Spatiotemporal objective and subjective factors influencing the usage of hybrid bike-sharing systems

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Introduction

On account of environmental, economic, and social negative impacts caused by urban transportation, actions are required to develop sustainable transportation systems in urban areas, such as, reducing the need to travel by private cars, reducing the trips' length, and shifting trips to active modes [3, 21]. An example of an active transportation mode is bike-sharing systems (BSS).

BSS are defined as the shared use of a bicycle, in which a user can access a fleet of bicycles offered in the public space within a service area [4, 22]. The user has to join an entity that maintains the fleet by usually paying a fee for the usage [20]. BSS can be classified into three categories regarding to the availability of docking stations or not: a) Station-based bike-sharing (SBBS), b) Free-floating bike-sharing (FFBS) and c) hybrid bike-sharing (HBS), which is a mix of station-based and free-floating [10]. In contrast with SBBS, FFBS avoids the cost of docking stations. Thanks to their installed GPS, this transportation system can be tracked in real time allowing smart management and reduced probabilities of bicycles theft. Mostly, FFBS is more convenient for users than SSBS because the average walking distance to their destination is shorter and they do not have to worry about the bike's storage in a docking station [19]. In contrast, HBS has the advantages of SBBS and FFBS together.

BSS are wide–spreading in more than 1,940 operating systems around the world (including SBBS, FFBS, HBS, and electric bikes) [16]. The widespread and growing trend of BSS can be associated with positive impacts such as "increased mobility, reduced greenhouse gas emissions, decreased automobile use, economic development, and health benefits" [5]. However, not all BSS have been deploying successfully. Some of them have been misused, vandalized and perceived as a public nuisance [12]. Historical reasons for a system failure were bicycles' poor quality, lack of funding, over–saturated market, delayed expansion, inconvenient system design, oversupply, unfair fares, low political support, among others [12, 17].

Commonly, to plan or expand BSS, the first stage is to estimate the potential demand. Therefore, the factors affecting the historical usage of BSS are identified and understood by learning them from historical trips. A categorization of spatial factors is objective and subjective. Objective factors are those that we can perceive with the senses (e.g. roadways length), while subjective factors are those that have to be asked to people in order to know them (e.g. social status of a person). Both objective and subjective factors and their interaction between each other will help us to understand and to identify a possible influence on mobility behavior and thus on a mobility culture.

Mobility cultures is a theoretical framework that integrates subjective and objective factors. They are defined as socio-cultural settings consisting of material and social dimensions of a transportation system, including mobility behavior, policy making, and governance, perceptions and lifestyle orientations, spatial structure and transport supply [6, 14, 13, 15]. Mobility culture framework also serves for analyzing the current and estimated behavior of a transportation system, because it integrates objective and subjective elements on a spatial-level [14], i.e. this concept can be used to understand the mobility behavior of a transportation system between different spatial regions beyond the infrastructure of a transportation system, including a wider set of norms, values, beliefs and meanings [13].

According to the most midterm influencing factors found in related work and design guidelines (see Table 1), they can be classified mainly in six components: 1) social environment, 2) mobility behavior, 3) political regulations 4) built environment, 5) user's preferences and 6) the BSS design itself. Previous work dealing with georeferenced (low scale) factors include mostly demography, the built environment and elements of the design of BSS (e.g., stations density). The main factors of the built environment are represented by the transport infrastructure, points of interest (POIs) and the urban structure.

To the best of the author's knowledge, these studies do not contemplate:

- Hybrid bike-sharing systems. To the best of the author knowledge, just few studies consider HBS.
- Trip-related spatial factors. Regularly the spatial factors are considered in the origin and destination of trips, however spatial factor during the trips are rarely considered.
- Georeferenced factors including political regulations or decisions, mobility behavior, social media use, and lifestyle milieus have not been considered. In other words, factor analysis beyond the regularly used built environment factors (e.g. built environment) and socio-demographics by including in the analysis georeferenced (low scale) subjective factors (e.g., lifestyles milieus, social media use, or political regulations). In order to promote BSS, mobility must no longer be considered a simple part of transport planning but as a part of a culture [15]. Due to BSS being part of a mobility culture, potential subjective factors such as preferences, lifestyle orientations, communications, and political regulations should be analyzed.

Research objectives

The delayed expansion, and the need to continue expanding active modes as HBS makes it imperative to understand how HBS work and to improve their design. The purposed research contributes by enhancing HBS's design by mitigating the system's drawback related to the "*inconvenient system design*". Specifically, we want to improve the understanding of the objective and subjective influencing factors on the usage of HBS.

Therefore, the main objective of the study is to identify the most influencing spatiotemporal objective and subjective factors on the usage of HBS. This research explores the question: Which objective and subjective factors influence spatiotemporally the usage of HBS?

Methodological approach

A three-steps methodology is proposed (see Figure 1) to meet the main objective, which includes: a) data collection, b) data analytics, and c) factor analysis and model building.

The data collected are objective and subjective factors (independent variables) (see Figure 2) and the historical HBS trips (dependent variable). The historical trips (OD-matrix between stations) act in the model building as dependent variables. Trips are aggregated in zones of influence of stations (maximum walking area that a user is willing to walk to rent a bike). To consider the temporal influence, OD matrix is differentiated in 6 day-time intervals: peaks and off peaks periods during the morning, afternoon and night.

According to the independent variables, in the study are consider two types: origin and destination-related and shortest path-related. The independent variables related to the origin and destination are based on objective and subjective included as actors in the concept of mobility culture (see Figure 2). Indicators of the different variables (e.g., proximity, density, entropy, weighted average) depend on the type and they are calculated in the zone of influence of the stations. Shortest path-related spatial variables are related to the accessibility between stations by different transport modes (considering travel time, distance, cost, and average slope), modal split, cycling infrastructure, number of roads intersections, level of service of roads and traffic counts.

Table 1: Example of influencing factors on bike-sharing usage

Factors			**Guideline**				**No georeferenced data studies**		**Georeferenced data studies**			
			[1]	[11]	[4]	[22]	[7]	[2]	[23]	[9]	[8]	[18]
Social environment	**Demography**	City population	✓	✓	✓				✓			
		Population density	✓	✓		✓				✓	✓	
		Employment density				✓			✓		✓	
	Socio-Demography	Age					✓	✓				
		Gender						✓		✓		
		Household income					✓	✓				
		Household size					✓			✓		
		Education level					✓					
Mobility Behaivor	Mode to commute (work/school)		✓		✓		✓					
	Time / distance to commute						✓					
	Bicycle ownership							✓				
	Cycling propose							✓				
	Driver license ownership							✓				
	Already combine cycling and PT							✓				
Political regulations	**Trans. Reg.**	Traffic calm zones	✓									
	Safety	Bicycle thefts						✓				
Built environment	**Topography**	Slope (max 4%)	✓			✓						
		Altitude							✓	✓		
	Urban Structure	Distance to city center	✓	✓				✓			✓	
		Accessibility		✓	✓			✓				
		Mixed use land use	✓	✓								✓
		Industrial land use		✓								
		Single land use		✓								
		Residential land use										✓
		Commercial activity				✓						
	Transport infrastructure	PT stops	✓	✓	✓	✓						
		Metro									✓	✓
		Railway station							✓			
		Major roads									✓	
		Streets									✓	
		Enbankment road							✓			
		Transport POIs								✓		
		Cycling infrastructure	✓	✓	✓	✓					✓	
	POIs	Student residence							✓			
		Cinema							✓			
		Worship POIs								✓		
		Hotel								✓		
		Restaurant							✓	✓	✓	
		Universities	✓			✓					✓	
		Parks		✓								
		Sports Centers	✓									
		Recreation POIs								✓		
		Tourist attractions				✓						
Preferences	Environmental consciousness						✓					
Design	Capacity		✓	✓	✓	✓			✓	✓	✓	✓
	Density		✓	✓	✓	✓			✓	✓	✓	

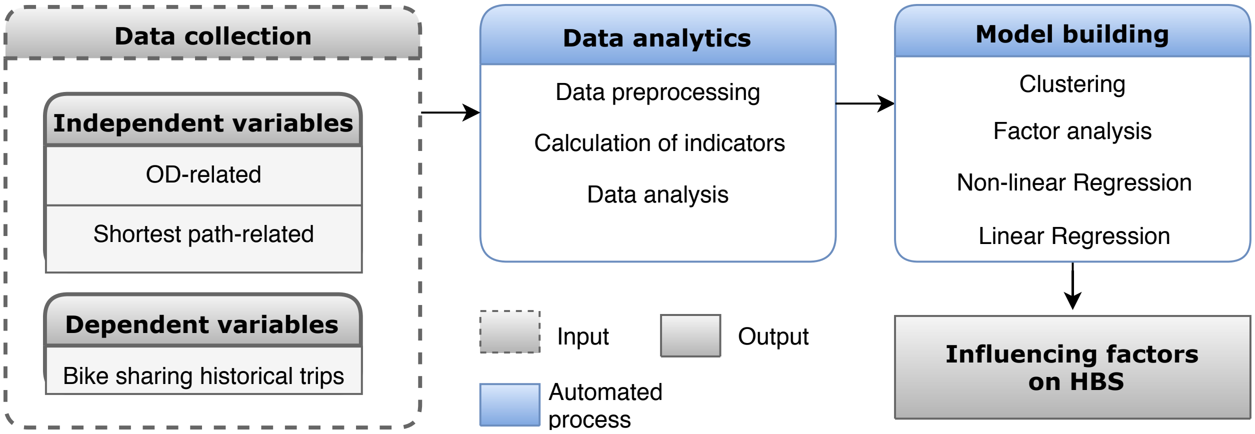

Figure 1: Methodology overview

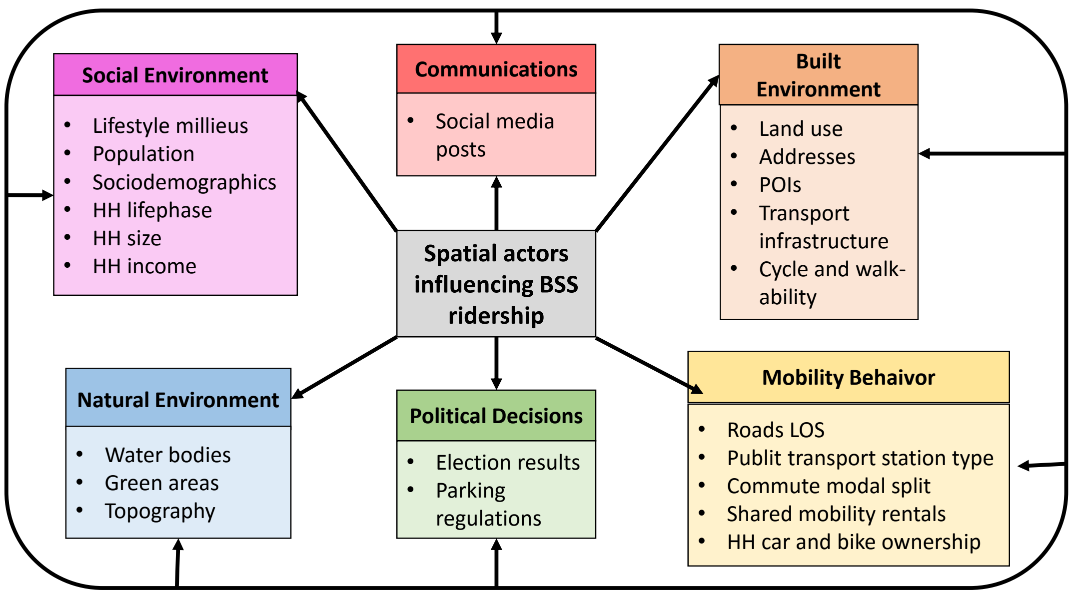

Figure 2: Potential OD-related objective and subjective factors

Finally, the model building estimates the number of trips between stations based on spatial variables (i.e., forecasts the OD matrix) per each time interval considering the season, day of the week (workday or weekend) and time of the day (morning, afternoon, night on peak and off-peak hours). Linear and non-linear regression techniques are tested to choose the technique that fits better the data (precise mode) and selects the fewest number of variables (simple model).

As a case study, a HBS system in Munich was selected due to its high performance and because HBS systems have not been deeply studied to the best of the author's knowledge.

Expected Outcome

The expected outcome is a potential demand model and a list of recurring spatiotemporal objective and subjective factors that influence the usage of HBS using OD and shortest path-related variables. Thre identification of spatial objective and subjective factors correlated to the usage or not of HBS will help:

- To assist operators and policymakers on their deployment of HBS.
- To increase the reliability of implementations and policies.
- To reduce the risk of supply-demand imbalance in existing systems.
- To understand BSS beyond the traditionally built environment perspective and include also subjective spatial factors.

The proposed methodology is not suitable to: a) assess if the implementation/expansion of a HBS is going to be successful or not, b) carry out a short-term forecast of rentals, c) forecast every possible trip purpose. The method learns from historical trips of HBS and searches for potential objective and subjective influencing factors. The method can be applicable to identify a pattern that looks for a potential optimal location of stations and boundaries of the service area.

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