Research in Transportation Economics 86 (2021) 100992

Contents lists available at ScienceDirect

Research in Transportation Economics

journal homepage: http://www.elsevier.com/locate/retrec

Examining spatio-temporal trip patterns of bicycle sharing systems in Southern European island cities

Suzanne Maas[a], Paraskevas Nikolaou[b], Maria Attard[c,*], Loukas Dimitriou[d]

[a] *Institute for Climate Change and Sustainable Development University of Malta, OH132, Msida, MSD, 2080, Malta*
[b] *Department of Civil and Environmental Engineering, University of Cyprus, 75 Kallipoleos Str., P.O. Box 20537, 1678, Nicosia, Cyprus*
[c] *Department of Geography, Faculty of Arts Director, Institute for Climate Change and Sustainable Development University of Malta, OH132, Msida, MSD, 2080, Malta*
[d] *LαB for Transport Engineering, Department of Civil and Environmental Engineering, University of Cyprus, 75 Kallipoleos Str., P.O. Box 20537, 1678, Nicosia, Cyprus*

ARTICLE INFO

Keywords:
Bicycle sharing systems (BSS)
Cycling
Southern europe
Island cities
Tourist destinations

ABSTRACT

Bicycle sharing systems (BSS) have been implemented in cities worldwide in an attempt to promote cycling. Analysing BSS usage in 'starter' cycling cities in Southern Europe (Limassol, Las Palmas de Gran Canaria and Malta) can aid in understanding how BSS use and cycling can be promoted in such a context. A year of trip data is used to understand to what extent the BSS is characterized by tourist use or by local residents, trips are classified based on trip type, trip duration and diurnal and seasonal usage patterns. An analysis of the origin-destination matrices highlights spatial patterns and temporal dynamics, and analysis of the spatial coverage is used to calculate what percentage of the city's population is served by the BSS. The comparative analysis shows that despite sharing commonalities, the cities exhibit differences in BSS use: while in Limassol BSS use is mainly for leisure, in Las Palmas de Gran Canaria and Malta there is more cycling for transport. Investing in connections between the BSS, public transport, points-of-interests and cycling infrastructure can encourage more cycling. In all cities there is scope to integrate the BSS with public transport and promote the service amongst tourists and visitors.

1. Introduction

As part of a shift towards sustainable mobility, cycling as a mode of transport is being promoted in cities around the world. Cycling, a form of active transport, has the potential to provide transport alternatives for those marginalized by car-based mobility, to reduce traffic related diseases and injuries, noise and air pollution, and to promote an active lifestyle and improve public health (Handy et al., 2014; Sallis et al., 2016). Bicycle sharing systems, or BSS, are shared bicycle fleets allowing short-term public use (Shaheen et al., 2010). BSS are a transport innovation that can enable cycling for a wider group of citizens and can be an alternative form of transport or act as a component of multi-modal trips (DeMaio, 2009). Since the late 1990s, when only a handful of bicycle sharing systems existed, the number of BSS has spread rapidly across the globe, growing to over 1000 active systems in 2016 (Médard de Chardon et al., 2017).

'Starter' cycling cities are cities with low cycling maturity, characterized by a low cycling modal share and limited cycling infrastructure (Félix et al., 2019). In such cities, BSS have the potential to contribute to creating a more cycling-friendly culture, both for transport and for recreation (Nikitas, 2018), by increasing the normality of cycling (Goodman et al., 2014) and by providing access to bicycles, as lack of bicycle ownership is a barrier to cycling (Félix et al., 2019). The main barriers identified for current and potential cyclists in such cities are issues related to actual and perceived road safety and a lack of a safe cycling network, as evidenced by findings from several cities in Southern Europe: in Lisbon, Portugal (Félix et al., 2019), in Limassol (Maas et al., 2019) and Larnaca, Cyprus (Nikolaou et al., 2020), in Drama (Nikitas, 2018) and Rethymno (Crete), Greece (Bakogiannis et al., 2019), in Las Palmas de Gran Canaria (Canary Islands), Spain (Maas et al., 2020) and in Malta (Maas & Attard, 2020).

Even in 'starter' cycling cities, bicycle sharing systems are being introduced. In this research, the focus is on three Southern European island cities, Limassol (Cyprus), Las Palmas de Gran Canaria (LPGC) (Canary Islands, Spain) and the Valletta conurbation (Malta), where BSS have been introduced in recent years. The aim of this research is to

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* Corresponding author.

E-mail addresses: suzanne.maas@um.edu.mt (S. Maas), nikolaou.paraskevas@ucy.ac.cy (P. Nikolaou), maria.attard@um.edu.mt (M. Attard), lucdimit@ucy.ac.cy (L. Dimitriou).

https://doi.org/10.1016/j.retrec.2020.100992
Received 16 July 2020; Received in revised form 16 October 2020; Accepted 16 October 2020

examine how and how much BSS are used in 'starter' cycling cities in Southern Europe, what is the impact of spatial and temporal factors on the cycling trips, and whether the use is characterized by tourist use or by local residents.

The following section provides the literature review and the contribution of this research. Section 3 introduces the case study. The methodology for data collection and analysis is presented in Section 4. In section 5, the results are presented and discussed. Section 6 discusses the results, limitations and further work, as well as the policy recommendations resulting from this research. The final section presents the conclusions.

2. Literature review

2.1. Bicycle sharing systems

BSS can be used by registered members who obtain a subscription on a monthly, semester or yearly basis, and casual users who pay-*as*-you-go (Jain et al., 2018). Third generation bicycle sharing systems, following earlier systems that were freely available or based on coin payments, are characterized by a system comprised of docking stations and bicycles, which can be unlocked using a monitor at the docking station or through a mobile app, with payment linked to the users' credit card (Fishman, 2016). BSS are usually presented as a service that is available to almost anyone, as they are a low-cost type of transport. In most cases, the only limitation for users is the need for a bank or credit card for payment (Beroud & Anaya, 2012), although in some cities the service is only available to residents, barring visitors and tourists from their use, such as in Barcelona (Hampshire & Marla, 2012). The majority of BSS research has focused on the introduction and uptake of BSS in larger cities (e.g. Fishman, 2016), with only limited BSS research taking place in smaller and medium sized cities (Bakogiannis et al., 2019; Caulfield et al., 2017). As distances between origins and destinations are typically shorter in smaller and medium sized cities, BSS can provide a transport alternative complementary to public transport, increasing travel options and promoting cycling for transport (Martin & Shaheen, 2014; Nikitas, 2018).

2.2. Theoretical framework for BSS use

Recent years have seen considerable interest in the use of BSS and the factors that explain shared bicycle use, as cities around the world aim to promote cycling as a mode of transport (e.g. Fishman, 2016; Médard de Chardon et al., 2017). Travel behaviour is affected by multiple levels of factors, including individual, social and spatial factors (Handy et al., 2010; Heinen et al., 2010; van Acker et al., 2010). Together these factors form a socio-ecological model of travel behaviour, which can be applied to cycling and BSS use (see Fig. 1 adapted from Handy et al., 2010). Travelling by bicycle is done for diverse purposes. Cycling for transport refers to cycle trips made for work, education and shopping. However, cycling is not always a means to an end, and is also done for leisure purposes, including cycling for sport, cycling as exercise, and cycling for recreation, including for holiday and tourism purposes (Handy et al., 2014).

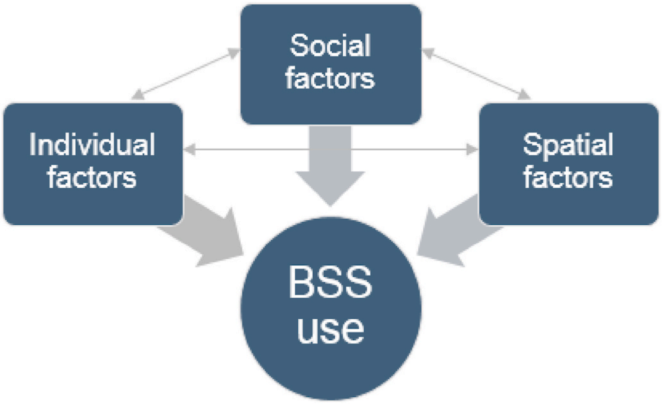

Fig. 1. A socio-ecological model of shared bicycle use (adapted from Handy et al., 2010).

2.3. BSS usage patterns

Only few BSS studies have focused on behaviour by different types of shared bicycle users (Zhang et al., 2016), utilizing usage patterns to try to classify the purpose of the trips. Data from BSS in e.g. Barcelona (Froehlich et al., 2009) and London (Beecham & Wood, 2014) showed that weekday use can be very different from weekend use. O'Brien et al. (2014) classified BSS based on temporal characteristics, aggregating diurnal hourly use to be able to identify dominant usage patterns, such as the 'weekday two peaks' characteristic of BSS dominated by commuter use for transport purposes, 'mainly weekend use' for leisure dominated BSS and 'single peak on all days', for BSS with high tourist usage. To understand and explain variation in system use, i.e. why certain stations and station pairs are more active than others, trips can be classified based on trip type (round trips, single trips), trip duration (short <20 min; longer >20 min) and land use at the station locations, to identify their purpose (e.g. for leisure or for transport) or the spatial and temporal variables influencing their use (Bordagaray et al., 2016; Borgnat et al., 2011; O'Brien et al., 2014).

2.4. Spatio-temporal characteristics of BSS usage

Analysis of spatial and temporal variation in BSS use has shown the influence of land use, socio-economic, network and weather variables. Factors such as the presence of retail and restaurants, cycling infrastructure, parks, university buildings, public transport connections, population density, distance to the city centre/business district, and proximity to other BSS stations have been found to be positively associated with BSS use in different cities in the US and Canada (Buck & Buehler, 2012; Faghih-Imani et al., 2014; Wang et al., 2016). Research in Southern European cities, e.g. in Barcelona and Seville (Faghih-Imani et al., 2017) and Rethymno (Bakogiannis et al., 2019) show that high BSS use is found in areas with a high land use mix, with many points-of-interest (POI), including commercial and recreational activities, as well as places of historic interest. Although many BSS operate in popular tourist destinations, most of the research about their use has focused on the usage by local residents, not by tourists (Kaplan et al., 2015). The influence of points of interest and tourism destinations within a buffer zone around BSS stations have been assessed in case studies of Santander (Bordagaray et al., 2016), Barcelona and Seville (Faghih-Imani et al., 2017) and Melbourne (Jain et al., 2018), but the influence of tourism numbers on BSS use has not been evaluated in such analyses thus far. Socio-demographic and -economic characteristics of the neighbourhoods at the station location, such as age, gender ratio, population density, and level of income and/or education can also influence the usage of the BSS (Faghih-Imani et al., 2017; Rixey, 2013; Wang et al., 2016). Despite the premise of being accessible to (almost) all, evidence from several BSS, e.g. in London, Dublin and Chicago, show that bicycle sharing users tend to be predominantly male, white, with relatively high levels of income and education (Fishman, 2016; Médard de Chardon et al., 2017). Rixey (2013) found that BSS usage was higher in areas with a higher median income. Network variables, the distance between stations and the centre of the system, and the connectivity with other stations, as well as the spatial coverage of the BSS also influence the usage, as bicycle sharing systems are often geographically limited, focused on the city centre and destinations such as university campuses and business districts. Clark & Curl (2016)found that, in Glasgow, only 9% of the population lives within a 400 m radius of a BSS station.

In this research, BSS trip data is used to analyse the usage patterns and understand the influence of spatio-temporal factors, including land use, socio-economic and network variables, as well as temporal variables, such as weather and tourism numbers. This work builds on the body of research described above and addresses the identified research gaps related to BSS use in the context of 'starter' cycling cities in Southern Europe.

3. Case studies

The three Southern European island cities included in this research, Limassol (Cyprus), Las Palmas de Gran Canaria (LPGC) (Canary Islands, Spain) and the Valletta conurbation (Malta), exhibit characteristics considered as barriers to cycling, such as hot summers and high humidity, hilliness and car-oriented culture and infrastructure. Furthermore, cities in Southern Europe, especially those on islands and the coast, need to provide for the seasonal influx of tourists, especially during the summer months, in addition to daily residents' movements for work, education and leisure (Cavallaro et al., 2017). Although cycling modal share is low thus far in the cities (<1%), bicycle sharing systems and policies promoting cycling have emerged in these cities too. Fig. 2 presents the case study cities, showing the BSS stations, cycling paths and land use. Analysing the introduction and usage of BSS in smaller and medium sized cities, in this case in the social and spatial context of 'starter' cycling cities in Southern Europe, can aid in understanding how BSS use and cycling can be promoted in such cities, in light of a broader shift towards sustainable mobility.

Limassol is the second largest city in Cyprus, located on the island's southern coast, with 100,000 inhabitants in Limassol municipality, and around 200,000 inhabitants living in the greater urban conglomeration (CyStat, 2019a). Limassol is home to the largest port in Cyprus, it is one of the main industrial hubs, and it is also a well-known tourist destination. The campus of the Cyprus University of Technology is located in the city centre. IGN, 2018, the modal share by private car was 91.8%, by bus 1.8%, on foot 5.7% and by bicycle 0.7% (PTV, 2019). The (inter)city bus service is currently being upgraded. The majority of tourist arrivals (84%) in Cyprus are between April and October (CyStat, 2019b). The BSS was introduced in Limassol in 2012 and is managed by private operator Nextbike Cyprus, with 170 bicycles and 23 active stations, which are concentrated along the coastal promenade and the city centre. Users can opt for a subscription at €120/year with free 120 daily minutes of use, or use the pay-*as*-you-go rate, which is €2 for the first hour, €1 for every subsequent hour, and capped at €8/day. The existing segregated bicycle paths are primarily found along the promenade from the city centre and Limassol Marina towards the eastern part of the city, where most of the hotels and the touristic zone are located, and the cycling paths along parts of the linear park Garyllis, in a northwest direction from the city centre (see Fig. 2a).

Las Palmas de Gran Canaria is the largest city and capital of Gran Canaria. The city is home to 379,925 inhabitants (INE, 2019). The city has two main city centres: firstly, the area around San Telmo and its bus station and secondly, the area around the Santa Catalina park and bus station. The main port area is located in the northeast of the city. The city has low elevation differences along the coast, but elevation differences of up to 300 m further inland (Ayuntamiento de Las Palmas de Gran Canaria, 2015). The University of Las Palmas de Gran Canaria (ULPGC) is located around 10 km south of the city, in the hills of Tafira. In 2012, the modal share by private car was 63%, by bus 13%, on foot 15% and by bicycle 0.5%. Due to year-round pleasant temperatures, mediated by the Gulf Stream, the majority of tourist arrivals (70%) in Las Palmas de Gran Canaria occur in the winter season, between October and April (ISTAC, 2020). SAGULPA, the municipal company responsible for parking management, introduced the BSS Sítycleta in April 2018, with around 375 bicycles and 37 stations, all located within the lower part of the city. The system is open daily throughout the year from 07:00 until 23:00. There are weekly (€15), monthly (€20), and yearly memberships (€40 for one person, €72 for a two-person membership and €102 for a three-person membership), with daily free 30-min use of the system, and a pay-*as*-you-go rate of €1.50 for every 30 min. The existing cycling infrastructure is mainly found along a main artery in the north of the city and along the eastern coastline. The Bicycle Master Plan (*Plan Director de la Bicicleta*, Estudio Manuel Calvo, 2016) identifies five additional main axes that together will create an integrated bicycle network for the lower part of the city, on which the first works started in summer 2019 (see Fig. 2b).

The Valletta conurbation in Malta refers to the urban area around the capital city Valletta, encompassing the Northern and Southern Harbour districts, which together are home to a population of 205,768 inhabitants (NSO, 2016). The area includes the tourist town of St. Julian's, residential, commercial and employment centres in Msida, Gżira and Sliema and the University of Malta (UoM) in Msida. In 2014, the modal share by private car was 75%, by bus 11%, on foot 7.5% and by bicycle 0.3% (Transport Malta, 2016). The majority of tourist arrivals (73%) in Malta are between April and October (NSO, 2019). In Malta, private operator Nextbike Malta introduced a bicycle sharing system in late 2016, with 60 stations and over 400 bicycles. The majority of the stations are located around the central urban area north of the capital Valletta. There are also some single and small clusters of stations in other parts of the island, for example a cluster of 4 stations around St. Paul's Bay. Pricing is €1.50 for the first half hour, and €1 for every consecutive half hour for pay-*as*-you-go users, in addition to weekly (€15), monthly (€25), quarterly (€35) and yearly (€80) memberships, which include a free first half hour ride. While some cycling paths and lanes are present alongside roads outside of the urban areas in Malta, there is no dedicated cycling infrastructure within the Valletta conurbation, where most of the BSS stations are located (see Fig. 2c; note: some outlying BSS stations are not included in this map).

4. Methodology

Trip and station data are used in this study to analyse and classify BSS usage. The BSS in Limassol, Las Palmas de Gran Canaria and Malta are third generation BSS, which produce different forms of data (Zhang et al., 2016): trip, or flow, data (time varying origin–destination matrices); point, or stock, data (station locations and statuses); and in certain cases, routing data (GPS routes). GPS data is not available for the BSS trips in Limassol, Las Palmas de Gran Canaria, and Malta, and is therefore not considered. Trip data of the three BSS was obtained from the operators, after negotiating and signing a data sharing agreement. Station data was extracted from the BSS operators' websites[1]. The trip data describes the bicycle trips made from origins (O) to destinations (D), including the location of the stations, the date and time when the bicycle was rented and returned, the bicycle number and an anonymised user ID. The datasets used for the analysis in this paper pertain to a one-year period, from April 1, 2018 until March 31, 2019, for the Limassol and Malta datasets. The dataset from Las Palmas de Gran Canaria starts on April 8, 2018, the day the BSS was inaugurated. To prepare the trip data for analysis, entries with a missing origin or destination station, as well as those pertaining to a temporary station or to a station outside of the city were removed. Any trips with a duration under 2 min were removed, as the literature identifies that these are likely the result of a mistake or malfunctioning bicycle (Fishman et al., 2014), as well as trips with a duration of longer than 500 min (Bordagaray et al., 2016). Data cleaning resulted in the removal of 12.3% of the initial 19,991 trips in the Limassol dataset, with 17,532 trips remaining. In Las Palmas de Gran Canaria, 7.8% of the initial 176,731 trips were removed in the data cleaning process, leaving 162,871 trips. Data

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[1] All three BSS are operated by Nextbike or using Nextbike bicycles and software. Station locations were extracted from: https://nextbike.net/maps/nextbike-live.xml

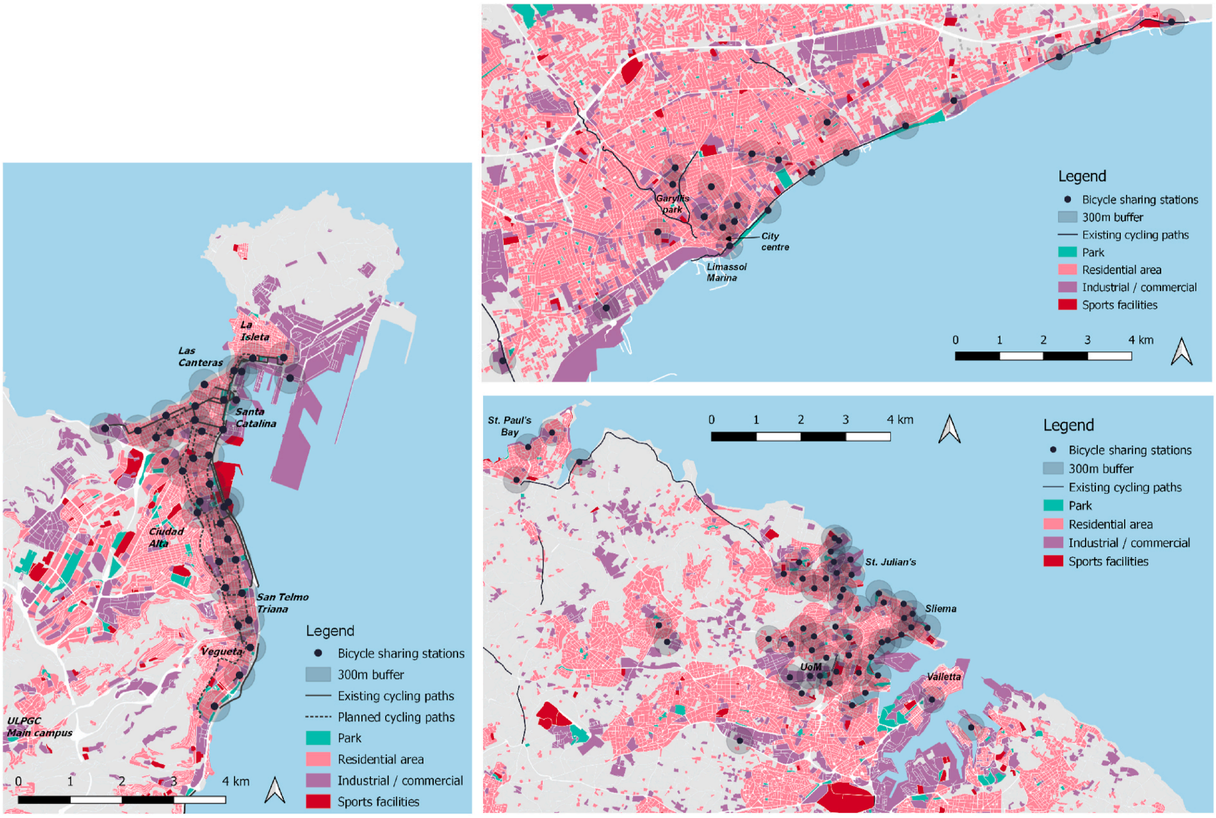


Fig. 2. BSS stations, cycling paths. and land use in the case study cities: a) Limassol (top right), b) Las Palmas de Gran Canaria (left), c) Malta (bottom right).

cleaning saw the removal of 10.7% of the initial 41,763 trips in the Malta dataset, with 37,306 trips remaining.

In order to better understand the BSS usage in the case study cities and what explains the variation in trip types, duration and use of stations, including seasonal influence, trips were classified based on trip type, duration and station location. Round trips, starting and ending at the same station location, are generally considered to be indicative of leisure use (Bordagaray et al., 2016), whereas single trips, between different origins and destinations, are typically understood to be for transport purposes. Trips were also classified based on their duration, with trips under 20 min typically associated with commuting or cycling for transport, whereas longer trips are considered to be for recreational purposes, such as fun or physical exercise (Fishman, 2016). The top flows between origin (O) and destination (D) were identified, so as to find out what characterizes these stations in terms of land use, socio-economic and network variables (see Table 1, described in more detail below). The distribution of typical weekday and weekend temporal patterns was identified through the aggregation of daily frequency distributions, to elicit underlying trends and understand temporal and seasonal variation, including potential influence of increased visitors as a result of seasonal weather and tourism patterns (Bordagaray et al., 2016; Jain et al., 2018).

Land use, socio-economic and network variables were identified through the literature review. Data was collected from secondary sources based on the location of the stations for the three case study cities: Limassol (LIM), Las Palmas de Gran Canaria (LPA) and the Valletta conurbation in Malta (MAL) (see Table 1). Data on land use was extracted from the Copernicus Land Monitoring Service - Urban Atlas (UA) 2012 dataset (EEA, 2018) and the OpenStreetMap (OSM) dataset (OpenStreetMap contributors, 2019). Elevation was extracted from the Digital Terrain Models (DTM) of Cyprus (MOI, 2019), the Canary Islands (IGN, 2018) and Malta (MEPA, 2012). Socio-economic data was obtained for Limassol from the 2011 Population Census with data on neighbourhood level (CyStat, 2012), for Las Palmas de Gran Canaria from statistical data on census tract and neighbourhood level (Ayuntamiento de Las Palmas de Gran Canaria, 2018; INE, 2011; INE, 2016), and for the Valletta conurbation in Malta from the 2011 Population Census and the 2014 Demographic Review at local council level (NSO, 2014; NSO, 2016). The value of a variable (e.g. the population density in the neighbourhood or locality, or the elevation) was determined based on the specific location of a station. For the count of features present (e.g. the count of hotels, cafés, etc.), a 300 m buffer around the station location was used, the most commonly used measure for a walkable distance to BSS stations (e.g. Jain et al., 2018). To understand to what extent the BSS serves the resident population of the cities, population data (per census tract, neighbourhood or locality) were used to calculate the percentage of the city's population living in a 300 m buffer around the BSS stations. In order to determine the high and low tourist season for each of the case studies, data on tourist arrivals and weather were used. Tourism data was collected from the Cyprus national statistical service (CyStat, 2019b) for Limassol, from the statistical institute for the Canary Islands (ISTAC, 2020) for Las Palmas de Gran Canaria, and from the National Statistics Office (NSO, 2019) of Malta.

5. Results

The flows between origin (O) and destination (D) stations in: a) Limassol (n = 17,532), b) Las Palmas de Gran Canaria (n = 162,871), c) Malta (n = 37,306), are visualized in Fig. 3, where the varying thickness of the lines indicates the relative strength of the flow (Leaflet © OSM, Carto). The top 5 OD flows per city are listed in Table 2. In Limassol it is clear the OD flows are very much concentrated along the bicycle path on the promenade. All top 5 OD flows are roundtrips. In Las Palmas de Gran Canaria, the strongest OD flows are related to the city centre in the north of the city, around Santa Catalina park and bus station (LPA Station 29). Although there are also popular stations further south (e.g. LPA Station

Table 1
Land use, socio-economic and network variables.

		Range of values		
Variables	Definition (unit)	LIM	LPA	MAL
Land use variables				
LU_RES	Percentage of residential land use in 300 m buffer (percentage points)	0.06–0.83	0.00–0.81	0.00–0.82
LU_COM	Percentage of commercial/ industrial land use in 300 m buffer (percentage points)	0.00–0.73	0.00–0.73	0.00–0.70
LU_PARK	Percentage of park land use in 300 m buffer (percentage points)	0.00–0.21	0.00–0.28	0.00–0.22
LU_TOUR	Count of hotels/ hostels within 300 m buffer (discrete number)	0–7	0–15	0–17
LU_CAFE	Count of cafés/ bars/restaurants in 300 m buffer (discrete number)	0–28	0–134	0–61
LU_SHOP	Count of clothes shops in 300 m buffer (discrete number)	0–13	0–40	0–11
LU_UNI	Count of university faculty buildings in 300 m buffer (discrete number)	0–9	0–3	0–14
LU_BEACH	Presence of beach/ promenade in 300 m buffer (dummy variable)	0–1	0–1	0–1
LU_BUS	Presence of bus station in 300 m buffer (dummy variable)	0–1	0–1	0–1
LU_CYCLE	Presence of cycling path in 300 m buffer (dummy variable)	0–1	0–1	0–1
LU_NODES	Count of nodes in transport network in 300 m buffer (discrete number)	123–712	114–550	24–634
ELEV	Elevation above sea level at station location (meters)	1.36–22.90	2.25–66.15	0.24–116.65
Socio-economic variables				
POP_DENS	Population density at station location (inhabitants/km^2)	107–7805	372–64,032	394–11,509
PERC_EDU3	Percentage of residents with tertiary education at station location (percentage points)	0.11–0.32	0.02–0.60	0.07–0.14
GEND_RATIO	Percentage of M in M/F ratio at station location (percentage points)	0.82–1.00	0.83–1.00	0.90–1.11
AGING_POP	Percentage of population over 65 years of age at station location (percentage points)	0.08–0.22	0.07–0.25	0.15–0.21
FORGN_POP	Percentage of foreign population at station location (percentage points)	0.12–0.54	0.02–0.22	0.02–0.21
Network variables				
DIST_MEAN	Station distance from centre of the BSS (distance in meters)	98–9878	73–4318	64–13,184
COUNT_STAT	Number of stations in 600 m buffer around station (discrete number)	1–5	2–12	1–9

6, at San Telmo park and bus station), these show more diffuse connections with many other stations and are therefore not in the top 5 OD flows. In Malta, the top 5 OD flows are concentrated in the urban area around the harbour north of the capital city Valletta, which is an area with high population, employment and entertainment density. All stations are close to or on the coastal promenade.

5.1. BSS usage patterns

Round trips, in which the origin of the trip coincides with the destination (O = D), are mainly associated with rides for recreation or for physical exercise (Bordagaray et al., 2016). In Limassol, of the total 17,532 trips, 42% (7288 trips) constitute round trips. In Las Palmas de Gran Canaria, of the total 162,871 trips, only 5% (8611 trips) constitute round trips. In Malta, of the total 37,306 trips, 13% (4698 trips) are round trips. In comparison, Bordagaray et al. (2016) found that around 19% of total trips with the BSS in Santander (Spain) were roundtrips, whereas Caulfield et al. (2017) found that in Cork (Ireland) only 4% of trips constitute round trips.

The aggregated diurnal hourly use, split by weekdays and weekend days, is shown in Fig. 4, allowing the identification of dominant daily usa ge patterns. Limassol's BSS shows a double weekday peak, which is usually indicative of commuting, but here more likely to be related to before and after work exercise and leisure behaviour rather than solely for commuting trips, considering the high incidence of round trips. Weekend use is high, with trips throughout the day, typically related to leisure activities (Fishman, 2016). Las Palmas de Gran Canaria's BSS shows a morning and evening peak, but also high use throughout the day. These observations are concurrent with observations in other Southern European cities, where next to the morning and evening commuting peaks, a lunch hour or afternoon peak can be observed, e.g. in Lyon and Seville (Borgnat et al., 2011; Castillo-Manzano & Sánchez-Braza, 2013). Malta's BSS shows a strong double peak on weekdays, associated with commuting behaviour, as well as some leisure use on weekend days.

Trips can also be classified as being for transport or for leisure based on the trip duration, with trips under 20 min typically associated with cycling for transport, and longer trips with cycling for transport (Fishman, 2016). Table 3 presents the median, mean and standard deviation (SD) of the trip duration in minutes. When comparing the three cities, Las Palmas de Gran Canaria and Malta have shorter median trip durations, in line with average trip duration of 16–22 min observed in BSS in Brisbane, London, Melbourne, Minnesota and Washington D.C. (Fishman, 2016). The higher median and mean trip duration in Limassol indicates more use for leisure. However, the longer trip duration observed in Limassol is also, at least partially, explained by the different pricing structure in Limassol, with a fixed pay-*as*-you-go rate for the first 1 h of use, and the first 2 h free of use for subscription users, as opposed to the more common 30-min flat fee interval (FFI) for casual users, and

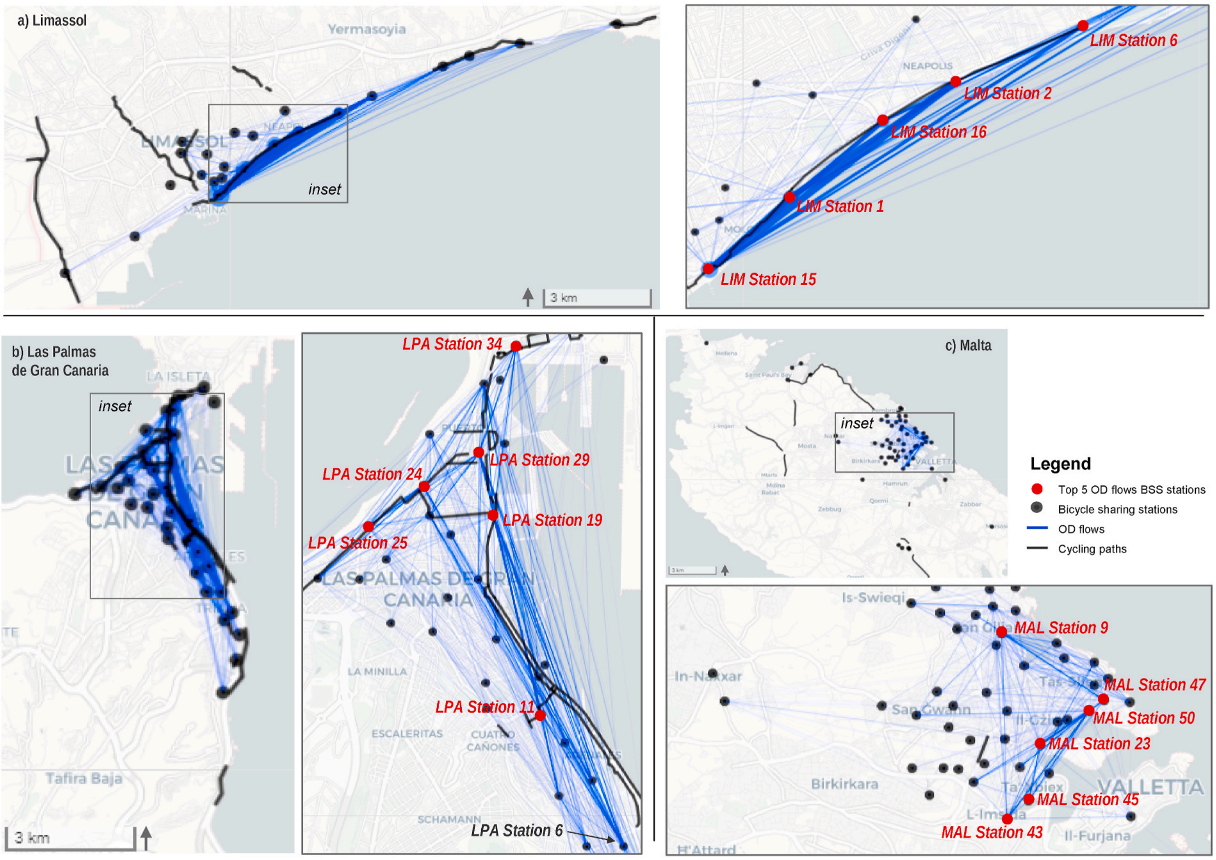


Fig. 3. Top 5 OD flows stations in: a) Limassol, b) Las Palmas de Gran Canaria and c) Malta.

Table 2
Top 5 OD flows in the three case study cities.

	Limassol	Las Palmas de Gran Canaria	Malta
1	LIM Station 15 roundtrip (n = 1503)	LPA Station 24 → LPA station 25 (n = 1475)	MAL station 23 → MAL station 50 (n = 582)
2	LIM Station 1 roundtrip (n = 1294)	LPA station 11 → LPA station 19 (n = 1380)	MAL station 50 → MAL station 23 (n = 416)
3	LIM Station 2 roundtrip (n = 1132)	LPA station 19 → LPA station 11 (n = 1352)	MAL station 45 → MAL station 50 (n = 406)
4	LIM Station 16 roundtrip (n = 827)	LPA station 25 → LPA station 24 (n = 1314)	MAL station 50 → MAL station 43 (n = 375)
5	LIM Station 6 roundtrip (n = 772)	LPA station 29 → LPA station 34 (n = 1147)	MAL station 47 → MAL station 9 (n = 355)

free rental time for subscribed users (Bordagaray et al., 2016).

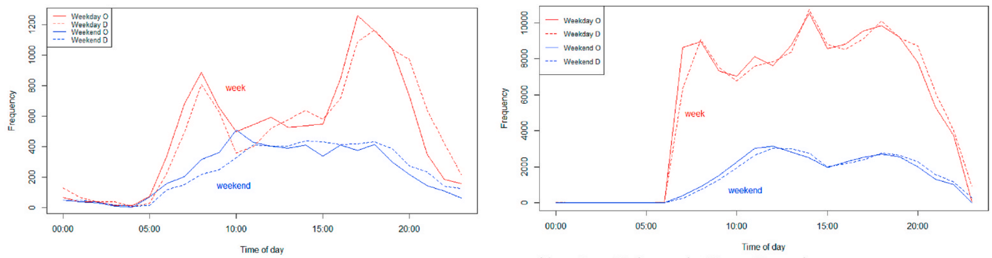
Looking at the distribution of trips and their duration between the high and low seasons, in Limassol, 73% of total trips take place in the high season (April to October). In Las Palmas de Gran Canaria, 61% of total trips take place in the high season (October to April) and in Malta, 74% of total trips take place in the high season (April to October). In none of the cities there is a large difference in the use of the BSS in terms of trip duration between the high and low season; the median trip duration varies by maximum 1 min between different seasons.

In order to understand differences in the frequency and distribution of BSS use in the three cities, patterns in OD matrices are visualized to understand the temporal variation and dynamics of BSS usage. Given the tridimensional structure of these ODs (Origin station; Destination station; Time) the identification of patterns in ODs is challenging. Fig. 5 presents the OD patterns in different timeframes to provide four snapshots of each BSS, at different moments in the day: in the morning, midday, late afternoon and in the evening, to give an indication of their structural difference in the spatial and temporal domains.

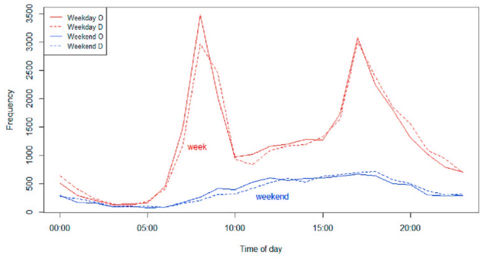
In Limassol, the spatial pattern, primarily between a handful of stations along the coastline, is relatively stable throughout the day, although the intensity of use varies with time, peaking in the period between the middle of the day and late afternoon. In Las Palmas de Gran Canaria, the snapshots give the impression of an all-round intensely used system, with prominent morning peaks, highlighting concentrated usage at specific stations, and more evenly spread use during the afternoon peak. In the evening, use is taking place between a smaller number of stations. Although of a smaller magnitude, in Malta, the effect of morning and afternoon commuting behaviour is visible, with the most prominent peaks in the 07:00 and especially in the 17:00 timeframes. The BSS in Las Palmas de Gran Canaria is the most intensely used, and shows more diffuse use between different stations when compared to the other two BSS.

5.2. *Spatio-temporal characteristics of BSS usage*

To understand what influences the usage of the stations with the most frequent OD flows, Table 4 presents the spatial and social characteristics of the stations identified in the top 5 OD flows. The median value and standard deviation (SD) of the values of all stations per city are also provided for comparison. Almost all stations have relatively high residential land use (LU_RES) and low commercial/industrial (LU_COM) land use. The positive influence of parks (LU_PARK) is primarily clear in Limassol, indicative of leisure use. The presence of cafés and restaurants (LU_CAFE), indicative of entertainment and leisure areas, is important for BSS use in all three cities, although hotels (LU_TOUR) only to a lesser



a) Limassol b) Las Palmas de Gran Canaria



c) Malta

Fig. 4. Temporal daily usage patterns of the BSS in: a) Limassol, b) Las Palmas de Gran Canaria and c) Malta.

Table 3
Descriptive statistics of trip duration (minutes).

	Limassol	LPGC	Malta
Median	39	13	14
Mean	61	19	30
SD*	66.97	29.08	51.11

*SD: standard deviation.

extent; they are not present in all top stations' buffer zones. The influence of the beach or promenade (LU_BEACH) on cycling in these coastal island cities is very evident, as well as the provision of cycling paths (LU_CYCLE). Whereas in Malta there are practically no cycling paths in the urban area where the BSS is present, the other two cities clearly show that all top 5 stations are in close proximity to cycling paths. The presence of public transport connections (LU_BUS) shows importance as an origin in Las Palmas de Gran Canaria (LPA Station 29), and as both origin and destination in Malta (MAL Station 50). In Limassol, none of the top 5 OD flows stations are in the vicinity of the bus station, which can be explained by the very low modal share of public transport in the city. The presence of the university (LU_UNI), a driver of BSS use in other cities (e.g. in Seville; Castillo-Manzano & Sánchez-Braza, 2013), does not show any correlation with the top stations in any of the three case study cities. While the university campus in Las Palmas de Gran Canaria is located outside of the city and the area covered by the BSS, the university campuses in Limassol and Malta are located in the urban area and are connected to the BSS. As all top 5 OD flows stations are located near the coast, the elevation is generally low. In Malta in particular, the elevation of the top stations is notably lower than the median.

In terms of socio-economic variables, the population density (POP_DENS) at the station locations varies. Certain stations have a higher population density than the median, but this is not the case for all stations. There is no clear influence of higher education level (PERC_EDU3), gender ratio (GEND_RATIO), or aging population (AGING_POP) at the station location. The percentage of foreign population (FORGN_POP) at the station location does is significantly higher than the median in all three cities, especially in Limassol. However, this may be (at least partially) confounded by the prominent seaside use of the BSS, which is likely a preferred location for foreign investors and expats.

The importance of network connectivity is evident from the values for the distance to the centre of the BSS (DIST_MEAN) and the count of other BSS stations within a 600 m buffer around the station (COUNT_STAT); in all three cities the top 5 OD flows stations are relatively close to the centre of the BSS and the number of stations is generally higher than the median for that city. The BSS in Las Palmas de Gran Canaria shows the highest compactness and density of all three BSS, as can be seen from the low distance to the centre of the BSS and high number of stations within a buffer, whereas the BSS in Limassol is the most spread out, with a long median distance to the centre of the system and only few stations within other stations' buffer zones.

5.3. Spatial distribution and population coverage of BSS

Buffers of 300 m and 400 m around the station locations were used to calculate what percentage of the cities' population is served by the BSS. In Las Palmas 33% of the city's population lives within a 400 m radius of a BSS station, and 28% live within a 300 m radius of a BSS station. In Limassol, 13% of the city's population lives within a 400 m radius, and 8% in a 300 m radius. In Malta, of the population in the Northern and Southern Harbour districts, 29% living within a 400 m radius of a BSS station, and 22% within a 300 m radius. In Las Palmas de Gran Canaria and the Northern and Southern Harbour districts of Malta, the BSS reaches a much larger portion of the population than in the example for Glasgow, where 9% of population live within a 400 m buffer (Clark & Curl, 2016). However, there are still areas that are not well covered. In Las Palmas de Gran Canaria, there are parts of the city with high population density and low average incomes, in the higher parts of the city, as well as on the peninsula to the north of the city centre around Santa Catalina station, that are currently not served by the BSS. In Malta, the BSS stations are mainly found in the Northern Harbour district, to the north of the capital city Valletta, whereas the other main urban area, the Southern Harbour district is much less covered, with only a few standalone stations. In Limassol, the BSS network is quite linear and spaced out, and very much concentrated along the coastline, therewith not serving the residential neighbourhoods to the north and west of the city centre.

6. Discussion

6.1. Comparative analysis of findings and policy recommendations

While in Las Palmas de Gran Canaria BSS use is more evenly spread over the year and seasonality is less obvious, in Limassol and Malta there

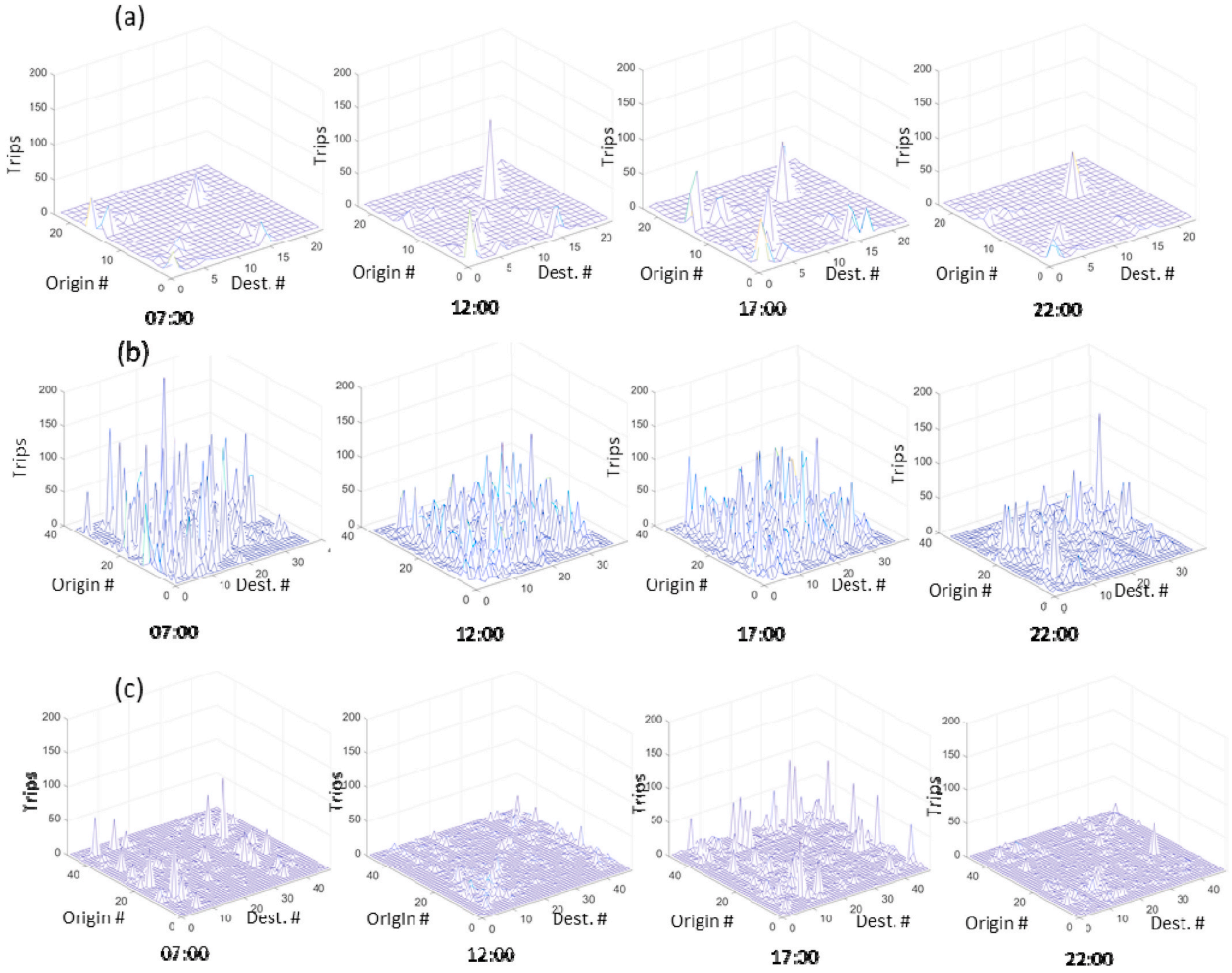


Fig. 5. Origin-Destination 'snapshots' in four time instances in: a) Limassol, b) Las Palmas de Gran Canaria and c) Malta.

is a clear domination of BSS use in the high season, with almost three-quarters of trips. This is however not necessarily due to increased use by tourists, as the temporal daily usage patterns show, but rather by the high season signifying the months characterized by outdoor leisure and exercise, for residents and tourists alike. In all three tourist destinations there is potential to promote BSS use amongst tourists and visitors, for example by direct collaboration and promotion at tourist accommodation and prominent touristic sites, and through the provision of a dedicated subscription option for tourists (e.g. a multi-day or week pass), potentially combined with the public transport smartcard. Tourists may also be more accustomed to using a bicycle or BSS in their own country and can therewith represent an accessible target group that can play a role in inspiring cycling as a mode of transport for local residents (Bakogiannis et al., 2019). As Limassol and Malta both have mild winters, there is opportunity to further promote cycling and BSS use, for transport and for leisure, in the low season months. Special offers could target local residents and the university community, where use is still low, as well as weekends and public holidays, since daylight before and after work hours is limited. In Las Palmas de Gran Canaria, the expansion of the system, and the provision of electric bicycles to neutralize the effect of inclines (Shaheen et al., 2010), can play a role in encouraging uptake among the student population, as the university campus is located relatively far from the city centre, as well as for residents of neighbourhoods located at higher altitudes.

In terms of population coverage, the BSS in Las Palmas de Gran Canaria and Malta reach a much larger portion of the population than in the example of Glasgow, 33% in a 400 m radius around a BSS station in LPGC and 29% in Malta, versus only 9% of the population in Glasgow (Clark & Curl, 2016). In Limassol, the figure is less than in the other two cities included in this study, 13%. This lower percentage is largely due to the fact that the BSS network is linear, following the coastline, and does not serve all of the residential neighbourhoods further inland. Limassol also has a lower population density and is more sprawling in nature, posing challenges for network coverage. Faghih-Imani et al. (2014) recommend to increase density of stations by creating more, small-sized, stations, to create better connectivity between stations and provide more connections between potential origins and destinations, particularly areas with many points-of-interest (POI). There is a clear potential in all cities to extend the BSS into residential neighbourhoods to better serve all of the city's population, not just those with origins or destinations in the city centre or near the seaside. Dedicated outreach to communities not currently served by the BSS, potentially including discounted memberships, could encourage people on lower incomes to use BSS as an affordable mode of transport (Rixey, 2013).

The shorter median trip durations in Las Palmas de Gran Canaria and Malta, as well as the morning and evening peaks in the usage patterns, indicate the predominant use is for transport. However, whereas the OD flows and matrices show that the system in Las Palmas de Gran Canaria

Table 4

Spatial and social variables at locations of stations in the top 5 OD flows.

	LU_RES	LU_COM	LU_PARK	LU_TOUR	LU_CAFE	LU_SHOP	LU_UNI	LU_BEACH	LU_BUS*	LU_CYCLE	LU_NODES	$ELEV$	POP_DENS	$PERC_EDU3$	$GEND_RATIO$	$AGING_POP$	$FORGN_POP$	$DIST-MEAN$	$COUNT_STAT$
Limassol																			
Median BSS stations	0.46	0.16	0.01	1	6	1	–	–	–	–	362	5.70	3866	0.28	0.92	0.16	0.33	2149	1
(SD)	(0.20)	(0.15)	(0.05)	(1.8)	(8.5)	(3.6)					(189)	(6.74)	(2429)	(0.07)	(0.05)	(0.05)	(0.14)	(2457)	(1.4)
LIM Station 1	0.38	0.22	0.17	3	5	0	–	✓	–	✓	297	1.36	4619	0.18	1.00	0.16	0.49	1175	2
LIM Station 2	0.83	0.00	0.01	0	6	3	–	✓	–	✓	176	1.95	7805	0.25	0.95	0.12	0.54	653	1
LIM Station 6	0.44	0.09	0.21	0	4	0	–	✓	–	✓	150	3.55	1871	0.32	0.94	0.08	0.46	1872	1
LIM Station 15	0.42	0.33	0.09	0	26	1	–	✓	–	✓	608	1.44	1583	0.15	0.90	0.19	0.48	2149	3
LIM Station 16	0.43	0.10	0.00	3	21	1	–	✓	–	✓	241	1.97	7805	0.25	0.95	0.12	0.54	98	1
Las Palmas de Gran Canaria																			
Median BSS stations	*0.57*	*0.11*	*0.04*	*0*	*20*	*3*	-	-	-	-	*324*	*6.69*	*13,998*	*0.32*	*0.91*	*0.21*	*0.09*	*1556*	*7*
(SD)	*(0.22)*	*(0.17)*	*(0.06)*	*(3.8)*	*(30.5)*	*(11.7)*					*(111)*	*(12.04)*	*(13,548)*	*(0.13)*	*(0.05)*	*(0.03)*	*(0.06)*	*(979)*	*(2.5)*
LPA Station 11	0.72	0.08	0.03	0	20	5	–	✓	–	✓	296	6.69	27,150	0.25	0.85	0.18	0.09	806	9
LPA Station 19	0.30	0.31	0.04	1	31	13	–	✓	–	✓	324	6.55	5115	0.37	0.87	0.22	0.15	1035	8
LPA Station 24	0.70	0.00	0.01	14	134	14	–	✓	–	✓	484	7.00	38,953	0.25	0.96	0.21	0.22	1511	9
LPA Station 25	0.60	0.08	0.00	4	27	2	–	✓	–	✓	328	6.33	42,845	0.17	0.91	0.20	0.12	1578	8
LPA Station 29	0.45	0.09	0.23	8	70	3	–	✓	✓ (B)	✓	486	4.74	5562	0.36	0.96	0.21	0.22	1602	9
LPA Station 34	0.45	0.23	0.07	4	13	4	–	✓	–	✓	340	2.67	3702	0.14	0.97	0.21	0.07	2510	6
Valletta conurbation, Malta																			
Median BSS stations	*0.53*	*0.13*	*0.01*	*0.5*	*5*	*0*	-	-	-	-	*240*	*19.97*	*4981*	*0.14*	*0.98*	*0.20*	*0.16*	*1683*	*4*
(SD)	*(0.24)*	*(0.16)*	*(0.04)*	*(4.0)*	*(13.5)*	*(1.9)*					*(142)*	*(29.92)*	*(3434)*	*(0.02)*	*(0.06)*	*(0.01)*	*(0.07)*	*(2552)*	*(2.2)*
MAL Station 9	0.68	0.13	0.01	3	29	1	–	✓	–	–	204	2.19	5638	0.14	1.11	0.20	0.18	1225	6
MAL Station 23	0.53	0.19	0.05	3	13	0	–	✓	–	–	340	0.24	7779	0.14	0.98	0.20	0.16	1317	6
MAL Station 43	0.62	0.12	0.01	0	8	0	–	✓	✓ (B)	–	370	0.79	4981	0.14	1.03	0.20	0.17	1750	2
MAL Station 45	0.74	0.00	0.00	0	3	0	–	✓	–	–	382	1.34	5452	0.14	0.94	0.20	0.11	1684	4
MAL Station 47	0.68	0.05	0.01	9	22	6	–	✓	–	–	432	12.1	11,509	0.14	0.93	0.20	0.19	2120	6
MAL Station 50	0.66	0.00	0.01	6	23	7	–	✓	✓ (B,F)	–	368	0.57	11,509	0.14	0.93	0.20	0.19	1891	6

Notes: For definition and units of the variables, see Table 1. SD: standard deviation. *B: bus station; F: ferry landing site.

is used diffusely, with use spread across many stations in the city, use in Malta is more concentrated between a limited number of stations, primarily those in the Northern Harbour area along the promenade. The high share of round trips, the longer median trip duration and higher use throughout the day on both weekdays and weekends in Limassol indicate a system dominated by leisure use. BSS use in Limassol is extremely concentrated on a handful of stations along the bicycle path lining the coastal promenade. The longer trip duration in Limassol is partly due to the different pricing structures, but also to the different nature of the use of the BSS. Leisure use can be a predecessor for cycling for transport, as people feel comfortable riding a bicycle and cycling is normalized (Goodman et al., 2014). Improvements to the connections between public transport and BSS in Limassol, extension and connection of the bicycle infrastructure network, as well as collaborations with employers and the university, could promote cycling for transport (Handy et al., 2014).

The presence of cycling infrastructure, particularly next to the beach or on promenades in these coastal cities, clearly contributes to the use of BSS stations as origins and destinations. The importance of providing a safe cycling network in conjunction to introducing a BSS is clear, for example from the experience in Seville, where the cycling modal share grew impressively after the creation of a connected network of separated bicycle infrastructure and the introduction of a BSS (Castillo-Manzano et al., 2015). The creation of dedicated cycling paths between residential, employment and entertainment areas could further promote cycling and BSS use, especially in the case of Malta, where almost no cycling paths are provided in the urban area. In Limassol, there is opportunity to connect the fragmented sections of cycling infrastructure, along the promenade, as well as the bicycle path along the linear park Garyllis, to start creating a cycling network, connecting different locations within the city with safe cycling infrastructure. The benefits of close collaboration between municipal partners, identified as a good practice in BSS operation by Nikitas (2019), is also shown by the example from Las Palmas de Gran Canaria, which shows promising initial results, with good uptake of the BSS in the first year of operations, while simultaneously improving the cycling network in the city.

The complementary relationship between BSS use and public transport is evident from the popularity of BSS stations in close proximity to bus stations in Las Palmas de Gran Canaria and Malta, and a ferry landing site in the latter. Promoting multimodal travel can provide an efficient alternative to private vehicle use and facilitate growth for cycling modal share and bicycle sharing use, by integrating the BSS with public transport hubs in physical terms, but also through integration of payment options (e.g. in a transport smartcard) and through real-time information provision (Handy et al., 2014; Heinen & Bohte, 2014). In Limassol, public transport modal share is low and analysis of the top 5 BSS flows show no relation between BSS use and public transport hubs. However, the current upgrading and reorganization of the (inter)city bus system provides opportunities for better integration between the bus service and BSS.

6.2. Limitations of the study and future work

Whereas the cities chosen as case studies in this research share a number of characteristics, they of course present their own idiosyncrasies. It is evident from the results that even cities that share similarities are different, with different urban fabric and different usage patterns. While lessons can be learned from the BSS usage in the different cities, the results presented in this paper highlight the importance of local context and how every city requires tailor-made solutions and different treatments. The operators of the BSS analysed in this research are embedded in their local context and are actively collaborating with local stakeholders. Other BSS, especially the wave of dockless bikesharing operators that overtook Europe in the past years, such as Ofo and Mobike, were less successful in creating such local connections and in many cases, have had to withdraw and cease operations (Nikitas, 2019).

This paper presented an initial descriptive analysis of BSS usage and the factors influencing their use. In order to better understand the influence of spatial, social and temporal characteristics on BSS use, further work will focus on a deeper analysis using regression models, to understand in more detail how BSS use is influenced by land use variables, socio-economic characteristics, network variables and temporal variables related to tourism and weather factors.

7. Conclusion

This research presents an analysis of the BSS usage and factors influencing their use in three ‘starter’ cycling cities in Southern Europe. While exhibiting certain barriers to cycling, these cities aim to promote cycling as a mode of transport and bicycle sharing systems have been introduced there. This examination included how and how much BSS are used in these cities, whether their use is characterized by tourist or local resident use and what the impact of spatial and temporal factors is on the OD patterns of cycling trips.

The comparative analysis between the three cities shows that despite sharing commonalities, the cities exhibit differences in their shared bicycle use. The BSS in Limassol is dominated by leisure use, whereas in Las Palmas de Gran Canaria and Malta, use is more related to cycling for transport. Analysis of the spatial coverage of the BSS shows that while currently 13% (Limassol), 29% (Malta) and 33% (Las Palmas de Gran Canaria) of the city’s population lives within a 400 m buffer around a BSS station, there is potential for improvement by targeted system expansion into neighbourhoods not currently served, increasing connections between origins and destinations. The presence of cycling infrastructure, particularly next to the beach or on promenades in these coastal cities, clearly contributes to the use of BSS stations as origins and destinations. There are lessons for promoting both BSS use for transport and for leisure. Investing in connections between the BSS, public transport network and cycling infrastructure can promote cycling for transport, whereas connecting leisure areas, such as beaches, parks and cafés, with cycling infrastructure can promote BSS use for leisure. Specifically targeting tourists as a potential user group, improving the BSS and cycling networks and their integration with public transport hubs, and forging collaborations with local companies, universities and employers, can encourage more BSS use and cycling in ‘starter’ cities such as those included here as case studies.

CRediT authorship contribution statement

Suzanne Maas: Conceptualization, Methodology, Formal analysis, Investigation, Visualization, Writing - original draft. **Paraskevas Nikolaou:** Conceptualization, Methodology, Formal analysis, Software, Investigation, Visualization, Writing - original draft. **Maria Attard:** Supervision, Conceptualization, Writing - original draft. **Loukas Dimitriou:** Supervision, Conceptualization, Methodology, Writing - original draft.

Acknowledgements

The authors have no competing interests to declare. The operators of the BSS in Limassol (Nextbike Cyprus), Las Palmas de Gran Canaria (Sítycleta) and Malta (Nextbike Malta) are gratefully acknowledged for having made the trip data available to us. Work partially supported by the H2020 CIVITAS DESTINATIONS project and an Erasmus + grant.

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