QATAR UNIVERSITY

COLLEGE OF ENGINEERING

ASSESSMENT AND CLASSIFICATION OF TRANSIT STATIONS FOR TRANSIT

ORIENTED DEVELOPMENT (TOD) POTENTIAL USING NODE-PLACE MODEL:

THE CASE OF DOHA GOLD METRO LINE

BY

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ABSTRACT

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Title: Assessment and classification of transit stations for Transit Oriented Development (TOD) potential using node-place model: The case of Doha gold metro line

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The State of Qatar, though a developing country, has been witnessing a rapid process of urbanization and development due to its rich natural resources base. Development has resulted in the expansion of its settlements leading to urban sprawl, particularly in Doha capital city. A high level of dependency on vehicular transportation along with sprawl, has led to prevalent congestion and transportation problems. Qatar, faces an unprecedented challenge in meeting the growing travel demand constrained by limited land and mediocre infrastructure. Recently as a result of the award for hosting of the world cup to Qatar, the State is introducing a metro system to both service the world cup as well as address its transportation problems. This metro system is projected to deal with rapid motorization and urbanization issues within the country, by meeting commuter travel demands, recovering urban traffic condition through reduced traffic load and offering efficient public transport system encouraging user accessibility/mobility. The Doha metro system along with its component stations are expected to impact the quality, amount and pattern of development in the city. Gold metro line stations show lack of interconnectivity between transportation and land use development densities. Also, problems such as wide residential streets encouraging vehicular usage (lower grid pattern,

dead ends and cul-de-scas); poor pedestrian walkable environments; lack of community gathering areas; overestimated or underestimated interchange modes exist within the station areas. Thus, it is imperative to address the impact of this introduced metro network at localized area around these metro stations. Therefore, research attempts to analyse the stations to make sure that multi-modal transit supportive urban development is executed through better planning, design and operational activities. Research aims to assess, compare and classify the gold line metro stations, by identifying potential for TOD type development. Bertolini's node-place model (N-P model) is used to identify, assess, classify and compare the metro stations. Using this model, deliverables such as the N-P graph and interpretations of node index, place index, and N-P TOD index, assists in classifying the stations as unbalanced nodes. Thus, stations exhibit a high quality of transit supply when compared to urban development of the surrounding built environment. Summary of results highlight that increase/decrease of particular node indicators such as direction and frequency of bus operation, proximity to road access, and car park-ride facility, influences accessibility and parking criteria of the station. Also, increase of place indicators such as degree of functional mix, intersection density, and IPCA, facilitates favourable land use density, diversity and walkable environments in the metro stations. Research concludes with policies/actions to enhance TOD type development of metro station areas based on the obtained node-place indicators.

DEDICATION

I dedicate my work to

my dear husband and beloved parents who have supported me throughout my life. Their

affection, love, encouragement, and prayers enabled me to achieve such success.

Thank you my beloved family.

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Firstly, I would like to express my sincere gratitude to my advisor Dr. Shaibu Bala Garba, for his continuous support, patience, encouragement and motivation. His guidance, and fruitful critics helped me all through this thesis. Thank you.

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Chapter 1: Introduction

Towards the second half of the 20th Century, the State of Qatar, being a developing country has been rapidly urbanizing at a fast rate. This resulted in more than half of the country's population to reside in the urban areas, around the capital city of Doha. Additionally, the State exhibits a monocentric structural pattern, where the Doha city core serves as major travel destination; hub of economic, public, governmental and cultural activities. This unprecedented urbanization has resulted in urban problems related to use of limited land causing urban sprawl.

According to Wiedmann et.al (2012), extensive urban development expansions are being undertaken to serve the national flow of people, capital, media, education, and oil industries to mitigate the increased distance due to urban sprawl. These improvements through enhanced transportation networks, aim at transforming Qatar into a world class economy by 2030, creating new developments and sustaining its own development. Consequently, the above interventions are anticipated to mitigate the current strain on Qatar's connectivity infrastructure.

In contrast, as argued by scholars and urban economists, large transportation projects influence the quality and amount of future developments (Berke & Godschalk, 2006). Furthermore, researches suggest that this influence, depends on specific transportation improvement characteristics and its comparison to available travel options (Ryan, 1999). Accordingly, the transportation interventions in Qatar, resulted in a negative effective on the traffic movement, due to high dependency on vehicular use and lack of availability of public transportation infrastructure. Consequently, this limited use of land and inferior infrastructure create inability in meeting the increased commuter travel

demands. Therefore, the Doha metro network system was introduced (planned) to reduce the traffic load, recover urban traffic condition, offer efficient public transport system and encourage user accessibility/mobility.

1.1 Research Problem & Significance

Scholars such as Berke & Godschalk (2006), argue that urban density and transport are interconnected. Thus, any urban transportation intervention such as metro transit system also affects the urban density/development. Planned introduction of the Doha Metro network is expected to influence the quality and amount of urban development in the State of Qatar. This is anticipated in terms of the effect of metro station on the land use density, land use distribution patterns and diversity of economic activities.

First, introduction of the Doha metro systems has the capacity to impact the development of the city, mitigating sprawl and vehicular use in the process. The Doha metro system consists of Red, Green and Yellow lines, with both underground and elevated station areas. These transit stations located within any dense development area, relatively increases the ease of access for different groups of people. This increased efficiency, in reaching destinations with reduced time and non-dependence on motorized transport, widen the horizon of desirable destinations. This facilitates the increase in supply of land for urban development (Shaaban & Khalil, 2012). Consequently, the increase of these urban amenities, necessitates the requirement for urban related services such as water, sewage, housing etc. This develops community cohesive environments within and outside Doha, enhancing urbanity. With time, natural expansion of these infill developments result in new urban environments.

Second, the Doha metro origin-destination stations are planned within the existing regional, urban and sub urban centers of the State. The metro transit stations are anticipated to attract possible commuters with the option of using motorized transport, rather than individuals who will use the transit system, but will eventually not affect the congestion on the roads. Thus, the metro will be able to provide an alternate option to using private vehicles, encouraging faster, easier, cheaper, without delays, less demanding and more efficient means to travel to places of work or leisure.

Accordingly, the metro systems is anticipated to result in a pattern of development around these station areas, with integration of compact mixed land use activities in high density population areas, environment friendly, pedestrian oriented (walking, cycling) urban economic centers. Also, application of the metro station areas connecting national growth centers of Qatar, develop the transit centers as both travel origin-destination (node) and center of urban development activities (place). This is achieved by using the assimilated concepts of urban development to solve the indications of urban sprawl and motor dependency.
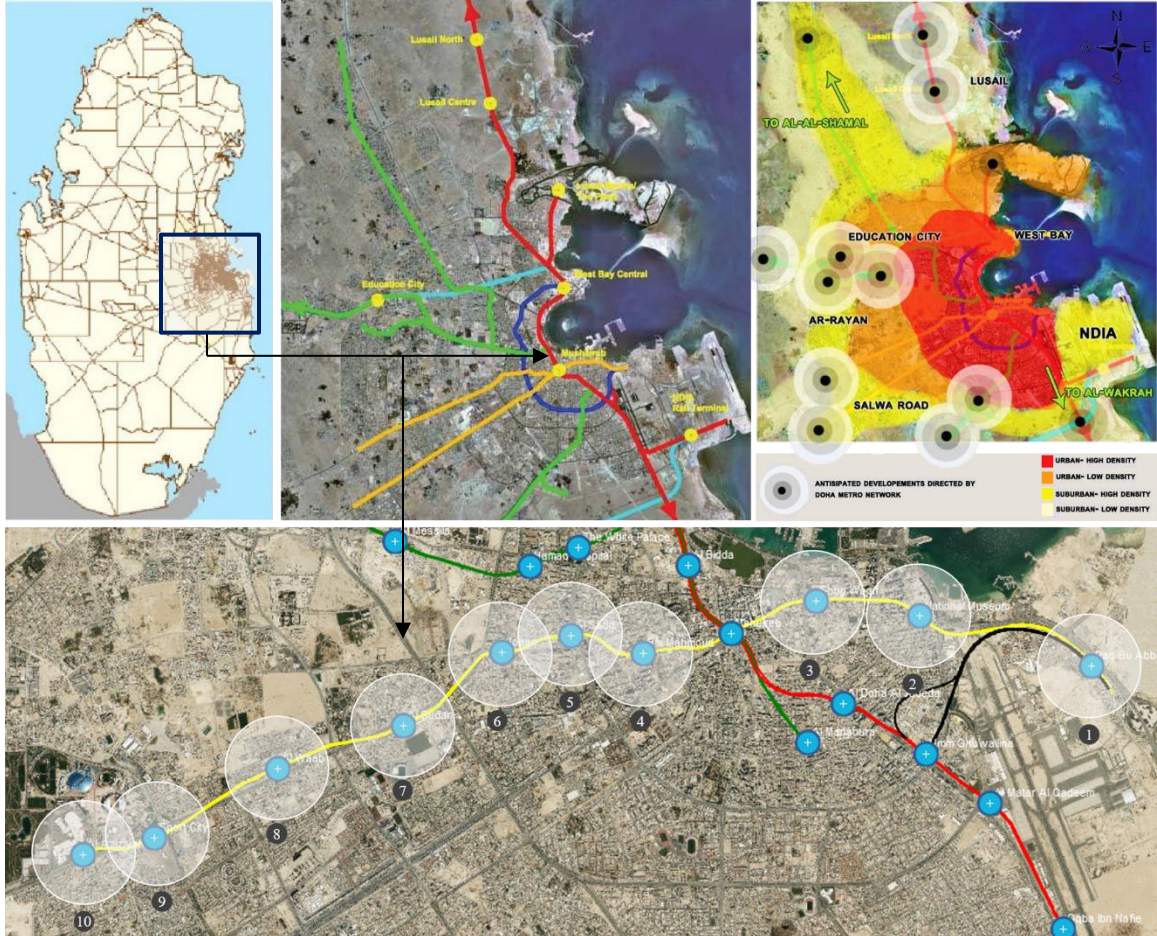
Figure 1. (a) Doha metro network within the context of the State of Qatar covering different density areas; (b) Doha Gold metro line station areas (Source: Shabaan & Kahlil, 2012; QRC, 2018; Author, 2018)

Placing the research in context (

Figure 1), Doha metro network is planned to connect north-south and east-west corridors of the State, with appropriate interchanges. In comparison to the Red and Green metro lines, the development density along the Gold metro line, serving the major populated municipalities of Doha and Al Rayyan (stations of Musheireb, Souq Waqif, Joaan, Al Sadd, Bin Mahmoud and Al Sudan), is much higher (Atlas, 2010). Thus, planned introduction of the Doha gold metro network is expected to influence the quality and

amount of land use development pattern and traffic congestion along the corresponding major road networks of the State-Al Waab street, Salwa road and Ras Bu Abboud expressways. These road networks serving dense areas of Musheireb, Souq Waqif, QNM, Al Sadd and Bin Mahmoud, show the highest travel time and highest congestion index (

Figure 2). Further, analysis of traffic indices by Qatar Mobility Innovations Center (QMIC), along these major roads reveal that the average extra hours spent due to congestion is 109 hours per commuter (QTR, 2016). Also, highest travel time index (increased travel time due to congestion) of 2.14 on working days and lowest travel time index of 1.97 on weekends results in an average Masarak congestion Index (reduced speed due to congestion) of 36% (QTR, 2016). Moreover, trip measurement validation research conducted by Hamra and Attallah (2012), using transportation modelling software, VISUM revealed that a high trip generation and demand is exhibited along the major transport roads of Al Waab street and Salwa road (Figure 3). Also, the study highlights the low value of trips met by company/school buses, taxi and public transport in these areas due to diverse activities. Although, the areas along the gold metro line display clustered O-D matrices, trip management is inadequate due to different activities in the station areas and higher dependency on private transport (

Figure 2). In addition to these traffic-land use issues, the station areas exhibit wide residential streets encouraging vehicular usage (lower grid pattern, dead ends and cul-de-scas), poor pedestrian walkable environments, lack of community gathering areas, lack of cycling amenities, overestimated or underestimated interchange modes, divergence within

the station area due wide traffic roads, and single non-diverse economic activities. Therefore, lack of connectivity exists between the transportation and development land use densities along these stations (Hamra & Attallah, 2012).
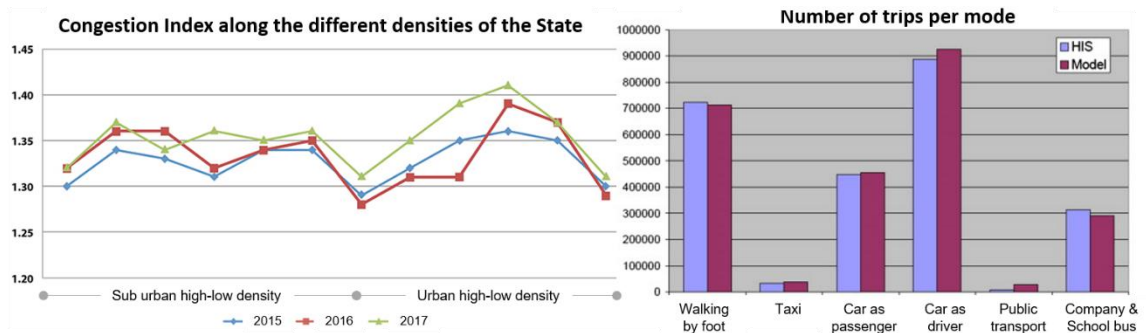
Figure 2. Congestion index along the major density areas of Qatar (Source: QRC, 2013); (b) Number of anticipated trips per mode (Source: Hamra & Attallah, 2012)

The effect of these anticipated developments, on the regional, urban and sub-urban transit stations along the Doha gold line will be effective only through transit supportive urban planning. One such planning concept is TOD, which is a planning redevelopment tool, focused on objectives such as use of public transit, growth of mixed density uses (residential, commercial or office) close to or around a transit stop, provision of multi-modal transportation opportunities without disrupting economic pattern of the area (Cervero, 1998). Furthermore, authors Ewing and Cervero (2010), support the view of introducing TOD type characteristics to an existing metro station to enhance accessibility and urban distribution compatible with the existing land uses.

Figure 3. Clustered O-D matrix obtained using HIS and VISUM model (Source: Hamra & Attallah, 2012)

The implementation of TOD type development around a metro station is a challenge. Researches show that the extensive principles of TOD emphasizing on the 5Ds (density, diversity, design, destination, and distance) are not sufficient in creating vibrant, rich and liveable urban spaces within metro station areas (Dittmar & Poticha, 2004; Ewing and Cervero, 2010; Vale, 2014). Additionally, comparison between existing metro stations through identification of potential TOD type development, successful bench marks and future adaptations allows for better planning, design and operational activities (Kamruzzaman, Baker, Washington, Turrell; 2014). Thus, important issues related to transportation (node) and land use (place) interaction, along the metro line stations should be studied and addressed carefully. As a result, the research attempts to assess and classify the stations, using model indicators to arrive at recommendations for supportive land use (density, diversity, walkable environments) and transport (accessibility, parking) strategies to encourage TOD type compact development around metro transit stations.

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1.2 Research Questions

The research aims to assess the potential for TOD type development in the vicinity of stations located on Doha gold metro line. The specific questions addressed by the research are:

1. What are the planning factors which determine/control the TOD potential of metro transit station areas?

2. Why is node-place theory more effective in evaluating TOD potential of metro station areas when compared to other methods?

3. How can node-place theory facilitate in identifying and implementing the TOD potential of metro transit stations?

4. What additional planning factors need to be addressed to implement TOD type development along the historic line metro stations?

1.3 Research Hypothesis

The research questions are further broken down to hypotheses attempting to solve the research problem. The following hypotheses set up will be assessed during the analysis of the metro transit stations:

1. There is a high potential for accessibility and TOD development around station areas on the gold line.

2. Gold metro stations with transit supportive density ranging between medium and high facilities TOD type development.

3. Metro stations along the gold line exhibit higher density and diversity of land uses and economic activities facilitating TOD type development.

4. There is potential for encouraging pedestrian friendly walkable environments along the gold line stations resulting in increased transit ridership.

1.4 Research Aim and Objectives

The research aims to determine the potential of TOD type development of the planned transit station areas of the Doha gold metro line. The research attempts to assess, classify and arrive at recommendations to enhance the TOD potential of metro transit stations along the historic line (gold line), using node and place indicators, based on Bertolini's N-P model. The objectives of the research are:

1. To examine the concept of Transit Oriented Development (TOD).

2. To identify different planning principles and factors which give rise to TOD type development in metro station areas.

3. To explore the different typologies and methods for assessing and implementing TOD type development in metro transit station areas.

4. To apply the enhanced selected method (Node-Place model) in assessing the potential of Doha gold line metro stations.

5. To identify and arrive at additional actions which facilitate the TOD type development of Gold line metro corridor based on the model.

1.5 Research Outline

The research was broken down into 6 chapters. Chapter 1 and 2 discusses and explores the concepts of TOD, planning factors and node-place model to evaluate TODs. The chapters define the TOD concepts, planning principles, implementation typologies, existing assessment methods and relevance of node-place model in identifying potential for TOD type development. Chapter 3 identifies and clarifies the research methodology

adopted to execute the research. This includes identifying the criteria and indicators of study, standardization, scoring methods and weighing of indicators. Chapter 4, then places the research in context, examining the gold metro line stations in terms of their transit functions within the regional, urban, sub-urban, and transit town centers, assessing node and place criteria. This facilitated the collection of node and place parameters for N-P model analysis. The research concludes with chapter 5 and 6, which discusses, the assessment and classification of station areas by implementing the N-P model (based on node index, place index and N-P TOD index of each station along the Gold line). Furthermore, findings of the node and place index, N-P graph and recommendations for developing potential TODs are included. The assessment comprised of applying the calculated results to determine: relation between the spatial and non-spatial indicators, strength of the relations and correlations between the criteria/indicators, the node and place index of individual stations, N-P graph and N-P TOD index. Classification included interpretations of stations along the N-P graph. Finally, interpretation of the node and place functions for each station areas were carried out to arrive at recommendations to facilitate TOD type development along the gold metro line based on N-P indicators.
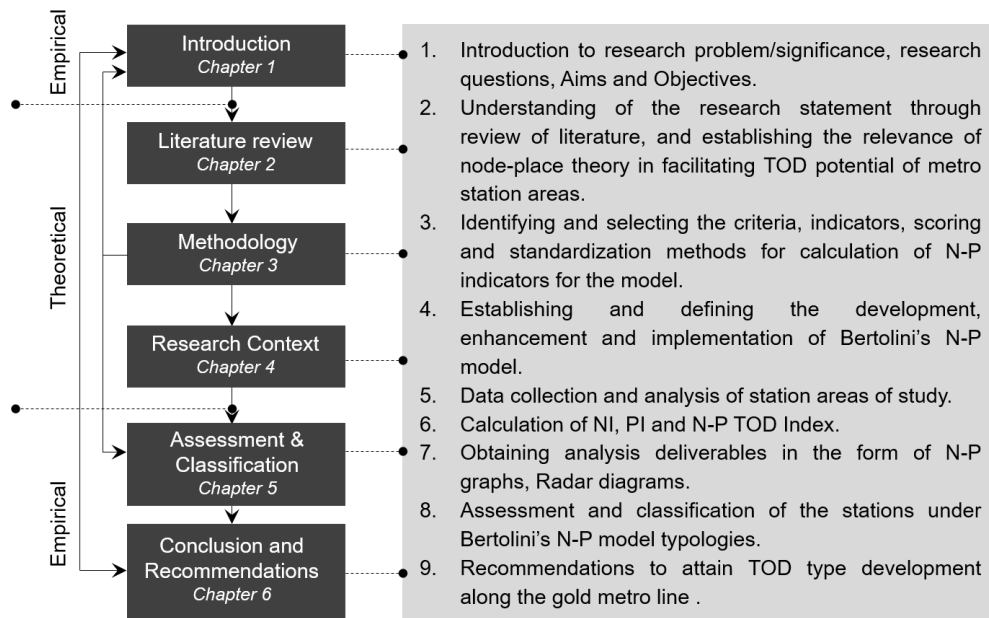
Figure 4. Diagram representing the research outline (Source: Author, 2018)

Chapter 2: Literature Review

Chapter 2 is divided into five sub-sections, which explores the concept of Transit oriented development, different factors/planning principles for TOD type development in metro station areas and methods to assess and evaluate TOD type development. Initially, the chapter identifies Transit Oriented Development as an urban redevelopment planning solution to tackle problems developed as a result of disconnect between transport planning and urban development. In this regard, critical review of literature is carried out to define the concept of TOD, its various interpretations and historic origins. Detailed emphasis is directed towards understanding the planning factors/principles governing TOD in metro station areas, different typologies to assess and evaluate TODs, and selection of the best suitable method for TOD assessment in Doha gold metro line. Furthermore, selected node-place theory (Bertolini's N-P model) facilitating the TOD assessment is elaborated and explained. This is discussed in terms of background theories of node-place interaction, analytical framework, model indicators and ideal transit situations generated. Towards the end, the chapter provides a strong base in using the node-place model for assessing the Gold line stations for TOD type development.

2.1 Introduction

Redeveloping city areas through urban development/re-development theories cover disciplines of new urbanism, smart growth, urban renewal, urban regeneration and land use distribution (Knowles, 2012). In general, certain planning tools or practices such as land use zoning-developing a master plan, urban form/growth management policies, community development corporations promoting community organizations, community–controlled planning, and high-capacity or multi-local CDCs, attempt to achieve redevelopment of an

existing city. Additionally, strategies such are large scale urban water front revitalization projects enhance the competitiveness of the city within the global market. Further, renovations involving public works such as construction of housing projects, transportation infrastructures, road networks, public parks and basic human services serve as urban redevelopment planning tools. However, new urbanism and smart growth policies address the issues related to interdependence of urban transportation/mobility and the surrounding built environment.

2.1.1 New Urbanism and Smart Growth. New Urbanism is an urban design movement started in the early 1980s in the US, which aims to promote environment friendly designs enhancing the quality of life for the urban users (Caramona, 2010). This concept served as a response to the urban sprawl or conventional suburban development, where people depended directly on the use of private cars and neglected public transport. New Urbanism as its fundamental goal encourages communities to perform a wide range of activities within walkable distances by implementing urban frameworks (Furlan, Eissa, Awwad, & Awwaad, 2015). Thus, new urbanism as a concept united urban planners, architects, sociologists and other specialists who argued that urban growth has an impact on accessibility and that enhanced quality of life is promoted by activity oriented nodes and neighborhood places encouraging vital aspects such as connectivity, walkability, smart transportation, mixed use and sustainability (Furlan, Eissa, Awwad, & Awwaad, 2015; Furlan, Nafi, & Alattar, 2015).

However, the concept is implemented through following themes such as walkability, connectivity, mixed use & diversity of land uses, urban design quality, traditional neighborhood structure, smart transportation, livability and sustainability (Nafi,

Alattar & Furlan, 2016). Thus, this movement supports the design and planning of compact mixed use urban fabric, encouraging walkability and maintaining a balance between land use and transportation supply. These implemented principles focus on sustainability, multi-modal smart transportation systems and compacted mixed use areas along the transit stations.

Smart growth is an initiative similar to new urbanism which aims at identifying and implementing policies to enhance/improve the relationship between development patterns and quality of life. This concept focuses on improved housing, transportation, economic development and sustainability through a shift in conventional development patterns. These growth policies and principles promote neighbourhood revitalization, affordable housing and create liveable communities.

The effective implementation of guidelines and policies of smart growth enhances mixed land uses with compact building design, preserves open spaces fostering distinctive attractive communities, encourages walkable neighbourhoods and provides multi-modal transportation choices (Tirado, 2016). Also, the rising housing prices leading to limited housing choices and home ownerships is a concern of smart growth. Transit Oriented Development is advocated as a smart growth response to congestion and sprawl (Zaina, & Furlan, 2017). Therefore, smart growth provides communities, which are productive and environmentally responsible (Li & Lai, 2014).

As agreed by architects, urban planners, sociologists, transportation planners and environmentalists, the Environment Protection Agency (EPA) advocates that enhancing transportation alternatives through walking, cycling and transit definitely influences the activities of the surrounding the area. Smart Growth principles implemented through the

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establishment of TOD type development around existing transit stations serves as a viable urban development solution to moderate the transport-land use balance (Bertolini, 1996, 1999; Dittmar & Poticha, 2004; Peek, Bertolini & Jonge, 2006; Vale, 2015).

2.2 Transit Oriented Development

2.2.1 TOD introduction

Due to rapid urbanization, sprawling urban settlements resulted in increased traffic congestion supplemented with environmental degradation. In order to maintain social and spatial integration of the urban areas, reverting back to the use of traditional land use patterns were adopted as a solution to this urban problem. These included high density, walkable environments with diversity of economic uses, located near transit centers such as metro stations. Thus, integrating the spatial development with multi-modal transit modes, served as a planning solution to sprawl.

TOD based urban planning practises are commonly identified in the US and European countries. TOD concepts have been incorporated by cities such as San Francisco and Atlanta, around existing transit stations such as rail projects. Newly, TOD planning policies has been envisaged by Asian countries such as China, India, Taiwan etc. as redevelopment solutions to urban problems such as traffic congestion due to impedance between the urban development and transportation (Sung & Oh, 2011). Similarly, the concept of TOD has been recognized as a planning method in the middle-east countries such as the state of Qatar, to resolve the issue of traffic congestion though high density developments. However, the concept is not completely operationalized due to the lack of convincing analysis methods for planning at suburban or urban scales. As a result, the

research attempts to assess and classify the Doha gold line metro stations for development potential of TODs, based on the theory of node-place.

In recent years, the concept of Transit Oriented Development (TOD) has gained importance as a smart growth approach to redevelopment within the disciplines of New Urbanism, Urban Fill, Urban Growth, Urban Regeneration and Land use distribution (Knowles, 2012). TOD typically consists of a mixed use development around a transit station. Scholars reveal that transit development encapsulates objectives such as use of public transit, growth of mixed density uses (residential, commercial or office) close to or around a transit stop, provision of multi-modal transportation opportunities ensuring liveability; without disrupting the economic pattern of the area (Cervero, 1998; Bailey, Grossardt & Wells, 2007; Curtis et al., 2009; Loo et al., 2010). Thus, design oriented towards non-motorized travel reduces private vehicles and stimulates active multi-modal/public travel. Overall, TOD at an urban scale represents a kinetic environment where travellers are encouraged to opt respectable public transport over private travel (Cervero, 1998).

2.2.2 Conceptual definitions. In the Western countries, Transit oriented development has gained importance as an approach of readdressing issues related to traffic congestion, housing shortages, air pollution, multi-modal public transportation and urban sprawl (Cervero, Ferrell, & Murphy, 2010). TOD concept was first proposed by the American architect Calthrope (1993), as a tool to reduce the use of private cars and develop compact, mixed use places around existing or new transit stations with the provision of providing alternate modes of public transport (Cervero, 1998, 2004; Curtis et al., 2009; Dittmar et al., 2004; Loo et al., 2010; and Mu & de Jong, 2012). They are envisioned as a

mix of residential, commercial, retail, office, open parks and public civic spaces within a walkable environment, encouraging residents and employees to travel by rail transit, bicycle, foot or private cars (Calthorpe, 1993).

Proponents of TOD provide different conceptual definitions and terminology such as 'Transit Villages', 'Transit Supportive Development', or 'Transit Friendly Design', however distinguishes itself due to differences in density, single use and car friendly development patterns (Calthorpe 1993; Cervero 1998; Cervero, Ferrell and Murphy 2002; Parker and Meyer 2000; Tumlin et al. 2003; Dittmar et al., 2004; Renne, 2009; Vos et al, 2014). TODs affect travel time, reduce car use, develop compactness and encourage mixed use neighbourhoods checking urban sprawls (Vos, Acker, & Witlox, 2014). Transit oriented development refers to any form of development oriented towards transit such as bus and rail. However, the thesis research narrows down the definition referring to development oriented towards metro transit. Although, there are various definitions for TOD, nonetheless they share common traits (Cervero et al., 2010).

Scholars such as Boarnet and Crane (1998), define TODs as practices initiated to intensify residential land uses around transit stations. Salvensen (1998) elaborates on the above by defining it as a geographically marked area around a transit with multiplicity of landowners, functions and uses. Also, Still (2002) views it from a community perspective, defining TOD a s mixed use sustainable community discouraging dependence on driving and encouraging living in areas near transit stops. The concept of bordering a geographic extend of a quarter mile from transit station, approximating to 5 minutes walking distance by foot, was conjured by Bernick and Cervero (1997). They also advocates the transit station as a medium connecting the residents of development to the rest of the region.

Furthermore, the transit catchment area are viewed as modern day Greek agoras performing as a community gathering/celebration spaces. Moreover, at a micro-scale, the concept extends to new construction or redevelopment of buildings within transit stop designed and oriented to facilitate better transit use (California Department of Transportation, 2001). Although definitions vary in scope and specificity, some common elements of focus are: (1) Mixed uses; (2) Closeness to transit; (3) Favorable transit ridership; (4) Compactness; (5) Pedestrian and Cycling friendly atmosphere; (6) Public civic center; and (7) Community/Activity hubs.

2.2.2.1 Similar concepts. Similar and closely related concepts to TOD include TJD (Transit Joint Development) and TAD (Transit Adjacent Development). Firstly, the general difference between TOD and TJD lies in scale. TOD focuses on neighbourhood around a transit station, whereas TJD extends its influence over a city. Also, TOD is project specific implemented by a public agency and TJD is achieved through a public-private partnership with an attempt to gain outcomes in the form of station connection fees and join share in capital construction cost.

Secondly, TAD (Transit Adjacent Development) as the name suggests is a land use planning strategy which does not fully integrate transit and land uses (Tumlin et al., 2003). The development is physically near a transit, however, fails to promote transit proximity and riding (Cervero et al., 2010). Also, they lack consumer services, walkways / cycle tracks and have distinctive physical barriers. Thus, TOD's have an impact on both the ridership and density-diversity of the urban development around the transit stops (Vos, Acker, & Witlox, 2014).

2.2.2.2 Interpretations. Scholars and researchers have interpreted TODs as: (1) Node (Transit) - Place (Neighbourhood) combination (Bertolini, 1999; Renne, 2009); and (2) Economic transformer (based on Market values) (Peek et al., 2007).

Bertolini (1999), interprets Transit Oriented Development (TOD) as a neighbourhood development model conceptualized as a combination of nodes (transit station) and places (neighbourhood). The place is characterised by moderate to high density development constituting a mix of land uses such as residential, commercial, recreational, open parks, institutional and civic spaces. The node represents the public transport services offered by an existing or new transit station inscribed within the mixed use neighbourhood. The planned neighbourhood model facilitates and attracts activity participation within the places interconnected by streets, facilitating integration of activities and active transport (Cervero and Kockelman, 1997; Lin and Gau, 2006). These activity oriented land uses fall within the catchment area of transit station, thereby reducing the need for motorized travel within the TOD area. Also, the well-connected public transport nodes can be used for people travelling to other parts of the city or other TODs to access goods and services. Therefore, Node-Place combination visualises TOD as not only an efficient public transit station, but as a place to live, work, socialize, shop and relax. As a result, Node-Place synergy theory enables the use of TOD type planning to be executed in metro station areas as an urban development planning strategy.

TOD can also be interpreted in terms of market values as an urban economic transformer due to increased privatization processes or market orientation of transport facilitators (Peek et al., 2007). The transit development is visualized as a means to recapture the provision of accessibility provided by transport companies in the form of transport

infrastructure and travel service. This implies the development of commercial activities within transit station along with redevelopment of surrounding land. In this case, the public–private partnership developers own both the railway transit station and surrounding land. Thus, the development of residences, offices, department stores and other recreational facilities together with the railway network took place in accordance to their policies. Therefore, transport operators working as 'lifestyle supporters' exploited synergies between transport, real estate and retail services. Thus, the services offered shaped and acted as natural choices made by the commuters pursuing their needs. Also, implementation of tools such as F.A.R (Floor area ratio) by government on private investors further enhanced the TODs due to higher F.A.R values of the centers when compared to surrounding land. As a result, these TODs emerged as central business or urban economic centers (Sorensen, 2001; Chorus & Bertolini, 2011).

Scholars argue that physical design principles for the above mentioned interpretations, involve a combination of commercial development around transit station, intensified mixed use development, layered public amenities (civic spaces, markets etc.) and healthier means of transport such as walking and cycling (Cervero et al., 2010). However, successful TOD depends on the close examination of these physical design principles along with community development, heritage preservation, Node-Place strength and attaining a liveable, sustainable community. Therefore, an attentive analysis of the present day built environment eases the facilitation of future TOD (Palombo & Kuby, 2011). As a result, the research assess and classifies the 10 existing metro stations along the Doha gold metro line using node-place theory to identify TOD potential (referred to as advanced TOD planning approach).

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2.2.3 Historic origins. Towards mid-20th century, urban sprawl resulted in increased social difficulties such as traffic congestion, environmental pollution and impedance of socio-spatial integration (Sung & Oh, 2010). These urban problems propagated movements with an intension to accept traditional land use patterns. Moreover, transportation scholars and architects such as Cervero and Calthorpe, admit that introduction of TOD dates back to the nineteenth century. Also, researches conducted by Adams (1970), Kellett (1969), Ward (1964) and Warner (1962), reveal that expanding railway routes, development of streetcar (electric tram) oriented development pattern and star shaped urban forms existed in the late 19th and 20th centuries. Although, form of these cities seem to be dependent on mass transportation, private car ownership was not prevalent at that time. Furthermore, "Garden City" concept by Ebenezer Howard, also centers the low sustainable suburbs along commuter rail stations. Therefore, the strong similarities in concepts between contemporary TOD and traditional urban patterns reveal that Transit oriented development is nothing but tracing back to the traditional urban patterns of suburban and city centers (Knowles, 2006).

Transit Oriented Development served as a revival tool to reflect on interrelated land use problems such as: (1) Lack of housing alternatives; (2) Reduced services and activity areas such as recreation centers, civic centers, retails within walkable distance of residential areas; and (3) Economic decline (Duany et al. 2000). As a result, in the present day context, TOD is promoted as an efficient/effective land use strategy and transportation planning tool. Therefore, TOD provides solutions to address land use and transportation services simultaneously (Dittmar et al., 2004).

2.3 TOD-Urban redevelopment planning tool

Researches suggest that TOD exercises as an urban planning tool, which requires long term planning at both the regional and local levels. Designation of land use and distribution of transport services demarcating the spatial structure are detailed out at regional level, whereas construction plan details, land use types, urban design characteristics and facilities are detailed out at local level (Bossard, 2002). Also, these city planning alterations necessarily begin with existing land uses and feeder transportation networks. Thus, TOD modifies existing land uses and transportation networks so as to enhance human interaction points, quality of life and health through reduced car travel and traffic congestion. Bertolini (1999), supports the above notion where TOD is conceptualized as a centralized decentralization of urban development process. Hence, scholars suggest that transit oriented development serve as a potential urban redevelopment tool, in addition to its role as an arena for development (Atkinson-Palombo and Kuby, 2011).

As previously discussed, TOD was initiated as a response to solve problems related to suburbanization during post war period. This theme developed a new vision based on pre-motor forms, were planned development was centered around transit (Calthorpe, 1993; Cervero, 1997). Also, this planning strategy introduced mixed use clusters with relative high densities oriented towards rail transit. In contrast, the present context of TOD is centered on institutional contexts, policies, practises and development models (Belzer & Autler, 2002). Also, the planning is exercised at different regional and local scales with involvement of investors and business financers (Dittmar & Ohland, 2004). However, interplay of institutional contexts, policies, models and execution through planning at different scales has made TOD a dominant and ideal planning practise in developed /

developing cities with transit. Thus, TOD has transformed from a pre-motor development planning tool into a centralized decentralization urban redevelopment tool.

As discussed above, TOD is a complete package covering the aspects of urban development at different scales. In this regard, the package includes construction plans, project finances, land use plans, zoning regulations as well as policies such as parking regulations and design guidelines (Cervero, Ferrell, & Murphy, 2002; Dittmar & Ohland, 2004). In comparison to other modes of transport, metro transit proves to be an effective urban revitalization tool due to its characteristics such as:

(1) Physically immovable and fixed infrastructure;

(2) Convenient accessibility due to spatially designated catchment area;

(3) Development of activity oriented land uses and

(4) Concentration of land values around transit stations.

Firstly, fixed route transit offers a sense of certainty, reliability and flexibility in terms of providing accessibility to its riders. Due to the fixed rail infrastructure, rail system minimizes uncertainty for travellers and risks for real estate developers, encouraging transit centered development. Secondly, rail transit has a specifically designated catchment area serves by limited number of stations. This concentrated catchment area ensures reliability in terms of accessibility to the users and concentrated land values (Rayle, 2015). Thirdly, from a political and economic point of view, economist Rayle (2015), highlights that transit centered areas directly favour funding from diverse investors and institutions. This designates specific activity oriented land use areas for investors and formulates policies and guidelines for compact development. Finally, businesses and entrepreneurs assign greater values towards existing transit station areas with concentrated activity and

accessibility. Thus, development of a metro transit area as centrepiece serves as an urban redevelopment tool (Rayle, 2015).

The Doha metro is a multi-modal project proposed as part of extensive urban redevelopment expansions of the capital city of Doha (Wiedmann et al., 2012). This high speed passenger rail and freight service attempt to meet the increased travel demand, in addition to linking industrial and residential hubs. Thus, the fixed Doha metro rail infrastructure would offer convenient accessibility and concentration of activity oriented land uses around the metro stations. However, previous discussions suggest that, integration of TOD, as a planning tool to these metro stations along the Gold line would enhance the node-place interaction facilitating, accessibility as well as urban land use distribution. As a result, implementing TOD strategies along existing Doha gold metro stations serves as a suitable urban development tool for better planning, design and operational activities.

2.4 TOD planning concepts and principles

Transit Oriented Development as an urban redevelopment planning tool is initiated by understanding the factors facilitating transit oriented development, concepts of node-place theory (co-development) and synergy, in facilitating TOD type development within a metro station, and rail transit related planning principles.

2.4.1 Node-place theory (co-development). TOD is conceptualized as a development model inclusive of nodes (Transit station) and places (urban development areas). The idea of place represents high density development constituting a mix of land supporting transit, whereas node represents the public transport services offered by an existing or new transit station within the mixed use development. This node-place model

facilitates activity participation within the place by integrating activities and active transport (Cervero and Kockelman, 1997; Lin and Gau, 2006). These places fall within the metro catchment areas, providing alternate means to motorized travel. Research conducted by Levinson (2008), elaborates on the relationship between: the place (urban development) which circumscribes the metro station, and the transit service offered by the inscribed node (metro). This relation between the infrastructure (node) and development (place) is referred to as co-development. Alternatively, the process encompasses both the notions of co-deployment and co-evolution. Deployment refers to the spatial extend within the influence of any technology, and evolution explains the change of a specific aspect through generations or time. Relating it to the context of urban planning, the idea is such that transport drives activity oriented land use and land use necessarily drives transport networks. This clearly does not imply that dense land use patterns generate metro investments or that connections established by metro infrastructure encourages high favourable land use density developments, but exhibits co-development process (Sanders, 2015). This is a salient concept to be adopted in formulating planning tools for city development (Levinson, 2005; Sanders, 2015).

Transportation studies conducted by King (2011), explains that any transport network is executed to serve economic and social needs. The reverse also holds true where, development of a place, achieved through economic and social opportunities offers better access to transportation by providing more riders. This interaction between land use and transport forms a feedback cycle where, each one supplements the other. Therefore, accessibility stimulates development on one hand and mixed land use activities generate more trips feeding the networks. As a result, any change in factors affecting transport or

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land use patterns necessarily generates a delayed change in the other (Wegener & Fürst, 2004) (Figure 5).
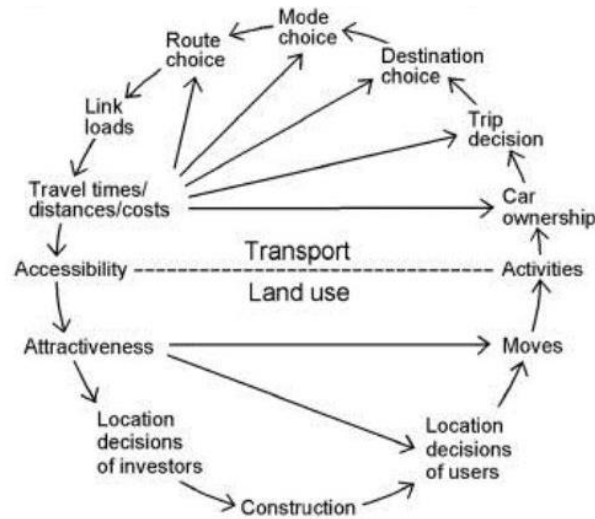
Figure 5. Transport-Land use feedback cycle (Source: Sanders, 2015)

Scholars argue that, an existing neighbourhood or place is always related to an existing transport network. However, an existing transport network may not necessarily relate to a developed place. As interpreted by scholars, here, the existing transport network connects different places (developed areas serving as destinations) by traversing through undeveloped land. As a result, the transport network serves 'placeless' (Levinson, 2008) areas where, these intermediate undeveloped lands may serve as future destinations (Levinson, 2008). Studies by Xie and Levinson (2007), suggest that transport may not necessarily generate or follow land use development, however, land uses develop necessarily following particular transportation networks. Therefore, a cyclic relationship exists between transport and land use development, which can be interpreted as: (1) The

increase in number of networks result in higher development density; or (2) Greater development of land use density patterns, enhance transportation networks through increased transit ridership.

As examined by researchers, increased development activities is an important factor for functioning of metro systems, due to availability of ridership within walking distance of the station (Cervero and Kockelman, 1997; Levinson, 2007; Sanders, 2015). However, dependence on land use development patterns inherently does not mean that: (1) land use pattern developments facilitate increased functioning of metro systems, or (2) metro systems build density land use activity areas around stations. The research, thus examines the metro station area in relation to node-place theory exhibiting co-development between the node (transport) and place (land use) in identifying the development potential of Transit Oriented Development (TOD) along the Doha gold metro line corridor.

2.4.2 TOD Planning principles. Scholars suggest that TOD planning factors play an important role in inducing a potential transit centered station area in redevelopment or new city development plans (Sung & Oh, 2011). The planning factors in the built environment influencing travel behaviour are categorized into 5D's as (1) Density; (2) Diversity; (3) Design oriented for pedestrians; (4) Destination accessibility; and (5) Distance to transit. However, combination of the above factors forming planning strategies, which influence the travel and land use pattern distribution are: (1) Enhancing accessibility and parking provisions; (2) Densifying and diversifying land uses and associated activities; and (3) Developing walkable environments through urban design characteristics (Figure 6). Accessibility to destination and transit distance were added to these factors by empirical studies conducted by Ewing and Cervero (2001).These TOD planning objectives ensure

that the development generates sufficient riders supporting transit service which intern improves the community development, thereby relieving traffic congestion and higher land consumption.
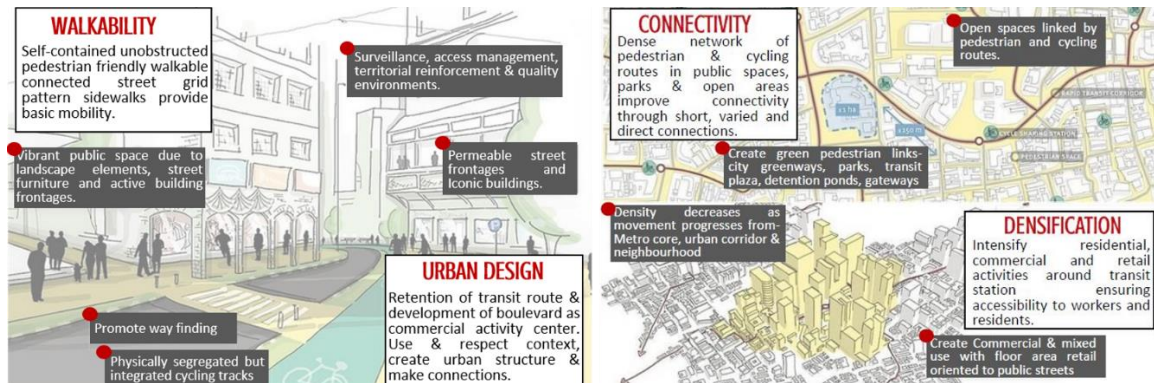
Figure 6. Planning strategies influencing travel - land use pattern (Source: Author, 2016)

2.4.2.1 Transit supply. Higher frequency of transit operations and services improve transit ridership (Sung & Oh, 2011). Provisions such as increase in number of bus stops and number of stations efficiently attract transit ridership. Also, maintaining longer distance between adjacent stations within a corridor invites more transit riders, effective in developing an active TOD. Furthermore, the number and location of bus stops are critical planning factors for devising intermodal transit systems such as buses or subways. Thus, establishing better connectivity between different modes such as buses and rail network attract more riders. Therefore, TOD is successfully promoted where synergy transfer exists between bus and rail services around an existing rail station.

2.4.2.2 Land use. The Land use characteristics of transit stations are planned in terms of density, diversity and accessibility to regional networks. Studies conducted by researchers suggest that increased variations in density and diversity of land uses promote increased transit ridership in an existing station area. A high density development strategy is significant in areas of low to medium density in promoting transit ridership. However, diversity in land use patterns with increased residential or business facilities ripple up the ridership demand. Also, pattern of land uses in terms of land use mix index also plays an important role in promoting transit ridership (weekday and weekend). Thus, emphasis on diversity of land use patterns is more efficient when compared to high density transit development in achieving transit ridership. The mixed land use pattern of residential and non-residential uses, trap more riders when compared to land use mix of only non-residential uses. Furthermore, studies suggest that the provision of economic incentives such as density bonuses to less developed areas around transit stations attracts more transit users. Therefore, mixed land-use strategy near a transit center attracting more ridership acts as a positive TOD planning tool (Sung & Oh, 2011).

2.4.2.3 Urban design characteristics. The urban design TOD planning factors include street network patterns and building design parameters which play an important role in promoting transit ridership (Sung & Oh, 2011). The two main factors influencing transit ridership positively include, high four way intersection densities and average area of individual building. The grouping of buildings like apartments or schools, creating single usage sites, potentially increases the chances of developing it as a node. Also, studies reveal that excessive usage of grid pattern with narrow streets reduces motor use due minimized traffic speeds and pedestrian friendly transit accessibility. Furthermore, a clear

distinction in the layout of pedestrian travel paths and building complex design is an essential factor leading to a TOD. As a result, a decrease in total road length, average road width, driveway percentage and building group area encourages transit ridership. However, the application of these urban design characteristics depends to a great extent on the existing urban growth pattern resulting in different relationship with the factors.

Previous discussions reveal that development of a transit oriented station depends not only on the density of the surrounding area, but also on the other TOD factors such as, quantity and quality of intermodality between the bus and rail transit, diversity of land uses, regional accessibility, street network patterns and building design parameters. These factors play an important role in devising planning principles for efficient TODs. Relating to the context of Doha, the question arises as to which developed transit stations along the Gold metro line would serve as a potential TOD. Therefore, implementation of the above applicable characteristics of transit supply, land use and urban design appropriately to identified stations, would lead to successful TODs (Sung & Oh, 2015).

2.5 Approaches to implement TOD

Transportation engineers, urban planners and designers concentrate on good urban design strategies such as transportation diversity, mixed land uses and development of public space for promoting TODs. Also, recent trends show a shift in focus of TOD as a planning strategy for balancing station and railway characteristics along an existing metro corridor (Jacobson & Forsyth, 2008). Therefore, approaches to implement TODs are as follows:

(1) "Upstream planning decision process" including regional planning, typology classification, transit station planning, transit route planning, transit delivery, district planning, and land use planning;

(2) "Downstream real estate development process" including site procurement, predevelopment and TOD delivery procedures.

Among the initial approaches to implement TOD, planning as well as execution of the strategies is possible only if the designated areas of transit development are classified and divided among categories with similar characteristics. Therefore, in order to enhance and implement the planning, design and operation of TODs, study of this unexplored arena of assessment and categorization into different typologies is essential. As a result, the thesis attempts to categorize the stations along the gold metro line based on a selected model typology for enhancing the TOD potential.

2.5.1 Developing TOD typologies. Development of typologies allow the categorization and grouping of areas which have common characteristics. Classification into different typologies helps to:

(1) Create common set of strategies to plan or improve the performance of similar type of development;

(2) Identify specific potentials, alterations, sites and actors for specific TOD types;

(3) Design TOD in accordance to site specifications of desired density and diversity of land uses and multi-modal transit systems (Zemp et al., 2011);

(4) Enable performance assessments through comparisons within the same classes;

(5) Reduce management complexities in delivering infrastructure across TOD geographic selections; and

(6) Identify and assign benchmarks for TOD quality judgement (Kamruzzaman, Baker, Washington, & Turrell, 2014).

Thus, for the purpose of studying the development of different typologies for TODs, the transit centered developments are categorized based on (1) Geographical contexts; (2) Densities; and (3) Indicators of study.

2.5.2 Categorization of TOD typologies

2.5.2.1 Geographic context. Scholars such as White and McDaniel (1999) have categorized Transit oriented developments into six divisions based on their geographical contexts as follows:

(1) "Single use corridors" represents developments were land use patterns, concentrating on single uses such as commercial, recreational etc. have intensively developed around transit centers along a corridor;

(2) "Mixed use corridors" represents developments were land use patterns constituting single land or groups of land, exercising multiple uses such as residential, commercial, recreational etc. around transit centers along a corridor;

(3) "Neo-traditional developments" represents developments were emphasis is given on reproducing traditional town or village using design features such as narrow streets, reduced parking and minimal setbacks;

(4) "Transit oriented development" represents mixed use, compact, multi-modal network developments around existing transit stops;

(5) "Hamlet concept" includes developments which emphasize on single family dwelling units oriented towards green open spaces; and

(6) "Purlieu" encompasses small restricted development of land parcels with limited residents, detailed design regulations and flexibility in uses (Cervero et al., 2010).

Further researchers argue that the above classification of transit oriented development areas, are based on the evolution of city, town or village land use patterns into transportation oriented city development patterns. Hence, the above typologies do not provide the necessary information at different scales (regional and local) and means to assess the TOD potential in terms of planning principles.

2.5.2.2 Density. Due to inability of the above system, transportation and urban planners proposed a new classification subdivision based on initial stages of development described as follows (Vos, Acker, & Witlox, 2014):

(1) NTODs-New Transit Oriented Development refers to the development of new compact and mixed use adaptive neighbourhoods around existing transportation services. The development is visualized as 'pearl on a necklace' whereby transportation networks are circumscribed by mixed use development (Cervero, 2007). A few examples mentioned by researchers include Copenhagen (Denmark), Stockholm (Sweden) and Curitiba (Brazil), were urban development is guided along linear corridors around transit stops.

(2) HTODs-High density Transit Oriented Developments refers to development of public transportation networks facilitating strong core neighbourhoods with high density and existing diversity. Also, introduction of high density public transportation and mixed use development discourage car use (Newman & Kenworthy, 1996; Cervero & Kang, 2011; Sung & Oh, 2011). A few examples mentioned by researchers include Zurich

(Switzerland) and Seoul (Korea), were urban planning of TOD factors is focused on diversity and design.

(3) LTODs-Low density Transit Oriented Development as the name suggests is restricted to low density neighbourhood developments with low diversity and car oriented design. Thus, in order to reduce urban sprawl and car use, development in terms of providing improved public transportation services with increased neighbourhood density and diversity is ensured. A few examples mentioned by researchers include Perth (Australia) and Calgary (Canada), were developments around the transit stations are transformed into mixed use and high density to develop potential TODs (Curtis & Olaru, 2010).

Scholars argue that, TOD divisions as NTODs, HTODs and LTODs are based not only on the stages of development, but also on the evolution and development of the cities towards transit oriented development initiatives. Hence, the above typologies do not provide a means to assess the potential of existing neighbourhoods around transit stops, in emerging as a TOD in terms of indicators such as walkability, connectivity of nodes, diversity of land use patterns etc. (Vos et al., 2014).

2.5.2.3 Indicators of study. Studies conducted by researchers reveal that classification of TOD typologies based on specific classes of indicators are successful in determining the development potential of transportation network and associated neighbourhood around the transit stations (Kamruzzaman et al., 2014). As discussed earlier, the conceptual interpretation of TODs as node-place combination is an attempt to determine the development potential of transit stations. This classification is based on specific contextual node and place functional indicators. The Dutch scholar Luca Bertolini

in the 1990s developed the node-place model which was the first attempt in exploring the relationship between node and place functions. Literature describes a few typologies as discussed below:

(1) Initially, based on node-place model, existing TODs were classified by Bertolini (1996) under four typologies as accessibility spaces, stressed stations, dependency places and unsustainable places.

(2) Further, this node-place model enhanced by Zemp et al. (2011) classified stations into seven typologies as "central station, connectors, medium commuter feeders, small commuter feeders, tourist oriented stations, remote tourist nodes and secluded destinations" (Chen & Lin, 2015).

(3) However, studies conducted by Reusser et al. (2008), in Switzerland using separate indicators for nodes and places identifies five typologies namely smallest station, small stations, mid-size stations (populated areas), mid-size stations (unstaffed areas) and large stations (Vale, 2015).

(4) Apart from the previous studies, typologies were also developed using pedestrian friendliness indicators by Schlossberg and Brown (2004). They implemented their major typologies which included positive TOD and negative TOD based on the good and poor performance with regard to the indicators.

(5) Moreover, studies conducted by Center for Transit Oriented Development (2010) added performance indicators in addition to place indicators to develop fifteen typologies.

(6) Additionally, evaluation of spatial distribution developed by Atkinson-Palomb and Kuby (2011) identified five typologies namely transportation nodes, high population

neighbourhoods, urban poverty areas, employment amenity centers and middle income mixed use.

Therefore, Bertolini's Node-place model which forms the basis of all the indicator based typologies, establishes itself on the transport feedback cycle, exploring the relationship between node and place functions. The model thus, attempts to understand the state of equilibrium or balance of an existing development, to determine its potential in emerging as a sustainable TOD (Bertolini, 1996). As a result, this N-P model further developed by Bertolini and Chorus, is used as a tool to assess the existing gold metro stations in order to advocate balanced development between node and place functions, thus, enabling sustainable TODs.

2.6 Assessment of TOD: The Node-Place model

The assessment and classification of TODs using Node-Place model requires an understanding of the underlying theories of synergy and closed supplementary loop action exhibited between transport and land use functions within a metro station. Furthermore, application of the model for potential TOD requires an elaborate understanding of the framework, indicators of study, classified ideal situations generated and applicability of the model.

2.6.1 Theory: Synergos and transport land use feedback cycle. The Greek concept of 'Synergos' indicates the association of two dependent functions to achieve a common objective. Similarly, the idea of synergy forms the backbone of node-place model, were nodes of network and places in the city synchronize to establish potential TODs (Figure 7). Synergy establishes the whole model as a summation of the coherence value of its components. Thus, the N-P model is not the sum of its components but viewed as a

resultant value of coherence of node and place values (Peek et.al, 2006). Accordingly, the array of node and place functions, local contextual actors such as public administrators, transportation providers and developers crowd the station area redevelopment process. Also, the coherent value of the indicators transform the station into passenger transfer machine, hustled business market, mutli-scale connector transport node or human interactive places. Therefore, a theoretical understanding of this uncoordinated heterogeneous array of indicators is essential prior to N-P model station assessment.

Adding to the previous concept, studies carried out in subway systems reveal that interaction exhibited between transportation infrastructure and land use development forms a cyclic process expressed as a feedback cycle (King, 2011; Sanders, 2015). Here, the land use development pattern generates activities around the transit stop, which in turn increases ridership and generates trips for the transport network. Further, this improved facility of accessibility enhances the activity patterns (Sanders, 2015). As a result, any changes either in the transportation network or land use development pattern stimulates a change in the other. Therefore, the transport feedback cycle provides an understanding of limitations and magnitude of delays in the node and place functions which are to be anticipated prior to practical application of the model (Wegener & Fürst, 2004).
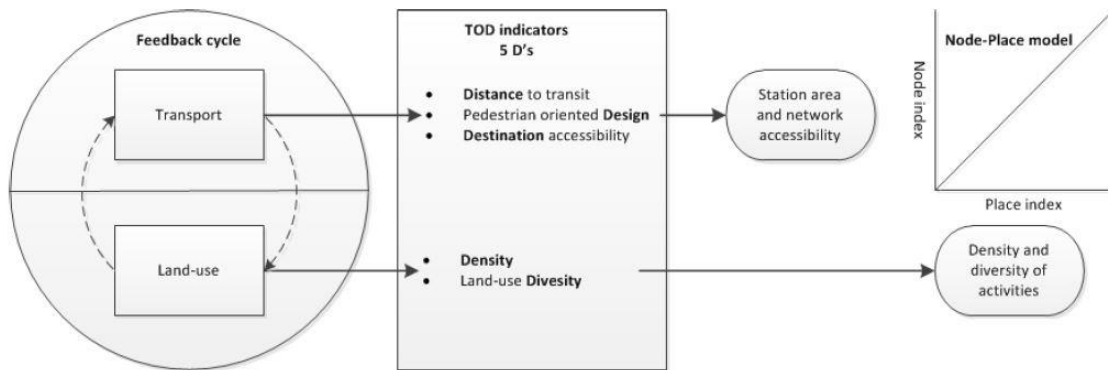
Figure 7. Synergos and transport land use feedback cycle (Source: Sander, 2015)

2.6.2 The N-P model

2.6.2.1 Framework. Dutch scholar Dr. Luca Bertolini (1999), developed an analytical framework to identify potential planning and development strategies with a focus on Randstad station areas in the Netherlands (Sanders, 2015). This Node-place model attempted to understand the synergy and reasoning of land use feedback cycle within the existing station area developments. According to Bertolini's model, station areas are 'nodes' of network and 'places' in the city. Here, the station areas are interpreted to serve as important 'nodes' for both transport and non-transport business networks. Also, the stations perform the function of inhabited 'places' in the city with dense and diverse accumulation of land use patterns and associated activities.
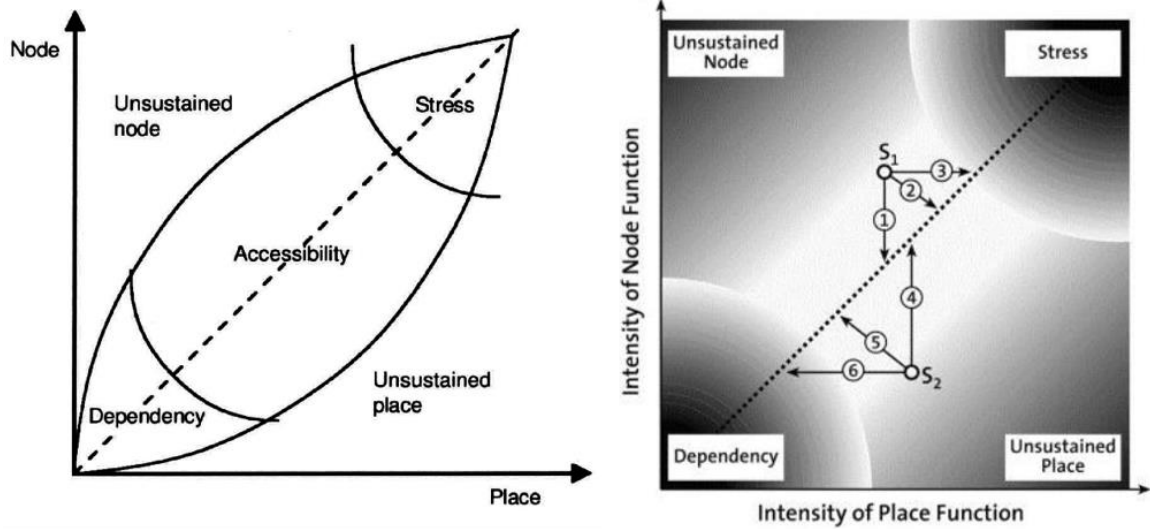
Figure 8. The Node-Place graph developed by Bertolini (Source: Vale, 2015)

The N-P model assesses the station areas with the notion that improvement of transport provisions of a location (node value) generates conditions favourable for further development due to improved transportation. Also, development of an area (place value) further generates development of transport system due to growing transport demand. This process of interdependency continues until the station attains equilibrium or is under the influence of external factors. As argued by scholars, a difference is exhibited between, attaining an existing development potential and realization of potential development which may or may not occur. This scenario depends on external factors other than transport and land use features which drive the development in varied directions. However, the N-P model emphasises on the present 'conditions' through separate contextual node and place indicators. As a result, the model categorizes into five ideal typical situations namely

balanced, stressed, dependent, unbalanced place and unbalanced node, which assess the TOD development potential.

2.6.2.2 Model Indicators. The model is based on node and place properties of a particular station, assessed in terms of key variables or indicators. The model analyses each station in terms of node index and place index. The node index denotes the station area and network accessibility. Here, network accessibility determines the count of opportunities available to traverse from one activity site to the other within a certain distance or limited travel time (Hanson & Giuliano, 2004). The place index measures the distribution of land uses in terms of density and diversity around the station. The node-place index is determined by combining and comparing the variables described by the TOD indicators using multi-criteria analysis.

As discussed earlier, based on the concepts of synergos and transport-land use feedback cycle, balance exists between node and place functions. The model reveals the node-place equilibrium of station areas graphically using N-P model diagram. This N-P graph represents place value along the x-axis and node value along the y-axis. Accordingly, N-P diagram provides node-place balance of the station areas, where the mean value for node-place index is plotted. The central line (diagonal) of the diagram represents balanced stations (Figure 8). In order to classify the stations, a straightforward method to access the equilibrium is to calculate the distance of node-place index plotted to the centreline. Thus, reviewed literature suggests that the node-place model is suitable for differentiating among station areas, expressing and identifying potential TODs (Hynynen, 2005).

2.6.2.3 Ideal situations. Bertolini's rugby ball shaped node-place model divides the station areas into five different typologies so as to identify potential transit oriented development station areas. The five ideal situations are as follows (Figure 8):

(1) Balanced – The following stations are found along the central diagonal where node and place indexes are equal.

(2) Stressed – The following stations are positioned at the top end of the diagonal line with maximum values for both the node and place index. Here, transport and land use needs compete with each other within a balanced place. In other words, the station is under stress as both the intensity and diversity of transport network accessibility and land use activities is maximum. Hence, these stations show high potential for land use development (strong node) around transit station (strong place).

(3) Dependent – Stations positioned at the bottom of center diagonal line close to the origin represent those station areas which cannot sustain by themselves and are dependent on external interventions or other station areas in the network. These represent minimum value for both node and place index. Here, the demand for transportation services from riders (weak node) and urban activities generated from travel (weak place) are both minimal due to station area constrains.

(4) Unbalanced node – Stations positioned at the top left of the center diagonal line offer higher travel potential with well-developed transportation networks (strong node) when compared to urban activities (weak place).

(5) Unbalanced place – Stations positioned at the bottom right of the center diagonal line offer higher intensity and diversity of land use urban activities (strong place) when compared to transportation supply (weak node).

The two unbalanced state have higher tendency to move towards a more balanced state. In order to achieve a balanced state, an 'unbalanced node' can either increase the place value by attracting new developments or decrease its node value by reducing the supply of transportation services. The reverse reasoning is true for an 'unbalanced place', where balanced state can be achieved either by increasing the transportation connectivity or decreasing the density and diversity of development. As agreed by scholars, N-P model successfully distinguishes among station areas and reveals the unbalance between land use and transport supply of various station areas. Thus, the model offers a criterion for assessing potential TODs along an existing railway metro corridor.

2.6.2.4 Model use. The N-P model provides an analytical tool to discuss the land use-transportation interaction process. Also, the position of stations in the N-P diagram determines the location and appropriate conditions of balanced state between land use and transportation process. Also, the findings are used in designing planning strategies for development of existing transit stations as implemented in Swiss National Railways (Reusser et al., 2008). Furthermore, the Node-Place model provides a platform for comparing station area developments over time. Additionally, the state of unstained node or place obtained from the N-P diagram, allows the comparison of cities in accessing its transport-land use infrastructure facilities (Bertolini, 2008).

From previous case studies, the model has been implemented in Dutch context by the Ministry of Infrastructure and Environment to identify potential development opportunities along the regional networks. Also, the model was used for characterization of spatial development strategies in Netherlands. Furthermore, the model assists in

formulating planning strategies with focus on multimodal transport and diverse land use development (Sanders, 2015).

2.7 Implementing the Node-Place model

Previous studies conducted by researchers on land use and transportation exchanges focussed on assessing its influence on urban patterns alone (Pagliara & Papa, 2011). However, the Node-Place model assesses the influence of land use and transportation interactions on the entire station area. Thus, the TOD potential is measured through evaluating and balancing both the transport network and land use distribution parameters. As a result, an understanding of the indicators assessing the station areas is essential for implementing the model over an existing metro station.

2.7.1 Balancing transport network. As discussed previously, urban planners necessarily initiate TOD with a desire to attain balance between the station area node and place functions. A balanced station can also be obtained improving the traffic flow with use of available infrastructure (Sanders, 2015). As a result, station area functions need to be developed to optimize traffic flow around stations with sufficient infrastructure.

2.7.1.1 The corridor approach. Scholars suggest that positive integration of land use and transport around rail transit is efficient and successful at a regional scale, when compared to local scale. Therefore, an approach to implement successful land use–transport interaction should focus on coordinated mobility at higher levels such as a corridor or rail network (Bertolini, 2008; Cervero, 1998). The corridor approach is most desirable due to the following reasons (Figure 9):

(1) The origin (residential areas) and destination (offices, recreation, public areas etc.) locations for the study can be developed in a logical manner. This enables

documentation of activity and mobility patterns of target groups to develop strategies for spatial design.

(2) Corridor approach enables the development of coordination plans between adjacent and distant stations. These coordination plans solve the destructive competition and develop synergies between station areas.

(3) Railway corridors also enable efficient use of public transport by identifying developments which generate peak travel and bidirectional flows (Chorus, 2012).

As discussed earlier, railway corridors or lines operate at local, regional, national and international level. In order to implement the N-P model in the state, analysis of development and traffic flow of a single metro corridor at the national level would be most suitable. As a result, the assessment and classification of TOD potential using N-P model along the Gold metro corridor avoids complexity. Thus, analysis and results of land use transport interaction obtained due to analysis of stations along a corridor is more successful when compared to individual station analysis.

Figure 9. The Gold metro line corridor (Source: Atkins, 2015)

2.7.2 Balancing station areas. Functionality of a railway station should be evaluated using both mobility and surrounding station areas. As discussed by scholars, stations serve as generators of activities and offer services in addition to providing access to railway system (Reusser et al., 2008). Thus, TOD indicators such as density, diversity, distance to transit etc. should be evaluated within the framework of N-P model. Hence, node and place value functions of a station should be balanced for a potential TOD.

2.7.2.1 Indicators from previous applications. The Node-Place model is a strategic framework developed for urban and transportation planning facilitating two main services. Firstly, it provides a platform to classify the overall transport (node) and land use (Place) equilibrium at a regional level of all the stations enabling their comparison. Secondly, the model identifies and categorizes the stations into five typologies based on the land use and transport features of the station areas (Vale, 2015). The node and place indexes for the model are determined by different key variables or indicators derived from the five TOD factors of Density, Diversity, Design oriented for pedestrians, Destination accessibility and Distance to transit (Sanders, 2015) (Figure 7). The possible indicators of node index (measuring network accessibility) and place index (measuring distribution of land uses) within the station area are obtained from previous studies. This include enhancements made in Bertolini's model depending on the contextual conditions of the analysed station.

Initial application of the model by Bertolini (1999) developed a node index using connectivity, number of directions facilitated, number of reachable stations within 45 min. of travel, frequency of travel, and diversity of transport alternatives provided. The place index is measured within walkable distance of 700m from the station. The place index

includes number of residents in the area, number of workers in economic cluster 1 (retail/hotel and catering), number of workers in economic cluster 2 (education/health and culture), number of workers in economic cluster 3 (administration and services), number of workers in economic cluster 4 (industry and distribution) and degree of land use multi functionality (Chen & Lin, 2015; Sanders, 2015; Vale, 2015).

Node-place frame work operationalized by Reusser et al. (2008) in Switzerland, used a total of eleven indicators to classify 1684 stations. The node index included seven indicators measuring number of directions facilitated, daily frequency, number of reachable stations within 20 min. of travel by train, number of reachable stations by bus and tram, frequency of bus and tram available, shortest distance to motorway access, length of bike path within 2km. However, the place index included population of inhabitants, workers in the secondary sectors, workers in the tertiary sectors and diversity of land uses. Also, six additional indicators were added based on interviews and questionnaires within the study area. These indicators for node value were ridership per day, ratio of long distance and regional services and availability of staff. The place value added workers in the education sector, city center accessibility and provision of market facilities (Sanders, 2015; Vale, 2015) (Table 8). This enhanced version fit well in to the context when compared to the previous model due to inclusion of contextual conditions as indicators.

Further studies carried out by Zemp et al. (2011), classified 1700 stations using 10 contextual indicators. The node index calculated accessibility in terms of number of reachable stations within 20 min., number of intercity train services, number of regional train services and number of multimodal buses. The place index summarized the measures of population and workers within the walkable station radius of 700m. As the model

indicators are based on 'conditions' the model successfully differentiated density and use of the station areas (Vale, 2015) (Table 8).

The node-place model used by Ivan et al. (2012) revealed the equilibrium of station areas of Ostrava, Czech Republic using 10 indicators. The node index measured the daily frequency of train services offered, daily frequency of bus services offered and car parking capacity. However, the place index summarized the residents in the area, workers in the secondary sectors, workers in the tertiary sectors, presence of core urban areas, number of apartments, rate of land availability and number of unemployed with basic education (Sanders, 2015; Vale, 2015) (Table 8).

Finally, Kamruzzaman et al. (2014) successfully applied the model in Brisbane, Australia using 6 indicators to develop TOD typology. The node index measured only "Public transport accessibility level" (Kamruzzaman et al., 2014), whereas place index measured residential density, employment density, multi-functional land use mix, intersection density and cul-de-sac density (Sanders, 2015; Vale, 2015) (Table 8).

The above literature studies on indicators suggest that classification of TODs to access development potential should necessarily be categorized based on context and include built environment indicators. Also, the indicators used should be able to address both urban planning and transportation related issues (Kamruzzaman, Baker, Washington, & Turrell, 2014).

2.8.2.2 Node value and Place value. Experimental implementation of the indicators through previous application of the model suggest common indicators, in addition to the contextual indicators. From previous discussions, possible indicators to determine the node index are; the number of connections served by train travel, type of connections established by train travel, closeness to a center and number of multimodal services from the station (bus). Also, the possible indicators to determine the place index are the inhabitants around the station area, number of workers within the walking radius from the station and degree of multi-functionality in terms of activity and land use diversity. The economic clusters are divide into four categories namely, retail/hotel and catering, education/health and culture, administration/services and industry distribution. As experimented by researchers, degree of multi-functionality provides an idea of quantity and diversity of land use oriented activities within the transit station area (Chorus & Bertolini, 2011; Chen & Lin, 2015; Sanders, 2015; Vale, 2015).

2.8 Summary

New urbanism and smart growth policies address the issues related to interdependence of urban transportation/mobility and the surrounding built environment. As agreed by architects, urban planners, sociologists, transportation planners and environmentalists, the Environment Protection Agency (EPA) advocates that enhancing transportation alternatives through walking, cycling and transit definitely influences the activities of the surrounding area. Smart Growth principles implemented through the establishment of TOD type development around existing transit stations serve as a viable urban development solution to moderate the transport-land use balance.

Due to rapid urbanization, sprawling urban settlements resulted in increased traffic congestion supplemented with environmental degradation. Integrating the spatial development with multi-modal transit modes, served as a planning solution to sprawl. The concept of TOD typically consists of a mixed use development around a transit station. It is interpreted to serve as a tool to reduce the use of private cars and develop compact, mixed use places around existing or new transit stations with the provision of providing alternate modes of public transport.

Although TOD is provided with different conceptual definitions and terminology such as 'Transit Villages', 'Transit Supportive Development', or 'Transit Friendly Design', however distinguishes itself due to differences in density, single use and car friendly development patterns. Some common elements of focus are: mixed uses; closeness to transit; favorable transit ridership; compactness; pedestrian and cycling friendly atmosphere; public civic center; and community/activity hubs.

The research identifies TODs as node (transit) - place (neighborhood) combination. The place is characterized by moderate to high density development constituting a mix of land uses such as residential, commercial, recreational, open parks, institutional and civic spaces. The node represents the public transport services offered by an existing or new transit station inscribed within the mixed use neighborhood. The planned neighborhood model facilitates and attracts activity participation within the places interconnected by streets, facilitating integration of activities and active transport. Therefore, node-place combination visualizes TOD as not only an efficient public transit station, but as a place to live, work, socialize, shop and relax. As a result, node-place synergy theory enables the

use of TOD type planning to be executed in metro station areas as an urban development planning strategy.

TOD exercises as an urban planning tool, which requires long term planning at both the regional and local levels. Interplay of institutional contexts, policies, models and execution through planning at different scales has made TOD a dominant and ideal planning practice in developed / developing cities with transit. Thus, TOD has transformed itself from a pre-motor development planning tool into a centralized decentralization urban redevelopment tool.

In comparison to other modes of transport, metro transit proves to be an effective urban revitalization tool due to its characteristics such as physically immovable and fixed infrastructure; convenient accessibility due to spatially designated catchment area; development of activity oriented land uses and concentration of land values around transit stations. Integration of TOD, as a planning tool to these metro stations along the Gold line would enhance the node-place interaction facilitating, accessibility as well as urban land use distribution.

The place (urban development) which circumscribes the metro station, and the transit service offered by the inscribed node (metro) are interrelated. This relation between the infrastructure (node) and development (place) is referred to as co-development. A cyclic relationship exists between transport and land use development, where an increase in number of networks result in higher development density; or greater development of land use density patterns, enhance transportation networks through increased transit ridership.

The travel behaviour within a built environment depends on the 5D's such as density; diversity; design oriented for pedestrians; destination accessibility; and distance to transit. Combination of the above factors form planning strategies, which influence the travel and land use pattern distribution which include enhancing accessibility and parking provisions; densifying and diversifying land uses and associated activities; and developing walkable environments through urban design characteristics.

Higher frequency of transit operations and services improve transit ridership establishing better connectivity between different modes such as buses and rail network attract more riders. Mixed land-use strategy near a transit center attracting more ridership acts as a positive TOD planning tool. The urban design TOD planning factors include street network patterns and building design parameters such as high four way intersection densities, average area of individual building, grouping of buildings, grid pattern with narrow streets and pedestrian travel paths. A decrease in total road length, average road width, driveway percentage and building group area encourages transit ridership. Thus, development of a transit oriented station depends not only on the density of the surrounding area, but also on the other TOD factors such as, quantity and quality of intermodality between the bus and rail transit, diversity of land uses, regional accessibility, street network patterns and building design parameters.

TOD is implemented through the following steps: "Upstream planning decision process" which includes regional planning, typology classification, transit station planning, transit route planning, transit delivery, district planning, and land use planning; and "Downstream real estate development process" which includes site procurement, predevelopment and TOD delivery procedures. In order to enhance and implement the

planning, design and operation of TODs, study of this unexplored arena of assessment and categorization into different typologies is essential.

Categorization and grouping of areas which have common characteristics is achieved through development of typologies. These classifications assist in identifying specific potentials, alterations, sites and actors for specific TOD types; enabling performance assessments through comparisons within the same classes; reducing management complexities; and assigning benchmarks for TOD quality judgement.

Development of different typologies for TODs are categorized based on geographical contexts; densities; and indicators of study. Based on the geographic context, six divisions of identified TODs include single use corridors, mixed use corridors, neo-traditional developments, transit oriented development, hamlet concept and purlieu. These are based on the evolution of city, town or village land use patterns into transportation oriented city development patterns lacking necessary information at different scales. However, TOD divisions such as NTODs, HTODs and LTODs are based not only on the stages of development, but also on the evolution and development of the cities towards transit oriented development initiatives. Comparatively, they do not provide a means to assess the TOD type development potential of existing neighborhoods around transit stops in terms of walkability, connectivity of nodes, diversity of land use patterns etc.

Above all, classification of TOD typologies based on specific classes of indicators proved successful in determining the development potential of transportation network and associated neighborhood around the transit stations. The different typologies included accessibility spaces, stressed stations, dependency places and unsustainable places. Further, enhancements based on indicators led to station types such as central station,

connectors, medium commuter feeders, small commuter feeders, tourist oriented stations, remote tourist nodes and secluded destinations. Based on size indicators TODs were classified as smallest station, small stations, mid-size stations (populated areas), mid-size stations (unstaffed areas) and large stations.

Bertolini's N-P model formed the basis of all the indicator based typologies, established on the transport feedback cycle, exploring the relationship between node and place functions. The N-P model attempts to understand the state of equilibrium or balance of an existing development, to determine its potential in emerging as a sustainable TOD. The assessment of TOD is based on the theories of synergy and closed supplementary loop action exhibited between transport and land use functions within a metro station.

Theory of synergy forms the backbone of node-place model, were nodes of network and places in the city synchronize to establish potential TODs. Thus, the N-P model is not the sum of its components but viewed as a resultant value of coherence of node and place values. A theoretical understanding of this uncoordinated heterogeneous array of indicators is essential prior to N-P model station assessment.

Dutch scholar Dr. Luca Bertolini (1999), developed an analytical framework to identify potential planning and development strategies and attempted to understand the synergy and reasoning of land use feedback cycle within the existing station area developments. According to Bertolini's model, station areas are 'nodes' of network and 'places' in the city. Thus, the N-P model framework assesses the station areas with the notion that interdependency continues between improved transport and land use activities and vice versa, until the station attains equilibrium or is under the influence of external factors. The model emphasizes on the present 'conditions' through separate contextual

node and place indicators. As a result, the model categorizes into five ideal typical situations namely balanced, stressed, dependent, unbalanced place and unbalanced node, which assess the TOD type development potential. These categories are obtained from the N-P model diagram which represents place value along the x-axis and node value along the y-axis. Accordingly, N-P diagram provides node-place balance of the station areas, where the mean value for node-place index is plotted. The central line (diagonal) of the diagram represents balanced stations. The findings including classification of station areas and state of unstained node or place parameters serve as a guide in designing planning strategies for development of existing transit stations.

Implementing the N-P model along the station areas, measures TOD type development potential through evaluating and balancing both the transport network and land use distribution indicators. Implementation of the model is successful at higher levels such as a corridor or rail network, due to focus on coordinated mobility. Also, along a single metro corridor, O-D matrix is developed in a logical manner, coordination plans between adjacent and distant stations solve competition and develop synergies, in addition to enabling efficient use of public transport. As a result, analysis and results of land use transport interaction obtained due to analysis of stations along a corridor is more successful when compared to individual station analysis.

Balancing the station area involves evaluating both mobility and surrounding station areas. TOD indicators such as density, diversity, distance to transit etc. are evaluated within the framework of N-P model in the form of node and place value functions. The possible indicators of node index (measuring network accessibility) and place index (measuring distribution of land uses) within the station area are obtained from previous

applications of the N-P model. This include enhancements made in Bertolini's model depending on the contextual conditions of the analyzed station. Node index is determined using possible indicators such as; the number of connections served by train travel, type of connections established by train travel, closeness to a center and number of multimodal services from the station (bus). Also, the possible indicators to determine the place index are the inhabitants around the station area, number of workers within the walking radius from the station and degree of multi-functionality in terms of activity and land use diversity.

Concept of TOD has been recognized as a planning method in the middle-east countries such as the state of Qatar, to resolve the issue of traffic congestion though high density developments. However, the concept is not completely operationalized due to the lack of convincing analysis methods for planning at suburban or urban scales. The research identifies Bertolini's N-P model as a suitable tool facilitating the implementation of TOD type development which is explained in the following section.

Chapter 3: Research Methodology

Chapter 3 is divided into four sub-sections, which explores the research design, research approach and methods/techniques of data collection and measurement. Both quantitative and qualitative approaches were used to analyse, compare, assess and classify the stations along the gold metro line. The first section focuses on the research design inputs, model relations/processes and resultant output. The research approach involving theoretical framework, selection of criteria and indicators, and analytical approach is discussed later. The second part describes the methods used to collect data and quantify the station area characteristics, node-place functions and calculations involving the N-P TOD Index Figure 10.
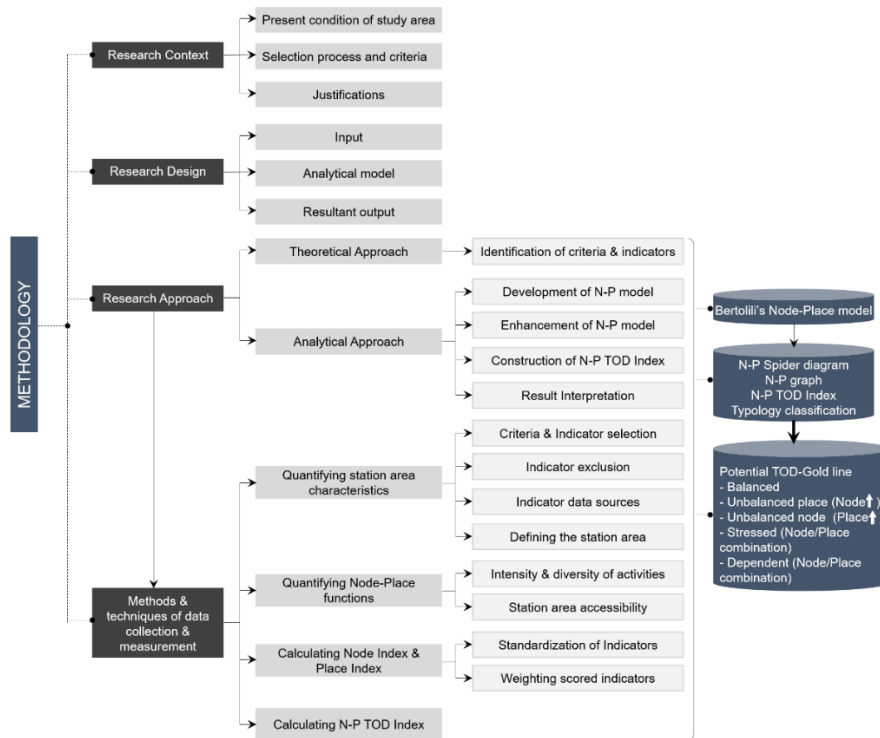
Figure 10. Diagram representing research methodology (Source: Author, 2018)

3.1 Research Design

The research design schematic diagram (Figure 11) is divided to include three main categories: (1) Theoretical input; (2) Analytical model; and (3) Resultant output. These include both quantitative and qualitative data input.
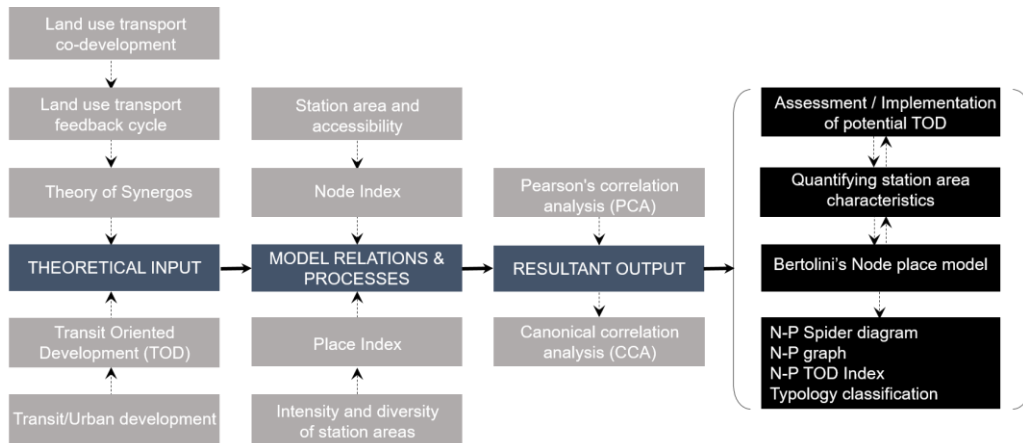
Figure 11. Diagram representing the research design including input, model and output (Source: Author, 2018)
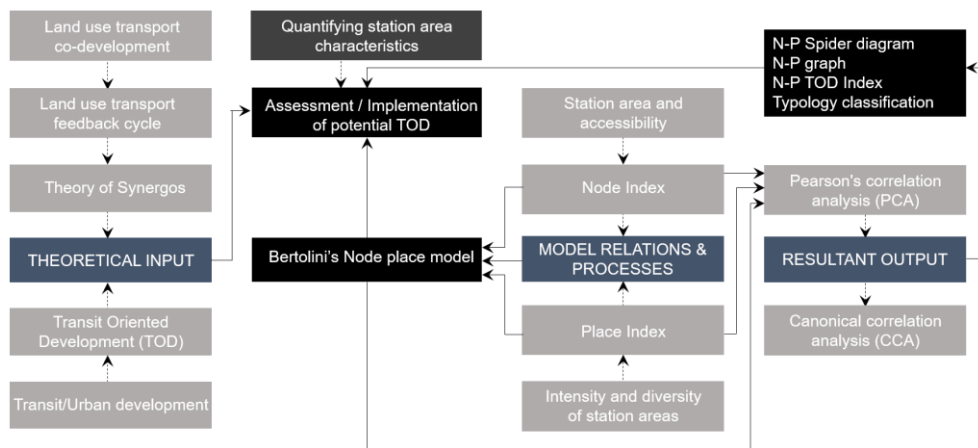
Figure 12. Representing relations-connections in research design (Source: Authors, 2018)

3.1.1 Input. The research required a variety of organized data to describe each of the processes. Left side of the schematic diagram thus represents the theoretical input for the research (Figure 11).

As discussed previously, the research examines the relation between transport and land use towards developing potential TODs within metro station areas. Studies by scholars suggest that land use transport co-development, land use feedback cycle and theories of synergos, justify the interdependency and imbalance between transport and land use (Bertolini et al., 2005; Curtis, 2005; & Lukman, 2014). Meanwhile, the concept of TOD is believed as one of the best solutions to achieve land use and transport integration. Thus, implementation of the planning principles with respect to transit and urban development strategies enhance the station area characteristics.

TOD planning principles focus on the development area around the transit nodes enabling improved accessibility, walkability and more dependence on public transport. Therefore, availability of more network connections, multi-modal transport facilities, transit quality and pedestrian supportive networks form important aspects of TOD. Moreover, density and diversity of activities surrounding the transit station area involving the residential population influences the TOD levels. As a result, the input framework exhibits the influence of TOD planning aspects in terms of quality, quantity and availability of transit system within appropriately dense, diverse and mixed use station areas.

Above studies, paved way for the assessment and classification of potential for TOD type development among the existing transit station areas. Thus, the assessment and implementation of TOD along the gold metro line, carried out by measuring the TOD level

around the transit station, forms the base for input data. This is achieved through Bertolini's node-place theory (Node-Place model).

Thus, this theoretical framework serves as the input to identify appropriate criteria and indicators to quantify the N-P TOD index of the stations along the gold metro line.

3.1.2 Analytical Model (Processes and Relations). The middle section of the research design diagram represents the analytical relations and processes involved in developing and implementing the N-P model (Figure 11). Also, this section focuses on the methods and techniques of data sorting, collection and measurement. This further involves two segments such as: (1) Node index (Transit-top segment); and (2) Place index (Urban development-bottom segment).

The top segment deals with quantifying the node functions for determining the N-P TOD index. The criteria of accessibility and parking within the node input parameters, are further subdivided into ideal indicators. Additionally, these indicators are enhanced through comparative case scenario analysis to obtain the final ideal node indicators. Finally, exclusion principles are applied to obtain selected node indicators for study. Place indicators are also determined similarly. The calculated node and place indicators of the 10 stations (through and terminus) serve as input for Bertolini's N-P model to obtain N-P TOD index.

The research emphasizes on the relation between node and place functions. Also, the model attempts to balance these functions by determining the strength of relation between the indicators. Thus, the traditional N-P model by Bertolini (1999), is developed and enhanced during this section.

3.1.3 Output. The right section of the research design diagram represents, the resultant output of the analytical model relations and processes (Figure 11). This section includes two segments; (1) Result of N-P model; and (2) Result of correlation analyses (PCA and RA).

Top segment represents the resultant deliverables obtained after comparative analysis of application of the N-P model at gold line station areas. The node and place indices are then plotted in N-P graph, the slope of which at designated points, represent N-P TOD index. Additionally, radar diagrams are generated with values of node and place indicators for each of the station areas. These enable to classify the stations into different typologies, assessing their potential for TOD type development.

The deliverables of this segment include: N-P radar diagrams (10 stations), N-P graph, N-P TOD index for the station areas, and classification under Bertolini's node-place typologies (balanced, stressed, dependent, unbalanced place and unbalanced node).

Bottom segment represents the effectiveness of generated model in terms of the relation of indicators in assessing the station areas (Figure 13). Thus, potential indicators facilitating the description of station area characteristics for assessing TODs are identified through Pearson's correlation analysis. These are used to obtain the strength of correlation among the indicators and arrive at the most effective land use-transport indicator combinations, enabling potential for TOD type development.

The two segments as shown below are then combined to obtain the development for potential TODs along the gold metro line. Classifications include: balanced station (no additions), unbalanced node (additive place indicator/ subtractive node indicator), unbalanced place (additive node indicators/subtractive place indicators), stressed station

(additive/subtractive node-place indicators) and dependent stations (additive/subtractive node-place indicators). The following sections describes the approach accepted to execute the research design.
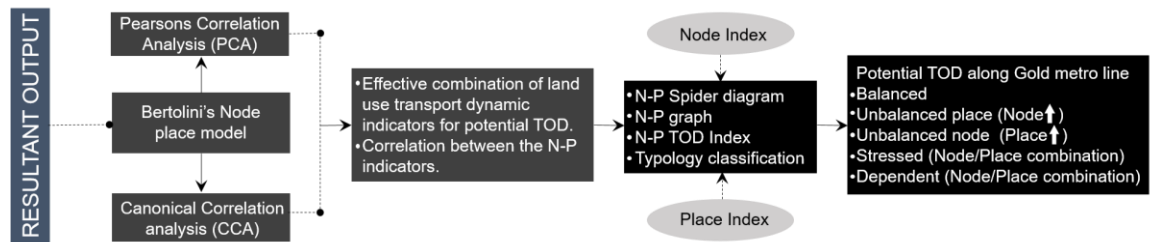
Figure 13. Diagram representing the resultant output section of the research design (Source: Author, 2018)

3.2 Research Approach

As discussed, transportation improvements such as the development of Doha metro network system influenced the initiation of new land use construction activities. The resultant urban expansion and enhanced infrastructure led to insufficiency of transport supply to meet the commuter needs. Hence, a gap exists between the commuter demands generated by existing and introduced land use patterns. Thus, an imbalance exists between the node and place functions along the gold metro line. As a result, the research study focusses on determining TOD potential of the existing 10 metro stations along the Gold metro line by enhancing Bertolini's Node-Place model. The study aims at identifying, assessing, comparing and classifying, the stations into typologies based on N-P model. The research approach includes two aspects: (1) Theoretical; and (2) Analytical.

3.2.1 Theoretical approach. Literature study of different disciplines contributed in developing a conceptual framework for the study, namely conceptual definitions of TOD, planning concepts and principles, approaches to implement TOD, assessment and implementation of TOD using the Node-Place model (Figure 14). However, identification of the criteria and indicators from theory, served as crucial part at the initial investigation stages.

3.2.1.1 Identification of Criteria and Indicators. The strength and precision of the N-P TOD index depends on the selected indicators. Careful analysis was employed at this stage, where criteria and ideal indicators were determined through literature review of TOD aspects based on top-down approach. This included translation of definitions of TOD, planning principles and concepts to form criteria, followed by indicators. These ideal indicators were then selected, based on comparison of case scenarios applying Bertolin's Node-Place model. Also, availability and significance of data determined the final selected indicators (Lukman, 2014).
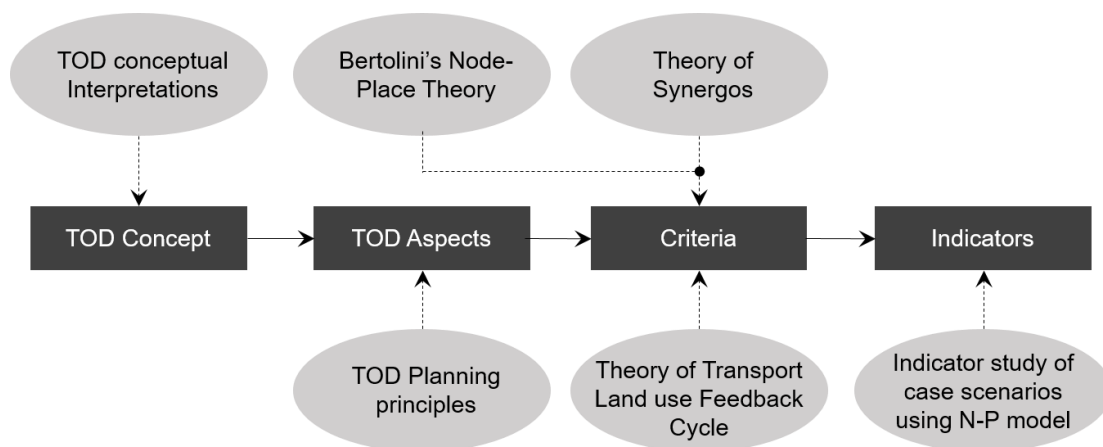
Figure 14. Diagram representing theoretical approach (Source: Author, 2018)

3.2.2 Analytical approach. The analysis of the existing metro stations along the gold line is executed through the following four phases (Figure 15): (1) Development of the N-P model; (2) Enhancement of the N-P model for spatial analysis; (3) Determining the effectiveness of the model; (4) Construction of the N-P TOD index and (5) Interpretation of the results.
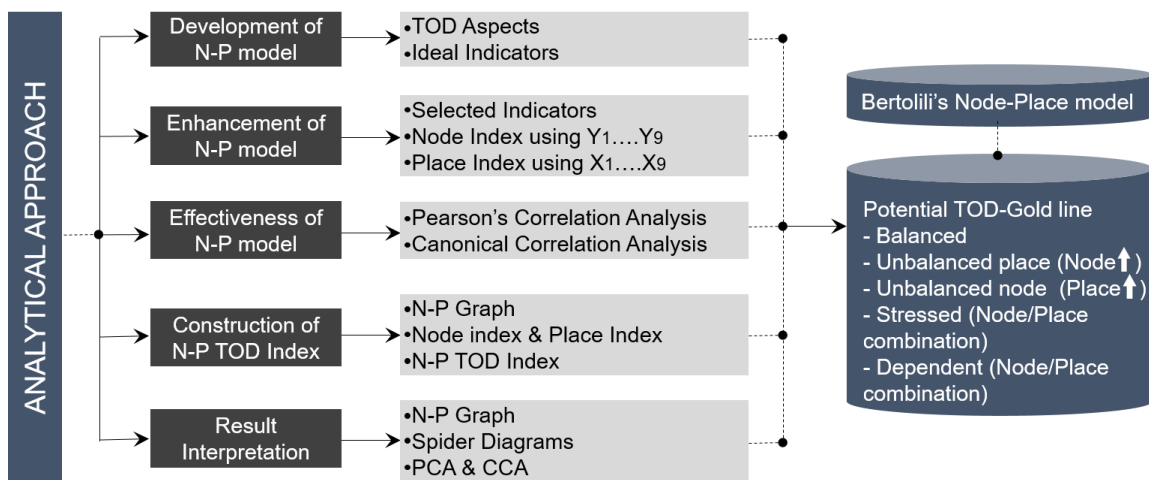
Figure 15. Diagram representing Analytical approach (Source: Author, 2018)

3.2.2.1 Development of N-P model. The research study uses Bertolini's rugby shaped model, which is based on two properties of a station area: transport and land use. The model visualizes each station as a combination of node and place. N-P model is developed on the concepts of synergos and transport-land use feedback cycle, where a balance exists between node and place functions. Thus, the node and place functions are developed separately using criteria and then broken down to ideal indicators.

The node function denotes the station area and network accessibility, whereas the place index measures the distribution of land uses in terms of density and diversity around the station. These functions are developed form traditional node-place model using the following steps:

1. The node (transit) function is developed by selecting appropriate criteria from the 5D's: destination accessibility and distance to transit.

2. The place function is developed by selecting appropriate criteria of density, diversity and design oriented for pedestrians.

3. The above criteria are then defined and translated based on two selection principles proposed by Lukman (2014) (Table 9).

4. Next, ideal indicators corresponding to the criteria were defined and translated based on seven selection principles proposed by Singh (2013) (Table 9).

5. Finally, 5 criteria with appropriate corresponding 28 ideal indicators were identified.

Thus, development of node–place model was completed with a total of 28 indicators for both node and place functions. After development of the N-P model indicators, these were then enhanced based on the comparison of case scenarios applying Bertolini's node-place model.

3.2.2.2 Enhancement of Node – Place model for spatial analysis. Enhancement of the model was essential to verify the effectiveness of the model within the context of Doha gold metro line in Qatar. The ideal indicators from the traditional N-P model, developed by Bertolini (1999), were compared with the application of the model in six different case scenarios (3.3.1.1). Thus, comparative analysis of the indicators were carried out to determine the selected indicators for research based on the relevance of indicators within

the context of Doha (as the Doha gold metro line is under construction) and availability of data. Further, Bertolini's N-P model were subject to exclusion criteria to obtain the selected indicators. The N-P model for research study was enhanced using the following steps:

1. First, six case scenarios (2.5.2.3) applying Bertolini's Node-Place model in analysing existing metro stations were identified through literature review.

2. Second, comparative analysis of the ideal indicators applied in different case scenarios were summarized.

3. Next, 2 selection principles were used to exclude certain indicators based on their significance, applicability to the Qatar context and availability of data.

4. Finally, the node index included 9 indicators namely Y_1 , Y_2 , Y_3 , Y_4 , Y_5 , Y_6 , Y_7 , Y_8 and Y_9 , whereas the place index included 9 indicators namely X_1 , X_2 , X_3 , X_4 , X_5 , X_6 , X_7 , X_8 and X_9 (Table 1).

Table 1

Node & Place Indicators

Measuring Node and Place Indicators
Node Indicators (Transit – Measuring station area and accessibility)
Y_1 = Daily frequency of train services
Y_2 = Number of directions served by train service
Y_3 = Accessible stations within 20min. of travel time
Y_4 = Type of train connections
Y_5 = Directions served by bus
Y_6 = Daily frequency of bus service
Y_7 = Proximity to the closest road access
Y_8 = Number of free standing bicycle paths

$Y_{9} =$ Car park and ride facility capacity

Place Indicators (Urban development – Measuring Intensity and diversity at station areas)

$X_{1} =$ Population of the area

$X_{2} =$ Net residential density

$X_{3} =$ Workers cluster grouping-Number of workers in Retail/hotel and catering

$X_{4} =$ Workers cluster grouping-Number of workers in Education/ health/ culture

$X_{5} =$ Workers cluster grouping-Number of workers in Administration and services

$X_{6} =$ Workers cluster grouping-Number of workers in Industry and distribution

$X_{7} =$ Degree of functional mix

$X_{8} =$ Intersection density

$X_{9} =$ PCA (Impedance Pedestrian Catchment Areas)

Moreover, the station area of analysis was defined with a buffer size of 700m (walkable distance). Since, the research focuses on assessing stations based on Bertolini's model, buffer radius of 700m was obtained as a result of comparative analysis of the case scenarios applying Bertolini's model with contextual modifications. All the case scenarios used a radius of 700-800m. Although, Bertolini's N-P model is enhanced, it is essential to determine the statistical significance of the model and its indicators. Thus, effectiveness of the N-P model for study is assessed using Pearson's correlation coefficient and regression analysis as discussed below.

3.2.2.3 Effectiveness of the model. Statistical significance of the model is assessed to understand the effective, relation between the same indicators and others, correlation among node-place indicators and to propose the effective node and place indicators in station areas which need to be improved/enhanced. This was achieved through two

processes: (1) Pearson's correlation analysis and (2) Regression analysis. Thus, correlation provides the relation between the indicators in terms of size and sign (positive/negative).

First, in order to determine the relation between the spatial and non-spatial indicators of node and place index, Pearson's correlation coefficient was defined between the indicators. The 18 indicators, 9 each of node and place functions were correlated as shown in Appendix B. Further, these relations were analysed based on the study by Field (2009), where r=+1 indicates positive correlation and r=-1 indicates negative relation between the indicators. Also, correlation of 1 indicates perfect relation and 0 indicates no relation at all (Sanders, 2015). Correlation coefficient of 0.3 exhibits a weak relation, a range between 0.3-0.7 exhibits medium relation and above 0.7 shows a strong favourable relation (Field, 2009; Sanders, 2015). The correlation was performed with a 95% confidence level. The bi-variate correlation results are shown in Appendix B and discussed in Chapter 5.

3.2.2.4 Construction of the N-P TOD index. The developed and enhanced Bertolini's N-P model was used to determine the potential for TOD type development along the gold metro line. The following steps were adopted to assess the station areas:

1. The selected indicators were scored and weighted appropriately as discussed in the following sections.

2. Next, the node index (NI) was calculated for each of the station areas as mean of the node (transit) indicators.

3. Similarly, the place index (PI) was calculated for each station area as mean of the place (urban development) indicators.

4. These indexes were then plotted in the N-P graph, where slope of the N-P graph at each marked station provided the N-P TOD index.

N-P TOD index = $\dfrac{\text{Node index}}{\text{Place index}}$

The derived N-P TOD index provided a platform to determine the TOD potential as well as to compare, analyse and assess the Doha gold line metro stations.

3.2.2.4 Result Interpretation. Interpretation of the results were based on the plotted N-P graph and N-P TOD index values. The following steps were adopted (Figure 16):

1. The N-P graph was used to classify the stations into typologies, namely balanced, unbalanced place, unbalanced node, stressed or dependent stations. This enabled to determine the state of balance of transport and land use functions in transit station areas. Also, this assisted in identifying potential for TOD type development and measures to implement it through appropriate node-place indicators.

2. Further, radar diagrams were developed using the scored, weighted node and place indicators for each of the station areas. The diagrams indicated and pointed out the aspects of node and place indicators which show the potential for being implemented or enhanced for developing TOD.

3. The results obtained from N-P graph, radar diagrams and correlation analysis (PCA), were used to substantiate and understand the strength of relation between the node and place indicators, most effective transportation and land use indicators required in in different station areas along the gold line. These results were examined for each station area, to address the aspects of node and place to be enhanced independently.

Finally, the research concludes by providing recommendations to facilitate TOD type development along the gold metro line stations in terms of node-place indicators.
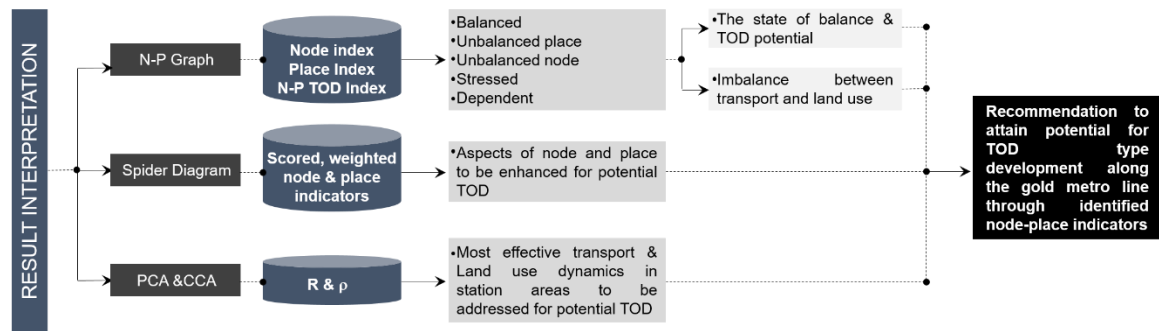
*Figure 16.*Interpretation of results to determine TOD potential (Source: Author, 2018)

3.3 Methods and techniques of Data collection and measurement

3.3.1 Methods to quantify station area characteristics. The research attempts to quantify the interrelation of transport and land use criteria in the stations along the gold metro line. For the purpose of research, measurement of station area characteristics is categorized into two areas of study namely: (1) Identification of criteria and indicator selection; and (2) Defining the station area (Figure 17). Thus, the node and place functions are established to measure the station area characteristics.

First, the section describes the process of identifying the important aspects of TOD and establishing criteria from the most appropriate aspects. Secondly, these criteria are elaborated into ideal indicators using appropriate principles of indicator selection (MCAP-Multi criteria analysis platform). Thirdly, these ideal indicators from different node-place model case scenarios are compared to arrive at appropriate selected indicators used in the research. The exclusion of these indicators is again based on the principles used in the

MCAP. Furthermore, these selected indicators are used for measuring the intensity and diversity of station areas and accessibility to the transit station. Finally, the method for defining the area of analysis around the metro station area is discussed.
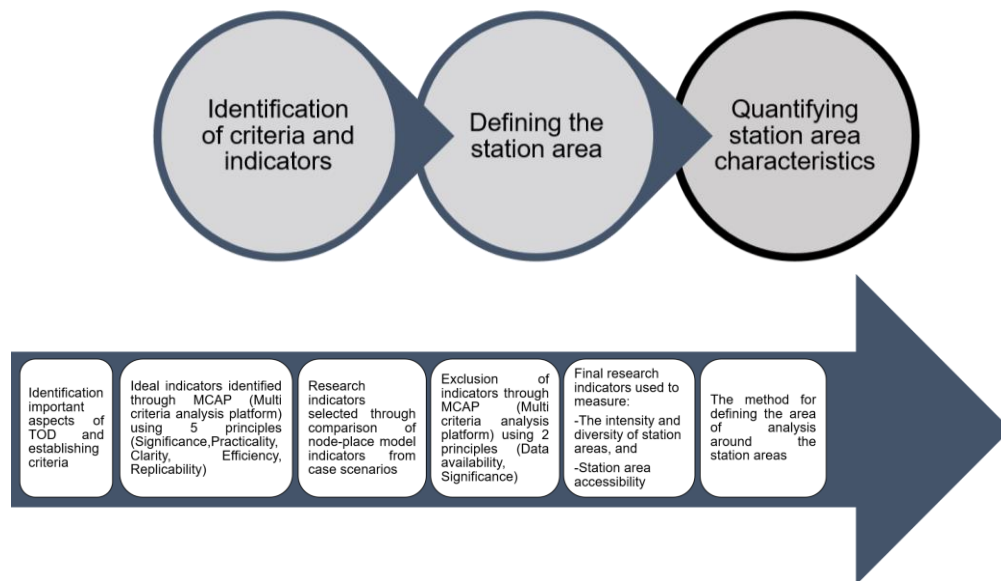
Figure 17. Measurement of station area and indicator selection (Source: Author, 2018)

The indicators described in this section form the input of Node-Place model in the following chapters. Also, station accessibility indicators, as well as intensity and diversity of activities indicators combine together to form the node and place functions.

3.3.1.1 Identification of criteria and indicators. Assessment and classification of stations for TOD potential, using Node-Place model, measures the orientation of the urban area developments towards the efficient use of public transit (Singh, 2012). Also, TOD defines itself in terms of both development as well as transit characteristics. Hence, measurement of criteria and indicators should necessarily define or characterize TOD in terms of nodes and places (Bertolini, 1999; Hendricks et al., 2005).

Indicator is defined as a quantifiable data which describes an occurrence and provides an assessment of the involved phenomena (Lukman, 2014). These serves as variables addressing development criteria with common goals. Also, Litman (2008), identifies indicators as numerical representation of selected variables measuring and addressing a particular objective. These objectives measured using various indicators are referred to as criteria. In this research, criteria point towards the selective ideal conditions necessary to promote important aspects of TOD. Thus, criteria-indicator combination provides a platform to access or quantify the contribution of each identified individual aspects towards promoting successful TODs.

The research employs 'deductive approach' to select the appropriate indicators. This top down approach is based on research results derived by researchers based on a scientific concept. First, an understanding was attained of Transit Oriented Development around transit nodes through literature reviews, which represented different interpretations of TOD concept. This in turn allowed to identify the main aspects to attain TOD in terms of balancing the node and place functions. Secondly, these important aspects were translated into criteria supporting TOD planning principles. Basically, these criteria were built within the framework using theories of Synergos, Transport land use feedback cycle

and Bertolini's Node-Place Theory. Finally, the indicators were selected based on these identified criteria from literature and various TOD case scenarios, which have used N-P model (Curtis et al., 2009), (Yang & Lew, 2009), (Howe et al., 2009), (Chorus, 2009), (Arrington, 2009), (Hoffman, 2006), (Cervero & Murakami, 2010). However, these indicators were selected based on their ability for progressive planning rather than recessive evaluation of station areas. Thus, the ability to measure the current situation, in addition to the changes brought about by introducing TOD strategies, was essential to determine the TOD potential in terms of node-place functions.

Many principles are available for selecting indicators of study based on literature. According to Haghshenas et al. (2012), indicators should be complete, quantifiable, clearly defined, easy to understand, independent, flexible with time changes, applicable in long term processes and reflect the required aspects of study. Also, Singh (2012) identifies indicators to have desirable characteristics which enable future assessment rather than backward evaluations, quantifiable, and both spatial and non-spatial. Thus, the principles for selecting the indicators are: (1) Reliability (documentation, validity, sensitivity); (2) Measurability (quantify, data availability) and; (3) Transparency (applicability, interpretability, relevance). As a result in this research, the criteria and indicators were selected based on operation possibilities, meaningfulness, reliability, data availability, applicability, transparency and appropriateness.

Based on literature review (2.2.2.2), two selection principles were identified for selecting the criteria and five selection principles for selecting the indicators (2.5.2.3). The criteria were defined using the below principles:

1. Significance – All the important interpretations, aspects and concepts of TOD should be represented by the criteria.

2. Completeness – All the aspects of TOD related to transport and land use functions should be covered by the criteria.

   Further, the ideal indicators were defined using the below five principles:

1. Significance – The indicator should be relevant towards TOD.

2. Practicality – The indicators should be applicable and measurable.

3. Clarity – The indicators should be direct and easy to understand and interpret.

4. Efficiency – The indicators should be less resource intensive in terms of availability of data and method of measurement.

5. Replicability – The indicators should be generic and applicable to contexts beyond the area of study.

   The indicators selected up to the above stage represent ideal indicators for the N-P model. The research attempts to measure the potential for TOD type development of station areas along the gold line using indicators applicable to the context. Therefore, all the above indicators cannot be included in the calculation of N-P TOD index and categorization of the station areas. Hence, the following two principles were used to exclude or modify the indicators to suit the research context. These can be enumerated as follows:

1. Data availability – The indicators for the study were excluded or modified to adapt with limitation of data resources and its availability for the study area.

2. Significance – Those indicators which were common and not variable between the stations within the corridor were excluded.

3.4.1.1.1 Criteria and Indicator selection. Measurement of TOD potential, deals with orientation of the urban area towards transit. Furthermore, since TOD is characterized by both transit and land use developments, both these aspects of node and place functions should be measured to arrive at an N-P index. On the basis of literature review and the above discussed governing principles, five aspects of TOD were selected to form the criteria. The node criteria include: (1) Accessibility to and from the station and (2) Parking at the stations. Also, the place criteria include: (1) Land use density, (2) Land use diversity and (3) Walkable environment (Figure 18).Thus, the selected criteria includes the 5D's as: (1) Density; (2) Diversity; (3) Design for pedestrians; (4) Destination accessibility; and (5) Distance to transit
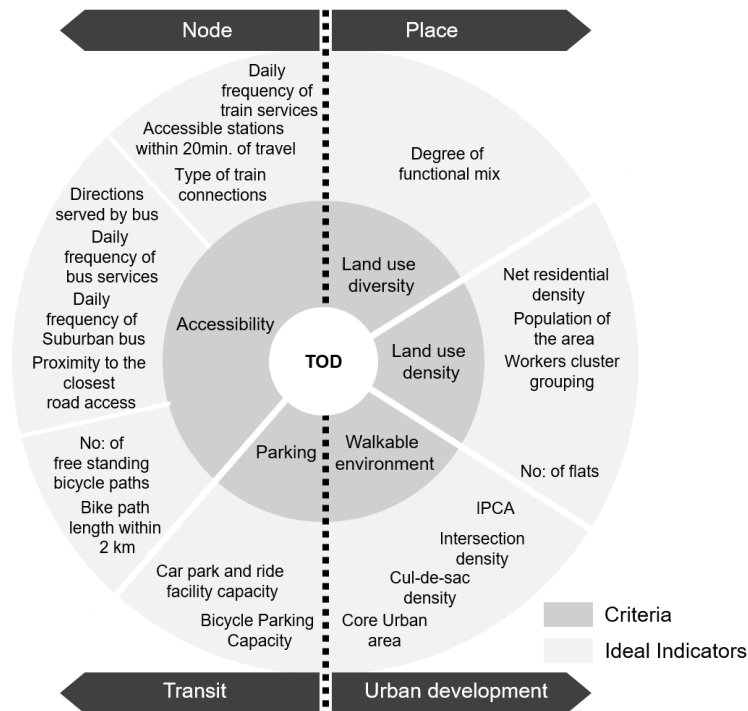
Figure 18. Node and Place criteria with ideal indicators (Source: Author, 2018)

The selected criteria are justified based on the fact that efficient operation of transit system is not possible without high transit supportive urban densities. Also, diversity of land uses provides balanced and consistent passenger flow. Similarly, walkable and pedestrian friendly built environment design encourages short cycle and bike trips. Furthermore, origin-destination access plays an important factor in evolving a TOD. The following part describes the various criteria and the related ideal indicators under two categories: (1) Station area and accessibility and; (2) Intensity and diversity of station areas.

3.4.1.1.1.1 Accessibility. Transport and land use planning is incomplete without accessibility. As discussed by researchers, accessibility is more important when compared to mobility. Undoubtedly, creating accessibility and interconnectivity of transit nodes is very important in accomplishing and assessing TODs (Cervero et al., 2008; Curtis et al., 2009; Singh, 2014). As a result, first criteria states that transit nodes must be easily accessible and provide efficient accessibility to the surrounding development area.

The criteria of accessibility was divided into three categories namely: (1) Accessibility by metro/ or public transport accessibility level (PTAL); (2) Accessibility by tram/bus; and (3) Accessibility by bicycle. Further, the three categories representing this criterion were sub- divided into ten ideal indicators (Table 2).These include: (1) Daily frequency of train services, (2) Number of directions served by train service, (3) Accessible stations within 20min. of travel time, (4) Type of train connections, (5) Directions served by bus, (6) Daily frequency of bus service, (7) Daily frequency of suburban buses, (8) Proximity to the closest road access, (9) Number of free standing bicycle paths, and (10) Bike path length within 2 km.

Table 2

Accessibility as Criteria and Ideal Indicators

Inputs	Criteria	Criteria aspects	Indicators
Node (Transit)	(1) Accessibility	Transit nodes must be easily accessible and must provide efficient accessibility to the surrounding development area.	<u>Accessibility by metro or Public transport accessibility level (PTAL)</u> (1) Daily frequency of train services (2) Number of directions served by train service (3) Accessible stations within 20min. of travel time (4) Type of train connections <u>Accessibility by tram/bus</u> (5) Directions served by bus (6) Daily frequency of bus service (7) Daily frequency of suburban buses (8) Proximity to the closest road access <u>Accessibility by bicycle</u> (9) Number of free standing bicycle paths (10) Bike path within 2 km

3.4.1.1.1.2 Parking. The configuration of parking facility to access transit station is one of the most important indicators to evaluate TOD. However, the focus should be directed to configuration of pedestrian friendly or motor free transport such as bikes and bicycles. Capacity of park and ride facility next to station areas should be considered in addition to the bicycle and bike parking facilities. Additionally, these car parking facilities also encourage commuters outside the station catchment area to take short trips to station

and then use the metro. As a result, the second criteria states that transit stations should facilitate optimum close proximity parking facility for diverse modes of transport.

The criteria of parking was divided into two ideal indicators (Table 3). These include: (1) Car park and ride facility capacity, and (2) Bicycle parking capacity.

Table 3

Parking as Criteria and Ideal Indicators

Inputs	Criteria	Criteria aspects	Indicators
Node (Transit)	(2) Parking	Transit stations should facilitate optimum close proximity parking facility for diverse modes of transport.	(1) Car park and ride facility capacity (2) Bicycle parking capacity

3.4.1.1.1.3 Land use density. One of the most important aspects under urban development of TOD is the densities of built environment within the catchment area (Lukman, 2014). Also, researchers highlight the significance of maintaining moderate to higher densities and intensifying residential land uses around station areas. As a result, the third criteria states that efforts are essential to maintain a minimum transit supportive density in a TOD.

The eleven ideal indicators used, represent this criterion covering details regarding population and workers (Table 4).These include: (1) Population of the area, (2) Net residential density, (3) Number of flats, (4) Workers cluster grouping, (5) Number of Jobs and (6) Net employment density.

Table 4

List of Land Use Density as Criteria and Ideal Indicators

Inputs	Criteria	Criteria aspects	Indicators
Place (Urban development)	(3) Land use density	Efforts are essential to maintain a minimum transit supportive density in a TOD.	(1) Population of the area (2) Net residential density (3) Number of flats (4) Workers cluster group: Retail/hotel and catering (5) Workers cluster group: Education/ health/ culture (6) Workers cluster group: Administration & service (7) Workers cluster group: Industry and distribution (8) Workers cluster group: Secondary sector (9) Workers cluster group: Tertiary sector (10) Number of Jobs (11) Net employment density

3.4.1.1.1.4 Land use diversity. Numerous experts address land use diversity as one of the important aspects of TOD (Calthorpe, 1993; Cervero et al., 2008; Curtis et al., 2009; Dittmar et al., 2004; Loo et al., 2010; Parker et al., 2002; Renne, 2007; Sung et al., 2011; & Lukman, 2014).Diversity of residential units and associated activities within the TOD catchment area around the transit nodes facilitates alternate choices for the residents. Hence, Cervero et al. (1997) expressed the significance of this criteria in terms of the 3D's (Density, Diversity and Design). As a result, the fourth criteria states that development surrounding the transit stations should necessarily be diverse in terms of land uses and activities to form vibrant and livable environments.

This criteria is expressed in terms of a single indicator referred to as degree of functional mix (Table 5).

Table 5

Land Use Diversity as Criteria and Ideal Indicators

Inputs	Criteria	Criteria aspects	Indicators
Place (Urban development)	(4) Land use diversity	Development surrounding the transit stations should necessarily be diverse in terms of land uses and activities to form vibrant and livable environments.	(1) Degree of functional mix

3.4.1.1.1.5 Walkable environments. A station area is clearly defined based on developments both residential and commercial, around transit stops within walkable distance. As discussed above, factors such as higher density, land use mix, connectivity and building design are essential for successful TOD. The integration of these factors within the catchment area of transit stop is determined by the accessibility accomplished through foot (Schlossberg et al., 2003). Thus, development of a pedestrian friendly environment complementing the 3D's is essential for TOD. As a result, the fifth criteria states that TOD should facilitate pedestrian friendly environment encouraging people to move by foot within the transit station area.

The four ideal indicators used include: (1) Intersection density, (2) Cul-de-sac density, (3) Core urban area, and (4) PCA (Pedestrian Catchment Areas) (Table 6).

Table 6

Walkable environment as Criteria and Ideal Indicators

Inputs	Criteria	Criteria aspects	Indicators
Place (Urban development)	(5) Walkable environment	TOD should facilitate pedestrian friendly environment encouraging people to move by foot within the transit station area.	(1) Intersection density (2) Cul-de-sac density (3) Core urban area (4) PCA (Pedestrian Catchment Areas)

Based on the above discussions and literature review of numerous case scenarios using Node-Place model, a list including details of all the ideal indicators identified and produced is presented in Table 7. These are considered as ideal indicators. Overall, the research identifies 5 criteria and 28 indicators.

Table 7

List of Criteria and Ideal Indicators

Criteria	Criteria aspects	Indicators
Node (Transit)		
(1) Accessibility	Transit nodes must be easily accessible and must provide efficient accessibility to the surrounding development area.	<u>Accessibility by metro or Public transport accessibility level (PTAL)</u> (1) Daily frequency of train services (2) Number of directions served by train service (3) Accessible stations within 20min. of travel time (4) Type of train connections <u>Accessibility by tram/bus</u> (5) Directions served by bus (6) Daily frequency of bus service (7) Daily frequency of suburban buses (8) Proximity to the closest road access <u>Accessibility by bicycle</u> (9) Number of free standing bicycle paths (10) Bike path within 2 km
(2) Parking	Transit stations should facilitate optimum close proximity parking facility for diverse modes of transport.	(11) Car park and ride facility capacity (12) Bicycle parking capacity
Place (Urban development)		
(3) Land use density	Efforts are essential to maintain a minimum transit supportive density in a TOD.	(13) Population of the area (14) Net residential density (15) Number of flats (16) Workers cluster group: Retail/hotel and catering (17) Workers cluster group:

		Education/ health/ culture
		(18) Workers cluster group: Administration and services
		(19) Workers cluster group: Industry and distribution
		(20) Workers cluster group: Secondary sector
		(21) Workers cluster group: Tertiary sector
		(22) Number of Jobs
		(23) Net employment density
(3) Land use diversity	Development surrounding the transit stations should necessarily be diverse in terms of land uses and activities to form vibrant and livable environments.	(24) Degree of functional mix
(4) Walkable environment	TOD should facilitate pedestrian friendly environment encouraging people to move by foot within the transit station area.	(25) Intersection density (26) Cul-de-sac density (27) Core urban area (28) PCA (Pedestrian Catchment Areas)

3.4.1.1.3 Indicator exclusion. Out of the 28 ideal indicators developed through indicator study, only 18 indicators were selected for the research (Figure 19). Firstly, some indicators were excluded due to intricacy of the methods to be adopted in measuring its characteristics and the limitations in availability of associated data. Secondly, common indicators with the same value for all the stations were excluded as these did not contribute significantly in developing the N-P index. Thirdly, certain indicators through literature review from case scenarios were omitted or modified based on their contextual

applicability and continuity of available data (Table 8). Next, indicators were also excluded due to possible errors related to human manual calculations providing distorted images. As a result, out of 28 identified indicators, 10 indicators were omitted for further analysis.

The node index representing the station area accessibility were represented using 9 selected indicators namely; (1) Daily frequency of train services, (2) Number of directions served by train service, (3) Accessible stations within 20min. of travel time, (4) Type of train connections, (5) Directions served by bus, (6) Daily frequency of bus service, (7) Proximity to the closest road access, (8) Number of free standing bicycle paths, and (9) Car park and ride facility capacity as shown in Table 9. The reasons for excluded indicators are as shown in Table 10.
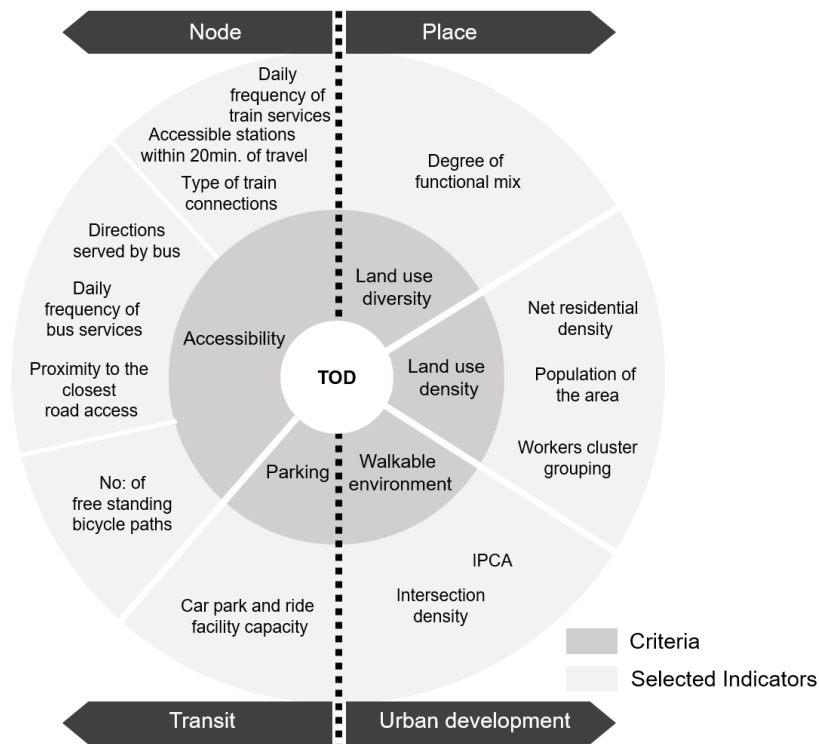
Figure 19. Diagram representing the selected indicators of study (Source: Author, 2018)

Table 8

Selection of Indicators from Reviewed Case Scenarios using N-P model

Ideal Indicators	Bertolini (1999)	Reusser et al. (2008)	Chorus, Bertolini (2011)	Zemp et al. (2011)	Ivan et al (2012)	Kamruzza man (2014)	Sele cted
Node Index (Transit – Measuring station area and accessibility)							
(a) Accessibility							
Daily frequency of train services	x	x		x	x	x	y_1
Number of directions served by train service	x	x	x		x		y_2
Accessible stations within 20min. of travel time		x		x			y_3

Type of train connections			x				y_4
Directions served by bus	x	x	x				y_5
Daily frequency of bus service	x	x		x	x		y_6
Daily frequency of suburban buses					x		
Proximity to the closest road access	x	x					y_7
Number of free standing bicycle paths	x						y_8
Bike path length within 2 km		x					

(b) Parking

Car park and ride facility capacity	x				x		y_9
Bicycle parking capacity	x						

Place Index (Urban development – Measuring Intensity and diversity at station areas)							
(b) Land use density							
Population of the area	x	x	x	x	x		x_1
Net residential density						x	x_2
Number of flats					x		
Workers cluster grouping							
Number of workers in :							
1. Retail/hotel and catering					x (5 & 6)		x_3 (1)
2. Education/ health/ culture	x (1-4)	x (5 & 6)	x (1-4)				x_4 (2)
3. Administration and services							x_5 (3)
4. Industry and distribution							x_6 (4)
5. Secondary sector							
6. Tertiary sector							

	Netherlands	Switzerland	Japan	Switzerland	Czech Rep.	Australia	Qatar
Number of Jobs				x			
Net employment density						x	
(d) Land use diversity							
Degree of functional mix	x	x	x			x	X[7]
(e) Walkable environment							
Intersection density						x	X[8]
Cul-de-sac density						x	
Core urban area					x		
PCA (Impedance Pedestrian Catchment Areas)			x				X[9]
Case study scenarios							
Study area	Netherlands	Switzerland	Japan	Switzerland	Czech Rep.	Australia	**Qatar**
Number of station areas	31	1684	99	1700	11	1734	**10**
Buffer size (walkable distance)	700 m	700 m	700 m	700 m	700 m	800 m	**700 m**
Number of Indicators used	15	11	9	5	10	6	**15**

Table 9

List of Selected Node Indicators

Inputs	Criteria	Criteria aspects	Indicators
Node (Transit)	(1) Accessibility	Transit nodes must be easily accessible and must provide efficient accessibility to the surrounding development area.	Accessibility by metro or Public transport accessibility level (PTAL) (1) Daily frequency of train services (2) Number of directions served by train service. (3) Accessible stations within 20min. of travel time

		(4) Type of train connections
		Accessibility by tram/bus
		(5) Directions served by bus
		(6) Daily frequency of bus service
		(7) Proximity to the closest road access
		Accessibility by bicycle
		(8) Number of free standing bicycle paths
(2) Parking	Transit stations should facilitate optimum close proximity parking facility for diverse modes of transport.	(9) Car park and ride facility capacity

Table 10

List of Excluded Node Indicators with Reasons

Indicators	Exclusion reason
Node Index (Transit – Measuring station area and accessibility)	
Accessibility	
Daily frequency of suburban buses	• Unavailability of a single data source on suburban buses per directions applicable to the context. • Possibility of manual errors in counting bus lines resulting in distorted image.
Bike path length within 2 km Parking	• Unavailability of data on bicycle lanes.
Bicycle parking capacity	• Unavailability of data on bicycle parking capacity.

The place index representing intensity and diversity of station area activities were represented using 9 selected indicators namely; (1) Population of the area, (2) Net residential density, (3) Workers cluster grouping (4/5/6), (5) Degree of functional mix, (6) Intersection density and (7) PCA as shown in Table 11. The reasons for excluded indicators are as shown in Table 12.

Table 11

List of Selected Place Indicators

Inputs	Criteria	Criteria aspects	Indicators
Place (Urban development)	(3) Land use density	Efforts are essential to maintain a minimum transit supportive density in a TOD.	(1) Population of the area (2) Net residential density (3) Workers cluster grouping in Retail/hotel and catering (4) Workers cluster grouping in Education/ health/ culture (5) Workers cluster grouping in Administration and services (6) Workers cluster grouping in Industry and distribution

(3) Land use diversity	Development surrounding the transit stations should necessarily be diverse in terms of land uses and activities to form vibrant and livable environments.	(7) Degree of functional mix
(4) Walkable environment	TOD should facilitate pedestrian friendly environment encouraging people to move by foot within the transit station area.	(8) Intersection density (9) PCA (Impedance Pedestrian Catchment Areas)

Table 12

List of Excluded Place Indicators with Reasons

Indicators	Exclusion reason
Place Index (Urban development – Measuring Intensity and diversity at station areas)	
(a) Land use density	
Number of flats	• Difficult to obtain.
Workers cluster grouping Number of workers in : • Secondary sector • Tertiary sector	• Anticipated similarity of data (to be analyzed) with other selected indicators used in the study. • Repetition of sub-divisions already analyzed by the indicator.
Number of Jobs	• Unavailability of data on employment of residents within the transit station. • Anticipated similarity of data to be analyzed with other selected indicators used in the study.

Net employment density	• Unavailability of data on employment of residents within the transit station. • Anticipated similarity of data (to be analyzed) with other selected indicators used in the study.
(b) Walkable environment	
Cul-de-sac density	• Not relevant to the context in majority of the stations.
Core urban area	• Not relevant to the context in majority of the stations. • Anticipated similarity of data (to be analyzed) with other selected indicators used in the study.

3.4.1.1.4 Indicator data sources. The data required for measuring station area indicators were collected for a year only due to unavailability of data. Also, an attempt was made to increase the model accuracy by maintaining qualified, common, reliable data sources for these indicators. This maintained a balance between the number of indicators and general trends used in data collection. Hence, quantitative data was obtained through Census data (MDPS), GIS data, interim land use maps (MME), Qatar Rail journey planner time tables, Qatar Rail geo maps, public transportation schedules (Mowasalat time table), Greater Doha bus service maps and traffic impact study data.

The census data were retrieved from Ministry of Development Planning and Statistics. This contained information on the population and number of jobs, grouped into number of job categories. These numbers were obtained from a geographic information system (GIS) based on location and descriptive attributes. Also, land use intensity and diversity details were calculated/interpreted/obtained from the interim land use planning maps. Further, train accessibility details were interpreted from Qatar Rail Journey planner timetable data. These datasets obtained from the journey planner generally include trip

origin, destination, transfer locations, arrival and departure times, trip purpose, mode and

duration. Table 13 represents the selected indicators and associated data sources.

Table 13

List of Selected Indicators and Data Sources

Indicators	Data Sources
Node Index (Transit – Measuring station area and accessibility)	
(a) Accessibility	
Daily frequency of train services	• Rail Geo Maps (Qatar Rail) • Rail Journey Planner (Qatar timetable data)
Number of directions served by train service	• Rail Geo Maps (Qatar Rail) • Rail Journey Planner (Qatar timetable data)
Accessible stations within 20min. of travel time	• Rail Geo Maps (Qatar Rail) • Rail Journey Planner (Qatar timetable data)
Type of train connections	• Rail Geo Maps (Qatar Rail) • Rail Journey Planner (Qatar timetable data)
Directions served by bus	• Public Transportation schedules (Mowasalat timetable data) • Greater Doha Bus Service Map
Daily frequency of bus service	• Public Transportation schedules (Mowasalat timetable data) • Greater Doha Bus Service Map
Proximity to the closest road access	• Interim land use planning maps (MME)
Number of free standing bicycle paths	• Interim land use planning maps (MME) • Site observation / Photographs
(b) Parking	
Car park and ride facility capacity	• Traffic impact study (MME) • Interim land use planning maps (MME)

Place Index (Urban development – Measuring Intensity and Diversity at Station Areas)	
(c) Land use density	
Population of the area	• Census data (MDPS)
	• GIS data (MME)
	• Interim land use planning maps (MME)
Net residential density	• Census data (MDPS)
	• GIS data (MME)
	• Interim land use planning maps (MME)
Workers cluster grouping	• Census data (MDPS)
Number of workers in :	• GIS data (MME)
• Retail/hotel and catering	• Interim land use planning maps (MME)
• Education/ health/ culture	
• Administration and services	
• Industry and distribution	
(d) Land use diversity	
Degree of functional mix	• Interim land use planning maps (MME)
	• Objective formulae calculation
(e) Walkable environment	
Intersection density	• Traffic impact study (MME)
	• Interim land use planning maps (MME)
	• Site observation / Photographs
PCA (Pedestrian Catchment Areas)	• Interim land use planning maps (MME)

Based on the above discussions, selected indicators and data sources, the research attempts to obtain a single outcome from 18 indicators.

3.3.1.2 Defining the station area. Measuring the station area requires analysis of activities and traffic flow within a station area, especially around the transit nodes (Lukman, 2014; Sanders, 2015; and Singh, 2015). First, definition of station area was required. As pointed out by researchers, the area of influence is defined as catchment area for measuring only traffic flow on railway lines. This is represented based on Voronoi diagram as shown in Figure 20 and takes into account only the accessibility characteristics neglecting the station area surrounding land use activities. However, the research attempts

to analyse the relationship between transit and surrounding station area activities. Therefore, definition of station area to determine the station influence should encompass the measurements for both traffic movement patterns and associated activities. As a result, the station area influence, as defined by Bertolini (1999), was considered for research (Sanders, 2015). This is defined as an area surrounding the transit station within a particular radius as shown in

Figure 21.
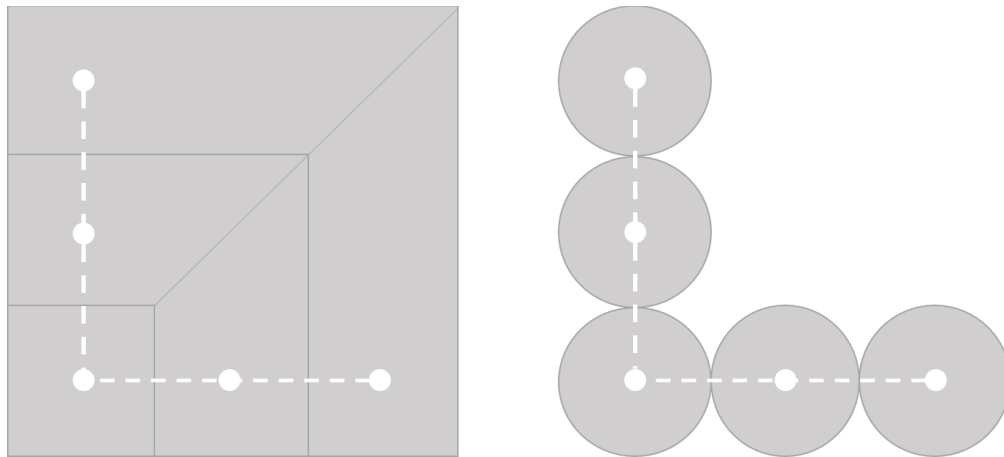
Figure 20. Catchment area and action radius for defining station area of analysis (Source: Author, 2018)

The area of influence of TOD is thus, walking limit from the transit station. As argued by authors, various limits exist for defining the pedestrian walkable limits. According to Schlossberg et al. (2003), reasonable satisfactory walkable distance within an urban environment range between 400-800m. Whereas, studies conducted by Calthrope

(2003), point out that 600m radius is the most preferred and comfortable walking distance. Additionally, Bertolini (1999), defines 700m as the most comfortable radius from the pedestrian entrance to the transportation node. Overall, these assumptions are based on the willingness of public to walk for not more than 10min. from the station to reach their destinations. Thus, as inferred from previous discussions, research utilized circular buffers of radius 700m around transit stations as area of influence referred to as 'area of analyses'.
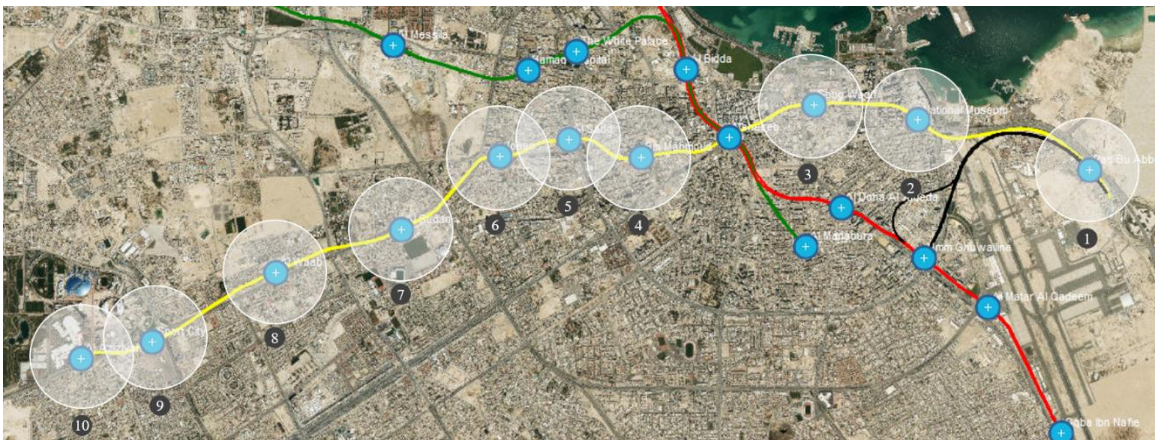
Figure 21. Station area influence as defined by Bertolini (1999) - an area surrounding the transit station within a particular radius of 700m (Source: Author, 2018)

For the purpose of research, 700m area of influence was assumed to be sufficiently dense with activities within walkable distance. Thus, all the activities outside the area of analysis was neglected in analysing the station area surroundings. Also, practically, the road networks were not accessed always along the radius, but with deviation along the available road infrastructure. Additionally, in areas were buffer overlapped, overlapping area was calculated twice for the associated indicators.

3.3.2 Methods to quantify node-place function indicators. This section deals with the quantifying node and place indicators for determining the N-P TOD Index. For this purpose, the indicators were divided into two categories: spatial and non-spatial. Non-spatial indicators such as number of directions served by train service, daily frequency of buses etc. were calculated using direct observations or available statistical data, without taking the spatial aspects around the station into consideration. On the other hand, spatial indicators such as density of population of the area, workers cluster grouping etc., required calculations which involved spatial analysis parameters of station area. Furthermore, the process of calculation of spatial indicators were directly affected by the 700m defined station area of analysis, whereas non-spatial indicator calculations were not dependent on this buffer size

Figure 21.
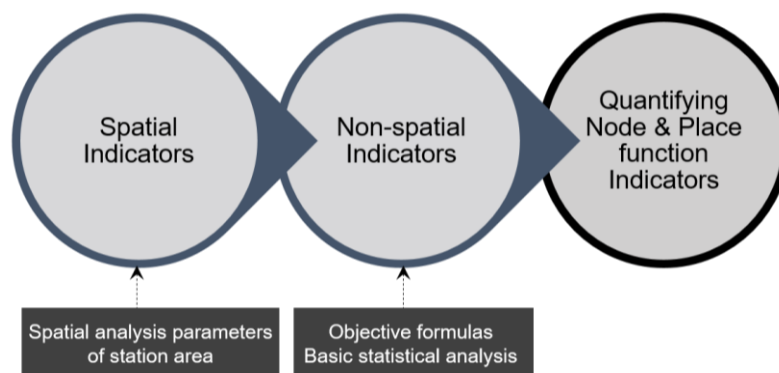
Figure 22. Quantifying node-place indicators-spatial; non-spatial (Source: Author, 2018)

The non-spatial indicators were calculated using objective formulas involving basic statistical analysis such as sum, average, maximum or minimum. These were derived directly from planning and land use maps, GIS data and observational data. However, the spatial indicators employed a variety of methods for their calculation. Thus, the following section describes the methods used to quantify the place indicators followed by node indicators.

3.3.2.1 Calculating intensity and diversity of activities. Intensity and diversity of activities within the station area are described by the 3 D's density, diversity and design oriented pedestrian design. As described in Table 13, land use activities within the station area were measured using the census data, GIS data and interim land use planning maps. The census data provided information on the population (residents), number/type of employment opportunities and number of employees in particular work categories. Furthermore, pedestrian friendly design indicators were measured using information obtained from the observational photographs and interim land use planning maps.

Prior to the calculation of indicators, processing the data obtained from the primary and secondary sources into useable information was very important (Sanders, 2015). Thus, the method of data processing was divided into three phases as discussed below and each solved accordingly to measure the indicators.

3.4.2.1.1 Data processing. The method of data processing was divided into three phases as follows:

1. Sorting the collected raw data from census and interim land use planning maps;

2. Translating the census data of different zones into station area data requirements; and

3. Solving the overestimation of area population and work force resultant data due to overlap between station area buffers. Also, the zones as well as blocks were irregularly shaped.

Thus, all the activity areas were not covered within the walkable distance of station areas, and certain activity areas only partially covered. As a result, the population as well as workers under different categories could not be obtained directly from the data.

Figure 23. Determining fractions of the zones as correction measure -Bin Mahmoud, Al Sadd, Joaan and Sports City (Source: Author, 2018)

Firstly, the census data from zones and municipalities were translated into the station areas. Hence, the population and worker numbers were directly used of the zones and blocks which were covered under walkable distance of the station areas as discussed by Chorus (2012). Additionally, a number of stations along the gold metro line such as Al Waab, Joan, Sports city have overlapping walkable station areas (

Figure 23). Therefore, the workforce and population of these overlapping areas were divided according to the principle of nearness (Sanders, 2015). Accordingly, the population and worker numbers were not added in the attractiveness of both the stations with an overlapping area of analysis. The numbers were considered as part of the nearest station so as to avoid overestimation of development or duplication of the indicators (Sanders, 2015).

For the purpose of study, variations encountered due to shape of the zones and blocks was accounted for, by redefining the edges or recalculating the particular zones. Also, the population of the areas were assumed to undergo a continuous change over a period of years (constant population density). This may result in either an underestimation or overestimation of effects on station usage and indicator relationships. Thus, in order to minimize the errors without affecting the results of the analysis, the data of a minimum of only three years is takes into consideration.

3.4.2.1.2 Population. Population is one of the important spatial indicators, which is approximated using the proportion of area of residential land use. Scholars suggest that population is an evaluator measuring the residential population size of an existing station area (Lukman, 2014). Also, the larger the population, greater the TOD potential due to attraction from local market supporters. Thus, measurement of the population of station area surroundings is essential to calculate the N-P TOD index.

The approximate number of population within the station area was calculated based on the proportion of residential land use of each of the neighbourhoods within the zonal outlines encompassing 700m buffer zone of the station area. This was based on the area of residential blocks in the zones within the TOD radius (Sanders, 2015). Also, the station

buffer zone areas may not necessarily include a single zone. This is due to the location of the metro station at the intersection of multiple zones or spreading across different municipalities. In such a case, an approximate fraction which is roughly equivalent to the area of the zone falling within the buffer zone was calculated. This was then respectively used as a correction measure to the population calculated for each zone. Thus, this method was used to obtain an approximate resident population (persons) per station area.

Previous literatures suggest that population decreases as the movement progresses away from the station centers. One possible reason may be due to the high standard of living and mixed activities in the center which attract sufficient employment. Also, this trend may be due to the geographic location occupied by the station itself. Furthermore, studies also reveal that the increase of population is observed over period of years. Thus, for the purpose of study all station areas were generalized without taking into consideration the aspects of living cost, geographic location, category of population or population changes through time. Additionally, duplication is avoided by considering the residential and worker population as two distinct indicators.

3.4.2.1.3 Net residential density. This indicator involves the calculation of residential population density within the station area radius. It is an extension or clear definition of residential population per unit of the TOD area (Singh, 2015). Additionally, the net residential density provides an understanding of the larger population with the proximity and potential to use the transit (Lukman, 2014). Thus, the indicator gives a clear idea of the station area to perform as potential TOD in terms of its persistent potential users.

The net population density was calculated by dividing the number of residents within the station area by the assumed buffer area. The population (persons) used in this

indicator calculation was derived from the previously calculated population indicator. For the purpose of study, this indicator assumed the same aspects as those discussed earlier for population.

3.4.2.1.4 Workforce clustering. The categorization of population within the study area in terms of activities related to work is essential to completely describe the intensity and diversity of activities in the station areas (Chorus, 2012). Workforce was clustered into four different economic clusters namely-Retail/hotel and catering, Education/ health/ culture, Administration and services, and Industry and distribution. The first cluster included workers in the retail, hotel and catering sectors, which is an indicator of the number of leisure activities in the station area. Also, the second cluster represented the office workers engaged in the education, health and culture. The third cluster represented the division of workers in office jobs and general services. However, the fourth cluster indicated the intensity of agriculture in the station areas. These four clusters provided an understanding of the activities which took place in the station areas along the network. Thus, this indicator enabled to track the percentage contribution of activities within the station area and identifying active and passive land uses attracting workers from within the transit station or adjacent station areas resulting in favourable TOD conditions.

Each of the workers cluster groupings were measured in terms of the number of workers employed in the assigned activities within 700m study area of the station. This indicator was calculated to obtain a single number, where employees in different sectors (origin-destination) within the station area municipality was obtained from the Census data (MDPS). GIS data (MME) provided the extracted information of the employees within the

station area and interim maps provided the area to be concentrated on for study (MME). Finally, the concentration of indicator was on determining the number of employees within the station area.

For the purpose of study, each of the workforce clusters include the type of activities taking place in the station area along the network. The grouping of activities within each of the clusters were decided so as to avoid overlap of the population involved. Furthermore, each of the clusters included more than one category of activities so as to reduce the number of clusters and to avoid duplication. This resulted in developing independent separate economic clusters.

3.4.2.1.5 Degree of functional mix. As discussed by scholars, stations may perform as a local, regional or national centers, which in turn affects the quantity and diversity of functions in the station area. Also, each station executes a different role in the transportation network (Chorus, 2012). In addition to measuring the intensity of land uses, it is essential to measure its diversity. This was measured by the objective formulae calculation of degree of functional mix, providing an insight into the role of the station area. Measuring this indicator provided an understanding of the functional activities which a particular station fulfils within the network. Most importantly, this indicator identifies not only the type of station but also measures whether the station acts as a residential center, an economic hub, a spatial culmination for culture, leisure, an entertainment center or a mix of all these functions together. Additionally, the diversity of land use activities within a station area is one of the 5D's shaping a successful Transit Oriented Development (TOD). As a result, measurement of degree of functional mix forms an important aspect of analysis of the station area characteristics.

The degree of functional mix was calculated using an objective formulae as shown below, where population (x_1) and the four defined worker cluster groups (x_2, x_3, x_4 and x_5) were the inputs.

Degree of functional mix $\quad = 1 - \dfrac{\left(\left(\frac{a-b}{d}\right) - \left(\frac{a-c}{d}\right)\right)}{2}$ $\quad with \begin{cases} a = max\{x_1, x_2, x_3, x_4\} \\ b = min\{x_1, x_2, x_3, x_4\} \\ c = Average\{x_1, x_2, x_3, x_4\} \\ d = Sum\{x_1, x_2, x_3, x_4\} \end{cases}$

Equation 1. Degree of functional mix

The formulae is based on the assumption that equality in size of each of the input indicators result in a perfect functional mix. The maximum value measured by the indicator is 1. The omission or absence of any of the input variables results in minimum functional mix. The number obtained as functional mix gave an insight into the relationship between the different stations. The functional mix increases with distance from the sub-centers or due to distribution of workers in different cluster groups (Sanders, 2015). Since, the results are represented as ratios, rescaling of indicators is not required prior to calculation.

3.4.2.1.6 Intersection density. According to scholars, intersections along the roadways provide alternate shorter routes for the pedestrians and cyclists. This increases the options of walking and cycling due to reduced travel distance. Comparatively, grid-system streets offer greater connectivity and walkability when compared to tree-like streets. According to Erwin and Cervero (2010), higher density of intersections mean higher walkability and cyclability due to the availability of choice to possibly shorten their paths. Likewise, the public transit use and walkability increase due to higher intersection

density and reduced motor travel (Malaitham, Fukuda, Vichiensan & Wasuntarasook, 2015).

Intersection density is defined as the number of intersections per sq. km within the area of 700m around the station area of analysis. This was determined by counting the number of intersections formed by the different hierarchy of road networks around the station area divided by the catchment area in km^2 (Singh, 2015) (Figure 24).
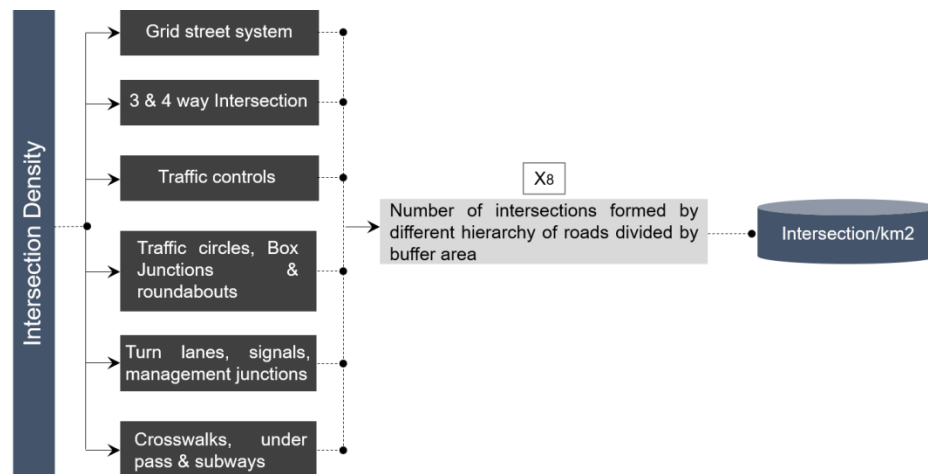
Figure 24. Calculation of Intersection density in station areas (Source: Author, 2018)

For the purpose of study, all the possible types of intersections were considered. These include intersections formed by the major arterials, arterials, street-patterns like grid street system, number of road segments (3 and 4 way intersections), traffic controls (uncontrolled, yield, stop and signal controlled intersections), lane design (traffic circles, box junction and roundabouts), turns (turn lanes, turn signals, lane managements junctions) and pedestrian aids (crosswalks, underpasses and subways).

3.4.2.1.7 Pedestrian catchment area (PCA). The PCA indicator is a tool used to measure the walkability within the potential TOD area. Also, this tool evaluates proximity which represents the reach and coverage of pedestrian networks within a designated area (Malaitham et.al, 2015). Pedestrian Catchment Areas (PCAs) are defined as definite areas within a metro station catchment area, which can be covered by walking within a specified time frame (5-10 min.). Also, referred to as Pedestrian-shed (Ped-shed), this is used as a means to suggest and compare improvements in locations for walkability and connectivity (Active Healthy Communities (AHC, 2018). PCA represents a ratio between the pedestrian network buffer and the Euclidean station walking distance buffer (Figure 25). This value ranges between 0 and 1, with figure closer to 1 representing the highest level of walkable coverage area (Lukman, 2014; Singh, 2015). Thus, the indicator was measured by calculating the possible pedestrian networks in the area of analysis.

Figure 25. PCA (Pedestrian catchment area) of Bin Mahmoud, Al Sadd and Joaan station areas (Source: Author, 2018)

Ped-shed ratio of each node-place site was calculated from the data obtained from interim land use planning maps. First, pedestrian catchment area of 350m was demarcated within the 700m defined area of analysis of each station (Figure 25). Second, the walkable distance from a destination along the pedestrian routes were measured which provided the actual walking distance. This was shaded inside the circle of 350m. Third, the possible destinations such as buildings, parks etc. were identified within 5 min. walking distance. The area surrounding these destinations after removing the motorways, non-walking segments and pedestrian paved paths of the major streets, represented the walkable catchment area. Finally, the score was calculated as a percentage of the maximum area which could be covered within 5 minutes under ideal situation (700m).

For the purpose of study, the pedestrian networks were considered as two way streets keeping in mind the reality of pedestrians to move in both directions (AHC, 2018).

3.3.2.2 Calculating station area accessibility. Accessibility within the station area are described by the 2 D's, distance to transit and destination accessibility. As described in Table 13, accessibility was measured using information form Rail Geo maps, Rail Journey Planner, Public Transportation Schedules and Greater Doha Bus Service maps. These data provided direct information on the number of directions, frequency of operation and station types. Furthermore, data from the interim land use planning maps and traffic impact study reports were used to determine the activities and station types.

Since, these indicators are not directly dependent on spatial analysis, the data obtained were directly used to measure the indicators.

3.4.2.2.1 Number of directions served by the train. Number of directions served by the train indicates the number of directions to which the train provides direct access after originating from a station. These are dependent on the number of lines intersecting the station area in different directions. Accordingly, studies suggest that a terminus station such as Ras Bu Aboud or Al Azeeziya, have one direction of travel, through stations such as Al Waab, Joan or Al Sudan have two directions of travel and interchange stations such as Msheireb, where multiple lines intersect have three or more directions (Figure 26). Thus, the number of directions served by the station was obtained from Qatar Rail Geo maps.
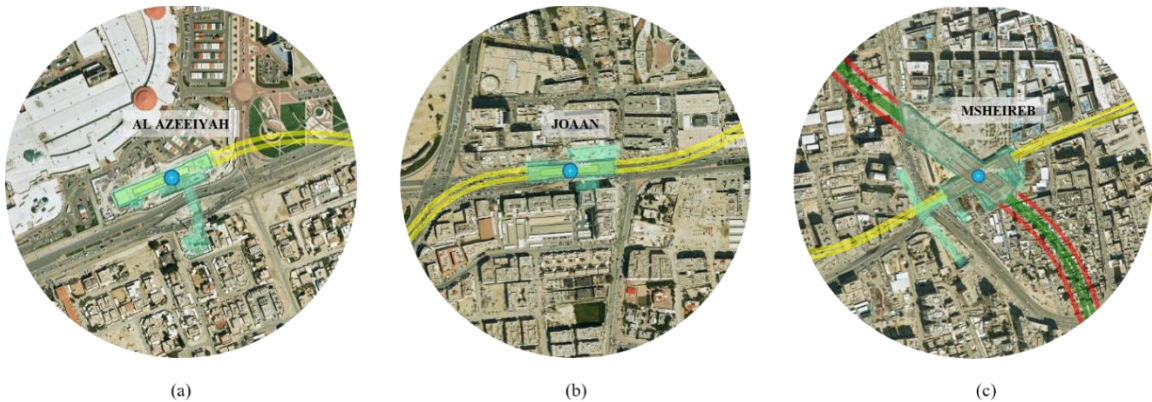
Figure 26. Representation of the three station types (a) Terminus station, (b) Through station, (c) Interchange stations (Source: Qatar rail, 2018)

It is assumed that the general direction of travel is considered as the same for two connecting stations. For ease of calculation, the number of adjacent stations served was considered as the number of directions served by the train.

3.4.2.2.2 Daily frequency of train operations. Frequency of train service provides a measure of accessibility by transit. The daily frequency of operation is based on the number of trains departing from each station within the busiest hour. This is measured in terms of trains crossing a particular station at the peak hour (Sanders, 2015). On the other hand, the maximum number of trains passing through a station within a defined timeframe (an hour) is considered as the indicator value. Indirectly, the indicator provides an understanding of the number of accessible train routes at a particular station. Literature studies suggest that higher number of train routes, increases the potential of transit due to increased number of connecting destinations. Additionally, frequency of operations also include interchanges measured at the stations with other transit modes such as bus-based systems. Hence, the daily frequency of train service is not measured as the total number of trains per day, but represented as the frequency during peak hours (an hour).

The daily frequency of train service was measured as number of trains crossing station per peak hour (number/hour) using the data obtained from the Qatar Rail Journey planner. The availability of trains crossing a particular station during peak hours were computed by keeping either the origin or destination as constant and shifting the other.

For the purpose of study, frequency was measured during peak hours, although data was available for off-peak and night. Also, daily frequency was not considered as the number of train services offered in a day, but approximated to the services within an hour. Since, all the trains form part of rapid transit, the speeds were considered constant. Furthermore, the interchange with other modes of transit such as bus-based system was not considered in the calculation and assumed as null or insignificant.

3.4.2.2.3 Station types. The station type is determined by the frequency of the type of trains serving the station areas (Sanders, 2015). Although different types of trains exists such as expresses, semi-expresses, local etc., the Doha metro system is based on rapid transit with local and not local trains. The metro is assumed to uniformly reach a speed of about 60-100km/hr in all the stations. Thus, the station type was divided based on the location of station area as local and not local areas.

The station types were determined not on the basis of type of the train service, but on the type of service/connection offered. Thus, the stations were divided as local and not-local on the basis of the connected destinations. Also, these local and not-local station types were given a dummy value for the purpose of calculation. This dummy variable was then coded as 0 for local and 1 for not-local, which was nullified while calculating the N-P TOD index (Figure 27).
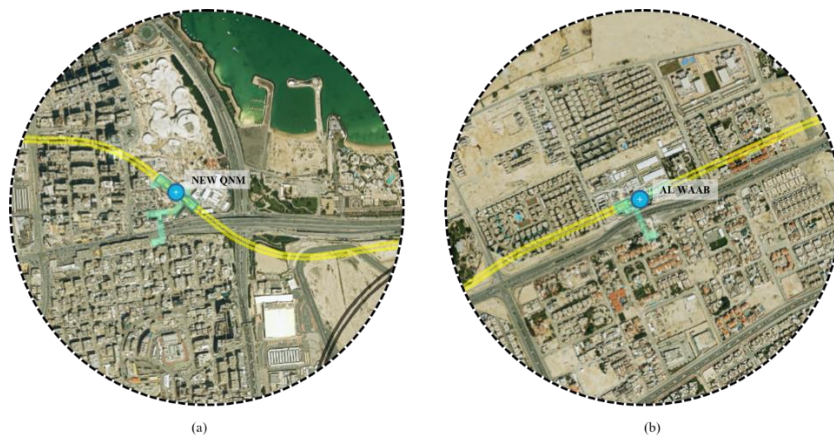
Figure 27. The two types of stations (a) Local station; (b) Not-local (Source: QR, 2018)

For the purpose of study, station types were determined without taking into context the time of arrival of the trains (peak, off-peak or night). Also, the types of stations were coded and categories limited to only two for the ease of calculation.

3.4.2.2.4 Accessible stations within a certain travel time or distance. Among the different accessibility indicators, availability of number of stations within a certain distance, cost or range of time, is very important. Studies conducted suggest that there are different methods to access this indicator which vary with accuracy and degree of implementation.

Among the three methods of accessing this indicator, due to the availability of data and accuracy of description, travel time of approximately 20min. was considered in place of travel cost and distance. Thus, the nearest stations which can be accessed within 20min. of travel time was calculated, from the Qatar Rail Journey Planner. This was calculated by fixing the origin and checking the travel time to destinations. Furthermore, destinations reached within 20min. was selected for the N-P model analysis.

For the purpose of study, this indicator was measured during the peak hours, to determine the possible destinations within 20min, in the general travel direction.

3.4.2.2.5 Direction served by bus. Number of directions served by the bus service indicates the number of directions to which buses provide direct access after interchange at a station. These are not necessarily dependent on the number of road access ways intersecting the station area in different directions. Additionally, these depend on the different routes undertaken by the buses crossing the station (Sanders, 2015). Accordingly, the number of routes made accessible by the buses passing the station during peak hour

was calculated for the research. This was translated from Public Transportation schedules (Mowasalat timetable data) and Greater Doha Bus Service Map for peak hour.

3.4.2.2.6 Frequency of bus services. A transit system of high quality offers not only accessibility to multiple destinations but also provides alternatives of interchanges to other transit modes (Singh, 2015). This indicator measures the accessibility at the metro stations provided by the interchange modes of transit. The daily frequency of bus services is based on the number of buses available at each station within the busiest hour (Lukman, 2014). Indirectly, the indicator measures the interchange to mode available at the station such as buses, trams or subways. Thus, the indicator gives an understanding of the availability of bus services at the interchanges.

This was measured in terms of availability of bus services during peak hours (Sanders, 2015). On the other hand, the number of bus transit serving the maximum number of trains passing through a station within a defined timeframe (an hour) was considered as the indicator value. Hence, the daily frequency of bus service was not measured as the total number of bus based systems per day, but represented as the frequency during peak hours (an hour). This was measured from the data obtained from the Public Transportation schedules (Mowasalat timetable data) and Greater Doha Bus Service map, where availability of bus transit as interchange mode were computed comparatively based on the timings of the metro and proximity of the bus system travel routes to the station areas. They were further divided into three categories as: no interchange available, on-street bus stops and off-street bus stops (Figure 28).

*Figure 28.*Images for off street bus terminus and on-street stops (Source: Hive mind, 2018)

For the purpose of study, the frequency was measured during peak hours, although data was available for every hour. Also, daily frequency was not considered as the number of bus services offered in a day, but approximated to the nearest bus service to any station within an hour. However, speeds of all the possible bus transits were considered constant.

3.4.2.2.7 Proximity to road access. This indicator measures the distance to nearby freeway or highway exit. This highway or freeway may be located within the station area or just outside the area of influence. Indirectly, this indicator measures the possibilities of accessing the metro station for public transit by users of the area of analysis and adjacent station.

The interim land use planning maps were used to measure the proximity to access road in terms of distance from the metro station. That is, distance to be travelled by a passenger to park his vehicle and access the metro service was obtained using this indicator. For the purpose of study, the road networks were not measured always along the radius, but with deviation along the road infrastructure.

3.3.3 Calculating node index & place index. As discussed above the node-place model utilizes 18 indicators to calculate the N-P TOD index. Among these, 9 indicators were used each to measure the node index and place index. Once, the indicators were calculated, the N-P TOD index was calculated from the node index and place index of each station.

As mentioned earlier, all the indicators were represented in different units. Thus, in order to compare and combine these, normalization of indicators was adopted, such that all indicators were reduced to a comparable range between 0 and 1 proportionately. Further, these indicators were equally weighted. Thus, node and place index for each station was determined as the mean value of corresponding weighted indicators. The resultant node and place index were then plotted in N-P graph. This enabled to identify the stations based on Bertolini's classification to fall under balanced, dependent, stressed, unbalanced place or unbalanced node typologies. Thus, TOD potential of stations along the gold line were analysed based on both TOD index and Bertolini's typologies (Figure 29).
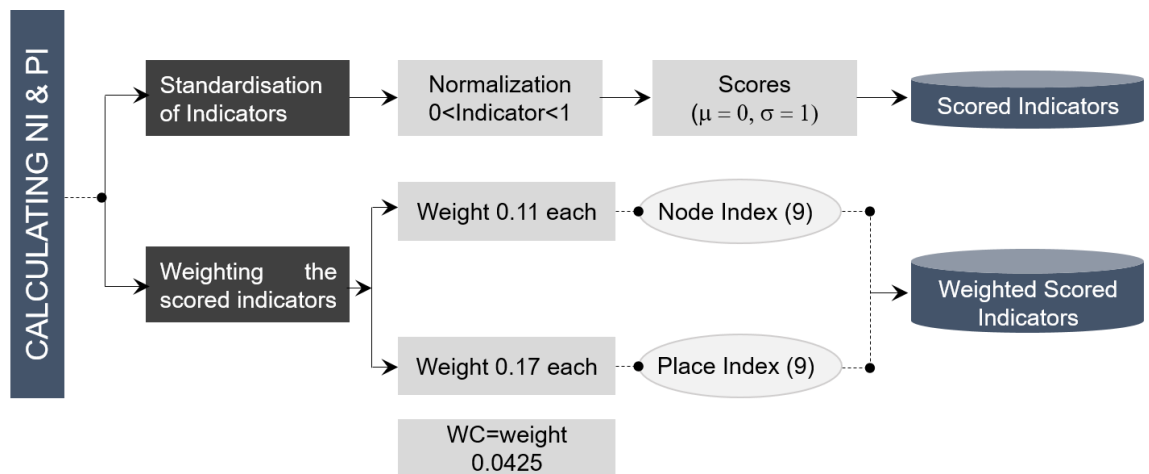
Figure 29. Diagram representing calculation of node-place index (Source: Author, 2018)

3.3.3.1 Standardizing the indicators. Identification of the indicators and its quantification provides an insight on how these indicators affect the TOD potential of station areas. This provided a base for identifying suitable method of standardization, since all the indicators calculated were represented in different units. The comparison and combination of these indicators for further calculation of the N-P TOD index was adopted by normalizing these indicators, to convert these indicators to a common identifiable scale between 0 and 1 (mean; $\mu = 0$ and standard deviation; $\sigma = 1$). This also reduced errors between the individual scores.

The scores were calculated separately for each indicator in the sample as the actual value minus the mean of indicator, divided by the standard deviation of the indicator (Appendix A). Thus,

$X' = \dfrac{(X_i - \mu)}{\sigma}$, where X' = score

X_i = Indicator value

μ = Mean of the sample

σ = Standard Deviation

The score took into account the standard deviation by providing the analysis of differences or similarities of each individual indicator from the sample. These normalized scores were then equally weighted as shown in Table 14.

3.3.3.2 Weighting the scored indicators. As observed from previous literature, emphasis was more on the urban development and on criteria such as density, diversity and pedestrian friendly environment. Although accessibility and parking were focussed for TODs, they were considered of lower priority. However, the research focus on both urban

development and transit. As a result, both the node and place indicators were weighted equally. However, equal weighting (EW) does not mean that the indicators were not weighted.

Node index was calculated using 9 indicators. Hence, each of the normalized indicator was assigned a weight of 0.11. Similarly, the place index was calculated using 9 indicators. These normalized place indicators were assigned a weight of 0.17. Further, the workers cluster grouping belonging to different categories were considered as one single indicator for weighting. Thus, each of the four clusters were divided and provided with individual weightings of 0.0425 as shown in Table 14.

Table 14

List of Node & Place Indicators with Weightings

Indicators	Weights
Node Index (Transit – Measuring station area and accessibility)	
Accessibility	
Daily frequency of train services	0.11
Number of directions served by train service	0.11
Accessible stations within 20min. of travel time	0.11
Type of train connections	0.11
Directions served by bus	0.11
Daily frequency of bus service	0.11
Proximity to the closest road access	0.11
Number of free standing bicycle paths	0.11
Parking	
Car park and ride facility capacity	0.11
Place Index (Urban development – Measuring Intensity and diversity at station areas)	
Land use density	
Population of the area	0.17
Net residential density	0.17

Workers cluster grouping	
Number of workers in :	
• Retail/hotel and catering	0.0425
• Education/ health/ culture	each
• Administration and services	
• Industry and distribution	
<u>Land use diversity</u>	
Degree of functional mix	0.17
<u>Walkable environment</u>	
Intersection density	0.17
PCA (Pedestrian Catchment Areas)	0.17

Finally, these scored weighted indicators for the node and place indices are calculated as below.

Node index=Mean of scored weighted transit indicators ($Y_1, Y_2, Y_3, Y_4, Y_5, Y_6, Y_7, Y_8, Y_9$)

Place index= Mean of scored weighted urban development indicators ($X_1, X_2, X_3, X_4, X_5, X_6$ X_7, X_8, X_9)

3.3.4 Calculating Node - Place TOD index. Node index and place index were plotted in the N-P graph for each station. The gradient of points on the graph was obtained as the ratio of vertical to horizontal change. That is, the slope of the N-P graph at each marked station point, provided the N-P TOD index for each station. This was further used for the analysis, comparison and assessment of potential for TOD type development.

Slope of N-P Graph (m) = <u>Vertical change (Y axis)</u> = <u>Node index</u> = **N-P TOD index**
Horizontal change (X-axis)   Place index

3.4 Summary

The assessment, analysis, comparison and classification of station areas include both theoretical and analytical approaches. The research design includes theoretical input; analytical model; and resultant output. The theoretical framework includes theories such as transport-land use feedback cycle, TOD planning principles focused on transit and urban development strategies and relevant literature related to TOD planning aspects in terms of quality, quantity and availability of transit system within appropriately dense, diverse and mixed use station areas. These serve as the input to identify appropriate criteria and indicators to quantify the N-P TOD index. Ideal indicators were selected through MCAP of reviewed literature using 5 selection principles.

The analytical model includes the development of the N-P model; enhancement of the N-P model for spatial analysis; determining the effectiveness of the model; construction of the N-P TOD index and interpretation of the results. The development of the model includes defining the node and place functions using the appropriate indicators. The node function denotes the station area and network accessibility, whereas the place index measures the distribution of land uses in terms of density and diversity around the station. Thus, the N-P model included 5 criteria and 28 ideal indicators. Enhancement of the N-P model includes selecting the ideal indicators to represent the node and place functions. Selected indicators of study were obtained as a result of exclusion criteria (2 principles) and comparative analysis of the 6 case scenario indicators using Bertolini's N-P model. Finally, the enhanced N-P model included 5 criteria and 18 indicators, 9 each for node and place index. Effectiveness of the model is established using statistical means-Pearson's Correlation Analysis (PCA) and Regression Analysis (RA) with confidence level of 95%,

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which determine the strength of relationship between the indicators. The correlation provides the relation between the indicators in terms of size and sign (positive/negative).

The model outcomes include N-P radar diagrams (10 stations), N-P graph, N-P TOD index for the station areas, and classification under Bertolini's node-place typologies (balanced, stressed, dependent, unbalanced place and unbalanced node). The scored, weighted indicators were used to calculate the node and place index of the 10 stations (through and terminus). This served as input for Bertolini's enhanced N-P model, was used to calculate the N-P TOD index. Slope of the N-P graph plotted using the node index and place index provided the TOD index. This ranked the station areas based on their potential to develop as TODs. The N-P graph classified the station areas into different typologies. This assisted in identifying potential for TOD type development and measures to implement it through appropriate node-place indicators. Radar diagrams indicated and pointed out the aspects of node and place indicators which show the potential for being implemented or enhanced for developing TODs.

Both quantitative and qualitative approaches of data collection and measurement were adopted to quantify the station area characteristics (node and place indicators). Qualified, common, reliable data sources for these indicators were obtained through Census data (MDPS), GIS data, interim land use maps (MME), Qatar Rail journey planner time tables, Qatar Rail geo maps, public transportation schedules (Mowasalat time table), Greater Doha bus service maps and traffic impact study data.

For measuring the station area, the research utilized circular buffers of radius 700m around transit stations as area of influence referred to as 'area of analyses'. This was assumed to be sufficiently dense with activities within walkable distance. In areas were

buffer overlapped, overlapping areas were calculated twice for the associated indicators. In order to quantify the node-place function indicators, they were classified as spatial and non-spatial. Spatial indicator calculations involved spatial analysis parameters of station area and employed a variety of methods for their calculation. On the other hand, non-spatial indicators were calculated using direct observations or available statistical data, without taking the spatial aspects around the station into consideration. Objective formulas involving basic statistical analysis such as sum, average, maximum or minimum were also used.

Data processing included three phases such as sorting the collected raw data; translating the raw data of different zones into station area data requirements; and solving the overestimation of area population and work force resultant data due to overlap between station area buffers. Transit indicators were measured during peak hours of 8:00am to 10:00am. Since, all the indicators were represented in different units, standardization of indicators was adopted using normalization method, where all indicators were reduced to a comparable range between 0 and 1 proportionately. Further, these indicators were equally weighted with weight of 0.11 for node indicators and 0.17 for place indicators. Finally, the node and place index for each station was determined as the mean value of corresponding weighted indicators.

Chapter 4: Research Context

Chapter 4 is divided into five sub-sections, which explores the Doha metro network system, present condition of the study areas, selection process - criteria undertaken for gold metro line corridor, and the node-place functions of individual station area of analysis along the selected line. The 10 stations (through and terminus) were assessed in terms of indicators of the N-P model. These include node functions under accessibility and parking conditions, and place functions under land use density, land use diversity and walkable environment. For the purpose of study, data described for metro stations based on their location such as regional, sub-regional, urban, sub-urban and transit stations areas, is followed by a comparative description of the stations for further assessment and classification to determine potential for TOD type development. Further, calculation of indicators for each of the station areas is described in Appendix-A.

4.1 The Doha metro network system

Qatar annual report (2014, 2016) highlights that the Doha metro network constitutes four lines connecting 93 stations with a total length of approximately 354km. These lines run through tunnels at underground level in central Doha and above ground as elevated overhead rail systems in the city outskirts. The four lines of Doha metro network are red line (under construction), green line (under construction), gold line (under construction) and blue line (planned) with expected completion of all phases by 2026 (Figure 30). According to Qatar Rail (2011), the Doha metro network is one among the six rail networks, which is planned to link the town centers, major venues, residential/commercial hubs and hotel/hospitality districts in Qatar. Also, links are

proposed connecting the national cities with Hamad International Airport and the Doha port.

First, the red line, also known as the coast line, starts from Al Wakrah in the south to Lusail in the north, running 55.7 km connecting 18 stations. Further, the line also connects the Hamad International Airport to the city center and allows passenger transfer with Lusail Tram (Qatar Rail Annual Report, 2016). Second, the east-west green line, also known as the education line, passes through education city connecting 31 stations for 65.3 km, starting from Al Riffa to Al Mansoura. Third, the gold line, also known as historic line, extends east-west for 30.6 km connecting 20 stations. However, the first phases witness the development of 11 stations from Ras Bu Abboud to Al Aziziyah (Qatar Rail Annual Report, 2016). These three lines radiate out from the largest Msheireb central interchange with an additional blue line providing a semi-orbital service with a length of 17.5 km and 4 stations (Qatar Rail, 2016). Thus, Doha metro system is anticipated to reduce congestion, offering sustainable alternate public transportation choices (Atkins, 2016).
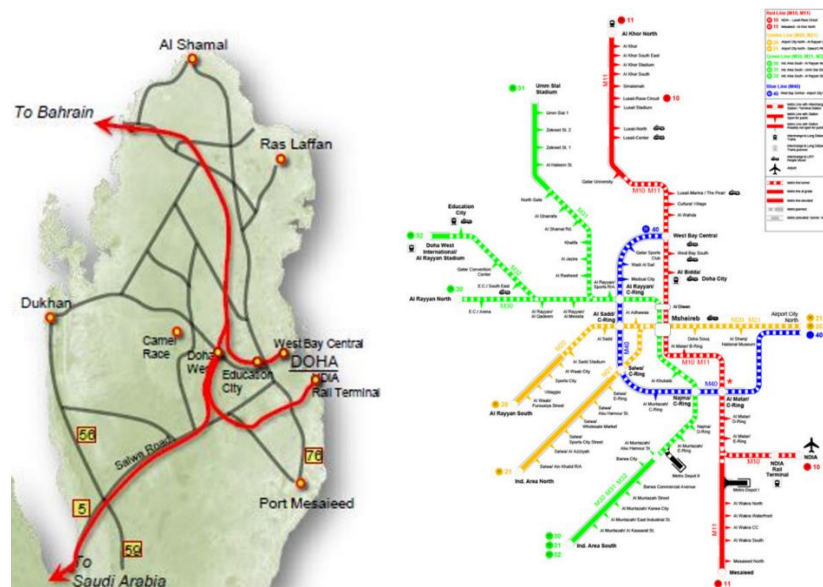
Figure 30. Qatar integrated rail system and programming of metro system lines (Source: QRC presentation, 2011)

4.2 The gold metro line corridor

The Doha metro in Qatar is central in delivering Qatar's 2030 vision of improved transportation and infrastructure across the city. Compared to the Red and Green metro lines, planned introduction of the Doha gold metro network is expected to influence the quality and amount of urban development in the state of Qatar. The gold metro line, extends from Ras Bu Abboud station (near Hamad International airport) to Al Aziziyah station in the west (near Aspire Zone) connecting 8 intermediate stations namely Qatar National Museum, Souq Waqif, Msheireb (interchange station), Bin Mahmoud, Al Sadd, Joaan, Al Sudan, Al Waab and Sports City (Figure 31). The line supports underground transportation system for over 13.3km in central Doha, with extension beyond Al Aziziyah to be elevated above ground (AKTOR, 2014).
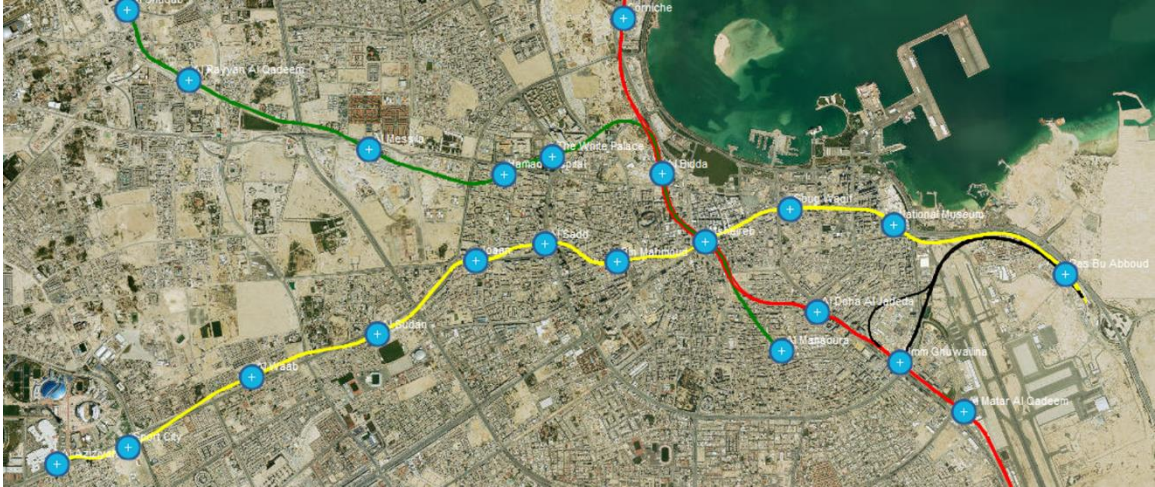
Figure 31. The Doha gold metro line connecting 11 station areas (Source: QRC, 2011)

Doha metro system is anticipated to effect the land use density, land distribution patterns and diversity of economic activities in Qatar. Thus, it becomes necessary to designate the stations in terms of existing urban densities. Accordingly, the Gold metro line extends (starts) from the sub-urban low density development areas (Ras Bu Abboud) to (ends) sub-urban high density development areas (Al Waab, Sports city, Al Aziziyah). The line passes through the urban high density areas of Doha, with QNM, Souq waqif, Bin Mahmoud, Al Sadd, Joaan, Al Sudan transit stations (Figure 32). Thus, the gold line is anticipated to influence the land use pattern and traffic congestion along the corresponding road networks of Al Waab, Salwa and Ras Bu Abboud Expressways.
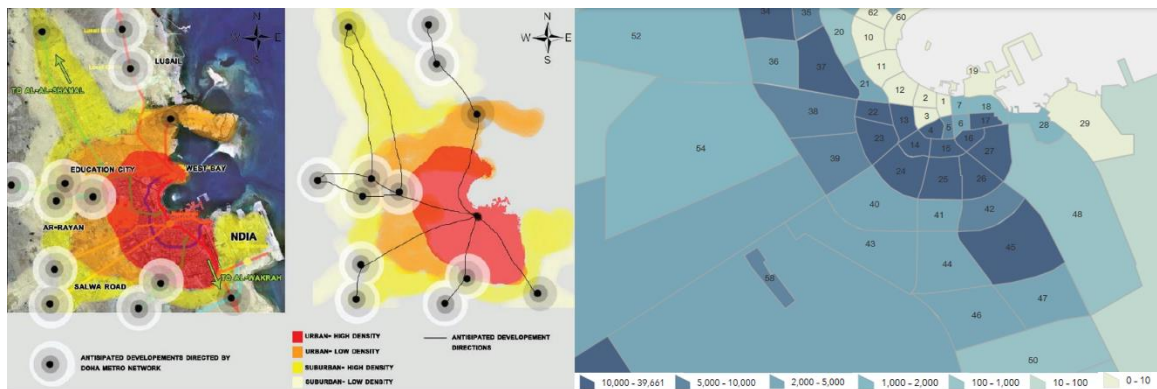
Figure 32. The location of gold line metro stations along the development density of the State of Qatar (Source: Shabaan & Kahlil, 2012)

The gold metro stations such as Musheireb, Souq Waqif, Joaan, Al Sadd, Bin Mahmoud and Al Sudan (6) are located in the districts with high population and land use density, compared to the other station areas along the red and green metro lines. High urban density is considered as a factor for successful performance of alternate transportation modes, enabling ease of access to transit, buses and trams. Consequently, improved accessibility urbanizes these dense station areas into cultural, economic and social centers of the city. Supportively, the transit culture to be created, will influence the land use density, diversity, degree of functional mix, accessibility, parking provisions, alternate interchange modes of transport and employment opportunities of these station areas.

The urban and sub-urban transit stations such as Al Aziziyah, Sports City, Al Waab, Souq Waqif, Al Sadd, Bin Mahmoud, QNM are strategically planned along the congested dense networks in municipalities of Doha and Al Rayyan (Al Waab, Salwa road and Ras bu Abboud Expressways). These transportation networks exhibit high congestion and high travel time indexes. Thus, the gold metro transit stations located along residential,

commercial souqs, shopping and recreational activity areas, are foreseen to attract commuters with the option of using cars, rather than those individuals (labourers/industrial workers) who will use the transit system, but will eventually not affect the congestion on the roads. Supportively, these gold line metro transit stations will be able to provide an alternate option to using private vehicles, encouraging faster, easier, cheaper, without delays, less demanding and more efficient means to travel to places of work or leisure.

In conclusion, the effect of these anticipated developments, on the regional, urban and sub-urban transit stations along the Doha gold line will be effective only through transit supportive urban planning. Transit oriented development (TOD) is a planning redevelopment tool, focused on objectives such as use of public transit, growth of mixed density uses (residential, commercial or office) close to or around a transit stop, provision of multi-modal transportation opportunities without disrupting economic pattern of the area (Cervero, 1998). Thus, important issues related to transportation and land use interaction, along the gold metro line stations should be studied and addressed carefully. As a result, the research attempts to classify and assess the stations based on Bertolini's N-P model, to arrive at recommendations for supportive land use (density, diversity, walkable environments) and transport (accessibility, parking) strategies to encourage TOD type compact development around metro transit stations.

4.3 The station area of analysis

Bertolini's N-P model (1999), identifies the area of station analysis as the walking limit from the transit station. This is defined as catchment area within a radius of 700m, focusing on comfortable 5min. walking distance from the pedestrian entrance to transportation node as shown in Figure 33.

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Figure 33. Defining the catchment area of metro stations within 700m radius – 5min. walking distance (Source: Author, 2018)

The 'area of analyses' was assumed to be dense with activities within walkable distance such as commercial souq/shopping centers, public institutions such as schools/governmental offices, Industrial heavy/light, park/recreation/open spaces and mosques. Thus, all the activities located outside the buffer area were not included in the calculation. Also, transportation services in terms of road networks were not accessed always along the radius, but with deviation along the available road infrastructure. Thus,

prior to data collection of the node and place functions, each of the through station areas were defined and certain characteristics identified as shown in Table 15.

Table 15

Defining the station area characteristics-Sub-urban transit stations

Station area characteristics	Al Aziziyah	Sports city	Al Waab
Zonal location	54 &55	54 & 55	54 & 55
Coverage within buffer area	Partial (1/2)	Partial (1/2)	Partial (1/2)
Station type	Terminal	Through	Through
No: of adjacent stations	1	2	2
Adjacent TOD overlap area	Yes (1-Sports city)	Yes (1-Al Aziziyah)	No
Land use overlap area	Not completely covered	Not completely covered	Almost completely covered
Road network overlap area	Almost completely covered	Almost completely covered	Almost completely covered
Edge redefinition for study	Not required	Not required	Not required
Spatial Indicator assumptions	Required	Required	Required
Defining the station area characteristics-Regional, Sub-regional and Transit stations			
Station area characteristics	Souq Waqif	Bin Mahmoud	Ras Bu Aboud
Zonal location	1,7, 3, 4, 5, 6,17,18 & 16	22,23,13,14 & 24	29,48 & 49
Coverage within buffer area	Partial (1/4) & Complete	Partial (1/5) & Complete	Partial (1/3)
Station type	Through	Through	Terminal
No: of adjacent stations	2	2	1
Adjacent TOD overlap area	No	Yes (1-Al Sadd)	No
Land use overlap area	Almost completely covered	Almost completely covered	Completely covered

Road network overlap area	Almost completely covered	Almost completely covered	Almost completely covered
Edge redefinition for study	Not required	Not required	Not required
Spatial Indicator assumptions	Required	Required	Required

Defining the station area characteristics-Urban transit stations

Station area characteristics	Al Sudan	Joaan	Al Sadd	QNM
Zonal location	54 & 55	38 & 39	38,39,22 &23	17,18,27, 48 & 28
Coverage within buffer area	Partial (1/3)	Partial (1/3)	Partial (1/4)	Partial (1/5)
Station type	Through	Through	Through	Through
No: of adjacent stations	2	2	2	2
Adjacent TOD overlap area	No	Yes (1-Al Sadd)	Yes (1-Joaan/2-Bin Mahmoud)	No
Land use overlap area	Almost completely covered	Almost completely covered	Almost completely covered	Almost completely covered
Road network overlap area	Almost completely covered	Almost completely covered	Almost completely covered	Almost completely covered
Edge redefinition for study	Not required	Not required	Not required	Not required
Spatial Indicator assumptions	Required	Required	Required	Required

Further, the location context, accessibility, parking, land use density and diversity of the metro stations along the Doha gold line to develop as TODs were identified. In accordance with the population, density of uses, diversity, bus system and location of the station areas within the development areas of Qatar, they are classified as:

(1) Regional transit station   -Souq Waqif

(2) Sub-regional transit station -Bin Mahmoud

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(3) Urban transit station -QNM, Al Sadd, Joaan, Al Sudan

(4) Sub-urban transit station -Al Waab, Sports City, Al Aziziyah

(5) Transit town station -Ras Bu Abboud

4.3.1 Regional transit stations-Souq Waqif

4.3.1.1 Location. Souq Waqif station area, spreads across zonal sections of 1, 3, 4, 5, 6, 7, 16, 17 and 18, which forms part of Doha municipality. Located adjacent to the shore, in the heart of Doha city, the station falls under Al Souq district forming the major traditional trading market. This forms a part of the high urban density traditional settlement areas of Doha. The station area serves as a tourist destination center, which culminates in cultural, recreational, leisure, entertainment and heritage sections. The central node is located at the intersection of secondary one way Ali Bin Abdulla Street and Banks Street. The neighbourhood study area of 1.5 km^2, includes parts of districts of Al Souq, Al Najada and Al Musheireb downtown. This is one of the metro stations bounded by building masses, roads and water edges along the circumference (Figure 34). The coastal connection forms part of the secondary areas along the periphery and includes commercial /traditional shopping areas, open parks, plazas and community centers.
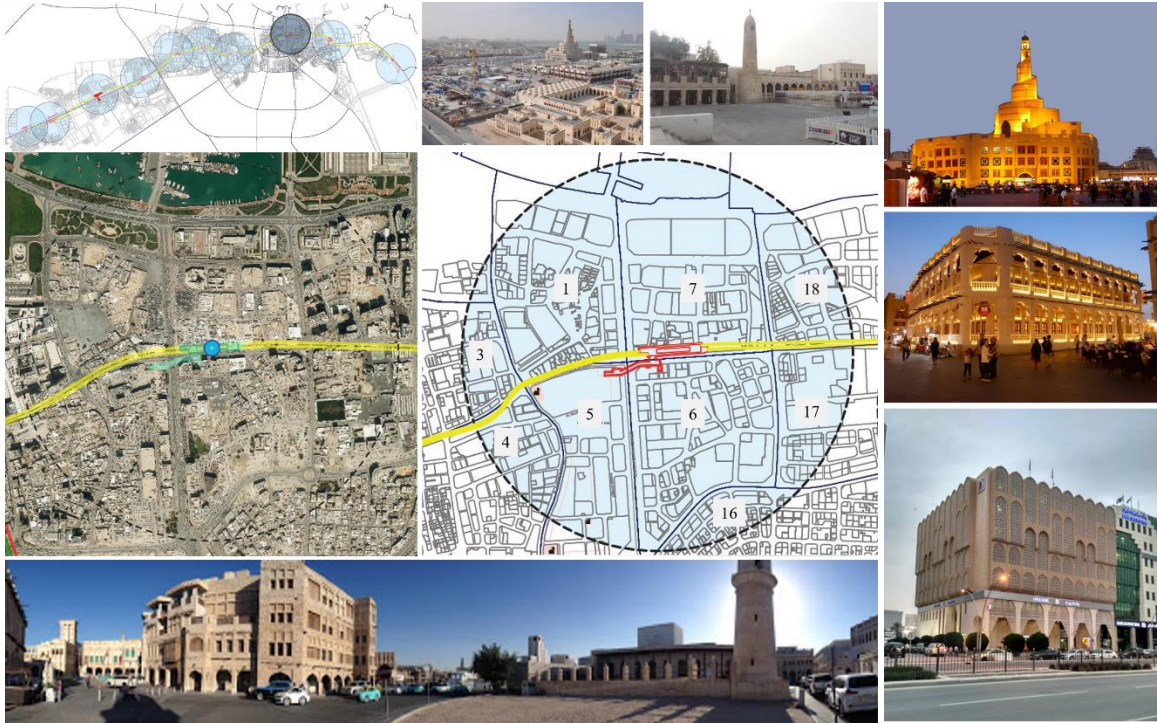
Figure 34. Location -Souq Waqif station (Source: Google earth, QRC & Author, 2018)

4.3.1.2 Accessibility and Parking. Being one of the highly dense station areas, an integrated system of train and feeder bus services determine the accessibility of the station area. Serving as an urban tourist center, the station area functions as a major origin-destination station. Thus, the through station allows train travel in two directions. Transit stations of Msheireb (1.1 km) and Qatar National Museum (1.4 km) are the two connecting stations, among which the former is an interchange station and later a through station. Frequency of trains crossing the station within the peak hour determines the stations which are accessed using bus based multi-modal interchanges. This provides access to town centers, down town area, recreational centers and mixed use urban centers. Enhancement of the connections to economic centers, leisure and recreational activity areas, mixed use

centers, traditional-heritage shopping destinations, assigns as dummy value of 1, identifying the station as not a local station.

    4.3.1.2.1 Circulation system. The surrounding station areas is connected by interconnected multi-modes including feeder bus services and club carts (Table 16). Although the station is not sited, either at major intersections or along primary networks, bus transit includes circulation system with other secondary and tertiary roads allowing fast-slow moving traffic as shown in Figure 35.
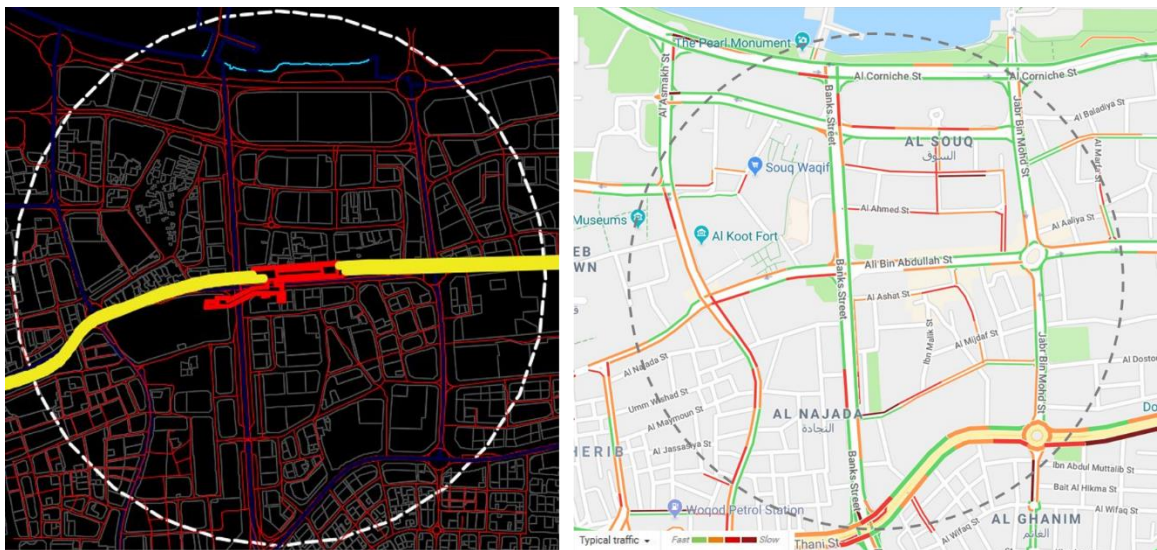
Figure 35. Circulation system of Souq Waqif metro station-major streets and traffic pattern (Source: Google earth; Author, 2018)

Table 16

Node characteristics of Sub-urban transit station

	Souq Waqif
Bus transit	Due to the integration of different zones, and location of Al Ghanim bus station, metro accessibility allows bus in 37 directions. These include both bi-directional and circular routes with 9 bus stops (5 bus stops and 4 transfer stops) (Figure 35). Also, 37 routes culminate in Al Ghanim bus station. 142 frequent buses serve Souq Waqif station area alone within a particular time.
Parking	Parking provisions are observed in three categories :(1) On-street/Off street parking, (2) Multi-Level Car Parking (MLCP), and (3) Basement parking. Thus, 1050 on-street, 3000 off-street, and 4000 basement parking spaces are observed to serve the users of the Souq and surrounding areas. Also, MLCP of capacity 10000 is designed to cater to additional parking provisions. Vacant plots are also observed with heavy service vehicle parking (8000) (Figure 36).

Figure 36. Parking provisions in the form of basement, above ground and MLCP (Source: Google earth, 2018)

4.3.1.2.2 Street Pattern. Function of the station area as tourist and recreational center has led to tertiary and local streets within the area form winding curves and cul-de sacs. Above-ground access is restricted from and to certain parts of the souq, without direct connection to the metro station. However, pedestrian underpasses are used as a means to obtain direct access to the metro station without direct influence of traffic. Additionally, the station encourages transit users from the adjacent station areas due to close road access such as Al Corniche Road (803 km). Although population density is high, pedestrian and bicycle movement are encourages through underpasses and designated paths. In addition to periphery underpasses, easy, safe and fast pedestrian access across street intersections to the transit station is met through pedestrian underpasses.

Figure 37. Street patters including winding curves, pedestrian friendly environment encouraging cycling (Source: Google earth, 2018)

4.3.1.3 Land use density and diversity. Souq Waqif metro station is a regional cultural center with activities focused around tourist attractions, commercial and local shopping, recreational activities, and community gathering opportunities. The station serves as a through station located within the dense section of the Gold metro corridor, close to the coastal areas.

The distribution of land uses, and diversity of activities for station area of Souq Waqif are as described in Table 17.

Table 17

Place characteristics of Sub-urban transit station

Souq Waqif	
Land use	Urban high density development of Souq Waqif metro station includes residential areas (0.09 km^2), Mosques (0.01 km^2), Public institutions: government (hospitals) (0.082 km^2), commercial shopping centers (0.18 km^2), retail frontages (0.029km^2), community center (0.044km^2), special use districts (0.1 km^2)and green open spaces/parks (0.121 km^2) (Figure 38. *Land use distribution of Souq Waqif (Source: Author; Google maps, 2018).*The station serves as a mixed use center with different functional activities, along with vacant plots.
Diversity of activities	The residential settlement areas such as Barahat Al Jufairi, include traditional residences with low heights and massing. Also, the frontage of the streets next to the station area include retail services such as restaurants, medical pharmacies, supermarkets and local shopping centers. Additionally, shopping in the local markets of Souq Waqif is the major attraction. In addition to Souq waqif, other souqs attracting transit users include City Souq, Souq Al Dira, Souq Al Feleh and Gold Souq. The secondary areas includes landmark mosques, heritage development complexes, Arts center, Galleries, downtown museums etc. Also, landscaped green pockets in the form of parks (Souq Waqif), open grounds and plazas are observed connecting different districts. In this economic cultural district, the working population of the station area contribute to the density/diversity of economic, tourist and other local shopping market activities.
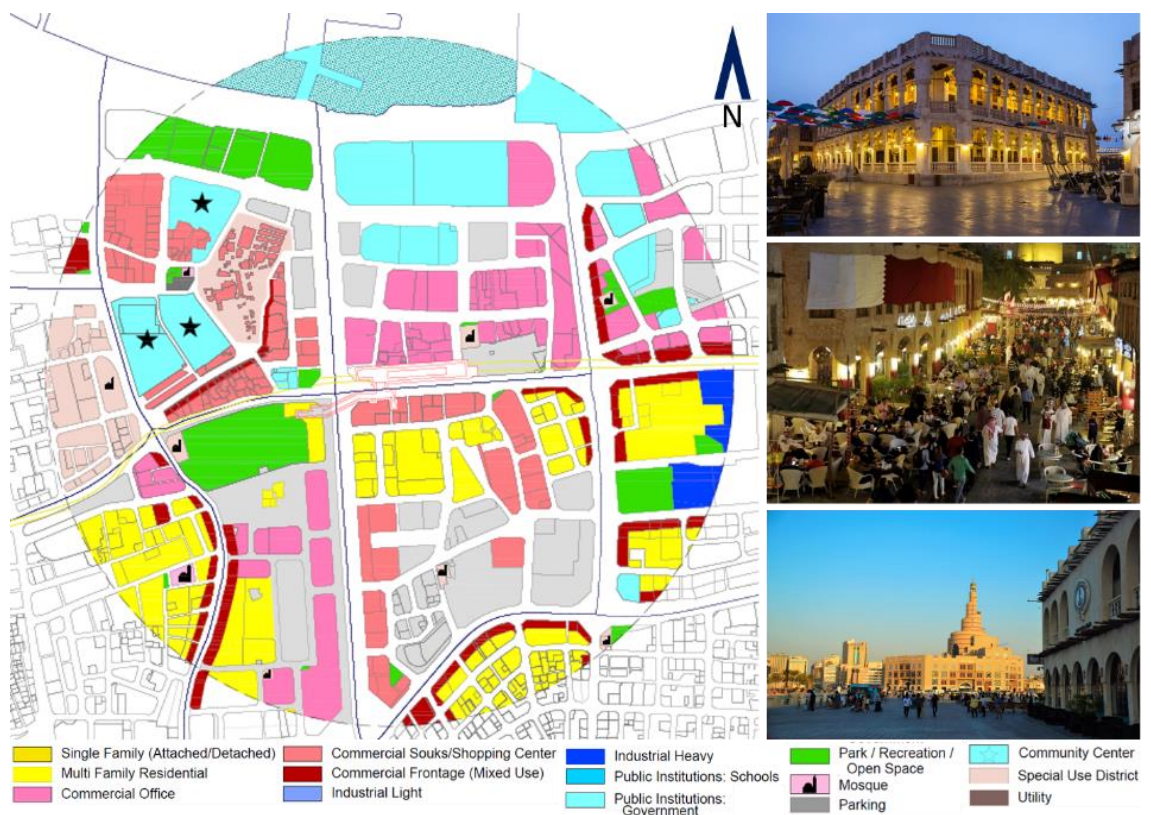
Figure 38. Land use distribution of Souq Waqif (Source: Author; Google maps, 2018)

The node and place indicators for the station areas assessing accessibility, parking, land use density and diversity for the N-P model are summarized in Table 18.

Table 18

Accessibility and Parking criteria of sub-urban transit station

Node & Place Indicators	
Daily frequency of train services	4
Number of directions served by train service	2 (through); QNM, Musheireb
Accessible stations within 20min.	28
Type of train connections	1 (not-local)
Directions served by bus	37
Daily frequency of bus service	142
Proximity to closest road access	803
Number of standing bicycle paths	18
Car park and ride facility	On-street, Off street, Private, Basement, MLCP, Vacant plot
Population of the area (ppl)	9824
Net residential density (ppl/km^2)	6379.44
Workers cluster grouping	
Number of workers in : (ppl)	
• Retail/hotel and catering	5800
• Education/ health/ culture	3007
• Administration and services	727
• Industry and distribution	198
Degree of functional mix	0.90

4.3.2 Sub-regional transit stations-Bin Mahmoud

4.3.2.1 Location. Bin Mahmoud station area, spreads across zonal sections of 13, 14, 22, 23, and 24, located within the municipality of Doha. Fereej Bin Mahmoud, which is one of the important residential districts, encompasses the metro station and falls under the urban high density development areas of Doha. The neighbourhood node is located at

the intersection of secondary one way Qatari Bin Al Fujaah Street and Al Khaleej Street (extension of B-ring road). The area is bounded by both building masses and roads along the circumference (Figure 39). Furthermore, the secondary areas along the periphery include multi-family residential, heavy industrial and commercial areas.
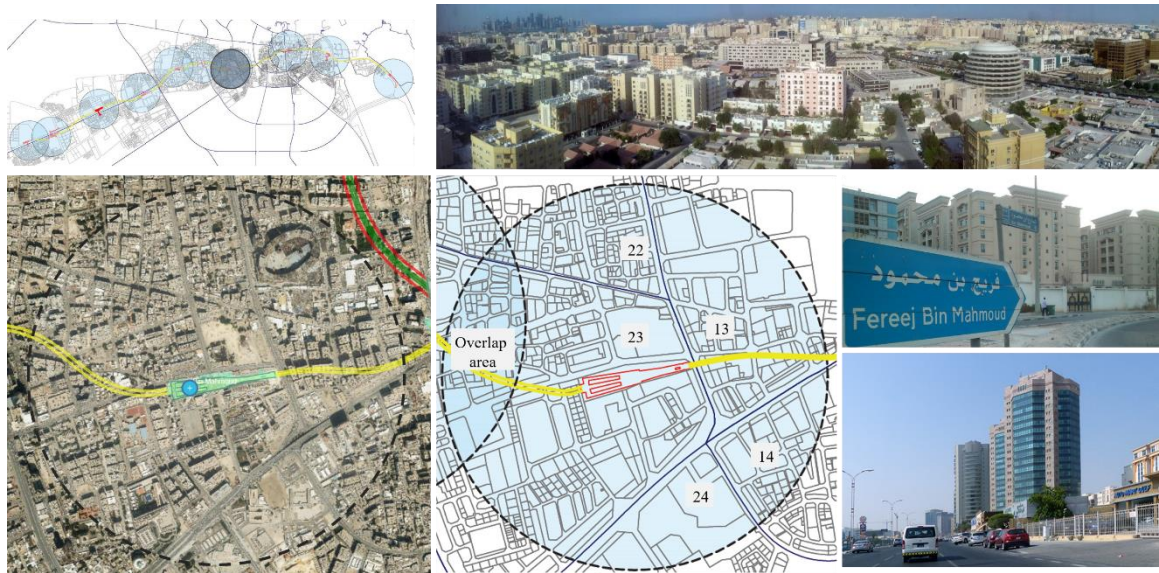
Figure 39. Location of Bin Mahmoud metro station area (Source: Google earth, QRC & Author, 2018)

4.3.2.2 Accessibility and Parking. An integrated system of train and feeder bus services determine the accessibility of the station area. Being a neighbourhood node, covering parts of Fereej Bin Abdul Aziz, Al Muntazah and Mushaireb districts, the station serves as intermediate origin and destination station. Thus, trains access other station areas in two directions and serves as through station (Figure 39).

Transit stations of Al Sadd (1.0 km) and Mushaireb (1.2 km) are the two connecting stations, among which the former is a through station and later an interchange station. The

interchange of train system with other modes of transport, such as bus system, measures the frequency of train service within the peak hour. This station thus connects other neighbourhood centers, town centers, recreational centers, economic hubs and mixed use urban centers. Thus, Bin Mahmoud is not a local station with access to public engaged in different functional activities. Thus, a dummy variable of 1 is assumed for calculation.

4.3.2.2.1 Circulation system. Movement to and from the station and surrounding areas is achieved through interconnected multi-modes such as feeder bus services (Table 19). The station is not sited, either at the major intersections or along primary networks, rather the circulation system includes secondary roads through the center of the station area connected by other secondary and tertiary roads allowing fast-slow moving traffic as shown in

Figure 40.
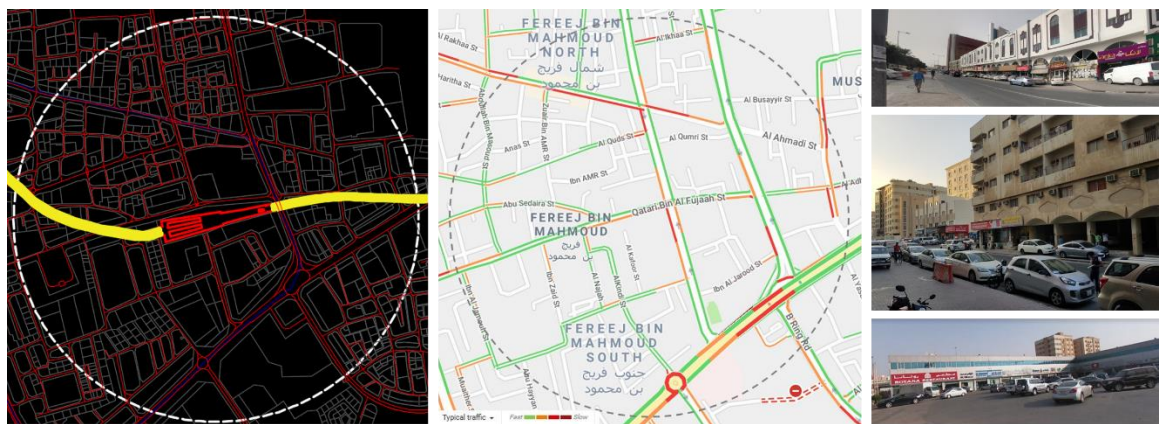
Figure 40. Circulation system of Bin Mahmoud metro station-major streets traffic pattern and parking (Source: Google earth; Author, 2018).

Table 19

Node characteristics of Sub-urban transit station

Bin Mahmoud	
Bus transit	The secondary areas are connected by linkages, which enable transit in particularly 13 directions. These include bidirectional routes R32, R137, R136 (1 transfer bus stop) and circular routes R31, R33, R33A, R33B, R34, R41, R49, R94 and R301 (7 bus stops) (Figure 40). 49 frequent buses serve Bin Mahmoud station area within a particular time using multi-modal means.
Parking	Due to higher density of multi-family residential areas with uses, both on-street and demarcated parking provisions are observed. Both above ground and basement parking areas are provided for commercial and retail frontages. Vacant plots with off-street parking spaces have also been observed (500). Thus, 1050 on-street, 2000 off-street, 6100 above ground and 800 basement parking spaces are observed (Figure 40).

4.3.2.2.2 Street Pattern. Furthermore, tertiary and local streets within the neighbourhood station area form winding curves, dead ends and cul-de sacs. Access is restricted in certain parts of the neighbourhood without direct connection to the metro station. However, the station encourages transit users from the adjacent station areas due to close road accesses such as Salwa road and B-Ring road (306 km). Although population density is high, pedestrian lanes or bicycle paths are not definitely designated. Easy, safe and fast pedestrian access across street intersections to the transit station is met through pedestrian underpasses.

4.3.2.3 Land use density and diversity. Bin Mahmoud is a sub-regional mixed use center with activities focused not only around private neighbourhood areas, but also includes community, commercial and shopping activities. Being located at the center of the corridor, the station serves as a through station, contributing in terms of economic, leisure and entertainment to Gold line corridor.

The distribution of land uses, and diversity of activities for station area of Bin Mahmoud are as described in Table 20.

Table 20

Place characteristics of Sub-urban transit station

Bin Mahmoud	
Land use	Urban high density development of Bin Mahmoud metro station includes multi-family residential areas ($0.553km^2$), Mosques and Eid praying area ($0.017 \ km^2$), Public institutions: Schools ($0.117 \ km^2$), commercial shopping centers ($0.113 \ km^2$) and retail frontages, and green open spaces/parks ($0.001 \ km^2$) (Figure 41). The station serves as a mixed use center with different functional activities, along with vacant plots.
Diversity of activities	The multi-family residential density, within the station area includes high rise apartments (G+7), with uniform massing. Also, the frontages of the streets next to the station area include retail services such as restaurants, medical pharmacies, supermarkets and local shopping centers. The secondary areas includes mosques, Eid prayer grounds, prep-schools, and real estate development complexes (Figure 41). The working population of the station area contributes to the density of economic and other neighbourhood activities.
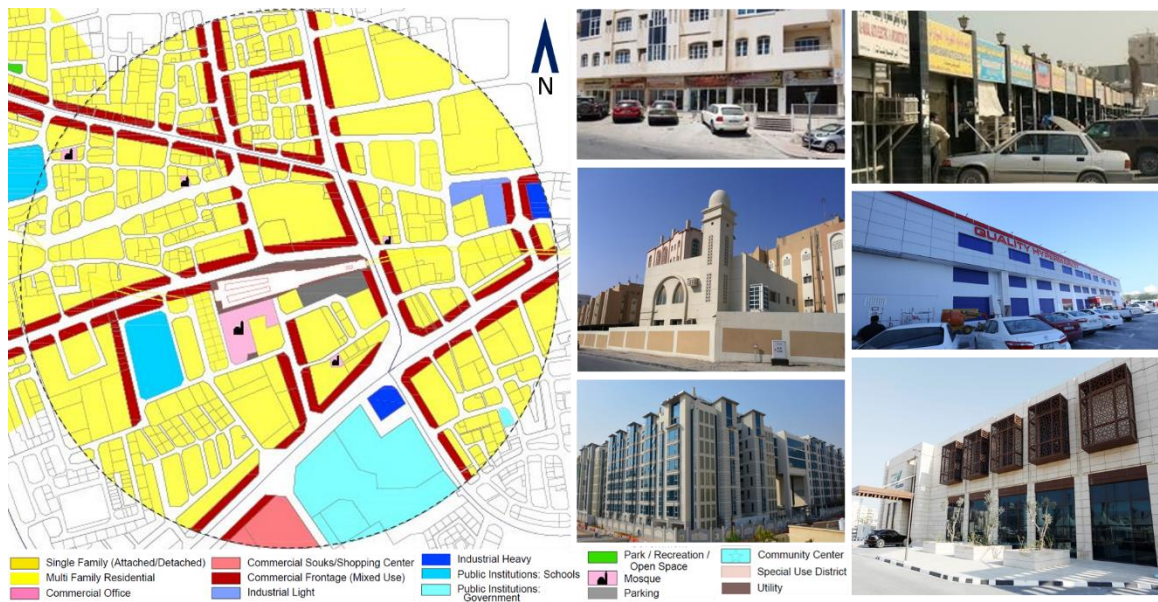
Figure 41. Land use distribution of Souq Waqif (Source: Author; Google maps, 2018)

The node and place indicators for the station areas assessing accessibility, parking,

land use density and diversity for the N-P model are summarized in Table 21.

Table 21

Accessibility and Parking criteria of sub-urban transit station

Node & Place Indicators	
Daily frequency of train services	4
Number of directions served by train service	2 (through); Al Sadd, Musheireb
Accessible stations within 20min.	28
Type of train connections	1 (not-local)
Directions served by bus	13
Daily frequency of bus service	49
Proximity to closest road access	306
Number of standing bicycle paths	0
Car park and ride facility	On-street, Off street, Private, Basement, Vacant plot
Population of the area (ppl)	27799

Net residential density (ppl/km^2)	18051.21
Workers cluster grouping	
Number of workers in : (ppl)	
• Retail/hotel and catering	4328
• Education/ health/ culture	1832
• Administration and services	6778
• Industry and distribution	2689
Degree of functional mix	0.92

4.3.3 Urban transit stations-QNM, Al Sadd, Joaan and Al Waab. The four metro station areas-namely Qatar National Museum, Al Sadd, Joaan and Al Sudan are located along the urban development density areas of Qatar (Figure 32). For the purpose of research, the station area of analysis is defined as 5min. walking distance from the station area, covering an area of 1.54 km^2.

4.3.3.1 Location. QNM metro station is located in the Municipality of Doha, spread across the municipal zones of 17,18,27,48 and 28. The station area encompasses predominantly leisure, public institutions: government and residential activities. This urban gateway connecting the old and new parts of Doha, is located along the intersection of primary Al Corniche Street, C-ring road and Ras Bu Abboud Expressway. The rough boundary includes secondary two-way streets/roads (Figure 42).
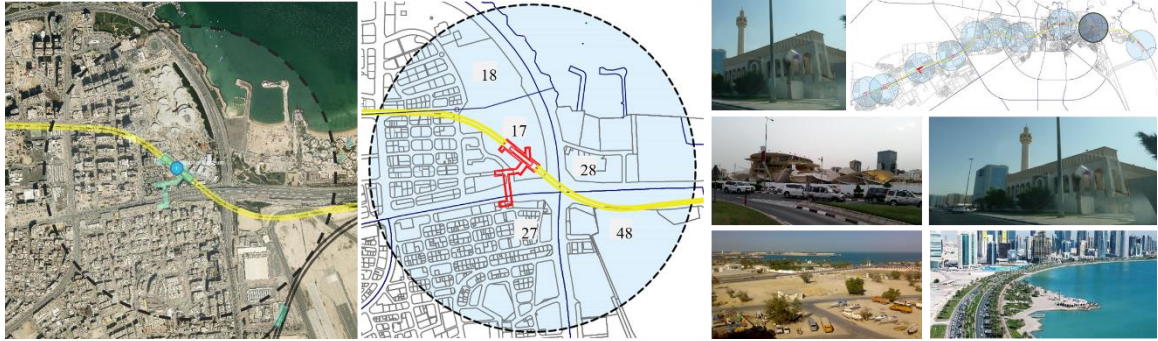
Figure 42. Qatar National Museum metro station area (Source: QRC & Author, 2018)

Al Sadd station is located in the municipality of Doha, with the station area spread out in the zones of 22, 23, 38 and 39. The station area is predominantly multi-family residential and is strategically located at the intersection of Primary one way C-ring road and secondary Al Sadd Street, forming part of the main metro line network (Figure 43).
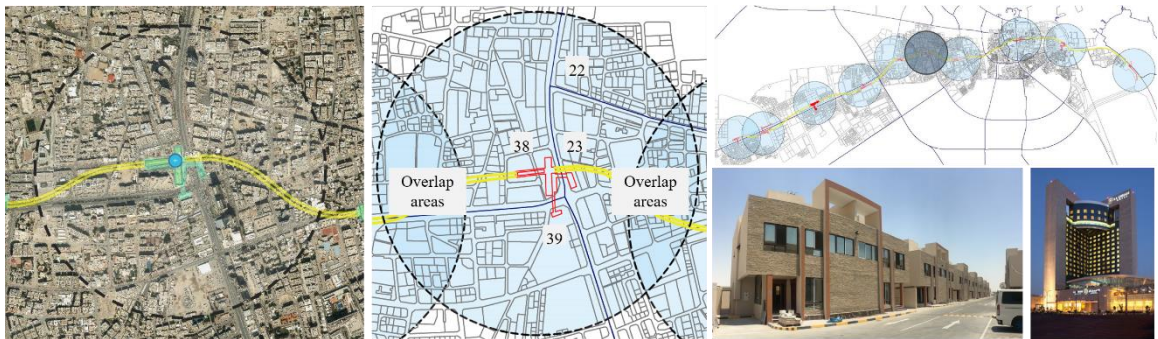
Figure 43. Location of Al Sadd metro station (Source: Google earth, QRC & Author, 2018)

The metro station of Joaan is located in Al Sadd district in the Municipality of Doha, spread across the municipal zones of 38 and 55. This urban metro station is located along the secondary one way Al Sadd Street, forming part of the main metro line network.

The enclosed area is not definitely bounded by transportation networks on all sides. However, rough boundary includes all secondary two-way streets/roads (Figure 44).
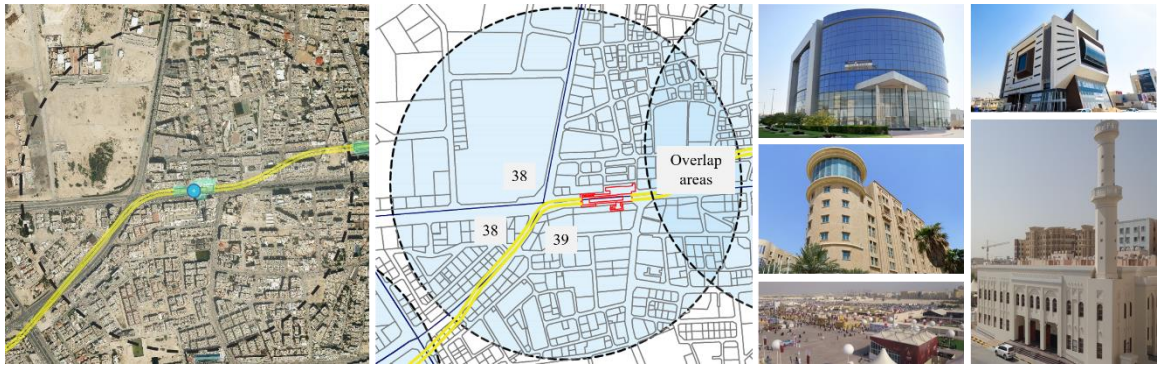
Figure 44. Location of Joaan metro station area (Source: Google earth, QRC & Author, 2018)

Al Sudan station is located between the municipalities of Doha and Al Rayyan, within the municipal zones of 54 and 55, adjacent to Al Waab station area. Al Sudan station area encompasses both residential and recreational land uses, located along the Primary one way Al Waab Street forming the main metro line network. The area is bounded by one-way streets along west, east and north; two-way streets/roads along the south (Figure 45).
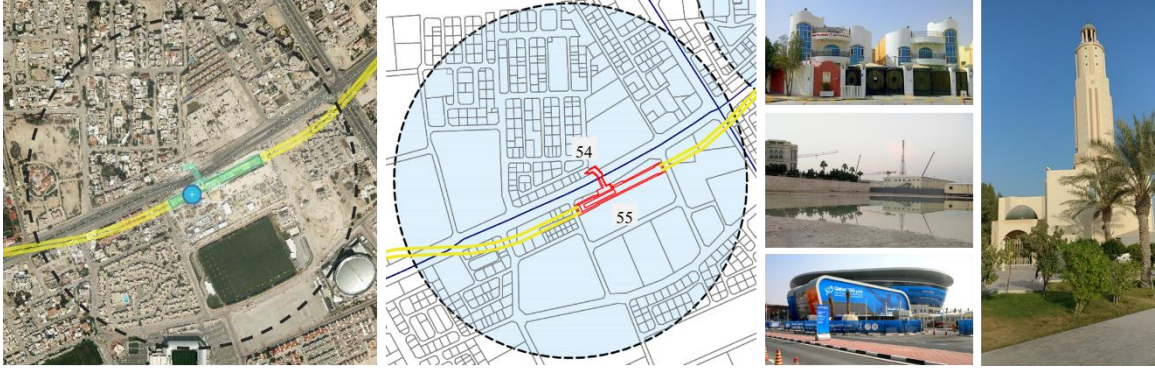
Figure 45. Location of Al Sudan metro station area (Source: Google earth, QRC & Author, 2018)

4.3.3.2 Accessibility and Parking. The station areas of Qatar National Museum, Al Sadd, Joaan and Al Sudan fall under the urban high density areas of the State of Qatar. Accessibility of these station areas is provided by integrated accessibility of train, bus and bicycle considered independently. All the four station areas serve as both immediate and regional trip origin-destination stations. Thus, trains from the stations provide access in two directions and serves as through stations.

As discussed earlier, the underground positions of the stations ensure that 4 trains pass each of the station areas within the peak hour. Also, access to other station areas of the Doha Metro network is ensured through Msheireb and Al Bidda interchange stations. Furthermore, connectivity, is ensured at each of the station areas, through interchanges, with other transit modes such as bus systems (Table 22).

QNM, as the name suggests includes the new Qatar National Museum and connects other national town centers, recreational centers, economic hubs and mixed use urban centers. Similarly, Al Sadd, Joaan and Al Sudan, do not perform as local stations and

contribute to economic benefits of the Doha gold metro line. Thus, a dummy variable of 1 is assumed for calculation.

4.3.3.2.1 Circulation system. As discussed earlier, movement to and from the recreational station and the surrounding areas is achieved through interconnected public transport such as feeder bus services and bicycle lanes (Table 22). The circulation system within the museum area includes interconnected train, bus and bicycle services. Movement within the neighbourhood and special use areas is achieved through secondary, tertiary and local streets, allowing fast moving traffic as shown in Figure 46. As observed from Al Sadd and Al Sudan station areas, the circulation system exhibits primary roads through center of the station area connected by secondary and tertiary roads as shown in Figure 46. However, in contrast, Joaan allows secondary roads through center of the station connected by other secondary and tertiary roads, without the presence of primary roads as shown in Figure 46.
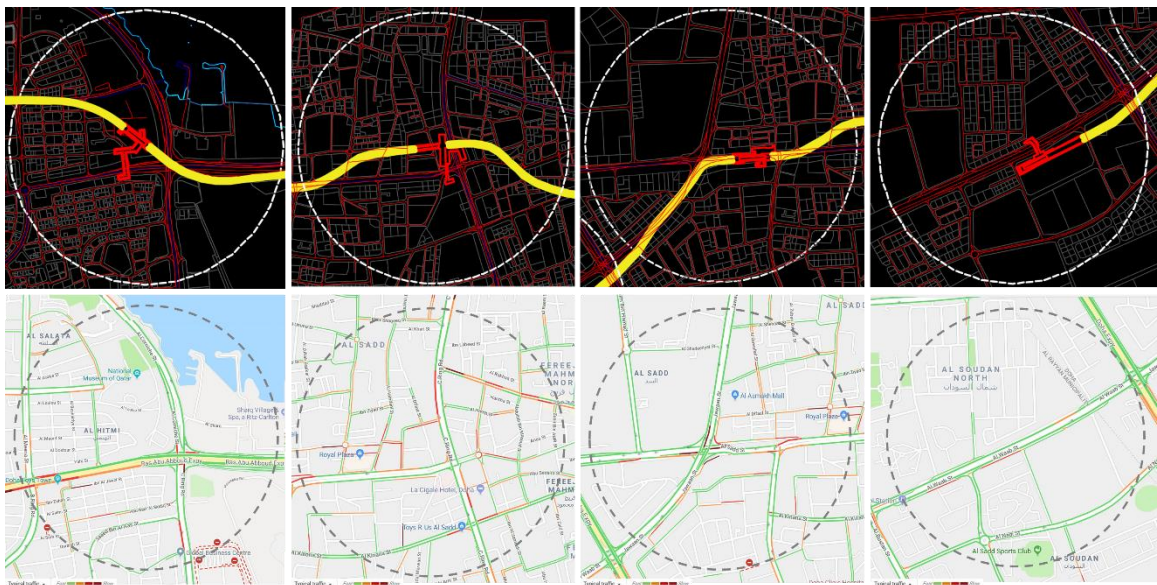
*Figure 46.*Circulation system of Souq Waqif metro station-major streets and traffic pattern (Source: Google earth; Author, 2018)

Table 22

Node characteristics of Sub-urban transit station

Sub-urban transit stations	
Qatar National Museum	
Bus transit	These road interconnections enable bus transit in particularly 3 directions. These include bidirectional routes R777, R109 (8 bus stops) and unidirectional routes R76, (1 transfer bus stop). A total of 17 buses serve the QNM station within a particular time. Thus, QNM extends the definition of accessibility through frequency of bus services within the station using multi-modal means.
Parking	The mix of land uses such as parks, shopping centers, museums, governmental commercial offices etc, lead to parking which includes 400 on-street parking, 2000 off-street parking, 2000 above ground MLCP slots and 3000 basement parking spaces. Off-street parking spaces are observed in vacant plot and special use district areas (Figure 47).
Al Sadd	
Bus transit	The road accesses enable bus transit in particularly 5 directions, similar to Joaan station. These include bidirectional routes R32 (4 bus stops) and circular routes R31, R41, R301, R304, R49, R94 (6 bus stops). Al Sadd multi-modal bus system allows a total of 26 buses to serve the station within a particular time.
Parking	Located within the high density residential areas with commercial frontages, both on-street and demarcated parking provisions are observed. Due to existence of the station with commercial frontage such as La Cigale hotel, Al Sadd Plaza and public institutions such as Paediatric emergency (health centers), 830 above ground and 520 basement parking spaces are observed. Additionally, vacant plots with off-street parking spaces have also been observed (Figure 47). Furthermore, multi-family residential areas have private parking spaces.
Joaan	
Bus transit	The road interconnections enable bus transit in particularly 8 directions. These include bidirectional route R32 (1 transfer bus stop and 1 bus stop) and circular routes R31, R41, R301, R304,

R49, R94 (3 bus stops). A total of 19 buses serve the Joaan station within a particular time.

Parking	The high residential density as well as shopping/leisure centers lead to 2000 on-street parking provisions. In total, certain activity generators such as shopping malls, plazas and hotels in the area, have provisions of 4000 basement parking spaces. Additionally, vacant plots with off-street parking spaces have also been observed (Figure 47). Approximately, the area has 2000 on-street parking, and 8000 above ground private parking spaces.

	Al Sudan
Bus transit	The road accesses enable bus transit in particularly 5 directions. These include 3 transfer bus stops (Circular-R31, R41, R301, R304 and Bidirectional-R 32). A total of 14 buses serve the Al Sudan station within a particular time.
Parking	Due to higher density of recreational facilities and possible inflow, both on-street and demarcated parking provisions are observed. Due to existence of the station as a recreational sports center, functional spaces of Al Sadd stadium and sports arena have provision of parking spaces. Additionally, vacant plots with off-street parking spaces have also been observed (Figure 47). Furthermore, single attached and detached residential areas have private parking spaces.

*Figure 47.*Parking on-street, above ground and along vacant plots (Source: Google, 2018)

4.3.3.2.2 Street Pattern. The street system of QNM includes secondary and tertiary streets within the governmental and residential areas forming grid pattern with minimum dead ends and cul-de sacs. Separate pedestrian paths, bicycle paths and traffic areas are observed. Un-interrupted pedestrian movement is achieved through pedestrian underpasses and over bridges across the express road and Corniche Street. Thus, the metro station serves accessibility without disrupting passenger mobility.

The street pattern of Al Sudan station area reveals a mix of irregular streets and grid patterns. Within the station area, tertiary streets close to the primary Al Waab Street loop to form dead ends and cul-de sacs in single residential and light industrial activity plots. However, tertiary and local streets beyond 100m from the station, form a grid pattern defining separate traffic and pedestrian areas. Moreover, pedestrian lanes or bicycle paths are not definitely designated. Due to the sports recreational activities pedestrian and cycle tracks are provided near the vicinity of these activities. However, a completely irregular, non-grid pattern of street development is observed in Al Sadd and Joaan station areas.

Al Sadd metro station, serves accessibility with restricted mobility of the passengers. Furthermore, closed loops, dead ends and cul-de-sacs formed by the secondary and tertiary streets within the residential areas, limit the direct, safe and formalized access to the metro station. The station area lacks grid pattern of street layout allowing high speed-free moving traffic. However, the access of the station is open from the adjacent station areas due to the interconnected area over laps and proximity to the Doha Expressway and C-Ring road. No pedestrian or bicycle paths are designated.

Similarly, Joaan station exhibits secondary and tertiary streets within the residential areas forming dead ends and cul-de sacs without grid pattern. Separate pedestrian and

traffic areas are not observed. Moreover, pedestrian lanes are not definitely designated. Easy, safe and fast pedestrian access across Al Sadd Street to the transit station is met through pedestrian underpass.

4.3.3.3 Land use density and diversity. The four station areas within the urban high density land use areas of the state exhibit a mix of uses. QNM station serves as a capital city center with high density activities focused around monuments of national significance, administrative/ commerce activities along with recreational, and local shopping. The station acts as a major national growth center contributing in terms of employment concentration and economic generative activities.

Al Sadd station serves as a transit center with activities focused not only around private neighbourhood areas, but also culminates in services such as hotels, education and shopping. Similarly, Joaan station serves as a mixed use transit center with high density activities focused around private neighbourhood areas, along with recreational, leisure, shopping, training and education services. Additionally, Al Sudan station serves as a mixed use transit center with activities focused not only around private neighbourhood areas, but also executes the role of a through station, origin and destination center with a commendable contribution in terms of sports, school activities, outdoor gaming, leisure and entertainment.
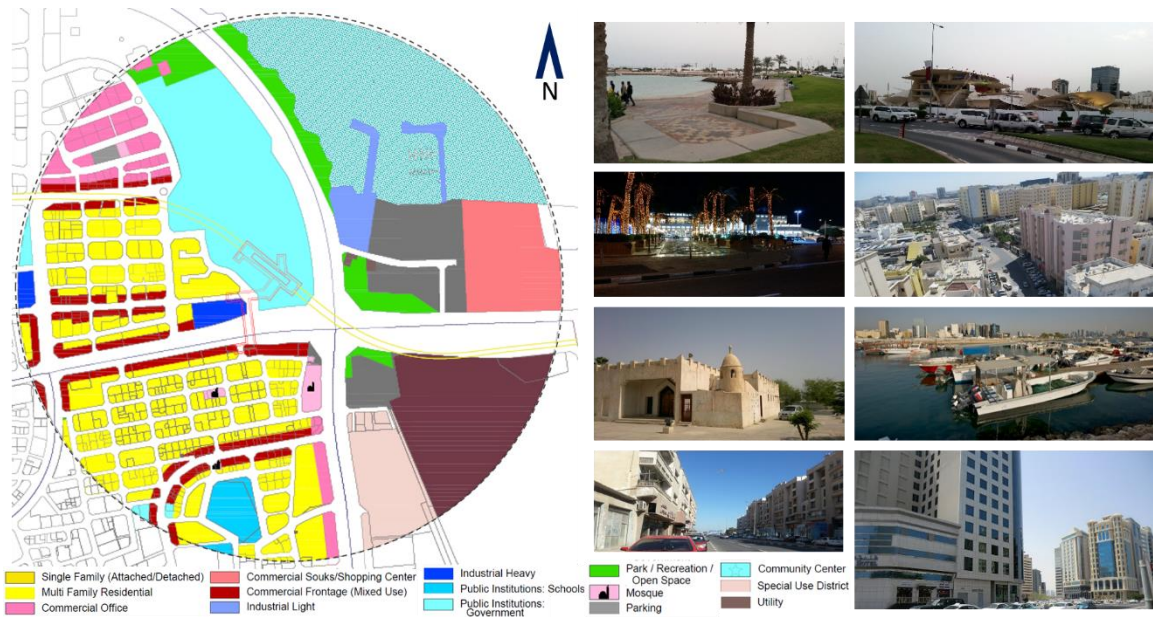
*Figure 48.*Land use distribution of QNM metro sattion (Source: Author; Google maps, 2018)

Being through stations, Al Sadd, Joaan and Al Sudan also contribue to Gold line corridor focused on attractive economic generative activities. The distribution of land uses, and diversity of activities for the four station areas of Qatar National Museum, Al Sadd, Joaan and Al Sudan are as described in Table 23.

Table 23

Place characteristics of Sub-urban transit station

Sub-urban transit station
Qatar National Museum
Land use	QNM within the urban high density development areas of Doha, includes multi-family residential areas (0.16km^2), mosques (0.01km^2), Public institutions: governmental (0.001km^2), commercial shopping centers (0.10km^2), commercial office spaces

(0.02km^2), retail frontages (km^2), Special use districts (0.051km^2) and green open spaces/parks (0.165km^2) (Figure 48).

Diversity of activities	The residential density within the station buffer area includes multi-family residential areas. A uniform massing with restricted heights is observed due to close proximity of HIA (G+7). Additionally, the frontages of Ras Bu Abboud Express, along the districts of Al Hitmi and Umm Ghuwailina, include retail frontages such as restaurants/catering services, supermarkets and local shopping centers. Furthermore, the secondary area includes mosques, parks, special use district grounds, parks, and residences. Also, green pockets such as the Sharq Village, Corniche park stretch and landscaped intersections are observed next to the metro station (Figure 48).
Al Sadd	
Land use	Urban high density development of Al Sadd metro station includes residential areas (0.64 km^2), Mosques (0.004km^2), Public institutions: Schools (0.02km^2), commercial shopping centers (km^2), commercial office spaces (km^2), retail frontages (0.17km^2), Public institutions: Governmental (0.02km^2), Hotels (0.02km^2), and green open spaces/parks (0.01km^2). A mixed use residential center is observed in addition to non-functional vacant plots.
Diversity of activities	The multi-family residential area within the station buffer area includes uniform massing (G+7). The metro station intersection includes governmental institutions such as Paediatric emergency, retail frontages such as commercial hotels, supermarkets, workshops and local shopping centers. Furthermore, the secondary areas include mosques, nurseries, and schools. Also, landscaped green pockets in the form of parks, are discovered next to the metro station and along the public streets, including vacant plots (Figure 49).
Joaan	
Land use	Joaan within the urban high density development areas of Doha, includes residential areas (0.51 km^2), mosques (0.01km^2), community centers (0.10km^2), commercial shopping centers (0.14km^2), commercial office spaces (0.02km^2), retail frontages (0.17km^2), and green open spaces/parks (0.21km^2) (Figure 49).

Diversity of activities	The residential density within the station buffer area generally includes single and multi-family residential areas. A uniform massing is observed due to buildings with similar heights (G+4, G+5, G+7). Additionally, the frontages of the Al Sadd Street include commercial retail services such as shopping malls, restaurants/catering services, supermarkets and local shopping centers. Furthermore, the secondary area includes mosques, nurseries, schools and residential suites. Also, landscaped green pockets are not found, however, vacant grounds and plazas are discovered within the buffer area, next to the metro station, along the public streets and retail building frontages (Figure 49).
	Al Sudan
Land use	Al Sudan metro station includes functional residential areas (0.63km^2), Mosques (0.05km^2), commercial shopping centers (0.05km^2), retail frontages (0.03km^2), and green open spaces/parks (0.29km^2) (Figure 50).
Diversity of activities	The residential density, within the station buffer area generally includes only attached and detached villas. A uniform massing is observed due to restriction on high rise buildings. Additionally, the frontages of the primary street include retail services such as petrol stations, medical pharmacies, supermarkets and local shopping centers. Furthermore, the secondary area includes mosques, nurseries, schools for special needs and primary schools. Also, landscaped green pockets in the form of parks, playing grounds and plazas are discovered within the buffer area, next to the metro station, along the public streets and retail building frontages (Figure 50). These also include vacant parcels of land without any functions.

*Figure 49.*Land use distribution of Al Sadd and Joaan overlapping metro station (Source: Author; Google maps, 2018)

*Figure 50.*Land use distribution of Al Sudan metro station (Source: Author; Google maps, 2018)

The node and place indicators for the station areas assessing accessibility, parking, land use density and diversity for the N-P model are summarized in Table 24.

Table 24

Accessibility and Parking criteria of sub-urban transit station

Node & Place Indicators				
	QNM	Al Sadd	Joaan	Al Sudan
Daily frequency of train services	4	4	4	4
Number of directions served by train service	2 (through) Ras Bu Abboud Souq Waqif	2 (through) Bin Mahmoud Joaan	2 (through) Al Sudan Al Sadd	2 (through) Al Waab Al Sadd
Accessible stations within 20min.	26	26	22	19
Type of train connections	1 (not-local)	1 (not-local)	1 (not-local)	1 (not-local)
Directions served by bus	3	5	8	5
Daily frequency of bus service	17	26	19	14
Proximity to closest road access	116	1968	885	571
Number of standing bicycle paths	1	0	0	0
Car park and ride facility	On-street Off street Private Basement Vacant plot	On-street Off street Private Basement Vacant plot	On-street Off street Private Basement Vacant plot	On-street Off street Private Basement Vacant plot
Population of the area (ppl)	12185	5733	9495	3298
Net residential density (ppl/km^2)	7912.17	3723.0	6165.81	2141.83

Workers cluster grouping				
Number of workers in : (ppl)				
• Retail/hotel and catering	4250	2221	1627	424
• Education/ health/ culture	1345	968	2195	578
• Administration and services	3650	471	1364	606
• Industry and distribution	624	288	2103	176
Degree of functional mix	0.91	0.991	0.94	0.91

4.3.4 Sub-urban transit stations-Al Waab, Sports City and Al Aziziyah. The three metro station areas-namely Al Waab, Sports City and Al Aziziyah are located along the sub-urban development density areas of Qatar (Figure 32). They are strategically located along the Primary one way Al Waab Street, forming the main metro line network. For the purpose of research, the station area of analysis is defined as 5min. walking distance from the station area, covering an area of 1.54 km^2.

4.3.4.1 Location. Al Waab is a settlement located between the municipalities of Doha and Al Rayyan, within the municipal zones of 54 and 55. The neighbourhood metro station includes residential land uses and local serving shopping facilities. The area is enclosed within a radius of 700m bounded by one-way streets/roads along the west and east; two way streets/roads along the north and south (Figure 51). The auto oriented secondary areas include residential and governmental activities.

Figure 51. Location of Al Waab metro station area within the Gold Line (Source: QRC & Author, 2018)

The adjacent Sports City metro station area falls within Al Rayyan municipality, in Al Waab district, within the municipal zones of 54 and 55. The metro station is located at the intersection of primary one way Al Waab Street and secondary one way Al Buwairda and Sports City Street, encompasses international sporting complex. The auto oriented secondary areas include residential facilities.

Al Aziziyah metro station serves as an extension of adjacent overlapping Sports City station area, within the municipal zones of 54 and 55. The station falls under Al Waab district, in Al Rayyan municipality, encompassing parts of international sporting complex and major shopping malls. The metro station area highlights a culmination of recreation, shopping, leisure and culture (Figure 52).
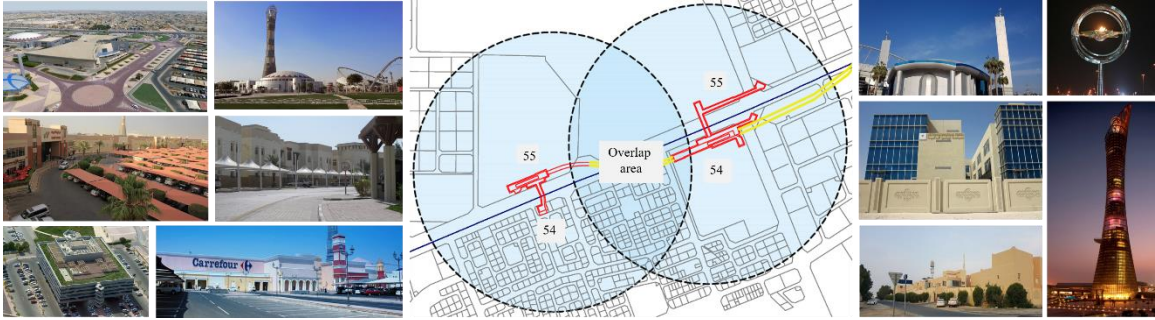
*Figure 52.*Location of Al Aziziyah and Sports city overlapping station areas (Source: QRC & Author, 2018)

4.3.4.2 Accessibility and Parking. Accessibility within the sub-urban metro station areas includes accessibility provided by train, bus and bicycle considered independently. With regard to train accessibility, The stations of Al Waab and Sports City, serve as both immediate and regional trip origin-destination areas (through stations) providing accessibility in two directions. Al Aziziyah serves as a terminus station in Phase I, providing access in only one direction.

Frequency of train service, measures the number of trains arriving or departing the station within the peak hour. Additionally, the stations also include interchanges at the stations with other transit modes such as bus systems. As obtained from the Qatar Rail Data, trains pass the station in every 15min. Thus, during the peak hour, 4 trains passes through each of the station areas. Further, efficiency of the transit system is governed by the accessibility provided within a distinct time or cost. Accordingly, trains originating from the respective stations provide accessibility to other transit destinations along the Doha metro network within 20 minutes.

Also, Al Aziziyah and Sports City stations serves as a major destination for recreational sporting/training and shopping activities. Thus, the metro stations are well connected due to its functional use attracting public. Due to the culmination of healthy recreational activities, leisure and culture, the station area serves as a major destination. Also, based on the other connected national destinations and locational context the stations are well exposed and do not serve as local stations. Thus, a dummy variable of 1 is assumed for calculation.

4.3.4.2.1 Circulation system. The primary Al Waab Street passes through the three station areas allowing fast moving traffic as shown in Figure 53. Multiple direct secondary/tertiary linkages connect the secondary station areas (located 100m inwards from circumference) of Al Aziziyah, Sports City and Al Waab to the primary road.

Additionally, movement to and from the station, recreational /leisure areas and surrounding neighbourhood areas is achieved through interconnected public transport such as feeder bus services (Table 25). However, movement within the Sports complex and Aspire park areas is achieved through designated walking/running trails and bicycle/club cart paths. Thus, the circulation system includes both public and private domains.
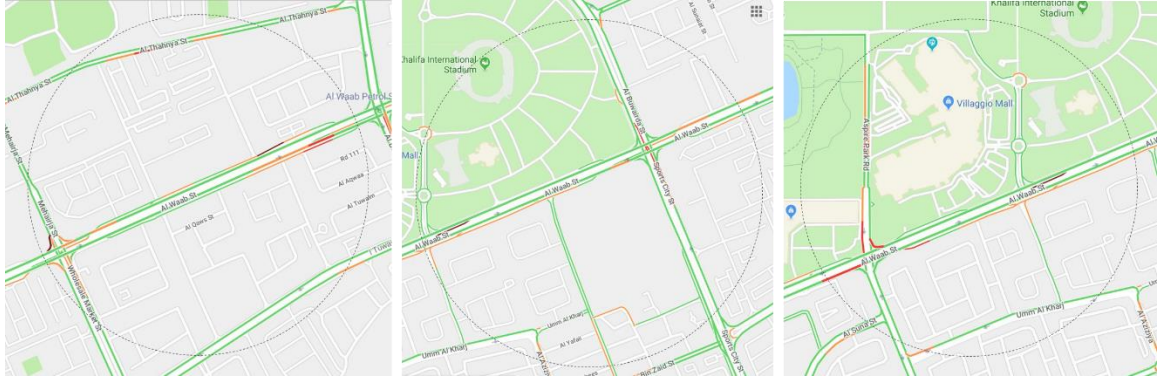
Figure 53. The circulation system with traffic pattern of urban transit station-Al Waab, Sports city and Al Aziziyah (Source: QRC & Author, 2018)

4.3.4.2.2 Street pattern. The tertiary and local streets form a grid pattern defining separate traffic and pedestrian areas for Al Aziziyah and Sports City. The metro stations can be accessed by transit users outside the buffer area due to proximity to major road accesses. These include Al Furousiya Street and Doha Expressway. Al Aziziyah presents close proximity to both the roads, whereas Sports city and Al Waab are located at 2220m from Al Furousiya St. and 2226m from Doha Expressway respectively.

Moreover, the Aspire zone area has specifically designated and marked pedestrian walking/running trails as well as bicycle/club cart paths. These paths radiate towards the Sports City station area and join at the entrances of the sports complex and Villagio shopping mall, adjacent to the metro station. However, pedestrian lanes or bicycle paths are not definitely designated in Al Waab station area.

Furthermore, direct access has been provided in the form of pedestrian underpasses to enable easy, safe and fast pedestrian access across Al Waab Street to the station areas

(Figure 54). Thus, the circulation system of the three station areas exhibit passenger mobility.
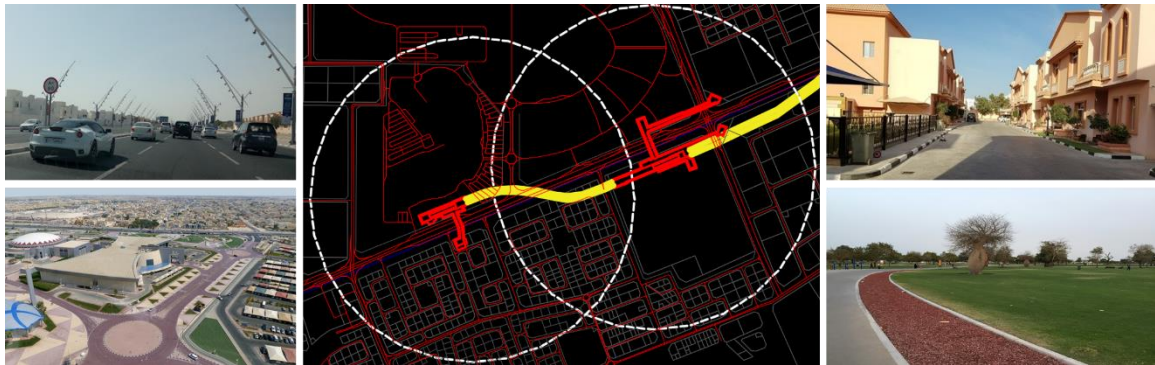
Figure 54. Hierarchy of networks in Al Aziziyah and Sports city overlapping station areas (Source: QRC & Author, 2018)

Table 25

Node characteristics of Sub-urban transit station

Sub-Urban transit stations	
Al Waab	
Bus transit	The road accesses enable bus transit in particularly 8 directions. These include 3 on-street bus stops (Unidirectional-R21, R81) and 1 transfer stop (Bidirectional-R 32, R31). Also, effectiveness of accessibility provided at the metro station by this interchange mode was based on the frequency of bus services. A total of 10 buses serve the Al Waab station within a particular time.
Parking	Due to high residential concentration, on-street parking is limited to 300 along the secondary street areas, 120 in the vacant plots. Further, the gated compounds have in total 2736 private parking spaces.
Sports City	
Bus transit	The road accesses enable bus transit in particularly 8 directions. These include 4 on-street bus stops along Al Waab Street (Circular-R31, R41, R304, R309, R 301; Bidirectional - R32, R 136, R137),

	3 on-street bus stops along Umm Al Kajr St (Circluar- R 43) and 1 on-street bus stop (Circular-R306) along Al Buwairda Street. A total of 11 buses serve the Sports City metro station within a particular time.
Parking	As the station area serves as sports recreational hub, designated off-street parking is provided within the Aspire complex (3000). Separate shaded parking spaces are provided for Sports halls, pitches and Khalifa International stadium. Due to residential land uses, on-street parking is limited to 320 along the secondary street areas. The gated compounds have private parking spaces. Additionally, vacant plots adjacent to the station area are also observed to be used for off-street parking (50).
Al Aziziyah	
Bus transit	The road accesses enable bus transit in particularly 8 directions with a frequency of 19 buses during peak hour. These include 3 transfer stops along Al Waab Street (Circular-R41; Bidirectional-R 31, R 32, R 136, R137, R 304, R 306, R 307) and 2 bus stop (Circular-R34; Bidirectional-R32) along Al Numan Street.
Parking	As the station area serves as a culmination of sports recreational, leisure and shopping hub, designated off-street parking is provided within the Aspire complex (3000), Villagio mall (206) and Hyatt plaza areas (418). These also include separate shaded parking spaces. Due to residential land uses, on-street parking is limited to 600 along the secondary street areas. The gated compounds have 650 private parking spaces.

4.3.4.3 Land use density and diversity. Sub urban high density land use developments of the three station areas exhibit a mix of uses (Figure 55). Al Waab station serves as a residential center with activities focused around private neighbourhood areas. The station executes the role of a through station, origin and destination center without much output contribution in terms of leisure, economy, entertainment or culture to the Gold line corridor. In contrast, Sports City station serves as a recreational center with activities

focused around international/local sporting and training events. The station contributes in terms of transit related to leisure, education, health and fitness training, entertainment, international sporting events and economy to the Gold line corridor by serving as a through station (origin and destination). Likewise, Al Aziziyah serves as a leisure/recreational center, executing the role of a terminus station, with output contribution in terms of recreation/leisure, economy, entertainment and culture.
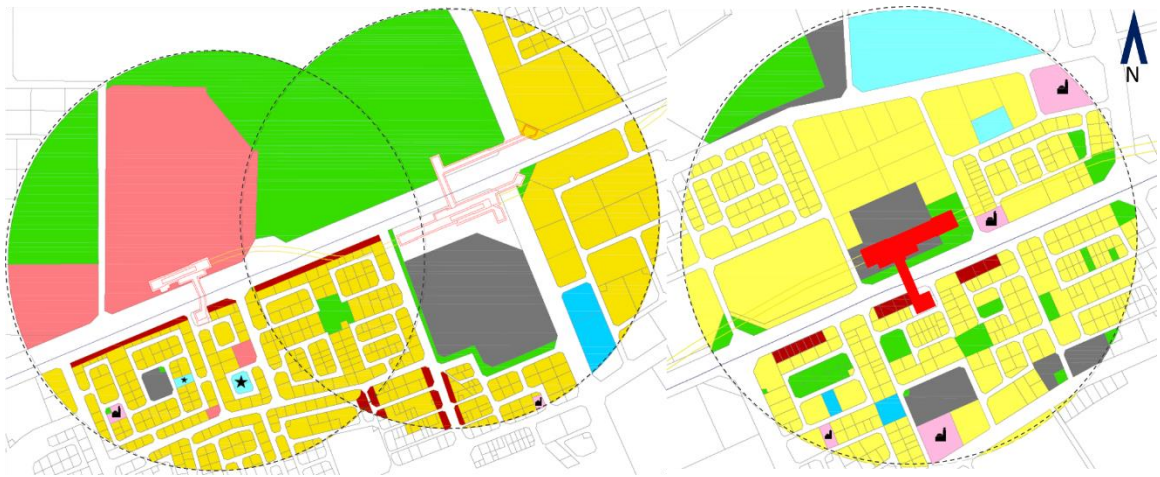
Figure 55. Land use distribution of sub-urban transit station areas-Al Aziziyah, Sports city and Al Waab (Source: QRC & Author, 2018)

The distribution of land uses, and diversity of activities for the three station areas of Al Waab, Sports City and Al Aziziyah are as described in Table 26.

Table 26

Place characteristics of Sub-urban transit station

Sub-urban transit stations	
Al Waab	
Land use	Sub urban high density development of the station area primarily includes single and multi-family residential (0.76 km²), Mosques (0.04 km²), Public institutions: governmental (0.10 km²), Public institutions: Schools (0.01 km²), commercial retail services (0.02 km²), open spaces/parks (0.11 km²) and vacant plots (0.10 km²) (Figure 55).
Diversity of activities	The residential area, within the station buffer area generally includes only attached and detached villas. The building massing in the area prevents the construction of flats. Additionally, the frontages of the primary street include retail services such as medical stores, laboratories, supermarkets and local shopping centers. Also, the secondary area includes mosques and primary schools. Furthermore, landscaped green pockets in the form of parks and plazas are discovered within the buffer area, next to the metro station, public streets and retail frontages (Figure 55).
Sports City	
Land use	Sub urban high density development of the station area primarily includes residential (0.51km²), public institutions: school (0.03km²), retail (0.02 km²), open spaces, plazas and parks (0.50 km²) (Figure 55).
Diversity of activities	The recreational land uses consists of aspire sports complex and related activities. These recreational activities include Aspire sports hall, Tennis courts, Fire tower, Tennis academy, auditoriums and rugby grounds. Additionally, completely open public accessible areas include Khalifa International stadiums, spread out 5-side pitches and open walking areas with exercise equipment. The frontages of the tertiary and local streets within the station area include retail services such as supermarkets and local shopping centers. The secondary area includes community centers and mosques. Furthermore, landscaped zones within the Aspire academy in the form of parks are observed next to the metro station, public streets and retail building frontages.

Al Aziziyah	
Land use	Al Aziziyah metro station vicinity includes land use activities such as shopping centers (0.38 km2), community centers (0.01 km2), multi-family residential areas (0.65 km2), mosques (0.001 km2), retail (0.02 km2), and open spaces/plazas/parks (0.42 km2) (Figure 55).
Diversity of activities	The recreational/leisure land uses consists of overlapping areas of aspire sports complex and shopping/kids play areas. The shopping and leisure activitiies include Villagio mall and Hyatt Plaza. Additionally, leisure areas of Kidzania and Gondoland are located very close to the station area. Further, the sports recreational activities include Aspire sports hall, areas of Khalifa International stadiums and open walking areas with exercise equipment. The frontages of the tertiary and local streets within the station area include retail services such as supermarkets and local shopping centers. Furthermore, landscaped zones within the Aspire academy in the form of parks are observed next to the metro station. These also include green pockets/ parcels of land which are not suited for any other types of function.

The node and place indicators for the station areas assessing accessibility, parking, land use density and diversity for the N-P model are summarized in Table 27.

Table 27

Accessibility and Parking criteria of sub-urban transit station

Node & Place Indicators

	Al Aziziyah	Sports City	Al Waab
Daily frequency of train services	4	4	4
Number of directions served by train service	1 (terminus) Sports City	2 (through) Al Aziziyah Al Waab	2 (through) Sports city Al Sudan
Accessible stations within 20min.	13	14	16
Type of train connections	1 (not-local)	1 (not-local)	1 (not-local)
Directions served by bus	8	8	8

Daily frequency of bus service	19	11	10
Proximity to the closest road access	1320	2220	2226
	(Furousiya St)	(Furousiya St)	(Doha Exp)
Number of free standing bicycle paths	3	3	0
Car park and ride facility	On-street	On-street	On-street
	Off street	Off street	Private
	Private	Private	Vacant plot
	Basement	Vacant plot	
Population of the area (ppl)	2626	3035	3060
Net residential density (ppl/km^2)	1705.51	1970.68	1986.74
Workers cluster grouping			
Number of workers in : (ppl)			
• Retail/hotel and catering	229	94	418
• Education/ health/ culture	344	403	800
• Administration and services	700	234	453
• Industry and distribution	194	133	175
Degree of functional mix	0.90	0.89	0.92

4.3.5 Transit station-Ras Bu Abboud

4.3.5.1 Location. Ras Bu Abboud is located within the municipality of Doha, and spreads across the zones of 29, 48 and 49. Located in an industrial area, containing power and desalination plants, falls under the suburban low density development areas of Qatar. The station area is located along Ras Bu Abboud Expressway, and defined as 5min. walking distance covering Public governmental economic zones, Doha International Airport premises and Qatar Aeronautical College grounds. The station area is not defined by road networks, rather include land boundaries (Figure 56), such as parts of Al Khulaifat and Ras Bu Abboud districts. The secondary areas include parts of New Doha International Airport (NDIA) and Industrial warehouses.
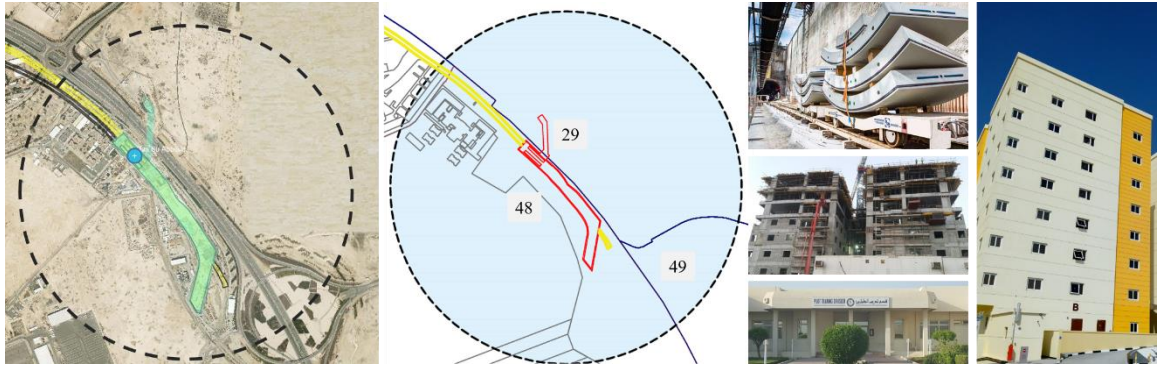
Figure 56. Location of Ras Bu Abbound metro station area (Source: QRC & Author, 2018)

4.3.5.2 Accessibility and Parking. Ras Bu Abboud station area serves as an origin-destination area, through interchangeable multi-modal means such as metro, bus and cycle paths. Trains through the metro station provide access in one direction and serves as a terminus station. Transit stations of QNM (1.8 km) is the adjacent through metro station.

4.3.5.2.1 Circulation system. The station provides connection to economic zones and industrial cities with less population. Being an industrial city center, movement in the area for workers is focused around interconnected public transport such as feeder bus services and bicycle lanes (Table 28). As observed from the station area, the circulation system exhibits primary roads through the center of the station area. Traffic connections are limited to the secondary areas, with few minimum traffic local streets. The secondary station areas (located 100m from circumference) are connected only within the premises of QAC.
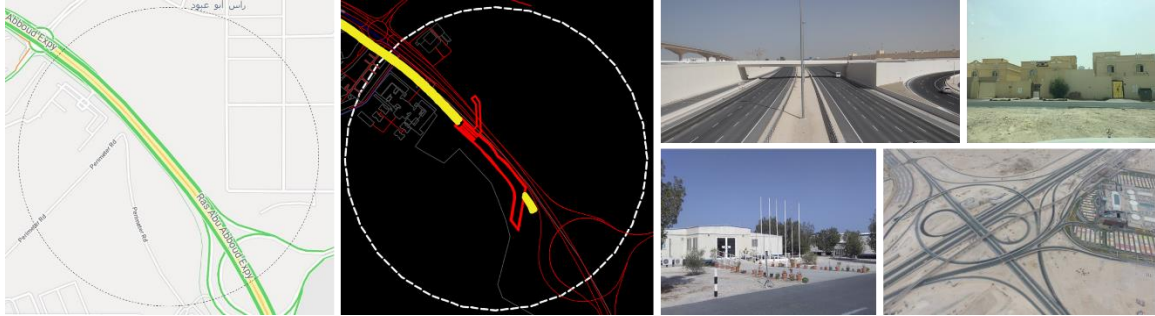
Figure 57. Circulation system of Ras Bu Abbound -Expresswas through station center, local streets (Source: QRC & Author, 2018)

Table 28

Node characteristics of Sub-urban transit station

	Ras Bu Abboud
Bus transit	The road accesses enable bus transit in particularly 1 directions. These include 2 transfer bus stops (Bidirectional-R777, R109). A total of 4 buses serve the station within a particular time.
Parking	Due to lower population density, off-street parking provisions for trucks and trailers are observed. These approximately include 230 parking spaces. On-street parking lots are not identified.

4.3.5.2.2 Street Pattern. The street pattern in occupied areas include closed cul-de-sac loops and winding road systems. Cycle paths form a major part of the circulation system. The Ras Bu Abboud Expressway, serves as the closest road access at 100 km, which allow transit users outside the buffer area. Pedestrian underpasses are used to cross the expressway (Figure 57).

4.3.5.3 Land use density and diversity. Ras Bu Abboud functions as a local transit center, serving the weekly and daily requirements around the industrial sites and contributes in terms of economic transfer, to the Gold metro line.
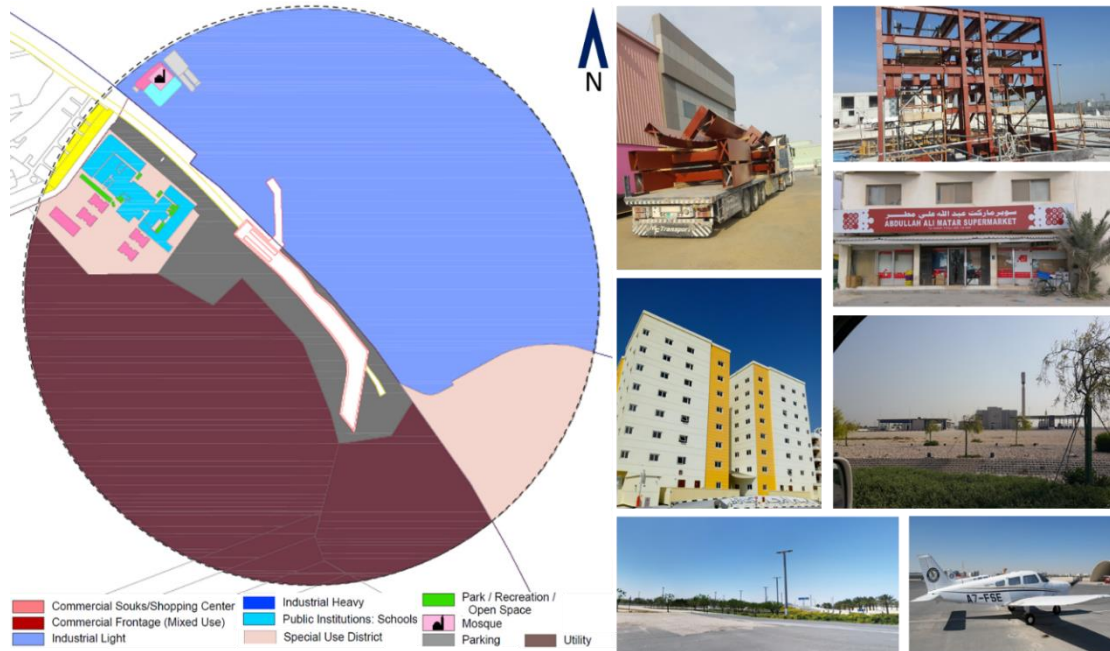
Figure 58. Land use density- diversity of Ras Bu Abboud (Source: QRC & Author, 2018)

The distribution of land uses, and diversity of activities for station area of Ras Bu Abboud are as described in Table 29.

Table 29

Place characteristics of Sub-urban transit station

Ras Bu Abboud	
Land use	The Sub-urban low density of the metro station includes institutions: governmental (0.54km^2), Public institutions: educational (0.02km^2), Mosques (0.003km^2), heavy industrial sites (0.52 km^2), special use districts (0.54km^2) and vacant plots (0.01 km^2) (
	Figure 58). The residential density, within the station buffer area generally include temporary warehouse worker quarters and QAITC stay facilities.
Diversity of activities	Lack of high rise buildings in the area, lead to dominance of the metro station. Also, the primary street frontages lack building structures, however, secondary areas include mosques, police stations, civic centers, bank facilities etc. Also, naturally vegetated parcels of vacant land are observed in the form of open parking grounds, next to the metro station with perimeter roads (Figure 57). These are designated as noise buffers.

The node and place indicators for the station areas assessing accessibility, parking, land use density and diversity for the N-P model are summarized in Table 30.

Table 30

Accessibility and Parking criteria of sub-urban transit station

Node & Place Indicators	
Daily frequency of train services	4
Number of directions served by train service	1 (terminus); QNM
Accessible stations within 20min.	23
Type of train connections	1 (not-local)
Directions served by bus	1
Daily frequency of bus service	4
Proximity to closest road access	100

Number of standing bicycle paths	1
Car park and ride facility	On-street, Off street, Private, Basement, Vacant plot
Population of the area (ppl)	128
Net residential density (ppl/km^2)	82.98
Workers cluster grouping	
Number of workers in : (ppl)	
• Retail/hotel and catering	34
• Education/ health/ culture	87
• Administration and services	60
• Industry and distribution	660
Degree of functional mix	0.92

4.4 Summary

Doha metro network constitutes four lines connecting 93 stations with a total length of approximately 354km. In comparison to the Red and Green metro lines, planned introduction of the Doha gold metro network connecting 10 stations is expected to influence the quality and amount of urban development in the state of Qatar. Ras Bu Abboud station in the east (near Hamad International airport) and Al Aziziyah station in the west (near Aspire Zone) serve as terminus stations, connecting 8 through stations namely QNM, Souq Waqif, Msheireb (interchange station), Bin Mahmoud, Al Sadd, Joaan, Al Sudan, Al Waab and Sports City.

Doha metro system is anticipated to effect the land use density, land distribution patterns and diversity of economic activities in Qatar. The anticipated developments, on the regional, urban and sub-urban transit stations along the Doha gold line will be effective only through transit supportive urban planning. Thus, important issues related to transportation and land use interaction, along the gold metro line stations are studied and

addressed carefully in this chapter. First, the research segregates the stations based on the population, density of uses, diversity, bus system and location of the station areas within the development areas of Qatar, as regional, sub-regional, urban, sub-urban transit stations.

The station 'area of analysis' is defined as a catchment area of 700m radius focusing on comfortable 5min. walking distance from the pedestrian entrance to transportation node. Prior to calculating the existing scenario indicators, the 'area of analysis' is defined by assessing the station characteristics in terms of zonal location, coverage within buffer area, station type, number of adjacent stations, adjacent TOD overlap area, land use overlap area, road network overlap area, edge redefinition for study and spatial indicator assumptions (Table 31). The location context, accessibility, parking, land use density and diversity of the 10 metro stations along the Doha gold line is summarized as below.

Table 31

Summary of accessibility, parking, density, diversity and walkable environment criteria

Gold metro line transit stations	
Regional transit station (Souq Waqif)	
Zonal location	1, 7, 3, 4, 5, 6, 17, 18 & 16.
Accessibility/ parking	Urban tourist center serving as major origin-destination through station. Station has established connections to economic centers, leisure and recreational activity areas, mixed use centers, traditional-heritage shopping destinations and does not serve as local station. Parking provisions are observed in the form of basement, above ground and MLCP.
Circulation system	Interconnected by multi-modes such as feeder bus services and club carts. Network systems include: • Primary networks - Not sited at major intersections

	• Secondary and tertiary roads - Bus transit allowing fast-slow moving traffic.
Street pattern	Tertiary and local streets constitute winding curves and cul-de sacs. Pedestrian underpasses enable direct access to the metro station without traffic. Pedestrian and bicycle movement are encouraged using designated paths.
Bus Transit	Highly connected using bus transit • 37 bi-directional and circular routes • 9 bus stops in total including 5 stops and 4 transfer stops.
Land use density/diversity	Highly dense and diverse with activities such as tourist attractions, commercial and local shopping, recreational activities, and community gathering opportunities. • Residential settlement areas such as Barahat Al Jufairi (low heights and massing). • Retail services including restaurants, medical pharmacies, supermarkets and local shopping centers. • Other souqs such as City Souq, Souq Al Dira, Souq Al Feleh and Gold Souq. • Secondary areas including landmark mosques, heritage development complexes, Arts center, Galleries, downtown museums etc. • Landscaped green pockets such as parks (Souq Waqif), open grounds and plazas.
Sub regional transit station (Bin Mahmoud)	
Zonal location	Area is bounded by both building masses and roads along the circumference within the zones of 13,14,22,23, & 24 (Doha).
Accessibility/parking	Neighborhood node which serves as intermediate origin-destination through station. Station has established cconnections to neighborhood centers, town centers, recreational centers, economic hubs and mixed use urban centers with different functional activities and does not serve as a local station. On street parking with no walkability. Lacks connectivity, congested streets and congested commercial centers due to on-street non-designated parking.
Circulation system	Interconnected by multi-modes such as feeder bus services and club carts. Network systems include:

- Primary networks -Not sited at major intersections
- Secondary roads - Passes through the center of the station
- Secondary and tertiary roads - Bus transit allowing fast-slow moving traffic.

Street pattern	Tertiary and local streets constitute narrow residential streets & straight roads. Access is restricted with no direct connection to the metro station. Pedestrian and bicycle movement are not encouraged due to absence of designated paths.
Bus Transit	Highly connected using bus transit • 13 bi-directional and circular routes • 8 bus stops in total including 7 stops and 1 transfer stop.
Land use density/diversity	Highly dense and diverse in activities such as private neighborhood areas, community, commercial and shopping activities. • Multi-family residential area including high rise apartments (G+7), with uniform massing. • Retail services along street frontages • Secondary areas including mosques, eid prayer grounds, prep-schools, and real estate development complexes.
Urban transit stations (QNM, Al Sadd, Joaan and Al Waab)	
Zonal location	QNM-17,18,27,48 & 28 Al Sadd-38,39,22 &23 Joaan-38 & 39 Al Waab-54 & 55
Accessibility/parking	The stations serve as intermediate origin-destination through stations. Stations have established cconnections to neighborhood centers, town centers, recreational centers, economic hubs and mixed use urban centers with different functional activities and does not serve as a local station.
Circulation system	Interconnected by multi-modes such as feeder bus services and club carts. QNM is interconnected by train, bus and bicycle services Network systems include: • Primary networks passing through center of station area (Al Sudan & Al Sadd).

	• Secondary networks passing through center of station area (Joaan) with no primary networks. • Secondary, tertiary and local streets - Bus transit allowing fast-slow moving traffic.
Street pattern	<u>QNM</u> Secondary & Tertiary streets form grid pattern with minimum dead ends and cul-de sacs. Pedestrian paths, bicycle paths and traffic areas are segregated. Pedestrian underpasses & Bridges provide direct access to the metro station without traffic. Passenger mobility is intermediately encouraged/discouraged. <u>Al Sudan</u> The area constitutes a mix of irregular streets and grid patterns. Tertiary streets include loops forming dead ends and cul-de sacs (residential and light industrial activity plots). Tertiary and local streets form grid pattern defining separate traffic and pedestrian areas. Pedestrian and bicycle movement are not encouraged due to no distinct designated paths. Pedestrian and cycle tracks are observed near the vicinity of sports activities. <u>Al Sadd & Joaan</u> Irregular, non-grid pattern is observed with restricted mobility of the passengers. Secondary and tertiary streets include closed loops, dead ends and cul-de-sacs. Pedestrian and bicycle movement are not encouraged.
Bus Transit	Highly connected using bus transit <u>QNM</u> • 3 bi-directional and circular routes. • 9 bus stops in total including 8 stops and 1 transfer stop. <u>Al Sadd</u> • 5 bi-directional and circular routes. • 10 bus stops in total <u>Joaan</u> • 8 bi-directional and circular routes. • 5 bus stops in total including 4 stops and 1 transfer stop. <u>Al Sudan</u> • 5 bi-directional and circular routes. • 3 bus stops in total including 3 transfer stops. <u>QNM</u>

Land use density/diversity	Highly dense and diverse in activities such monuments of national significance, administrative/ commerce activities, recreational, and local shopping.

- Multi-family residential area including high rise apartments (G+7), with uniform massing (HIA).
- Retail services along Street frontages (Districts of Al Hitmi and Umm Ghuwailina)
- Secondary areas with mosques, parks, special use district grounds, and residences.
- Green pockets such as Sharq Village, Corniche park stretch and landscaped intersections.

Al Sadd

Area includes activities such as private neighbourhood areas, hotels, education and shopping.

- Multi-family residential area including high rise apartments (G+7), with uniform massing
- Governmental institutions such as Paediatric emergency
- Retail services along street frontages (Districts of Al Hitmi and Umm Ghuwailina)
- Secondary areas including mosques, nurseries, and schools
- Green pockets such as parks next to the metro station and public streets.

Joaan

Station area includes activities such as private neighbourhood areas, recreational, leisure, shopping, training and education services.

- Single & multi-family residential area with uniform massing (G+4, G+5, G+7)
- Retail services along street frontages
- Secondary areas including mosques, nurseries, schools and residential suites
- Vacant grounds & Plazas with lack of green pockets.

Al Sudan

Station area includes activities such as private neighbourhood areas, sports, school activities, outdoor gaming, leisure and entertainment.

- Residential Villas with uniform massing with restricted height
- Retail services along street frontages
- Secondary areas including mosques, nurseries, schools for special needs and primary schools

- Landscaped pockets such as parks, playing grounds and plazas; vacant lands.

Sub urban transit station (Al Waab, Sports City, Al Aziziyah)	
Zonal location	54 & 55
Accessibility/parking	Sub-urban transit stations serve as immediate and regional trip origin-destination through stations (Al Waab and Sports City) and terminus station (Al Aziziyah). Stations established connections to national town centers, recreational centers, economic hubs and mixed use urban centers and does not serve as local stations.
Circulation system	Interconnected by multi-modes such as feeder bus services (Al Waab), walking/running trails and bicycle/club cart paths (Al Aziziyah, Sports city). Circulation system includes both public and private domains.
Street pattern	Al Waab Pedestrian and bicycle movement are not encouraged as designated paths are not observed. Station area exhibits passenger mobility. Al Aziziyah and Sports City Tertiary and local streets form grid pattern; separate traffic and pedestrian areas were observed. Aspire zone exhibited designated/marked pedestrian walking/running trails and bicycle/club cart paths.
Bus Transit	Highly connected using bus transit. Al Waab • 8 bi-directional and circular routes. • 4 bus stops in total including 3 stops and 1 transfer stop. Sports City • 8 bi-directional and circular routes. • 8 bus stops in total including 7 stops and 1 transfer stop. Al Aziziyah • 8 bi-directional and circular routes. • 5 bus stops in total including 2 stops and 3 transfer stops.
Land use density/diversity	Highly dense and diverse with activities such as Private neighborhood areas with no output contribution in terms of leisure, economy, entertainment or culture (Al Waab).

Sports city area includes activities such as international/local sporting and training events, leisure, education, health and fitness training, entertainment, and economy related. Activities within Al Aziziyah include recreation/leisure, economy, entertainment and culture.

Transit station (Ras Bu Abboud)	
Zonal location	Located in an industrial area, containing power and desalination plants within zones of 29, 48 and 49 (Doha). Station is defined by land boundaries (parts of Al Khulaifat and Ras Bu Abboud districts) including secondary areas such as parts of New Doha International Airport (NDIA) and Industrial warehouses.
Accessibility/parking	Transit origin-destination terminus station serves as industrial node with station area
Circulation system	Interconnected by multi-modes such as feeder bus services and bicycle paths. Networks include: • Primary networks passing through center of station area. • Local streets are restricted to secondary areas.
Street pattern	Closed cul-de-sac loops and winding roads systems. Major part of the circulation system includes cycle paths.
Bus Transit	• 1 bi-directional route. • 2 bus stops in total including 2 transfer stops.
Land use density/diversity	Less dense and diverse with activities such as serving weekly and daily requirements around the industrial sites. • Lack of high rise buildings resulting in dominance of metro. • Lack building structures along street frontages • Secondary areas include mosques, police stations, civic centers, bank facilities etc. • Naturally vegetated parcels inclusive of parks, playing grounds and plazas in addition to vacant lands.

The node and place indicators for the station areas were calculated based on the 5 criteria and are assessed and analyzed in chapter 5.

Chapter 5: Assessment and Classification of Station Areas

Chapter 5 is divided into six sub-sections, which describes the indicator calculation and analytical interpretation of the N-P values for the stations. The chapter summarizes the calculation of certain non-spatial indicators of walkable environment criteria, values of node index, place index and N-P index, in addition to the spatial indicators described in Chapter 4. Furthermore, correlation and regression analysis carried out during the research, examines the strength of relation between the indicators. Also, results are obtained of the criteria effective in structuring the station. Next, the stations are plotted in the N-P graph, which enables the classification based on Bertolini's N-P model. Additionally, the chapter ranks, describes and assesses the station areas, based on interpretations of the plotted node-place functions and N-P TOD index to arrive at effective strategies enabling potential for TOD type development along metro stations.

5.1 Calculating walkable environment indicators

Walkable environment indicators include the summative influence of intersection density and PCA (Impedance Pedestrian Catchment Area). Unlike the node and other place indicators, these are calculated specifically for each station areas based on blocks and transport networks.

5.1.1 Intersection density. Walkable environments are created in station areas by segregating pedestrian and traffic environments. A measure of intersection density determines the provision of multiple shorter routes coinciding with the streets, developing pedestrian friendly, memorable and easy to navigate areas. Higher the intersection density, higher the potential to develop walkable environment along existing transport network. The intersection density of station areas are summarized in Table 32, where Al Sadd

displays the highest and Ras Bu Abboud the lowest intersection density. High to moderate intersection densities are observed for Joaan, QNM and Al Aziziyah station areas. Also, Al Waab, Al Sudan and Al Waab illustrate moderate value with low values presented by Souq Waqif and Sports City. The possible reasons for these have been discussed as below.

The circulatory street systems in the sub-urban density areas of the state, in stations such as QNM, Al Waab and Al Aziziyah, is facilitated by grid patterns formed by local, secondary and tertiary streets (Figure 59). A pedestrian friendly environment is created through a clear, formalized and interconnected grid pattern. Accordingly, the street pattern is not overburdened and enables few fast moving traffic encouraging pedestrians with reduced crossing distances. Traffic is reduced at these intersections which reduces pedestrian crossing distances.

Figure 59. Intersection density calculated using 3/4-way intersections, turns and traffic controls for (a) Al Waab, (b) Sports City and Al Aziziyah (Source: Author,2018)

Although clearly demarcated pedestrian paths are missing, walking is promoted in some stations through foot paths along the blocks and speed breakers. Additionally, bicycle lanes are provided at intersections, in station areas such as Al Waab, Sports city, Al Aziziyah, QNM and Ras Bu Abboud, which provide alternate modes reducing motor dependency. However, walking paths/trails without any intersection are observed in Sports City resulting in low value.

Additionally, station areas located within the urban dense areas of Doha such as Al Sudan, Joaan and Al Sadd, exhibit moderate to high values. Such stations either lack grid pattern or include streets forming both grid patterns towards the periphery and cul-de-sac closed loops within the residential areas. In some station areas such as Bin Mahmoud, pedestrian environments provide indirect access to the station area through winding turns within small internal blocks. Pedestrian foot paths are designated only along intersections of certain residential apartments or commercial retail frontages.

Figure 60. Intersection density calculated using 3/4-way intersections, turns and traffic controls for Bin Mahmoud, Al Sadd and Joaan (Source: Author,2018)

The circulation system of Souq Waqif located within the heritage areas of Doha, include narrow tertiary streets, alleyways, and local streets forming closed loop accessing inward building areas. Direct access to the metro station is prevented here due to winding turns, closed cul-de-sac loops and dead ends within small internal blocks. The pedestrian environment is encouraged by promoting walkability through pedestrian zones within the souq area in the form of open courtyards and plazas. However, intersections are avoided in such open spaces. Stations such as Ras Bu Abboud, which serve as industrial center, lacks walkable environments due to lack of residential uses (Figure 61). However, bicycle paths are designated along the airport areas, next to major road intersections.

Figure 61. Intersection density calculated using 3/4-way intersections, turns and traffic controls for Al Sudan, Souq Waqif, QNM and Ras Bu Abboud (Source: Author,2018)

Table 32

Intersection density of station areas

Name of station	Intersection density
Al Aziziyah	111
Sports City	86
Al Waab	92
Al Sudan	99
Joaan	171
Al Sadd	201

Bin Mahmoud	90
Souq Waqif	76
QNM	153
Ras Bu Abboud	14

5.1.2 PCA. Walkability and connectivity within the station area is accessed using Ped-shed ratio as shown in Figure 62. PCA value provides a percentage of maximum area anticipated to be covered within 5 minutes from within residential centers to major destinations in the station area. The PCA values for the station areas are as described in Table 33. Higher the PCA, greater the potential of walkable environments to be developed. QNM exhibits the highest PCA value, whereas Ras Bu Abboud displays the lowest. Al Sudan, Souq Waqif, Joaan, Sports City and Bin Mahmoud displays moderate areas of the station covered within 5 min. Al Aziziyah, Al Waab and Al Sadd station areas, despite being residential centers, present low PCA values.

Figure 62. PCA of stations along Gold metro line corridor (Source: Author, 2018)

The stations such as Sports city, Al Sudan focusses on reduced motor use through designated paths for pedestrian movement. Although transport networks are altered as pedestrian paths, these do not fall under the maximum coverage of 5min. walkable area. Moreover, the stations located at major intersections, such as Joaan and Bin Mahmoud connects the pedestrian areas of different zones to the station. Additionally, due to overlapping station areas, influence is also observed from adjacent residential neighbourhoods, which contributes to moderate coverage areas. Although the street patterns in Al Waab, Al Sadd station areas provide clear, formalized and direct access to the metro station and local shopping stores, these station areas are not within the 5min. walkability range due to conversion of intersections and networks as pedestrian areas.

Souq Waqif station area aids walkability through provision of land marks such as Turkey mosque, Al Fanar Islamic Center, Domes mosque and Downtown Musheireb mosque. Being a commercial souq center, pedestrian coverage is high, however, not from within residential neighbourhoods to major destinations. Stations such as QNM witness walkability to the station area encouraged by means of overbridges and underpasses. Thus, areas not within the coverage of 5min. by road networks are easily accessible by these multiple shorter routes. However, Ras Bu Abboud station area lacks accessible networks due to lack of residential uses. Thus, PCA value is due to pedestrian catchment area influenced by adjacent station.

Table 33

Pedestrian catchment area of station areas

Name of station	Pedestrian Catchment Area (PCA)
Al Aziziyah	0.28
Sports City	0.31
Al Waab	0.21
Al Sudan	0.38
Joaan	0.33
Al Sadd	0.29
Bin Mahmoud	0.30
Souq Waqif	0.36
QNM	0.45
Ras Bu Abboud	0.14

5.2 Indicator analysis: PCA and RA

The relation between the spatial and non-spatial indicators of the node and place indicators were defined using the Pearson's correlation coefficient. The results obtained are as shown in Table 36. This section attempts to determine the strength of relation between the indicators, in addition to identifying positive and negative correlations.

Along the Gold metro line, population of station area (X_1), within the catchment area was negatively correlated to the node indicators, except for slight positive correlation towards directions served by the train in accessing stations within a particular time (Y_3).This shows that stations along the metro line, with high number of bus services serving multiple directions (Y_6, Y_7) with adequate parking and cycling facilities (Y_8,Y_9), have relatively small residential population. Also, large residential population concertation were found in areas with close proximity to major city center road accesses (Y_7) and increased access to high number of stations within a designated time (such as 20min.). Furthermore, high value of correlation was observed between population (X_1) and workforce clusters

(X_3, X_4, X_5, X_6). This indicates that the station areas with high population density, also enable high concentration of workers due to jobs of public functions being found in residential areas. Thus, it can be inferred that station areas of high population, served by frequent bus systems through multiple routes, attracts the inflow of a large workforce.

The worker cluster grouping inclusive of workers in the retail/hotel/catering, administrative services, education/health/cultural activities and industrial distribution was positively correlated to the node indicators. Thus, metro stations with frequent bus services (Y_6), multiple bus connection access routes (Y_5) and ease of access to station areas within 20min. (Y_3), have relatively large concentration of workers. Also, location of the stations with close proximity to major road accesses such as expressways and highways (Y_7), encourage worker concentration (X_3, X_4, X_5, X_6). As a result, this improved transit infrastructure facility provides opportunity for the workers to reside in nearby neighbourhood areas, increasing the population.

The multitude of activities encouraged by a station area was identified by its degree of functional mix. It was observed that the degree of functional mix (X_7), calculated within the station area was positively correlated to the node indices except for negative correlation with nearness to major transport access leading to the city center (Y_7). Thus, stations providing frequent bus services with multiple directions of access, accessibility to and from the station areas of network within a particular time are noticed as multi-functional. However, activities are noticed as mono-functional, for those metro stations which are at increased distance from major road accesses. This was highlighted by the negative low value of correlation between degree of functional mix (X_7) and proximity to road access (Y_7) ($r = -0.30$). Additionally, this improves the functionality of metro stations in relation

to better potential of transit system by inviting more passengers. This was confirmed by the high value of positive correlation coefficient ($r = +0.61$) between diversity of activities in form of functional mix (X_7) and provision of car park and ride facility (Y_9).

The place indicators of intersection density (X_8) and PCA (X_9), also showed positive correlation with the node indicators. Thus, walkable environments with reduced traffic, pedestrian aids, and designated park and ride facility (Y_9) are observed in station areas along the Gold line. On the other hand, station areas with less bicycle paths (Y_8), increased motorways and lower car parking facility (Y_9) are observed closer to the road accesses leading to city center (Y_7). This was indicated by the negative medium correlation value of $r = -0.54$.

A negative correlation value between accessibility by train (Y_2) and bus systems (Y_5), indicates that access is ensured by frequent (Y_6) and multiple bus routes (Y_5), close to major road accesses (Y_7), where trains originating from the station do not serve multiple directions. Also, a positive correlation existed between accessibility of stations within a particular time located close to major road accesses (Y_7) ($r = +0.13$), where these stations show improved transit by efficient, highly frequent rapid bus transit system serving multiple directions ($r = +0.20$ & $r = +0.08$)(Y_5 and Y_6). Thus, accessibility to multiple station areas within a short duration is achieved by frequent bus transit system, enabling multiple routes due to major road accesses.

In conclusion, the node indicators; direction served by train, station accessible within 20min., direction and frequency of bus services, proximity to road access, car park and ride facility, shows the strongest relationship with the place indicators-population, workforce, degree of functional mix, Intersection density and PCA.

Finally, regression analysis was carried out, using the node and place indices of the station areas, to determine $R^2 = 0.96952$. This suggests that 96% variation in the node index is explained by variations in the place index. The closeness to one indicates best fit curve for the data. As obtained, f and p value of 0.0187 (<0.05), reveals that a logical relation exists between the node and place indicators, in reference to context of Doha.

In order to assess and classify the stations into Bertolini's typologies, the node-place indices of the station areas along the Gold metro line were plotted in the N-P graph. In addition to the N-P TOD index, typology classification assisted in emphasising on the criteria to be altered to develop as potential TODs.

5.3 Calculating the N-P TOD index of station areas

The Node-Place index (TOD level) of station area determines the TOD potential. This was calculated as the slope of node and place index for each station area. Lower the value of N-P TOD index, greater the ability to attain a balanced integrated state and higher the potential of the station to emerge as TOD. Thus, the node and place index of station areas were calculated first followed by calculation of the N-P TOD index (Appendix-A)

5.3.1 Node and place index. As discussed earlier, node index and place index were calculated as the sum of all their respective node and place indicators. However, prior to calculation of the index, the measured and calculated indicators, were standardized using normalization, due to different units of measurement. Following this, the scored indicators were weighted equally (EW) such that a factor of 0.11 and 0.17 were assigned for the node and place indicators respectively. The following Table 34 indicates the node and place index for the 10 station areas.

Table 34

Node and Place Index of station areas

Name of station	Node index	Rank	Place Index	Rank
Al Aziziyah	0.184	3	0.059	7
Sports City	0.180	5	0.075	4
Al Waab	0.183	4	0.070	6
Al Sudan	0.158	9	0.055	8
Joaan	0.159	8	0.087	2
Al Sadd	0.162	7	0.054	9
Bin Mahmoud	0.167	6	0.144	1
Souq Waqif	0.320	1	0.072	5
QNM	0.167	6	0.082	3
Ras Bu Abboud	0.210	2	0.013	10
Mean	0.189		0.083	

The station areas were then ranked based on their node and place indicators, prior to plotting on the N-P graph. Ranking of the Gold metro line stations, based on the N-P index enabled to focus on the appropriate criteria for improvement. These criteria were then targeted as means to develop the station as TOD. A higher value of Node Index indicated the high connectivity offered by the transit system. Also, a high value of Place index indicated an area of appreciable built environment and high economic activities surrounding the station. As observed from the Table 34, Souq Waqif revealed the highest node Index (NI=0.320) and Al Sudan showed the least (NI=0.158). Also, Al Sadd exhibited high urban development (PI=0.054), when compared to other station areas. A Place Index of 0.013 for Ras Bu Abboud station, indicated an un-developed area within the sub-urban premises of Doha.

5.3.2 N-P TOD index. The N-P TOD index was calculated as the slope of node and place Index. This index value was used as a measure to rank the stations in order of their potential to emerge as TODs. According to Bertolini's N-P model, the N-P value provides the variations between node and place criteria, which needed to be enhanced to attain a balanced state. Higher the calculated TOD index, greater the potential of station area to develop as TOD. This was based on the assumption that greater the ability of the station area to undergo interventions to reach a balanced state, higher the potential for improvement towards TOD. Furthermore, the research used this balanced state as a pointer for stations to attain TOD levels. The stations were then ranked based on their N-P TOD index as shown in Table 35.

Table 35

N-P TOD index of station areas based on rank

Name of station	Node index	Place Index	N-P TOD Index	Rank
Souq Waqif	0.320	0.072	4.43	1
Al Aziziyah	0.184	0.059	3.13	2
Al Sadd	0.162	0.054	3.00	3
Al Sudan	0.158	0.055	2.89	4
Al Waab	0.183	0.070	2.61	5
Sports City	0.180	0.075	2.41	6
QNM	0.167	0.082	2.03	7
Joaan	0.159	0.087	1.83	8
Ras Bu Abboud	0.210	0.013	1.62	9
Bin Mahmoud	0.167	0.144	1.16	10

Due to highest value of N-P TOD index, Souq Waqif exhibits the highest potential for TOD, where Bin Mahmoud in a roughly balanced state exhibits the least potential.

5.4 Assessment and classification of station areas

5.4.1 The N-P graph. The N-P graph (Figure 63) illustrates the position of each of the 10 station areas according to Bertolili's N-P model and Node- Place index. As observed, the values revealed that node index was higher than the place index (all 10 stations), with a mean value of 0.189 for node and 0.083 for place. Thus, a large number of stations fall under the typology- unbalanced node, where the station areas have more significant relative position on the node scale. These station areas form national town centers, recreational centers, mostly in the sub-urban areas located away from the city center with parks, museums and public government institutions. Thus, it can be inferred that these station areas witness more developed transit/transport systems when compared to the urban development activities. As a result, further development in these areas in terms of transportation become problematic due to limited mixed amount of urban activities. This partly explains the lower place values of station areas. However, Bin Mahmoud approaching the central line in the graph, roughly reaches the balanced state, where the transportation and land use activities co-exist (NI=0.167, PI=0.144). It is also noted that none of the stations fall under the stressed, dependent or balanced states.
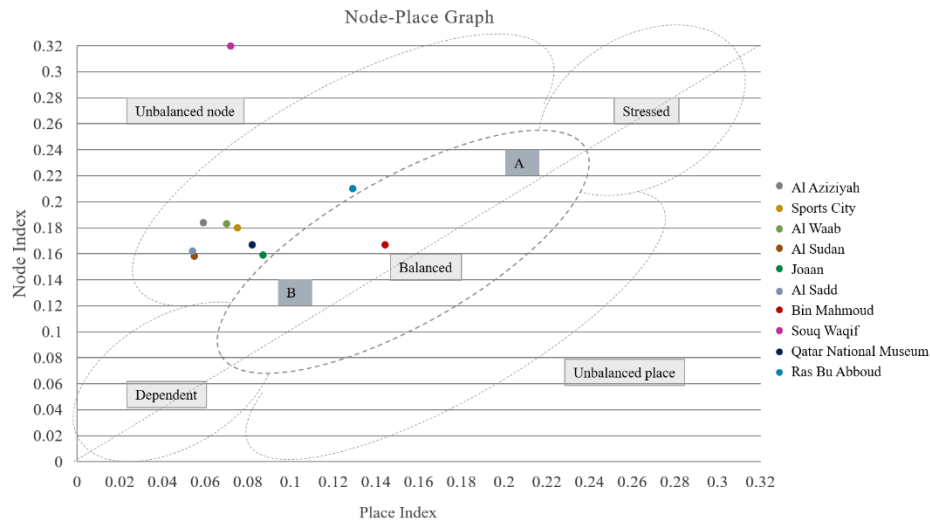
Figure 63. N-P graph used to classify stations based on N-P model (Source: Author, 2018)

For the purpose of research, these relative positions of station areas were compared, due to the assumption of land use transport interaction. As explained by the Figure 63, Souq Waqif station showed the highest Node Index (0.320) and is located at the top-left corner. Souq waqif is a recreational regional center with government public institutions and commercial souq. This partly, explains the high connectivity due to interconnected bus, cycle and metro system. Alternatively, Al Sudan metro station exhibited the least Node Index (0.158), being a mixed use urban center in the high density development areas with a stronger place value. Bin Mahmoud presented the highest Place Index (0.087), due to contextual location as a mixed use urban center with multiple functional activities. Also, Al Sadd, displayed the least place index (0.054), due to multi-family residential uses in urban high density development areas with lower diversity of economic activities. These only partly, explain the unbalance of the station areas. As a result, comparative analysis of the node and place indicators of these station areas was necessarily undertaken. This

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revealed the land use and transport conditions, which favoured urban development activities around transit station areas, taking advantage of the public transport supply, to emerge as TODs.

In the context of Doha gold metro line, development of TODs were attempted to be achieved by opting to either increase the place value (a) or decrease the node value (b) of the unbalanced node (Figure 63). Thus, the unbalanced node and roughly balanced stations were ranked as follows based on the N-P TOD index: Souq Waqif (4.4), Al Aziziyah (3.1), Al Sadd (3), Al Sudan (2.9), Al Waab (2.6), Sports City (2.4), Qatar national museum (2.0), Joaan(1.8), Ras Bu Abboud (1.6), and Bin Mahmoud (1.2) (Table 35).

5.5 Interpretation of Node and Place functions

5.5.1 The Gold metro line. As observed, the center of the metro line constitutes high density metro station areas such as Joaan, Al Sadd, Bin Mahmoud, Souq Waqif and Qatar National Museum. Further, the terminus stations witness decreased development density. Additionally, these stations were observed as highly populated with greater workforces. This indicates that adjacent metro stations located close to each other with overlapping station areas, at high proximity to the city center exhibit high residential population. These areas encouraged the inflow of workforce due to availability of economic activities.

Stations such as Souq Waqif and Bin Mahmoud, served by multiple bus routes and experiencing high frequency bus transit system were located towards the high density areas. Moreover, as observed from Table 18, Table 21and Table 24, stations of Joaan, Al Sadd, Bin Mahmoud and Souq Waqif, located towards the center of the metro line indicated high degrees of functional mix representing the diversity of activities. This progressively

decreased towards the terminus stations. A similar trend was observed in the potentially walkable environments of the station areas. The stations of Joaan, Al Sudan, Bin Mahmoud, Souq Waqif and Qatar National Museum, showed favourable PCA's towards the center of the metro line which progressively decreased towards the terminus stations. Similarly, higher intersection densities were observed towards the city center station areas enabling higher potential for walkable environment.

Based on the results of the N-P graph and Node-Place index, the east extension of the gold metro line constituted stations with higher node index, which gradually decreased towards the center and then progressively increased as it approached the west end. In contrast, central section of the line, displayed stations of high place index which diminished at the terminus stations. Thus, unbalanced station nodes followed a pattern of occurrence along the Gold metro line, based on variations in the node and place indicators. Thus, interpretation of the criteria of node and place along the east-west extension of the Gold metro line for each station area is necessary to emphasis on the distinct criteria to be focused for the overall improvement of TOD level of unbalanced nodes.

5.5.2 Station areas. In addition to the N-P graph and calculated N-P TOD index, which identify the unbalanced nature of the station areas; radar diagrams were developed for each of the 10 station areas. These diagrams identified the individual criteria and indicators scoring low to suggest potential improvements to develop the station area as TODs. Also, it helped to identify similar pattern in terms of node and place functions between the different station areas. Accordingly, the 9 node and 9 place indicators (Total=18), were calculated for the station areas. Figure 64, presents the result of station area accessibility and parking provisions within the metro stations. Also, Figure 65,

represents the land use density, diversity and availability of walkable environments in the station areas. The discussion is arranged such that station area with the highest potential is discussed first.
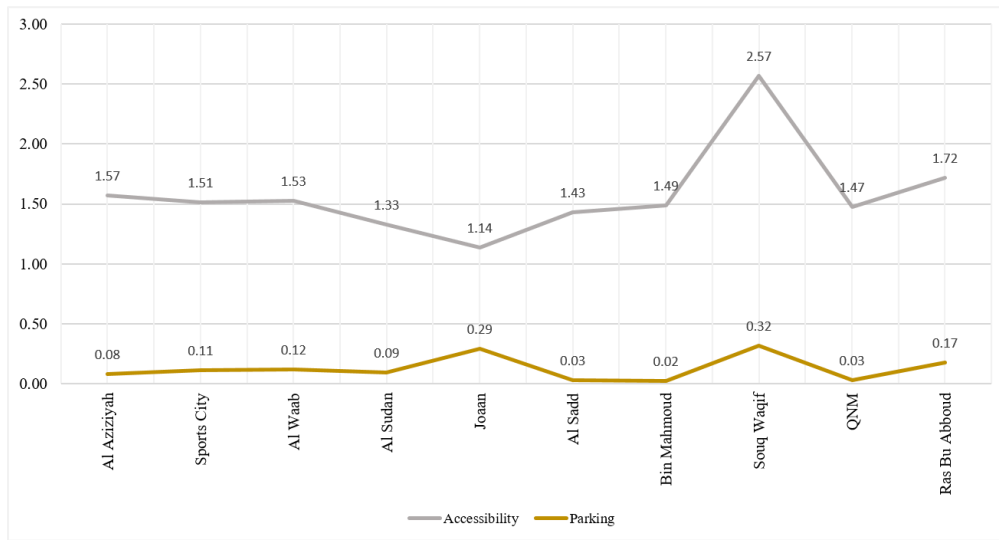
*Figure 64.*Graph presenting accessibility and parking results (Source: Author, 2018)
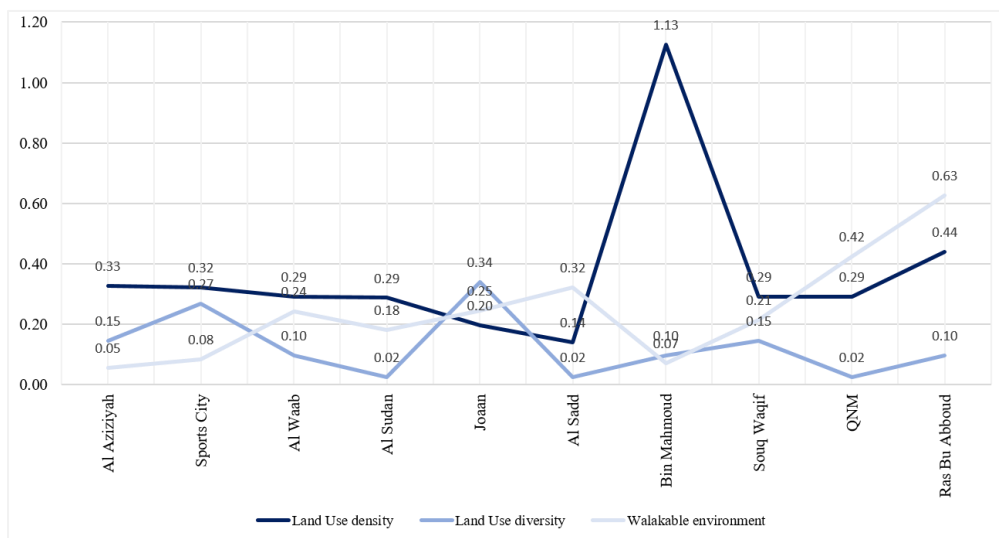
*Figure 65.*Graph representing the land use density, diversity and walkable environment indicator results of station areas (Source: Author, 2018)
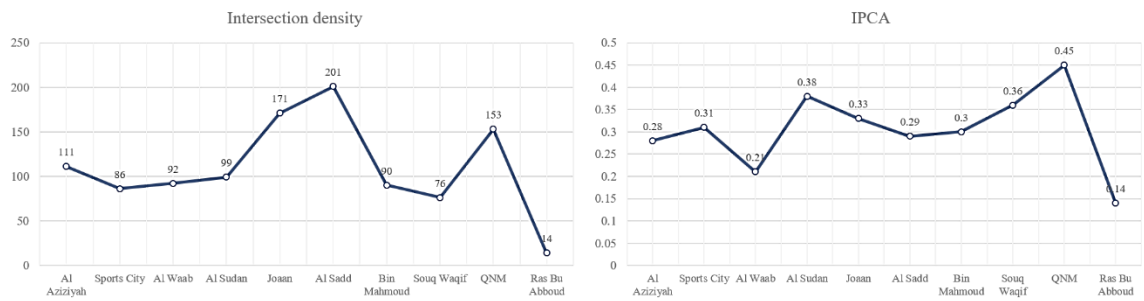
*Figure 66.*Graph representing the walkable environments-Intersection density and PCA indicator results of station areas (Source: Author, 2018)

5.5.2.1 Souq Waqif. Souq Waqif is a regional transit station area, being one of the most crowded stations in the transport network. This is shown by an extremely high node index score when compared to the other station areas (0.320-1st rank). This is related to the quality of the transit system, which is owed to the fact that the station has improved accessibility contributed by high frequency of bus transit (142), increased number of routes (37), maximum stations covered in 20 min. (28), in addition to the close proximity to B-ring road access (Table 18). The walkable area provides high parking capacity (designated and vacant plots) when compared to other stations, in addition to encouragement of through movement by bicycles.

Figure 67. Radar diagrams representing place indicators, node indicators and overall TOD criteria-Souq Waqif (Source: Author, 2018)

In comparison, the station exhibits a low place index score of 0.072 (5th rank). Being a recreational center, concentration of certain activities alone such as commercial souqs and public government institutions, results in comparatively low degree of functional mix (.90). Thus, the station area lacks diversity and mix of functional activities. Again, this is due to the combined contribution of low residential population, land use density, diversity and unfavourable walkable environment indicators. Further, below average intersection density (76), results in obstructed access to pedestrians (Figure 66). This indicates poor integration of street network within the station area. These lack winding turns, closed cul-de-sac loops and dead ends disabling pedestrian environments in small internal blocks. Also, a PCA of 0.36, indicates low percentage of accessibility to the resident users.

The TOD potential of the station can be improved by either reducing the node indicators or improving the place indicators. The former is attempted by altering parking indicators. A large amount of vacant land is wasted as designated unused car parking space. These spaces can be developed as mixed use environments by accommodating other

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functions and activities. This can develop the recreational center as a mixed use urban economic hub with a strong sense of place. Furthermore, efforts to enhance TOD type development should be focussed on development of built environment and activities around the station areas. This is attempted by increasing the place value by improving place indicators such as diversity of activities, PCA and intersection densities.

Thus, attempts to enhance the station area should be focused on indicators such as car park and ride facility, degree of functional mix, intersection density, and PCA (Table 36).

5.5.2.2 Al Aziziyah. Al Aziziyah station is ranked as station with second most TOD potential, where a high variation is observed between the node and place index in comparison to other station areas (Figure 63). A node index of 0.184 (3rd rank), is exhibited by the station, located within the sub urban high density development areas, which highlights a culmination of recreation, shopping, leisure and cultural activities. The station area has advantages due to the high frequency of bus systems, close proximity to two road accesses enabling passenger flow, but reduced connectivity being a terminus station in Phase I. It shows low values for indicators such as bus transit routes and accessibility to stations within a particular time (Table 27). Comparatively, the station area provides for through movement in the station area by designated walking/running trails and bicycle/club cart paths, with adequate parking provisions.

The place value of 0.059 (7th rank) is low when compared to other station areas. The station being a sub-urban transit center, serves as a destination for recreational sporting/training and shopping activities alone. Relatively, the place dimension has not witnessed any spatial development during the years due to lack of diversity of economic

activities. This is shown by 0.9 score of degree of functional mix. As a result, reduced

economic investments decreases the inflow of passengers and workers into the area. Again,

the low score is due to the low value for the criteria of walkable environment. Furthermore,

the highest intersection density of 111, due to three way, four way intersections, turns and

traffic controls in well-organized grid systems encourage pedestrian movement. However,

mobility here is focussed on both the pedestrians and cars. Low score for the PCA (0.28)

validates that the pedestrian friendly accessibility to major destinations within the station

area is restricted from the residential areas, due to walkable environment along clear,

formalized and footpaths of interconnected grid system. These walkable environments are

focussed only around and within the Aspire zone.

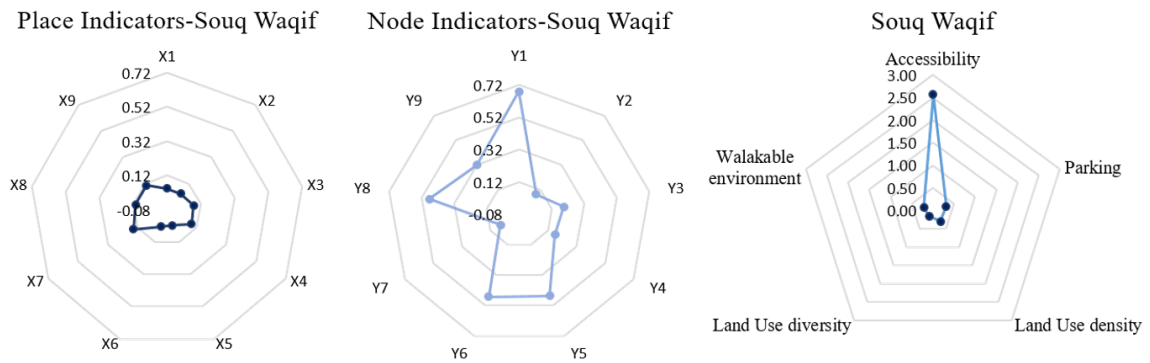*Figure 68.*Radar diagrams representing place indicators, node indicators and overall TOD criteria-Al Aziziyah (Source: Author, 2018)

Thus, the TOD potential can be improved by focussing on built environment around

transit stations and restricting the public connectivity and enhancing alternate private

domain connections. This is achieved by motivating the walkability indicators such as encouraging improved intersection density and PCA values. Developing the walking/running trails to more pedestrian friendly environments by removing/reducing motor movement in small streets. This can be extended to allow bicycles and club carts. Enhancing the degree of functional mix by removing and replacing obsolete station area surroundings such as higher concentration of open spaces/plazas/parks (0.42 km2), by more economic activities. Developing the terminus station as a complete sub-urban transit station, with a pedestrian friendly environment through a clear, formalized and interconnected grid pattern surrounding the station areas from the low density residential uses.

Thus, attempts to enhance the station area should be focussed on indicators such as degree of functional mix, intersection density and PCA (Table 36).

5.5.2.3 Al Sadd. Al Sadd station is a residential center in urban high density areas of Doha, with comparably lower node (0.162-7th rank) and place values (0.054-9th rank). The station area is ranked third due to its potential to improve/enhance in both the node and pace values to emerge as TOD. The lower node index is highlighted by the low score of accessibility (1.43). This is due to reduced value of connectivity (5) and frequency offered by interchange modes such as bus transit (26) (Table 24). Being located within the traditional districts of Doha, the circulation system includes connections between the primary, secondary and tertiary road networks, allowing typical fast moving traffic. This station has disadvantage in terms of greater distance from road access.

*Figure 69.*Radar diagrams representing place indicators, node indicators and overall TOD criteria-Al Sadd (Source: Author, 2018)

As observed, the urban development of Al Sadd, exhibits a very close pattern with Al Aziziyah in terms of place indicators (Figure 68and Figure 69). The lowest score of land use diversity (0.02), is due to high residential concentration and local retails, when compared to other economic activities. This is also shown by low degree of functional mix (0.91). The traditional street patterns lead to highest intersection density (201). The station area has high scores for provision of walkable environment (0.32). In contrast, the low PCA (0.29), in this sub-regional residential center may be due to lack of designated pedestrian routes from residential centers to reach the metro station.

The station area can be developed as TOD by working around quality of transit system as well as urban development. Basically, the station has better scores related to quality of transit system. Thus, efforts to improve the TOD potential should be focussed more on quality of transit system. Increasing the number of bus stops, allowing for more frequent interchanges, enables higher node values. Additionally, bus routes can be diverted from adjacent station areas such as Joaan and Bin Mahmoud to compensate for the distance

from major road access. Improvement for this station to reach the desired TOD level, should further focus on enhancing the intensity (diversity) of commercial activities. Additionally, designated pedestrian paths and bicycle lanes within the metro station surrounding areas can contribute to an improved place. However, the intervention within the criteria of density and other indicators of walkable environment may not result in the desired output.

Thus, attempts to enhance the station area should be focussed on indicators such as directions served by bus, daily frequency of bus service and proximity to major road access (Table 36).

5.5.2.4 Al Sudan. Al Sudan station areas serves as an urban transit center with low values of node (0.158-9th rank) and place index (0.055-8th rank). This low node index is due to low score for criteria of accessibility (1.33). The restricted movement of passengers is assumed due to decreased frequency of multi-modal services such as bus transit (14), resulting in lower number of stations accessed within 20min. (14) (Table 24). However, close proximity to major road access encourages passengers from adjacent station areas. The station area improvement strategies include enhancing the criteria of accessibility, by introducing more on-street bus-stops. Another attempt to improve TOD potential, is to attempt re-routing bus transit routes serving the adjacent stations to increase the frequency of interchange mode passing through Al Sudan area. This should be adjusted such that accessibility of the adjacent through station areas are not affected.
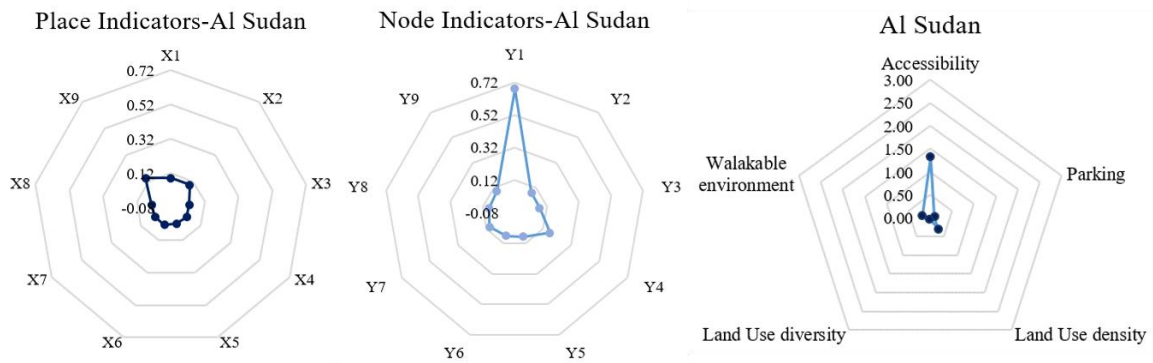
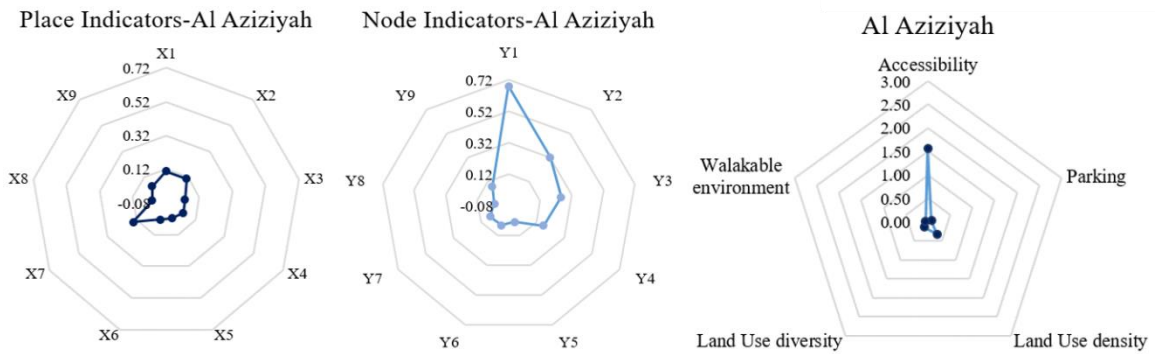*Figure 70.* Radar diagrams representing place indicators, node indicators and overall TOD criteria-Al Sudan (Source: Author, 2018)

In addition to residential concentration, Al Sudan culminates in activities of leisure, recreational sports, education and shopping. The low value of place index is due to low scores for criteria of land use density (0.29) and walkable environment (0.02). The place index can be improved taking advantage of the criteria of land use diversity (score=0.18) which is comparatively high among the station areas. The mixed use center can be used as a means to encourage more economic activities which further attract workers to the area. This positively stimulates the land use density criteria of Al Sudan station. Additionally, TOD type development of the station area can be enhanced through introduction of designated paths/footpaths and winding roads encouraging pedestrian movement with reduced motor traffic. Therefore, the comparatively low value of intersection density can be altered (99).

Thus, attempts to enhance the station area should be focused on indicators such as number of directions served by the bus, frequency of bus operations, workers cluster grouping, and intersection density, and net residential density (Table 36).

5.5.2.5 Al Waab. Al Waab residential station is located within the sub-urban high density areas with commendable connectivity and is ranked fifth to attain TOD type development. The station shows a high node value of 0.183 (4th rank), due to the criteria scores of accessibility (1.53) and parking provisions (0.12). Attaining a favourable TOD potential, depends on either reducing the dependence on transit system or increasing the urban development in the metro station area. Efficient accessibility within the station area is managed by bus transit system, with adequate frequency (10), providing access to 16 stations within 20min. (Table 27). Advantage can be taken of the central location of the transit station, where the feeder bus routes can be rerouted within the residential secondary networks and allowed to loop into the station area. This encourages pedestrian movement within the residential areas improving the criteria of walkable environment. Intervention in the areas allocated for parking can be used for other economic activities such as commercial offices and public institutions. The economic land uses along the metro, relying on auto trips such as light industrial facilities, car washes, and petrol stations should be avoided to encourage more pedestrian movement. These intrusions can reduce the focus on quality of the transit system, emphasizing on the place index.

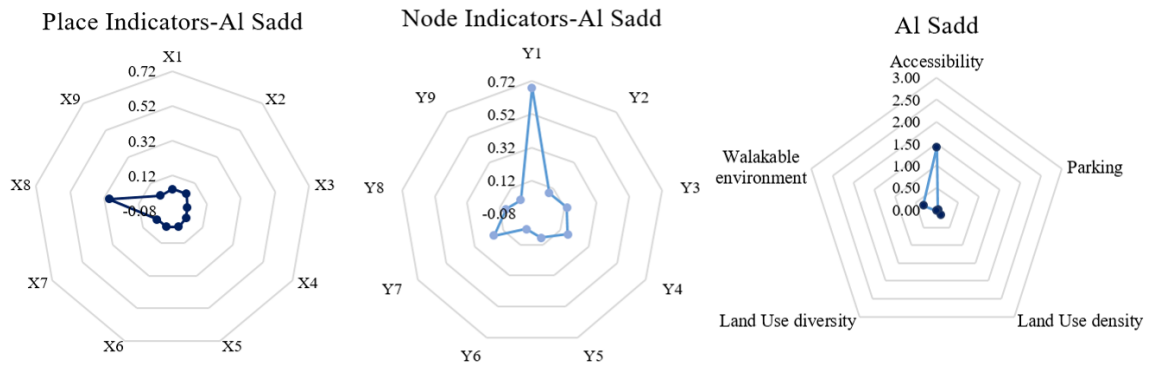*Figure 71.*Radar diagrams representing place indicators, node indicators and overall TOD criteria-Al Waab (Source: Author, 2018)

The place index value of the station area is low (0.070-6th rank), which highlights that improvement need to be focussed around the surrounding urban environment. As observed, the place indicators of both Al Waab and Al Sudan station areas show a similar pattern, which is possibly due to the adjacent location within similar sub-urban density. The station serves as a sub-urban transit center (residential) with activities focused around private neighbourhood areas. However, diversity of activities is maintained through commercial offices, shopping centers, and public institutions. The degree of functional mix is high compared to other station areas (0.92). Possibly, the criteria of walkable environment (0.24), lowers the sense of place due to lowest PCA value (0.21). This shows that difficulty is encountered by pedestrians, in reaching the metro station within 5min.. Furthermore, moderate value of intersection density (92), suggests that multiple shorter routes coinciding with the streets encourage slow through motor traffic. Improvement of this station area can be focussed around criteria of walkable environment, where advantage can be taken of low intersection density. The secondary areas can be connected to the metro

station using these intersections, offering short multiple routes with speed breakers. The intersections should ensure reduced motor flow with designated clear, formalized and convenient pedestrian bicycle access.

Thus, attempts to enhance the station area should be focused on indicators such as number of directions served by the bus, car park and ride facility, and PCA (Table 36).

5.5.2.6 Sports City. Sports city metro station located adjacent to and sharing overlap area with Al Aziziyah is ranked sixth in terms of N-P TOD index. Thus, a similarity in pattern of overall node and place indicators is observed (Figure 68 and Figure 72). The sub-urban high density Sports City metro area has comparatively high values for node (0.180-5th rank) and place (0.075-4th rank) index (Table 35). The high value of node index is contributed by high scores for criteria of accessibility (1.51) and parking provisions (0.11). Although, accessibility score is comparable with other station areas, re-interpretation of the parking score can alter the quality of transit system. On-street parking spaces can be replaced by designated walking/cycle trails, so as to encourage pedestrian movement and reduce motor usage. As observed from N-P graph, interventions to develop as transit center should focus on compensating the quality of transit system with an increase in station development. Also, a similar pattern is observed for node indicators for Al Waab and Sports City, probably due to location along the same primary Al Waab Street. This can be taken as an advantage, where shared bus stops/transfer stops and re-routed bus services meeting transit ridership can be used to reduce the node index.

Figure 72. Radar diagrams representing place indicators, node indicators and overall TOD criteria-Sports City (Source: Author, 2018)

Other attempts to achieve a TOD can be achieved by improving the place indicators around the transit system. The sports city station area has a lowest degree of functional mix (0.89), due to only recreational activities. This criteria can be improved by introduction of economic activities replacing small pockets/parcels of greenery within residential areas. This further, increases the inflow of workers, increasing density. A score of 0.08 for criteria of walkable environment suggest that place improvements, encouraging pedestrian activity should be focussed for TOD. Low intersection density (86) and high PCA values (0.31) suggest that there is potential for encouraging pedestrian environments. Grid pattern intersections formed by tertiary and local streets in residential areas should be enhanced using designated footpaths and traffic controls. Attempts to increase the walkability should include reduction of traffic movement by speed breaks. Specifically, these designated paths should be increased connecting residential and sporting activities to station area premises. As observed, restriction of the pedestrian environment to major recreational activities (Aspire sports complex) should be avoided.

Thus, attempts to enhance the station area should be focused on indicators such as number of directions served by the bus, frequency of bus operations, car park and ride facility, degree of functional mix, intersection density and PCA (Table 36).

5.5.2.7 Qatar National Museum. QNM station is an urban transit city center with high density activities focussed around monuments of national significance. The station has a node index of 0.167 (6th rank) and place index of 0.082 (3rd rank) (Table 35). Thus, the node index is low and place index is high in comparison to other station areas along the Gold metro line. An attempt to balance this station to develop as TOD, requires the increase of node index bringing favourable changes in the place index. Low node index is due to low score for parking provisions (0.03) (Figure 64). Thus, concentration on the criteria of parking through provision of designated off-street park and ride facility, MLCP, basement parking, can improve the quality of transit system. The station has good score for alternate interchange mode indicators (bus transit). However, the frequency of bus transit routes is minimal (3) when compared to other stations, which is mitigated by coverage of these routes (Table 24).
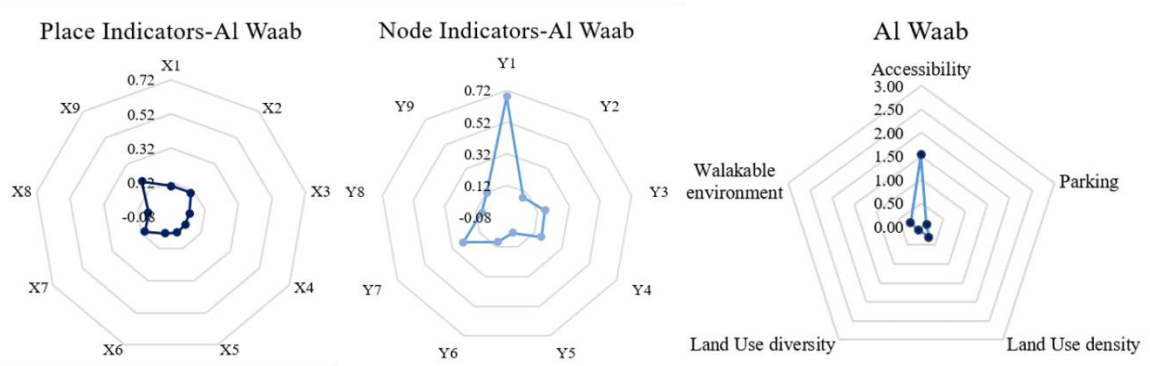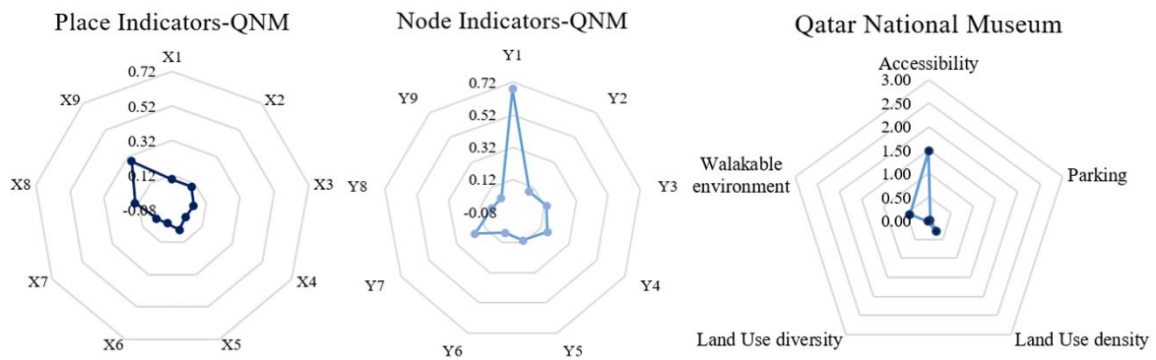

*Figure 73.*Radar diagrams representing place indicators, node indicators and overall TOD criteria-QNM (Source: Author, 2018)

As observed, the place indicator radar diagrams of QNM, Al Sudan and Al Waab exhibit a similar pattern. Due to the moderate degree of functional mix (0.91), intensifying the density can be attained by designation of land uses in terms of employment concentration and economic generation. This alters the place index due to the increased density of worker groups and station users flowing into the station. Furthermore, this necessitates the improvement of alternate directional routes served by interchange transit, which influences the indicator-directions served by bus. The station exhibits the highest PCA (0.45), encouraging pedestrian accessibility and high walkable coverage within the station area. This is achieved by un-interrupted pedestrian movement underpasses and overbridges across the express road and Corniche Street.

Thus, attempts to enhance the station area should be focused on indicators such as number of directions served by the bus, and car park and ride facility (Table 36).

5.5.2.8 Joaan. Joaan serves as an urban transit center within the urban high density areas of Al Sadd, focussed on activities feeding the private neighbourhood areas, along with recreational, leisure, shopping, training and education services. The patterns of place indicator diagrams of Joaan, Al Aziziyah and Sports city show similarity (Figure 68, Figure 72 and Figure 74). As realised from Table 35, the station has node index of 0.159 (8th rank) and place index of 0.087 (2nd rank). In comparison to other station areas, the node index is low and place index is high. The high place value of the station is contributed by moderate to high values of criteria, ranking Joaan as 8th in the list to reach TOD.
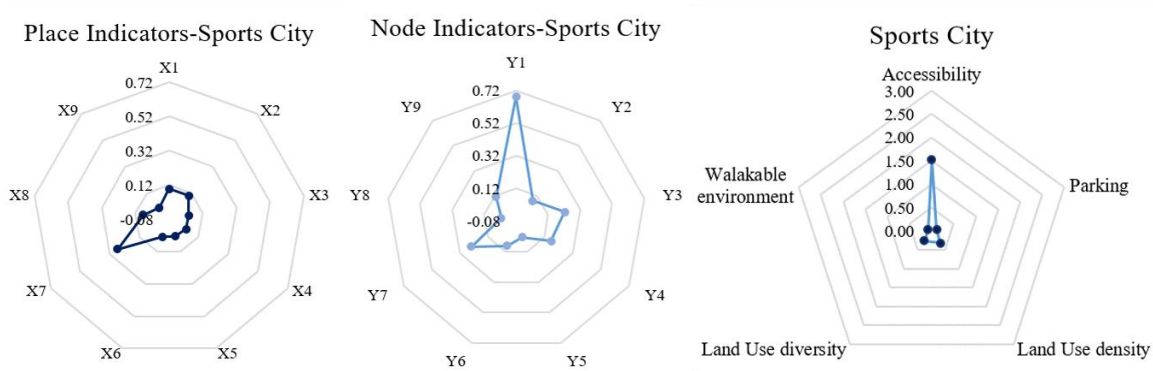
Figure 74.Radar diagrams representing place indicators, node indicators and overall TOD criteria-Joaan (Source: Author, 2018)

As analysed, in order to emerge as TOD, indicators contributing to the node index need to be increased supplementing the existing place value. The low value of node index is contributed by low score of accessibility (1.14). This can be improved by introducing bus and transfer stops, along the primary routes to increase the directions served (8). Additionally, advantage can be taken of high PCA value (0.33) and high intersection density (171), where maximum coverage by foot can be encouraged within the limited grid pattern. The grid patterns in the secondary areas formed by secondary and tertiary streets can be introduced with designated footpaths/trails with reduced traffic, connecting the station area with the community centers in Joaan. Additionally, this enhances the accessibility to bus stops and transfer stations improving the number of stations accessed within a particular time (22).

Additionally, the highest degree of functional mix (0.94) and workers cluster groupings indicates diversity of uses, demanding enhanced re-routing of buses to serve the station (19). Overlap of Joaan with Al Sadd station area can be interpolated to extend the

bus services in the overlap area. Thus, Joaan through station can be accessed easily as both regional trip origin and destination.

Thus, attempts to enhance the station area should be focused on indicators such as number of directions served by the bus, frequency of bus operations and number of stations accessed within 20min. (Table 36).

5.5.2.9 Ras Bu Abboud. Ras bu Abboud is the second terminus station of the Gold metro line, which is ranked as 9th among the stations to develop as TOD. As observed, the station shows comparatively higher node index of 0.210 (2nd rank) and lower place index of 0.0129 (10th rank). To improve the TOD potential, the station area has to encourage improvements to increase the place index corresponding to the node index.

The low value of place index is possibly due to moderate to low scores of place indicators related to walkable environments and density of the area. One main possible reason is the lack of development density in Ras Bu Abboud station being an industrial city center. Additionally, the station lacks development diversity due to concentration of power and desalination plants in this suburban low density area of Doha. In contrast, the high value of functional mix indicates the diversity of uses such as public institutions, airport facilities, educational and training centers in the limited station area (1.54 km^2). Thus, the degree of functional mix (0.92), does not take into consideration the density of the area, but focuses on workers inflow alone. This low diversity of land uses can be altered to cater to the existing activities in the area. Advantage can be taken of the conditions such as educational campus (QAC), where residential accommodations for faculty and students can be introduced. Additionally, labour accommodations and commercial local shops introduced to serve the desalination plant workers can possibly initiate development in the

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area. The low values of PCA (0.14) suggest that possible improvements in developing pedestrian networks can improve the place value along proposed development areas. Furthermore, quality of the transit system through interconnected public transport such as feeder bus services and bicycle lanes, favour the development density and vice-versa, for Ras Bu Abboud station area.

Thus, attempts to enhance the station area should be focused on indicators such as, degree of functional mix, workers cluster grouping and PCA.
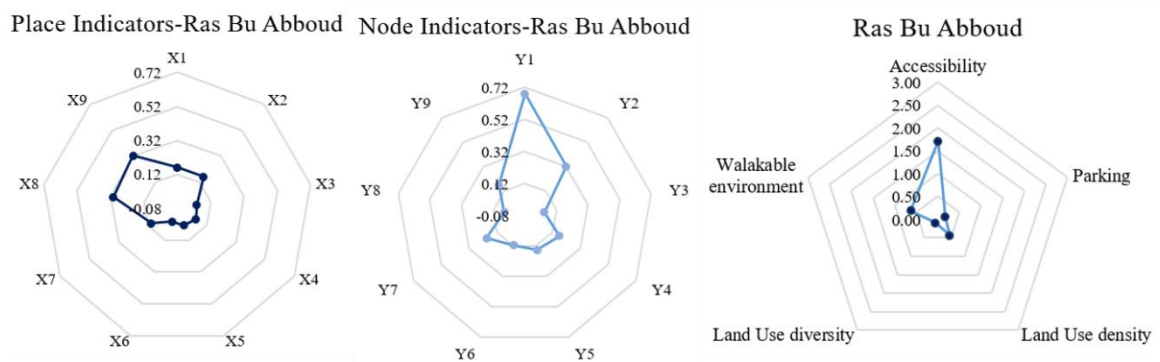
Figure 75. Radar diagrams representing place indicators, node indicators and overall TOD criteria-Souq Waqif (Source: Author, 2018)

5.5.2.10 Bin Mahmoud. Bin Mahmoud station is located within the urban high density areas of Doha. The station serves as a sub-regional transit center with activities focused not only around private neighborhood areas, but also includes community, commercial and shopping activities. The station is roughly balanced due to close values of node and place index. Further, the metro station exhibits advantages from the criteria of land use density, diversity and pedestrian friendly walkable environment. It is ranked 10th among gold metro line stations to emerge as TOD.
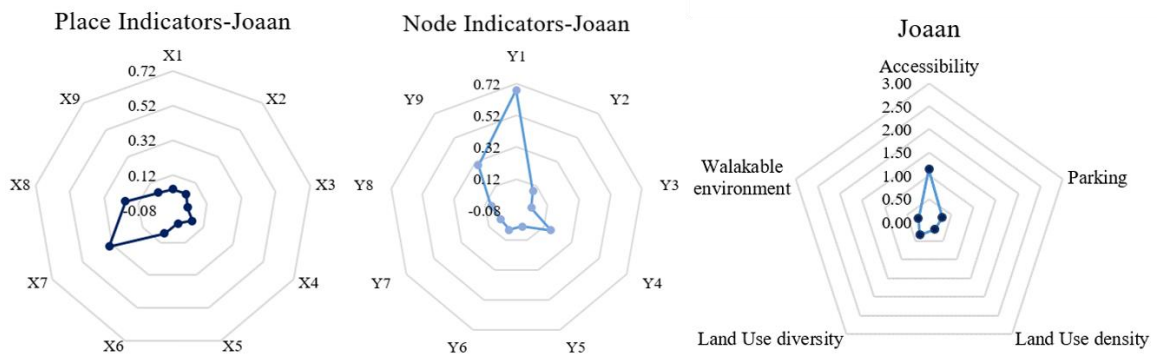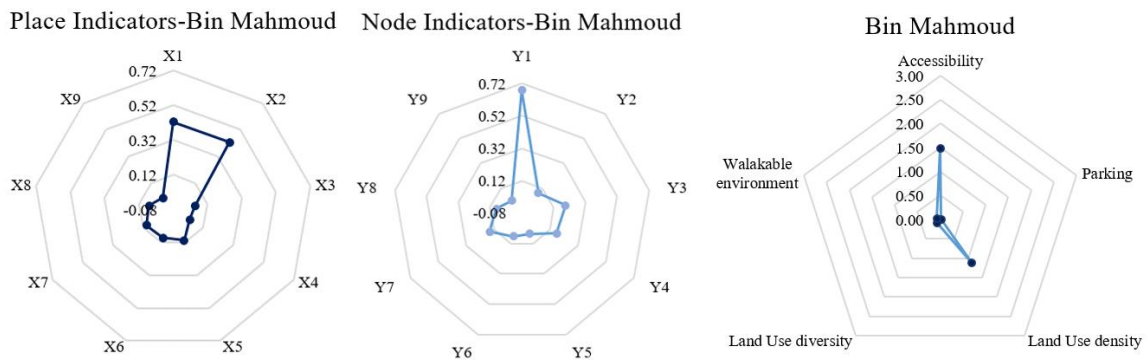

*Figure 76.*Radar diagrams representing place indicators, node indicators and overall TOD criteria-Souq Waqif (Source: Author, 2018)

As observed in Table 35, the station receives a moderate node index of 0.167 (6th rank) and the highest place index of 0.144 (1st rank). As observed, the station is a residential center with diversity of uses, enabling pedestrian environments. This is verified by moderate to high values of place indicators such as PCA (0.3), intersection density (90) and degree of functional mix (0.90) (Figure 66). In order to develop the station as TOD, interventions should be focussed to decrease the criteria of node index.

The low value of node index is possibly due to moderate scores for parking provisions (0.02) and accessibility (1.49) (Figure 64). The station area provides access to 28 stations through interchange bus system served by 19 buses along 13 routes (Table 21). The number of bus stops (8) can be reduced as the station area is predominantly residential. Multiple routes serving the station area can be reduced, which can be re-routed to other station areas. Furthermore, moderate to low value of diversity indicator (degree of functional mix) reduces the demand of excess interchange modes. The walkable environment criteria, which exhibits the lowest value (0.07) can be increased to mitigate the reduced accessibility within the station area. Pedestrian environments can be created in the secondary areas using designated paths/cycle trails for walking, to reach the premises of metro station. Furthermore, activities such as carwashes, storages and mechanic shops should be discouraged as these do not contribute to pedestrian activity.

Thus, attempts to enhance the station area should be focussed on indicators such as number of directions served by the bus, frequency of bus operations, degree of functional mix and PCA (Table 36).

5.6 Summary

The node-place index (TOD level) of station area determines the TOD potential, where lower the value of N-P TOD index, greater the ability to attain a balanced integrated state and higher the potential of the station to emerge as TOD. The station areas were then ranked based on the N-P index which enabled to focus on the appropriate criteria for improvement. These criteria were then targeted as means to develop the station as TOD.

Souq Waqif revealed the highest node index (NI=0.320) and Al Sudan showed the least (NI=0.158). Also, Al Sadd exhibited highest urban development (PI=0.054) and place

index of 0.013 for Ras Bu Abboud station indicated an un-developed area. Based on the N-P TOD index the stations were ranked in order as Souq Waqif (4.4), Al Aziziyah (3.1), Al Sadd (3), Al Sudan (2.9), Al Waab (2.6), Sports City (2.4), Qatar national museum (2.0), Joaan(1.8), Ras Bu Abboud (1.6), and Bin Mahmoud (1.2). Due to highest value of N-P TOD index, Souq Waqif exhibits the highest potential for TOD, where Bin Mahmoud in a roughly balanced state exhibits the least potential. All the station areas fall under the unbalanced node typology in the N-P graph. Interpretation of the criteria of node and place along the east-west extension of the Gold metro line for each station area emphasized on the distinct criteria to be focused for the overall improvement of TOD level of unbalanced nodes as shown in Table 36.

Table 36

Criteria and indicators for improvement to attain TOD type development

Name of station	Node/Place	Criteria	Indicators
Souq Waqif	Decrease NI Increase PI	Parking Land use diversity Walkable environment	Car Park & ride facility Degree of functional mix Intersection density PCA
Al Aziziyah	Increase PI	Land use diversity Walkable environment	Degree of functional mix Intersection density PCA
Al Sadd	Increase NI	Accessibility	Directions served by bus Daily frequency of bus operation Proximity to road access
Al Sudan	Increase NI	Accessibility	Directions served by bus Daily frequency of bus operation
	Increase PI	Land use density	Net residential density

			Workers cluster grouping
		Walkable environment	Intersection density
Al Waab	Decrease NI	Accessibility	Directions served by bus
		Parking	Car Park & ride facility
	Increase PI	Walkable environment	PCA
Sports City	Decrease NI	Accessibility	Directions served by bus
			Daily frequency of bus operation
		Parking	Car Park & ride facility
	Increase PI	Land use diversity	Degree of functional mix
		Walkable environment	PCA
QNM	Increase NI	Accessibility	Directions served by bus
		Parking	Car Park & ride facility
Joaan	Increase NI	Accessibility	Directions served by bus
			Daily frequency of bus operation
			Stations accessed within 20min.
Ras Bu Abboud	Increase PI	Land use density	Workers cluster grouping
		Land use diversity	Degree of functional mix
		Walkable environment	PCA
Bin Mahmoud	Decrease NI	Accessibility	Directions served by bus
			Daily frequency of bus operation
	Increase PI	Land use diversity	Degree of functional mix
		Walkable environment	PCA

Recommendations to facilitate the TOD type of development is obtained as general conclusions to increase/decrease the node and place value of the station areas.

Chapter 6: Conclusion and Recommendations

Chapter 6 is divided into three sub-sections which concludes with the research findings and recommendations to develop the stations along the Gold metro line as potential TODs. Finally, the limitations of research and implications for future research are discussed.

The Doha metro network system integrates the concept of urban development around transit stations, with an attempt to integrate compact mixed land use activities in high density population areas. Although, the metro system is introduced as a solution to traffic congestion, pollution, vehicle kilometre travelled etc., it gives rise to important issues related to density, urbanity and transportation. These issues are studied and addressed carefully in order to ensure success of the mega infrastructure projects.

Doha metro system attempts to develop environment friendly, pedestrian oriented (walking, cycling) urban economic centers, incorporating the principles of TOD. The TOD planning principles include the 5 D's of density, diversity, design oriented for pedestrians, distance to transit and destination accessibility. Assessment of the station areas within the aspects of these planning principles (transit and built environment) determine the TOD potential in terms of the indicators of study. Thus, TOD concept is projected as an urban redevelopment tool reducing the use of private cars and developing compact, mixed use places around existing or new metro transit stations with the provision of providing alternate modes of public transport.

Implementation of TOD type development within any transit metro station depends on assessing and classifying the transit station into suitable typologies. Different methods of assessment and classification exist which area based on geographic context, density and

combined indicators of transport and land use. This research uses Bertolini's node-place model, which is the most effective model for the implementation of TOD type development based on indicators of transit and urban development. The anticipated metro development serves economic and social needs. Also, development of built environment is achieved through economic and social opportunities as in case of station areas of Souq Waqif, QNM, Al Aziziyah, which offer better access to transportation by providing more riders. This interaction between land use and transport forms a feedback cycle where, each one supplements the other. Therefore, assessment of metro stations using node-place concept stimulates development on one hand and mixed land use activities generate more trips feeding the networks.

Bertolini's node-place model establishes itself as an analytical tool to facilitate the evaluation of TOD type development of gold metro line stations. Research uses the model to assess and classify the stations based on land use-transportation interaction process. Further, the N-P model provides a platform for the comparison of gold line metro station areas based on transit (node) and urban development (place) criteria. Using indicators of node and place, the model attempts to identify, assess, compare and classify the quality of transit system and surrounding built environment of 10 through and terminus metro stations, to emerge as TODs.

Research assesses each station based on node criteria of accessibility, parking and place criteria of land use density, diversity and walkable environment. The results of node index reveal that, Souq Waqif serving as regional transit center exhibits high quality transit system (NI=0.320), whereas lowest quality is exhibited by Al Sudan serving as mixed use urban transit center (NI=0.158). Additionally, Bin Mahmoud serving as sub-regional

transit center shows the highest quality of urban development surrounding the station area (PI=0.144), due to highest value of place index. In comparison, Ras Bu Abboud station area serves as transit center within the undeveloped areas of Qatar with the lowest place index (PI=0.013). Additionally, the N-P TOD index revealed that Souq Waqif (N-P TOD=4.43) qualified as the closest to exhibiting potential for TOD type development, whereas Bin Mahmoud (N-P TOD=1.16) showed the lowest potential.

The improvement of TOD potential of the stations, based on their classification using the N-P graph, disclosed that all the station areas fall under the unbalanced node area. No stations were observed in the stressed, dependent, balanced or unbalanced place, except with a station close to the balanced state. Furthermore, this showed that TOD potential of gold metro line station areas can be improved by either reducing the node indicators or improving the place indicators specific to station areas depending on their individual node and place index, so as to emerge as TODs.

Above all, each of the analysed station areas exhibit their potential characteristics which are important in formulating the best TOD type development. These opportunities are based on the analysis of 18 indicators, 9 each of node and place for each station areas. The unbalanced nodes along the Gold metro line which have potential to develop as TOD type development include:

(1) Regional transit center-Souq Waqif

(2) Sub-regional transit center-Bin Mahmoud

(3) Urban transit center- Al Sadd, Al Sudan, QNM, Joaan

(4) Sub-urban transit center- Al Aziziyah, Al Waab, Sports City

(5) Transit center-Ras Bu Abboud

Thus, the direction for TOD type development of these station areas is based on decrease or increase of specific node and place indicators which enable in formulating the recommendations. In this manner, the node-place theory identifies and facilitates the TOD type development.

6.1 Recommendations

Research results using N-P model provide a framework which can be easily related to the 5 D's of TOD planning principles, evaluating both spatial and non-spatial characteristics of station areas. It is expressed that a roughly balanced node-place station does not necessarily represent a TOD (such as Bin Mahmoud). Also, the stations serving as high quality transit center or highest development density alone does not represent a TOD (Souq Waqif, Bin Mahmoud). The potential for TOD type development can be attempted by improvement of either node or place criteria depending on the type of station. Classification of station areas based on improvement of 5 D's (Node index-accessibility, parking; Place index-land use density, land use diversity, walkable environment), can be used as a planning tool for the development of TOD within existing metro station areas. The following conclusions are drawn from the above results for TOD type development of metro stations along gold metro line:

1. The regional/sub regional transit stations along the Doha gold line, with comparable high node index and low place index should focus on TOD type development by reducing the node value (overestimated quality of transit system) or increasing the place value (underestimated urban development).

2. The sub-urban/urban transit station areas along the Doha gold line, with comparable low node index and high place index should focus on TOD type development by

increasing the node (underestimated transit system) or decreasing the place value (overestimated urban development) .

3. Attempts to reduce the node value of metro stations should focus on alterations/improvements in the indicators such as: Directions served by bus, Daily frequency of bus operation (accessibility) and Car park and ride facility (parking).

4. Attempts to increase the node value of metro stations should focus on alterations/improvements in the indicators such as: Directions served by bus, daily frequency of bus operation, proximity to road access, accessible stations within 20min. of travel time (accessibility) and car park and ride facility (parking).

5. Attempts to increase the place value of metro stations should focus on alterations/improvements in the indicators such as: Net residential density, workers cluster grouping (land use density); degree of functional mix (land use diversity); pedestrian catchment area and intersection density (walkable environment).

Thus, the additional policies and actions which can facilitate the evolution of the gold metro line stations as potential TODs are discussed as follows:

6.1.1 Node value. Doha gold metro line is planned with the intention to facilitate ease of access to multiple destinations, with reduced traffic congestion and dependence on motor use. The following strategies should be taken into consideration in order to enhance transit quality within the station areas in terms of accessibility and parking criteria. This can be executed through indicators such as directions served by bus, frequency of bus services, park and ride facility and proximity to road access.

6.1.1.1 Accessibility

1. The points of origin and destination of interchange bus routes should be increased within the secondary residential/office locations of the metro stations. The location of these bus stops should not be restricted towards the periphery of station areas. Rather, existing bus routes serving the outer peripheries of the station area should be rerouted, allowing ease of access from/to the station. This improves the quality of station transit system (increase node value).

2. Within the context of gold line metro stations, feeder buses should not be concentrated only along the primary networks. In case of non-central location of the metro station, the buses should be rerouted to loop into the station area from secondary network within the transit supportive developments. This increases the directions served by the bus in terms of catchment area and improves the quality of station transit system (increase node value).

3. The bus stops and transfer stops should be located along mixed use and moderate high density development areas to support public transport. These should form focal points within the neighbourhood areas through orienting local uses and activities towards it. Thus, bus routes passing through transit supportive land uses increases the transit ridership through ease of access to the metro station from areas of residence or work and vice versa. This increases the direction served by buses within the metro station area, improving transit quality (increase node value).

4. The node characteristics of the station areas should be improved by increasing the number of on-street bus stops. Thus, the frequency of bus operations should be increased, with regards to number of buses passing the metro station during peak hour.

This reduces the number of transfers and at the same time enable faster and easy access to destinations. This improves transit quality (increase node value).

5. Bus circulation system should be designed in such a manner that multiple direct linkages are established between the primary connections of immediate and secondary metro station catchment areas. This offers flexibility of choice for the riders. Hence, this improves transit quality (increase node value).

6. The bus routes originating or terminating at the gold line transit metro stations should be designed with flexibility allowing the passengers to reroute avoiding peak hours and traffic congestion. This offers flexibility of choice for the riders, improving transit quality (increase node value).

7. Within the gold metro corridor, travel should be encouraged along the transit line in both directions at all times, by locating and promoting mixed use all day activities at the stations. This increases the catchment of destinations station areas which can be accessed within a particular time, improving accessibility potential (increase node value).

8. Within the context of overlapping station areas, multiple on-street bus stops should not be located close to each other. The bus stops or transfer stops should be located such that the trips within the catchment area of one bus does not coincide with the other. This reduces the overestimated requirement of direction served by buses within the metro station area (reduce node value).

6.1.1.2 Parking

1. Within the context of metro stations, innovative parking management strategies such as shared parking, carpool parking, restricted parking hours, payed-parking with appropriate rates should be encouraged to prevent oversupply of TOD parking

provisions (increase node value).

2. Car park and ride facility should be located near the metro stations, at easy access close to the origin points. This develops efficient transit service to work, attracting more riders to the transit system, enhancing the quality of transit system (increase node).

3. On-street parking spaces located in close proximity to local retail services, and vacant plots designated as unused car parks, should be developed as mixed use transit supportive environments. This should be encouraged by accommodating functions and activities as required by the station area. This would enable the development of mixed use urban economic hubs with a strong place index (reduce node value).

4. Parking options in the form of off-street parking, multi-level car parks (MLCP), and basement parking should be discouraged in the workplace destinations for the success of the metro transit system. This decreases the transit quality (reduce node value).

5. Focus on the parking provisions within the TOD areas, even if available should be diverted, by reducing its dominance and locating the parking facilities at the rear side of the station (reduce node value).

6. Within the context of sub-urban transit stations of the gold line metro system, on-street parking services should be developed as parallel parking spaces to the street. These parking provisions maintain the focus of community on the street activities and should not be discouraged or replaced (reduce node value).

6.1.2 Place value. The quality of built environment surrounding a transit station is inclusive of land use density, diversity and pedestrian oriented environments. Strategies to enhance the transit oriented function of the station area should be executed through indicators such as degree of functional mix, PCA, residential density, intersection density

and workflow.

6.1.2.1 Land use density/diversity

1. Functional mix of developments including residences, commercial offices, and public institutions such as schools, government centers, hospitals and community centers should be encouraged within the sub urban metro station areas. The mixed use centers encourage employment and economic generative activities attracting inflow of workforces throughout the day. This increases the efficiency of the transit system through coverage of short distance shopping and recreational trips, using non-motorized modes.

2. Within the context of the gold line metro stations, areas of residential uses or high density of employment should be introduced within the walking distance of the station areas, compatible with the existing land uses of the station area.

3. The employment/economic generative land uses along the metro station, relying on auto trips such as light industrial facilities, car washes, and petrol stations should be discouraged to encourage more pedestrian movements. This reduces the dependency on interchange modes of transit such as bus or cycles.

4. Existing land uses within industrial transit centers, not combatable with TOD type development should be integrated with the TOD concept by introduction of provisions such as pedestrian environments, supplementary land uses and opportunities for transit travel. However, the on-going processes and access requirements of the transit station should be retained.

5. Within the context of gold metro line stations, exhibiting moderate density and diversity of mixed uses, enhancement in terms of decentralizing the uses should be adopted by encouraging vertical or horizontal mix of uses, clustered grouping of different single use buildings or single building with multiple uses, and all day activities near the transit station.

6.1.2.2 Walkable environment

1. Develop a pedestrian oriented area within the transit oriented metro station, facilitating walkability and improved connectivity through open parks and plazas serving as community gathering grounds located centrally and close to shopping centers. They should not be formed as part of replacing vacant plots, or non-functional parcels of land. These areas enhance the place characteristics by encouraging pedestrian environments.

2. Multi-modal transportation systems such as bicycles and walking should be encouraged using grid pattern of development within the areas around the transit station. This promotes a civic spirit and walkable environments through clear, formalized walking trails/paths with traffic controls.

3. Within the urban transit centers of the gold metro line, the circulation system of residential areas should be designed as grid pattern formed by tertiary and local streets with reduction of through motor traffic. These connect the different economic activities within the premises of TOD type development.

4. The tertiary and local streets within the station area should be designed to discourage excessive through traffic by introduction of speed breakers, curvilinear and

discontinuous road patterns. This enhances the place characteristics through walkability.

5. The Pedestrian catchment area (Ped-shed) within the regional/sub-urban/urban metro stations with existing cycle paths should be developed by undertaking a bicycle- transit strategic plan. This extends the pedestrian walkable catchment area, due to ease of accessibility of cyclists to same destination faster within walkable time limit, when compared to pedestrians.

6. Doha gold metro line stations with low intersection density should connect the secondary areas be the immediate station area using these intersections, offering short multiple routes with controlled through traffic.

7. Interconnected street system with reduced intersections and absence of winding roads, cul-de sac and dead end streets should be encouraged, to facilitate pedestrian movement to core commercial areas and transit stops.

6.1.3 Node and place value influence

1. The potential regional/sub-regional/sub-urban or urban transit centers along the gold metro line with more frequent and multiple directional bus transit, should promote pedestrian routes located along or visible from the streets, bordered by commercial or economic activities. This enhanced node characteristics of the station area enhance the place characteristics of the potential TOD.

2. Within the context of unbalanced node stations, improvements should be introduced in the surrounding built environment of the station area to enhance the quality of transit system. Thus, introduction of mix-uses attracting large inflow of workers in the station area increases the travel demand, which should be met by re-routed existing bus

systems enhancing the directions served by existing interchange bus transit. This improves the quality of transit system with enhancement of place characteristics.

6.2 Limitations of research

Bertolini's N-P model, being a conceptual framework, allows for the comparison of different station areas with focus on the functions of transport and land use. The unbalance between the two design factors of the various stations is taken as the basis for distinguishing the stations. Thus, this model serves as an indicator for comparing the different stations on the basis of balanced node-places and identifying the possibilities of development of these stations as a potential TOD.

Firstly, the research focuses on the assessment of station areas based on the aspects of only transport and land use factors. Additional factors such as social, cultural, economic and governmental (local policies) are not considered. Secondly, certain criteria for research using N-P model, were excluded based on the non-availability of data. One of the most important limitations of this model is the method of calculating node-index and place-index values which can be defined and operationalized differently by different researchers based on the context. Hence, the method to quantify metro station node and place values remains a challenge even within a balanced development. Furthermore, an important criteria for the assessment of effectiveness of a transit system-passenger transit ridership is not included due to the on-going construction phase of the Doha metro network (not operational).

6.3 Implications for practise and advancement of research

The research study using Bertolini's N-P model reveals that stations along the Doha gold metro line have potential for TOD type development. Research identifies the station areas as unbalanced nodes based on the node and place index. The N-P TOD index ranks

the station areas based on their potential for TOD. Also, the results suggest that strategies to enhance particular criteria/indicators of node and place indexes-accessibility, parking, land use density, diversity and walkable environment for each of the terminus and through stations, assist in implementing TODs. In sum, the research offers a number of significant insights into the ways in which the station areas can be enhanced/improved as TODs.

With regard to possible future research, an interesting issue raised is the application of the model to assess and classify stations along multiple metro lines within the Doha networks including interchange transfer stations such as Al Musheireb or Al Bidda. This research uses Bertolini's N-P model to assess and classify the stations for TOD potential along a single metro line (Gold metro line-terminus and through station areas alone). Consequently, further studies can be carried out in order to analyse the node-place equilibrium to determine the balance of transport-land use development dynamics of the station areas using passenger transit ridership characteristics.

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Appendix A- Calculation of Node and Place Index

Node/Place Functions	Al Aziziyah	Sports City	Al Waab	Al Sudan	Joaan	Al Sadd	Bin Mahmoud	Souq Waqif	QNM	Ras Bu Abboud	Mean	SD
X1	2626	3035	3060	3298	9495	5733	27799	9824	12185	128	7718.3	8037.6
X1 (score)	0.63	0.58	0.58	0.55	0.22	0.25	2.50	0.26	0.56	0.94		
X1 (weighted)	0.11	0.10	0.10	0.09	0.04	0.04	0.42	0.04	0.09	0.16		
X2	1705.51	1970.68	1986.74	2141.83	6165.809	3723	18051.21	6379.44	7912.18	82.98	5011.9	5219.2
X2 (score)	0.63	0.58	0.58	0.55	0.22	0.25	2.50	0.26	0.56	0.94		
X2 (weighted)	0.11	0.10	0.10	0.09	0.04	0.04	0.42	0.04	0.09	0.16		
X3	229	94	418	424	1627	2221	4328	5800	4250	34	1942.5	2126.5
X3 (score)	0.81	0.87	0.72	0.71	0.15	0.13	1.12	1.81	1.09	0.90		
X3 (weighted)	0.03	0.04	0.03	0.03	0.01	0.01	0.05	0.08	0.05	0.04		
X4	344	403	800	578	2195	968	1832	3007	1345	87	1155.9	934.7
X4 (score)	0.87	0.81	0.38	0.62	1.11	0.20	0.72	1.98	0.20	1.14		
X4 (weighted)	0.04	0.03	0.02	0.03	0.05	0.01	0.03	0.08	0.01	0.05		
X5	700	234	453	606	1364	471	6778	727	3650	60	1504.3	2117.8
X5 (score)	0.38	0.60	0.50	0.42	0.07	0.49	2.49	0.37	1.01	0.68		
X5 (weighted)	0.02	0.03	0.02	0.02	0.00	0.02	0.11	0.02	0.04	0.03		
X6	194	133	175	176	2103	288	2689	198	624	660	724.0	911.4
X6 (score)	0.58	0.65	0.60	0.60	1.51	0.48	2.16	0.58	0.11	0.07		
X6 (weighted)	0.02	0.03	0.03	0.03	0.06	0.02	0.09	0.02	0.00	0.00		
X7	0.9	0.89	0.92	0.91	0.94	0.91	0.92	0.9	0.91	0.92	0.9	0.0
X7 (score)	0.86	1.57	0.57	0.14	2.00	0.14	0.57	0.86	0.14	0.57		
X7 (weighted)	0.15	0.27	0.10	0.02	0.34	0.02	0.10	0.15	0.02	0.10		
X8	111	86	92	99	171	201	90	76	153	14	109.3	53.4
X8 (score)	0.03	0.44	0.32	0.19	1.16	1.72	0.36	0.62	0.82	1.79		
X8 (weighted)	0.01	0.07	0.06	0.03	0.20	0.29	0.06	0.11	0.14	0.30		
X9	0.28	0.31	0.21	0.38	0.33	0.29	0.3	0.36	0.45	0.14	0.3	0.1
X9 (score)	0.29	0.06	1.10	0.87	0.29	0.17	0.06	0.64	1.67	1.91		
X9 (weighted)	0.05	0.01	0.19	0.15	0.05	0.03	0.01	0.11	0.28	0.32		
Node index	0.18	0.18	0.18	0.16	0.16	0.16	0.17	0.32	0.17	0.21		
Y1	4	4	4	4	4	4	4	4	4	4	4.0	0.0
Y1 (score)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00		
Y1 (weighted)	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68		
Y2	1	2	2	2	2	2	2	2	2	1	1.8	0.4
Y2 (score)	1.90	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	1.90		
Y2 (weighted)	0.32	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.32		
Y3	13	14	16	19	22	26	28	28	26	23	21.5	5.7
Y3 (score)	1.49	1.32	0.96	0.44	0.09	0.79	1.14	1.14	0.79	0.26		
Y3 (weighted)	0.25	0.22	0.16	0.07	0.01	0.13	0.19	0.19	0.13	0.04		
Y4	1	1	1	1	1	1	1	1	1	1	1.0	0.0
Y4 (score)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
Y4 (weighted)	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17		
Y5	8	8	8	5	8	5	13	37	3	1	9.6	10.2
Y5 (score)	0.16	0.16	0.16	0.45	0.16	0.45	0.33	2.69	0.65	0.84		
Y5 (weighted)	0.03	0.03	0.03	0.08	0.03	0.08	0.06	0.46	0.11	0.14		
Y6	19	11	10	14	19	26	49	142	17	4	31.1	40.8
Y6 (score)	0.30	0.49	0.52	0.42	0.30	0.12	0.44	2.72	0.35	0.66		
Y6 (weighted)	0.05	0.08	0.09	0.07	0.05	0.02	0.07	0.46	0.06	0.11		
Y7	1320	2220	2226	571	885	1968	306	803	116	100	1051.5	837.6
Y7 (score)	0.32	1.40	1.40	0.57	0.20	1.09	0.89	0.30	1.12	1.14		
Y7 (weighted)	0.05	0.24	0.24	0.10	0.03	0.19	0.15	0.05	0.19	0.19		
Y8	3	3	0	0	0	0	0	18	1	1	2.6	5.5
Y8 (score)	0.07	0.07	0.47	0.47	0.47	0.47	0.47	2.78	0.29	0.29		
Y8 (weighted)	0.01	0.01	0.08	0.08	0.08	0.08	0.08	0.47	0.05	0.05		
Y9	5074	3574	3156	4534	25050	8030	10450	26350	7800	230	9424.8	9050.3
Y9 (score)	0.48	0.65	0.69	0.54	1.73	0.15	0.11	1.87	0.18	1.02		
Y9 (weighted)	0.08	0.11	0.12	0.09	0.29	0.03	0.02	0.32	0.03	0.17		
Node index	0.184	0.180	0.183	0.158	0.159	0.162	0.167	0.320	0.167	0.210		
N-P TOD Index	3.13	2.41	2.61	2.89	1.83	3.00	1.16	4.43	2.03	1.62		
RANK OF THE STATIONS	2	6	5	4	8	3	10	1	7	9		

Node/Place Functions	Al Aziziyah	Sports City	Al Waab	Al Sudan	Joaan	Al Sadd	Bin Mahmoud	Souq Waqif	QNM	Ras Bu Abboud
PI	0.06	0.07	0.07	0.05	0.09	0.05	0.14	0.07	0.08	0.13
Land Use density	0.33	0.32	0.29	0.29	0.20	0.14	1.13	0.29	0.29	0.44
Land Use diversity	0.15	0.27	0.10	0.02	0.34	0.02	0.10	0.15	0.02	0.10
Walakable environment	0.05	0.08	0.24	0.18	0.25	0.32	0.07	0.21	0.42	0.63
NI	0.18	0.18	0.18	0.16	0.16	0.16	0.17	0.32	0.17	0.21
Accessibility	1.57	1.51	1.53	1.33	1.14	1.43	1.49	2.57	1.47	1.72
Parking	0.08	0.11	0.12	0.09	0.29	0.03	0.02	0.32	0.03	0.17

Appendix B-Indicator Analysis

Correlation Analysis Results

Pearson's Correlation Analysis results

Node-Place functions	Population of the area	Net residential density	WC1-Retail/hotel/catering	WC2-Education/health/culture	WC3-Administration/services	WC4-Industry and distribution	Degree of functional mix	Intersection density	IPCA	Daily frequency of train service	Directions served by train	Stations within 20min.	Type of train connection	Directions served by bus	Daily frequency of bus service	Proximity to road access	Free standing bicycle paths	Car park & ride facility
Population of the area	1.00																	
Net residential density	1.00	1.00																
WC1-Retail/hotel/catering	0.36	0.36	1.00															
WC2-Education/health/culture	0.59	0.59	0.55	1.00														
WC3-Administartion/services	0.94	0.94	0.31	-0.21	1.00													
WC4-Industry and distribution	0.62	0.62	-0.10	0.10	0.54	1.00												
Degree of functional mix	-0.17	-0.17	-0.16	0.47	-0.30	0.39	1.00											
Intersection density	-0.22	-0.22	-0.37	-0.01	-0.16	-0.26	0.05	1.00										
IPCA	-0.13	-0.13	0.22	-0.07	-0.10	-0.64	0.44	0.30	1.00									
Daily frequency of train service	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00								
Directions served by train	0.06	0.06	0.02	0.20	0.13	0.34	0.02	0.14	0.31	0.00	1.00							
Stations within 20min.	0.22	0.22	0.46	0.01	0.27	0.04	0.04	-0.61	-0.44	0.00	0.04	1.00						
Type of train connection	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00					
Directions served by bus	-0.20	-0.20	0.74	0.73	0.11	0.23	0.12	0.12	0.19	0.00	-0.07	0.08	0.00	1.00				
Daily frequency of bus service	-0.16	-0.16	0.78	0.82	0.13	0.11	0.08	-0.08	0.07	0.00	-0.11	0.20	0.00	0.95	1.00			
Proximity to road access	0.18	0.18	0.08	0.58	0.28	0.30	-0.30	0.18	0.29	0.00	-0.13	0.13	0.00	0.33	0.34	1.00		
Free standing bicycle paths	-0.20	-0.20	0.64	0.73	0.14	0.01	0.01	0.02	0.03	0.00	-0.27	0.11	0.00	0.94	0.95	-0.42	1.00	
Car park & ride facility	-0.43	-0.43	0.21	0.84	0.53	0.03	0.61	0.15	0.04	0.00	0.01	-0.32	0.00	0.56	0.66	-0.54	0.63	1.00

Figure 77. Correlation analysis results of node-place indicators of Gold metro line station areas. (Source: Author, 2018)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.754673787
R Square	0.969532525
Adjusted R Square	0.508037171
Standard Error	0.402576267
Observations	9

ANOVA

	df	SS	MS	F	Significance F
Regression	1	1.500971907	1.500971907	9.261391165	0.018760692
Residual	7	1.134473554	0.162067651		
Total	8	2.635445461			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	3.009696795	0.291382335	10.32902972	1.72759E-05	2.32068706	3.69870653	2.32068706	3.69870653
1.255786116	-0.68407295	0.224783436	-3.04325338	0.018760692	-1.215601314	-0.15254459	-1.21560131	-0.152544588

Figure 78. *The Summary output obtained for regression analysis of the indicators. (Source: Author, 2018)*

تَمَّ بِحَمد الله