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Rail transport, commodity flows and sustainable urban development: An appraisal to the complementarity of a 'Railway Town' in India

Transport ferroviaire, flux de marchandises et développement urbain durable : évaluation de la complémentarité d'une « ville ferroviaire » en Inde

Transporte ferroviario, flujos de mercancías y desarrollo urbano sostenible: una evaluación de la complementariedad de una "ciudad ferroviaria" en la India

Iman Banerjee
Banaras Hindu University, Varanasi, India
imanbanerjee64@gmail.com

Apala Saha
Banaras Hindu University, Varanasi, India
apala2010@gmail.com

Abstract: The present paper seeks to conceptualise the notion of complementarity with the help of rail-based commodity flow data in one of the most prominent railway towns in India i.e. PanditDeenDayalUpadhyaya Nagar (Mughal Sarai).Referring to the theoretical notion of 'complementarity' and a modified form of 'gravity model' from the 'Family of Spatial Interaction Models', this research puts an intensive discussion forward on the existing nature of spatial interaction of PanditDeenDayalUpadhyaya Nagar (Mughal Sarai) with its complementary areas and a comparison of these areas in terms of their relative complementarity with the town concerned.The resultant outcome in the form of a Complementarity Index, portrays a different, if not entirely contradictory picture from the crude values of material shipments to PanditDeenDayalUpadhyaya Nagar (Mughal Sarai). This analysis thus well-indicates that merely supplying greater amount of commodities of any kind does not necessarily reflect greater complementarity and vice versa. Therefore, a more comprehensive

analysis of commodity flows is imperative to have a deeper insight into the notion of spatial interaction.

Keywords: Spatial interaction, complementarity, PanditDeenDayalUpadhyaya Nagar (Mughal Sarai), commodity flow, railway town.

Résumé: Le présent article cherche à conceptualiser la notion de complémentarité à l'aide de données sur les flux de marchandises ferroviaires dans l'une des villes ferroviaires les plus importantes d'Inde, à savoir Pandit DeenDayalUpadhyayaNagar (MughalSarai). Faisant référence à la notion théorique de « complémentarité » et à une forme modifiée de « modèle de gravité » de la « Famille des modèles d'interaction spatiale », cette recherche propose une discussion intensive sur la nature existante de l'interaction spatiale du Pandit DeenDayalUpadhyayaNagar (Moghol). Sarai) avec ses zones complémentaires et une comparaison de ces zones en termes de complémentarité relative avec la ville concernée. Le résultat qui en résulte, sous la forme d'un indice de complémentarité, dresse un tableau différent, voire totalement contradictoire, des valeurs brutes des expéditions de matériaux au Pandit DeenDayalUpadhyayaNagar (MughalSarai). Cette analyse indique donc bien que le simple fait de fournir une plus grande quantité de produits de toute sorte ne reflète pas nécessairement une plus grande complémentarité et vice versa. Par conséquent, une analyse plus complète des flux de matières premières est impérative pour avoir une compréhension plus approfondie de la notion d'interaction spatiale.

Mots clés: Interaction spatiale, complémentarité, PanditDeenDayalUpadhyaya Nagar (Mughal Sarai), flux de marchandises, villeferroviaire.

Resumen: El presente artículo busca conceptualizar la noción de complementariedad con la ayuda de datos sobre el flujo de mercancías por ferrocarril en una de las ciudades ferroviarias más importantes de la India, es decir, Pandit DeenDayalUpadhyaya Nagar (MughalSarai). Haciendo referencia a la noción teórica de "complementariedad" y una forma modificada de "modelo de gravedad" de la "Familia de modelos de interacción espacial", esta investigación plantea una discusión intensiva sobre la naturaleza existente de la interacción espacial de Pandit DeenDayalUpadhyaya Nagar (MughalSarai) con sus zonas

complementarias y una comparación de estas zonas en términos de su relativa complementariedad con la ciudad en cuestión. El resultado resultante, en forma de índice de complementariedad, muestra una imagen diferente, si no totalmente contradictoria, de los valores brutos de los envíos de materiales a Pandit DeenDayalUpadhyaya Nagar (MughalSarai). Por lo tanto, este análisis indica bien que el simple hecho de suministrar una mayor cantidad de productos básicos de cualquier tipo no refleja necesariamente una mayor complementariedad y viceversa. Por lo tanto, es imperativo realizar un análisis más completo de los flujos de productos básicos para tener una visión más profunda de la noción de interacción espacial.

Palabras clave: Interacción espacial, complementariedad, PanditDeenDayalUpadhyaya Nagar (Mughal Sarai), flujo de mercancías, ciudad ferroviaria.

1. Introduction

The notion of *'spatial interaction'* seeks to explain the dynamics of movement of material and human resources, as well as the circulation of energy, services and information, between and among the locations of human activities. It subsumes the demand-supply mechanism in the context of a particular geographical space, and conventionally refers to a wide variety of movements and circulations, including commodity flow, migration and transmission of capital or information. Therefore, analysis of commodity movements may serve for a satisfying method to reflect a geographer's approach towards the explanation and elaboration of the phenomenon of spatial interaction. Furthermore, it has been acknowledged since long that spatial interaction is merely a consequence of areal differentiation. To a certain degree this reasoning is true, but mere differentiation does not produce sufficient forces for interaction, as many different areas on the earth surface do not have any apparent connection with each other (Ullman, 1956, p.867). For spatial interaction to take place, there must be a certain degree of demand-supply relation between places that essentially operates over a network of transportation, which itself is a product of spatial interaction. In simple words, transport development and spatial interaction operate in a bi-directional manner, each inducing some amplifying externalities on the other. Thus, specific complementarity and a network of transport system serve as necessary preconditions for spatial interaction between and among places.

The purpose of the present paper is to conceptualise the notion of complementarity, with the help of rail-based commodity flow data in one of the prominent railway towns in India i.e. PanditDeenDayalUpadhyaya Nagar (Pt. DDUN), previously known as Mughal Sarai. It aims to contribute to the existing literature of urban and transport geography of India and seeks to get a place in the vast body of scholarly works, pertaining to complementarity and spatial interaction. Referring to the theoretical notion of *'complementarity'* by Edward L. Ullman (1956), its subsequent modifications, and a modified form of *'gravity model'*, this research puts an intensive discussion forward on the existing nature of spatial interaction of Pt. DDUN (Mughal Sarai)with its complementary areas and a comparison of these areas in terms of their relative complementarity

with Pt. DDUN(Mughal Sarai). It solely considers rail-based inward flow of some specific commodities to the townunder consideration and therefore, does not incorporate road or water transport in the analysis; because, this research seeks to establish the notion of complementarity in the context of a railway town, rather than explaining the precise pattern of movement of different types of goods by different modes of transport. The choice of commodities is grounded on the availability of data from the respective sources.The results of this research can assist the endeavour of transport policy analysis to recognise the essential transportation (rail) infrastructure requirements for better management of rail-based commodity traffic in Pt. DDUN(Mughal Sarai). Moreover, the results can also be used to analyse future commodity-flow patterns in the town being attributed to a number of recent changes in rail transport infrastructure, including those in freight transportation routes and carrying capacity of Indian Railways.

2.The theoretical background

Perhaps the most formal statement on spatial interaction and flow of commodities is associated with Edward L. Ullman and his monumental work *'The Role of Transportation and the Bases for Interaction'* (1956). In one hand this is an explanation of flow systems, on the other hand this serves as a descriptive analytic device (Hay, 1973, p.121). This notion has progressed with the most acknowledged works of Ullman (1956, 1957), who is appraised as the pioneer of this theory and is recognised for developing three theoretical conditions under which, according to Ullman, interaction takes place, such as *complementarity, intervening opportunity* and *transferability*. These notions, espousing demand and supply mechanism (complementarity), alternative sources for interaction (intervening opportunity) and friction of distance effects (transferability), were endorsed as being useful for the explanation of spatial interaction system in general (Smith, 1964). Complementarity, in simple terms, implies a demand for or a deficit in a product in a place and a supply or surplus of the same product in another place (Wang, 2017). However, Hay (1979) in his review of Ullman's theory, had recognised three different dimensions of complementarity: *latent, potential and actual*. The notion of *latent complementarity* is grounded on the principle

of comparative advantage of a region, caused by its differential natural resource base, specific political system and human way of life that in turn leads to the formation of regional specialisation and exchange with other interacting regions. *Potential complementarity*is conceptualised as the condition which appears when the specialised and productive abilities of two interacting regions are being utilised in such a manner that the prevailing deficit in one region is partially or fully supplemented by thesurplus in another region.The third dimension of complementarity mentioned by Hay (1979), termed as *actual complementarity*arises when in an interacting regional system, surplus in one region is specifically being produced to meet the deficit of another region.

Furthermore, in the analysis of commodity flows, one might wish to obtain an indication of the relative significance with respect to complementarity of the volume of commodities among interacting locations (Smith, 1964). The variable allocation of resources by nature and resulted uneven concentration of human activities culminate into regional specialisation in production of goods and services, which in turn serves for the ideal prerequisite for the development of spatial complementarity between and among places. However, crude analysis of the flow of material or human resources does not necessarily provide a complete picture of *'greater'* or *'lesser'* complementarity between specific locations. Understanding complementarity between two places largely requires the consideration of intervening opportunities i.e. alternative locations capable of deviating the direction of flow as well as transferability, consisting of distance decay parameters including spatial distance, time distance and cost (Ullman, 1956; Smith, 1964; Wang, 2017). The ubiquity of presence and the variability of form of these factors make them the phenomena of little explanatory value, but together they constitute an empirical regularity with which any theoretical explanation of transport flow must be consistent (Hay, 1973, p. 118). Therefore, the prevalence of complementarity is implied in any commodity flow map; but in order to gain a deeper understanding of spatial interaction, it appears to be desirable to establish quantitative measures of the levels of complementarity (Smith, 1964; Ogden, 1978; Yeow and Cheah, 2019).

3.A brief history of Indian Railways and the evolving geography of railway tracks

With the expansion of political and economic power of British administrators in India, the importance of improved means of transportation and communication was realised. The core of the pressure for building railways in India came from London in the 1840s (Thorner, 1955). In August 1850, after a long and complicated process of negotiations in Britain, the Imperial Government of India ultimately granted for the construction of the first section of experimental railway lines in the Bombay and Bengal Presidencies. Subsequently, Lord Dalhousie's *Policy of Trunk Routes,* proposed in his famous minute in 1853, which later became the basis of British railway policy in India, expressed the social, economic and political needs of railway construction in India that in turn could facilitate British interests (Munsi, 1984, p.33). As a consequence, in the decade that followed a number of railway companies constituted in Britain undertook the construction of some experimental lines and it was on April 16, 1853, when the very first passenger train of India ran over a stretch of nearly 34 km. from Bori Bandar (Bombay/Mumbai) to Thana with 14 carriages and 400 guests along with Lord Dalhousie in the midst of loud applause of horde and to the salute of 21 guns (Shani, 1953).This line wasconstructed and operated by the Great Indian Peninsula Railway (GIPR) Company, which in the later decades became instrumental in expanding railway tracks over the Deccan Plateau in south-western India. The first train in the eastern part of Indian subcontinent steamed out of Howrah Station (Calcutta/ Kolkata agglomeration), destined for Hooghly, covering a distance of approximately 39 km. on August 15, 1854. This line was constructed under the aegis of East Indian Railway (EIR) Company (Thorner, 1955), which was entrusted with the job to connect the eastern city of Calcutta (Kolkata) - the then capital of British India with the northern city of Delhi - the present capital of India.[1]Initiated by the Madras Railway (MR) Company, in southern part of India the first passenger train ran over a stretch of nearly 101 km., linking Veyasarpaudy (Madras/Chennai) with Walajah (Shani, 1953). From 1853 to 1947 when India got her independence from colonial rule, the railway system had undergone several administrative changes – where the partition of British Indian

1 The capital of India was shifted from Calcutta to Delhi in 1911.

Empire and consequent trifurcation of India brought some catastrophic externalities over the functioning of the railway system. Together the East and West Pakistan got nearly 19% of the total track of undivided India and the Republic of India accounted for nearly 33,230 miles or 53,500 km. of railway lines (Kerr, 2007, p. 10).

The independent India and the Indian Railways, both emerged with a consolidation of several different entities. The independent India was born out of an agglomeration of several British Presidencies, native Indian States and partially controlled British territories; similarly, the Indian Railways took birth through a consolidation of nearly 42 different railway systems, administrated by 37 different authorities. Following the new policy adopted by the infantile Indian Government, the newly independent India would nationalise all the essential sectors including Railways under a single government-controlled organisation.

The task of consolidation of Indian Railways was not easy for the Railway Board under the Government of India. The Government had to begin from the very bottom to integrate all the railway assets, stocks and finances of different companies to nationalise the entire railway system. As the railway was one of the most important elements of national integration, the first and foremost priorities of the newly formed Indian Railways were the integration of different discrete railway systems, bringing a uniform service for railway operation, up-gradation and modernisation of the new railway network. As a consequence, in 1950 the Railway Board proposed an idea of reorganising the entire network of railways in India, into six major zones. Following the plan, the Southern Railway Zone was created on April 14, 1950, covering 9,654 km. of route in southern India. In the same year on November 5, the Western Railway Zone (9,122 km.) and the Central Railway Zone (8,689 km.) were established; the Northern Railway Zone (9,667 km.), Eastern Railway Zone (9,109 km.) and North Eastern Railway Zone (7,726 km.) were formed on April 14, 1952 (Khullar, 2014). These zones were further reorganised in the subsequent years and currently, Indian Railways consist of17 zones which are subdivided into 68 operating divisions (Ministry of Railways, 2022). Furthermore, at present (2022) Indian Railways comprises 68,043 km. of route length and 1,28,305 km. of overall trackage, served by 7,308 railway stations, 74,744 passenger service vehicles, 3,18,896 wagons and 13,215 locomotives (Ministry of Railways, 2022).

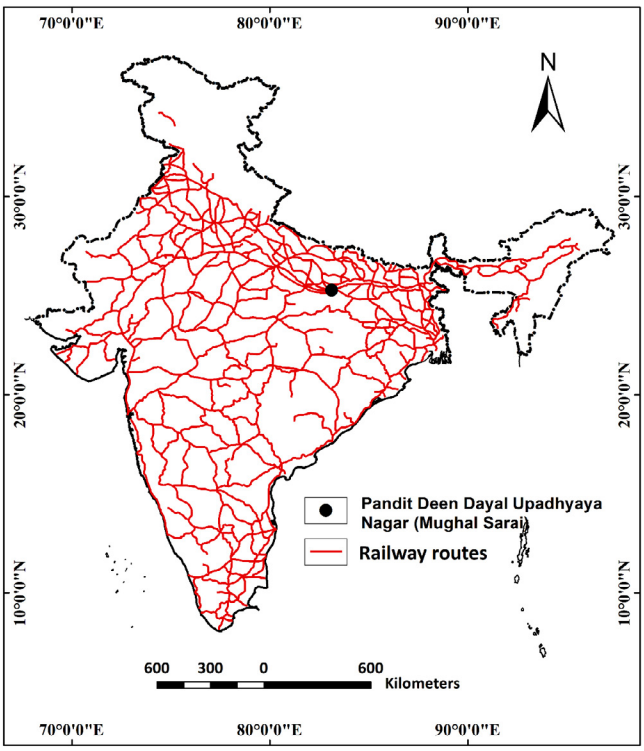

Fig. 1: Railway map of India (2019) and location of PanditDeenDayalUpadhyaya Nagar (Mughal Sarai)

Source: Ministry of Railways, 2019

4. Contextualising rail-based commodity flow in Pandit-DeenDayalUpadhyaya Nagar (Mughal Sarai):

Urban places being the principal nodes in transport network, have long been appraised for their role as the points of inception of modern transportation infrastructure. Simultaneously, it is also true that their very existence as the centres of production and distribution largely depends on the available transport facilities. Moreover, concerning the subject of complementarity and commodity flow, the role of railway transport infrastructure is well-evident throughout the entire world (Golledge, 1963; Smith, 1964; FDOT, 2021; Banerjee, 2022). India is not an exception in this regard. The history of railways in India dates back to 1853 and presently it is not very easy to recognise a city in mainland India that has not been physically and functionally affected by the Railways. Nevertheless, the main focus of the present study is confined around a select railway town in India, Pt. DDUN(Mughal Sarai), which is a bright creation of colonial railways and has successfully retained its position ever since. Such a town is arguably more representative than any other

town when the subject of *railways being mother of urban settlements* is concerned and it is possible with it to put forward a strong case for the railways as the predominant urban growth factor (Kellet, 2007, p.3; Banerjee, 2023a).

Located at the cross-section of 25° 17' N latitude and 83° 11' E longitude, the city of Pt. DDUN (Mughal Sarai) is confined along the historical Grand Trunk Road (currently NH 19) and one of the largest railway junctions in the country (Fig. 1). Mughal Sarai was in existence as a small rural centre since the reign of Mughal Emperor Akbar, but the township was founded by Britishers. The township and railway junction was developed by the East India Railway Company in 1881, with a population of 1,118 (Imperial Gazetteer of India, 1909, p. 529). Therefore, Mughal Sarai fits well in the definition of *'railway town*' by J. Simmons (1986, p.171):

> *'It* [a railway town] *may be confined to those places that were developed by railways for their own purpose, either from nothing or by the addition of a new industrial plant to an existing village or market town, an addition so large as to engulf the older place and to make the combined settlement a town dominated by the railways.'*

Fig. 2: PanditDeenDayalUpadhyaya(Mughal Sarai) Yard, the biggest railway yard in Asia and the second biggest in the world2

Source: Photograph taken by authors; January 2023

2 The Union Pacific Bailey Yard in the United States is reported to be the biggest railway yard in the world.

In 1919, a notified town area committee was constituted to administrate the township of Mughal Sarai, which had been upgraded to a municipality in 1957. After independence, Mughal Sarai became a part of Uttar Pradesh, a northern Indian state which by accommodating nearly 200 million inhabitants (Census of India, 2011) have been emerged as the largest state of India in terms of demographic size. The 1961 Census recorded the population of the Urban Agglomeration of Mughal Sarai as 21,086, which was increased by 152,091 in 2011. However, in 2011 the Municipality was the home of 109,650 individuals, whereas the Railway Settlement accounted for 20,441 heads and the census towns of Dulhipur and Satpokhari were the residences of 8,243 and 13,757 people respectively. Mughal Sarai was designated as the second largest *'transport town'* of India with a population of 91,505 in 1991 (Jain, 1994). Census of India, 1991 recorded that 38% of the total working population of the town was associated with transport and communication. After several reorganisations of Indian Railways, the railway station and railway settlement of Mughal Sarai is presently administrated by East Central Railway Zone of Indian Railways. In the year 2018, the municipality and the railway station of Mughal Sarai was renamed after PanditDeenDayalUpadhyaya. Currently on an average more than 134 passenger carrying trains and over 210 freight trains pass through the station / yard every day and Mughal Sarai yard, about 12.5 km. long, is the biggest railway yard in Asia and the second biggest in the world (East Central Railway, 2022) (Fig. 2).Hence, the physical and functional proliferation of the town largely depend on the rail transport infrastructure and services, and therefore, it serves for an ideal case to conceptualise the notion of complementarity with the help of rail-based commodity flow data.

5. Data and methods

The present research seeks to explicitly analyse and portray the level of spatial interaction of Pt. DDUN(Mughal Sarai)with its complementary areas. Rail-based inward flow of mineral resources is taken as the illustrative examples to establish specific complementarity of Pt.

DDUN(Mughal Sarai) with the places (districts) of interest. Data on rail based commodity flow has been obtained from the Office of Divisional Railway Manager, Pt. DDU(Mughal Sarai). Subsequently, commodities are grouped into five categories, such as clinker, limestone, coal, iron ore and gypsum. These account for the lion's share of mineral shipments in Pt. DDU(Mughal Sarai) by the railway medium. Since, the present research not only aims to identify the complementary areas of Pt. DDU(Mughal Sarai), but also wants to compare those areas with respect to their relative complementarity with the city, the notion of *Complementarity Index* (after Smith, 1964) has been referred in the research. The Complementarity Index is defined as the ratio between actual shipment of specific materials (either in terms of volume or monetary value) in the destination to the potential shipment which is a calibrated figure (either in terms of volume or monetary value) based on the friction of distance effects. The potential complementarity between interacting locations can be *'compared with the actual flow, as ratios, differences and so on, and the pattern of these values may be expected to identify an important pattern in the system'* (Hay, 1973, pp.121-122). It simply is grounded on the assumption that if two areas are maintaining same volume of trade with a city then the area having a longer distance will depict a greater complementarity, compared to its closer counterpart. Because, it is maintaining same volume of trade over a greater distance, overcoming the friction of distance effects with greater efficiency; hence, has a greater complementarity. In order to calibrate the potential flow, this study makes use of an *'Attraction Constrained Gravity Model'* from the *'Family of Spatial Interaction Models'* (see Haynes and Fotheringham, 1985; Fotheringham, 2001 for details) (Fig. 3). In the present study the model assumes that 'the level of interaction between two locations is a function of their attributes pondered by their level of separation' (Rodrigue, 2020, p.392). Supplemented by the contemporary literature, the model has been calibrated on the basis of monetary value of select commodities, instead of their actual volume of shipment. It is defined as:

$$\hat{T}_{ij} = v_i^{\lambda} B_j D_j d_{ij}^{\beta}$$

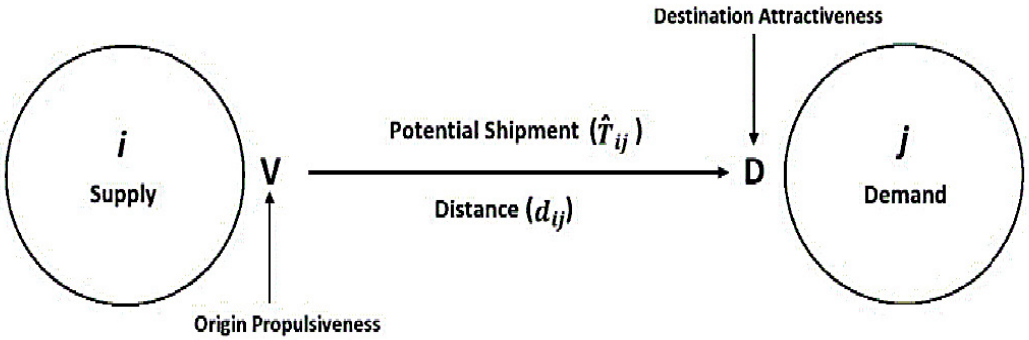

Fig. 3: Gravity model of spatial interaction

Source: Modified from Rodrigue, 2020, p. 392

In words, $\hat{T}_{ij}$ stands for the potential value of shipments between i origin (districts) and j destination (Mughal Sarai); v_i is the actual value of shipped minerals from respective origin i to destination j; D_j represents total value of shipments of minerals from all the origin districtsto destination j; d_{ij} depicts the measure of separation (shortest railway distance in the present study). Finally, λ (1 in this regard) and β (-1 in this regard) represents the weightages to the actual value of shipped minerals and measure of separation respectively. B_j is a balancing factor to ensure that the value of total potential shipments at Pt. DDU(Mughal Sarai) $\sum \hat{T}_{ij}$ equals the actual value of the total shipments).is defined by

$$B_j = \left[\sum_i v_i^{\lambda} d_{ij}^{\beta}\right]^{-1}$$

which ensures that

$$\sum_i \hat{T}_{ij} = \sum_i v_i = D_j$$

6. Results

The *Complementarity Index*, grounded on equation 1, shows that out of 12 districts, having some amount of spatial interaction with Pt. DDUN(Mughal Sarai), vary markedly in terms of their relative complementarity with the city (Table 1). The value of *Complementarity Index* ranges from 1.22 for Bhadrak to 0.51 for Bokaro. Bhadrak, a district in Orissa, recorded maximum complementarity with Mughal Sarai in terms of mineral supply, despite the fact that it holds sixth position in terms of the absolute value of shipment. This is principally attributed to a longer spatial distance of Bhadrak from Pt.

DDUN(Mughal Sarai). In other words the shipment of minerals from Bhadrak to Pt. DDUN(Mughal Sarai) is 22% higher than that might have been anticipated on the basis their mutual distance and total mineral inflow in Pt. DDUN(Mughal Sarai) (Fig. 4).

The district of Durg (Chhattisgarh) accounting for maximum mineral shipment to Pt. DDUN(Mughal Sarai), ranks second in terms of relative complementarity with a *Complementarity Index* of 1.18. Mayurbhanj, Bilaspur, Keonjhar and Sundargarh do also belong from the upper part of the complementary spectrum, in this regard. On the contrary, Bokaro records least complementarity with Pt. DDUN(Mughal Sarai), where rail shipments of minerals and clinker were nearly 49% lesser than that might have been expected. Bokaro is closely followed by Ramgarh, Katni and Satna respectively. Despite having lower absolute value of shipped commodities from West Singbhum and Bhind, these two districts perform well in terms of their relative complementarity with Pt. DDUN(Mughal Sarai). However, they also depict a lesser supply of the commodities of concern, compared to the value that might have been looked for.

Table 1: Shipment of mineral resources by railways (April, 2019 – March, 2020) and measure of complementarity of PanditDeenDayalUpadhyaya Nagar (Mughal Sarai)with interacting districts

Districts supplying mineral resources to Mughal Sarai	Actual shipment of mineral resources to Mughal Sarai (in terms of monetary value)	potential shipment (based on the gravity model equation)	Index of Complementarity (ratio of actual shipment to potential shipment)	Remarks (>1 = High; 0.75 - 1 = Moderate; <0.75 = Low)
Durg	265960052	225141798.70	1.18	High
West Singbhum	4258319	5117019.15	0.83	Moderate
Katni	26797758	47377936.89	0.57	Low
Bilaspur	19407504	18155012.78	1.07	High
Satna	4281123	7357719.31	0.58	Low
Bhind	2363867	2863829.57	0.83	Moderate
Ramgarh	21672185	38686222.40	0.56	Low
Bokaro	12189598	23706080.38	0.51	Low

Bhadrak	21182269	17297282.00	1.22	High
Keonjhar	90437891	85685984.19	1.06	High
Mayurbhanj	26300097	23559027.97	1.12	High
Sundargarh	6640494	6543243.63	1.01	High

Source: Calibrated by the researchers from the data collected from the Office of Divisional Railway Manager, Mughal Sarai (Pt. DeenDayalUpadhyaya) in January, 2022

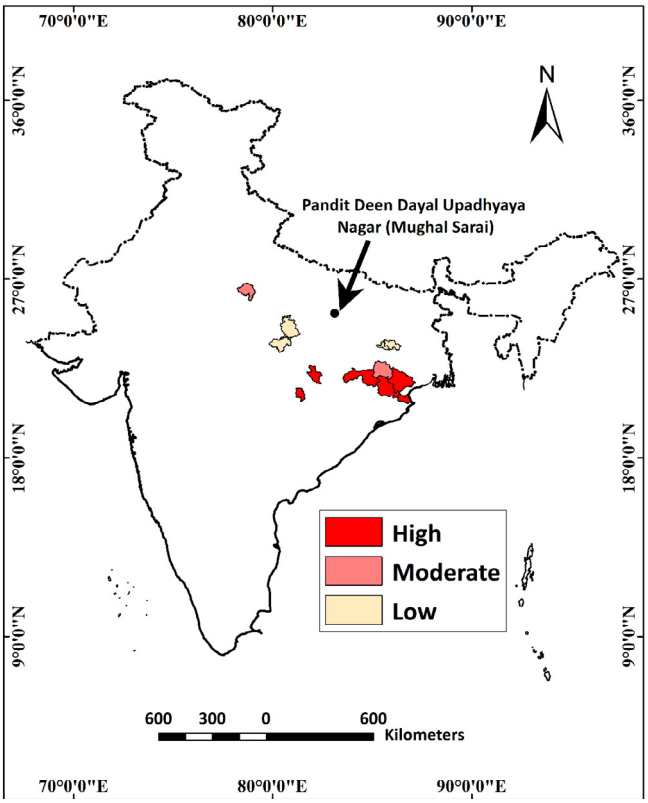

Fig. 4: Relative level of complementarity of PanditDeenDayalUpadhyaya Nagar (Mughal Sarai) with interacting districts

Source: Based on Table 1

Therefore, in order to acquire a more intensive understanding of spatial interaction, it is imperative to calibrate as explicitly as possible spatial interaction models, especially when raw data is either inefficient or sketchy. In such a context, the intension of a spatial interaction model will be to complement and/or even replace empirical data through reliable estimates of flows between interacting locations (Rodrigue, 2020, p.391).

7. Discussion: Spatial interaction, complementarity and urban development

Analysis of commodity flow data for understanding the trends in the transportation of goods, mapping spatial patterns of interaction, forecasting demands for the movement of commodities and determining the needs for associated infrastructure and equipment, is a common practice among a wide group of specialists ranging from geographers to spatial policy makers (Bevrani et al., 2020). It has been fairly evident from the above discussion that the functional proliferation of the city of Pt. DDUN(Mughal Sarai)largely depends upon rail-based commodity flows to the city, which in turn has evidently contributed to the status of Pt. DDUN(Mughal Sarai)as a regional trade and distribution centre. Hence, an intensive understanding of the nature of spatial interaction of the city with its complementary areas may come up with more wise apprehension on the system of urban activities as well as its potential for economic growth.Being largely dependent on the system of railways for economic proliferation, the realisation of the economic opportunities for the sustainable development of the city needs to refer the mechanism of spatial interaction between the city and its complementary areas. Because, the nature of spatial interaction drives the formation of urban activity system, which in turn markedly governs the possibilities for economic growth.Finally, any kind of urban development strategy for the city and its hinterland must acknowledge the physical and functional role of rail transport on the development of the city and the region, from past, present and futuristic perspectives (Banerjee, 2023b).

The results of the present study indicate a visible dependence of Pt. DDUN(Mughal Sarai)on east and central Indian districts for the supply of mineral resources. Urban and transport policy-makers can fully make use of this information in order to pursue a comprehensive urban planning and rail traffic management for the city. In other words, the results are helpful for understanding the regional pattern of interaction between Pt. DDUN(Mughal Sarai) and its complementary areas, and therefore, can effectively assist the planning endeavour for strengthening the process of regional integration. Moreover, the contemporary trends of modernisation of Indian Railways introduced

many newly developed infrastructural facilities that in turn contribute significantly to the prospect of Pt. DDUN(Mughal Sarai)to become a new-generation rail-freight terminal and a smart logistics hub. Additionally, the proximity of the city to Varanasi, a major religious and educational centre of India, as well as its close association with the National Highway (Grand Trunk Road), further strengthens its potentials to become a mega-freight collection and distribution centre of northern India.

While Pt. DDUN(Mughal Sarai)has long been regarded as a developmental straggler compared to its neighbouring cities like Varanasiand other urban places in the eastern Uttar Pradesh, it too has substantial potentials that is grounded on its strategic location and consequent probabilities of regional integration into national networks of production and distribution.What truly sets Pt. DDUN(Mughal Sarai) apart is the immense prospect of the city to become a thriving marketplace and logistics hub in the northern India. The city's historical importance as a railway town and itsshrewd location at the intersection of major rail routes make it a principalprospect for the formation of a vibrant trade centre. As India continues to entre in the trajectory of robust economic proliferation, the insistence for streamlined transportation and distribution system for goods continues to grow. Mughal Sarai, with its well-integrated railway connections, can capitalise on this demand, transforming itself into a bustling marketplace where businesses can thrive. Moreover, recent improvements in India's freight transport system have further enhanced Pt. DDUN(Mughal Sarai)'s potential to become an urban centre of commercial and industrial interest within the agricultural tracts of northern India. Investments in infrastructure and the modernisation of the rail network have made the movement of goods more seamless and cost-effective. This not only benefits the existing industries in the region but also paves the path for new ventures and commercial activities to flourish. With an efficient and interconnected railway system, Mughal Sarai is poised to play a pivotal role in India's economic landscape, becoming a beacon of opportunity and progress for individuals and businesses alike.

The city's progression into anurban marketplace and logistics hub has enough possibilities to drive financial growth, create employment

opportunities, and prosper the quality of life for its residents. As Pt. DDUN(Mughal Sarai)continues to utilise its strategic locational advantages and leverage the advancements in India's freight transport system, it stands on the verge of a visible transformation that could mould the future of freight transportation and associate trade scenario in contemporary India.

8. Conclusion

The notion of *Complementarity* is of great importance in the analysis of commodity movement, but practical difficulties tend to arise when the subject of *'greater'* or *'lesser'* complementarity stands up. Simple flow maps, constructed on the basis of crude movement of commodities are not capable enough to establish an understanding on relative degree of spatial interaction between and among places of human activities. Against this backdrop, the present research calls attention to the concept of *Complementarity Index*, in order to facilitate understanding of the degree of spatial interaction between interacting locations. Data on actual shipment of a specific type of commodities (minerals and clinker), friction of distance effects (shortest railway distance) and calibrated values of potential shipment seems to be sufficient enough to get an important insight into the level of relative complementarity between the places of interest. A modified form of Gravity Model serves for an ideal methodology to pursue the calibration. The resulted outcome in the form of *Complementarity Index* serves for an efficient assessment criterion to be cognizant of the relative significance of different places in the system of spatial interaction.

Pt. DDUN(Mughal Sarai)'s strategic position on the network of Indian Railways and its very existence as a railway town make it an ideal case for conceptualising the notion of complementarity, with the help of rail-based commodity flow data. Supplemented by the existing body of literature and the availability of data, this endeavour refers to the flow of a specific type of commodities i.e. minerals and clinker, assuming that Pt. DDUN(Mughal Sarai)being located at the heart of a fertile agricultural belt of India is more prone to import mineral and power resources than agricultural commodities. The resulted outcome in the form of *Complementarity Index*, portrays a different, if not entirely

contradictory picture from the crude values of mineral shipments to the city. This analysis thus well-indicates that merely supplying greater amount of commodities of any kind does not necessarily reflect greater complementarity and vice versa. Therefore, a more comprehensive analysis of commodity flows is imperative to have a deeper insight into the notion of spatial interaction.

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Iman Banerjee

Doctoral Research Fellow in the Department of Geography, Banaras Hindu University, Varanasi, India; Master in Geography from the Department of Geography, Banaras Hindu University, Varanasi, India.
Station Road, Alipurduar, West Bengal, India, PIN - 736121
Email: imanbanerjee64@gmail.com
Orcid: 0000-0003-1775-7766

Apala Saha

Assistant Professor in the Geography Section, MahilaMahaVidyalaya, Banaras Hindu University, Varanasi, India; PhD in Geography from the Centre for the Study of Regional Development, Jawaharlal Nehru University, New Delhi, India; Master in Geography from the Centre for the Study of Regional Development, Jawaharlal Nehru University, New Delhi, India.
Geography Section, MMV, BHU, PIN- 221005
Email: apala2010@gmail.com
Orcid: 0000-0003-1592-7848

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