Assessing the Sustainability of Dockless Bike-Sharing in Singapore

Yeo Ming Jie, Jonathan[1], **Dr. Jenson Goh**[2]

[1]**(Undergraduate) National University of Singapore, Faculty of Science; yeomj@u.nus.edu**
[2]**(Supervisor) National University of Singapore, Residential College 4; jenson.goh@nus.edu.sg**

Keywords: *system dynamics model, sustainability, dockless bike-sharing, Singapore*

ABSTRACT

This paper seeks to assess the sustainability of dockless bike-sharing services in Singapore. Privately-operated dockless bike-sharing services were first introduced in Singapore at the start of 2017. While immensely popular in the initial months of its launch, the unregulated growth of the industry that resulted in a massive influx in the number of bikes distributed island-wide came at a cost; bikes were abused and parked indiscriminately, and existing bicycle-parking infrastructure were overwhelmed. In this paper, we propose the formulation of a system dynamics-based model of the bike-sharing industry, the objective of which is to understand the issues hindering its sustainability. We found that an oversupply of bikes and the overall costs of operations pose a significant challenge towards the overall sustainability of the system and propose several policy implementations that may be adopted to overcome them.

1. INTRODUCTION

The dockless bike-sharing service model was one that rapidly grew in popularity around the globe within its initial year of launch in China. It was first introduced in the Singaporean market by private start-ups Ofo, Mobike, and oBike in January 2017. Within the first year, the number of bikes distributed island-wide grew exponentially. While this new means of transportation has afforded Singaporeans with increased accessibility for first and last-mile commutes and leisure use, the dockless nature of these shared-bicycles also brought about a slew of problems.

The lack of regulatory groundwork at the time of its introduction in Singapore led to an uncontrolled growth in the fleet size of bike-sharing operators competing for market dominance in the industry. In addition, the dockless nature of the shared bikes also gave rise to indiscriminate parking of bicycles by users and misuse leading to damage of the bikes.

In response to these problems, the Land Transport Authority (LTA) acted by imposing fines on operators for illegally parked shared bikes by users. In addition, a licensing regime was also introduced, requiring operators to pay a licensing fee to operate while enabling LTA to impose restrictions on the fleet size of operators (Land Transport Authority, 2018). The introduction of this license, in conjunction with the costs incurred by operators from fines and the repair of damaged bikes contributed significantly to operation costs for operators. Consequently, this led to several operators, most prominently oBike, announcing their withdrawal from the Singapore market. The following behavior over time graph illustrates the change in the total number of bikes over a time period of the first 18 months.

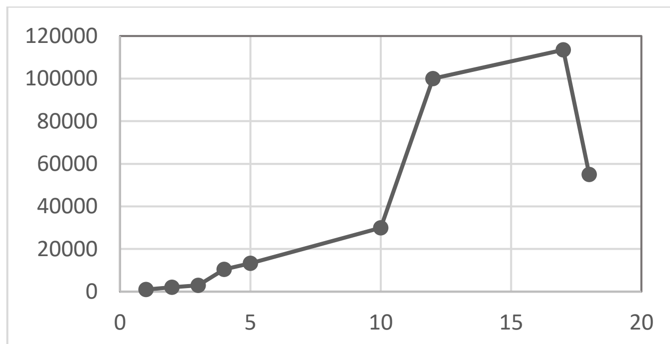


Figure 1: Total number of bikes in Singapore over time (months) from January 2017 to June 2018

The continuing withdrawal of operators has resulted in the generation of strong public uncertainty towards the sustainability of the dockless bike-sharing industry as a whole.

This paper is structured in the following manner: Section 2 provides a Literature Review, while Section 3 introduces some of the main concerns towards dockless bike-sharing in Singapore's context. In Section 4, the System Dynamics Model is presented, following which an analysis of the simulated results is conducted in Section 5. We discuss some of the limitations and detail an extension to our model in Section 6, before we round off with our conclusions.

2. LITERATURE REVIEW

The history of bike-sharing services, as summarized by DeMaio (2009), can be dated back to over half a century ago with the introduction of the “White Bikes” in the city of Amsterdam. This programme, however, was only able to sustain itself for a short duration before quickly succumbing to public misuse involving thefts or vandalism of the bikes. Over the years, the bike-sharing model underwent successive iterations of improvements. It was not until the emergence of a third-generation bike-sharing model in the mid-2000s that it gained popularity and widespread adoption throughout cities around the globe. Some features of this third-generation bike-sharing system, as characterized by Shaheen et al. (2010) include docking stations for the bicycles, cashless payment methods and automatic bicycle locks to deter theft.

Several cited benefits of bike-sharing services include its capacity to bridge first-mile/last-mile commutes between public transit networks, promoting active mobility within the community and numerous other social and environmental benefits afforded by this alternative eco-friendly mode of transport to motorized vehicles (Ricci, 2015).

With reference to Fishman's review of recent literature on modern bike-sharing systems (2015), we note that the majority of existing literature focus on issues including examining usage patterns of bike-sharing in different cities, policies to promote growth, and studying the barriers of implementation in cities. However, none of the literature examined focus on the problems that have arisen as a consequence of the implementation of bike-sharing systems in the city. It is also noted that while there is a growing literature on earlier generations of the docked bike-sharing scheme, there are few academic studies on the dockless bike-sharing scheme. (Spinney & Lin, 2018)

In the context of Singapore, only two studies on bike-sharing are known to have been published. While the first is a feasibility study on bike-sharing in Singapore (Zhang, Koh, Meng, Leow, & Wong, 2017) conducted before it was first introduced, the latter by Shen et al. (2018) studied the usage patterns of the dockless bike-sharing system in Singapore within the initial months of its introduction.

This suggests the relative newness in the area of research that this paper seeks to explore. By conducting a systems-based analysis of the new dockless bike-sharing system in the context of Singapore, it can enable us to develop a better understanding of the dynamics that influence its sustainability, and thus pave the way for potential refinements to this system to encourage its further adoption in other cities.

3. DOCKLESS BIKE-SHARING CONCERNS IN SINGAPORE’S CONTEXT

The dockless bike-sharing system is the first form of bike-sharing system to be available in Singapore. While a tender was called for by LTA in July 2016 to appoint an operator for a pilot government-funded bike-sharing scheme in Singapore’s Jurong Lake District (Land Transport Authority, 2016), the unanticipated entrance of the dockless bike-sharing operators in 2017 led to a cancelation of the aforementioned tender (2017). This resulted in a lack of regulatory framework for the management of bike-sharing in Singapore, and insufficient bicycle infrastructure to accommodate the overwhelming number of bicycles brought in by operators. This posed an especially severe problem given Singapore’s land space constraints[1].

Another concern raised, as cited by National University of Singapore transport expert Dr. Lee Der-Horng, is that demand, as influenced by an actual need to utilize the bikes for first/last-mile commutes is overestimated in Singapore given its already efficient transportation network (Baharudin, 2018). This creates an uncertainty towards the overall financial profitability of dockless bike-sharing systems.

The concern of low revenue streams due to low demand and usage is further supported by a research conducted by the Singapore-MIT Alliance for Research and Technology (SMART) studying the usage of dockless bike-sharing in Singapore (Shen, Zhang, & Zhao, 2018). The study found that most bikes, on average, were only used less than 2 times per day, suggesting low usage levels. LTA also confirmed in a press release in September 2018 that “the average utilization rate for the entire shared bicycle is slightly more than one trip per day”, and additionally, “about half of the population is not used actively.” (Mohan, 2018)

Lastly, several difficulties cited by bike-sharing operators in a local news report included the high costs of operations associated with recovering indiscriminately parked or damaged bicycles, and the maintenance costs associated with the fleet size (2018). Based on interview data with one of the bike-sharing operators, we noted that public misuse in the form of vandalism was at least one of the major cost-contributing factors incurred by the operator in Singapore, having affected at least 20% of the entire fleet size at one point. This emphasizes the severity of the bike misuse problems in Singapore as a major contributing factor to the cost of operations.

[1] Land Area of Singapore: 722.5 km^2 (Figure extracted from Wikipedia)

4. SYSTEM DYNAMICS MODEL

The following model boundary chart summarizes the scope of our model on the bike-sharing system in Singapore:

Endogenous Variables	Exogenous Variables
Adopters	Population
Non-Adopters	Average Fare per Usage
No. of Operators	Frequency of Usage
Total No. of Usable Bikes	No. of Parking Lots
Total No. of Damaged Bikes	Repair Costs of Bikes
Costs of Operations	Impound Cost
Potential Revenue	
Actual Revenue	

Figure 2: Model Boundary Chart

4.1. Causal Loop Diagram (CLD)

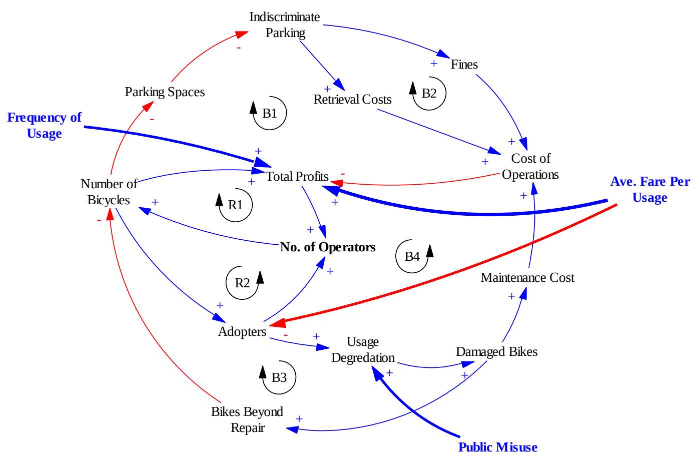


Figure 3: Causal Loop Diagram

The CLD above models the interactions within the bike-sharing industry in Singapore by identifying the different feedback loops that exist in the system. For our model, we conducted an aggregated analysis of the fleet size, total profits and costs of operations among the total number of operators in the system.

4.2. Stock and Flow Model

The Stock and Flow Model (SFD) we will be running can be found in the Appendix section. Building upon the feedback loops that we have identified in our CLD, the SFD constructed simulates the behavior of the bike-sharing model in Singapore, over a time horizon of 50 months. In this section, we detail some of the key assumptions and logic utilized in the formulation for our model.

1. *Population* is assumed to be a constant at 2 Million
2. A constant *Adoption Rate* is assumed, whereas for the *Drop-Out Rate*, we define a *Drop-Out Multiplier* as a lookup table against the *Average Fare Per Usage*. The lookup table follows an increasing curve, to simulate how an increase in *Average Fare Per Usage* causes the *Drop-Out Rate* to increase due to cheaper and more efficient transport alternatives.
3. Number of *Initial Operators* is set at 3, while *Initial Bikes Per Operator* is set at 1000. These reflect the initial conditions in Singapore as uncovered in our literature research.
4. To reflect the usage levels uncovered in our literature review, *Frequency of Usage* per month is set at 0.1 (each adopter utilizes a bike-sharing service 3 times per month). *Average Fare Per Usage* is assumed to be 5 dollars.
5. Market Entrance *(Entering Market)* conditions are defined in the following manner: If *Potential Revenue* exceeds *Cost of Operations*, the number of operators entering the market per month will be 1. [2]
6. Exit Conditions (*Exiting Market*) are defined in the following manner: If *Costs of Operations* exceeds (*Exit Tolerance*)*(*Actual Revenue*), the number of operators leaving the market per month will be 1.[3]
7. For market entrance, there are no delays, whereas a 6 month *Exit Delay* is defined from the onset. This is because we assume that operators are willing to tolerate any form of profit loss at the start.
8. For each bike supplied, capital costs incurred in supplying the bikes are assumed to be sunk costs, and do not contribute to our computation of the cost of operations.
9. The *Public Misuse Multiplier* is defined to be a lookup table as a graph with an S-Shaped curve, against the number of adopters, as higher number of adopters increase the likelihood of misuse leading to more damaged bikes.
10. *Fix Cost Per Bike* (repair costs) are assumed to be 100 dollars, whilst *Retrieval Costs* is assumed to be 500 dollars for every 2000 bikes.
11. *Fines Per Impounded Bike* is assumed to be 200 dollars, rounded up from the actual impound value of $140.
12. The main exit in stock for total number of bikes is through scrapping of bikes that cannot be repaired, or through the exit of operators from the market. In the latter case, this is modelled via a *Usable Exiting Market* outflow that removes bikes from the system upon each instance of an operator exit. By assuming that the total number of bikes in the system is split equally amongst all operators, we

[2] Here, *Potential Revenue* is computed as a function of the number of Adopters, the *Average Fare per Usage* and the *Frequency of Usage.*

[3] Here, *Actual Revenue* is computed as a function of *Usable Bikes*, *Average Fare per Usage* and *Frequency of Usage*. In other words, we assume all *Usable Bikes* are fully utilized.

remove the number of bikes equal to that owned by a singular operator for each exit instance.

13. Lastly, we assume minimal policy interventions in the market by the government.

5. MODEL SIMULATION

In this section, we analyze the outputs generated from the SFD model that we have constructed. First, we seek to validate the model against our known understanding of the bike-sharing system based upon our literature research, and against our behavior over time reference modes. We then discuss some of the key insights that we can uncover based on the results generated by our model.

5.1. Model Validation

Based on the results generated by our model, we can observe the following trends and dynamics.

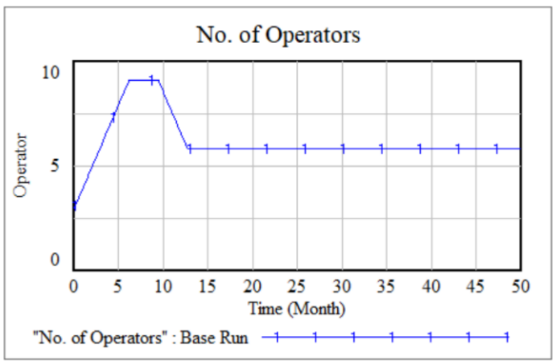


Figure 4: Base Simulation Result for No. of Operators

Firstly, the No. of Operators experienced initial growth within the first 6 months before the exit delay was over. Given our model assumption of a normal increase in adopters of bike-sharing over time, we naturally expect it to encourage operators to enter the bike-sharing industry. As a consequence of having more operators, the total number of bikes in the system increases.

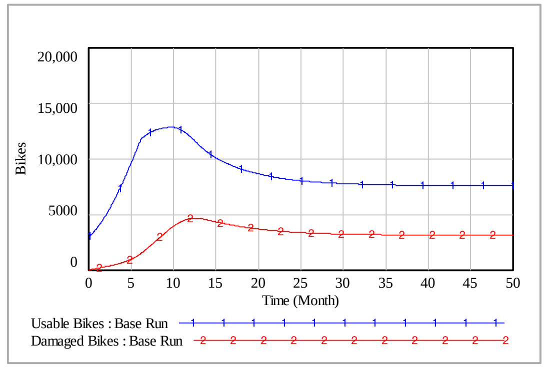


Figure 5: Base Results for Usable Bikes and Damaged Bikes

This led to increased growth in the number of damaged bikes, given our assumption that the rate of misuse and degradation is likely to increase with greater number of bike-sharing adopters. Moreover, with the growth in total number of bikes exceeding the carrying capacity of the parking lots, this creates the opportunity for more indiscriminate parking to occur, the effect of which is an increase in retrieval costs.

The cost factor of retrieval, in addition to the increased maintenance costs borne from the increase in damaged bikes created a rapid inflation in the Costs of Operations. Thus, once costs of operations began exceeding the revenue generated significantly (defined by the Exit Tolerance factor of being twice the revenue), this spurred the exit of operators from the market before an equilibrium was eventually established.

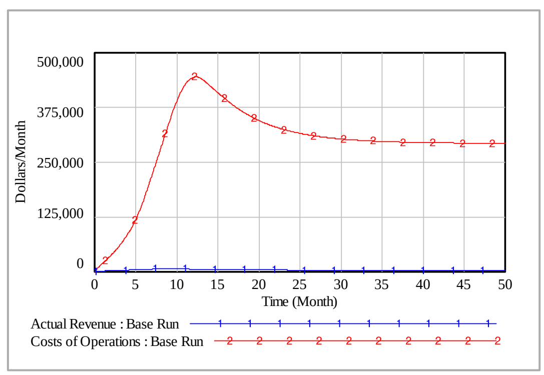


Figure 6: Base Results for Actual Revenue and Cost of Operations

Holistically, the results of our SFD are representative of the growth trends that we have uncovered through our behavior over time reference modes on the total number of bikes over time (Figure 1) and the trend in the change in number of operators over time (Figure 7). The model is also able to represent the entrance and exit dynamics of operators and their corresponding effect on the number of usable bikes in the system.

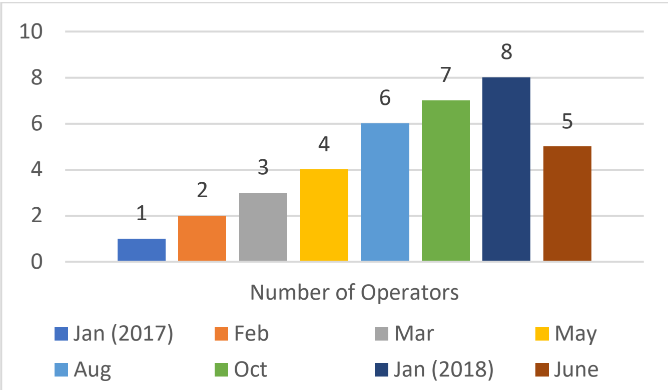


Figure 7: Change in number of operators over time from January 2017 to June 2018

Based on these findings, we conclude that our model is able to model the problem dynamics with a sufficient level of accuracy.

5.2. Analysis and Discussion

To test the robustness of the model, we explore the effects of varying different variable parameters on the overall system behavior. This is conducted with the intention to not only better understand the dynamics of the system, but also search for ways in which the revenue-cost disparity can be minimized to ensure the sustainability of bike-sharing operators in the system.

I. Impact of Varying Usage Levels on System

Firstly, we investigate the effect of varying the usage levels on the dynamics of the model simulation. The most immediate effect in lowering usage levels is a fall in Actual Revenue, leading to the collapse in the number of bike-sharing operators at a much faster rate, even to the extent of a complete shutdown for all operators.

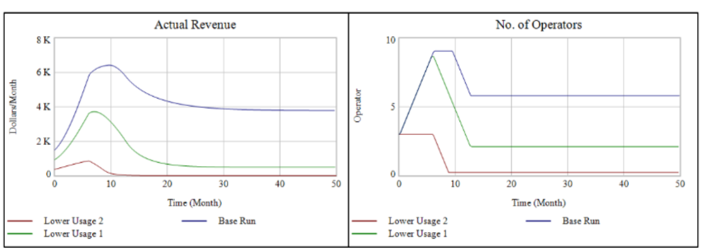


Figure 8: Effect of Lower Usage Levels on Actual Revenue and No. of Operators

Correspondingly, increased usage levels would create a positive impact on the system. As it appears from our results that increased usage levels not does create any significant negative feedback in the system, we conclude that this may be a potential avenue for bike-sharing operators to target to reduce the disparity between their actual revenue and costs of operations to increase profits.

II. Impact of Varying the No. of Bikes Supplied Per Operator

Next, we assess the impact of varying the No. of Bikes Supplied Per Operator. Based on the results obtained, we observe that while a reduction in the number of bikes supplied does lead to a reduction in revenue, an equilibrium in the no. of operators in the market can be established.

Conversely, if the no. of bikes supplied per operator is too high, it creates a rapid inflation in costs of operations. An immediate consequence of this is that we observe an overshoot and collapse scenario in the system, based on the results below.

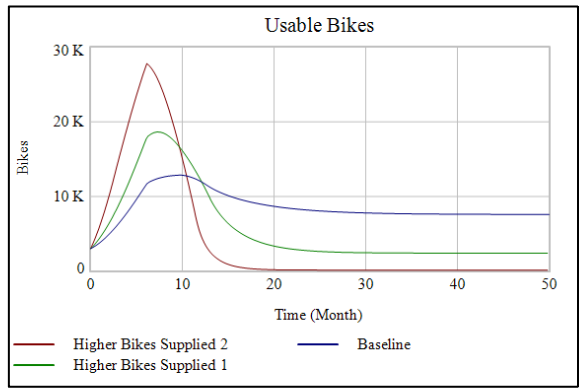


Figure 9: Effect of Higher Bikes Supplied on Usable Bikes

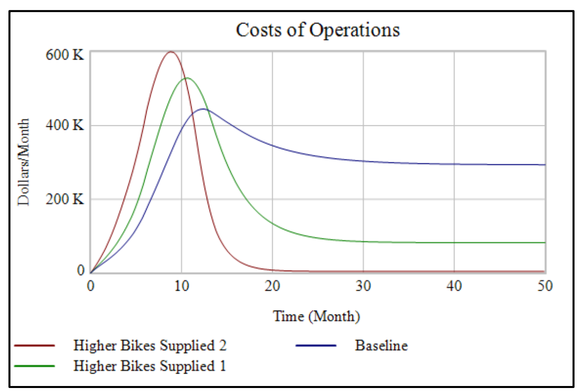


Figure 10: Effect of Higher Bikes Supplied on Costs of Operations

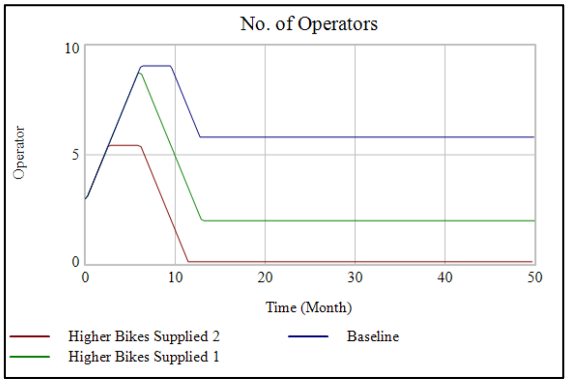


Figure 11: Effect of Higher Bikes Supplied on No. of Operators

Given that we already exclude capital costs of supplying the bikes into the market which in reality contributes significantly to the overall expenditure of bike-sharing operators, it is likely that more operators would exit the market to cut their losses.

This highlights the need for government intervention in the form of controlling the overall fleet size of operators, in order to prevent an oversupply of bikes in the market leading to an overshoot and collapse of the system.

III. Analysis of Effect of Costs of Operations

Lastly, we analyze the effect of the varying factors that contribute to the costs of operations for bike-sharing operators, to identify the greatest cost-contributing factor. To do so, we conduct an extreme value test for each respective cost variable in the system by maximizing these values through the Vensim SyntheSim Mode.

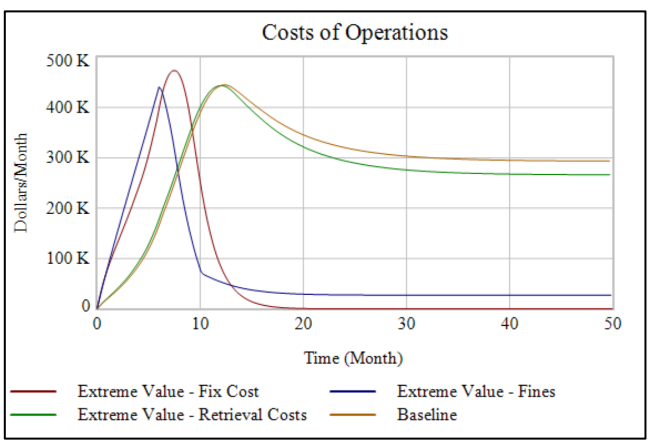


Figure 12: Effect of Extreme Values of Fix Costs, Retrieval Costs and Fines on Costs of Operations

From the results obtained, it appears that Fines Per Impounded Bike and Maintenance Costs contribute most significantly to increase in costs of operations only within the first 10 months, whereas the Retrieval Costs experience a more gradual increase that eventually dominates as the main cost contributing variable in the long run.

This suggests that if one is to try to minimize costs of operations in the long run, policy implementations should seek to avoid inflating these costs, particularly through the implementation of fines by authorities.

To minimize indiscriminate parking, government regulators can increase the carrying capacity of parking lots to ensure it can accommodate the fleet size of bike-sharing operators. Given that land constraint can be a limiting factor towards doing so, it suggests the need for some level of fleet size control that should be imposed upon operators.

On the operator side, they should work towards reducing their retrieval costs in the long run. One possible method of doing so can be through adopting geofencing technologies to create virtual fencing around localized areas in Singapore for their service operations. Doing so could improve the ease of retrieval and management for bike-sharing operators.

6. LIMITATIONS OF MODEL AND EXTENSIONS

One of the greatest limitations of this model revolves around our use of estimates in the establishment for our model, given the lack of statistical datasets on bike-sharing in Singapore.

We acknowledge that numerous other factors exist in influencing the market entrance and exit of operators, and operator decisions on the number of bikes supplied. Thus, we try to consider one possible extension to our model in the form of additional revenue sources, which can be generated using the bikes and bike-sharing app as advertising platforms.

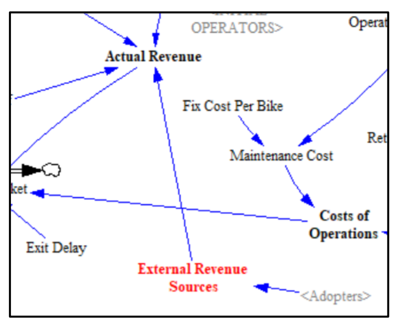


Figure 13: Addition of External Revenue Source Variable

In this instance, we inject an External Revenue Source that is dependent on number of adopters which adds to the Actual Revenue. From this addition, we can observe notable variations in the results obtained from the simulation.

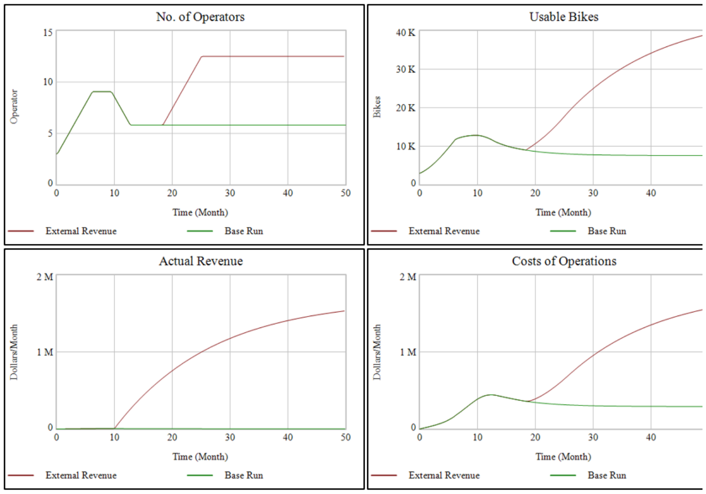


Figure 14: Effect of new External Revenue variable

The introduction of an external revenue source appears to be beneficial to overall operator growth based on the increase in actual revenue and usable bikes. Thus, while it may appear from the results that operator growth could potentially be sustainable, realistically having an uncontrolled increase in the number of bikes would likely further exacerbate the problems of indiscriminate parking. This would hold even if the government tries to increase the carrying capacity of parking lots again due to space constraints and due to the likelihood that the increase in bikes is going to be at a much faster rate than the rate at which more bike parking slots are built/allocated.

7. CONCLUSIONS

In conclusion, our findings have verified that costs of operations can present itself as a significant problem in the sustainability of the dockless-bike sharing system. While high usage levels were shown to have positive feedback on the system, an oversupply of bikes is noted to run the risk of an overshoot and collapse scenario, due to an overly rapid increase in costs of operations for bike-sharing operators.

From our proposed model, it showcases how the System Dynamics framework can be applied to analyzing the sustainability problems of dockless bike-sharing in Singapore. This model can thus serve as a useful framework for government regulators to evaluate policy decisions to ensure the sustainability of the bike-sharing industry, or operators to evaluate their cost factors or revenue streams, hence enhancing their decision-making.

7.1. Acknowledgement of Additional Work Completed

The author would like to acknowledge that in the time since this paper was first submitted for this conference, additional work building upon the model and work presented in this paper has been completed, in collaboration with the Land Transport Authority's Active Mobility Unit. Accurate user statistics and ride data were incorporated into building an updated model that is presented below. We were also able to engage local bike-sharing operators directly to develop a deeper understanding into their operations, in order to improve upon some of the assumptions made in the model presented in this paper. Due to industry-sensitive information, however, we will only briefly discuss qualitatively on the improvements and certain insights generated from this new model.

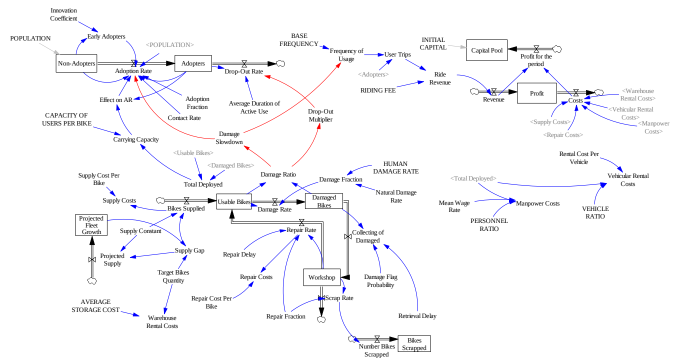


Figure 15: Improved Bike-Sharing System Dynamics Model

The updated model as presented above preserves the underlying structure of modelling users, total bikes, and operator finances as distinct subsystems interacting with one another to generate the feedback structures studied in this paper. Given that we now had access to user data, we found that we were able to fit a modified Bass Diffusion model in modelling the adoption dynamics using Vensim's built-in optimization function against the user trip data to account for the speed of user adoption, in comparison to our previous model's assumption of a constant adoption rate. As a further extension, we also subsequently introduce a regeneration flow into the adoption cycle.

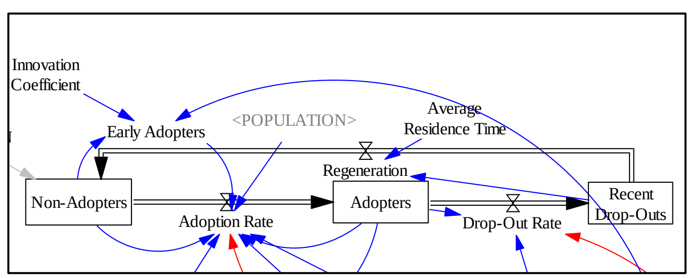


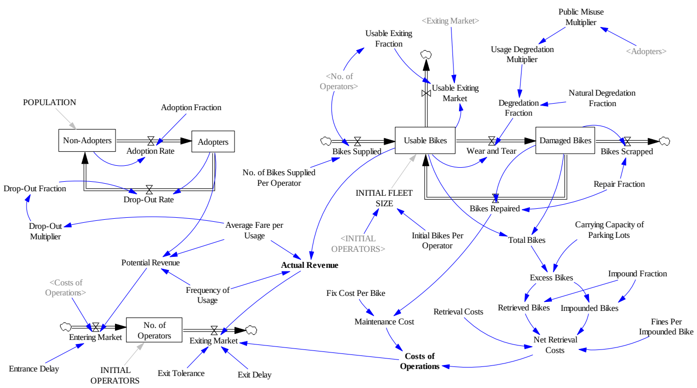
Figure 16: Regeneration Flow for User Subsystem (Extension)

By studying the behavior over time graph of how total bikes changed in the system as a consequence of human usage degradation of the bikes, we were also able to generate projections on profits of bike-sharing operators, which were subsequently presented to and verified by local bike-sharing firms themselves.

Lastly, as a means of modelling competition dynamics, instead of taking a macro-approach to studying how the dynamics of how the number of operators change over time, as we did in this paper, we made use of model subscripting to study two firm competition dynamics. Using this technique, we were able to study different effects such as firms having different fleet capacities, and different entry times into the industry, and the relevant effects that had on user adoption dynamics. We concluded that the results of studying the two firm competition dynamic using subscripting would be a useful base case in generalizing the results to an arbitrary number of firms.

Given that we were able to improve our model using data and using more realistic assumptions that were made in the context of bike-sharing operations in Singapore, this further reinforces our conclusion point on how the model serves as a useful framework towards the study of bike-sharing dynamics in cities globally.

8. APPENDIX



9. REFERENCES

Baharudin, H. (2018, February 15). *Bike-sharing a hit with S'poreans*. Retrieved from The New Paper: https://www.tnp.sg/news/singapore/bike-sharing-hit-sporeans

DeMaio, P. (2009). Bike-Sharing: history, impacts, models of provision, and future. *Journal of Public Transportation*, 41-56.

Fishman, E. (2015, April 24). Bikeshare: A Review of Recent Literature. *Transport Reviews*, pp. 92-113.

Is dockless bike-sharing doomed to fail in Singapore? (2018, July 6). Retrieved from Channel News Asia: https://www.channelnewsasia.com/news/business/is-dockless-bike-sharing-doomed-to-fail-in-singapore-10505662

Land Transport Authority. (2016, July 28). *Jurong Lake District to Have Bicycle-Sharing Scheme by End-2017*. Retrieved from Land Transport Authority: https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=1d2be988-2d74-47aa-9960-cfe1916dc351

Land Transport Authority. (2017, March 24). *Non-Award of Bicycle-Sharing Tender*. Retrieved from Land Transport Authority: https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=ea2e677b-262f-48f6-9a54-50e7494eb161

Land Transport Authority. (2018, March 5). *First Reading of the Parking Places (Amendment) Bill*. Retrieved from Land Transport Authority: https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=d35fdfa6-6cfb-477d-ac12-c93aa5a6a78f

Mohan, M. (2018, September 28). *LTA to grant bike-sharing licences to six operators; sets limits on fleet size*. Retrieved from Channel News Asia: https://www.channelnewsasia.com/news/singapore/lta-grant-bike-sharing-licences-six-operators-sets-limits-fleet-10768666

Ricci, M. (2015, June). Bike sharing: A review of evidence on impacts and processes of implementation and operation. *Research in Transportation Business & Management*, pp. 28-38.

Shaheen, S. A., Guzman, S., & Zhang, H. (2010). Bikesharing in Europe, the Americas, and Asia: Past, Present, and Future. *Transportation Research Record: Journal of the Transportation Research Board*, 159-167.

Shen, Y., Zhang, X., & Zhao, J. (2018). Understanding the usage of dockless bike sharing in Singapore. *International Journal of Sustainable Transportation*, 686-700.

Spinney, J., & Lin, W.-I. (2018). Are you being shared? Mobility, data and social relations in Shanghai's Public Bike Sharing 2.0 sector. *Applied Mobilities*, 66-83.

Zhang, J., Koh, P. P., Meng, M., Leow, B. W., & Wong, Y. D. (2017). Feasibility study of bike sharing in Singapore. *ICE Publishing*.