EVALUATING TOD READINESS OF LEBANESE TOWNS ALONG THE NORTHERN COASTAL HIGHWAY

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Abstract

The concept of transit-oriented development (TOD) has been gaining noticeable appreciation in cities that pursue urban and transport sustainability. This term was coined in the late 1980s when the alarming outcomes of vehicle-dependent planning started to materialize. TOD is characterized basically by mixed land-use that fosters the use of transit services by minimalizing the walking distance to its service point. Thus, a transit station must be centered based on the neighborhood typologies to encourage the largest number of people who live or work near the station to use transit as a transport mode. Setting this objective at the onset of planning a development can result in a TOD with varying successes. But when introducing transit into an already developed and car-based city, realizing a TOD can be quite challenging. The objective of this research is to investigate the feasibility of such an endeavor. Lebanon is planning to introduce its new mass transit system, the Bus Rapid Transit (BRT), where several alignments are proposed. Five cities housing the BRT stations along the northern corridor will be evaluated to study their adequacy to be transformed into a transit-oriented city. In this thesis, we will develop an evaluation methodology and implement it on five cities housing BRT stations. As a first step, the general TOD characteristics and objectives are discussed as well as the neighborhood typologies. Second, a method of how TOD concepts can be applied to an existing city is elaborated. Third, the evaluation methodology is chosen which is the 5Ds method. TOD characteristics are compared with the city's existing characteristics; as a result, certain features are identified for necessary modifications, and new components are proposed. Finally, recommendations of priority-ranked interventions are developed that best satisfy the TOD required criteria along with general reflection on the process.

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1. Introduction

Sustainable cities promote economically, socially and environmentally resilient habitat for the current population, while taking into consideration that future generations must benefit from the same conditions later on (ICLEI local governments for sustainability, 2016) with a target of building human settlements that least impacts the environment (Cohen, 2018). To accomplish sustainable development and empower communities, investments in infrastructure are considered an essential element that improves health, education and productivity (United Nations, 2015).

1.1. The need for public transport

With population growth in cities that is projected to rise to five billion people by 2030, efficient urban planning and management must happen to face urbanization challenges. However, most cities in developing countries lack basic urban infrastructure and it is predicted that, by 2030, 95% of the urban sprawl will occur in developing countries (United Nations, 2015). Also, it was estimated that, by the end of this year 2020, vehicle ownership would have increased by 32% and motor vehicle kilometers by 40% (United Nations, 2015). These numbers are alarming if we were to achieve the targets of several indicators of the United Nations' sustainable development goals. Thus, supporting the economic development and well-being must start through developing quality, sustainable and resilient infrastructure which provides affordable access to everyone to sustainable transport systems while improving road safety, specifically by broadening public transport systems that consider different people's needs particularly those with disabilities (United Nations, 2015). Therefore, integrating public transport in cities constitutes a major step to achieve sustainable development, where transit improves health because it encourages people to walk to stations, it reduces road congestion from private cars, it also has a positive impact on economy where it was

found that for every ten million dollars of transit investment made, business sales increase by thirty million dollars and residential properties that exist near transit-services are considered more valuable. Moreover, public transport is considered safer than private cars where, each year, around 30,000 people die from road crashes. It was also found that, when relying on public transport instead of private cars, household expenses decrease by around 10,000$ per year, and people are found to be more productive, because when in transit, one can sleep, read, write, relax, which he cannot do while driving (Berggren, 2017). Thus, integrating transit plays a major role in developing sustainable cities.

1.2. Transit-Oriented Development

A concept that integrates efficient urban planning with transit is the concept of transit-oriented development (TOD). This concept has been gaining noticeable appreciation in cities that pursue urban and transport sustainability since it has the potential to merge transport engineering and planning with land-use planning and urban design which offers solutions to contemporary urban problems (Ibraeva, Silva, Antunes, & de Almeida Correia, 2020). This term was coined in the late 1980s when the threatening outcomes of vehicle-dependent planning started to materialize. TOD is characterized basically by mixed land-use that fosters the use of transit services by minimalizing the walking distance to its service point. Thus, a transit station must be centered based on the neighbourhood typologies to encourage the largest number of people who live or work near the station to use transit as a transport mode. Setting this objective at the onset of planning a development can result in a TOD with varying successes. But when introducing a novel transit system into an already developed car-based city, realizing a TOD can be quite challenging. The objective of this research is to investigate the feasibility of such an endeavor. The research is done while taking different cities in Lebanon as a case study. This thesis aims to study the adequacy of those cities to be transformed into transit-oriented cities. In this research,

the general TOD characteristics and objectives are first discussed as well as the neighborhood typologies. In contrary to other researchers' work, who attempted to plan cities from scratch to be transit-oriented, we will be applying TOD concept to five already existing cities: Zouk Mosbeh, Zouk Mkeyel, Jounieh, Dbayeh and Adma. Then, TOD characteristics are compared with the city's existing characteristics; as a result, an improvement strategy is proposed. Finally, recommendations of priority-ranked interventions are established that best satisfy the TOD required criteria along with general reflection on the process.

2. Research Objectives

In contrary to the literature review, where researchers planned cities from scratch as being transit-oriented, the two main objectives of our research are:

2.1. To develop the corresponding evaluation methodology that will be used in this research

2.2. To implement this methodology on five cities along the northern highway

First, the cities housing BRT stations along the northern corridor are studied and screened according to the density criteria, since population density cannot be controlled in each city, so the cities with low densities are removed and the five cities satisfying this criterion are then chosen. These cities are: Zouk Mosbeh, Zouk Mkeyel, Jounieh, Dbayeh, and Adma. Second, we will choose the appropriate evaluation method that will then be used to evaluate them, to be able to discover whether they are transit-oriented or not. Third, after evaluating these cities based on specific criteria, we will conclude if they are transit-oriented or not, and we will be discussing efficient and feasible ways that can be done in order to modify them to become transit-oriented later on.

3. Literature Review

Transit-Oriented Development Task Force at Maryland Department of Transportation defines TOD as “a place of relatively higher density that includes a mixture of residential, employment, shopping and civic uses and types located within an easy walk of a bus or rail transit center” (Maryland Department of Transportation, 2000). This concept has lately been used in different places to solve transportation issues, to minimize travel distances, to reduce air pollution and congestion, to enhance transit ridership, walking and cycling, and to ensure a better quality of life (Kumar, Sekhar, & Parida, 2020). Also, “a developed country is not where the poor drive cars, it’s one where the rich use public transportation” as said by the mayor of Bogota. Therefore, TOD’s target is to affect people’s mode choice, regardless of their social rank, and to encourage a significant modal shift from private cars to transit (Bonin & Tomasoni, 2018).

3.1. TOD characteristics

Nasri and Zhang characterize TODs by a reduced walking distance from residents’ houses to a major station or to any other facility which aims to promote transit ridership by allowing access to more job centers, educational opportunities, and cultural facilities and to encourage pedestrian activities (Nasri & Zhang, 2014). To add up, TOD has lately been used to encourage Smart Growth strategies such as energizing areas, improving the economy, and enhancing the quality of life. Also, TOD aspects as defined by Nasri and Zhang, are the presence of high residential and employment densities and a mixed-use development surrounding transit centers. In their quantitative methodology, they take into consideration three essential factors which are walkability and high density, walking distance to a transit station, and collaboration of mixed uses and transit (Nasri & Zhang, 2014). They concluded that residents living in TOD areas had smaller households, lower levels of car ownership, and higher rates of zero-car households.

Moreover, TOD was found to reduce vehicle kilometers traveled in auto-oriented regions (Duncan, 2019). According to Khin and Natachai, TOD's objective is to minimize the use of private vehicles while encouraging the use of public transportation and non-motorized trips by developing the studied area with the appropriate functional design including multiple uses such as administrative, recreational, retail, and residential (Nyunt & Wongchavalidkul, 2020). Also, time spent to arrive at the station, and time spent using public transport is a major factor affecting one's choice of transport, as well as the proximity. Therefore, TOD, which helps in upgrading these features and attracts ridership, can highly impact riders' mode choice.

3.2. TOD typologies

However, identifying TOD typologies is one main task to be able to characterize whether a certain city is transit-oriented or not or if it can be modified to become one. Two main approaches for differentiating TOD typologies exist in the literature (Higgins & Kanaroglou, 2016). The first approach is qualitative, and it consists of labeling typologies based on the geographic and functional characteristics of neighborhoods. According to this approach, Calthorpe (1993) defined two TOD types: urban TODs characterized by high density and small walking distance to transit, and neighborhood TODs characterized by a lower density and a small distance to local or feeder bus lines (Calthorpe, 1993). The key principles proposed by Calthorpe for designing cities were to place commercial, residential, employment, parking and civic uses within a walking distance of transit stations, creating pedestrian-friendly networks, organizing growth to be compact and to support transit, preserving open spaces, and many other principles (Chen, Hamilton, Kindel, Macek, & Pinch, 2007). Other researchers went further and divided TOD into six types (Dittmar, Belzer, & Autler, 2004). The second approach, called the node-place approach is quantitative. It was first developed by Bertolini (1999). This approach converts data into an XY-diagram where the Y-axis is the node-index which describes the variety and

frequency of transit supply and the X-axis is the place-index which describes the functional mix of the area near the station (Ibraeva, Silva, Antunes, & de Almeida Correia, 2020). Each station must be located on the diagram depending on the two indexes' performance and their location will show whether they are sustained or unsustained. For example, stations with a good transit supply surrounded by a land-use diversity appear in the middle of the diagram whereas stations with a high demand on transit and an extremely diverse area around it are placed near the upper right corner where both indexes are close to 1. Regarding unsustained nodes, stations with low diversity but high transit supply are qualified as such and vice versa.

Another alternative approach for realizing TOD is the network governance approach proposed by Mu & de Jong (Mu & de Jong, 2016). Network governance means the mechanisms that aim to enhance the voluntary or forced alignment of goals and tasks of networked actors. In TOD planning, network governance positively influences planning and policy integration between urban transport and land use through progressive and cumulative stages. It explains why some TOD projects succeed and others fail to deal with substantive complexity, strategic uncertainty and institutional deficiency. This approach also detects areas where policy integration is missing in governance strategies.

3.3. TOD evaluation methods

Evaluating TOD started using the 3Ds: density, diversity, and design (Cervero and Kockelman, 1997). Density, which represents the population and employment relative to the service area, is a key criterion in evaluating whether a certain city is transit-oriented or not, since the more there exists houses and jobs within a short walk of a transit station, the greater the ridership. According to a report published by the Transit Cooperative Research Program in 1996, when the population density increases by 10%, transit ridership increases by 5% and when density doubles, vehicle

ridership decreases by almost 20% and vehicle ownership falls to reach an average of one car per household (Tumlin, Millard-Ball, Zucker, & Siegman, 2003). Moreover, a mixed land-use development encourages a better usage of transit since residents can easily walk from their houses to shops, and employees can either walk or use transit to go to work due to the mixed-use design which includes different urban activities such as residential, retail, office, recreational and open space which makes bicycling or public transport more suitable for their trips than motorized vehicles (Nyunt & Wongchavalidkul, 2020). As for the third D, the design of a city plays an important role in orienting it to become a transit-developed city. When the designer expects streets to have fewer vehicular movement and trips, streets are designed with lower traffic volume which ensures a more pedestrian-friendly environment easier for walking or biking (Tumlin, Millard-Ball, Zucker, & Siegman, 2003). Also, the topography of the road must be adequate for pedestrians to walk at ease, with no large slopes, which would require more time to arrive at feeder bus stations. Streetlights and pedestrian crossings must exist to ensure a safe environment to walk during the day and at night as well as greenery to ensure a sustainable urban design concept.

Khin and Natachia also used the 3Ds method in their evaluation, but they defined two types of indicators to evaluate TOD which are nonspatial indicators such as passenger load, safety in transit, frequency of service, number of route connections, and parking utilization, and spatial indicators such as land-use diversity, mixed-use level, access path, intersection density, pedestrian catchment area, and location accessibility of the transit system (Nyunt & Wongchavalidkul, 2020). In Table 1 below, the authors defined the corresponding indicators used to evaluate Bangkok with the 3Ds method.

Table 1: TOD indicators (Nyunt & Wongchavalidkul, 2020)

Group	Indicators	Definitions
Density	Transit ridership	Number of passengers at the stations
	Population density	Population per developed area
Diversity	Entropy	Degree of mixed land use across categories
	Land-use intensity	Units of developed areas for residential, commercial, office, industrial, parks, or recreational use
	Vertical mixture	Proportion of commercial/retail parcels with more than one land use category on the site
Design	Access to municipal public service facilities	Average Euclidean distance from stations to municipal public service facilities
	Access to opportunities	Number of jobs or accessible services within walking distance of the stations
	Public transport accessibility	Measure of public transport network accessibility in terms of walk access time and service availability
	Expressway accessibility	Number of expressway exits/entrances in proximity to the station
	Transit interchanges	Number of accessible train routes at each station
	Public transport	Number of public transport services offered at the stations
	Parking availability for cars/fourwheelers	Number of optimum parking provided by transit nodes for different modes (cars/fourwheelers/cycles/bicycles)
	Street network density	Total length of the street network around a station area representing less automobile-oriented development
	Street connectivity	Number of intersections in proximity

After the 3Ds evaluation method, researchers added new Ds to the list which are distance to transit, and destination accessibility. What is meant by distance to transit is how easy is walking to the transit stations. Destination accessibility is the degree of accessibility to the station area measured by the number of public service facilities such as shopping centers, kindergartens, libraries, sport

centers, elementary schools, etc... (Niu, Hu, Shen, Huang, & Mou, 2021). So, the main typologies a city must have to be transit-oriented are green, walkable blocks and streets, the proximity of housing and shopping centers, accessible public spaces, and successful development around transit stations. Thus, residences, offices, open space, commercial buildings, and public uses must be all mixed in a walkable and sustainable environment near stations (Ibraeva, Silva, Antunes, & de Almeida Correia, 2020). Two main areas can be distinguished in TOD. The primary area includes major commercial and employment areas, including public space and a residential zone with a high to medium density. The secondary area surrounds the primary area and is located at around 1.6 km from it. It contains low-density housing, schools, park areas and streets which ensure easy, fast and direct access to the primary area (Ibraeva, Silva, Antunes, & de Almeida Correia, 2020).

4. Public transport status in Lebanon

4.1. History

The main focus of planning in Lebanon before 1963 was on the capital Beirut when economic growth was considered important, and environmental impacts were marginalized (El Asmar, Ebohon, & Taki, Bottom-up approach to sustainable urban development in Lebanon: the case of Zouk Mosbeh, 2012). Later on, during the civil war between 1975 and 1990, certain regions in Lebanon suffered extensive infrastructure damage and building destruction which forced residents to relocate to safe regions. Different rural areas became the home to many displaced people which lead to an exceptional unexpected urban growth as a result (El Asmar & Taki, Sustainable rehabilitation of the built environment in Lebanon, 2014). Rapid physical developments occurred in these areas which evolved from being rural and industrial areas to becoming mixed-use urban cities containing industrial, commercial, and residential buildings.

Regarding the transport sector in Lebanon, it is dominated mostly by private vehicles since the existing public transport is neither efficient nor regulated (Mikhael & Saadeh, 2015). The same research also found that investment in cars constitutes over 7.5% of the GDP including maintenance and other related costs (Mikhael & Saadeh, 2015). Public transport in Lebanon relies mainly on an informal fleet of shared taxis and microbuses. Also, according to studies by the World Bank Urban Transport Development Project in Lebanon, 75% of Lebanese households own a minimum of one car. This car-dependency practice leads to a high number of traffic accidents as well as all-day traffic congestion with an indirect cost that reaches two billion dollars annually (CDR, 2018). To add up, the senior transport specialist at the World Bank Ziad El-Nakat assumes

that traffic congestion cost in Lebanon accounts for around 10% of the national GDP, constituting around $2 billion annually (Ziade, 2018).

These numbers, as well as the number of accidents, are subject to an increase if the number of vehicles grows since traffic volume will increase. Additionally, due to the lack of funds, Lebanon has a poor infrastructure that is worsening with time and the influx of around 1.5 million Syrian refugees has caused more deterioration due to the sudden increase in traffic levels assumed to be around 20% (Ziade, 2018). Thus, a sustainable public transport system is required in order to improve transportation in Lebanon, to reduce traffic volumes on roads which would reduce stress levels and lost time due to congestion and allow employees to be more efficient and focused, and to decrease accidents, air pollution and noise pollution (Mikhael & Saadeh, 2015). One efficient method towards a sustainable transport system starts with Transit-Oriented development.

4.2. BRT project in Lebanon

Realizing the unsustainable transport sector with its high direct and indirect cost, the government of Lebanon is planning to introduce a country-wide new mass transit system, the Bus Rapid Transit (BRT), where several alignments are designed: the northern corridor, the southern corridor, the eastern corridor, and two major arterials in Beirut connecting the South. The BRT System will be implemented for the Northern Corridor of Greater Beirut, which links Beirut to Tabarja (CDR C. f., 2018). Also, the BRT corridor will be connected into the city of Beirut at an Outer and Inner Ring. As a first step, the implementation of this project addresses the Northern Entrance to Beirut. However, the Southern and Eastern Entrances will be studied at later stages. The planned scope of work for each phase are as follows: in phase 1, the BRT system on the Northern Highway and on the outer ring road of Beirut will be constructed with complementary feeder lines/buses. In phase 2, the BRT system on the Southern highway and on two major arterials

in Beirut will be constructed connecting the south, with complementary feeder lines/buses. In phase 3, the BRT system on the Eastern highway and an additional arterial within Beirut will be constructed with its feeder lines/buses. The Council for Development and Reconstruction (CDR) will be the main agency responsible for the implementation of the Greater Beirut Public Transport Project (Global Mass Transit, 2020).

The construction was estimated to be done within 5 years (from 2018 to 2023). 120 18-meter buses with a capacity of 120 passengers will be purchased to serve the highway lanes and 250 feeder buses will be operating in the inner areas (Ziade, 2018). It is composed of two lanes with a park and ride system. Three central "park and ride" spaces have been planned in Tabarja, the Charles Helou station, and the Mar Mikhael bus station to ease access to the BRT.

The sections along the Northern Highway will be connected from Tabarja to Beirut (Charles Helo) as shown in Figure 1 with 24 km length having 28 stations in the median that are spaced at 850 m. These will be connected to the sides of the highway by bridges for pedestrians with elevators and stairs.

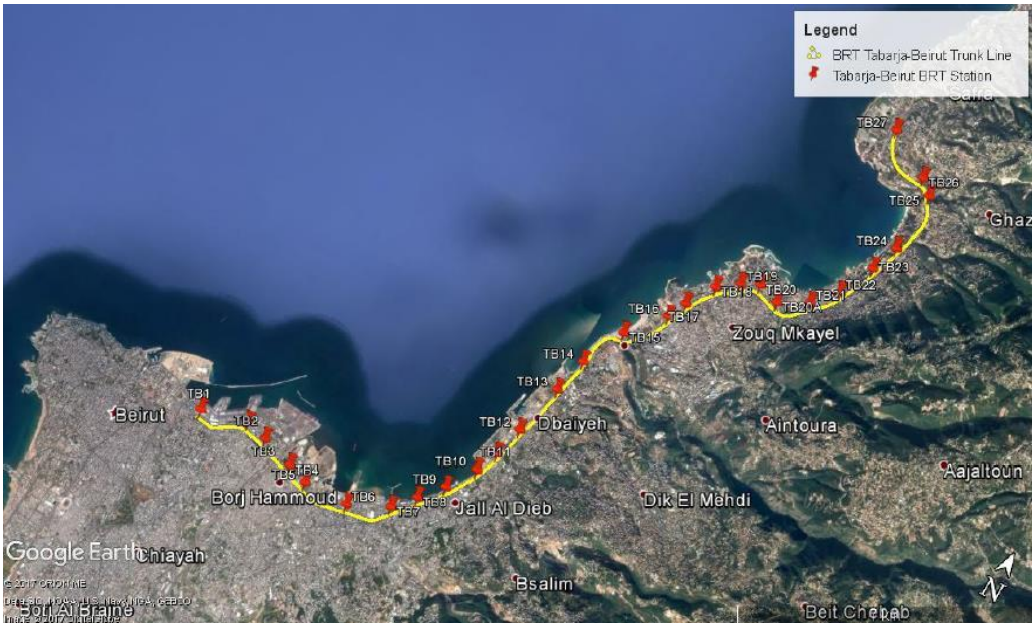

Figure 1: BRT stations along the northern highway (CDR, 2018)

The Beirut Outer Ring that has a length of 18 km, will follow the Mirna Chalouhi Boulevard - Emile Eddeh - Jisr El Wateh – Corniche Al Mazraa- Corniche Al Baher – Charles Helo – Nahr Al Mot path, with 21 stations at 700 m apart in addition to Road-Level pedestrian crossings (CDR C. f., 2018) as shown in Figure 2 and Figure 4.

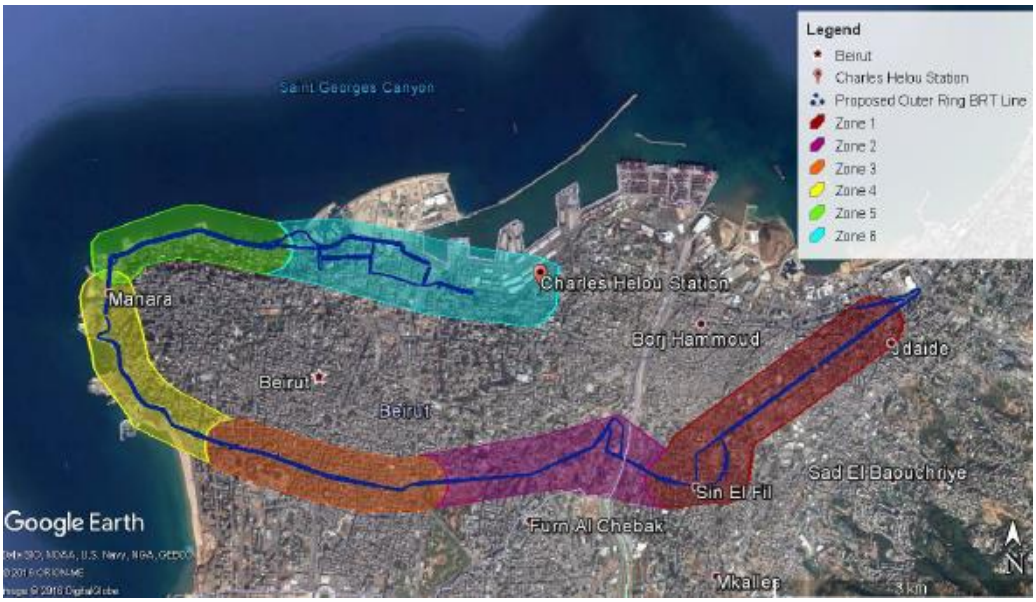

Figure 2: Proposed Beirut BRT outer ring (CDR C. f., 2018)

In addition, the Beirut Inner Ring, which has a length of 16 km and 19 stops on the right-hand side of the road, and keeps within the administrative boundaries of Beirut, passes Independence, Charles Malek, General Fouad Chehab, Spears, Omar Bin Abdel Aziz, Bani Maarouf and Algeria streets and avenues. They will be 570 m apart (CDR C. f., 2018) as shown in Figure 3. Additionally, feeder buses will also be implemented to collect people from and to the BRT stations.

Figure 3: Proposed Beirut BRT inner ring (CDR C. f., 2018)

Figure 4: Proposed Beirut BRT stations at the inner and outer rings (CDR C. f., 2018)

The northern corridor, the southern corridor, the eastern corridor, and two major arterials in Beirut connecting the South are all shown in Figure 5 below. The green route connects Beirut to the North, the blue route is complementary to the green one, also linking the North with Beirut. The purple route links Beirut to the East, the orange route links Beirut to the South, and the red and black are the two major arterials in Beirut connecting the South.

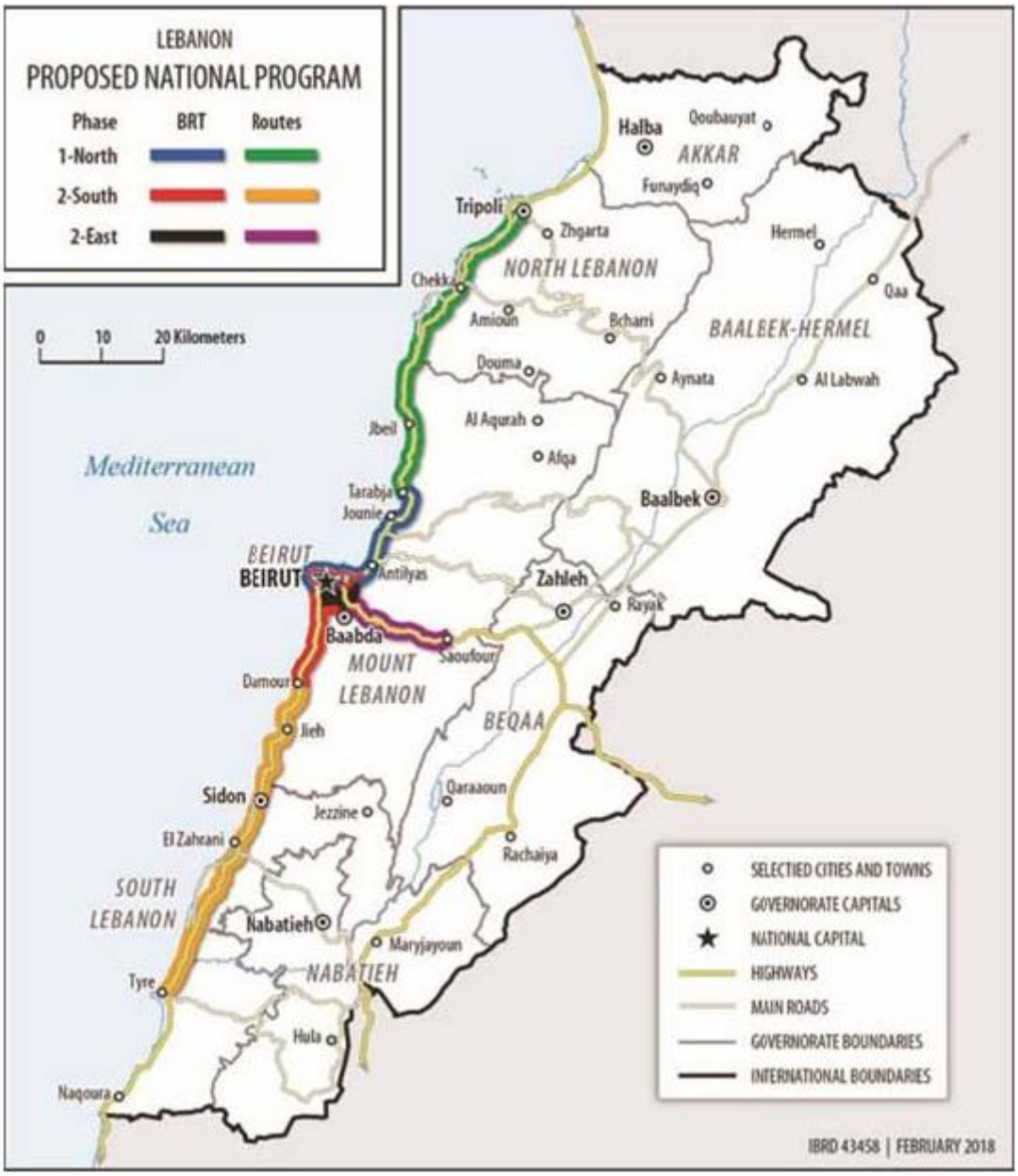

Figure 5: Overview of the BRT project's routes (Global Mass Transit, 2020)

The estimated total cost to finish phase 1 of the project is around 345 million USD with a breakdown shown in Table 2. The International Bank for Reconstruction and Development (IBRD) and Global Concessional Financing Facility (GCFF) will be providing funds amounting to 295 million USD. Funds amounting to 50 million USD will be generated through private sector financing. Moreover, almost 80% of the BRT bus fleet will be financed by the private sector (Global Mass Transit, 2020).

Table 2: Breakdown of BRT project's cost (Global Mass Transit, 2020)

Scope of work	Cost (USD million)
Developing the associated infrastructure (including land acquisition cost)	160
Buses and ITS	70
Implementing the regular and feeder network of 20 lines and 250 buses	100
Conducting the necessary capacity building and studies	15
Total	**345**

Now concerning the elements of the BRT system, they include:

1. **Dedicated right of way** which is the bus's specific lane: An exclusive right-of-way is vital to ensuring that buses can move rapidly and without congestion (ITDP, 2018). This will reduce the number of accidents between cars and buses on one hand, and would make less congestion if an accident between two buses occurs because this won't be blocking the highway. Also, the removal of the bus in case of any accident would then be easier. Enforcement of the dedicated lane can be handled in different ways, such as delineators, bollards, or colorized pavement.
2. **Off-board fare collection** which is the specific place in the station that collect money either through a "barrier controlled" or "proof-of-payment" method (ITDP, 2018). It is one of the most important factors in reducing station dwell time and therefore total travel time, thus improving the customer experience. And this is also a solution to avoid distracting the bus's driver and thus it reduces accidents.
3. **Platforms-Level Boarding**, which means that the station should be at level with the bus to deliver an easy and quick boarding (wheelchairs) (ITDP, 2018). Having the bus-station platform level with the bus floor is one of the most important ways of reducing

boarding and alighting times per passenger. The reduction or elimination of the vehicle-to-platform gap is also key to customer safety and comfort. A range of measures can be used to achieve platform gaps of less than 5 cm.

4. **Bus way Alignment (Corridor)** that is the center of the roadway, it keeps the buses away from the curbside (ITDP, 2018). Thus, conflicts with other traffic can be minimized. Options include exclusive bus only corridor, median aligned and curb aligned where there are infrequent intersections to cause traffic conflicts and delays.
5. **Intersection Treatments**, which is the omission turns for traffic across the bus lane (ITDP, 2018). There are several ways to increase bus speeds at intersections, all of which are aimed at increasing the green signal time for the bus lane. Forbidding turns across the bus lane and minimizing the number of traffic-signal phases where possible are the most important

Figure 6: Example of a BRT System (Al-Youm, 2020)

However, due to the economic crisis in Lebanon and the bad situation, this project is currently suspended and the funds are currently frozen.

4.3. Federation of Keserouan Ftouh municipalities Project

The federation of Keserouan Ftouh municipalities have done the Feasibility Study of the Public Transport Project at Keserouan-Ftouh in 2018. In this project, adequate bus lines, bus stops/stations and headquarter locations were proposed, the demand and service frequency of buses was estimated and a comparative study before and after the project's implementation was done (Monsef, 2021).

This project is considered to have a lot of advantages such as reducing traffic volumes and the number of private cars which would reduce the CO_2 emissions, reducing stress levels and improving productivity, promoting connectivity at Keserouan Ftouh region, saving parking and car maintenance cost, and regulating and organizing the Lebanese mentality towards public transport.

After mentioning the advantages that everyone would benefit from if this service is implemented, the bus tracks and the bus stops' locations were studied. An important factor taken into consideration in this study was the publicly-owned and privately-owned lands. This factor is essential if we want to implement a beneficial project without having to increase the cost of implementation, because, if a bus track passes through a privately-owned land or street, the government must pay the land-owner a specified amount of money to be able to cross his land. Another important factor they took into consideration was the maximization of the coverage area that a certain station must serve, so they located the stops at almost equally distant locations. In Figure 7 below, the bus tracks along with the stops are illustrated. The two tracks that are in dashed lines are not as important as the ones shown in solid lines but can be implemented at a later stage.

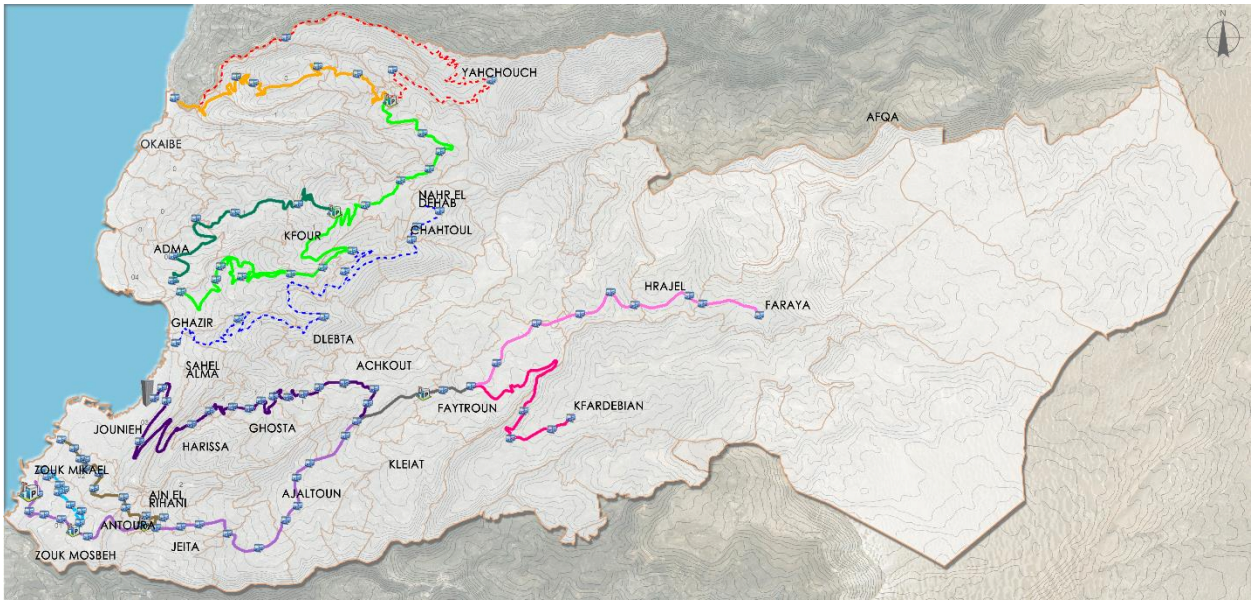

Figure 7: Proposed bus tracks and stops (Monsef, 2021)

Seven bus lines were proposed in Keserouan area and three in Ftouh area. Fouad Chehab stadium will be considered the headquarter, one station will be constructed near Yassouh El Malak in Zouk Mosbeh, and five mini-stations will be distributed as follows: one near NDU junction, one at Jeita roundabout, one in Faytroun, one in Kfour and one in Aazra. Regarding the number of stops, 190 bus stops are suggested in total, 142 at Keserwan and 48 at Ftouh with an estimated travel time range between 13.5 minutes (Line 6) minimum to 41.5 minutes (Line 8) maximum. The proposed bus types to be used are turbo-charged buses with a diesel engine of 4 cylinders with a carrying capacity of maximum 30 passengers, equipped with an AC, a wifi access, a ramp access for persons with disabilities, and payment machines via tickets & smart cards. The project cost is estimated to vary between 5.2 and 12.9 billion LBP depending on the chosen type of bus stop and bus.

After the implementation of this project, at a first stage, the estimated number of passengers that might use the bus is 3,233 in one way or 6,466 in two ways. Since this project is expected to reduce the number of private cars which would reduce CO2 emissions, traffic volume and

gasoline use, the percentage reduction in cost is assumed to be 7.31% with a net profit of 194,634,411 LBP in the first year (Monsef, 2021).

4.4. Comparison of the federation's project with this research

To compare this project with the BRT project and the research done in this paper, what was mainly discussed in the federation's project is the bus system as a whole: its total cost from bus types to bus stations to operating costs, its tracks, the location and number of bus stops, and the profit that this project would return. Our research is somehow complementary to their project, where 4 of the 5 chosen cities are located in the Keserouan Ftouh region and these towns were evaluated according to the transit-oriented development concept to check whether they can integrate a public transport system or not based on all the criteria of a TOD concept and how can we transform them to comply with this concept and be able to incorporate this project.

Regarding the stations' location, since the federation has taken into account more criteria that we cannot have access to, such as private and public lands, the distribution of stations was prepared in a way to make the work more efficient by minimizing cost and tasks. Therefore, the proposed lines and stations locations for Jounieh, Adma, Zouk Mkayel and Zouk Mosbeh by the federation will be used later in our research.

5. Research Evaluation Methodology

As discussed in the literature, different methods exist to evaluate whether cities are transit-oriented or not. Some researchers designed the city from scratch while taking into consideration their goal of making it transit-oriented. However, few studies and researches discuss the matter of transforming already existing cities to become transit-oriented. In such cases, cars were the ideal transportation mode.

Considering the current conditions and the scarcity of available data, the method used to evaluate the cities housing BRT stations in terms of TOD potential is based on the 5**D**s:

Density, **D**iversity, **D**esign, **D**estination accessibility, and **D**istance to transit.

5.1. Density

Regarding the *density*, a city with low-density developments and poor integration of land uses is considered to be more automobile-dependent. Thus, a high-density area with mixed land-use and investments promotes the use of public transport because it is assumed that the existence of residential buildings near transport nodes and workplaces will motivate citizens to use transit (Ogra & Ndebele). Also, presumably, high-density cities are characterized by a low average trip distance to nodes that encourages more walking and cycling than private car usage.

5.2. Diversity

As for *diversity*, what is referred to is land-use diversity. It is agreed that a high mix of land-use indicates that a city is more suitable for TOD. The land use Diversity Index (LD) will be calculated using Simpson's diversity index which measures the distribution and the evenness of the individual land uses within the mix of land uses where the larger value of LD indicates a greater land-use mix

in the area and 1 is the maximum possible diversity (Mohamad Zulkifli, Kadar Hamsa, Noor, & Ibrahim, 2017).

The formula used to calculate this index is:

$$Land\ use\ diversity\ (LD) = 1 - [\sum_{i=1}^{n} IA_i] \text{ where } 0 \leq \text{LD} \leq 1$$

$$Individual\ Areas = IA_1, \dots\ IA_n = \frac{A_1^2}{A^2}, \frac{A_2^2}{A^2}, \dots\ \frac{A_n^2}{A^2}$$

Where A_i is the individual land-use area and A is the total area.

5.3. Design

As for the *design*, a well-designed city is known for its land-use mix and its safe and easy accessibility. It also contains well-designed streets and intersections with continuous sidewalks and streetlights as well as amenities such as benches, parks, libraries. Also, bicycle lanes and pedestrian crossings must exist. All these elements are essential to assuring a good built environment, enable sustainable mobility for cities, and encourage transit ridership (Ogra & Ndebele).

5.4. Destination Accessibility

Concerning *destination accessibility*, the existence of public service facilities such as schools, shopping centers, sports centers, clinics, kindergartens, community centers, and libraries defines the accessibility of a pedestrian's destination.

5.5. Distance to transit

Finally, for the *distance to transit*, it is measured by how much it is easy to access the transit station, for example, the time required to arrive at the station along with the slopes of the roads that pedestrians need to take to arrive at the required bus stop.

5.6. The analysis conduction

To conduct the 5D evaluation, a detailed analysis of the area is needed. The analysis entails collecting information on cadastral maps, land use, building density, zoning, and streets network. The BRT project to be implemented is studied as well as the location of the proposed BRT stations. The basic information required to evaluate the cities housing stations such as boundaries and population are obtained from municipalities. Using google earth, each city is delineated, subdivided into equal portions where feeder bus stations are proposed, and the number of buildings is counted to be able to find the population in each small area and conclude the population density at each feeder bus station. Concerning land-use diversity, both google earth and site visits are needed to be able to define the existence of commercial, residential, institutional, recreational buildings, and calculate the diversity in these sub-areas around stations accordingly. Moreover, the existing status of public transport in each city is detailed and criticized based on collected information from local authorities or citizens living in these areas, visual inspections, and Open Street Map. Later on, BRT stations are evaluated regarding the typologies of the surrounding buildings and the pedestrian travel time needed to arrive at the station either from work, home, or any commercial center. These characteristics are further examined with respect to the feeder bus loops that must be implemented.

In the thesis, we will be implementing the 5Ds evaluation method on five towns located on the northern highway where BRT stations exist, which are Zouk Mosbeh, Jounieh, Dbayeh, Adma, and Zouk Mkayel, to evaluate them according to the TOD concept, and we will make conclusions about whether these areas are transit-oriented or not and how can different criteria be modified to make them become transit-oriented.

5.7. The choice of the five cities

The choice of these five cities was mainly based on the density criteria since this is the only aspect that cannot be modified. After collecting data from municipalities, the population was the main aspect that helped in the screening process. Site visits were also done to double-check if these areas were condensed or not, since we cannot only count on the population density with respect to the area, where the whole area of a town includes roads, open spaces, green areas, which makes the total density of the town less than the density in specific areas. The five chosen towns were: Zouk Mosbeh, Jounieh, Dbayeh, Adma and Zouk Mkayel.

Table 3: Details of the five chosen cities

	Area (km^2)	**Population**	**Elevation (m above sea level)**
Zouk Mosbeh	4.48	45,000	37 to 200
Jounieh	8	200,000	8 to 265
Dbayeh	5	65,000	0 to 100
Adma	3.7	20,000	25 to 300
Zouk Mkayel	3.9	33,000	0 to 220

The choice of Zouk Mosbeh was based on both the high population and the actual situation of this city which is really condensed and which always has traffic congestion in its streets. This was the

same case for Jounieh and Dbayeh which have a high population with respect to the city's area. However, if we look at

Table 3, we can notice that the population in Adma and Zouk Mkayel are much lower than the three other cities, but this is due to the green and open spaces in these cities where the population is too small, but it is considered much higher in areas where mixed developments exist. In Figure 8, the cities are shown. Adma is shown in blue, Jounieh in yellow, Zouk Mkayel in green, Zouk Mosbeh in red and Dbayeh in pink.

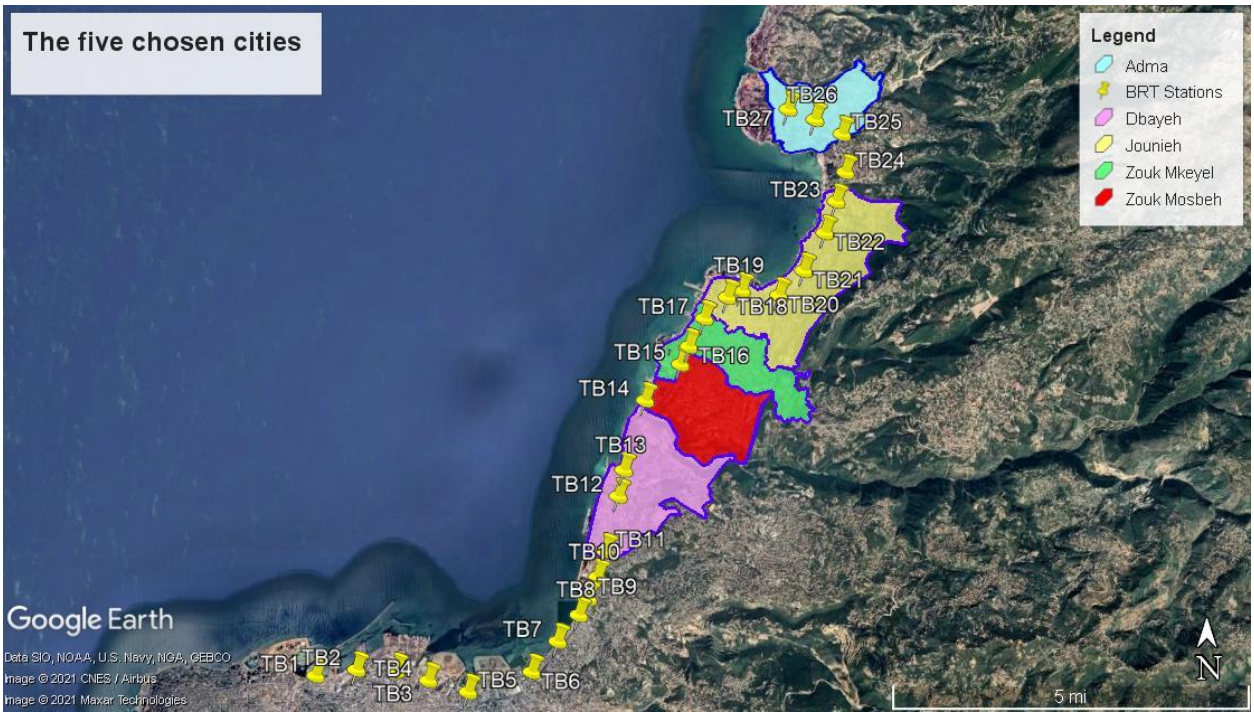

Figure 8: The five chosen cities along with the BRT stations

6. Results and Discussion

6.1. Zouk Mosbeh

6.1.1. Analysis of Current Status

Zouk Mosbeh area is a condensed city with an area of 4.48 km^2 where around 45,000 people live in a mixed land-use. Figure 9 illustrates the map of Zouk Mosbeh where zoning designation is characterized as residential commercial, industrial, and future expansion.

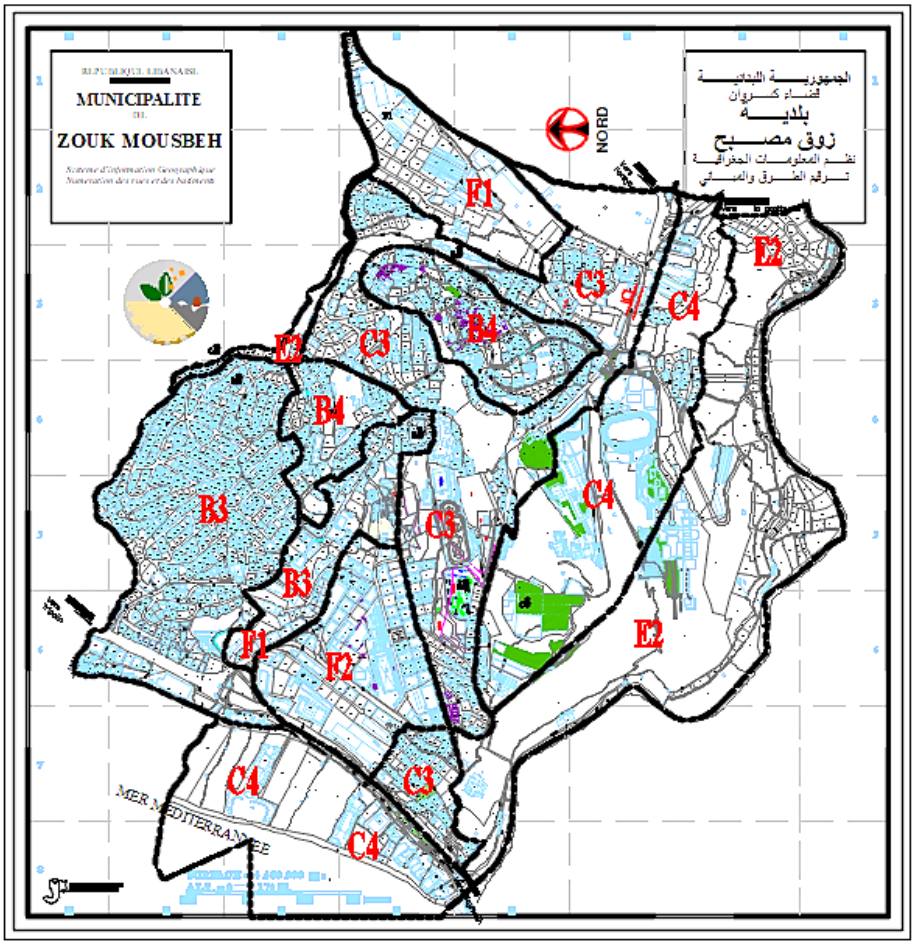

Figure 9: Zonning and Zouk Mosbeh area

The current land-use includes also educational, religious, and recreational zones. Under the educational land-use, is a major university in the region attracting more than 6,000 people between students, faculty, and staff. The existence of a university is particularly important to the TOD

context because of its high trip generation coupled with the growing likelihood of university students to rely on transit.

The transport sector in Zouk Mosbeh is no different from other areas in Lebanon with its high dependency on vehicular traffic and a large percentage of single-occupant vehicles using its streets. The street network is for the most parts well distributed with two main arterial roads crossing the city: the northern coastal highway and the Ajaltoun highway (west-east), other streets are either collectors or local roads. The public transport sector does not accommodate more than 5% of travelers with unreliable service and low levels of service. Currently, public transport relies mostly on shared minibusses or cars, mostly privately-owned. Only one route of government-operated public buses crosses Zouk Mosbeh along the northern coastal highway. Four main bus stops exist, two of them along the northern coastal highway (in each direction) and two of them along Ajaltoun highway. No public buses that may transport the traveler to other areas exist internally in this city, so people who wish to take the bus in this area have to either walk, cycle, carpool, or take a taxi to arrive at any nearby bus stop before reaching their destination. In this area, there are more than 15 taxi operators.

6.1.2. BRT project in Zouk Mosbeh

As mentioned earlier, the planned BRT project in Lebanon has one of its main alignments along the northern coastal corridor with Zouk Mosbeh housing two of its stations. In Figure 10 below, it can be seen that the proposed BRT stations in Zouk Mosbeh are located where two of the existing bus stops are located. In addition to the main BRT stations, minor bus stops are planned inside the city where feeder buses can pick people up and drop them off at the BRT stations.

The feeder bus system is proposed as a main component of the BRT project but detailed designs are yet to be finalized. To conduct a comprehensive evaluation of Zouk Mosbeh in terms of TOD potential, a preliminary feeder bus system is proposed. Several different factors were considered in bus stop placements along the feeder bus routes. The ridership potential is one important factor in determining an adequate location for stops and therefore, several bus stops were placed near the two most prominent trip generators in Zouk Mosbeh which are the highly active commercial areas along the main arterial road (Zouk Mosbeh – Ajaltoun Road) where retail shops, activity centers, banks, offices, restaurants, and supermarkets are located, in addition to the major trip generator Notre Dame University. Another considerable trip generator zone taken into consideration is the heavily populated residential zone in Zouk Mosbeh where an exclusive feeder bus loop was designed to provide transit service for that zone.

Figure 10: Map of Zouk Mosbeh with the planned BRT stations

The *Transit Capacity and Quality of Service Manual* (National Academies of Sciences, Engineering, & Medicine, 2013) suggest that 50% to 95% of transit passengers walk no further than 0.25 miles (400 meters) to reach a bus stop (equivalent to a 5-min walk). According to the manual, this walking distance is affected by the street connectivity, the grade of the street, the pedestrian crossing environment, and a population factor that takes into account the number of elderly people among the population. Those factors directly affect the reliability and the willingness of the residents to use the transit system.

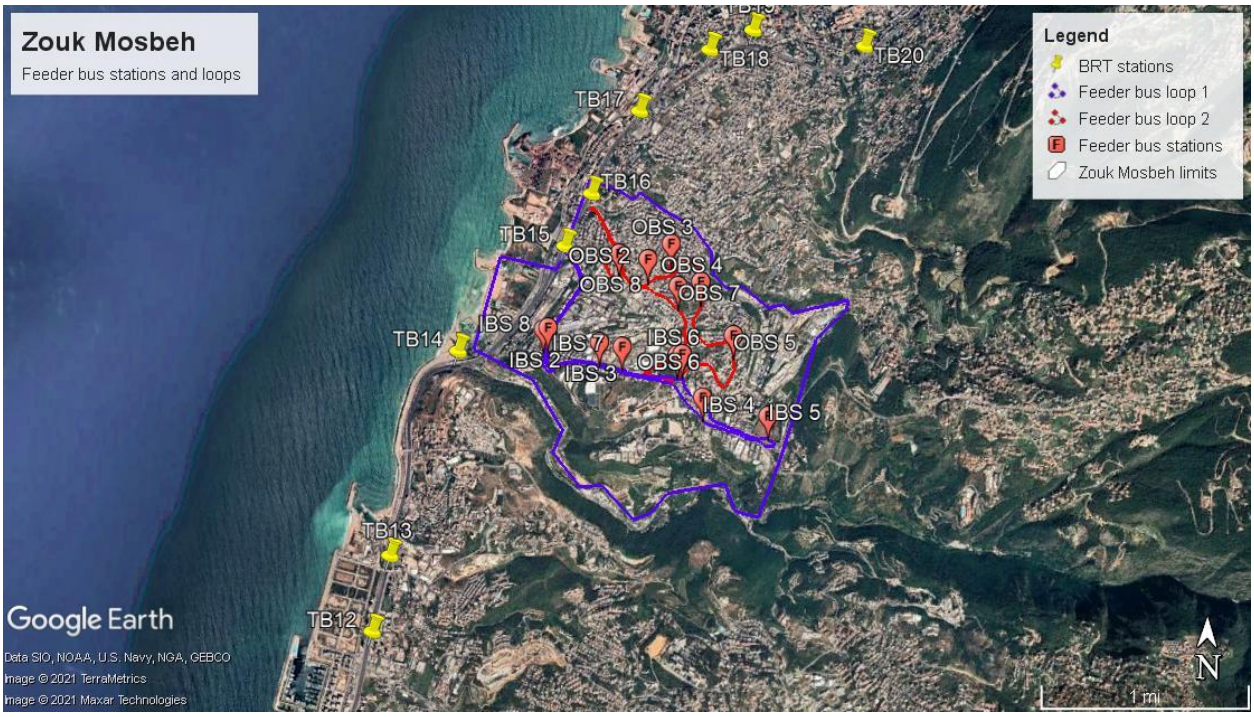

Figure 11: Proposed inner and outer feeder bus loop and bus stations

The bus stop placement was chosen in a manner to maximize coverage area while carefully taking into consideration the effects of the high number of stops on the speed of the bus facility and on the implementation costs. The layout of each bus stop was designed to conform to the on-site situation, including sidewalk presence and traffic flow. Traffic counts were made at peak hours on the main arterial road and on the inner roads where the bus stops were to be located, specifically

the curb-side lane volume. Figure 11 above illustrates the alignment of the two proposed feeder bus loops with 18 bus stops.

6.1.3. Analysis Results

Once all data are obtained, the 5Ds evaluation is done accordingly. The results shown in Table 4 indicate the density and land-use diversity at the two BRT stations and the 16 inner and outer feeder bus stations.

For the density, it was calculated by adding both the population and the employment density in the area. It can be seen that two stations exist in a high-density area, twelve in a medium-density area, and the rest in a low-density area. This proves that Zouk Mosbeh satisfies the first criteria of the 5Ds.

Table 4: Density and diversity results for all stations in Zouk Mosbeh

Stations	Density (pers/km^2)	Scale	Diversity (LD)
OBS 3	45000	High density (above 30,000 pers/km^2)	0.47
OBS 8	30000		0.75
OBS 6	26211	Medium density (between 10,000 and 30,000 pers/km^2)	0.74
TB16 (St Charbel)	23184		0.95
IBS 4	22615		0.88
OBS 7	22000		0.76
OBS 2	18000		0.72
OBS 5	17857		0.73
OBS 1	15000		0.77
OBS 4	13435		0.89
IBS 5	12828		0.93
IBS 8	12000		0.64
IBS 7	11040		0.83
TB15 (Yasouh Malak)	10979		0.99
IBS 2	8432	Low density (less than 10,000 pers/km^2)	0.90
IBS 1	6474		0.95
IBS 3	6000		0.86
IBS 6	4500		0.89

For the diversity, as mentioned previously, the higher the LD, the more the land-use is mixed. In Shanghai, Mohamad Zulkifli et al. classified LD values in the Shanghai case study as follows: a value between 0.2 and 0.36 is classified as a low diversity area, between 0.37 and 0.53, medium diversity area, and higher than 0.53, a high diversity area (Mohamad Zulkifli, Kadar Hamsa, Noor, & Ibrahim, 2017). The LD was calculated for the areas around the bus stops in the city of Zouk Mosbeh. Almost all values are above 0.64 except for one value which is 0.47. At some locations, LD has a value above 0.9 getting closer to 1 which indicates that the Zouk Mosbeh area can be considered a mixed land-use area.

Regarding the design dimension, site investigation of Zouk Mosbeh streets was done to assess the existing situation with regards to an adequate environment for pedestrians. Sidewalks are seldom found on local roads. When found, most of the sidewalks present are in poor condition and disrupt safe pedestrian movement. As for the streetlights, none can be found on the roads except on the main Zouk Mosbeh-Ajaltoun highway. There are no pedestrian crossings on any road and no signalized intersections. However, two streets underwent reconstruction recently and one was newly constructed. These are the only roads that have continuous sidewalks with almost level slopes and are equipped with streetlights and trees ensuring a good environment for pedestrians.

Concerning destination accessibility, it can be noticed that different public service facilities exist in Zouk Mosbeh, specifically around the suggested bus stations. Zouk Mosbeh has two schools, one university, lots of kindergartens, libraries, sports centers, and clinics, and a large number of shopping centers which can be explained also in the results of the land-use diversity. Therefore, this city satisfies this criteria of the 5Ds method.

As for the distance to transit with regards to the walkability dimension, the results found were worrisome. As the topography of the area varies between level and mountainous and elevation that varies between 37 m and 200 m above sea level, some roads have steep slopes which is a major factor when considering pedestrians' ease in walkability. However, as the area is subdivided into service areas each containing a feeder bus station, the time for pedestrians to arrive at these stations is around 5 minutes where slopes encountered are for short distances.

Hence, almost all the streets in this area need to be rehabilitated or reconstructed to be considered pedestrian-friendly, and these modifications include, as a minimum, constructing sidewalks, adding streetlights, pedestrian crossings, and greenery along the sidewalks. In certain streets, one limitation to sidewalks construction is the limited right-of-way due to proximity or encroachment of buildings on public space. When these conditions exist, further modifications can be implemented such as reducing allocated space for vehicular movement by converting streets to one direction if feasible and dedicating the gained space to sidewalks.

6.2. Jounieh

6.2.1. Analysis of Current Status

Jounieh is a condensed city with an area of around 8 km^2 where approximately 200,000 people live in a mixed land-use. In Figure 12 below, the map of Jounieh is shown where it can be noticed that the city is somehow large since it is composed of four smaller cities which are Sarba, Ghadir, Sahel Alma and Haret Sakher. However, in the local authorities, all these cities exist under the name of Jounieh.

This city is known for its mixed land-use where it has residential, commercial, educational, recreational, religious, touristic zones. The most important part to focus on are the educational regions because this city has three universities attracting more than 10,000 people including

students, faculty, and staff. Also, 13 public and private schools exist in this area which plays a major role in the TOD concept where universities and schools are considered an attraction for people who would most likely rely on public transport.

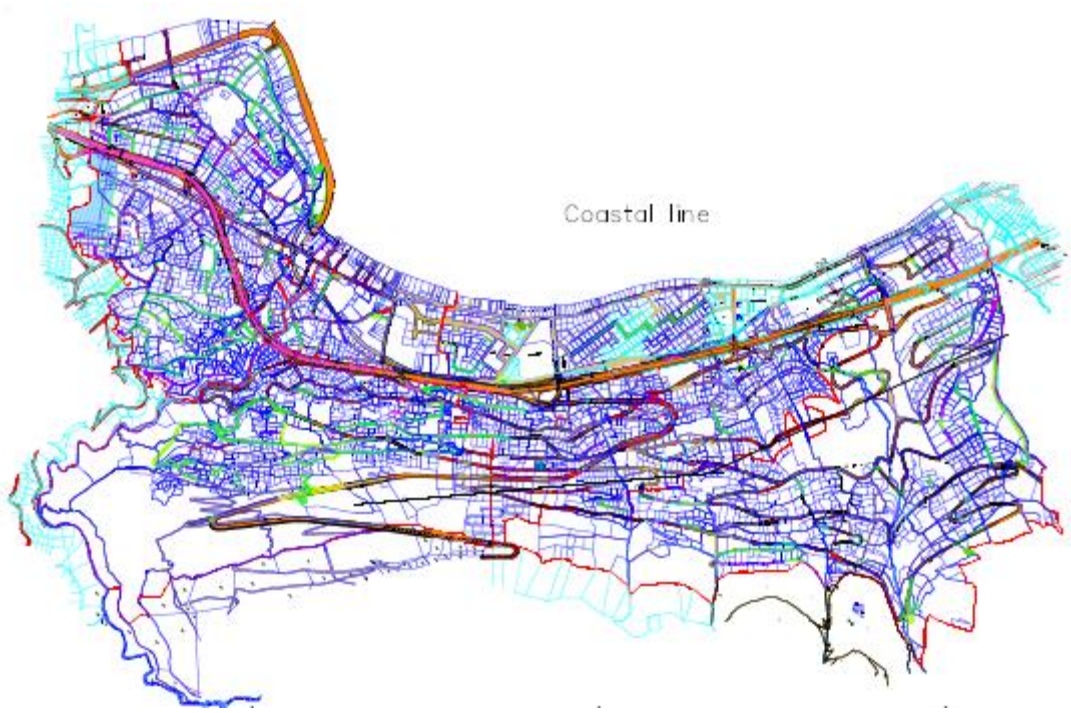

Figure 12: Map of Jounieh

Concerning the transport sector in this city, people mostly use private vehicles on almost all their trips which causes traffic congestion along the streets during the whole day. The northern coastal highway crosses the city which is the main arterial road, and there are also collectors and local roads. In this area, less than 5% of people use public buses since the stations only exist on the highway, so passengers using public buses are mainly changing buses or leaving “service” cars because they do not drive further. Citizens rarely use buses because they do not deliver passengers inside the city. Other than buses, public transport in this area also includes privately-owned minibusses or cars. The buses along the coastal highway are government-operated and there exist

seven bus stops on this road, one near Soldini shop and another one facing it in the other direction, one near Pharmacie Ghadir and another one facing it on the other side of the road, one near Apotres School and another one facing it in the other direction, and one near Fouad Chehab Stadium. Concerning internal bus loops, no public buses enter the local streets in this area, so if people want to use them, they would have to walk, cycle, carpool or take a taxi to arrive at the nearest bus stop before taking the bus and arriving at the destined location.

6.2.2. BRT project in Jounieh

Concerning the BRT alignment along the northern coastal highway, the city of Jounieh houses six planned BRT stations. In Figure 13 below, two of the proposed stations exist where the current bus stops are located. Moreover, feeder bus stations will be planned inside the local roads of Jounieh to provide people with an easier and faster way to reach the public buses.

Figure 13: Map of Jounieh with the planned BRT stations

Feeder bus loops, which constitute an essential element in the BRT project, will be proposed for this city as a first step but must be finalized later on. The same procedure used for the feeder bus loops in Zouk Mosbeh is applied here concerning the important factors that determine the right location for the stops. Three feeder bus loops were suggested for each side of the highway connecting every BRT stations to the inside of the city, which makes them six in total. While distributing the feeder bus stations, many important factors were taken into consideration which are the proximity of the station to the whole area that it will be covering so that pedestrians won't have to walk more than 5 minutes to arrive to the station, the existence of schools or universities which are considered high trip generators, and the diversity of types of centers near stations such as commercial, institutional, governmental, administrative, medical, and touristic centers. To add up, residential buildings occupy a large area in Jounieh which is also considered an important trip generator. All designed feeder bus loops were planned as per the previously mentioned criteria, to be able to cover the largest area and to serve the highest number of citizens while taking into consideration the existence of sidewalks and an adequate pedestrian environment, which would encourage people living near stations to use transit instead of private cars. In Figure 14 below, the six bus loops can be shown along with the 18 feeder bus stations.

Figure 14: Proposed feeder bus stations and loops in Jounieh

6.2.3. Analysis Results

After gathering all this information from the municipality and from google earth, we will be applying the 5Ds evaluation method. In Table 5, the results are shown indicating density and land-use diversity at the six BRT stations and the 18 feeder bus stations.

Using the same procedure applied for density calculation in Zouk Mosbeh, the density in Jounieh area was calculated. As we can see from Table 5 below, five stations are categorized as high-density areas where density around these stations is higher than 30,000 people/km^2, 16 stations with density between 10,000 and 30,000 people/km^2 are categorized as medium-density areas, and three are low-density areas with a density less than 10,000 people/km^2. This proves that Jounieh satisfies the first criteria of the 5Ds.

Table 5: Density and diversity results for all stations in Jounieh

Stations	Density (people/km^2)	Scale	Diversity (LD)
FB1	35143	High density (above 30,000 people/km^2)	0.78
FB6	35100		0.78
TB18	32727		0.89
FB2	30947		0.80
FB10	30176		0.86
FB5	29217	Medium density (between 10,000 and 30,000 people/km^2)	0.70
TB21	26023		0.93
FB11	24857		0.79
FB18	24429		0.84
FB13	24316		0.74
FB12	21500		0.69
TB23	21441		0.90
TB19	20103		0.93
FB17	19350		0.79
FB16	17960		0.90
FB7	14781		0.89
TB22	14579		0.97
FB9	13935		0.93
FB4	13297		0.80
FB3	13135		0.73
TB20	12775		0.97
FB15	9926	Low density (less than 10,000 people/km^2)	0.95
FB14	9822		0.91
FB8	9429		0.94

Concerning the diversity criterion, the higher the LD, the more there exists a mix in the land use. It was previously mentioned that a value between 0.2 and 0.36 is classified as a low diversity area, a value between 0.37 and 0.53 is a medium diversity area, and a value higher than 0.53 is a high diversity area (Mohamad Zulkifli, Kadar Hamsa, Noor, & Ibrahim, 2017). After calculating LD for all the BRT stations and the proposed feeder bus stations, it was found that all values are above 0.53 and this was noticed while examining the area on Google Earth where, in each station's service area, a variety of land-uses was found such as restaurants, commercial buildings or stores,

hospitals, hotels, touristic locations, residential buildings, local authorities, churches and convents, schools, universities and kindergartens, beach resorts, recreational facilities and green areas. This demonstrates that Jounieh city can be considered a mixed land-use area.

As for the design criterion, we visited Jounieh and explored its streets one by one to conduct an assessment concerning the existing situation and whether it is adequate for pedestrians or not. In contrary to Zouk Mosbeh, this area's streets are almost all designed with sidewalks that are in a good condition and are subject to maintenance every once in a while as we were told by the municipality. Trees can also be seen on the streets ensuring a beautiful environment to walk in. Concerning streetlights, we rarely found them missing in some streets but the majority of streets were equipped with streetlights ensuring a safe environment for people who would walk at night. However, only two signalized intersections were found in the whole area and no pedestrian crossings were found at all.

Now regarding the destination accessibility, as we previously mentioned in the land-use diversity criteria, this city contains different public service facilities around the proposed stations. In fact, this city contains three universities, 13 schools, three hospitals, five convents, a park, all types of local authorities, touristic spots, hotels, beach resorts, churches, commercial centers and shops, banks, offices, and residential buildings. Hence, we can say that this criterion is also satisfied by this city.

Now for the last D which is the distance to transit, and the ease in walkability for pedestrians, the location of the feeder bus stations was proposed in a manner to optimize travel distances for pedestrians so that they won't have to walk for more than 5 minutes. Concerning the ease in walkability, as mentioned earlier, Jounieh is a city containing four sub-cities, which makes the

altitude above sea level vary between one sub-city and the other. However, if we take each sub-city by itself, it can be seen that the roads do not have steep slopes which makes it easier for pedestrians to move.

Therefore, concerning Jounieh, minor modifications are required to ensure a safe environment for pedestrians such as adding pedestrian crossing and signalized intersections. But it can be said that Jounieh is somehow considered transit-oriented. The result we found can be explained by the fact that this city exists since 1867, where people didn't have private cars and used to travel by walking, which explains why its streets are pedestrian friendly.

6.3. Dbayeh

6.3.1. Analysis of Current Status

Dbayeh is a city with an area of around 5 km^2 where approximately 65,000 people live in a mixed land-use area. The Dbayeh map is shown in Figure 15 where we can see that it is a large town, since it is composed of four smaller towns which are Zouk El Kharab, Haret El Bellane, Mazraet Deir Aoukar and Dbayeh, yet, in the local authorities, all these towns exist under the name of Dbayeh.

Dbayeh is known for its commercial buildings and shopping centers at most since it contains two well-known malls which are Le Mall and ABC Dbayeh. It also has a large industrial area containing stainless steel factories, electrical elevators companies, juice, chocolate, and sweets production industries, carpentry, plastic and nylon factories, detergent production factories, etc… and four schools attracting around 3000 people including students, faculty members and staff. These land-use types attract a large number of people who would most probably use transit, without also mentioning that Dbayeh has a lot of residential buildings, spas and hotels too.

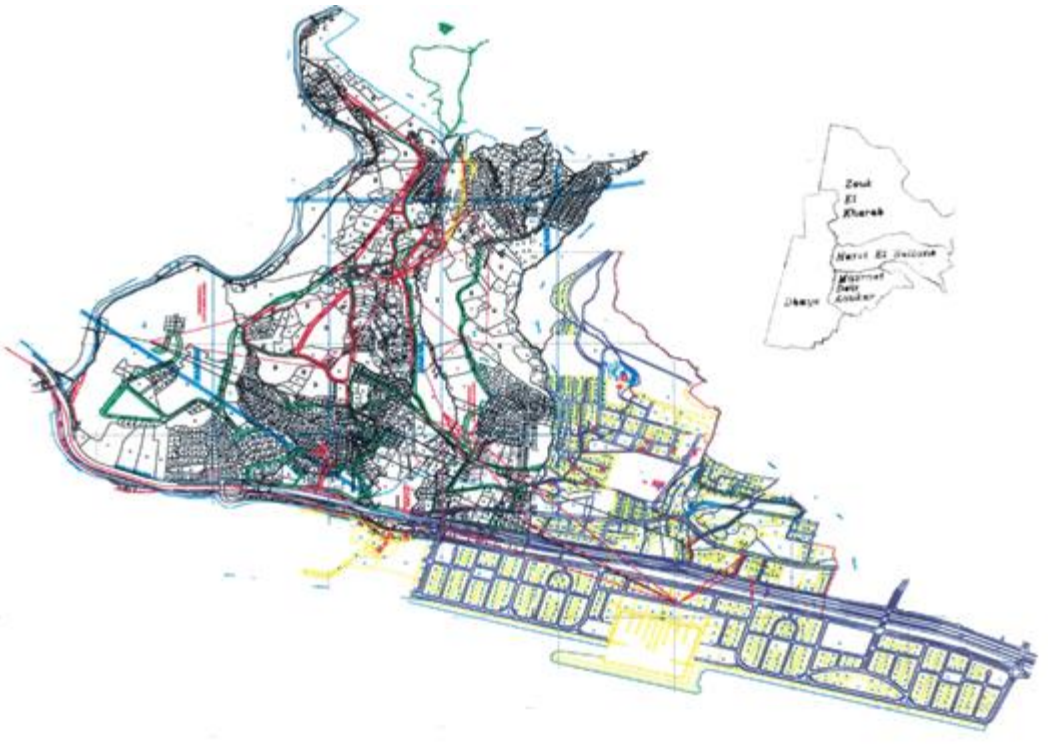

Figure 15: Map of Dbayeh

Regarding the transport sector in this city, same as all other cities in Lebanon, people mainly rely on private cars on their trips. The main arterial road passing through Dbayeh is the northern coastal highway, and the other roads are collectors and local roads. Due to the low number of bus stops that exist in this area, which are two on the highway only, and since government-operated buses do not drive through the city to pick up people from a place relatively close to their houses or workplace, a very small percentage of people, estimated to be 3 to 4% only rely on these public buses. However, other means of public transport exist which are private minibusses and private taxi cars, so people who wish to take the bus can either use these means or they can walk or cycle to arrive at the bus stop before taking the bus. The two bus stops in this area already mentioned previously are located one near Le Mall Dbayeh and the other one near Total gas station.

6.3.2. BRT project in Dbayeh

This city houses three planned BRT stations along the northern coastal highway. In Figure 16 below, Dbayeh limits are shown as well as the three stations proposed by the government.

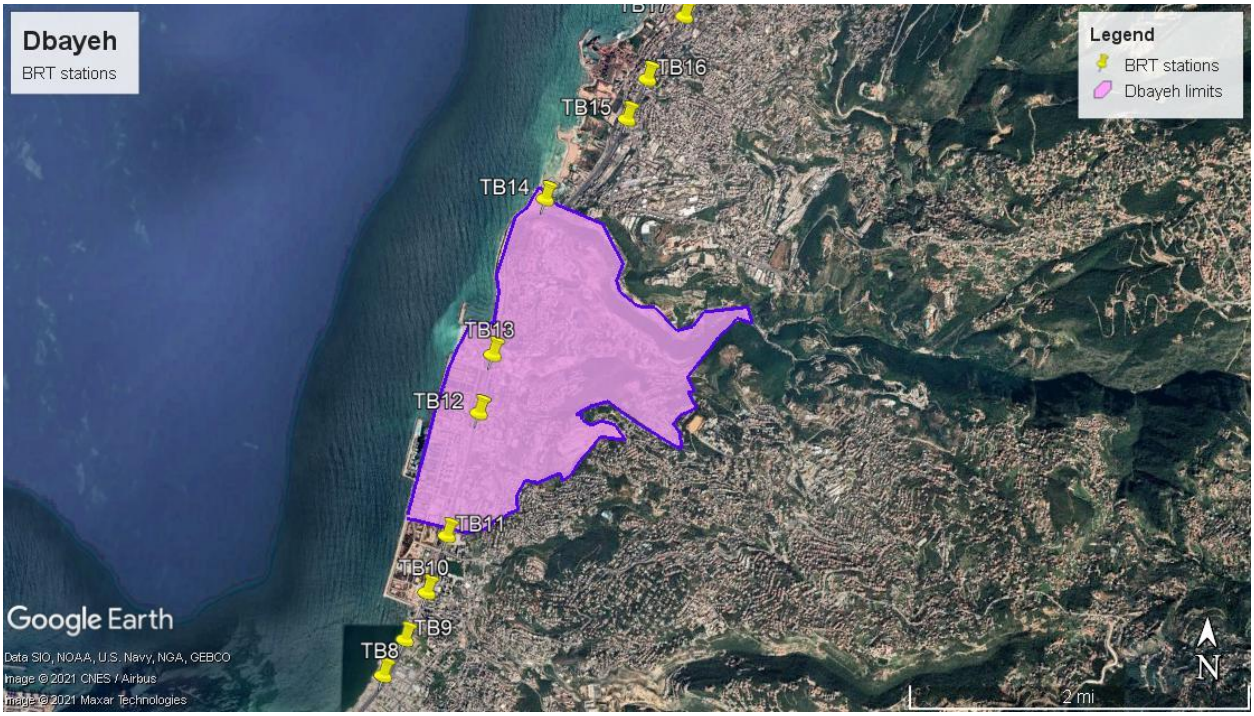

Figure 16: Map of Dbayeh with the planned BRT Stations

We will be proposing feeder bus loops inside the city to encourage people to use transit by making this service faster and easier and to decrease the reliance on private cars. Using the same procedure already used for Zouk Mosbeh and Jounieh, we will propose these stations according to the same factors which determine the most convenient location for feeder bus stations. In order to connect the three proposed BRT stations with the inside of the town, five feeder buses were suggested, connected with two feeder bus loops taking into consideration the same factors used previously in distributing stations. Stations must be equally far from each other to be able to cover a maximum surrounding area while keeping the walking travel time for pedestrians less than 5 minutes. In this town, major trip generators exist such as shopping centers, industrial zones, schools, and

recreational areas which attract a lot of people from outside Dbayeh area. Moreover, large residential zones also exist, specifically the waterfront city which is a residential compound containing restaurants, shops, 16,000 m^2 of green spaces where residents have the perfect environment for walking with everything being near to them. In Figure 17 shown below, the three proposed BRT stations, as well as the five feeder bus stations, can be seen along with the corresponding loops.

Figure 17: Proposed feeder bus stations and loops in Dbayeh

6.3.3. Analysis Results

After the data collection from the municipality, Google Earth, and Open street map, the same evaluation methodology will be applied to Dbayeh. The results of the density and the land-use diversity criteria for the three BRT stations and the five feeder bus stations are found in Table 6 below.

Table 6: Density and diversity results for Dbayeh

Stations	Density (people/km^2)	Scale	Diversity (LD)
FB1	19143	Medium density (between 10,000 and 30,000 people/km^2)	0.63
FB4	18217		0.83
TB13	17075		0.82
TB14	16909		0.83
TB12	16892		0.91
FB3	16677		0.88
FB5	16611		0.88
FB2	15818		0.89

For the density criteria, the population density and the employment density were taken into consideration in our calculations. The results for density found in Table 6 show that all stations are categorized in medium-density areas between 10,000 and 30,000 people/km^2. However, these numbers aren't considered low, because Dbayeh has a lot of large green spaces in some areas, and in other areas, it is condensed, which largely influences the density making it a medium-density area. Therefore, it can be concluded that Dbayeh satisfies this criterion.

Regarding the land-use diversity index, all values are abox 0.53 which means that this area has a variety of land uses. The station with the lowest LD value is where Waterfront City exists, and this value can be explained by the large spaces taken by the residential buildings and the green spaces, however, this area is considered to be a perfect location for a person to live in where everything can be found near residents in approximately 5 minutes at most. These results show that Dbayeh satisfies the land-use diversity criteria since all areas around the stations have multiple land-use mixes such as industrial, residential, commercial, recreational, institutional, religious, restaurants, hospitals, embassies and local authorities and green spaces.

Concerning the design, after visiting Dbayeh and sightseeing its roads and streets, we were able to come up with a clear assessment of the current situation of this town regarding its capability of

becoming pedestrian-friendly. Regarding sidewalks, we could rarely find them on the streets and where found, they were really tight and disrupted. Streetlights can be found in a good condition on almost all streets where pedestrians can feel safe if walking at night. This area contains green spaces making it environmentally friendly. However, we didn't find any signalized intersection or pedestrian crossings. Therefore, regarding the design aspect, Dbayeh needs some modifications in order to fulfill the necessary design criteria to become transit-oriented.

As for the fourth D which is the destination accessibility, we already discussed in the land-use section that this town has multiple public service facilities near each other around each station. This city contains four schools, two hospitals, three embassies, 19 factories in different industrial zones, three large malls, pools and beach resorts, hotels, commercial centers, offices and banks, restaurants and residential buildings. Therefore, this town satisfies this criterion.

Finally, concerning the distance to transit and pedestrians' ease in walkability, two factors need to be evaluated which are the pedestrians' travel time to arrive at the station, and the slopes encountered when walking to the station. In our proposed feeder bus stations and loops, we took into consideration a maximum travel time of 5 minutes from the station to any destination and vice versa which means that pedestrians won't have to walk more than 5 minutes to reach their target. However, Dbayeh's altitude varies between 0 and 100 m above sea level and this altitude reaches 252 m above sea level in Zouk El Kharab area, which is not acceptable if pedestrians would have to encounter such steep slope roads along their way, but, considering that the stations are 5 minutes away of everything surrounding them, these steep slope roads are encountered for short distances only which would then be tolerable.

To conclude, Dbayeh satisfies the density, diversity, destination accessibility, and distance to transit criteria. Concerning the design factor, the most important aspect to start with is the implementation of sidewalks in all streets while ensuring the existence of streetlights. Also, pedestrian crossings and signalized intersections must be added to guarantee a safe environment for pedestrians. After applying these modifications to this town, it could then become transit-oriented.

6.4. Adma

6.4.1. Analysis of Current Status

The city of Adma has an area of 3.7 km^2 having approximately 20,000 residents. The map shown in Figure 18**Error! Reference source not found.** below shows the limits of this town which contains both Adma and Dafne towns. Adma is known as a residential town, having some commercial, and institutional buildings such as the SABIS international school which attracts a large number of students, faculty and staff members, and it also contains some restaurants, supermarkets, hotels, and churches.

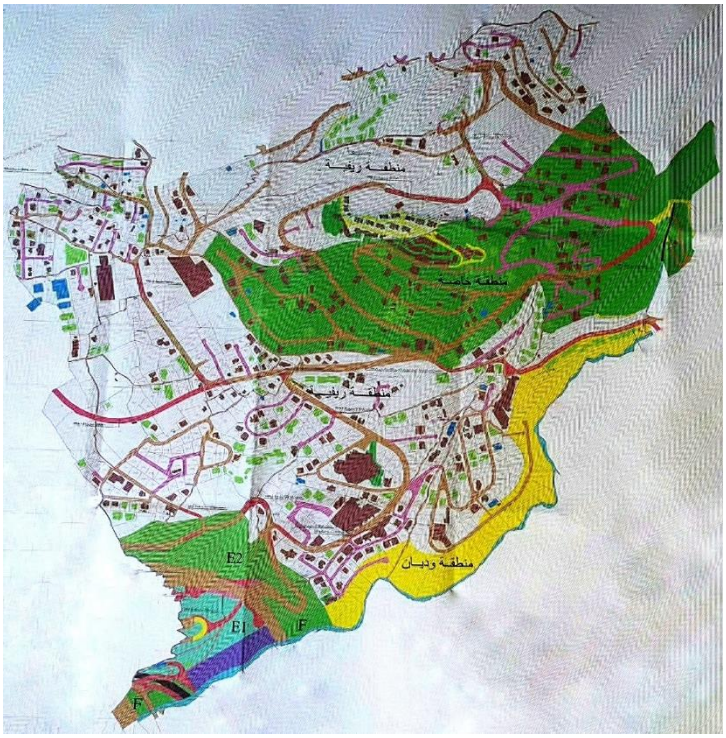

Figure 18: Map of Adma

Concerning the transport sector in this area, same as the above-mentioned cities, this town has a poor public transport service. Two main arterial roads cross this town which are the northern coastal highway, and the Adma-Ghedres highway, others are local roads. Only one stop for buses exists and it is located at the entrance of the town. Also, the buses are in a poor condition where most residents prefer to use their car, and no buses are allowed to drive in the city so residents who wish to use the bus have to walk or cycle for a long distance before reaching the bus stop, which causes less than 4% of residents only to use buses. Moreover, there are some known spots where taxis pick up people at different times of the day.

6.4.2. BRT project in Adma

Two of the 28 BRT stations are located in this town which is why we chose to evaluate it and this can be seen in Figure 19 below where Adma limits are shown as well as the two proposed stations.

Figure 19: Map of Adma with the planned BRT Stations

Since the proposed stations exist along the highway only, feeder bus loops must be proposed to pick up people from and to BRT stations. We will be distributing evenly these stations based on distance in a way to center them in each subdivided area so that people living near each station won't have to walk more than 5 minutes to reach it. To connect the two BRT stations with the inner town, five feeder bus stations were recommended, all connected with one loop. In this town, two major trip generators exist which are the SABIS international school attracting around 5000 students, faculty members and staff, and Casino Du Liban attracting 1000 visitors per day which both cause traffic congestion. The five feeder bus stations, the two BRT stations and the loop connecting all stations are illustrated in Figure 20.

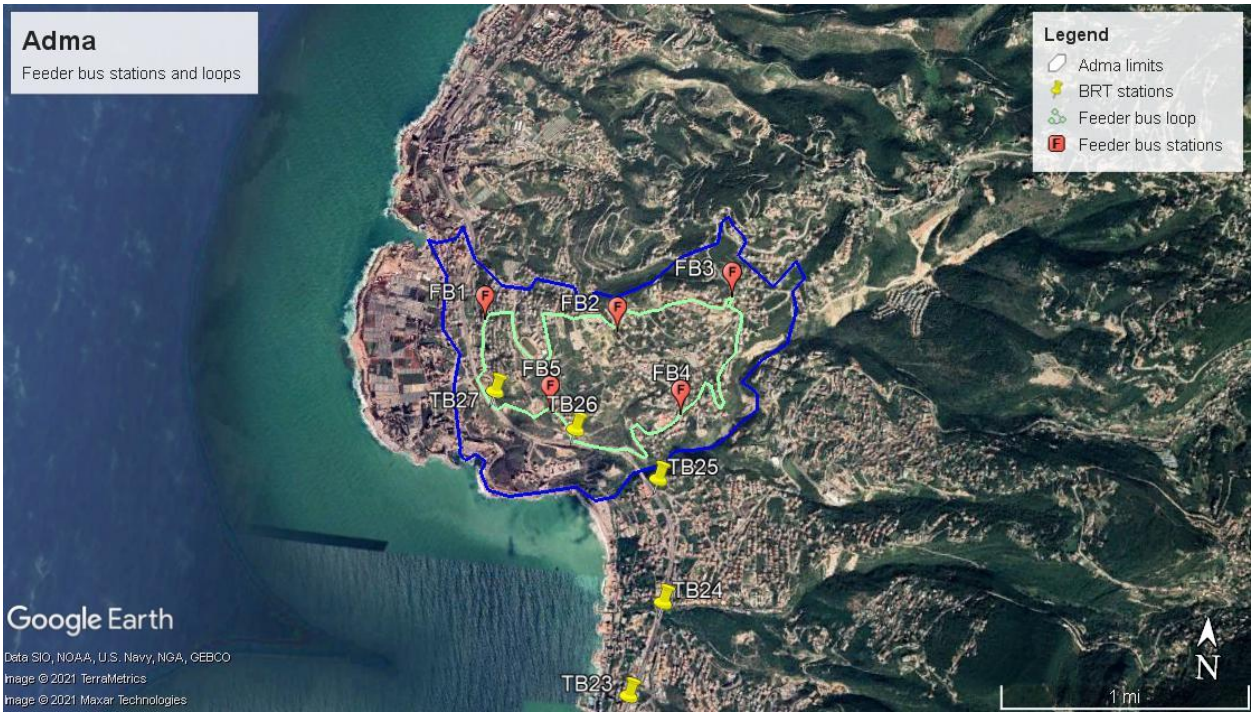

Figure 20: Proposed feeder bus stations and loops in Adma

6.4.3. Analysis Results

After gathering the required information for our evaluation from the municipality and Google Earth, we applied the same evaluation methodology already used on Adma. Density and diversity results for the two BRT stations and the five feeder bus stations are shown in Table 7 below.

Table 7: Density and diversity results for Adma

Stations	Density (people/km^2)	Scale	Diversity (LD)
FB1	22333	Medium density (between 10,000 and 30,000 people/km^2)	0.52
TB26	15677		0.87
FB2	15441		0.76
FB4	10813		0.64
FB3	10313		0.50
TB27	10183		0.82
FB5	9511	Low density (less than 10,000 people/km^2)	0.63

After applying the 5Ds evaluation method, the results were tabulated. Regarding the density which was found by adding both the employment and population density, the results obtained show that six stations are categorized as medium-density stations and one station only has a low density. This can be explained by the existence of green spaces, which can be seen all around this town, not only at this station. However, this town can be considered a medium-density area which means that it satisfies the density criteria.

Concerning the land-use diversity, the results found were somehow expected after the site visit of this town. It can be seen in the table that two stations have an LD of less than 0.53 which means that they are medium-diversity areas. Other stations have values of LD larger than 0.53 with a maximum value of 0.87. This classifies the area by being a medium-diversity town with fewer land-use diversities than the previously discussed towns. Given that Adma contains two major trip generators which are a school and the casino, and that it contains hotels, a hospital, a few commercial shops and restaurants, few churches, more developments can be made around stations to make the areas become high-diversity areas.

As for the design, after conducting site visits to Adma's streets and examining the status of the roads, we evaluated them to check whether they can be considered pedestrian-friendly or not. Concerning the most important factor for pedestrians which are sidewalks, we can say that almost all streets have sidewalks for pedestrians to walk at ease. Also, streetlights are installed on all streets to ensure a safe environment at night and the existence of green spaces ensures environmentally friendly areas. However, no signalized intersections nor pedestrian crossings exist at all in this town, which might be causing accidents. Therefore, Adma needs some modifications for the design criteria in order to guarantee a safe environment for the pedestrians.

Regarding the destination accessibility criterion, as already mentioned in the land-use diversity discussion, not all public service facilities exist near each station, so residents who live for example near Feeder Bus station 1 do not have access to everything they might need such as offices, banks, commercial buildings and restaurants. This is not the case near all the stations where others are surrounded by all the needed public service facilities. Hence, we can say that Adma partially satisfies this criterion, and more developments around some stations are required to fulfill the fourth D.

Lastly, concerning the distance to transit and pedestrians' ease in walkability where two factors are taken into consideration which are the travel time to reach the station and the slopes encountered, since we took into consideration the travel time in proposing the location of the feeder bus stations, we can assure that this factor is satisfied and pedestrians won't have to walk more than five minutes to reach the nearest station. Concerning the slopes, the elevation of Adma varies between 25 m above sea level and 300 m above sea level, which is why it can be noticed that the highway from Adma to Ghedres has steep slopes. However, local streets within the service area of a station mainly have mild slopes which makes it easier for pedestrians to walk to access the station. This means that this criterion is satisfied by Adma town.

To sum up, Adma satisfies the density and distance to transit criteria. It partially satisfies the design criteria where signalized intersections and pedestrians crossings must be added to ensure a safer environment for people which would encourage them to rely on public buses. As for the land-use diversity and the destination accessibility criteria which are inter-related, more developments around stations are required to make the town more diverse, such as adding more commercial buildings, constructing sports centers, offices, banks, malls, and restaurants reachable for all

residents and also attracting people from outside Adma. After modifying the specified criteria, Adma can become transit-oriented.

6.5. Zouk Mkayel

6.5.1. Analysis of Current Status

Zouk Mkayel is a town having an area of approximately 3.9 km^2 with a population of 33,000 people. As we can see in Figure 21, the map shows the limits of Zouk Mkayel. Zouk Mkayel is one of the oldest towns in Lebanon, and it is known for its touristic orientation where the Roman Amphitheater, the Old Souks, and Nouhad Naoufal Stadium, the largest stadium in Lebanon, are visited by tourists. It also includes residential, commercial, institutional and recreational buildings.

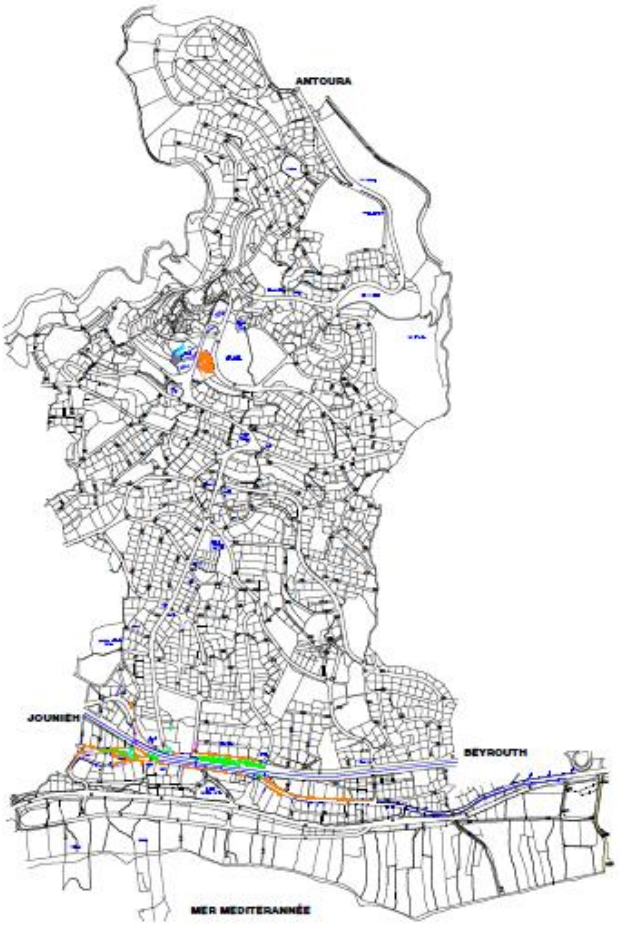

Figure 21: Map of Zouk Mkayel

The transport sector in this area is the same as in all other areas discussed previously. People mainly rely on their cars, and they barely use public transport since it is a poor service and buses do not drive inside the city, which makes them believe private car usage is easier, safer and less complicated than public transport. One main arterial road crosses the city which is the northern coastal highway and the other roads are local roads and collectors. The bus stops in both directions of the highway at the same location near Saydet El Najat church. There are also known stops for taxis all day long.

6.5.2. BRT project in Zouk Mkayel

We chose Zouk Mkeyel town to evaluate it since it houses one of the 28 BRT stations which can be illustrated in Figure 22 below where the town limits are shown as well as the BRT station.

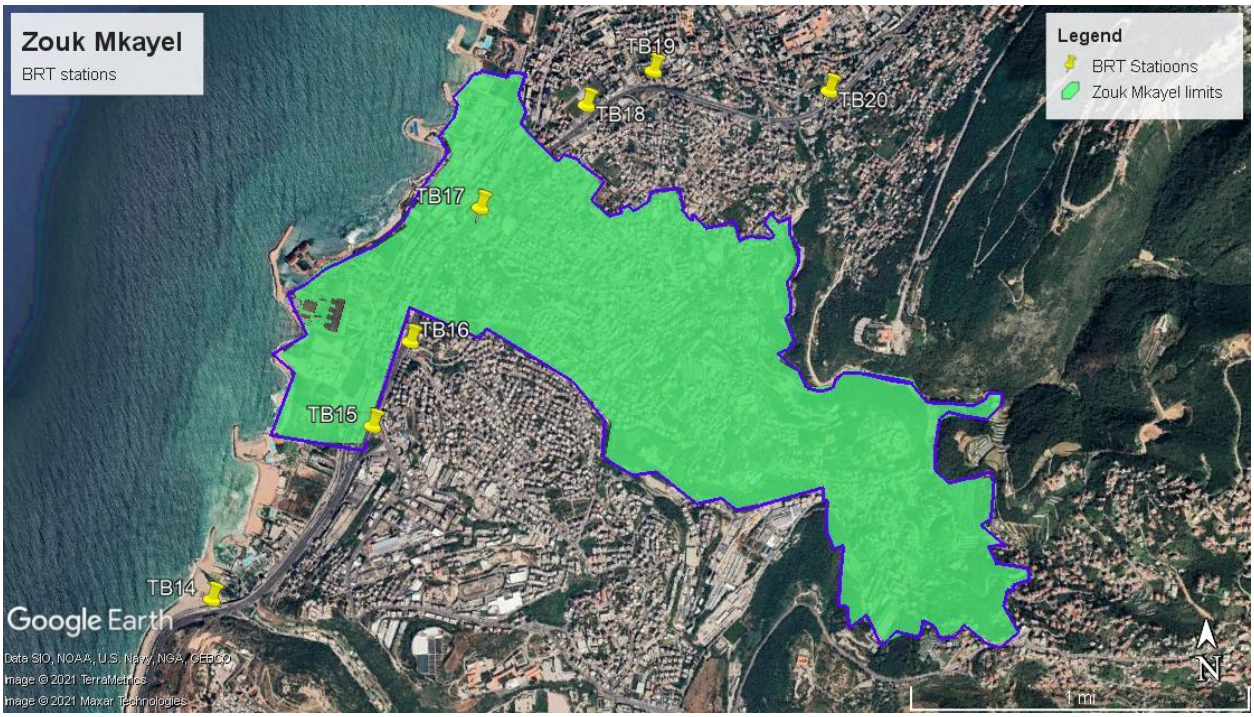

Figure 22: Map of Zouk Mkayel with the planned BRT Stations

As we can see from Figure 22, the proposed station is located on the highway and feeder bus stations and loops must be proposed to link the BRT station with the inside of the town, so that

residents would be encouraged to use transit. These stations are evenly distributed in a way to maximize coverage and to minimize the distance traveled from and to the station to a maximum of five minutes walk. We linked the BRT stations with the town by proposing five feeder bus stations distributed at equal distances to serve the maximum number of people. Different major trip generators exist in this town, such as Saint Joseph School, the Lebanese Canadian University, the old souks, the roman amphitheater, zouk power station, Zouk Mkayel's public garden and Nouhad Naoufal stadium, which all attract a large number of people daily. Figure 22 below shows the BRT station in Zouk Mkayel along with the five proposed feeder bus stations.

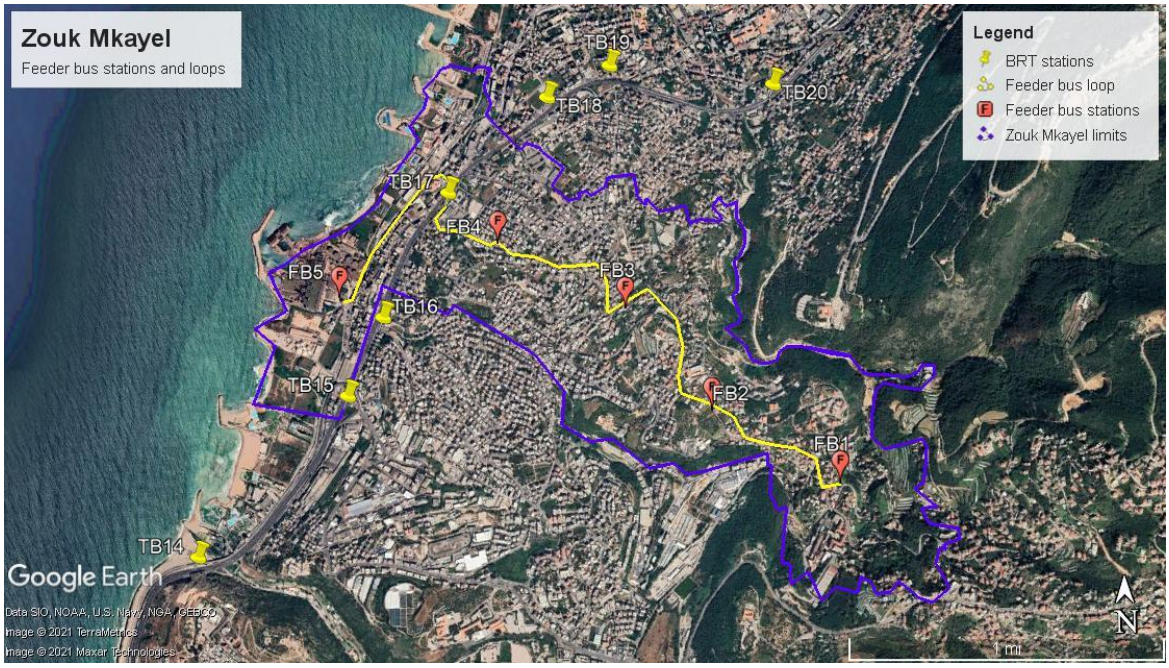

Figure 23: Proposed feeder bus stations and loops in Zouk Mkayel

6.5.3. Analysis Results

The 5Ds evaluation methodology is applied now to Zouk Mkayel after acquiring the basic information needed for our evaluation. In Table 8 below, the density and land-use diversity results are presented for the BRT station and the five feeder bus stations.

Table 8: Density and diversity results for Zouk Mkayel

Stations	Density (people/km^2)	Scale	Diversity (LD)
FB4	30070	High density (larger than 30,000 people/km$^{2)}$	0.87
FB3	23921	Medium density (between 10,000 and 30,000 people/km^2)	0.88
FB1	17016		0.90
FB2	15205		0.87
FB5	11124		0.88
TB17	10301		0.97

The results obtained in Table 8 represent the population and employment density, and the land-use diversity index. Concerning the density, the results show that one station is located in a high-density area having a density larger than 30,000 people/km^2, and five stations in a medium-density area having a value between 10,000 and 30,000 people/km^2. For people who have been to Zouk Mkayel, this can actually be noticed, since this area is a condensed area always having traffic congestion. Therefore, Zouk Mkayel satisfies the density criterion.

Regarding land-use diversity, Zouk Mkayel is an old town that has been subject to a lot of development every once in a while. In this town, everything that residents might need can be immediately found without the urge to go to another town. This can be translated in the LD index that was found to be larger than 0.53 for all stations, and specifically, larger than 0.87 which shows that this town is a mixed land-use area containing major trip generators such as schools, a university, a museum, the Old souks, and Nouhad Naoufal basketball stadium, in addition to all other types of developments such as residential, commercial, recreational, and administrative buildings. This leads us to conclude that Zouk Mkayel fulfills the diversity criteria.

Now for the design, as already mentioned previously, this town is usually subject to new developments, and the municipality always aims to keep the city organized and well-designed,

especially because it has different tourism locations that attract visitors. So if we consider the existence of sidewalks factor, after our site visit to this area, we found that almost all streets have continuous sidewalks with a very good condition and that the same applies to the streetlights where we could seldom find a street without light which ensures a good environment safe for pedestrians to walk in. Regarding signalized intersections and pedestrians crossings, these cannot be found in this area. Consequently, to put Zouk Mkayel on track towards satisfying the design criteria, we must add signalized intersections and pedestrian crossings to make residents feel safer and more comfortable when they need to walk towards a station.

Concerning the destination accessibility measured by the number of public service facilities that exist near stations, it was already discussed that the land-use in this town is diverse. Everything can be found near any bus station, such as banks, offices, schools, churches, shops and supermarkets, pharmacies and medical centers, a public garden, the old souks where people also come to walk, a museum visited mainly by toursits but also by residents, sports centers, and restaurants. Also, a large industrial zone exists at the coastline, as well as a large area containing hotels and beach resorts. Thus, Zouk Mkayel satisfies the fourth D.

Concerning the fifth D, distance to transit, which is composed of both the time required for a person to arrive at the station and how easy this process is. Since we located the feeder bus stations at equal distances taking into consideration that residents must not walk more than 5 minutes to reach their destination, the travel time is considered to be very minimal. As for the slope, Zouk Mkayel's elevation varies between sea level and 220 m above sea level, which might cause steep slopes on some encountered streets. However, since the distances traveled are small, this is not considered an issue to worry about.

To conclude, Zouk Mkayel satisfies the density, diversity, destination accessibility and distance to transit criteria. The design criterion requires some modifications such as the addition of pedestrians crossings and signalized intersections in order to reduce the number of accidents and to encourage pedestrians to walk and use transit. If the mentioned suggestions were adapted, Zouk Mkayel would become transit-oriented.

6.6. Summary

As a summary, Table 9 below shows all the results for the five evaluated towns concerning density, diversity, design, destination accessibility and distance to transit aspects.

Table 9: Results summary for all cities

		Zouk Mosbeh	**Jounieh**	**Dbayeh**	**Adma**	**Zouk Mkayel**
Density	Density highest value (people/km^2)	45,000	35,143	19,143	22,333	30,070
	Density lowest value (people/km^2)	4,500	9,429	15,818	9,511	10,301
	Average density (people/km^2)	16,975	21,040	17,168	13,461	17,940
Diversity	LD highest value	0.99	0.97	0.91	0.87	0.97
	LD lowest value	0.47	0.69	0.63	0.50	0.87
	Average LD	0.81	0.85	0.84	0.68	0.89
Design	Sidewalks	Poor condition	Exist in almost all streets	Poor condition	Exist in almost all streets	Exist in almost all streets
	Streelights	Rarely found in 2 streets	Exist in almost all streets	Exist in almost all streets	Exist in almost all streets	Exist in almost all streets
	Signalized intersections	Do not exist	Only two in the whole area	Do not exist	Do not exist	Do not exist
	Pedestrian Crossings	Do not exist				

		Zouk Mosbeh	Jounieh	Dbayeh	Adma	Zouk Mkayel
Destination accessibility	Existence of different public service facilities	A lot of public service facilities: schools, universities, industries, kindergartens, libraries, sports centers, clinics, shopping centers, residential bldgs	A lot of public service facilities: universities, schools, hospitals, convents, local authorities, hotels, beach resorts, churches, commercial centers and shops, banks, offices, and residential buildings	A lot of public service facilities: schools, hospitals, embassies, industrial zones, large malls, pools and beach resorts, hotels, commercial centers, offices and banks, restaurants and residential buildings	Not all public service facilities exist near each station	A lot of public service facilities: schools, banks, offices, churches, shops and supermarkets, pharmacies and medical centers, a public garden, the old souks, a museum, sports centers, and restaurants
Distance to transit	Time required to arrive at the station	<= 5 minutes				
	Ease in walkability	37 m and 200 m above sea level → steep slopes; encountered for short distances only	This area contains 4 sub-cities → in each sub-city by itself, slopes encountered are mild	0 m and 100 m above sea level → steep slopes; encountered for short distances only	25 m and 300 m above sea level, the highway: steep slopes; local streets: mild slopes	Sea level and 220 m above sea level → steep slopes; encountered for short distances only

Concerning density, Jounieh is found to have the highest average density (21,040 people/km^2) and Adma is found to have the lowest average density (13,461 people/km^2). These values can be

deduced from the previous tables where Jounieh had five cities located in the high-density zone, 16 stations in the medium-density zone, and three stations in the low-density zone, and Adma had six stations located in the medium-density zone, and one in the low-density zone.

Regarding diversity, Zouk Mkayel has the highest LD (0.89) and Adma has the lowest LD (0.68). This has been explained previously in detail where the land-use diversity in Zouk Mkayel contains a higher mix of different developments such as schools, shops, residential buildings, touristic regions, restaurants, gardens, supermarkets, etc… than Adma which has a limited mix in land-use development where new developments are required to take place to make it more diverse.

Concerning the design, sidewalks were rarely found in Zouk Mosbeh and Dbayeh, and were found, they were in poor condition. However, in Jounieh, Adma and Zouk Mkayel, almost all streets had sidewalks. As for the streetlights, in Zouk Mosbeh, we rarely found two streets equipped with streetlights in contrast to Jounieh, Dbayeh, Adma and Zouk Mkayel where streetlights existed in all streets ensuring a safe environment. Two signalized intersections exist in Jounieh only and the other cities do not have any. Pedestrian crossings do not exist at all.

Regarding destination accessibility, a lot of public service facilities exist in all cities except for Adma which was already discussed in the land-use diversity section.

Finally, concerning distance to transit, the design of stations was proposed in a way to maximize coverage and to limit the walking travel time to 5 minutes maximum. As for the ease in walkability, even if there exists some difference in elevation in one town, this should not be an issue since the encountered steep slopes would be only for a short distance. This is the case of Zouk Mosbeh, Dbayeh, and Zouk Mkayel.

As it can be seen from this table, Jounieh seems to be the best city to house a public transport system which was already explained by the fact that Jounieh is an old town. Moreover, Jounieh used to house a train station when the train system functioned in Lebanon since the 1890s which caused this city to develop as a transit-oriented city since the beginning. And even after ending this system in the 1990s, Jounieh continued its developments as a transit-oriented city, which is the reason why it satisfies best all the criteria of a transit-oriented development city.

6.7. Possible future suggestions

Concerning the possible suggestions and the required modifications already discussed that would help us to put the evaluated cities on track towards becoming a TOD, the validation of this methodology can be a direction for future research. Two validation methods can be applied, one in the short term and one in the long term. Regarding the short-term validation of the methodology, this can be done through a wide range of surveys distributed to current residents of all the evaluated cities, to check if these changes can be done and would benefit the cities and if they can adapt to the changes that will occur to these cities before implementing the public transport system. However, this cannot give a complete clear validation of the discussed methodology. A long-term validation can occur after modifying all the discussed criteria, adding the missing design aspects to all the cities, and then, implementing the BRT project in Lebanon. When this project is implemented, its impact can be studied along with the major improvements made, which would then validate our methodology and would clearly show whether the discussed aspects (5Ds) were enough to evaluate the city, and to put it on track towards becoming transit-oriented and being able to house a public transport system, or more aspects are required for the evaluation process.

7. Conclusions

With the prospect of implementing the BRT project in Lebanon, cities housing the BRT stations must evaluate their current condition and prepare their transport infrastructure where needed if they seek to benefit from the economic and social benefits that the BRT project will bring. In this research, the methodology to evaluate five cities housing the BRT stations along the highway from Tabarja to Beirut was chosen and applied on Zouk Mosbeh, Jounieh, Dbayeh, Adma and Zouk Mkayel. The adequacy of these cities to maximize their benefits from the BRT project by preparing it to be a TOD was studied. The study looked at five TOD aspects: density, diversity, design, destination accessibility, and distance to transit. Concerning Zouk Mosbeh and Dbayeh, it was found out that these two towns satisfy the density, diversity, distance to transit and destination accessibility aspects taking into consideration introducing feeder bus loops. Conversely, the study concluded that the design aspects need major improvements such as the rehabilitation of its streets in terms of walkability by implementing sidewalks to all the streets along with streetlights. Regarding Jounieh and Zouk Mkayel, they satisfy the density, diversity, destination accessibility and distance to transit criteria. Two important factors to be added to ensure a safer environment are the implementation of signalized intersections and road marking with pedestrians crossings. Lastly, concerning Adma, major improvements are required for the land-use diversity aspect where different types of land-uses must be found around stations which would also influence the destination accessibility factor. The design aspect also requires modifications such as adding signalized intersections and pedestrian crossings. Adding or modifying the mentioned aspects for the five cities would put them on track towards becoming successful TODs. Two major limitations to these modifications are, first, the limited right-of-way due to the proximity of buildings on public space which would be making the task of adding sidewalks to some cities harder. However,

as a suggestion, we can reduce the allocated space for vehicular movement by converting streets to one direction if feasible and dedicating the gained space to sidewalks. The second limitation is concerning the low land-use index and the development of new land-uses around stations, this development might be limited due to the high rental fees someone might pay to open a shop or any other type of land-use. Therefore, as a suggestion, reducing the rental fees can cause new developments, specifically in Adma, which means a higher land-use index. The significance of this research is two dimensional: for existing cities in terms of how they can prepare to better capture the potential benefits of converting into a TOD, and for transit planners where locating stations can take into consideration an additional factor that is the potential of the area to be a TOD. This factor can bring about increased ridership and better system efficiency.

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