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Analyzing the effects of improper bus stop operations using shock wave analysis, and the application of an Intelligent Bus Utility System (iBus) as a solution

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Abstract: We analyze the effect of buses on EDSA that do not stop in the proper place and time using traffic shock wave analysis. Our analysis shows that the congestion effect of improper bus stop, under typical traffic flow condition, could potentially build up to 20 times of the stopping time before it dissipates. We propose a solution that we call as Intelligent Bus Utility System (iBus) to manage the buses in Metro Manila.

***Key words*:** shockwave, analysis for traffic engineering, iBus, bus stop design

1. INTRODUCTION

To establish a sustainable transport system that meets society's economic, social and environmental needs we face challenges of satisfying the rising demand for accessibility in the context of growing sustainability concerns. The most immediate priority is to improve the overall efficiency of the system and the acceleration of the development and deployment of innovative technologies that create win-win situations for all the stakeholders concerned.

In Metro Manila, the problem lies in the fact that public utility vehicles (PUV) such as buses and jeepneys are operated by private businesses, whose primary concern is profit. This creates a situation where buses become competitive with other buses in their effort to service as many passengers as possible. Buses endure long lines just to reach loading/unloading zones causing traffic congestion. Aggravating the situation are buses that would cut into those long queue thus blocking other lanes intended for private motorists. In the loading/unloading zones, buses would wait for an indefinite period of time to load passengers. Buses infringe on other bus routes' loading/unloading zones and do not their own zones as indicated by traffic loading signs. Buses would also stop at any location just to load passengers even to the point of blocking crucial intersections and corner streets.

Table 1 shows that among the registered operators of buses in Metro Manila, almost 70% operate along a single route passing through EDSA. LTFRB also reported that there are more illegal bus operators (tagged as `colorum buses`) that take the same main route of EDSA, which increase traffic volume and cause more congestion to the already heavily dense road. Efforts to reduce or eliminate illegal bus operators (through the installment of RFID and camera) have not been effective in deterring the illegal bus operators that easily adapt to the enforcement.

Table 1. Number of buses in Metro Manila

Total Metro Manila Buses Plying Along EDSA	3,732	69.5%
Total Metro Manila Buses Non-EDSA	1,640	30.5%
GRAND TOTAL	5,372	100.0%

Source: LTFRB, Dec. 2013

In this paper we use traffic shock wave analysis to analyze the dynamic pattern of traffic flow speed and density and describe the effect of improper loading and unloading of buses in EDSA.

Using this model, we can gain understanding on how platoon of vehicles behave behind the stopping bus. At the end of this paper, we also show how an intelligent technological solution could potentially control the illegal bus operators and at the same time, reduce the shock wave effect.

We are currently in the midst of a call for better and real-world solution regarding the traffic problem in our metropolis. We believe that our metropolitan streets need to maximize our existing mass transport in order to give people, especially private car owners, a viable alternative from bringing their cars. We believe we have the solution to entice people to ride the bus not as a mass transport of last resort but as a mass-transport of first option.

2. SHOCKWAVE THEORY

Shockwave analysis in traffic has been a standard theory for more than two decades (Papacostas & Prevedorouros, 1993, 1990). Shockwaves in traffic happen when there is a sudden hindrance on the traffic, such as a vehicle, pedestrian, or obstruction, that starts to slow down traffic, followed by a release of the blockage. The wave is produced by the chain reactions from bottlenecks, U-turns, accident, red traffic signal, stopping public utility vehicles, and the release of the blockage such as sudden acceleration of vehicles in front of the platoon or a green traffic signal.

The shockwaves model allows us to estimate the growth rate of the platoon; the length of the traffic platoon, how many vehicles or pedestrians are in the platoon, at what time will the platoon dissipate after the blockage occurs. It can also estimate the effect of the duration of the blockage, the congestion relief time and when the next waves will occur.

In particular, we examine below some events of temporary traffic blockage due to buses that stop in the improper place. A typical shock wave analysis will consider five shock waves in three events

Event 1: traffic blockage occurs (i.e. the bus stops in improper place)

    a. First shockwave is between the empty traffic in front of blockage and the queue or platoon build-up right behind the blockage

    b. Second shockwave is between the platoon and the normal traffic approaching the platoon

Event 2: blockage is released (i.e. the culprit bus moves away)

    a. Third shockwave is between the releasing traffic after the blockage was removed and the platoon that build up earlier

    b. Fourth shockwave is between the platoon and the normal traffic approaching the platoon

Event 3 : the platoon disappears

    c. Fifth shockwave is between the releasing traffic after the blockage was removed and the normal traffic approaching the platoon

For each shockwave we compute the shockwave speed using the following formula:

$$u_{sw} = \frac{q_f - q_b}{k_f - k_b} \qquad (1)$$

The subscripts f and b is to indicate traffic situation in front and the back of the shockwave. The

shockwave speed is positive when the shockwave is moving forward in the direction of the traffic. The shockwave speed is negative when the shockwave is moving backward in the reverse direction of the traffic.

The above formula is based on fundamental traffic flow equation that traffic flow q is equal to the product traffic speed u and traffic density k.

$$q = uk \qquad (2)$$

For Events 1 and 2, where two shockwaves define the platoon of vehicles, we can compute the growth rate of the platoon simply by taking the shockwave speed difference. Platoon growth rate between the first and second shockwaves is given by the following equation:

$$g_{12} = u_{sw_1} - u_{sw_2} \qquad (3)$$

Platoon growth rate between the third and fourth shockwaves is given by the following equation:

$$g_{34} = u_{sw_3} - u_{sw_4} \qquad (4)$$

Positive platoon growth rate means the length of the platoon will continue to grow over time. Negative platoon growth rate indicates the platoon will dissipate over time.

The length of the traffic platoon is equal to the product of platoon growth rate and the traffic density in the queue.

If the time duration of the blockage is denoted by t_1 then the length of traffic platoon is equal to the product of blockage duration and the platoon growth rate.

$$l_{12} = g_{12}t_1 \qquad (5)$$

$$l_{34} = g_{34}t_1 \qquad (6)$$

The number of vehicles inside the platoon is computed as

$$n_{12} = l_{12}k_b^{(12)} \qquad (7)$$

$$n_{34} = l_{34}k_f^{(34)} \qquad (8)$$

There are two time components of the duration of the platoon. First time component is the time from the blockage until it is removed, which we denoted by t_1. The second time component is the time to completely remove the platoon from the time when the blockage was removed and we use notation t_1. The total time of the existence of the platoon is equal to congestion to relief time, which is given by the following formula.

$$\mathrm{T} = t_1 + t_2 \qquad (9)$$

The duration time for the platoon dissipated after the blockage was removed is computed as

$$t_2 = \frac{l_{12}}{g_{34}} \qquad (10)$$

We propose an index to show the congestion effect of the blockage as the ratio between the blockage time (i.e. the duration of the bus that stops in the improper place) and congestion to relief time.

$$\lambda = \frac{\mathrm{T}}{t_1} \qquad (11)$$

Finally, we can predict that when the fifth shock waves will occur at congestion to relief time T.

3. SHOCKWAVE AND THE FLUID DYNAMICS: THE PHYSICS BEHIND TRAFFIC JAMS

William Beaty (2008) made several traffic experiments to find a cure for waves and jams in his article entitled The Physics Behind Traffic Jams. He found out that its not really a traffic jam, nor an accident that caused a traffic condensation but drivers competing against each other and not paving the way for some reasonable space for vehicles to move freely. These waves of jam can be dissipated by giving what it lacked –a Gift of Space. When cars will only slow down and allow

some space in between, traffic can move freely, unlike when, at the bottleneck or at every turning point, vehicles would squeeze into one another with the idea of competing against each other for some space and get the opposite effect.

The key is time and space. Time in such a way that drivers should be mindful of their speed, slow enough to "chew" the wave and Space since this should give enough legroom for vehicles to maintain a reasonable speed and vice versa to keep the traffic flowing. It is a balancing act all together. A system should be in place to do this that would allow a bi-directional pressure of the wave.
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4 ANALYSIS OF IMPROPER BUS STOPS ALONG EDSA USING SHOCKWAVE THEORY

Typical situation of daily traffic condition in Metro Manila is illustrated in Figure 1. Though there is a provision for a separate bus lane or bus way along EDSA, the buses would improperly stop to load and unload passengers, blocking lanes intended for other road users. Even with the existence of fences to physically restrict the buses to move only along the bus way, the condition did not improve due to improper enforcement and lack of driver education.

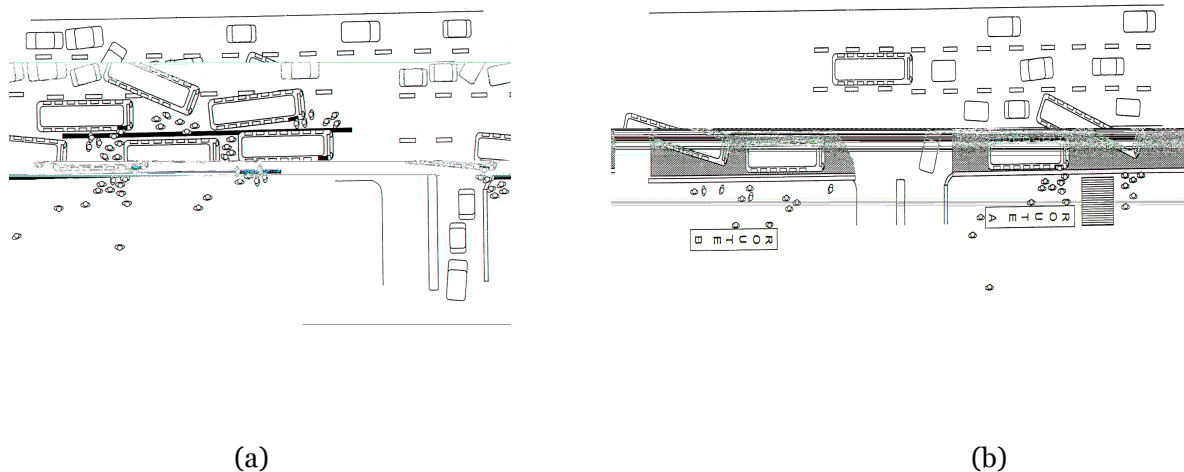(a)   (b)

Figure 1. Diagram of typical situation of blockage due to bus stops :
along the bus way (a) or bus lane (b)

In this section, we will show our quantitative analysis on how much each second of improper bus stop will affect the traffic. For our analysis, we use assumption of typical values for traffic condition in Metro Manila   Table 2 shows these typical values.

Table 2. Input for the Shock Waves Analysis

Input	Value
Average vehicle length	4 meters
Jam density	250 vehicles/km/lane
Normal traffic flow	1500 vehicles/hour/lane
Normal traffic speed	30 km/hour
Bus blockage time	15 seconds
Releasing traffic flow	1500 vehicles/hour/lane
Releasing traffic speed	25 km/hour

Assuming the average length of vehicles is 4 meters, the jam density of the queue happens per km

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[1] William Beaty The Physics Behind Traffic Jams http://www.smartmotorist.com/traffic-and-safety-guideline/traffic-jams.html

of a lane at 1000 meters/4 meters, which is 250 vehicles/km/lane.

During normal traffic conditions, vehicles run at 30km/hour with 1500 vehicles/hour/lane. This gives us a density of 50 vehicles/km/lane for normal traffic.

When a bus stops in an undesignated loading/unloading zone for 15 seconds, the first shockwave speed is at zero because the bus stops. The second shock wave speed would be at 7.5 km/hour (How was this derived? This is not in Table 1 above).. This means a platoon growth rate of 7.5 km/hour. Once the bus that stopped moves again, the blockage is released. The platoon is now released with front speed of 25 km/hour with equal flow of 1500 vehicles/hour/lane.

For 15 seconds blockage time, there are only 8 vehicles in the platoon. However, the platoon still continues to grow with negative growth rate of 0.395 km/hour. After the blockage is removed, at this rate there would still be 148 additional vehicles joining the platoon until the whole platoon gets dissipated. The total time to dissipate the platoon from the time the blockage was removed is t_2 = 285 seconds. Thus the congestion to relief time T is equal to 300 seconds or 5 minutes.

The congestion effect of 15 seconds blockage is $\lambda = \dfrac{T}{t_1} = \dfrac{300}{15} = 20$. In other words, the 15 seconds blockage has multiplier effect of 20 times toward congestion. It also means that for 1 second of blockage, the congestion to relief time would be 20 seconds. If the bus stops improperly for 30 seconds, the congestion to relief time would be 20*30 seconds = 600 seconds or 10 minutes. This is the actual cause of apparent congestion in major roads in Metro Manila.

5. NEW PARADIGM IN MANAGING TRAFFIC

Around the world, there has been an increasing traffic management systems being developed to better manage the increasing number of people and vehicles, thus giving birth to an era of intelligent transport systems.

5.1 Officials in Dublin are hoping to solve the Irish city's traffic problems by making smarter use of data.

This stream of "big data" — from bus timetables, closed-circuit television cameras, traffic detectors and GPS devices on board 1,000 city buses — is being used to build a digital, real-time map of which vehicles are where on Dublin's roadways. Coupled with improved reporting procedures, this information is designed to help

high-accuracy GPS and vehicle-mounted sensors to monitor a bus's position on the roadway. It is believed to have improved driver performance. "The fact that bus operators had a positive reaction overall is also encouraging for the adoption not only of this specific technology, but the wide spectrum of connected-vehicle technologies that are on the near horizon." – Mike Abegg, Minnesota Valley Transit Authority (MVTA) transit planning manager. [3]

5.3 Horizon 2020, The EU Framework Program for Research and Innovation, New intelligent bus system transports Europeans to the future (August 26,2014) – The European Bus System of the Future (EBSF) team has created an intelligent system for buses to make it attractive in both urban and suburban areas by developing new technologies for both vehicles and infrastructure "which makes efficient use of information and provides different bus system solutions adapted to the specific needs of all stakeholders."

The bus, being the most versatile solution in the urban environment as it meets the passenger's real needs and helps cities become greener, the innovations can offer improved and enhanced comfort to drivers and passengers, accessibility to all users and smart use of energy. They called the outcome of the project a "bus renaissance" [4]

6. RECOMMENDATION: AN INTEGRATED INTELLIGENT SOLUTION

In this section, we propose a solution to the traffic congestion caused by improper bus stop practices, loading/unloading or stopping in undesignated stops or zones. Our proposed solution would integrate the use of RFID, Wifi, broadband, satellite and ICT technologies and is called the Intelligent Bus Utility System (iBus). The iBus is an invention patented and registered under the Intellectual Property Office of the Philippines with Patent No 1-2008-000419. The invention hopes to alleviate heavy traffic in the Philippines, and assist bus and jeepney drivers, traffic enforcers and commuters, thereby enhancing the earning capacity of bus operators. The award-winning iBus is a first Filipino patented traffic management system that was internationally acknowledged by the British Inventors Society[5]. It has also gained interests and hailed in several local publications[6]. Recently featured in Hyundai's Spotlight magazine[7] and Rajesh Tadivada (2011) studied the feasibility for the implementation of iBus system to improve the traffic flow in EDSA.

Figure 2 shows how the iBus can decongest our roads. The rightmost (or innermost) lane of the road in front of the Loading/Unloading Zone (LUZ) station is the LUZ lane. It is on this lane that buses are authorized to load and unload their passengers. The boundaries of the LUZ station and its corresponding lane are defined by the existence of scanners and interrogators, which will be installed in such a way as not to obstruct traffic flow. One obvious benefit from this system is its ability to specifically define and delineate a certain place as LUZ area making it possible for city traffic engineers to establish bus stops away from traffic prone areas such as intersections and road exits.

It must be implemented and enforced in conjunction with seven requirements. The proposed

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http://www.cts.umn.edu/Publications/catalyst/2012/september/driverassist

[4] New intelligent bus systems transport Europeans to the future, European Commission, Horizon2020,
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[6] Innovensy website www.innovensy.com Recognitions
[7] Hyundai Asia Resources Inc (HARI) Publication, 2013

requirements are as follows:

1. Bus stop must be designed as separate lane with taper for acceleration and deceleration to the main lane. (See illustration in Figure 2.)

2. Only buses of certain route numbers can stop in a designated bus stop.

3. Buses will be allowed to stop, load, and unload in the designated zones for a limited duration. The iBus technology as described below is could help enforce this time limitation.

4. The law would have to require that every public utility bus must have the iBus installed in their buses.

5. There must be a single controller for dispatching buses along EDSA according to the demand.

6. Traffic enforcers must be equipped with an innovative way of apprehending bus drivers and operators who do not comply in the proper enforcement of iBus technology.

7. Traffic enforcers, through the notifications generated by the iBus technology, would be able to impose a sanction fairly.
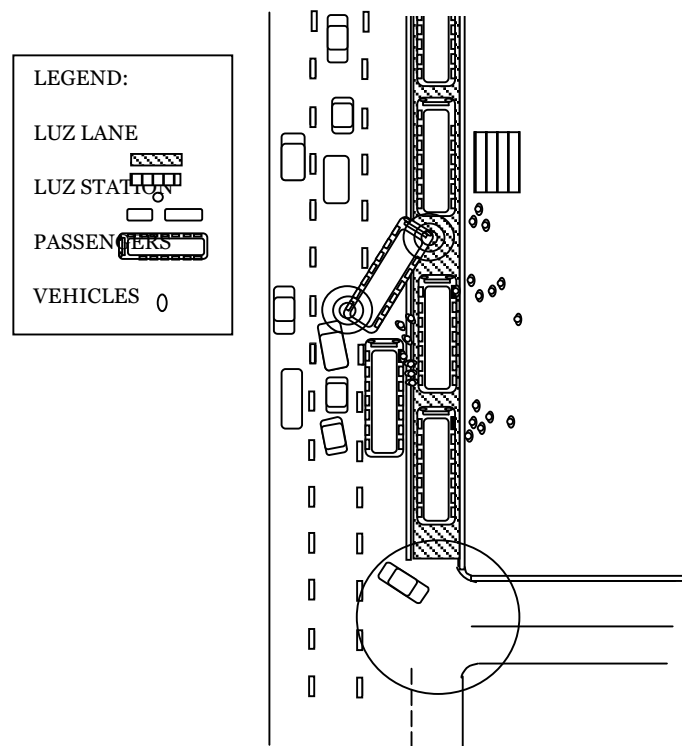

Figure 2. Loading and unloading zone (LUZ)

The first requirement is a major limitation along EDSA. Since there are so many buses running on EDSA, the queue of buses would overflow from the separate lane built for bus stops and infringe on the lanes beside it. In this case, the existence of separate lane bus stop with taper would become a provision for the system to work.

The second requirement is the proper distribution and scheduling of buses to be dispatched. Without this, there would be a continuous overflow of buses plying the same highway, using the same bus stops, thereby clogging the regular traffic lane.

The third requirement is the most important and the key to this proposed intelligent system. Our iBus technology, with its ability to automate the loading and unloading of buses in its designated zones can play a central role. The mechanism locks the doors of buses if they do not stop in the proper time and place, unlike in the current situation where drivers have complete control of their doors and they stop for several minutes to wait for passengers. The iBus technology also has the ability to limit the time duration of the door opening thus forcing the driver to move the bus away from the bus stop as soon as it closes. The iBus technology will be able to alert and communicate to the nearest traffic enforcers if a driver that stopped the bus beyond the designated time duration. Without the iBus, even with a physically well-designed bus stop, driver behaviors do not change due to lack of proper enforcement, which in turn is due to a lack of tools

and reliable system for monitoring. The iBus technology is designed to help the enforcer implement and enforce the time limit for buses to stop

The fourth requirement is the prerequisite for the third requirement. A law for common use of the iBus system must be in place. A partially implemented iBus system will not work. Non-compliant drivers may get more passengers than compliant drivers who use the iBus system. The only way to make the system work is to require all buses along the same route to be obligated to use the iBus system.

The fifth requirement is important to ensure that adequate numbers of buses are dispatched to cope with demand. Since the iBus only recognizes registered bus with unique identification number, illegal bus operators cannot use bus stops and therefore can easily be captured by the traffic enforcers.

The sixth and seventh requirements will enable traffic enforcers to have proof and legal basis for apprehending non-compliant bus drivers. The iBus would be an added tool for traffic enforcers to monitor buses. Monitoring and feedback system is part of the most important aspect of traffic enforcement. This will lead to a fair and equal application of the traffic law and not leave traffic enforcers to make judgment calls every time they apprehend buses that are not stopping properly. If application of the law is subjective, the drivers would resort to the old habit of block and cutting other buses as long as they could get away with it.

The current traffic control system in the Philippines relies heavily on traffic personnel to monitor buses and enforce compliance with various bus regulations. This reliance on manpower is what makes the system fail primarily because of human error and the difficulty of exerting constant vigilance over the conduct of these buses, rain or shine, 24 hours a day, 7 days a week. Shortage of manpower also occurs and this could also cause the system to fail. With such an unreliable traffic system buses have been known to take advantage of these loopholes to break traffic laws time and again.

The proponents of this new bus automation system believe that for a reliable bus system to work, human intervention should be limited and automation should be used to make the system more effective. A simple example would be traffic lights. Mechanical and impersonal, traffic lights give a fair opportunity for everyone using the road lanes without bias. These are not affected by weather changes, works 24 hours a day, 7 days a week unless it is interrupted by a power outage. Traffic lights are followed by every motorist taking credence in its impersonal and objective ability to give each one a fair opportunity to use the road. A reliable bus system should also work the same way. It can be made ubiquitous and standardized as the conventional traffic light.

The bus is a mass transport system though not as effective as a mass and light rail transit, it is still a viable alternative because it is able to haul 40-50 people although it is often used as the mass transport of "last resort". This is mainly due to its unpredictable travel time, and the risk that reckless bus drivers expose their passengers to. People only choose the bus when other forms of efficient transport are either inaccessible or non-existent. The lack of choices result in straining our mass transit rail systems to overcapacity. Private vehicle usage has risen dramatically leading to further road congestion in Metro Manila. Traffic congestion is a serious problem that affects

each and everyone living in the city. It involves us all in a vicious cycle that we ourselves perpetuate and, as explained in a current statistics report, has already cost us 180 Billion pesos in lost time and revenue.

There is a need to properly overhaul the bus system to work. Or else all government efforts to increase its effectiveness will be in vain: e.g creating bus lanes, creating specific loading and unloading lanes and docks. The government has identified the correct cause of our congestion, but the systems they put in place to maximize the bus's efficiency are ineffective. Some buses plying through EDSA are "half-empty". These are indications that people are not enticed to ride the buses since there are still problems with their operation.

The iBus technology is an automated IT-based solution that will:

1. **Manage the compliance of buses to use their assigned bus stops.** The system is designed with safeguards to assure that the buses will constrain buses to follow their designated routes approved by the Land Transportation Franchise and Regulatory Board (LTFRB). It will help traffic enforces to determine and distinguish instantaneously the LTFRB authorized PUBs from colorum and unregistered PUBs. It will identify instantaneously and error-free all PUBs that stop at non-designated areas and use this as evidence for infraction or penalty purposes.
2. **Forces the buses stopping to position and align itself neatly inside a loading/unloading zone.** The system prevents the buses from spilling out into other traffic lanes intended for other motorists (private and public) thus ensuring the constant flow of traffic.
3. **Give the flexibility to create loading and unloading zones (bus stops) bordered by an electronic and invisible perimeter that will authenticate, validate and process buses authorized to stop at certain areas.** Since the area is "invisible" there will be no structures built such as concrete barricades or metal fences that ultimately lead to more congestion as they take up much needed road space that should have been left to moving traffic. Also, these structures become road hazards, as they are the cause of most traffic accidents.
4. **Give traffic planners the unrivaled ability to designate bus stations away from traffic congested areas since the system will offer exact loading and unloading perimeters –** traffic planners are given the ability to construct bus stations away from intersections or traffic congested-prone areas, thus decreasing the chances of traffic gridlock. It will provide traffic planners with archived data as well as real-time information on the number of existing PUBs vis-à-vis loading and unloading zones giving them the ability to schedule PUBs at appropriate intervals that would ease traffic flow.
5. **Offer simultaneous PUB processing ability that prevents traffic congestion –** loading and unloading zones (bus stations) are able to process all the buses that enter its jurisdiction simultaneously. This means that if 5 buses enter a bus station, given the predetermined 3-minute countdown to load and unload passengers, all these 5 buses are simultaneously processed by the computer all at once and "released" back to traffic. Buses will not be allowed to stay longer inside the bus station as these will cause incoming buses to form another queue on the adjacent lane, blocking the flow of traffic. With a steady stream of incoming and outgoing buses, traffic is constantly managed to keep on moving thus managing traffic build-up. This will provide a reliable, and quantifiable allotment of time for loading/unloading giving each PUB equal opportunity to use the road and bus stops.
6. **Prevent Colorum PUBs from ever operating –** the iBus tag to be required must be LTFRB certified (Land Transportation Franchise and Regulatory Board) to operate and thus eliminate the entry of illegal or "colorum" buses that crowd our already vehicle-congested streets.
7. **Level the playing field among bus drivers –** all bus drivers are paid on a commission based on total gross fares collected. This is why bus drivers are pressured to pick-up as many commuters on the street without consideration to other motorists or buses behind them. Infringing on other bus routes' designated stop also become rampant and dangerous, as it leads to road rage between rival bus drivers and compromising the safety of the public. With the iBus in place, all registered PUBs could be properly distributed to

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