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Measuring and Evaluation on Priority Lanes

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Abstract—**Along with economic development, cities are increasingly congested in China. In order to eliminate peak-hour congestion, many cities establish priority lanes, commonly bus lanes. Although priority lanes could help Local Authorities gain its short-term management objectives, at the same time, it would greatly infringe on the legitimate rights of other vehicles and waste the scarce road resources, which is rigorously proved by mathematical models in this paper. In the long run, priority lanes would make social conflicts more intensified, and therefore highly undesirable. On the contrary, the social system engineering, combined with High Occupancy Vehicle (HOV) lanes and High Occupancy Toll (HOT) lanes, is the right way to alleviate overcrowding and build a Low-Carbon harmonious society.**

Index Terms—**priority lanes, congestion, HOV, measuring and evaluation, intersection**

I. INTRODUCTION

A bus lane [1] is a lane restricted to buses, and generally used to speed up public transport that would be otherwise held up by traffic congestion. Often taxis and high occupancy vehicles or motorcycles and even bicycles may use bus lane as well, though these uses can be controversial since they can reduce the capacity of the bus lane for its originally intended function.

Bus lanes give priority to buses [2] and cut down on journey times where roads are congested with other traffic. A bus lane is not necessarily very long, as it may only be used to bypass a single congestion point such as an intersection. Some cities have built large stretches of bus lanes amounting to a separate local road system, often called a busway system.

Bus lanes are normally created when the road in question is both likely to be congested and heavily traveled by bus routes. Entire roads can be designated as bus lanes (such as Oxford Street in London or Fulton Street in New York City), allowing buses, taxis and delivery vehicles only, or a contra-flow bus lane can allow buses to travel in the opposite direction to other vehicles. Some bus lanes operate at certain times of the day only, usually during rush hour, allowing all vehicles to use the lane at other times.

According to the American Public Transportation Association (APTA) and the National Transit Database (NTD), the world's first designated bus lane was created in Chicago in 1939. The first bus lanes in Europe were established in 1962 in the German city of Hamburg. Other large German cities soon followed, and the implementation of bus lanes was officially sanctioned in the German Highway Code in 1971. Many experts from other countries (Japan among the first) studied the German example and implemented similar solutions. On January 15, 1964 the first bus lane in France was designated along the quai du Louvre in Paris and the first counter-flow lane was established on the old pont de l'Alma on June 15, 1966. On 26 February 1968 the first bus lane in London was put into service on Vauxhall Bridge. By 1972 there were over 140 km of with-flow bus lanes in 100 cities within OECD member countries, and the network grew substantially in the following decades. The El Monte Busway between El Monte and Downtown

Los Angeles was the first busway in the USA, constructed in 1974.

The installation of bus lanes requires additional space to either be constructed, which increasing the impact of the road on the surrounding area, and possibly requiring private land or taken from existing lanes, which reducing the capacity of the road for private vehicles. The latter is especially controversial because that it is hard to explicitly combine improved public transport options with reducing or at least not improving convenience for motorists.

They can become inefficient if weak traffic enforcement encourages illegal parking on them (for example in shopping areas). The bus then has to merge back into traffic, which may be totally stopped, causing substantial schedule delays. They are also often used by vehicles not authorized, which reduces their capacity for the intended purpose.

As an international metropolis, Beijing has not only implemented a bus lane policy, during the Olympic Games and Paralympic Games in 2008, but also implement the Olympic lanes [3], Although it is an international common practice for host cities to use Olympic lanes during the Olympic Games , the scale of Beijing Olympic lanes is the largest [4]. Obviously, this is not worth showing off, because it clearly indicates that, in order to ensure the normal operation of the Olympic Games, the interference to ordinary people is the greatest in the world. To know that, in foreign countries, the voice of opposing the Olympic lanes is growing, ever since 1996 Atlanta Olympic Game, almost all the host cities are not willing to overuse Olympic lanes except Beijing. As for the upcoming London 2012 Olympics, the London Mayor Boris Johnson even have cancelled it but for the fear of "a reputational catastrophe that engulfed Atlanta''. [5]

Actually, the Olympic lanes are not compulsory. As the head of the International Olympic Committee (IOC) Jacques Rogge said, "Olympic lanes are the means we are looking for but let's see what London comes up with. If a good solution like traffic controls could be found, then yes." [6]

The newly example is the Singapore Youth Olympic Games. A Youth Olympic lane to facilitate timely arrival of Game participants and officials at competition venues will be introduced along selected stretches of roads from Aug 5 to 26. Jointly set up by The Land Transport Authority (LTA) and the Singapore Youth Olympic Games Organizing Committee (SYOGOC), the Youth Olympic lane is based on a give way concept.

Motorists only need to give way when they see Youth Olympic vehicles approaching, similar to what they would do when they see an emergency service vehicle. Other Olympic Games host cities have introduced Olympic lanes but their schemes were based on a dedicated lane concept for the exclusive use of Games vehicles.

During Games Time, a fleet of 700 Youth Olympic Vehicles will operate between the Youth Olympic Village and the competition venues. These vehicles will spot the Singapore 2010 look and will have special YOG license plates. Motorists are to give-way when they see these vehicles travelling behind them with their flashing lights.

Clearly, developed countries have been aware of the adverse impact of the priority lane to local residents, and try to safeguard their interests. Unfortunately, in China, some officials and scholars still applaud highly for this measure. The frequent usage of priority lanes can meet short-term management objectives, but at the same time, infringe on the legitimate rights of other vehicles and waste the scarce road resources which will be rigorously proved below.

II. METHODOLOGY

As close to the intersection, the dotted dividing lines become solid ones, we delimit the area between the stop line and the start point of solid lines as the junction area. And then, we randomly selected 10 intersections in Beijing, each intersection recorded for 1 hour.

According to the data records, we obtain Table I by SPSS17, the inter-arrival times of vehicles are exponentially distributed [7] and thus vehicles arrive in accordance with a Poisson process [8]. Since the average inter-arrival time is 0.68 seconds, the average arrival rate of entering vehicles $\lambda = \frac{1}{0.68} = 1.47$.

TABLE I.

ONE-SAMPLE KOLMOGOROV-SMIRNOV TEST **1**

		V1
	N	55435
Normal Parameters [a, b]	Mean	0.6822
Most Extreme Differences	Absolute	0.003
	Positive	0.003
	Negative	-0.003
	Kolmogorov-Smirnov Z	0.753
	Asymp. Sig. (2-tailed)	0.622

a. Test distribution is Exponential.

b. Calculated from data.

According to the data records, we obtain Table II by SPSS17, the service times (the times of vehicles entering and leaving the intersection) are exponentially distributed. Since the average service time $v = 1.21$, the average service rate $\mu = \frac{1}{1.21} = 0.84$.

TABLE II.

ONE-SAMPLE KOLMOGOROV-SMIRNOV TEST 2

		V1
	N	55445
Normal Parameters [a, b]	Mean	1.2086
Most Extreme Differences	Absolute	0.004
	Positive	0.004
	Negative	-0.002
	Kolmogorov-Smirnov Z	0.946
	Asymp. Sig. (2-tailed)	0.332

a. Test distribution is Exponential.

b. Calculated from data.

Hence, we can simulate a road with or without the priority lanes. Consider a three-line system in which cars arrive at Poisson rate $\lambda = 1.5$ and are served by any lanes, each of whom provide service at a rate $\mu = 0.8$. This is a $M/M/c$ Queue. $c = 3$, $\frac{\lambda}{\mu} = 1.875$, $\rho = \frac{\lambda}{c\mu} = \frac{1.875}{3} (< 1)$.

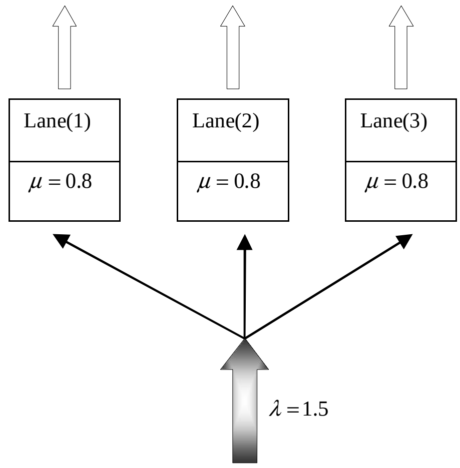

Figure 1. Three regular lanes

As Fig. 2 shows, if it goes from state 1 to state 0,that is one vehicle have been serviced and gone, the transition probability is μP_1; if it goes from state 2 to state 1,that is one vehicle in two lanes have been serviced and gone, the transition probability is $2\mu P_2$; in a similar way, if it goes from state n to state $n-1$, the transition probability is $n\mu P_n$ ($n \le c$) or $c\mu P_n$ ($n > c$).

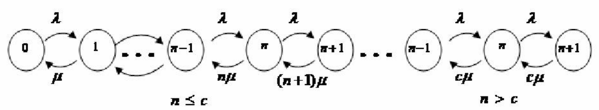

Figure 2. The transition probability

From Fig. 2, we obtain that

$$\begin{cases} \mu P_1 = \lambda P_0 \\ (n+1)\mu P_{n+1} + \lambda P_{n-1} = (\lambda + n\mu) P_n & (1 \le n \le c) \\ c\mu P_{n+1} + \lambda P_{n-1} = (\lambda + c\mu) P_n & (n > c) \end{cases} \quad (1)$$

Subject to $\sum_{i=0}^{\infty} P_i = 1$, and $\rho \le 1$.

With recurrence method, we obtain the solutions of these difference equations.

$$P_0 = \left[\sum_{k=0}^{c-1} \frac{1}{k!} \left(\frac{\lambda}{\mu} \right)^k + \frac{1}{c!} \bullet \frac{1}{1-\rho} \bullet \left(\frac{\lambda}{\mu} \right)^c \right]^{-1} \quad (2)$$

$$P_n = \begin{cases} \frac{1}{n!} \left(\frac{\lambda}{\mu} \right)^n P_0 (n \le c) \\ \frac{1}{c! c^{n-c}} \left(\frac{\lambda}{\mu} \right)^n P_0 (n > c) \end{cases} \quad (3)$$

The fundamental quantities of queue are as follows.

The average number of vehicles in the system

$$L_s = L_q + \frac{\lambda}{\mu} \quad (4)$$

$$L_q = \sum_{n=c+1}^{\infty}(n-c)P_n = \frac{(c\rho)^c \rho}{c!(1-\rho)^2}P_0 \quad (5)$$

With Little formula [9], we obtain the average amount of time a vehicle spends in the system W_q and the average amount of time a vehicle spends waiting in queue W_s.

$$W_q = \frac{L_q}{\lambda}. \quad (6)$$

$$W_s = \frac{L_s}{\lambda} = W_q + \frac{1}{\mu}. \quad (7)$$

A. The empty probability in the system

$$P_0 = 0.1322.$$

B. The average number of vehicles waiting in queue and in the system

$$L_q = 0.6457.$$

$$L_s = 2.52.$$

C. The average amount of time a vehicle spends waiting in queue and spends in the system

$$W_q = 0.43 \text{ s}.$$

$$W_s = 1.68 \text{ s}.$$

If every lane is full, the following vehicles must queue, the probability of waiting is $P(n \geq 3)$.

$$P(n \geq 3) = 0.3875.$$

When Olympic lane and bus lane be established, the vehicles should choose one lane to queue and not change lanes, thus there should be 3 lanes in one road. See Fig. 3.

The average rate of each lane $\lambda_1 = \lambda_2 = \lambda_3 = 1.5/3 = 0.5$ (per second), hence, the $M/M/3$ becomes to $3\,M/M/1$ [10].

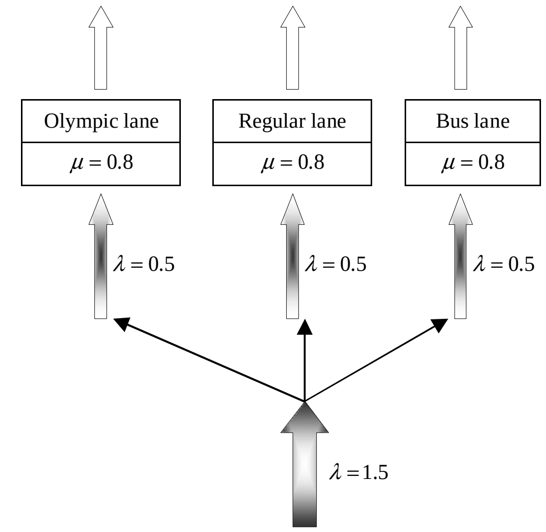

Figure 3. The Olympic lane, the regular lane and the bus lane

As Fig. 4 shows, if it goes from state 1 to state 0,that is one vehicle have been serviced and gone, the transition probability is μP_1; if it goes from state 0 to state 1,that is one vehicle have arrived, the transition probability is λP_o.

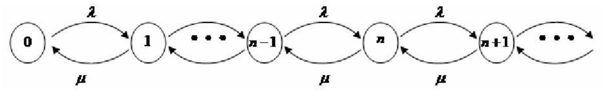

Figure 4. The transition probability

From Fig. 4, we obtain that

$$\mu P_1 = \lambda P_0 \quad (8)$$

$$P_n = (\frac{\lambda}{\mu})^n P_0 \quad (9)$$

Subject to $\sum_{i=0}^{\infty} P_i = 1$, and $\rho < 1$.

With recurrence method, we obtain the solutions of these difference equations.

$$P_0 = 1 - \rho \quad (10)$$

$$P_n = (1-\rho)\rho^n, n \geq 1 \quad (11)$$

The fundamental quantities of queue are as follows.

$$L_s = L_q + \frac{\lambda}{\mu} \quad (12)$$

$$L_q = \frac{\rho\lambda}{\mu - \lambda} \quad (13)$$

With formula (6) and formula (7), we obtain the following results.

A. The empty probability in each subsystem

$$P_0 = 0.625.$$

B. The average number of vehicles waiting in queue in each subsystem.

$$L_q = 1.04$$

C. The average number of vehicles waiting in the whole system

$$L_s = c(L_q + \lambda / \mu) = 5.01$$

D. The average amount of time a vehicle spends waiting in queue and spends in the system

$$W_q = 2.08 \text{ s}.$$

$$W_s = 3.33 \text{ s}.$$

For each lane, If it is full, the following vehicles must queue, the probability of waiting is $P(n \geq 1)$.

$$P(n \geq 1) = 1 - P_0 = 0.625 .$$

We list the solutions of $3M/M/1$ and $M/M/3$ in Table III.

Table III.

THE COMPARISON OF $M/M/3$ AND $3\ M/M/1$

Index \ Model	(1)$M/M/3$	(2)$M/M/1$
The empty probability in the system P_0	0.1322	0.375(each subsystem)
The probability vehicle must wait	$0.3875P(n \geq 3)$	$0.625P(n \geq 1)$
The average number of vehicles waiting in queue L_q	0.6457	1.04 (each subsystem)
The average number of vehicles in the system L_s	2.52	5.01 (the whole system)
The average amount of time a vehicle spends in the system W_s	1.68s	3.33s
The average amount of time a vehicle spends waiting in queue W_q	0.43s	2.08s

As Table III shows, the priority lanes unreasonably occupy the scarce road resources.

III. STRATEGIES AND RECOMMENDATIONS

Therefore, the mandatory establishment of priority lanes is not only indefensible morally, but also unreasonable economically.

A useful attempt is HOV lanes [11]. In transportation engineering and transportation planning, a high-occupancy vehicle lane is a lane reserved for vehicles with a driver and one or more passengers. These lanes are also known as carpool lanes, commuter lanes, restricted lanes, diamond lanes, express lanes, and are called transit lanes in Australia and New Zealand.

Qualification for HOV status varies by locality, and may require more than two people. When an automobile is used as an HOV, the group of people using it is often called a carpool, though the term HOV includes buses and vans. However, bus lanes may not necessarily be intended for use by carpools. An HOV or carpool may be allowed to travel on special road lanes, usually denoted with a diamond marking in the United States and Canada, on which vehicles not meeting minimum occupancy are prohibited, called restricted lanes, carpool lanes or diamond lanes.

Since drivers during peak hours do not have to bear the costs of the delay their presence on highways imposes, many drivers enter roads during peak hours. If a toll were charged during congested periods—and if it were set high enough—the number of drivers entering the road could be reduced enough to maintain rapid traffic flow.

The relative rarity of high-occupancy vehicles compared to single occupancy vehicles—estimated at 7% of the traffic—in the United States and Canada makes HOV lanes work for the drivers who can use them. When it is uncongested, an HOV lane can move at full speed even when parallel (non-HOV) lanes suffer delays from queueing at bottlenecks.

In theory, although the HOV lanes restricts some vehicles and waste part of the road resources, an HOV lane moves more people per lane at a higher speed while moving fewer vehicles. As a whole, it alleviates the road congestion and reduces the motor vehicle emissions effectively.

In practice for some communities, including Atlanta, Houston, Los Angeles, Washington, D.C., and Seattle, HOV lanes regularly carry more people than adjacent regular lanes of travel, as reported by the Transportation Research Board HOV Committee.

Various organizations and services make it easier for commuters to utilize HOV lanes. Regional and corporate sponsored vanpools, carpools, and rideshare communities give commuters a way to increase occupancy. For locales where such services are lacking, online rideshare communities can serve a similar purpose.

However, experience shows that the number of vehicles using HOV lanes is usually well below the capacity of each lane. Thus, HOV lanes are often underutilized.

Another approach is HOT lanes [12]. These are lanes that can be used by both high-occupancy vehicles (either without charge or with a reduced toll) and single-occupancy vehicles (with a variable toll during peak hours). The toll is determined by hourly vehicle flows and is set high enough in peak hours to keep the number of users down and, consequently, speeds of vehicles on the road up.

HOT lanes, however, do not eliminate peak-hour congestion on a crowded expressway, since such lanes comprise only a limited part of the road's total capacity. The normal lanes remain heavily congested during peak hours. But HOT lanes do provide all drivers with a choice of paying a toll and moving rapidly or using toll-free normal lanes and experiencing congestion. HOT lanes have been used successfully on State Route 91 in Southern California since 1995, where they have notably reduced commuting times on both the HOT and normal lanes.

HOT lanes work best on roads where there is heavy traffic and long delays during peak hours. Without such congestion, drivers would have little incentive to pay significant tolls.

To solve peak-hour congestion on a crowded expressway, we should use Express Toll Lanes [13] (ETLs). ETLs is a similar concept with HOT. The main difference between HOT and ETLs is that, in HOT lanes, HOVs are granted free access, whereas in ETLs all vehicles pay according to the same schedule.

Another solution is reversible lane. A reversible lane (called a counterflow lane or contraflow lane in transport engineering nomenclature) is a lane in which traffic may travel in either direction, depending on certain conditions. Typically, it is meant to improve traffic flow during rush hours, by having overhead traffic lights and lighted street signs notify drivers which lanes are open or closed to driving or turning.

In the United States and Canada, reversible lane markings are typically a dashed or broken double yellow line on both sides. Most often done on three-lane roads, the reversible lane is typically used for traffic in one direction at morning rush hour, the opposite direction in the afternoon or evening, and as a turning lane at most other times. There is also a transition period (typically 30–60 minutes) between reversals prohibiting traffic of any kind in the reversing lane, in order to prevent collisions. Sometimes, lane control signals are placed over the roadway at regular intervals (within sight of each other) indicating which lanes are allocated to which travel direction; a red X indicates the lane is closed or reserved for the opposite direction; a green arrow indicates a permitted travel lane. The center lane is marked with either one of those (depending on time of day), and often a flashing yellow X at other times to indicate an imminent closure of a lane, becoming solid yellow before turning red. Other setups had double-turn-lane signs backlit with white fluorescent lighting instead of the flashing yellow X.

To develop Low-Carbon Economy (LEC) [14], we should put more emphasis on environment protection, so we even could allow owners of qualifying Hybrid Vehicles to apply for a permit to use HOV lanes and HOT lanes. Qualifying vehicles must display the required HOV exemption decal and transponder. A hybrid vehicle is a vehicle that uses two or more distinct power sources to move the vehicle. The term most commonly refers to hybrid electric vehicles (HEVs), which combine an internal combustion engine and one or more electric motors. A hybrid lane could encourage people to use hybrid vehicles and reduce vehicle emissions.

IV. CONLUSION

Traffic management is a social system engineering, which is not only a matter of traffic management department, but needs the participation of the whole society. To solve the city's traffic congestion problem, we must improve the capacity of roads and transport facilities through proper planning and strong construction; adopt scientific and effective means, such as the use of intelligent transportation systems; improve the efficiency of transport facilities, so that each vehicle and each passenger can get traffic information at anytime, anywhere; improve traffic management, to solve the problem of order, such as the queue by signal control, that is the choice of passage right; distribute preferential right to high-occupancy or high-speed vehicles by economic methods. Believe that to learn the advanced traffic management technology and experiences from developed countries modestly, we can get rid of the rude and simple mode of city management, and achieve the goal of harmonious development of the whole society, and the interest of each motorist and each vehicle could be respected.

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