Asia Pacific Journal of Information Systems
Vol. 29 No. 3 (September 2019), 414-427

ISSN 2288-5404 (Print) / ISSN 2288-6818 (Online)
https://doi.org/10.14329/apjis.2019.29.3.414

Special Issue on Smart Services and Internet of Things

Riding a Bike Not Owned by Me in Bad Air: Big Data Analysis on Bike Sharing

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ABSTRACT

The sharing economy has significantly changed the way of living for years. The emergence and expansion of sharing economy empowered by the mobile information technologies and intellectual algorithms reconfigure how people use transportation means. In this paper, the bike sharing phenomenon is highlighted. Combining a big data set provided by the Seoul government about user logs and air quality data set, the empirical findings reveal that temperature change is tightly associated bike sharing activities. Also, the concentration of particulate matter is weakly related to bike sharing, but the trend should be carefully examined. By considering external environmental factors to bike sharing businesses, this work is differentiated. To further understand empirical data, data mining methods and econometric approaches were adopted.

Keywords: Sharing Economy, Big Data Analysis, Air Quality, Bike Sharing

Ⅰ. Introduction

To own or not to own, that is the problem. We have witnessed that new businesses emerge from collective peer-to-peer platforms, known as “Sharing Economy.” In this new world, people make use of under-utilized things through information systems intermediating sellers and buyers intelligently (Schor, 2016). People have so far adopted sharing economy business models seemingly enthusiastically such Uber, Lyft, Airbnb, Ola, Careem and DiDi to name a few.

We should note that mobile information technologies become engines that boost up sharing economy by helping people search and buying various services at anytime and anywhere (Zervas et al., 2017). For example, the Uber app easily connects a driver who wants to share his or her car to provide a ride with a potential rider who needs to travel. Every detail required to complete this transportation transaction, including identification, geo-information exchange and payment, is autonomously handled by

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functional cloud-based information systems and mobile internet devices. It is true that the notion of sharing economy is not new (Bardhi and Eckhardt, 2012). More meaningful and impressive fact is that convenient and intellectual ICT artifacts make this concept a real (Matzler et al., 2015; Rosenberg, 2013).

There are various businesses based on the sharing economy idea. Among them, one of the most active and popular models is probably a bike sharing service (Ricci, 2015). Sharing economy is particularly interesting in developed cities where transportation demand is expanding rapidly (Campbell et al., 2016). Cohen and Kietzmann (2014) discussed the importance of cooperation between service providers and the local government in bike sharing businesses. Möhlmann (2015) indicated that utility perception and cost savings would be key success factors in the sharing economy like bike sharing and car sharing. Shaheen and Chan (2016) also insisted that shared mobility would supplement existing public transportation means with reducing greenhouse gas. In line with Greenblatt and Shaheen (2015), innovative companies and researchers emphasize that electric-powered personal mobility in the form of the sharing economy has potential to alleviate the problem of greenhouse gas emission.

Although the stream of research about the sharing economy has documented beneficial knowledge on theoretical or/and empirical work for better business design, issues relating to bike sharing are not rooted in its characteristics. First, riding bike is affected by environmental conditions a lot. If it rains, road conditions become unfriendly. If air quality is bad, riders will suffer from undesirable symptoms. Those kinds of external and environmental events should be carefully examined and considered in understanding bike sharing businesses. In this paper, big data collected from a city bike sharing program run by a metropolitan government to expand our knowledge on relationships between air quality and bike sharing. Especially, the paper focuses on the effect of the concentration of particulate matter on bike sharing frequencies and riding distances. This paper adopts a cross-industry standard process for data mining (CRISP-DM, in short) approach, which is consists of business understanding, data understanding, data preparation, modeling, evaluation and deployment (Chapman et al., 2000; Vorhies, 2016).

The question to be answered through this process is, “How does air quality differentiate bike sharing preference patterns?” Understanding this aspect is important since many public bike sharing stations are managed by local governments that should pursuit both public health improvement and frequent usage of bike sharing services. It should be noted that people can access weather condition and air quality information conveniently by using a mobile app, which means bike sharing service has a chance to be significantly affected by judgment to negative assessment to those (Campbell et al., 2016).

In the following sections, research background is introduced with discussions. Based on the common ground, sources of big data and descriptive analysis results are explained. Subsequently, multivariate regression findings are documented and discussed. The paper will conclude with remaining issues and future directions.

Ⅱ. Research Background

Data-driven decision making becomes one of key strategy formation in modern organizaitons (Provost and Fawcett, 2013). Reserach based on data mining results has provided insights to business practitioners in creating competitive advantages; however, the lack of systematic approach to new knowledge discovery may hamper the accumulation of academic efforts (Sharma et al., 2012). To fill this gap, in this paper, the CRISP-DM guideline is applied, which is a step-by-step approach to delive insights from data analytics. As the first step, in this section, we are going to discuss what bike sharing business is about and how air quality information influences.

2.1. Sharing Economy

The term "Sharing Economy" appeared in 2008 denotes the collaborative consumption by sharing or exchanging resources without owning the goods (Lessig, 2008). In the view of business, the concept is describing a process of producing service benefits coordinated through community- or intermediary-based information systems in C2C transactions (Hamari et al., 2016). The principle of the sharing economy per se is not new. Sharing resources is known in business-to-business (B2B) domains including the sharing of machinery in agriculture and forestry, car rental, public libraries and self-service in laundry and parking in a broad term. Truly, a proliferation to consumer-to-consumer (C2C) transactions is new.

According to Botsman and Rogers (2010), there exists three types of sharing economy as listing: (1) the product-service system, (2) redistribution markets, and (3) the collaborative lifestyle. First, a company owns products, and members who are pays for service fee can temporarily have a right to use a product in the umbrella of the product-service system. Although consumers are not obligated to own the goods, they are considered to have temporary ownership during the term of the contract. Redistribution markets are related to on-demand services including private selling and buying of products and services at online market platforms. In this case, mutual benefits by transferring ownership becomes a key motivation.

Collaborative lifestyle is positioned in a primary method of sharing economy in the era of the mobile internet. It should be noted that the collaborative lifestyle became more popular as the owner of the original product could position in an active service provider by easily accessing demand information. For example, if a car owner can identify in real time a passenger who wants to go in the same direction the driver is currently heading, he or she can easily be repositioned as a transport service provider who can make money by sharing the car.

Distributing information cheaply and constantly is a key activity in the sharing economy (Hamari et al., 2016). It should be carefully noted that the sharing economy requires the separation of ownership, which put real costs to the owner. If someone, for example, shares a car, he or she must sacrifice the freedom to use it temporarily. Unclear benefits from abandoning ownership makes it difficult to participate in the sharing economy. Thus, the company of providing sharing economy service needs to constantly provide information about possible demand via information and communication technologies with low cost (Luchs et al., 2011). In this sense, a mobile device and the mobile internet infrastructure play an import role to distribute real time information for both demand and supply.

2.2. Bike Sharing Service

Reducing greenhouse gas becomes a real and serious problem. According to Paris Agreement in December 2015 to solve this issue, not only international cooperation but also persistent efforts in local are needed. Nations that have agreed to the protocol have a duty to reduce carbon emissions by means of addressing climate change and sustainable growth. Reducing greenhouse gases means huge changes in domestic industries that are mainly based on energy from fossil fuel. Since modern transportation is also likely to count on fossil fuel, following the agreement heralds a big impact on public commute in daily life.

Bike sharing is recognized as a useful means of dealing with greenhouse gas. The original idea of sharing bikes has a historical root of White Bikes, the first-generation bike sharing program in 1965. Although things did not go well as planned in Amsterdam, this initiative evoked the other trial in 1993 in Denmark. This small bike sharing program collapsed without impact, and Bycyklen, a city bike sharing program in Copenhagen, was launched in 1995. The Copenhagen bikes introduced customer-oriented features for improving continence. In line with this, Bikeabout in England and Vélib in France were introduced. A huge leap in bike sharing was observed in China around year 2016. The number of bike sharing subscribers was around 15 million in the late 2016, and the number was doubled in a year.

In the 2016 annual report of customer survey, Capital Bikeshare located in Washington, DC, the U.S., reported that 71% of respondents used the bike sharing service to access other transportation mode, and 65% of them said that bike sharing was an important means of commuting to work (CapitalBikeshare, 2016).

Although the research stream of sharing economy relating to bike-sharing is in the early stage, there are interesting and important studies that inform us key aspects of the success of bike sharing businesses. For example, Campbell et al. (2016) tried to uncover factors influencing the decision making to turn from an existing transportation mode to bike-share or e-bike sharing in Beijing. They found that trip distance, temperature, precipitation and poor air quality would be negatively associated with demand. In line with Campbell et al. (2016), Faghih-Imani and Eluru (2015) insisted that various external factors would influence demand. Based on data from Chicago's Divvy bike sharing system, Faghih-Imani and Eluru (2015) found that membership types would differentiate the destination preferences of bike sharing customers. User motivation to choose bike sharing service is one of important topics. Fishman et al. (2014) found that relatively less accessible public transportation opportunities would increase the motivation of adopting bike sharing services. Interestingly, Fishman (2016) noted that not only bike sharing was likely to be associated with daily commute, but also it could be a utility service for tourists. Since customers may perceive various different benefits from bike sharing, the service provider of bike sharing needs to consider effective promotion channels based on preferences and purposes (Ricci, 2015; Vogel et al., 2014; Zhang et al., 2014). Generally, studies on bike sharing show that data analytic is a key to find preference patterns for customers in different conditions.

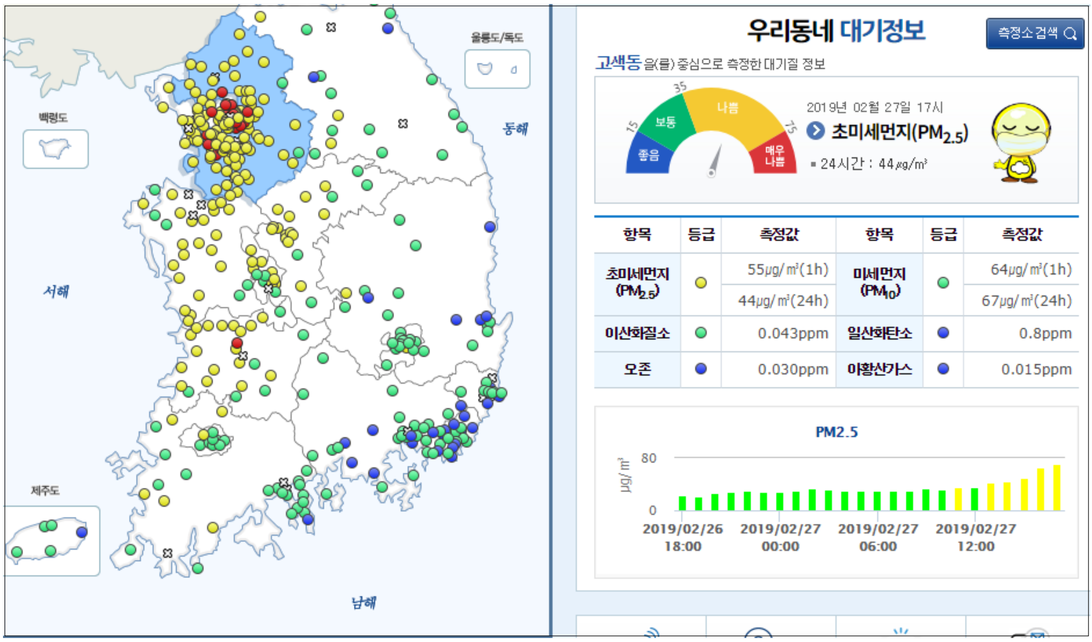
2.3. Air Quality Issue in Korea

South Korea is the fast-grown country based on rapid industrialization since 1970s. Unfortunately, it is true that the country has not pursued a balance view between growth and environmental soundness at the same time. In 1980s, smog in cities became a real problem in Korea due to the rapid increase of automobiles. Since 1996, the environment information agency of the government has distributed measured numbers about air pollution to public.

Recently, key pollution factors are summarized by air quality indices including particulate matter 10 micro meters (PM_{10}, in short) and $PM_{2.5}$. Airborne particulate matter has potential negative effects on human health including cardiovascular disorder, cerebral infraction, asthma attack and orthostatic dyspnea due to its size and particle compositions (Davidson et al., 2005).

The Ministry of Environment in South Korea predicts the status of particulate matter pollution four times a day to inform citizens about risks of doing outdoor activities. In the case of $PM_{2.5}$, the government classifies status into four: Good (0 ~ 15), Ordinary (16 ~ 35), Bad (36 ~ 75) and Very Bad (over 76). According to the criteria, only 210 days (57.5%) were Ordinary in 2017. 96 days (26.3%) were classified by Good, and 59 days (16.2%) were Bad or worse.

It should be noted that bike sharing is a kind of outdoor activities. Unlike usual vehicles, bike riders are directly exposed to the outside environment. Especially, if the service mainly targets to city residents, the degree of air pollution can influence the intention of riding a bike. On the other hand, we need to note that bike sharing is becoming one of important means of commuting to work. In this case, the impact of air pollution on the use of shared bicycles may be limited, unless it is in bad weather, such as rain or snow. To date, information system research communities have not published empirical results on the relationship between bike sharing and air quality with analyzing big data. Knowledge about sharing economy should be accumulated increasingly since emerging technologies have been adopted to create new businesses based on this new concept. The limit understanding to the exemplar case of sharing economy in the transportation area is likely to develop better management theories for policy makers and entrepreneurs.



<Figure 1> Air Pollution Information System in South Korea (https://www.airkorea.or.kr)

Ⅲ. Big Data Analysis and Result

As the second step of CRIPS-DM, data preparation and data inspection are going to be discussed in this section. China and Korea have been in conflict for years because of the cross-border influence of air quality. Key debates have been formed surrounding the transition of particulate matter or fine dust, wherether or not Korean air quality is really affected by Chinese facilities and cities. Although there are more scientific issues to be clarified, it is apparent that both China and Korea need to address the air quality problem relating to fine dust. Like bike sharing service, information technology plays a key role for decision making in this case; namely, jusk like people use a smartphone for renting a bicycle, information about air quality can be easily obtained via the smartphone at any time. The use patterns of bicycles are also logged in datawarehouses. By combining both big data sources from the Department of Environment and the Seoul Metropolitan Government, we can investigate associations between bike sharing patterns and air quality.

3.1. Big Data Source

This study adopted a data set provided by Seoul Metropolitan Government. Seoul, the capital city of South Korea, has collected big data for improving public service quality including public health, government administration, travel, industry and transportation to name a few. Among those kinds of open datasets, bike sharing service for citizen, also known as '*Tha-Rung-Yi*,' was focused. As shown in <Figure 2>, this bike sharing service is run by the city government. The city government owns all the bikes, and people who want to ride can use this service by a mobile app. Like Uber, City Bike, Mobike and Ofo, Tha-Rung-Yi is a typical sharing economy example to solve traffic issues in a big city.

The big data set provided by the Seoul government consists of individual log records about bike use. Each item includes information on rider's characteristics except personal identification, location of bike, total distance, riding duration, reduced CO_2 by riding, consumed calories and so on.

To understand the influence of air quality to bike riding, two additional big data repositories were used. First, air quality data were queried to get daily information regard to the concentration of particulate matter. Two different measurement items were focused in this study: PM_{10} and $PM_{2.5}$. As shown <Table 1>, all the data sources are open to public so that researchers can easily access big data repositories.

<Figure 2> Bike Sharing Service in Seoul (source: Yonhap News 2016 ~ 2018)

<Table 1> Data Sources and Descriptions

Source	Category	Row Count	Description
Seoul Open Data Plaza	Bike sharing	3,301,404	An open data access system for searching and querying big data administered by the Seoul government
Air Quality Database of the Ministry of Environment	Air quality	26,682	A website where people get information about air quality in Korea
The Korean Meteorological Administration Open Data	Weather	786	A public data repository where researchers can search and download various weather-related metrics

In this study, different data sets were merged based on time stamp data that sorted by day.

3.2. Descriptive Analysis

<Table 2> and <Table 3> summarize data used in this study. First, bike sharing data from Tha-Rung-Yi use contains key items about daily use count. Because riders must access the bike sharing information systems, all use records are kept regardless of regular membership. Users of the system can choose different options: regular use for all day (65.19%), regular use for one day (24.40%), regular use for 2 hours (2.12%), temporary use for one day (5.96%), temporary use for 2 hours (1.39%) and special group use (for exceptional cases, 0.94%). Those riders consist of 55.57% of male and 44.43% of female, and the majority was range from 23 to 49 years old. The total amount of reduced Carbon dioxide in the data was measured at 8,045,821 kilograms in sum. If we assume that an eco-friendly vehicle emits 97 gram per kilometer, the use of bike sharing yields to about 82,947 kilometers with zero CO_2 emission.

As shown in <Table 3>, the air quality of South Korea was not good. The average of PM_{10} was 44.184, which is slightly over by the European Union safe guideline. The number is twice than the WHO guideline. However, other air quality measurements such as NO_2, Ozon and SO_2 were near satisfiable guidelines recommended by both the Korean government and EU. Thus, in this study, the concentration of particulate matter was mainly focused for more parsimonious econometric modeling.

In the analysis of correlations regarding use frequency, air quality measurements were negatively correlated with the number of bike riding except Ozon. As show in <Table 4>, temperature is highly

<Table 2> Descriptive Statistics on Tha-Rung-Yi Data

Variable Name	Description (unit)	Mean	Std.
Age	Bike riders' age (year)	35.98	12.91
Gender	Bike riders' gender, 55.57 % of male and 44.43 % of female		
Experience	Experiences of riders on Tha-Rung-Yi (count)	2.61	3.10
Exercise	Calories consumed by riding (Calorie)	953.56	2,246
Reduced CO_2	CO_2 reduced by riding (kilogram)	2.44	4.06
Riding distance	Riding distance (meter)	10,504	17,479
Riding time	Riding time (minute)	75.04	127.12
Data collection	Data time range from 1 Jan. 2017 to 30 Jun. 2018		

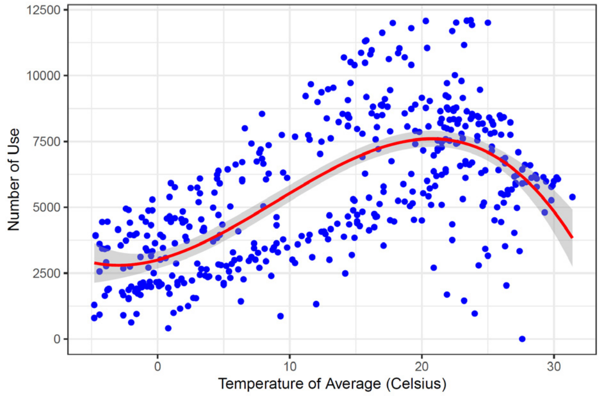
<Table 3> Descriptive Statistics on Air Quality and Weather Data

Variable Name	Description (unit)	Mean	Std.
NO_2	The concentration of nitrogen dioxide (ppm)	0.033	0.015
Ozon	The concentration of Ozon (ppm)	0.021	0.012
CO_2	The concentration of carbon dioxide (ppm)	0.553	0.220
SO_2	The concentration of sulfur dioxide (ppm)	0.005	0.002
PM_{10}	The concentration of particulate matter 10 (㎍/㎥)	44.184	24.345
$PM_{2.5}$	The concentration of particulate matter 2.5 (㎍/㎥)	24.308	15.169
Station count	The number of data collection stations in Seoul: 46		
Data collection	Data time range from 1 Jan. 2017 to 30 Jun. 2018		

<Table 4> Correlations (Number of Count, Weather and Air Quality)

	BS	_W1	W2	A1	A2	A3	A4	P1	P2
BS: Number of Count	1								
W1: Temperature (℃)	0.63***	1							
W2: Rain (mm)	-0.18***	0.19***	1						
A1: NO2 (ppm)	-0.12**	-0.17***	-0.17***	1					
A2: Ozon (ppm)	0.39***	0.52	-0.04***	-0.41***	1				
A3: CO2 (ppm)	-0.27***	-0.37***	-0.15***	0.86***	-0.53***	1			
A4: SO2 (ppm)	-0.31***	-0.34***	-0.2***	0.7***	-0.2***	0.69***	1		
P1: PM10 (㎍/㎥)	-0.18***	-0.17***	-0.17***	0.56	0.03***	0.59***	0.66***	1	
P2: PM2.5 (㎍/㎥)	-0.2***	-0.17***	-0.11***	0.69*	-0.11***	0.78***	0.66***	0.81***	1

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$



<Figure 3> Non-linear Relationship between Temperature and Rental Counts

correlated with use count (p-value < 0.001).

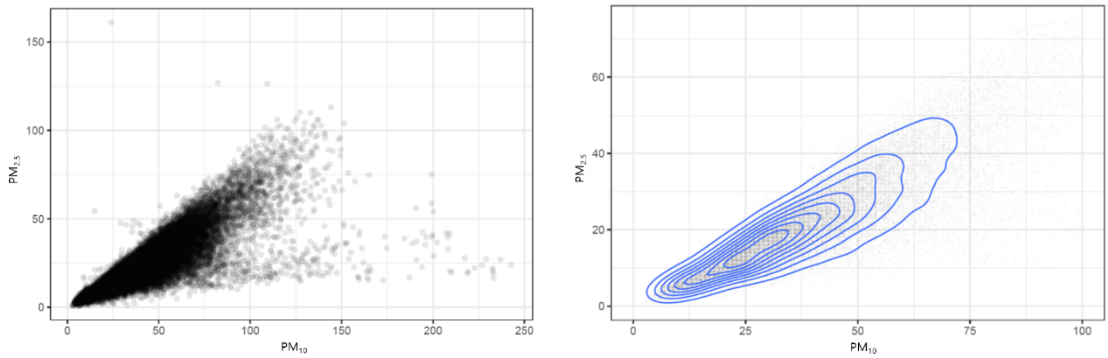
As shown in <Figure 3>, temperature regresses to bike sharing use in a quadratic form. When the temperature rises, the number of use increases; however, over 25 Celsius, the trend turns to negative direction (Adjusted R^2 = 42.59%, F-statistics: 182, p-value < 0.001).

3.3. Effects of the Concentration of PM on Bike Sharing

The main question in this paper is that how air quality information influences biks sharing pattern. According to CRISP-DM, data analysis and findings are discussed in this section.

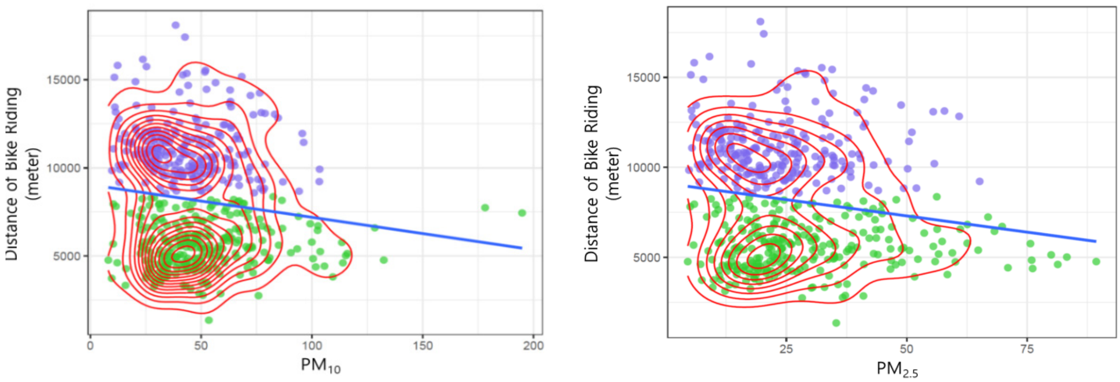
It can be easily guessed that there is an intrinsic relationship between PM_{10} and $PM_{2.5}$. Because both are measurements of the same dimension about particulate matters. However, since $PM_{2.5}$ is focusing on smaller matters in size, its impact on health can be different. <Figure 4> shows a scatter plot and a density plot consisting of PM_{10} and $PM_{2.5}$.

Overall, the concentration of particulate matter is weakly associated with bike riding distances. We may guess that the low quality of air evokes a shorter travel distance by warning people about potential risks; however, the big data analysis shows counter intuitive results as shown in <Figure 5>. The further analysis by data mining (K-means clustering) indicates that there are two different groups. The first



(a) Scatter Plot (b) Density Plot

<Figure 4> Correlation Plot Between PM10 and PM2.5



(a) PM_{10} and Riding Distance (b) $PM_{2.5}$ and Riding Distance

<Figure 5> Relationship Between PM and Riding Distance Based on K-Means Clustering

<Table 5> Influence of PM on Bike Sharing Activity

	Model		
	1	2	3
Response variable: bike sharing use (Count), count data regression (Quasi-Poisson distribution)			
Temperature (T)	0.0330***	0.0179***	0.0227***
Amount of rain (R)	-0.0143***	-0.0160***	-0.0169***
PM_{10} (P10)		-0.0069***	
$PM_{2.5}$ (P2)			-0.0088***
P10 ×× R		0.0001	
P10 ×× T		0.0003***	
P2 ×× R			0.0001
P2 ×× T			0.0004**
Response variable: Riding distance, multivariate linear regression (ordinary least squares)			
Temperature (T)	227.766***	169.558***	190.616***
Amount of rain (R)	-69.5173***	-65.101***	-69.838***
PM_{10} (P10)		-21.781***	
$PM_{2}5$ (P2)			-27.137***
P10 ×× R		-0.161	
P10 ×× T		1.224**	
P2 ×× R			-0.0051
P2 ×× T			1.3212*
R^2	0.628	0.635	0.634

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

group (the upper parts over the lines in <Figure 5> (a) and <Figure 5> (b)) travels a lot regularly. In this case, the contour lines skews to negative direction, which means the group does seem to be sensitive to the concentration of PM compared to the other group.

As shown in <Figure 5>, points are concentrated within a certain range less than 100 PM10 or 50 PM2.5, which means the rider of a sharing bike is likely to be sensitive to air quality measured by fine dust density. This pattern seems to be natural since people may want to avoid suffering from exposure to air pollution. However, it should be noted that the smartphone app for Tha-Rung-Yi, the name of sharing bike in Seoul, does not provide information relating to air quality. Possibly, people search air pollution information for personal protection outside the Tha-Rung-Yi app, or they may decide not to rent a sharing bike when bad air quality is visually apparent.

To understand the effects of the concentration of PM on bike sharing more precisely, two different response variables were regressed by independent variables including temperature, amount of rain (zero

= no rain, positive number = rainy all day or temporarily rainy), and PM degree. Since three combinations of variables were used so that 2 by 3 multivariate regression models were tested as shown in <Table 5>. When bike sharing use was considered as independent variable, generalized linear modeling assuming Quasi-Poisson distribution was conducted. Since the outcome of interest is a nonnegative integer, its discrete nature may produce biases results if an ordinary least square (OLS) method is applied. However, riding distance was analyzed based on linear OLS assumption.

In line with the previous big data analysis with visual representation, temperature explains a lot of positive influence on both bike sharing and travelling distance. Also, the weather condition measured by the amount of rain significantly influences dependent variables in negative direction. The results indicate that the concentration of PM is negatively associated with bike sharing. Although the impact seems to be limited, the relationship between PM and riding distance needs to be examined more carefully. In the regression model, one unit increase of PM can reduces 21 to 27 meters of travel. In terms of CO_2 reduction effects of bike sharing, this impact can be huge in accumulation.

Ⅳ. Conclusion

The sharing economy is growing. This emerging trend represents that efficient matching algorithms and business design for enhancing mutual benefits of demand and supply are crucial for industry players to accomplish business goals. Yet, management researchers have barely scratched the surface on the sharing economy phenomena, it is true that new theoretical knowledge and empirical evidences are accumulated incrementally in information systems communities.

In the last few years, bike sharing has been growing at an impressive rate in Asia; but, academic efforts to reveal surrounding issues were limited. By shedding light on the topic of bike sharing based on big data analysis, the findings of this paper may contribute to policy makers and entrepreneurs.

Or course, this paper has limitations, which offer fruitful areas for future work. First, the findings are primary rooted in one case of sharing economy. Although its uniqueness and quality of Tha-Rung-Yi data are beneficial in expanding our knowledge, there are huge chances to supplement findings by considering Chinese bike sharing data. Since those two neighboring countries have suffered from the common problem of air quality, the findings of this paper can be greatly extended by using bigger data. Additionally, because the sharing economy is relatively new, this paper is exploratory in nature. Econometric analysis is helpful in discovering further theoretical edges, but still we need to put much attention to mathematical work for designing better business models. At the same time, design science efforts are required to test and improve new solutions based on ideas discovered and developed in academic fields. Future work by collective efforts is worth of pursue.

The increase of demand to sharing bike helps not only protect the environment by lowering carbon dioxide emission into the atmosphere, but also improve citizens' health. Additionally, bike sharing provides an economic opportunity for city tourists to explore attractions. As shown in the findings, there is room for further improvement of the service by actively providing information on weather and air quality to both citizens and tourists.

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Submitted: March 15, 2019; 1st Revision: July 5, 2019; 2st Revision: August 24, 2019; Accepted: August 27, 2019