, 3 Federal University of Tocantins (UFT)

Centro-regionais A são fortes aspirantes para melhorar a interação espacial no CNB por serem socialmente e economicamente relevantes no contexto espacial.

Palavras-chave: Sistemas urbanos. Policentrismo. Centro Norte brasileiro. Interações espaciais.

CONSIDERACIONES PARA QUE EL CENTRO NORTE BRASILEÑO HAGA EFECTIVOS LA ODS 11

Resumen: el articulo utilizo como hipótesis principal que el alto nivel de interacción entre las ciudades del Centro Norte Brasileño (CNB) es un factor determinante para que esta región alcance los parámetros trazados por los Objetivos de Desarrollo Sostenible (ODS) n°11. El concepto policéntrico, el modelo gravitacional y la cantidad de personas que viajan en autobús se emplearon como herramientas metodológicas. Los resultados de los estimadores sugieren que el CNB tiene una función monocéntrica, una estructura que restringe la cohesión interna y en consecuencia, la capacidad de la región para alcanzar el objetivo n°11 de los ODS. En conclusión, las Regiones Centrales A son fuertes aspirantes para mejorar la interacción espacial en el CNB debido a que son social y económicamente relevantes en el contexto espacial.

Palabras-clave: Sistemas urbanos. Policentricidad. Centro Norte Brasileño. Interraciones espaciales.

The Sustainable Development Goals number 11, created by the United Nations (UN) and Brazilian partners, stipulates that until 2030 Brazil´s cities and villages will support the process of community cohesion at local and regional scale. The movement is crucial because the quick urbanization observed in the last four decades originated social and environmental disorders in the country (AGRA FILHO *et al*., 2019). The issue encouraged institutions such as Institute of Applied Economic Research (IPEA) to elaborate a set of indicators to track the SDG 11 progress in the national territory.

Despite the monitoring allowing the assessment of scenarios across time, the procedure focus on accessibility, ignoring the urban interactions nature in the Brazilian regions. Without a good understanding of the potentials and liabilities to the current spatial organization of the cities (BERTAUD, 2004), the SDG 11 is far from achieving its main goals in the country. To solve it, spatial indicators and models, developed by economists, geographers and regional planners, can be applied in different structures. Among them, the polycentrism is a concept emerged in the beginning of 21st century, powered by European Union regional politics, as an important tool to investigate the cohesion level in an urban system (NORDREGIO, 2005).

However, in order to use the polycentrism, the region needs to develop multiple urban centralities. In the midlands of Brazil, currently five cities (Palmas-TO, Araguaína-TO, Barreiras-BA, Imperatriz-MA and Marabá-PA) attained these characteristic overlapping cities around them. Furthermore, due to relative geographic approximation, they consolidated an interaction zone in the country named Brazilian Center North or BCN (OLIVEIRA, PIFFER, 2017a, 2017b; OLIVEIRA *et al.*, 2020). The question is if this multicentric region should be considered a polycentric functional urban system as well, a framework which could improve the spatial cohesion (DAVOUDI, 2003; NORDREGIO, 2005) among BCN cities.

In order to analyze it, the Gravitational model and data about the flow of people, available in the National Land Transportation Authority (ANTT) website, were used in this study.

The results from this methodology collaborated on understanding the current functional linkage in Brazilian Center North and gave insights on region achievements in SDG 11.

Beyond of this introduction, the study has six further sections. The next section deals with the evolution of theories on spatial interaction in an urban system. The following section describes the factors that droved urban occupation in the midlands of Brazil. The design and research methodology is presented in the subsequent section. The rest of paper is organized as follows: Results, Discussion and References.

FROM CENTRAL PLACES TO POLYCENTRIC FUNCTION: THE INTERACTION LEVELS IN AN URBAN SYSTEM

In the beginning of the studies on urban systems, the cities were identified as an agglomeration of people and businesses surrounded by rural areas and villages (OORT *et al*., 2010). This theoretical concept originated from the Central Place Theory and urban localization, and it was developed by Walter Christaller (1883-1969) and August Lösch (1906-1945). The main idea is that one higher-rank city interconnects with six subordinate cities, which are spatially distributed around the core city (central place) as an equilateral hexagon, following the marketing, transportation and administrative principles (SHI *et al*., 2020). The next figure summarize this theoretical idea.

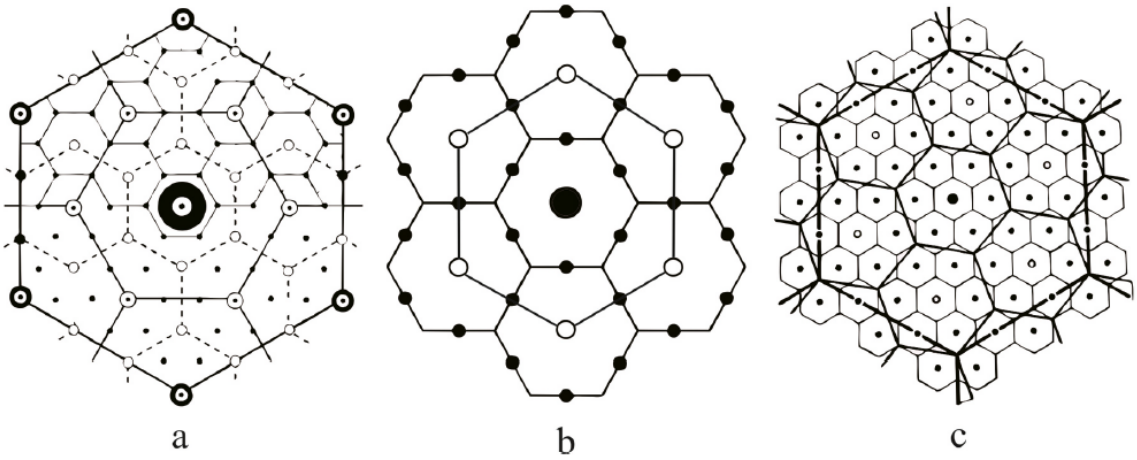

Figure 1: Central Place Theory scheme
Notes: (a) marketing principle; (b) transportation principle; (c) administrative principle.
Source: Shi *et al*. (2020).

Usually, the model is applied in empirics analysis explaining the spatial organization of a local economy through urban hierarchization (BURGER; MEIJERS, 2011). However, when the study focuses in a national urban system, not all its regions are close to be incorporated in the Central Place idea (SHI *et al*., 2020). It means that the cities are organized without being surrounded by one urban core or the domination of larger cities over small cities and rural areas is weak.

The new considerations resulted in new variations of the Central Place Theory such as "interlocking network" and the Central Flow Theory, knowledge which have been introduced in the 1950s (SHI *et al*., 2020). The changes in the interpretations of urban sys-

tems aimed to explain the diversity of economic and urban development level between the regions (ZIVANOVIC *et al*., 2019). Also, in the 1970s, due to the availability of cheaper lands outside the urban agglomeration core and the increase of mobility and communication structure, a multiplicity of productive activities in the peripheric areas emerged (DAVOUDI, 2003). Thus, the farmlands near to the central cities were replaced by suburban households turning these zones in metropolitan regions (NORDREGIO, 2005).

The high demographic density changed the urban interactions between core cities and small cities. If before the middle of the 20th century the flow of people was irregular, suggesting that everywhere is almost isolated from everywhere, in this new context the trips happen more often having multiple origins (suburbs, peripheries or subcenters) and one destination, which is the central city, where all jobs are located (BERTAUD, 2004). This spatial structure, named as monocentric, is linked with the principles of polarization such as intensive industrialization, better infrastructure, concentration of skilled labor and positive externalities (ZIVANOVIC *et al*., 2019). Consequently, the Central Place Theory and ramifications became incapable of explaining the urban interactions in contiguously urbanized zones.

In the end of the 20th century, hinterlands increased their population size and overlap the core cities in functions regarding regional specificities (e.g., geographical, political or institutional aspects). In the phenomena, known as multicentric urban system, the agents (residents or firms) can be served by two or more urban cores (SUN *et al*., 2019). The idea is conceptually different from suburbanization, which is a regionalized process of morphological, economical, political, social and cultural transformation in peripheric areas (PAGLIARIN; DECKER, 2018).

In the multicentricity, the cities are still insufficiently integrated among themselves (SUN *et al*., 2019). The next figure shows the differences between monocentric and multicentric morphological structures.

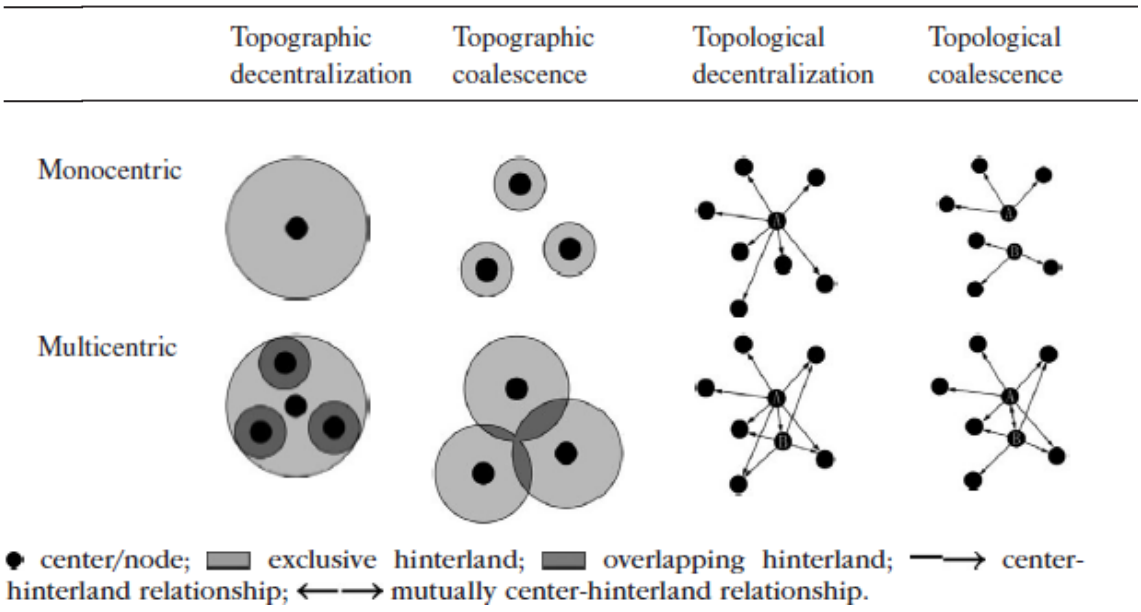

Figure 2: Monocentric and Multicentric scheme
Source: Adapted from Shi *et al.* (2019).

In the monocentric urban system, the flows, which are represented by arrows (Figure 2), converge to one center. Also, this central city just interacts with the small cities, in the hierarchical aspect, surrounded by it. Regarding the multicentric scheme, there is a mutual center-hinterland relationship. However, it is limited in one zone of the urban system, shaping a monocentric linkage functionally. When the flows have a balanced and multidirectional set of relationships between cities, the urban system is considered as functionally polycentric (BURGER; MEIJERS, 2011).

To summarize, a polycentric urban region or PUR is a network of cities with rich, strong and multifaceted interactions among them (NORDREGIO, 2005). The flow of people is supported by a road corridor linking two or more central cities, or multiple modals (highways and railways). The advantage of this ideal concept is its applicability in the formulation of regional policies towards the urban development, territorial cohesion and spatial organization (BREZI, VENERI, 2014; MULICEK, MARLÝ, 2018; SADEWO *et al*., 2020). These interventions allow the residents to have access to facilities and basic services which are difficult to acquire in the neighborhoods, and increase the regional competitiveness trough integrated economic zones (LIU *et al*., 2019; MARLÝ, 2018).

Currently, the polycentricity, which is a logical method to examine the interaction levels among cities in the urban system (TAUBENBÖCK *et al*., 2017), is stretched in terms of scale and scope with borrowed size, agglomeration shadows (MEIJERS *et al*., 2016; MARLÝ, 2016), borrowed performance and borrowed function (VOLGMANN; RUSCHE, 2020). These conceptions describe the types of urban connections, and their theoretical details are beyond this study borders. The focus is only to measure the functional linkage in the research area following the Figure 3.

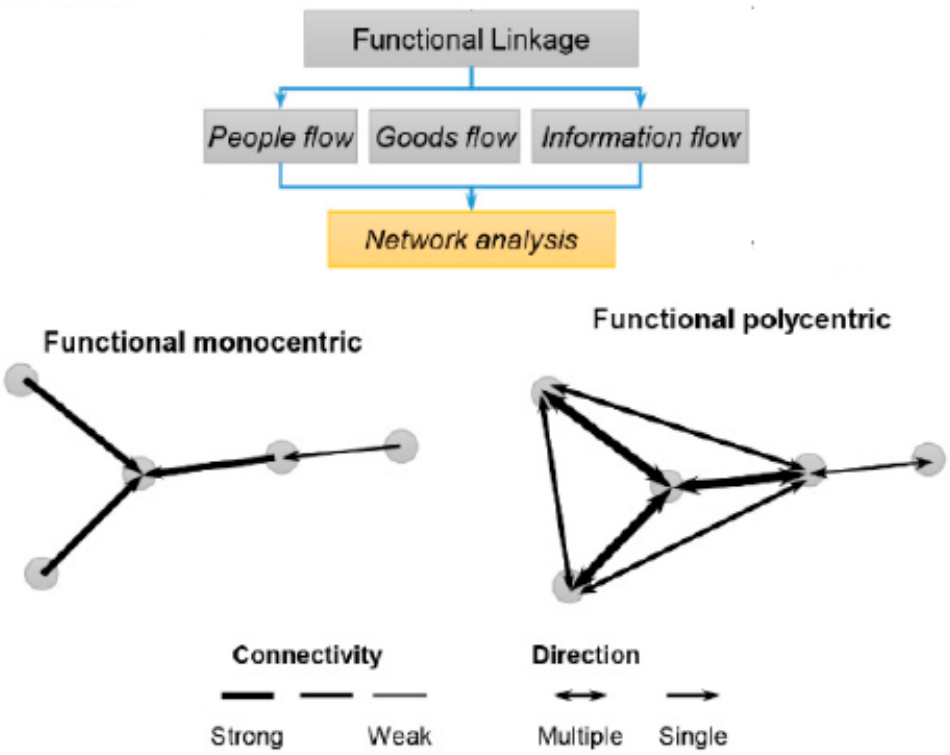

Figure 3: Analytical framework of polycentric function
Source: Adapted from Liu *et al.* (2019).

Despite the polycentricity usually being applied in researches on urban network system in large metropolitan areas (OORT *et al.,* 2009; GOEI *et al.,* 2010; HANSSENS *et al.,* 2012), in the last years this method was used in different contexts such as mountain regions (LIU *et al*., 2019), regions with diversity of urban structure (MARLÝ, 2018), rural depopulation regions (GASCÓN; MASOT, 2020) and could be validated in studies on agribusiness regions (OLIVEIRA, RODRIGUES, 2020a, 2020b; SURYA *et al*., 2021). In Brazil, the method is concentrated in a few studies which aimed to investigate the morphological aspects (population and facilities) in countryside regions dominated by medium cities (FERREIRA, 2018; SPINELLI, MESQUITA, 2020) or analyzing the transportation network in metropolitan regions (KNEIB, 2016).

THE RISE OF AN URBAN SYSTEM IN THE MIDLANDS OF BRAZIL

In according to Influence of Cities over Regions 2018 (REGIC 2018), an official study from the Brazilian Institute of Geography and Statistic (IBGE), the urban system is under the command of São Paulo-SP, the largest national metropolis, and a degree below, Rio de Janeiro-RJ and Brasília-DF (national metropolises). Regarding the federal capital, its inauguration, in the 1960s, changed the spatial relationships in the midlands of Brazil (DINIZ, 2001).

However, it would be unfair to ignore the relevance of Goiânia (GO), capital of Goiás (GO), founded approximately 30 years before the inauguration of Brasília (DF), as a vital component in this context (MELLO, 2015). These two capitals are the main urban centers in the Middle-West of Brazil, and they have stablished the most important road corridor outside the coast as well (HADDAD, MOURA, 2016; SANTANA *et al*., 2016), which lies in the route on highway BR 060 (Figure 4).

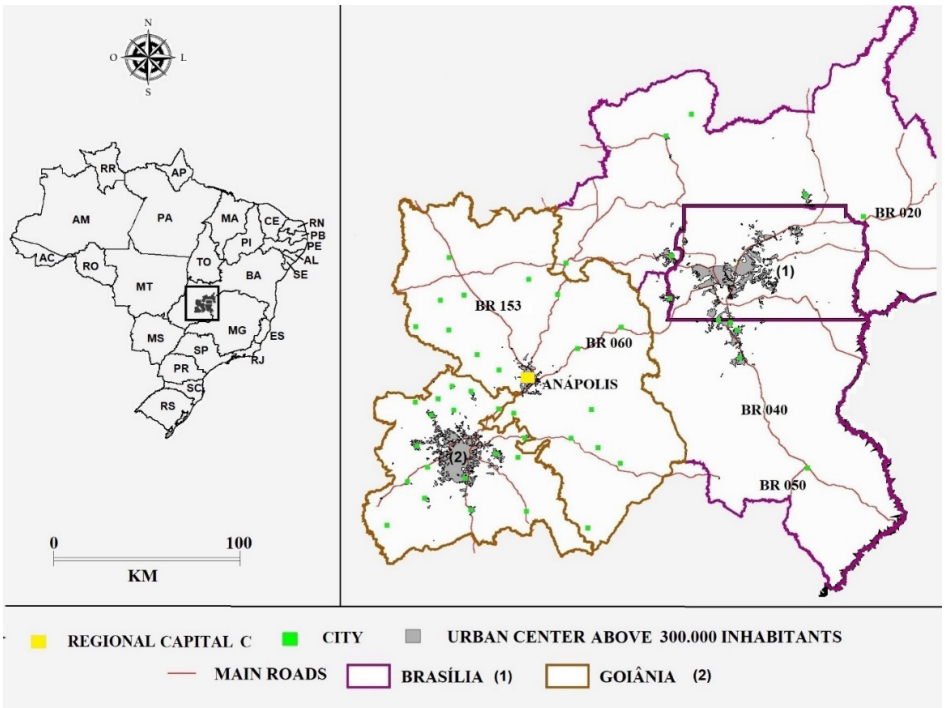

Figure 4. The road corridor Brasília (DF)-Anápolis(GO)-Goiânia (GO) on the highway BR 060
Source: Regic (2018).
Note: Elaborated by authors.

In BR 060 between Brasília (DF) and Goiânia (GO), Anápolis (GO) emerged as an important regional urban center, while the other cities in this route increased its urban occupation (BIRD; STRAUB, 2020). Furthermore, the radial roads[4] have boosted the formation of urban agglomerations across BR 153 (Belém-Brasília), BR 020 (Brasília-Fortaleza), BR 040 (Brasília-Belo Horizonte-Rio de Janeiro) and BR 050 (Brasília-Uberlândia-São Paulo).

As a result, the Brasília-Goiânia urban system have promoted strong connections beyond the Mid-West of Brazil, particularly in the east of Amazon and *Cerrados* (Brazilian Savannas) in the Northeast (BRASIL, 2008). These areas became a target because Palmas (TO), state capital of Tocantins (TO) Araguaína (TO), Barreiras (BA), Imperatriz (MA) and Marabá (PA) consolidated themselves as regional capitals according to REGIC 2018. The five cities are crucial to support the flow of people between BCN and large cities across Brazil (OLIVEIRA *et al*., 2020), especially to Brasília (DF) and Goiânia (GO) as Figure 5 shows:

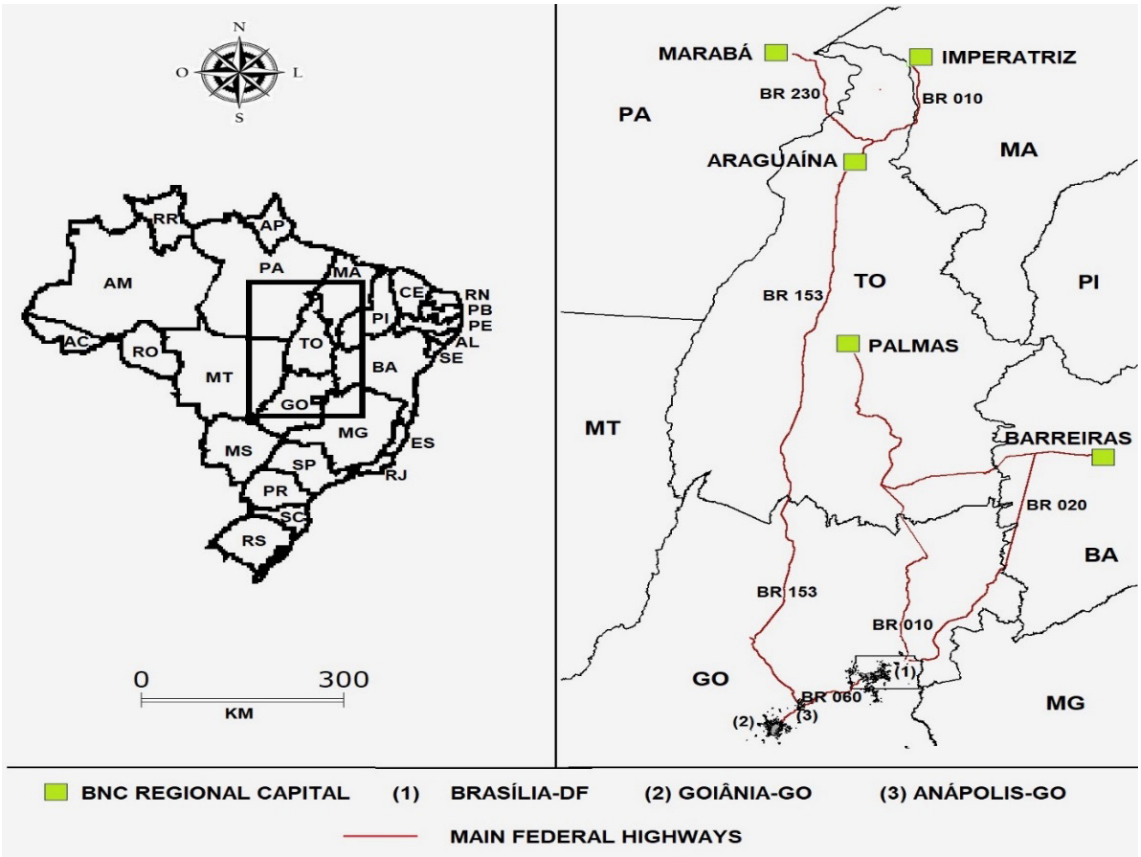

Figure 5: The roads access between BCN regional capitals and the road corridor on BR 060
Source: Regic (2018).
Note: Elaborated by authors.

The other function of Palmas (TO) Araguaína (TO), Barreiras (BA), Imperatriz (MA) and Marabá (PA) is offer essential services to improve the economic activities and welfare to the people that live in subregions of Brazilian Center North. The task is hard

4 Highways built after the creation of Brasília which connect the new capital to state capitals and ports.

due to high road distance between BCN regional capitals and their countryside (OLIVEIRA *et al*., 2020). Even Araguaína (TO), Imperatriz (MA) and Marabá (PA) have a morphological polycentric distribution, social issues block a more intensive relationship in the junction between Maranhão (MA), Pará (PA) and Tocantins (TO) state (OLIVEIRA, PIFFER, 2017b; PACÍFICO FILHO *et al*., 2020).

The function of BCN cities in the national urban system is secondary due to the high dependence on public administration, agricultural and mineral production (OLIVEIRA; PIFFER, 2015). Also, the lack of dynamic economic activities such as manufacture industries and specialized services, which demand labor skilled, keeping the region subordinate to Brasília (DF) and Goiânia (GO). In other hand, as Brazilian Center North is a recently stablished area (OLIVEIRA *et al*., 2020), it creates an unique opportunity to put the SDG 11 goals in practice.

RESEARCH DESIGN

The study area is the Brazilian Center North polycentric (OLIVEIRA *et al*., 2020), a concept (Annex) which has the intention of improving the spatial cohesion among its cities, an idea adherent to SDG 11 goals. To achieve it, the BCN urban system needs to interact with many cities inside and outside its territory. The purpose is to avoid the monocentric relationships (restrictions in access to facilities and basics services to BCN residents) as fair as possible.

The general hypothesis, Brazilian Center North, despite having a morphological polycentric framework, is monocentric in terms of functional linkage (Figure 2 and 3). This structure hampers the region to achieve the goals in SDG 11. Following this idea, two other specific hypothesis were formulated:

H1) The first hypothesis considers that, even being on a long road distance from the Brazilian Center North cities, Brasília-DF, Goiânia-GO and Anápolis-GO are the central cores to this region. To respond it, the flow of people to these three representants of the Middle West were analyzed separately and compared to other metropolises and regional capitals in Brazil;

H2) The second hypothesis affirms that despite the importance of Palmas (TO), Araguaína (TO), Barreiras (BA), Imperatriz (MA) and Marabá (PA), there is a lack of urban agglomerations capable of increasing the spatial interactions into Brazilian Center North urban system. To analyzed it, the flow of people between the BCN regional capitals and others BCN cities was compared.

If the two hypothesis were confirmed, it would validate the general hypothesis (monocentric functional linkage). Otherwise, the rejection of H1 or H2 corroborates the suggestion that BCN urban system is tending to polycentrism in terms of functional linkage.

Database

The ANTT is a federal autarchy in charge of controlling the flow of people and goods in the Brazilian roads, provides information about the number of passengers by intenerate (BRASIL, 2021). Thus, it is feasible to use this official database as a variable which determines the flow of people between two urban centers in Brazil. Although, the ANTT only inspects interregional commutes because currently the states authorities have the responsibility of controlling the flow of people within their cities and metropolitan regions.

Regarding physical distances, GIS (Geographic Information System) software measure the distance between the cities precisely. However, *Google Maps* offers information about roads distances across Brazil easily. This advantage saves time and drives the analysis focus to more relevant factors.

Empiric Strategy

The analysis of urban system is measured by many methods: Gravitational Model, Reilly´s Model, Rank-Size Rule, the Law of the Primate City, to name a few (ZIVANOVIC *et al.*, 2019). All these theoretical methods have advantages and disadvantages, turning the decision to apply them in the analysis an arbitral ruling of the researchers. The recommendation is that the model is being used as a complementation to the investigation, leading the authors on formulating correct conclusions.

As the main objective of the study is to analyze the functional linkage of Brazilian Center North in the national urban system, the Gravitational model fits in the research due to its accuracy in the results despite being less easily interpreted than other methods (MARQUES *et al.*, 2019). The theoretical approach derives from Sir Isaac Newton´s law of universal gravitation and holds that the gravitational force between two mass is directly proportional to the product of these mass units and inversely proportional to the physical distance between them. Its advantage is the capability of this model to assess the spatial independencies within one modeling framework (BURGER *et al.*, 2019). The Gravitational model is expressed by:

$$I_{ij} = K \frac{M_i^{\beta 1} M_j^{\beta 2}}{d_{ij}^{\beta 3}}, \quad (1)$$

where I_{ij} is the interaction intensity, K a proportionality constant, M_i the size of place i, M_j the size of place j, d_{ij} the distance between the two places, β_1 the potential to generate flows, β_2 the potential to attract flows and, β_3 an impedance factor reflecting the rate of increase of the friction of distance. Usually, the model transforms into a linear stochastic form, resulting in an equation that is testable using Ordinary Least Squares (OLS). Thus, there is a possibility to analyze the development of spatial interactions across time. Its most basic form is describe by:

$$\ln I_{ij} = \ln K + \beta_1 ln M_i + \beta_{2ln} M_j - \beta_{3ln} d_{ij} + \varepsilon_{ij} \quad (2)$$

where ε_{ij} is assumed to be independent and identically distributed. Also, the procedure can include variables to check the spatial interdependencies in an urban system. For example, dummy variables that reflect the barriers between places such as lack of physical accessibility or language and cultural differences (BURGER *et al*., 2019).

Otherwise, the application of the linear regression model leads to inefficient, inconsistent and biased estimations, hampering the correct interpretation of the results (GOEI *et al.,* 2010; MARQUES *et al*., 2019). Thereby, studies on international trade have reformulated the gravity model (2) adding the country-specific fixed effects on the equation (BURGER et al. 2009). Formally, the model only deals with physical distance as barrier to trade:

$$\ln I_{ij} = \beta_{3ln} d_{ij} + \gamma_i + \eta_j + \varepsilon_{ij}, \quad (3)$$

where γ_i is the fixed-effect of the country of origin (the exporter) and η_i is the fixed-effect of the country of destination (the importer).

However, from a methodological point of view, there are some serious problems with previous equation such as the biased estimators and the presence of heteroskedasticity, a situation which keeps the model´s results unpredictable (BURGER *et al.,* 2009). Given the problems, the method is improved conversing the equation 3 to Poisson and modified Poisson, a feasible alternative to standard Poisson and its log-normal counterpart (GOEI *et al*., 2010; HANSSENS *et al*., 2012). Hence, the observed amount of trade between countries *i* and *j* has a Poisson distribution with a conditional mean that is a function of the independent variables (4). As *Iij* is assumed to have a non-negative integer value, the exponential of the independent variables is taken, to ensure that μ_{ij} is zero or positive. More formally:

$$\Pr[I_{ij}] = \frac{\exp(-\mu_{ij})\, \mu_{ij}^{I_{ij}}}{I_{ij}!}, \qquad (I_{ij} = 0, 1 \ldots) \quad (4)$$

where the conditional mean μ_{ij} is linked to an exponential function of a set of regression variables, X_{ij}:

$$\mu_{ij} = \exp(\alpha_0 + \beta' X_{ij} + \eta_i + \gamma_i) \quad (5)$$

where α_0 is a proportionality constant, X_{ij} is the 1 x *k* row vector of explanatory variables with corresponding parameter vector β, which represent the different dimensions of transactional distance between countries, η_i is an effect specific to the country of origin (an exporter-specific effect), and γ_i is an effect specific to the country of destination. The fixed-effects estimation in the model is related to importers and exporters. It is important to recognize that the Poisson model assumes equidispersion ($E(T_{ij}|x \propto E(I_{ij}|x)$), for which the conditional variance of the dependent variable should be equal to its conditional mean. If not, the data set displays over-dispersion (GOEI *et al*., 2010).

The Poisson regression normally shows consistent results, but yet inefficient, which is exemplified by spuriously large z-values and spuriously small p-values due to downward biased standard errors (BURGER *et al*., 2009). Again, a new approach, which belongs to the family of modified Poisson models, was formulated to correct the issue. Here, the variance is specified as a function of both conditional mean (μ) and a dispersion parameter (α), thereby incorporating unobserved heterogeneity into the conditional mean. In other words, an additional error term has been added to the negative binomial regression model. By allowing the dispersion parameter to take on other values besides 1, overdispersion can be taken care of by explicitly modeling between-subject heterogeneity. Formally:

$$\Pr[I_{ij}] = \frac{\Gamma(I_{ij} + \alpha^{-1})}{I_{ij}!\,\Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1} + \mu_{ij}}\right)^{\alpha^{-1}}\left(\frac{\mu_{ij}}{\alpha^{-1} + \mu_{ij}}\right)^{I_{ij}} \quad (6)$$

where $\mu_{ij} = \exp(\alpha_0 + \beta' X_{ij} + \eta_i + \gamma_i)$, Γ is the gamma function, and α is a parameter that determines the degree of dispersion in predictions, allowing the conditional variance to exceed the conditional mean. If the α is larger, the Negative Binomial regression is preferred over a Poisson distribution.

Beyond this Poisson model extension, there are other Poisson variations such as the zero-inflated Poisson regression and the zero-inflated negative binomial regression. These options solve the problem of the excess zero in the count which normally results in biased estimations (GOEI *et al*., 2010). However, it was unnecessary to apply them in this study because all the zeroes in the database were previously eliminated[5].

Regardless of the three equations (3), (5) and (6) being usually applied in the studies concerning international trade, in the last two decades they have been used in the analysis on urban systems. Among the studies, which investigated the level of urban interaction, Oort et al. (2009) analyzed in Duth Randstad, Goei et al. (2010) in Central Belgium, and Hanssens et al. (2012) in Great South East, United Kingdom, all of them reaching reliable results. These papers used people commuting as a dependent variable. The classical approach (equation 1) is still being applied in urban studies, particularly in the analysis about migration in metropolitan regions of Mexico (ESCAMILLA *et al*., 2018) and formulating new regions in the state of Paraná, Brazil (GOTARDO; STADUTO, 2017).

In a nutshell, the Gravity model deals with negative effects of geographic distance on *ceteris paribus* urban interactions. The description is the model´s simple form. The researchers have options to add new variables as dummies to improve the analysis or control the variables performances, but such actions could negatively influence the interpretation of the results, hampering the formulation of conclusions.

Modeling the Urban System in Brazilian Center North

The study follows Regic (2018), an official document which established the urban hierarchy in the Brazil´s territory sorting the cities according to its influence level. In the Bra-

5 The zero values are important in the analysis (BURGER *et al*., 2009). Nonetheless, the lack of information in ANTT database forced to eliminate the zeroes in order to avoid any future misunderstandings.

zilian Center North, Palmas, capital of Tocantins state (TO), is the only Regional Capital B in the region, whereas Araguaína (TO), Barreiras (BA), Imperatriz (MA) and Marabá (PA), are in the Regional Capital C. These groups of cities are the most responsible for making a feasible constant flow of people between BCN and the rest of Brazil, and into BCN region. They have the support of other relevant cities for example, Gurupi (TO), Redenção (PA) and Floriano (PI), both Sub-regional Centers A and 11 Sub-regional Capitals B (more details in Table 1). The junction of this cities received the name "BCN poles" (2.1 in Table 1).

Usually, the people from Brazilian Center North travel to São Paulo (SP), the only Large National Metropolis, Rio de Janeiro (RJ) and Brasília (DF), sorted as National Metropolis, and to Metropolis, a group that includes 15 cities. The other cities across the national territory such as Regional Capitals A, B and C, Sub-regionals Centers A and B could interact to BCN poles. However, the high road distances suggest a hard interaction between them.

Modifications from Regic (2018) were made to simplify the modeling applied in this study (Table 1). São Paulo (SP) was included together to Rio de Janeiro (RJ) and Brasília (DF) in the group National Metropolis (1.1). The Sub-regional Centers A and B, Zones Centers A and B, and Local Centers are in 1.4 (Other urban centers). The BCN Zones Centers A and B, and BCN Local Centers are in 2.1.4 (Other urban centers). Despite of Confresa (MT) and Vila Rica (MT) being sorted as Zone Centers, in the model these cities are considered as relevant Brazilian Center North poles (2) because they have an influence, even limited, on the Northwestern Mato Grosso (MT), Southern Pará (PA) and Western Tocantins (TO).

Following the research design, the Gravity model measured the flow of people between BCN poles and Brasília (DF), Goiânia (GO) and Anápolis (GO) separately. Also, the method was applied to estimate the interaction level between a group of Goiás (GO) state cities (except Anápolis-GO and Goiânia-GO) and the BCN poles (Table 1).

Table 1: Conceptualization of urban interdependencies

Group		**Urban centers**
1	Brazilian territory	
1.1	National Metropolis	São Paulo (SP), Rio de Janeiro (RJ) and 1.1.1 Brasília (DF)
1.2	Metropolis	14 cities and 1.2.1 Goiânia (GO)
1.3	Regional Capitals	95 cities and 1.3.1 Anápolis (GO)
1.4	Other urban centers	4,543 cities and 244 Goiás (GO) state cities (1.4.1)
2	Brazilian Center North	
2.1	BCN poles	Palmas (TO), Marabá (PA), Imperatriz (MA), Barreiras (BA), Parauapebas (PA), Gurupi (TO), Redenção (PA), Floriano (PI), Tucuruí (PA), Açailândia (MA), Xinguara (PA), Porto Franco (MA), Bom Jesus do PI (PI), Paraíso do TO (TO), Balsas (MA), Vila Rica (MT), Porto Nacional (TO), Luís Eduardo Magalhães (BA) and Confresa (MT)
2.2	Regional Capitals	Palmas (TO), Marabá (PA), Imperatriz (MA) and Barreiras (BA)
2.3	Sub-regional Centers A	Gurupi (TO), Parauapebas (PA),Redenção (PA) and Floriano (PI)
2.4	Sub-regional Centers B	Tucuruí (PA), Açailândia (MA), Xinguara (PA), Porto Franco (MA), Bom Jesus do PI (PI), Paraíso do TO (TO), Balsas (MA), Vila Rica (MT), Porto Nacional (TO), Luís Eduardo Magalhães (BA) and Confresa (MT)
2.5	Other urban centers	316 cities across BCN territory

Source: Regic (2018).
Note: Organized by authors.

The groups allow the creation of regimes (type of interactions) which correlates to the hypothesis. Thereby, 1,616 bus itineraries in ANTT database were gathered in 11 regimes[6]. For example, the data about volume of passengers in the route Araguaína-TO (origin) to Brasília-DF (destination) was used to measure the interdependence (Gravity Model) between 1.1 and 2.1 (Table 1). The route Barreiras-BA (origin) to Corrente-PI (destination) estimated the relationship level between 2.1 and 2.4. Bus itineraries which displayed low quantity of passengers (below 10 people per month in a year) were ignored in this study.

Nevertheless, the majority of Brazilian Center North cities do not have a daily bus schedule due to a low demand, inadequate road infrastructure or politician decisions. Without regular transportation options, people who live in peripheric regions usually become passengers in unlicensed buses and microbuses. The lack of appropriate management for these vehicles put the travelers in risk of suffering an accident. Also, this illegal transportation, known as "pirate service" in Brazil, contributes to increase crimes such as drug and weapons trafficking and extorsion. In other hand, some cities are served only by locals service buses, a type of transportation which ANTT is not in charge of inspecting.

Currently, several softwares provide functions to estimate the spatial interactions in a research area. The Rstudio freeware and the "fixest" package easily allow the use of the Gravity Model and its variations (OLS, Poisson and Negative Binominal[7], showed in section 4.2). All of the regimes were estimated in this program, and the results in each variation of the model were compared to detect inconsistences.

The data was gathered in Microsoft Excel, where the information was arranged in bus itinerary (line) according to its regime (Table 1) and number of passengers (column). Therefore, the dependent variable is the flow of people travelled by bus and the independent variable is the logarithmic road distance in kilometers, both sorted by bus travel itinerary. The adopted fixed-effects were origin, destination and year (2014, 2015, 2016 and 2017), except in the regimes 1.1.1 (Brasília-DF) and 2.1, 1.2.1 (Goiânia-GO) and 1.3.1 (Anápolis-GO) because the origin and destination are specific. In these cases, only the year variable was used as fixed-effect.

RESULTS

The flow of people is more intensive in regime 1.3 and 2.1 (Nationals capital across Brazil and BCN Poles), while the 2.2 and 2.3 (BCN capital regionals and BCN Sub-regional centers A) were less concentrated (Table 2). Overall, the high volume of bus passengers between Brazilian Center North poles and cities outside of this region suggested that this transportation is essential to promote urban relationships at an interregional scale. In addition, the elevate dispersion of passengers in the majority of

6 1.1 and 2.1; 1.1.1 and 2.1; 1.2 and 2.1; 1.2.1 and 2.1; 1.3 and 2.1; 1.3.1 and 2.1; 1.4 and 2.1; 1.4.1 and 2.1; 2.2 and 2.3; 2.2 and 2.4 and 2.2 and 2.5. The regime that represents the interactions among BCN capital regionals was ignored because the number of bus itineraries was insufficient to estimate the flow of passengers in the Gravity Model. This discussion have more details in the next chapters.

7 Equations 4, 5 and 6 in the section 4.2, respectively.

regimes (see mean and standard deviation in Table 2) indicated that the BCN residents had priority routes to travel.

Table 2: Exploratory analysis on bus passengers by itinerary

Regime	Max	Min	Sum	Mean	Std. Dev.
1.1 and 2.1	65.577	103	388.377	5.110	11.008
1.1.1 and 2.1			344.783	6.760	13.094
1.2 and 2.1	47.734	102	357.708	3.888	8.556
1.2.1 and 2.1		112	300.356	8.343	12.388
1.3 and 2.1	33.061	102	501.495	1.327	3.552
1.3.1 and 2.1	8.493	118	60.565	1.376	1.707
1.4 and 2.1	25.212	102	370.688	911	2.116
1.4.1 and 2.1	12.914	102	204.925	1.265	2.294
2.2 and 2.3	7.720	121	36.347	887	1.326
2.2 and 2.4	48.804	102	175.405	3.508	8.836
2.2 and 2.5	39.148	102	380.578	2.035	4.460

Source: research results. Elaborated by authors.

Notes: (Max) Maximum value; (Min) Minimum value; (Mean) Mean by bus itinerary; (Sum) sum of all passengers in the regime; (Std. Dev.) Standard Deviation by bus itinerary; (1.1 and 2.1) National metropolises and BCN poles; (1.1.1 and 2.1) Brasília-DF and BCN poles; (1.2 and 2.1) Metropolises and BCN poles; (1.2.1 and 2.1) Goiânia-GO and BCN poles; (1.3 and 2.1) National capitals across Brazil and BCN poles; (1.3.1 and 2.1) Anápolis-GO and BCN poles; (1.4 and 2.1) Other urban centers across Brazil and BCN poles; (1.4.1 and 2.1) Goiás (GO) state cities and BCN poles; (2.2 and 2.3) BCN regional capitals and BCN Sub-regional centers A; (2.2 and 2.4) BCN Regional capitals and BCN Sub-regional centers B and (2.2 and 2.5) BCN Regional capitals and Other BCN urban centers.

Among the priority routes, Brasília (DF) is the most important origin or destination of bus travelers. Between 2014 and 2017, almost 355.000 people from Brazilian Center North were in the federal capital, equivalent to 88,8% of all flow of people in the National Metropolises group (1.1) and close to the volume of passengers in Metropolises (1.2). As a result, the estimators from Gravity model (OLS, Poisson and Negative Binominal) showed a robust monocentric relationship in regime 1.1.1 and 2.1 (Table 3).

Table 3: Results from Gravitational model (between Brazilian territory and BCN poles)

Regime	OLS	Poisson	Negative Binominal
1.1 and 2.1	(-39,96)***	(-48,26)***	(-40,38)***
1.1.1 and 2.1	(-0,51)*	(-1,32)***	(-1,05)**
1.2 and 2.1	(-2,07)**	(-2,09)*	(-1,87)***
1.2.1 and 2.1	(-2,93)*	(-2,25)***	(-2,59)***
1.3 and 2.1	(-2,26)***	(-2,13)***	(-1,95)***
1.3.1 and 2.1	(-1,68)*	(-0,26)***	...
1.4 and 2.1	(-0,10)	(-0,95)*	(-0,48)
1.4.1 and 2.1	1,01	0,15	...
Fixed-Effects	Yes	Yes	Yes
Origin	Yes	Yes	Yes
Destination	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observation	953	953	953
BIC	-	505.214	13.905
Overdispersion	-	-	1.401

Source: research results. Elaborated by authors.

Notes: (***) 99,99% significance level; (**) 99,9% significance level; (*) 99% significance level; (…) To avoid the multicollinearity problem, the model recommended to use the results from Poisson model; (1.1 and 2.1) National metropolises and BCN poles; (1.1.1 and 2.1) Brasília-DF and BCN poles; (1.2 and 2.1) Metropolises and BCN poles; (1.2.1 and 2.1) Goiânia-GO and BCN poles; (1.3 and 2.1) National capitals across Brazil and BCN poles; (1.3.1 and 2.1) Anápolis-GO and BCN poles; (1.4 and 2.1) Other urban centers across Brazil and BCN poles; (1.4.1 and 2.1) Goiás (GO) state cities and BCN poles;

In other hand, Goiânia-GO (1.2.1 and 2.1) interacted in minor level in relation to other Metropolises (1.2 and 2.1). It means that the state capitals which belong to this regime such as Belém (PA), Fortaleza (CE) and Salvador (BA) had more influence, due to administrative aspect, than the capital of Goiás (GO) state in the BCN urban system. Regarding national capitals across Brazil, the estimators from Anápolis-GO (1.3.1 and 2.1) are statistically significant, suggesting that this city has strong connection with Brazilian Center North. At last, no other urban centers across Brazil (1.4 and 2.1) or Goiás (GO) state cities (1.4.1 and 2.1) had relevance in the analysis context.

Into BCN region, the interaction level between the other urban centers and its poles (2.2 and 2.5) is strong according to estimators (Table 4). The same considerations were observed in the regime 2.2 and 2.4 (BCN Regional capitals and BCN Sub-regional centers B). However, the interdependence to Sub-regional centers A is statistically irrelevant (regime 2.2 and 2.3), suggesting that the Brazilian Center North urban system has a considerable level of spatial fragmentation (Table 4).

Table 4: Results from Gravitational model (between BCN capital regionals and BCN cities groups)

Regime	OLS	Poisson	Negative Binominal
2.2 and 2.3	0,03	0.99	0,56
2.2 and 2.4	(-1,38)*	(-1,63)***	(-2,79)***
2.2 and 2.5	(-0,97)**	(-0,53)***	(-1,15)***
Fixed-Effects	Yes	Yes	Yes
Origin	Yes	Yes	Yes
Destination	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observation	288	288	288
BIC	-	1.166.539	4.433
Overdispersion	-	-	35

Source: research results. Elaborated by authors.

Notes: (***) 99,99% significance level; (**) 99,9% significance level; (*) 99% significance level; (2.2 and 2.3) BCN Regional capitals and BCN Sub-regional centers A; (2.2 and 2.4) BCN Regional capitals and BCN Sub-regional centers B and (2.2 and 2.5) BCN Regional capitals and Other BCN urban centers.

The problem in regime 2.2 and 2.3 (BCN Regional capitals and BCN Sub-regional centers A) could be linked to the low quantity of routes and passengers between them. Another hypothesis is the spatial function of these four Sub-regional centers A. As examples, firstly due to geographic localization, probably Floriano-PI and Gurupi-TO have a higher level of interaction with cities outside of BCN (respectively to the cities in states of Ceará-CE and Goiás-GO) than inside of BCN; secondly, Parauapebas-PA is an urban core which serves entirely for miner activity (OLIVEIRA; PIFFER, 2017); finally, Redenção-PA has conditions to turn into an important regional center, but it still needs to gather more firms and people (OLIVEIRA *et al*., 2020).

DISCUSSION

In the light of the results, this section discussed the research hypothesis and the level of territory cohesion (SDG 11) in Brazilian Center North. According to the flow of people (bus passengers), it is notable the high degree of spatial interactions that the BCN poles established in the national urban system, under the leadership of the five regional capitals. In addition, the estimators from Gravity model confirmed that these cities are capable to support a multicentric framework.

Even though having a polycentric morphology, BCN is far from becoming a polycentric urban region. One of the reasons is the high subordination to Brasília (DF) and Anápolis (GO). This city in Goiás (GO) showed close estimators to the federal capital, an observation which reinforced its status as one of the main poles in the Brazilian hinterland (HADDAD; MOURA, 2016; SANTANA *et al.,* 2016). The polycentrism

scheme is observed in regimes 1.2 and 2.1, and 1.2.1 and 2.1. In these parameters, the urban interaction level linked to Goiânia (GO) is lower than Metropolises, suggesting that the capital of Goiás (GO) shares its influence with Belém (PA), Fortaleza (CE) and Salvador (BA).

As noticed in the previous chapter, the urban interactions promoted by Brazilian Center North Sub-regional centers A into BCN is minimal. Despite these cities having a lesser degree of economic complexity than Regional Capitals, they are essential to improve the territory cohesion levels acting as links between these main urban cores and small cities. The question is if Floriano (PI), Gurupi (TO), Parauapebas (PA) and Redenção (PA) are able to overcome central cities such as Palmas (TO), Araguaína (TO), Barreiras (BA), Imperatriz (MA) and Marabá (PA) in the next decades, an investigation which demands a deeper research.

The strong correlation to Brasília (DF) and Anápolis (GO), both being in main road corridor on BR 060, and the inconclusive results from the regime 2.2 and 2.3, are evidences which confirmed the hypothesis. This affirmation confirmed that the BCN region faces structural problems to accomplish the SDG 11 goals.

CONCLUSION

The study analyzed the functional linkage of Brazilian Center North in the national urban system and how this structure influences in SDG 11 context. The evolution of urban interactions theories across time collaborated in the elaboration of the research design. Also, the Gravitational Model and variations allowed to estimate the flow of people among cities, displaying empiric robust evidences that confirmed the main hypothesis (BCN has a morphological polycentric framework and its functional linkage is multicentric). Thus, the objectives in this investigation were entirely fulfilled and the results led to future studies on the subject.

However, the analysis faced a set of limitations which hampered to reach a deeper knowledge on Brazilian Center North urban system. One of them is the irregularity of data in the ANTT website over time. In the context of state bus transportation, the lack of information available to the public and the presence of "pirate services" hid a considerable quantity of passengers travelling on the roads. Furthermore, the flow of people by car and airplane were ignored in this research. The main conclusion is that the results from the methodology just showed a piece of the BCN spatial interactions.

Nonetheless, the information gathered in this scientific document is enough to debate the policies implications for Brazilian Center North. The elaboration of a plan evidencing the spatial function of each city and establishing funds to increase the power of their interactions are crucial to the urban development at interregional scale in this region. As the financial sources are limited, the recommendation is prioritize cities with potential to turn into regional capitals. In this sense, the Sub-regional centers A are strong candidates due to their social and economic relevance in the BCN.

Another implication involves polycentricity and its applicability. This theoretical framework is able to adjust to different scenarios. For example, in the studies about

metropolises the dependent variable is commute, an information unavailable in regions where the cities are far from each other similar to Brazilian Center North. The solution adopted in this research was to use the number of bus passengers by route to measure the flow of people through Gravitational model. Innovative methodologies to analyze the urban interactions could emerge from these creative actions.

Finally, about the Sustainable Development Goals number 11, the suggestion is to apply spatial indicators to monitor the evolution of urban system at regional scale across time. The initiative is feasible and gives evidence to the potentials and liabilities (BERTAUD, 2004) in the Brazilian regions, helping to understand their territorial cohesion levels.

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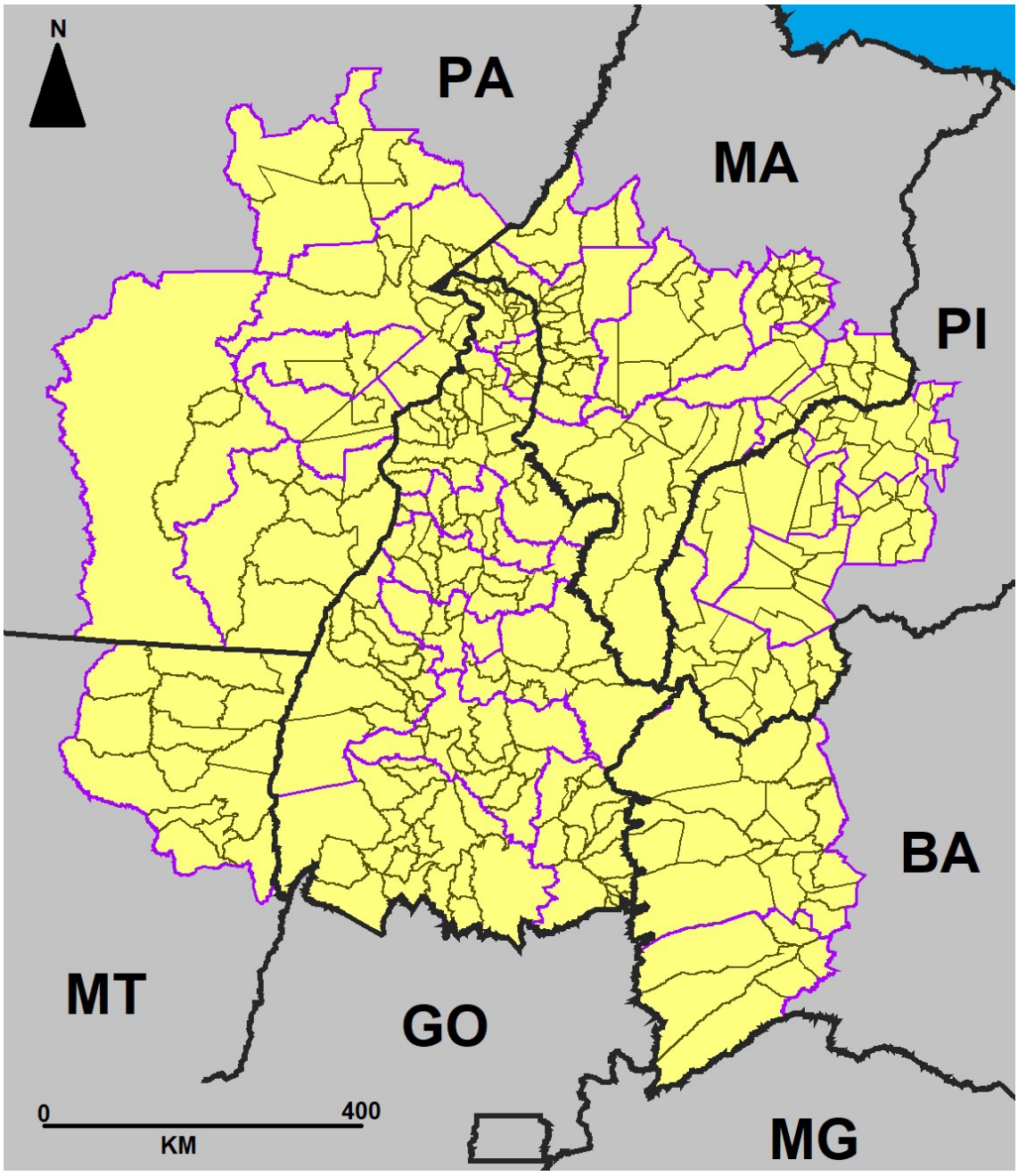
ANNEX



The Brazilian Center North polycentric

Adapted from Oliveira et al. (2020). Notes: 335 municipalities represented in yellow color. The purple lines are the borders of Regiões Geográficas Imediatas, equivalent to NUTS 3 from European Union, and the grey lines are the states borders: (BA) Bahia; (MG) Minas Gerais; (GO) Goiás; (MT) Mato Grosso; (PA) Pará; (MA) Maranhão; (PI) Piauí. Tocantins (TO) is above Goiás (GO) and Brasília (DF). The federal capital is into the rectangular area into Goiás (GO).

THIAGO JOSÉ ARRUDA DE OLIVEIRA
Ph.D. in Regional Development and Agribusiness at the Western Paraná State University (UNIOESTE). Pos-doc fellowship researcher at the Federal University of Tocantins (UFT), Palmas -TO. E-mail: thiago.arruda85@gmail.com.

WALDECY RODRIGUES
Ph.D. in Social Science at the University of Brasília (UnB). Professor at the University Federal of Tocantins (UFT), Palmas -TO, Brasil. E-mail: waldecy@terra.com.br.

JOEL ISAAC HERNANDEZ LANZA
Master in Regional Development at the Federal University of Tocantins (UFT) and Master in Government and Culture of Organizations at the Navarra University (UNAV). E-mail: issac_lanz@hotmail.com.