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PREFACE

Dear Readers,

Welcome to the March issue of Volume 7 of our online peer-reviewed International Journal of the Society of Transportation and Traffic Studies (JSTS). This issue presents 5 interesting papers from various countries, Indonesia, Sri Lanka, United States of America and Thailand. Two papers deal with road network development and ridesharing, an ongoing and emerging issues in developing countries. Two deal with the improvement of pavement materials which are becoming an issue as environmental concerns are putting constraints on the use of new natural resources. One interesting paper from the US, addresses the critical subject of road safety, Guidelines for Road Diet Conversions. Road diets are about conversions of four-lane undivided roads into three lanes (two through lanes plus a centre turn lane). The fourth lane may be converted to bicycle lanes, sidewalks, or on-street parking.

Again, we thank all authors who contribute to these issues of our journal and we express our gratitude to members of the International Editorial Board and reviewers for their valuable comments and continued supports. A big thanks must go to the Editorial staff under the guidance of Assoc. Prof. Dr. Jittichai Rudjanakanoknad and Assoc. Prof. Dr. Pawinee Iamtrakul who prepared the backroom work for this issue. We trust our readers will enjoy and benefit from the articles in our online publication.

With Best wishes from all of us,

Professor Pichai Taneerananon
Chair of Editorial Board

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General Issue

OPTIMIZATION OF MULTI-OBJECTIVE OUTBOUND LOGISTICS OPERATION

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Abstract: Distribution, one of major outbound logistics functions draws attention due to high cost incurred. This study investigates the planning of a real time distribution operation achieving three objectives simultaneously. Route optimization, truck utilization and equal delivery make-span have been accompanied in order to address the problem giving financial benefits to company and satisfying the stake-holders. It is a real challenge to fulfill these three objectives concurrently; however, this research provides promising solution for the problem combining both exact and heuristics techniques. Heuristics techniques exploits to cluster the customers ensuring equal delivery make-span and Dijikstra algorithm has been modified to generate optimal route in terms of distance and delivery quantity. Algorithm was developed in C++. Results reveal that proposed route planning reduces the cost by 11.5 % included with 50% reduction of fleet size and 37% saving of travel distance.

Keywords: Outbound logistics, Distribution, Exact, Heuristic

1. INTRODUCTION

Management of the logistics function is a crucial process for any supply chain as to function it efficiently and effectively. Under the phenomenon of globalization, deregulation, and time based competition the pressure for cost reduction and productivity improvement is ever increasing and a must for private companies as well as for the economy as a whole (Derigs, 2002). One of the most important aspects of supply chain management is maintenance of effective and efficient distribution network in order to fulfill customer requirements and expectations while achieving cost benefits. Efficient and effective logistic is all about providing the right products to the right place at the right time with the right cost (Lim, 2000).

Distribution network is an interrelated arrangement of people, storage facilities and transportation which brings products from producer to consumer. Good distribution can be used to achieve a variety of supply chain objectives ranging from low cost to high responsiveness. As a result, companies in the same industry often select very different distribution networks (Chopra, 2001).

A fast and reliable distribution network is essential for a successful company to provide goods and services to their customers right time with right quantities. Simultaneously they should highly force on distribution network optimization to sustain in highly competitive market. Complexity of the distribution networks are ever growing and in global context, therefore, many research studies have been conducted to optimize distribution network operations with efficient tools to support its decisions leading to a maximal service level at minimal costs.

According to the theoretical or mathematical programming view routing means the determination of optimum set of cycles within the graph or network. Different configurations of the underlying graphical structure, different objectives as well as different constrains have led researches to develop great varieties of optimization problems (Derigs, 2002). Optimization can be done considering single objective as well as multiple objectives. Mostly it would be cost optimization of distribution process. Moreover, the objectives may not always be limited to cost, it has extended to balancing of work load in terms of time and distance, capacity optimization can be taken into account by simply adding new objectives (Jozefowiez et al, 2008). Techniques used to solved mathematically formulated problems varies from exact algorithms to Meta-heuristics algorithms. Further many researches (Jozefowiez et al, 2008. Dharmapriya et al, 2012) accompanied hybrid of meta-heuristics in order to yield promising results in this context.

This study expands its focus into different objectives (Route optimization, truck utilization and equal delivery make-span) so as to address a current requirement of one of Sri Lankan companies. Due to the computational difficult of this problem both exact and heuristics approaches have been accompanied.

2. DATA ANALYSIS METHOD

2.1 Approaches

The proposed approach was developed integrating two main techniques such as exact algorithms and heuristics techniques at two different stages to achieve the objectives of the study.

Exact algorithm: Dijikstra algorithm was used to get the shortest path from Distribution Centre (DC) to Dealer point (DP)s. Dijikstra is the most efficient algorithm to get the shortest path for a single source problem. This algorithm itself can't provide a solution for the whole problem which only helps to derive the shortest path from DC to DP.

Heuristic Approach: To schedule the distribution operation with optimal assignment and equal delivery make-span, heuristic approach has been adopted by developing new order capturing policy. This was done with the experience gained by the current order capturing policy and redesigned it to achieve objectives of the study by accommodating average distances. New order capturing policy is given in Table 2.

2.2 Methodology

Figure 1 shows the steps of the sequential procedure of the entire methodology. Initially clusters were identified with the heuristics technique and routes were derived within the cluster upon vehicle capacity, size of the order and optimal sub structure concept. The steps of the algorithm are clearly explained in the example given below.

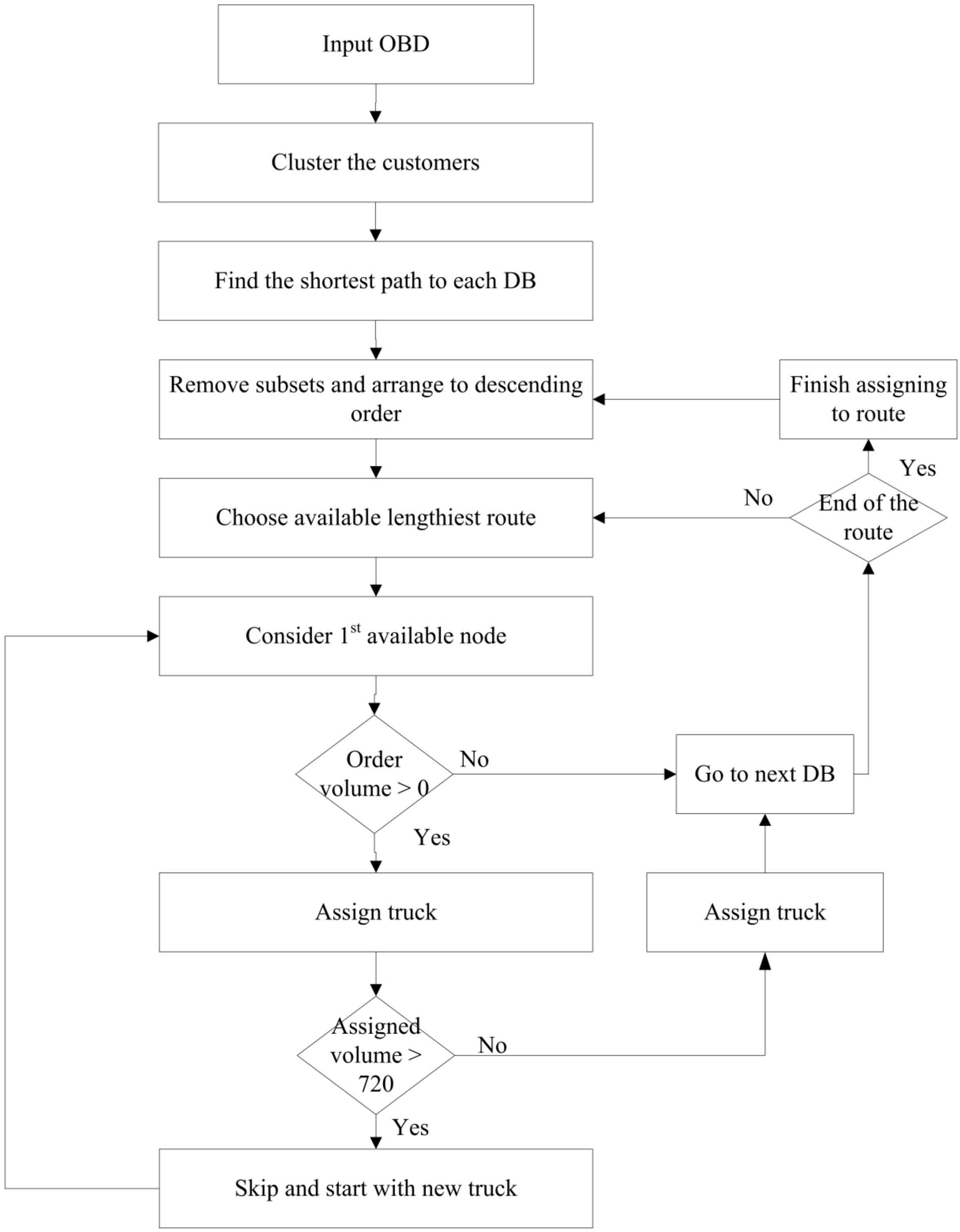

Figure 1. Flow Chart of algorithm

Example:

The steps of the proposed methodology are presented in Figure 1. Assume A,B,C,E,F,X,Y,Z,P,Q,R,S are DPs of network and O is the DC as indicated in Figure 2. Orders have been captured from all DPs except B and Y. Order placed by each DP is given in the Table 1.

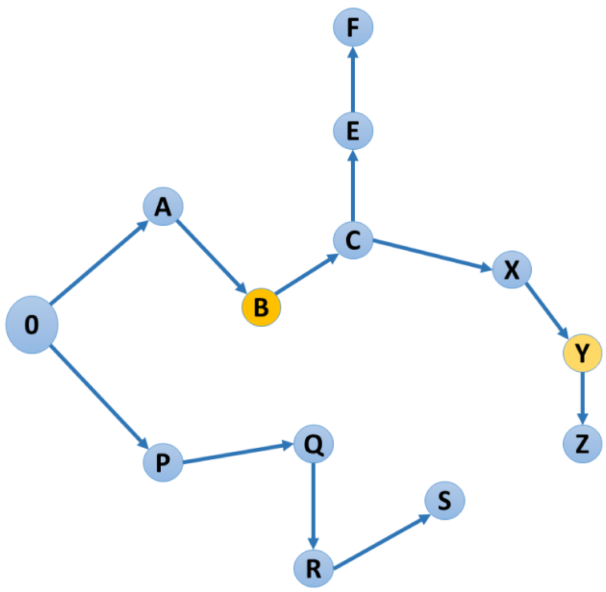

Figure 2. Example Network

Table 1. Example order volumes

A	250
B	0
C	240
E	210
F	285
X	222
Y	0
Z	274
P	212
Q	233
R	256
S	240

Step 1: Generating the shortest path from O to each DP using Dijikstra algorithm.

[O,A], [O,A,B,C], [O,A,B,C,E], [O,A,B,C,E,F], [O,A,B,C,X], [O,A,B,C,X,Y,Z], [O,P], [O,P,Q], [O,P,Q,R], [O,P,Q,R,S]

Step 2: Here author has used the technique called optimal substructure. If an optimum solution can be made from the solutions of its sub problems, it is called optimum substructure. Then these sub problems can be incorporated to main problem and remove these subsets and keep unique routes.

[O,A,B,C,E,F], [O,A,B,C,X,Y,Z], [O,P,Q,R,S]

Step 3: Re-arrange these routes according to the descending order.

[O,A,B,C,X,Y,Z], [O,A,B,C,E,F], [O,P,Q,R,S]

Step 4: These routes might contain the nodes which don't have orders. That means their order quantity is zero and they should be skipped when orders are assigned to trucks.

Start from the lengthiest route and assign orders to truck until its capacity exceeded. If truck capacity exceeded then next node should be started to assign a new truck and process continues until its capacity exceeded.

Truck 1:- [A+C+X] = [250+240+222=712]
Truck 2:- [Z] =274
Truck 3:- [E+F] = [210+285=495]
Truck 4:- [P+Q+R] = [212+233+256=701]
Truck 5:- [S] =240

In this example truck 1 and 4 have been allocated to full truck loads and truck 2, 3 didn't have suitable nodes to be paired since they were at the end of each route.

3. RESULTS

This section presents a comparison between the present system and the proposed schedule of the developed system on a sample of Outbound Delivery.

Case study: Sample 1

Order capturing policy

The entire distribution network was divided into 25 zones based on Sri Lankan district division and they were again assigned to seven days of the week referring to the average travel distance to each zone. Average distance to each zone is calculated by taking the average displacement of all dealer points within the zone. For example, if Zone A consists of 3 DPs called X, Y, Z with distances of 10, 20, 30 average was calculated by [(10 + 20 +30) / 3]. Accordingly, following order capturing policy was developed considering the kilometer range as indicated in Table 2. This is the primary heuristics mechanism of getting fairly equal length for each route.

Table 2. Order capturing policy

Day	Average kilometer range	Zones
Monday	0-51	Gampaha, Kurunegala
Tuesday	52-100	Colombo ,Kandy, Matale,Puttalam, Kegalle
Wednesday	101-150	Kaluthara, Nuwara Eliya, Ratnapura
Thursday	151-200	Anuradhapura, Galle, Polonnaruwa, Trincomalee
Friday	201-250	Badulla, Hambantota, Matara, Monaragala, Vavuniya
Saturday	251-300	Batticaloa, Kilinochchi, Mannar
Sunday	301-400	Ampara, Jaffna, Mullattivu

Table 3 shows a sample of outbound delivery has been fed to both current system and the developed algorithm.

Table 3. Sample Outbound Delivery

Code	DP	Demand (in cases)
90	Colombo 06	231
57	Colombo 3	198
91	Moratuwa	232
58	Mount Lavinia	199
59	Piliyandala	200
61	Polgasowita	202
56	Rajagiriya	197
60	Thalawathugoda	201
89	Battaramulla	230
86	Galagedara	227
34	Galaha	223
15	Kandy	204
40	Katugastota	229
14	Kengalla	203
80	Kundasale	221
33	Peradeniya	222
13	Teldeniya	202
87	Ukuwela	228
47	Chilaw	236
48	Nainamadama	237
46	Puttalam	235

Delivery plan for above delivery sample given by the transport coordinator of current system is given in Table 4. Table 4 summarizes the details of demand points, travel distance, size of the vehicle used and related transportation cost factor. Accordingly, 16 trucks have been assigned while travelling 1292km creating the transportation cost of Rs.144, 788.

The same sample was fed to the developed algorithm and results are shown in Table 5 in the same format of Table 4. The proposed system has given priority to 32 CBM trucks considering their economic of scale.

Table 4. Truck assignment under existing system

Demand points	Travelled distance (km)	capacity of fleet (CBM)	Transportation cost (Rs)
Battaramulla & Rajagiriya	68	22	8759
Colombo 3	63	16	7804
Colombo 06 & Mount Lavinia	72	22	8775
Thalawathugoda	74	16	7913
Moratuwa	79	16	8371
Piliyandala & Polgasovita	90	22	11091
Hettipola	40	16	5751
Peradeniya	89	16	8958
Kengalla & Teldeniya	110	22	12689
Chilaw & Putalam	106	22	12689
Ukuwela	104	16	7508
Katugastota & Galaha	109	22	12111
Kandy	94	16	9457
Galagedara	75	16	8500
Kundasale	102	16	9333
Nainamadama	21	16	5079
Total	1292.5		144,788.00

Table 5. Output of Program

Truck No.	Travelled distance (km)	Capacity of the fleet	Transport Cost
1	75	32	13050
2	94	32	16356
3	106	32	18444
4	117	22	14508
5	74	32	12876
6	113	16	12882
7	112	32	19488
8	118	32	20532
Total	809		128,136.00

Results were compared and presented in table 6 in terms of Total number of trucks used, travelled distance and transportation cost. According to the results presented Table 6, it is clearly shown that new algorithm has optimized the distribution network and order assignment. No of trucks have been reduced by 50% and total kilometers have been reduced by 37% compare to the existing system. Cost reduction is 11.5% and Rs.16,652 has been reduced from original value. This significance reduction of the proposed system is mainly due to the newly implemented operation policy, fully utilization of vehicle capacity and the selection of most economical vehicle.

Table 6. Comparison between existing and proposed system

Parameter	Existing system	Proposed system
No of Trucks	16	8
Total travelled distance (km)	1292.5	809
Total cost (Rs)	144,788.00	128,136.00

In addition to minimizing the transportation cost, one of the main objectives of this study is to derive routes with equal delivery makespan. Variation of the length of truck routes in the previous and the existing system is given in Figure 3 and Figure 4 respectively.

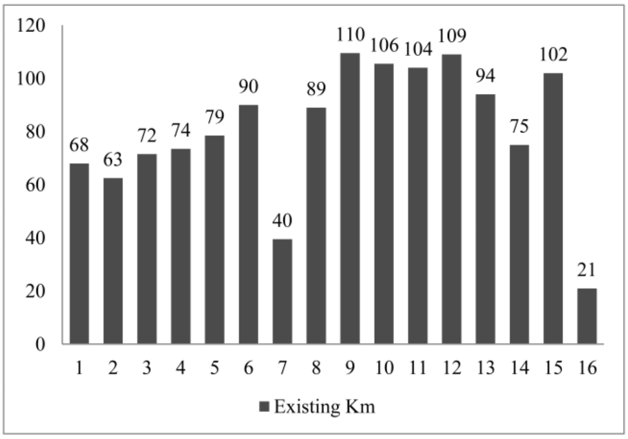

Figure 3. Distance variance of routes of the existing system

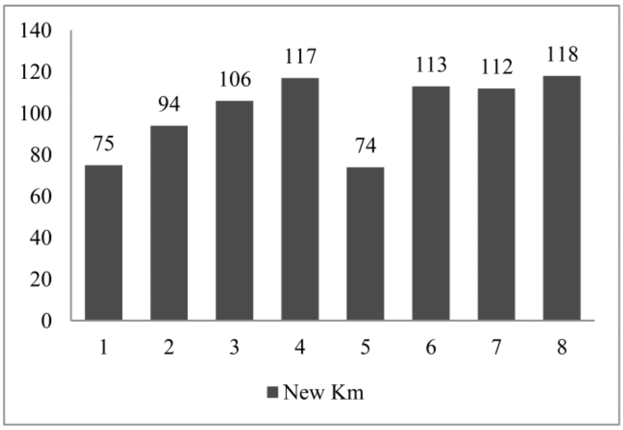

Figure 4. Travelled distance variance under new system

These results illustrate the success of proposed algorithm. Under existing situation there is a variation of 89km between lengthiest route and shortest route. But when it comes to the new system that variance has been reduced from almost 50%, which is from 89km to 44km.

4. CONCLUSION

This research has contributed to widen the boundaries of distribution optimization achieving three different objectives simultaneously. Practically, it is challenging to optimize the distribution operation with multiple objectives, however, using exact algorithms (Dijikstra) and heuristic approach objectives were achieved to a satisfactory level. Order coupling is done in the best possible way, reducing the fleet size by 50% and cost by 37%. Experience based heuristic approach ensures the total length of each route is within the acceptable km range. In addition, proposed system was able to distribute equal work load among the all transport contractors.

This research could be further developed by considering time window instead of equal delivery make span. However, distance is not the only factor affecting to same workload. Though the distances are similar there might be some routes which take more travel time than others due to traffic and road conditions. Therefore, time window would be more practicable solution to this kind of scenario.

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APPLICABILITY OF RIDESHARING USING PARATRANSITS: A CASE STUDY FROM A UNIVERSITY COMMUNITY IN SRI LANKA

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Abstract: Recent increase in number of singly hired para-transit usage in Sri Lanka favors ride shared para-transit modes. Applicability of ridesharing is studied in a selected corridor by examining the attitude of the passengers and drivers. The undergraduates of University of Moratuwa (passengers) were selected as the population and one of the access road (between Katubedda junction and university) was selected as the study area with Three-Wheel (3W) mode as common para-transit mode in Sri Lanka. Structured questionnaire was used to gather users (3W passengers) preference and drivers willingness along with road side survey on 3W movements to study the existing situation in the study area. The study focused on effects of ridesharing on three aspects while identifying barriers for ridesharing implementation; (1) demand for 3W, (2) monetary benefit for 3W operators and (3) Environment. It is found that implementing ridesharing with pool of three passengers and with fare of LKR (Sri Lankan currency-Rupees) 20 (less than ⅓ of the current fare, LKR 70) per head; (1) increases 3W ridership by 42%, (2) increases daily profit of the drivers by 13.3% compared to the existing (average vehicle occupancy=1.4) operating cost and (3) Reduces emission cost per user by 50% per passenger. Barriers to ridesharing from users are reluctant to share rides with unknown passengers (stranger-danger) and also with opposite gender while that of from operators is the fear from peer operators like other 3W drivers and bus operators. Implementing ridesharing is certainly a win-win case for both users and operators.

Keywords: Ridesharing, Para transit, Three wheel, User behavior, Questionnaire survey

1. INTRODUCTION

Ridesharing is not a new concept to the world's transportation. The roots of ridesharing goes back to the era of world war II where USA introduced 'car sharing clubs' to conserve resources, especially as rubber as it was a need of that era (Chan & Shaheen, 2012). Ever since, the concept of ridesharing has been used by people to protect resources to cope up with the challenges they faced. Today, it has evolved to the extent of 'technology enabled ride matching' where passengers can log on to websites to find another passengers who travel to the same destination.

The concept of ridesharing is a way of increasing the occupancy of the vehicle traveled and thus it will reduce the number of vehicle-kilometers traveled than a passenger travels individually. Also ridesharing is a promising approach to save the consumption of energy and it is a solution to assuage the traffic congestion while satisfying the transportation needs of the general public.

Three-Wheel (3W) is a commonly used Para-transit mode in Sri Lanka comparable to Tuk-Tuk in Thailand. 3W contribute 13.4% of all the vehicle modes in 2010 and it is tend to increase even further (DMT, 2013). The same trend is applicable to most of the other individually used modes such as cars. This may lead to higher traffic congestion, increased travel time and environment pollution due to the emission of greenhouse gasses.

As far as the impacts to the environment and safety are concerned, 3W is not the best mode for Studying for ride sharing. However, considering the nature of the selected study corridor (Figure 2), there are only two options available for captive riders namely bus and 3W. During morning (± 08:00am SL time) peak, when university community rushing towards the university, buses stopped at "Katubedda junction" at least for about 10 min to get it packed using higher demand which forces some, affordable, users to switch to 3W. With passengers this utilize the following aspects can be highlighted.

The objectives of the research were to (1) quantify the future demand for 3W under ridesharing, (2) identify monetary benefit for 3W operators and (3) quantify environmental benefit while attempted to identify barriers in implementing ridesharing.

2. CONCEPT OF RIDESHARING

Numerous number of studies have been done in the areas of ridesharing, passenger and operator attitude towards ridesharing, benefits of ridesharing and barriers to implement ridesharing. However, there were no previous research done on ridesharing using 3Ws in Sri Lanka. Most of the previous research is based on carpooling. In the developed countries, standard modes like cars and vans are used for ride sharing whereas in developing countries relatively cheaper modes are used for ride sharing (in this case 3Ws). Comparing car and a 3W for the purpose of ride sharing, both modes in terms of ride sharing have few commonalities; (a) Spatial limitation (route choice), (b) temporal limitation (time of demand need to fall into a window). Therefore, in this study, "car pool" and similar concept were reviewed for applying those to the '3W-Ridesharing'.

2.1 Types of Ridesharing

Ride sharing is considered under different concepts. Srivastava (2012) categorized it using car as depicted below in Figure1.

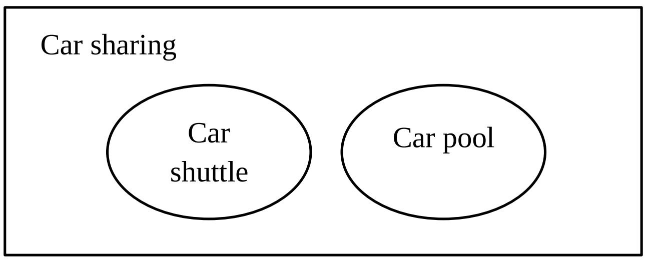

Figure 1. Venn diagram for Car Sharing, Shuttle and Pooling Relationship

Srivastava, (2012) explains that car sharing is a way of traveling which involves two or more passengers ride in a car. This category includes family trips, escorting friends who travel to the same destination or to a destination en route. Whereas car shuttle is about one or more passengers ride on the car for monetary considerations where there is a designated driver for the vehicle. Thirdly he explains about carpooling which is about a group of car owning people traveling in one vehicle regularly from one region to the other with a rotating basis of using their own vehicle. Comparing the above three explanations, ridesharing using 3Ws has more or less the same attributes which has in car shuttles.

2.2 Benefits of Ridesharing

It is imperative that passengers shift towards ridesharing only if there are clear benefits for them. This is also declared by Dewan & Ahmad (2007) and Horowitz & Sheth (1976), where they explain ridesharing will only increase significantly if there exist clear and direct incentives to the participants. Brownstone & Golob (1991) state that this is one of the function comes under Transport Demand Management (TDM) in USA, where they focus on the means which they can provide incentives to the passengers to promote ridesharing. Their research identifies the following four incentives / privileges that can be enjoyed by the commuters if they share rides;

- Reserved or other preferential parking for ride sharers.
- Direct carpooling and/or vanpooling cost subsidies by employers.
- Guaranteed rides home for ride sharers.
- Ability to travel on high occupancy vehicle lanes (HOV lanes)

Brownstone & Golob, (1991) claim that with all the above mentioned incentives, there would be a reduction in drive- alone commuters between 11 and 18 percent. Also it was found that commuters who have large households with multiple workers, longer commuters and larger work sites are more likely to ride share.

Horowitz & Sheth (1976) claim that studies on ridesharing incentives are based on the presumption that solo drivers can be induced to carpool by offering them direct incentives. Value of arrangement such as ridesharing is immense. Implementing real-time ridesharing in Beijing (China), 120 million liters of gasoline can be saved. The amount saved is equal to 2.3 million kilograms of carbon dioxide gas. Also this proposed service serves 25% additional taxi users while saving 13% of the total distance traveled as indicated by (Ma, et al., 2013). Dewan & Ahmad (2007) conducted a similar study and found that if carpooling system is implemented in New Delhi - India, it will be able to save 301,307 kiloliters of gasoline per year.

2.3 Barriers for Ridesharing

This section identifies the barriers towards ridesharing in the context of the countries such as USA, Canada. Amey (2010) identifies the challenges for ride share from a variety of perspectives which are described below.

2.3.1 Economic barriers

- Favorable economics of all other modes

Amey (2010) argues that ridesharing (in this research, author defines carpooling as ridesharing) has been challenged by the subsidies given for the other modes of transport (i.e. employer-paid parking, transit, vanpooling and cycling). It is discussed that parking subsidies are given to HOVs (High Occupancy Vehicles) to encourage ridesharing. But, with the employer-paid parking, employees will no longer feel the impact which parking price make on their disposable income and they tend to drive alone. Transits and van pooling can also be identified as modes of ridesharing which reduce the number of vehicle kilometers traveled in the network whereas cycling is an ‘emissions free’ mode of transport. Ergo transits, vanpooling and cycling can be identified as sustainable modes of transport as same as ridesharing (carpooling).

2.3.2 Social/ Behavioral barriers

- Stranger – danger

It is found that ridesharing between unknown travelers represents a small portion of shared-rides that takes place. According to (Amey, 2010), surveys have found that as little as 3% to 10% of shared-rides occur between / among unknown passengers whereas the majority of the shared-rides occur between / among family members, co-workers and neighbors. The statistics clearly states the phenomenon of 'stranger danger' has affected.

- Reliability of service

Amey (2010) points out that the perception of low reliability of the ride share arrangements is one of the largest behavioral challenges to overcome. Typically the passengers agree to share rides with a single driver for a long period of time with small changes as needed. In case the driver has an unexpected appointment of emergency, the passengers may not have a way to complete the return trip, which is unacceptable for many commuters. Both the passenger and the driver should understand the emergencies and adjust their perception to build-up the relationship over the time so that both of the parties will get benefited.

3. METHODOLOGY

3.1 Study Area

Access roads to the main entrance of University of Moratuwa were considered for this study to investigate ridesharing applicability. As depicted in Figure 2, among the three access roads (1) Campus road from Katubedda junction - AR1, (1) Campus road from Piliyandala - AR2 and Molpe road - AR3, AR1 was selected due to high 3W movements compared to others. There are two main three-wheel parks located at "Katubedda junction" and at the University. Two busses are being operated in the selected road link (route number 255, 255/1) with a 10 minute headway on average.

3.2 Sample of the Study

The population for this study was university community consists of staff members, post graduates and undergraduates of University of Moratuwa (6,000 students in total) as majority of the 3W users along AR1 are fall in to that category. The appropriate sample size was considered as 361 with 95%confidence level and 5% margin of error (Krejcie & Morgan, 1970) and the responses were collected from a structured online questionnaire. From the 3W number plate survey it was found that there are 37 three-wheel operate in the day time. From that a random sample of 17 three-wheel drivers were interviewed with the aid of structured questionnaire. The research was carried out in three stages (1) Online questionnaire survey, (2) road side number plate survey and (3) interview with three-wheel drivers.

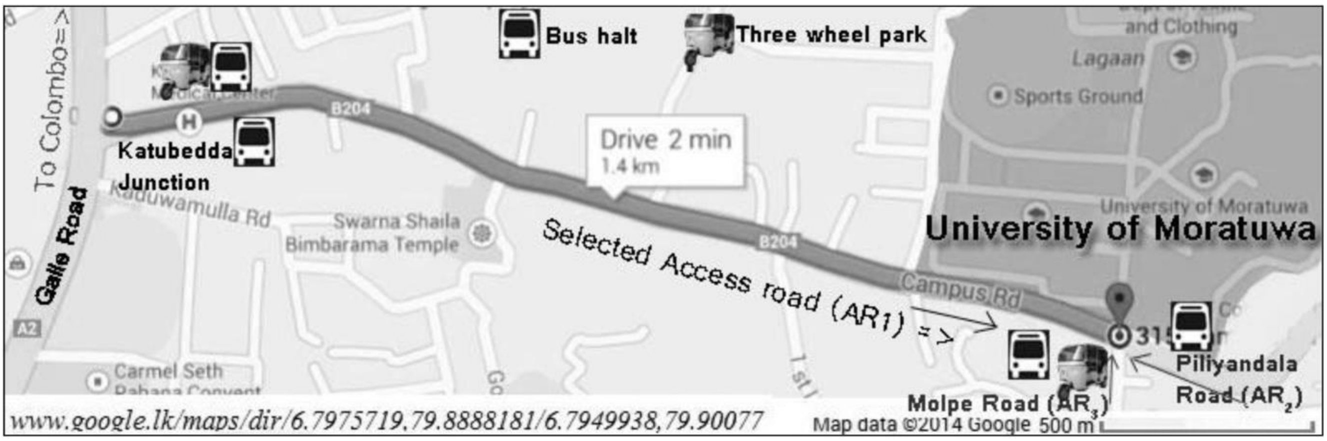

Figure 2. Location of the study area *(URL: http://goo.gl/maps/QvPEd)*

3.3 Online Questionnaire Survey for Passengers

An online questionnaire was prepared and circulated via emails to collect responses from the academic staff members, non-academic staff members, post graduates and the undergraduates of University of Moratuwa, who employed/studied in the university during the period of the research (Dec 2013 – Jan 2014). The online questionnaire survey was three fold. The first part of the questionnaire was addressed to collect passenger's demographics (age, employment category, income etc.) and present travel related characteristics (vehicle ownership, general access mode to the university etc.).

In the second part of the questionnaire, respondents were asked about their willingness to share ride under different circumstances given below;

- Sharing a ride with a friend(s).
- Sharing a ride with a person in university other than friends.
- Willingness to wait for some other person to join with rideshare.
- Willingness to share rides if one of the colleagues/ friends has already joined with ride sharing.

Seven level likert scale was used to identify the willingness of the passengers towards ridesharing.

Table 1. Measurement of variables and scale

Level	Level Value
Definitely will not	1
Very unlikely	2
Somewhat unlikely	3
Cannot say	4
Somewhat likely	5
Very likely	6
Definitely will	7

3.4 Three-wheel Number Plate Survey

A three-wheel number plate survey was conducted for 12 hours on a day time to identify the present 3W movements of the study area along with bus counts bus arriving and departing patterns were observed at the two bus stops adjacent to each 3W parks (as shown in Figure 2). The survey was conducted from 08:00am to 08:00pm on a Wednesday (18th Dec 2013). The survey was conducted using four enumerators who were strategically located at places so that the observer can observe both bus movements and 3W movements. Two of the observers gathered data about the busses (bus arrival time and departing time) and 3Ws (departing time, number of passengers on board) while other two observers observe only about the arriving time of the 3Ws and alighting passengers from each 3W.

This survey results were used to analyze the demand for 3Ws in different times of the day. Also it was used to identify the trips which were run between the selected access road and beyond the selected access road. These results were then cross-checked with planned interview with the 3W drivers (explained below). The average 3W occupancy was also measured using the data in order to identify the current situation along the selected corridor.

3.5 Personal Interviews With 3W Operators

Finally an interview was conducted with the 3W drivers from the 3W parks at Katubedda junction and in front of the main entrance of the university. The demographics factors of drivers and average daily trips operated within the selected corridor (AR1) were collected in addition to their opinion on ridesharing and barriers to it.

3.6 Analyzing the Effectiveness of Implementing Ridesharing

To calculate the variation of the trips under the existing system and proposed system of ridesharing, responders were asked a question about their current frequency as well as the future frequency of using 3Wers in the selected corridor. The below Table 2 shows the frequency related options given to the respondents and corresponding numerical values as per weekly basis.

The respondents were asked about their usage of 3Wers under the existing operating system and under ridesharing. In the existing system the vehicle occupancy can be vary from 1 to 3 depending on passenger's choice with LKR 70 per trip whereas in ridesharing it is expected to keep the vehicle occupancy at 3, so that 3 passengers can get together and share the fare. In ridesharing situation, it is expected to offer this service at a reduced fare of about LKR 60 which translates the fare per passenger as LKR 20. Based on Q1 and Q2, as given in Table 3, the respondents were subdivided into several categories as illustrated below in Figure 3.

Table 2. Frequency of 3W usage

Frequency	Frequency of trips per week
Never1/ Rarely	0
1 time / week	1
2 times / week	2
3 times / week	3
4 times / week	4
5 times / week	5
6 times / week	6
1 time / day	7
2 times / day	14
3 times / day	21
4 times / day	28

Table 3: Questions about trip frequency

(Q1) Existing system	(Q2) Ridesharing
In any case if you use a 3Wer for the last trip, how often do you use a 3Wer to complete the last trip? (Respondent were allowed to select a frequency as shown in Table 2)	If Three-wheel ride-sharing exists with reduced fare, what will be your future trip frequency using three-wheel? (Responder were allowed again a frequency from Table 2)

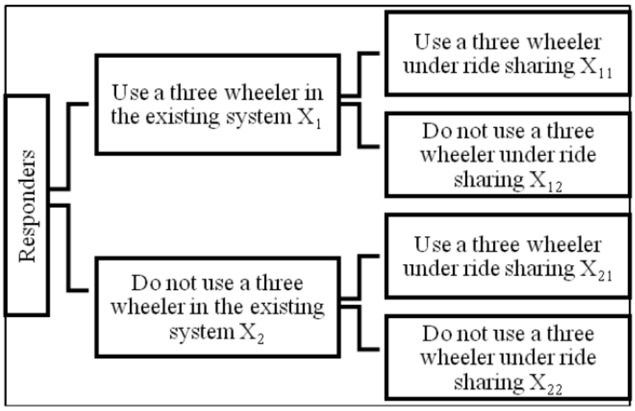

Figure 3. Method of analyzing the effectiveness of ridesharing

The above categorizations, shown in Figure 3, were elaborated below.

X1 : Expected number of trips by the students in the existing system

X2 : Expected number of trips by the students in the existing system who do not use a 3W to come to university (= 0)

X11: Expected number of trips by the students who continue to use a 3W to come to university when ride sharing is implemented.

X12: Expected number of trips by the students who do not willing to use ridesharing though they use a 3W in the existing system

X21: Expected number of trips by the students who newly attracted to 3W by the implementation of ride sharing

X22: Expected number of trips by the students who do not want to use 3W in any given method (= 0)

By multiplying the number of responses for each category (from Figure 3) with relevant trip frequency value (from Table 3), the expected number of 3W passenger trips can be calculated. The calculated total passenger trip divided by vehicle occupancy is the 3W demand (D) also known as number of 3W trip would be generated by the users. Therefore, existing demand for 3W (D_1) will be calculated using Equation 1 as given below where the current average occupancy of the 3W (O_1) was found to be 1.4 from road side occupancy count made during number plate survey.

$$D1 = (X_1 / O_1) \quad (1)$$

The future demand for 3W combined from normal and ridesharing (D_2) can then be calculated using Equation 2 as given below where ridesharing vehicle occupancy (O_2) is assumed to be three (3) while that of normal 3W (continued to operate under existing scenario) is assumed to be one (1).

$$D_2 = [(X_{11}+X_{21})/O_2] + X_{12} \qquad (2)$$

Ridesharing could be said applicable if newly attracted 3W demand (D_2 - D_1) promises the benefit to the 3W operators in terms of net profit.

3.7 Calculating the Environmental Impacts

The emission cost for any vehicle operates in a given corridor can be calculated by the Equation 3 (Kumarage & Weerawardana, 2013) given below. It has been taken in to account that volumes of specific emissions are directly proportionate to the quantity of the type of fuel consumed. The emission cost for a vehicle type j on a link k during the time period t can be expressed as;

$$TEC_{j,k,t} = V_{j,k,t} \times F_{j,t} \times E_{j,k} \times D_{j,k} \qquad (3)$$

Where:

$TEC_{j,k,t}$ = Emission cost by a vehicle type j on link k during time period t.

$V_{j,k,t}$ = Flow of vehicle type j on link k during time period t.

$F_{j,k}$ = Fuel consumed per unit distance traveled by vehicle type j at on a link k.

$D_{j,k}$ = Estimated value of emission cost per liter of fuel for vehicle type j at on link k

According to Department of National Planning of Sri Lanka (2001), it is calculated that the total emission cost per liter of fuel for a 3W was LKR 0.62.

4. RESULTS AND DISCUSSION

Altogether 364 responses were collected from the questionnaire survey and during data refining, there were 7 responses found with errors. Therefore only 357 (=364-7) responses were taken for the rest of the analysis. Out of those responses 334 responders were undergraduates of the University of Moratuwa. Since negligible number of responses from others (staff members and post graduates), the responses only from the undergraduates (334) were considered in this research. Out of the 334 responders, again only 189 responders were using the selected study corridor (AR1) to university thus this study analyzed only those 189 responses.

4.1 Future Demand for Three-Wheel Trip Under Ridesharing

The calculations based on the data collected is summarized in the table given below. The values which will be taken for the analysis is highlighted in Table 4.

Table 4. Summary of the data collected and calculations

Frequency		(1)		(2)		(1/1)		(1/2)		(2/1)		(2/2)	
Description	f	X_1	f X_1	X_2	f X_2	X_{11}	f X_{11}	X_{12}	f X_{12}	X_{21}	f X_{21}	X_{22}	f X_{22}
Never & Rarely (0)	0	0	0	119	0	0	0	0	0	0	0	34	0
1 time / week (1)	1	28	28	0	0	6	6	2	2	17	17	0	0
2 times / week (2)	2	14	28	0	0	11	22	0	0	28	56	0	0
3 times / week (3)	3	6	18	0	0	5	15	0	0	10	30	0	0
4 times/ week (4)	4	2	8	0	0	9	36	0	0	1	4	0	0
5 times / week (5)	5	2	10	0	0	10	50	0	0	1	5	0	0
6 time / week (6)	6	0	0	0	0	1	6	0	0	3	18	0	0
7 times / week (7)	7	10	70	0	0	13	91	0	0	13	91	0	0
14 times / week (14)	14	8	112	0	0	8	112	1	14	10	140	0	0
21 times / week (21)	21	0	0	0	0	2	42	0	0	2	42	0	0
28 times / week (28)	28	0	0	0	0	2	56	0	0	0	0	0	0
		Σ f X_1	274	Σ f X_2	0	Σ f X_{11}	436	Σ f X_{12}	16	Σ f X_{21}	403	Σ f X_{22}	0

Demand for 3W under existing and future could be then calculated using Table 4 and equations (1) and (2) as shown below.

D1 = (X1 / O1)
D1 = 274/1.4
D1 = 196 trips per week

D2 = [(X11+ X21)/O2] + X12
D2 = (436+403)/3 +16
D2 = 280+16 trips per week

Though calculation of future demand (D2) has two components (ride sharing and conventional 3W ride). The majority of the trips are generated through ride sharing (280) and while continued to using 3W under conventional method is only 16 and it is neglected for rest of the calculations.

The 'x' axis of Figure 4 represents the frequency of using a 3W per week while the 'y' axis on the left indicates the number of responses for each trip frequency in the existing system and ridesharing one and the 'y' axis on the right indicates the cumulative 3W trips traveled per week.

Based on interview conducted with 3W drivers, it was found that they run 15 trips on average in a given day. According to Figure 4, the cumulative trips traveled per week in the existing system is 196 while the cumulative trips per week in ridesharing has increased to 280. Therefore implementation of ridesharing will increase 42% ([280-196]/196) of the total trips traveled than in the existing system. With the increase of 42% of trips, a 3W operator will be able to increase his 3W trips on a given day from 15 to 22.

4.2. Monetary Benefit Three-Wheel Operators

According to daily basis calculation shown in Table 4, a 3W driver will have at least 22 trips per day if ridesharing is implemented. The Table 4 also attempts to calculate the monetary benefit in implementing ridesharing for a single operator per day where fuel economy* is assumed to be remained same even though weight (kg) carried under ridesharing would be higher than existing system as the vehicle occupancy increases. It is clear that ridesharing will increase their daily profits by 13.3%.

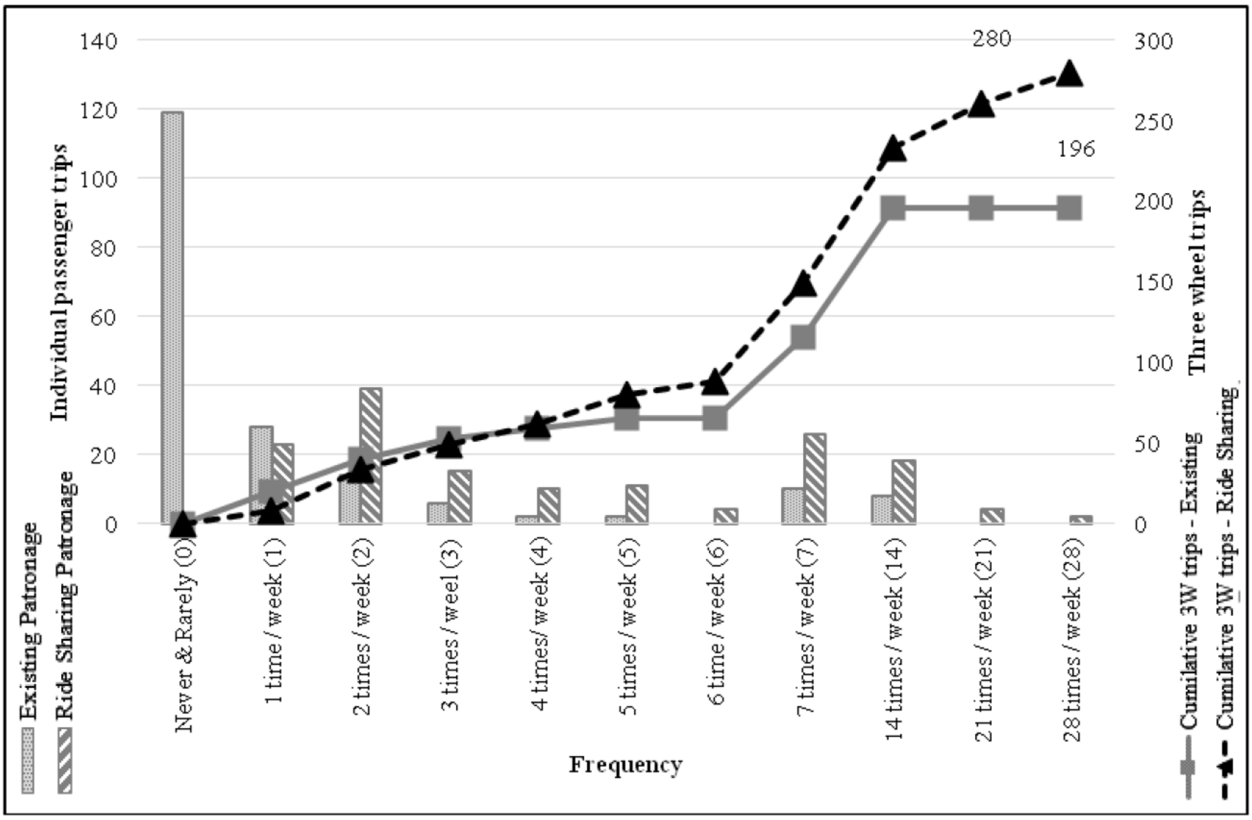

Figure 4. Comparison of Existing system and Ridesharing

Table 5. Monetary benefits to 3W operator on daily basis

Criteria	Calculation method	Cost elements		% increase / decrease
		Existing	Ridesharing	
Fare per trip (LKR)	a	70	60	14.2%↓
No of 3W trips	b	15	22	42%↑
Trip Distance – two way(km)	c	2.8	2.8	-
Fuel Price (LKR)	d	162		
Fuel Economy (km/liter)*	e	22 (Assumed same)		-
Maintenance cost (LKR per km)	f	1.92 (Assumed same)		-
Calculation				
Daily Income (LKR)	g = a×b	1,050.00	1,320.00	25.7%↑
Daily fuel usage (liters)	h = b×c/e	1.91	2.80	46.6%↑
Daily fuel expenses (LKR)	i = h×d	309.27	453.60	46.6%↑
Maintenance cost (LKR)	j = b×c×f	80.64	118.27	46.6%↑
Daily profit (LKR)	l = g-i-j	660.09	748.13	13.3%↑

Table 6. Conversion of Environmental Impacts into Monetary Values

Criteria	Calculating method	Existing	Ridesharing
Fuel Economy (km/ Liter)	a = Fj,k	15	22
Trip distance (km)	b = Dj,k	2.8	2.8
Number of Trips per week	c = Vj,k,t	196	280
Vehicle occupancy	d = O	1.4	3.0
Total number of passengers/week	g = Vj,k,t × O	274	840
Fuel Consumption per week (liters)	h = Vj,k,t × Dj,k / Fj,k	25.0	35.6
Per passenger fuel usage (liter / passenger)	i = F/E	0.09	0.04
Emission cost per liter of gasoline (LKR)	Ej,k	0.62	0.62
Emission cost per week (LKR)	TECj,k,t = Vj,k,t×Fj,k×Ej,k×Dj,k	15.5	22.1
Per passenger emission cost (LKR / passenger)	K = TECj,k,t /G	0.06	0.03

4.3 Environmental Benefit

Though implementation of ridesharing will increase the number of trips run by 3Ws in the selected corridor, it is quantified in Table 5 that ridesharing save both per user costs of fuel and emission (monetary value) approximately by 50%. The Equation (3) was used to calculate the emission cost per week.

4.4. Barriers for Ridesharing

4.4.1 Stranger – danger

The behavior of ‘stranger-danger’ is observed in this study based the responses from the online questionnaire. Cultural barrier from gender is also observed from Figure 5. Especially female users are reluctant to share rides with strangers when analyzing the cumulative curves.

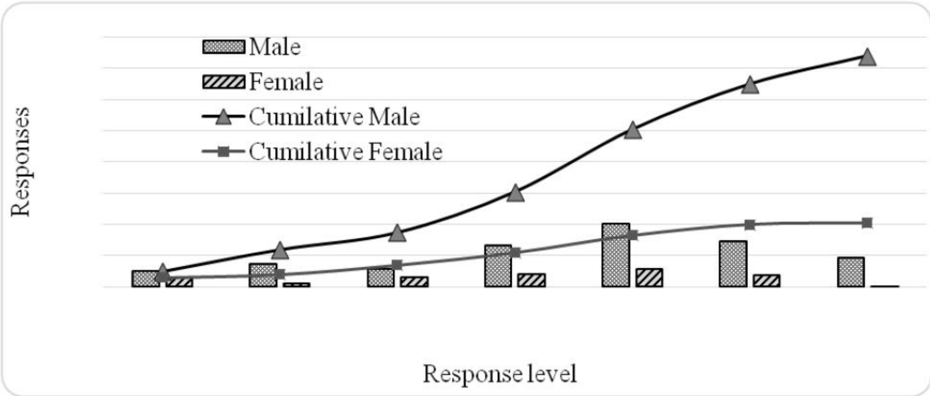

Figure 5. Willingness to share rides with strangers

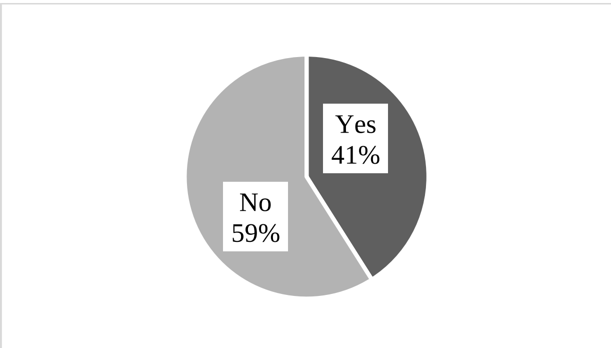

Figure 6. Willingness of operators to change to ridesharing

4.4.2 Reluctance to change

Explained the fact that ridesharing increases three-wheel trips to the drivers, the drivers were not convinced to brace the concept and implement ridesharing. Interview with drivers reveals that 59% (Figure 6) of the drivers were reluctant to implement ridesharing as they believe that there will be some 3W operators will continue to operating under current model and then it turn out to be peer pressure for ridesharing operators. They also mentioned that implementing ridesharing may create issues with the bus operators as more passengers would shift for 3W from bus thus reduces income for bus operators.

5. CONCLUSION

Based on research analysis and findings, implementing ridesharing is certainly as a win-win case for both users and operators and ridesharing is highly applicable along this selected corridor with following proven benefits;

- Increases future demand for three-wheel (ridership) under ridesharing by 42%,
- increases daily profit of a driver by 13.3% under ridesharing with vehicle occupancy of 3.0 and fare per trip of LKR 60, translated to LKR 20 per head, compared to the existing operation with average vehicle occupancy of 1.4 and fare per trip of LKR 70,
- Energy efficient by saving about 50% of fuel cost per passenger while saving emission cost per user also by 50%.

Users from Sri Lanka shows the following barriers in implementing ridesharing; (1) Attitudinal issue of 'stranger-danger' (insecure feeling with unknown passenger) and (2) cultural issue of 'gender' (dislike to travel with opposite gender) while 3W operators are also reluctant to implement ridesharing as they believe that there will be some 3W operators will continue to operate under current model and then it turn out to be peer pressure for ridesharing operators. They also mentioned that implementing ridesharing may shift a portion of passengers from 'bus' to '3W' and they believe this would create unnecessary problems between 3W operators and bus drivers.

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GUIDELINES FOR ROAD DIET CONVERSIONS

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Abstract: Road diets, which convert four-lane highways to three-lane cross sections, are an innovative solution to address mobility and safety concerns under budgetary constraints. These improvements can assist in the development of multimodal corridors with minimal impact on automobile mobility, while retaining the original right of way. Past research has focused on evaluating road diet safety, but minimal guidance exists on determining when such conversions are appropriate from an operational perspective. The proposed guidelines focused on evaluating and comparing the operation of three- and four-lane roads at signalized intersections to provide basic guidance as to when the road diet conversion is appropriate. One of the important findings of this research is the expansion of the usable range for road diets. Prior experience has limited road diet application to roadways with ADTs less than 17,000 vehicles per day. This research identifies the importance of side street volumes and supports the utilization of road diets on roadways with volumes up to 23,000 vehicles per day. This paper provides comprehensive guidance for road diet evaluation including operational performance, correctable safety problems and identifies a list of evaluation elements that should be examined when in-depth analysis of alternatives is required.

Keywords: Road diets, safety, highway design

1. INTRODUCTION

Rural and urban roadways are becoming increasingly congested throughout the US and other countries, and solutions frequently seek to improve modal options including, bike, pedestrian and transit facilities. A typical approach for solving this problem has been the addition of lanes, but this approach is an expensive and environmentally disruptive practice that frequently offers only short-term relief. The need for innovative solutions in addressing mobility and safety concerns in an environment with budgetary constraints is paramount. Such innovative solutions seek to develop multimodal corridors while retaining the original right of way and among them is the concept of road diet, where the number of travel lanes is reduced. Road diets usually involve restriping a four-lane undivided road as a three-lane road with two through lanes and a two-way left-turn lane (TWLTL). This creates surplus roadway width that can be used to widen existing lanes, create bicycle lanes, supply on street parking, widen sidewalks, or provide opportunities for landscaping and aesthetic improvements.

On roadways with high access density, the inside through lane on a four-lane undivided roadway often acts like a de facto turn-lane. This operation can block through traffic, diminishing operations, as well as introduce crash patterns such as rear end crashes and sideswipe crashes resulting from the stopped left-turn traffic. The introduction of a TWLTL can often meet the left-turn demand for both directions of travel in a single lane. This modification can then improve safety and mobility by removing turning traffic from the through lanes. Therefore, road diets are a design tool that can be used within existing right of way at a very low cost to improve mobility, and they frequently have no or few negative impacts.

Road diets have been shown to improve operating efficiency and safety for all users. Case study review has shown road diets to be effective on roads with an average daily traffic (ADT) of up to 25,000 vpd, while other studies have indicated that capacity is not affected by the elimination of the lane and often no increase in congestion is observed (Burden and Lagerway 1999; Welch 1999). Improvements in livability conditions and associated benefits are elements to be considered during road diet conversions, as review of past case studies has indicated (Rosales and Knapp 2005). Road diets make it easier for pedestrians to cross the road at both signalized and unsignalized intersections, increase feeling of a "safer and more comfortable" street, encourage an increase in pedestrian and bicyclist traffic, and encourage economic growth and redevelopment at a quicker pace (Rosales and Knapp 2005).

Past research has focused primarily on case study evaluation of road diets and on safety performance of these treatments. However, there is little literature providing guidance on the details of the designs or information as to when such conversions will work. The first attempt in defining operational guidelines for road diet conversions was completed in 2001 relying on evaluating before-after conditions on existing road diet projects completed at that time (Knapp and Giese 2001). The study recommended that a road diet conversion could be considered feasible for roads with an ADT between 15,000 and 17,500 vpd. A more recent attempt to improve on these guidelines was completed in 2006 again based on assessing existing road diets and identifying associated benefits (Rosales 2006). However, the step-by-step process developed is general in nature and does not provide specific guidance regarding volumes or left-turn percentages indicating when such a project could result in improved operational and safety conditions.

The need to identify criteria to be considered for establishing road diets is critical and should be addressed so that state and local agencies can expand their use. A review of all State DOT design manuals did not identify any guidance for road diet conversions, which can hinder their adoption. This study provides such guidance in determining the appropriateness of road diet conversions and identifies parameters to be considered during such evaluations.

2. METHODOLOGY

Typically, road diet conversions will operate at acceptable levels as long as the signalized intersections do not present any operational problems. Therefore, this analysis focused on evaluating and comparing the operation of three- and four-lane roads at signalized intersections. In order to adequately evaluate signalized intersection operations, a full range of mainline and side street volumes, as well as left turn percentages, needed to be evaluated. Evaluation of a full range of these parameters examines a wide array of the potential operating conditions for road diet roadways. The analysis conducted through micro simulation to compare operational performance of three-lane and four-lane sections through the full range of volume combinations. A total of 480 combinations were used for the simulations, i.e. 10 volume scenarios for eight left-turn percentages and six cross street volumes. These scenarios included:

- Mainline volumes ranging from 6,000 to 24,000 vpd with 2,000 vpd increments and assuming that 10 percent of the volume will occur during the peak hour. One directional split (50/50) was utilized.
- Cross street volumes were varied between 3,000 to 13,000 vpd with 2,000 vpd increments. There was only one directional split (50/50) and a 10 percent estimate of left and right turns was used.
- Left-turn percentages were used ranging between 5 to 40 percent with increments of 5 percent.
- Right-turn percentage was set at 15 percent and not varied as right-turn volume has minimal effect on capacity of the through movement.
- All cross-street scenarios utilized a three-lane cross-section which limited the capacity of the cross street.

Simulations were performed with the CORridor SIMulation (CORSIM) and vehicular delay was calculated for each approach independently. The data obtained from the simulation analysis was then used to develop predictive models of intersection delay that could be used in establishing potential guidelines for the implementation of road diets. The Statistical Package for the Social Sciences (SPSS) was utilized to develop these models.

3. RESULTS

The analysis completed here was used to develop prediction models that could allow for establishing guidelines and identifying the conditions under which road diets could improve the operational efficiency of the roadway. Linear regression models were used to model the delay for each condition, i.e. three- and four-lane options, and identify the variables that could predict these differences. The variables considered include the volumes of the main and side streets as well as left-turn percentage.

The model for the three-lane included all three variables of concern and had a good predictive power with an R2 of 0.48. The model coefficients are summarized in Table 1. The four-lane model also utilized all three variables but the predictive power was lower (R2=0.28). The variables included in the equations reflect the effect of traffic volumes on delays and their signs indicate that increasing volumes will result in greater delays. The same is true for the left-turn percentage where larger percentages will lead to greater delays.

Table 1. Coefficients for Predictive Models

Variable	Three-lane		Four-lane	
	Parameter	P value	Parameter	P value
Intercept	-29.113	0.00	-47.968	0.00
Main street volume (vph)	0.013	0.00	0.022	0.00
Side street volume (vph)	0.025	0/00	0.037	0.00
Left-turn percentage (number)	0.313	0/00	0.314	0.00

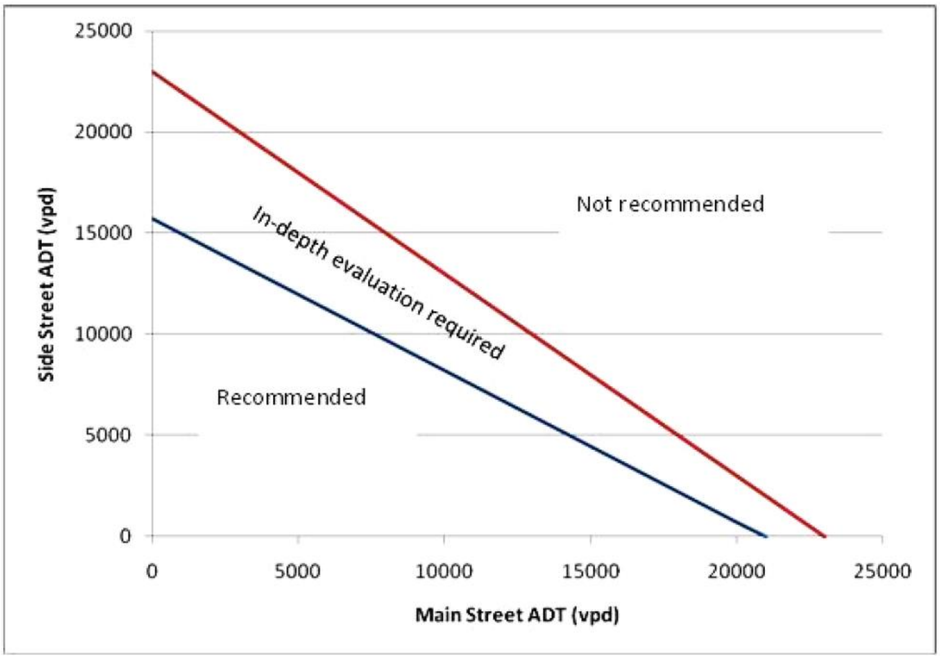

Figure 1. Guideline for operational performance at signalized intersections

These models can be used to define the scenarios where the three- and four-lane options produce a delay difference of zero, i.e. both options will perform equally well. This will produce the line of equality which can then be used to establish the regions where road diets are advisable and those where they are not. Figure 1 presents this concept with the blue line identifying when delays are the same for both options. The combinations below the blue line indicate lower delays associated with the implementation of a road diet. The red line in the figure identifies the volume combinations where the roadway will operate under capacity with a road diet and is based on the critical lane volumes between three and four-lanes are equal. Utilizing these concepts, Figure 1 defines three areas with respect to road diet installations. The lower area called "Recommended" identifies the volume combinations where the road-diet will perform below capacity and result in operational gains. The upper area "Not-recommended" identifies the volume combinations where the roadway will operate above capacity, and will have higher delays than the four-lane alternative. Undesired congestions could be the result from a road diet operating in this range. The area between the two lines is considered as the area requiring additional investigation to determine the feasibility of a road diet conversion. A road diet in this area will operate under capacity, but may have higher delays than the four-lane section. Thus analysis should be completed to determine the impacts that would result from the road diet.

The operational guidance developed is based only on main and side street volumes, since it was determined that the operation of the signalized intersection is the critical aspect for a road diet conversion based on the analysis conducted here and since road diets will result in improved conditions at unsignalized intersections. While left-turn percentage was shown to be a significant parameter for the capacity and delay of an intersection, it has the same effect for both the four-lane and three-lane sections and therefore provides no differentiation between the alternatives, i.e., the left-turn percentage does not contribute any additional delay to the difference between the two options.

The evaluation of the unsignalized intersections indicated that for all scenarios evaluated, the road diet results in lower delays along the side street, which could outweigh the minor increases along the main street. It was therefore deemed appropriate to not develop a similar guidance as the one shown in Figure 1 for unsignalized intersections. Therefore, unsignalized intersections or access points are not a significant determinant of the success or failure or a road diet project. Even unsignalized access points with high volumes of left turn traffic on the major street will continue to operate at acceptable levels of service while signalized intersections may fail due to the reduced mainline capacity. The primary concern for unsignalized access points is overlapping left turn movements within the two-way left turn lane, which is avoided with the four-lane section. The existing KYTC auxiliary turn lane policy currently addresses this concern by recommending against the use of TWLTLs for access point densities greater than 85 access points per mile (KYTC 2009).

4. GUIDELINES

The data analyzed here was utilized to develop guidelines for road diet conversions. The guidelines have been developed as a standalone document and they can be used to determine the steps required for a road diet conversion (Stamatiadis et al. 2011). A brief description of the guidelines is provided here.

4.1 Road Diet Conversions

The guidelines focus on the determination of whether a road diet application is appropriate considering operational, safety, and other factors that could have a bearing on the decision to implement a road diet conversion. To achieve this, a flow chart was developed that identifies the various steps to be taken when such decision is evaluated (Figure 2).

The flow chart allows the user to identify the appropriate action to be undertaken to determine whether the road diet will improve the operations, safety or other performance issues. To address this, lists of possible problems correctable by a road diet implementation are identified (Table 2). In addition to these lists, the required items for conducting an in-depth evaluation are also identified in order to allow for a complete evaluation of the implications from a road diet implementation.

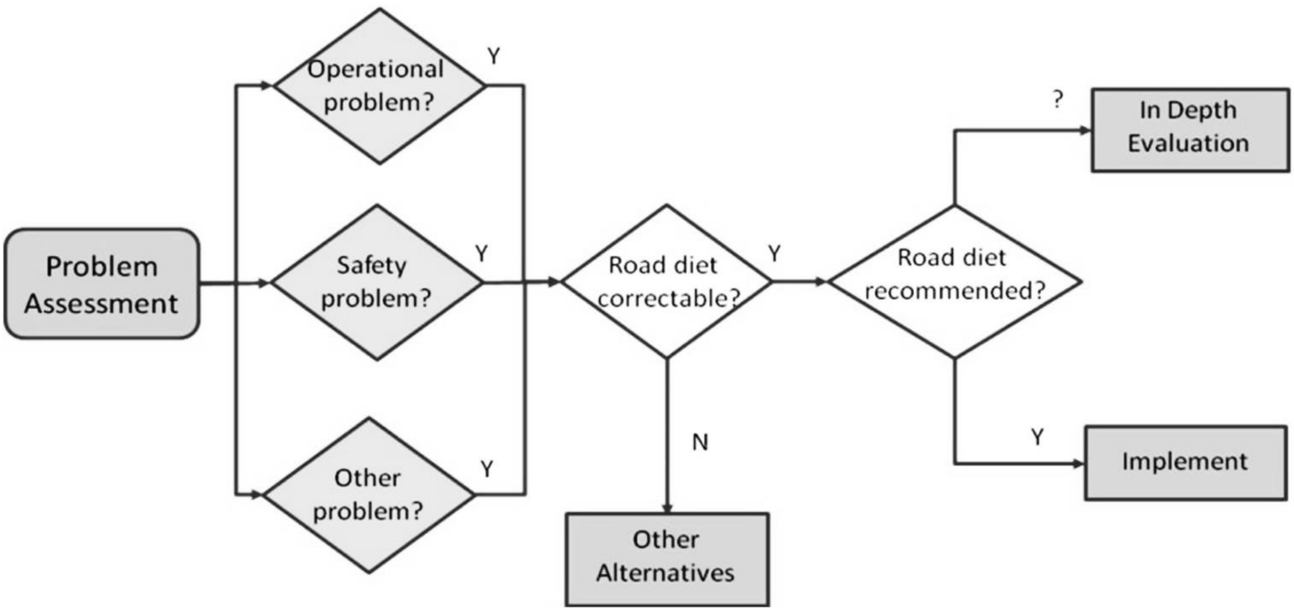

Figure 2. Decision-Action Flow Chart for Road Diet Evaluations

Table 2. Road Diet Correctable Problems

Category	Problem	Rationale
Operational	Delays associated with left-turning traffic	Separation of left-turning traffic have shown to improve delays at signalized intersections
	High side street delays at unsignalized intersections	Side street traffic requires shorter gaps due to the consolidation of left-turns into one lane
	Other operational problems	Potential inclusion of bicycle lane could reduce delays
Safety	Rear end crashes with left-turning traffic	Removal of stopped turning vehicles from the through lane could reduce rear end crashes
	Sideswipe crashes	Elimination of need to change lanes to avoid delays behind a left-turning vehicle in the inside through lane reduces sideswipe crashes
	Left-turn crashes due to offset left turns	Elimination of the negative offset between opposing left- turn vehicles and increase of available sight distance reduces left-turn crashes
	Bicycle and pedestrian crashes	Bicycle lane separates bicycles from traffic; pedestrians have shorter distance to cross and can use a refuge area (if one provided)
Other	Bicycle/pedestrian accommodation due to lack of facilities	Opportunity to provide appropriate or required facilities increasing use by such users
	Aesthetics	Provision for landscaped medians and other treatments as see fit
	Traffic calming	Potential for uniform speeds and consistency; opportunity to encourage pedestrian activity

4.2 Road Diet Considerations

Typical considerations for road diet conversions include traffic volumes of the main and side streets and main street left-turn percentages. However, compatibility of the treatment with roadway functional classification, access frequency and land use should also be considered when determining the feasibility of a road.

Road diets may be proposed to address both safety and operational issues on roadways. The guidelines provide criteria to be considered in determining whether a road diet conversion is appropriate. These criteria include operational performance ranges that would support a road diet project as well as safety considerations that need to be evaluated. The operational performance identifies three ranges: 1) Volume combinations where the road diet is recommended because it will improve the operational performance (i.e. delays will be lower with the road diet), 2) Volume combinations where the road diet is not recommended because the operational performance deteriorates (i.e. delays will increase), and 3) Volume combinations where an in-depth evaluation is needed. The last range identifies cases where the road diet will operate under capacity, but may have higher delays than the four-lane section. Thus analysis should be completed to determine the impacts that would result from the road diet.

The crashes that could be affected by a road diet implementation were also identified. These included:

- Sideswipe crashes, which can result from vehicles changing lanes to avoid delays behind a left-turning vehicle in the inside through lane. These types of crashes can occur at midblock access points and major intersections. Road diets eliminate these types of crashes by removing the turning vehicle from the through lane. Sideswipes can also occur between vehicles traveling on the two-way left-turn lane and those attempting to enter it but these crashes are not a frequent occurrence as prior research and case studies indicate.

- Rear end crashes, which can be the result of vehicles traveling in the inside through lane behind a stopping or stopped left-turning vehicle. A road diet reduces these types of crashes by removing the stopped turning vehicle from the through lane. Road diets are anticipated to reduce rear end crashes on roadways with high volumes of left-turn traffic; however, increased congestion resulting from the lane reduction may increase rear end crashes on the main street under other conditions.
- Left-turn crashes, which can result from restricted sight distance caused by opposing turning traffic. Road diets address these types of crashes by providing a dedicated left turn lane and correcting the negative offset between opposing left-turn vehicles.

There are additional elements that should be considered when road diets are evaluated including:

- multimodal operations, which can be improved with the implementation of a road diet,
- pedestrian safety, which can be improved with the addition of the refuge within the two-way left-turn lane,
- operational consistency where more uniform speeds along the corridor can be achieved, and
- livability, which can be improved by increasing opportunities for residential and commercial growth with a road diet.

4.3 Design Considerations

Various design aspects of the road diet conversion have been identified including recommended cross sections (dimensions of elements and possible components) along with methods to properly transition to and from the road diet to the existing roadway cross section. Transitions are recommended to occur at major change points, such as intersections, since they could allow for a more appropriate accommodation of turning movements. However, if necessary, transitions can occur at midblock sections, where it is recommended to place this away from intersections and/or high volume access points that would place stopped turning traffic in the through lanes of the merging traffic.

If not designed properly, these transitions can increase crashes removing any safety benefit of the road diet. All transitions should follow AASHTO’s Policy on Geometric Design for Highways and Streets and MUTCD guidance for the reduction of through lanes.

An additional design issue of concern is the potential of high access densities to increase the likelihood of conflicts between traffic turning into and exiting the access point. This could affect safety along the corridor, since there is the potential for rear end crashes from vehicles slowing down to negotiate entering the access point and overlapping of left-turns between the main street and adjacent access points. According to KTC Auxiliary Turn Lane Policy, a non-traversable median and turn restrictions are recommended when a corridor exceeds 85 access points per mile (based on number of access points on both sides of the street).

Prior to the implementation of a road diet, it is recommended that a capacity analysis be completed for the major signalized intersections on the corridor to ensure that they would operate acceptably with a revised lane configuration. Analysis based on Highway Capacity Manual (HCM) methodologies is sufficient to check intersection capacities. For special cases, such as closely spaced intersections, coordinated signal systems, or corridors with at-grade rail crossings, micro-simulation is recommended to adequately evaluate arrival patterns and queue formation and dissipation.

4.4 Road Diet Not Recommended

The guidelines provide a list of conditions when a road diet may not be appropriate. These conditions include corridors where the operational efficiency may degrade as a result of the road diet, corridors where at-grade rail crossings or other conditions exists that may create queues that require a long time to dissipate; and high crash rates resulting from conditions not correctable by road diets. The latter condition reflects cases where crashes such as right angles are a problem. The use of a road diet will not address such crashes. Other scenarios include cases where adequate transitions cannot be developed or if left-turn lanes already exist on the corridor.

The expert panel analysis was the next safety analysis performed for each case study using all the information and analyses conducted as input. The expert panel reviewed each documented crash after the completion of the given project and determined the potential influence of project design features on crash. This approach utilized specific crash data (including location, crash type, environmental conditions, etc.) and the expertise of panelists, who first examined the potential influence of the driver, roadway, environmental, and vehicular factors on crash occurrence. The second examination determined the likelihood of the crash being associated with the project design and to each design element. The expertise of the panel included highway safety, highway design, planning, project development, crash reconstruction, traffic operations, and human factors.

5. CONCLUSIONS

This paper provides the background and process used to develop a set of guidelines to determine when road diet conversions are feasible. A structured approach was followed that considered the operational evaluation of three- and four-lane roads and identified parameters significant to the successful operation of road diets.

An important aspect of the work completed here is the extension of the usable range of volumes where road diets could be beneficial. Past work recommended their application for roads with an ADT up to 17,500 vpd. The current research indicates that such conversions could work for roads with greater volumes, up to 23,000 vpd. Moreover, the findings here identify the effect of the side street volume, indicating that both volumes need to be considered when determining whether such a conversion should be considered.

Road diets may also improve the operational efficiency of signalized and unsignalized intersections on a corridor. Operational improvements are typically seen when high ADTs and high left-turn percentages are present on the primary and cross-street. Typically road diets are shown to have reduced delays and reduced queues when high left-turn percentages AND high volumes are present.

The data analysis focused on the safety and operational characteristics of each case study and is based on the before and after crash analysis, the crash type expectation analysis, the speed comparisons, and the expert panel analysis. The overall results for each case study are presented in Table 2, where the safety, operational, and expert panel analyses are summarized. The safety and operational results are assessed relative to their influence on safety with a designation of an algebraic sign (+ or -) to denote the differences between the after and before conditions of the project and statewide differences. The negative numbers indicate an improvement in safety or a lower operating speed than the design speed. The positive cells are also shaded to highlight the cases where deterioration in safety was noted or the operating speeds were higher than the design speed. Finally, the expert panel scores are presented for each case study (scoring range 0: no influence, 1: least influence, 5: most influence).

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GUIDELINES FOR THE IMPLEMENTATION OF BICYCLE LANES ON SRI LANKAN HIGHWAYS

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Abstract: Bicycle lanes have become an integral part of the highway networks of many countries including Sri Lanka. They are encouraged as a pollution free, economic and healthy mode of transport throughout the world. So it is high time that a proper guideline for the same is introduced taking into account the local conditions of this country. Bicycle lanes are so far introduced to the road projects of Sri Lanka on ad hoc basis without consideration of the proper guidelines such as continuation of bicycle lanes on the road network, intersection treatment, avoidance of abrupt termination etc. Sri Lanka being a developing country with more or less a feudal framework of thinking, there is a social stigma towards the bicycling as a poor man's vehicle. In such a context, how should a design engineer in cooperate this green technology into our local highway projects so the common man can be immensely benefitted and our cities will be left with some fresh air to breath in the coming days of the future? This research was aimed at addressing these issues and finally coming up with a proper guideline to implement bicycle lanes in the future road projects carried out by Road Development Authority.

Keywords: Bicycle lanes, Bicycle lane design, Non motorized transport

1. INTRODUCTION

1.1 General Background

Bicycle lanes are introduced to Sri Lanka as an integral part of the highway network. In an environment where the world is fast moving to the greener technologies, this introduction will offer many benefits to a country that is trying to emerge as a middle income economy in South Asia. In such a context stripping out the cons and associating the pros of this concept becomes an inevitable endeavor faced by the highway designers in the future. In Sri Lanka, bicycle lanes are so far introduced to the highways on ad hoc basis. The actual performance of such bicycle lanes is in question.

1.2 Objectives

Objectives of this research are as follows.

- Have the bicycle lanes/paths implemented been successful in the recent projects?
- What is the public opinion of the bicycle lanes?
- What could be the reasons for failures if any?
- Recommendations for the implementation for bicycle facilities in the future projects.

1.3 Scope of the Study

This study is restricted to the study of common objectives and design concepts of bicycle lanes and attempts to make recommendations on the implementation of bicycle lanes in the future road projects carried out by Road Development Authority.

2. LITERATURE REVIEW

2.1 Necessity of Bicycle Facilities

Bicycle facilities toady have become an inevitable part in highway design. In addition to the promotion of non motorized transport to save energy, it serves as a low cost alternative for the ever increasing travel demand. Michael Replogle [1991:1] says NMVs offer low cost private transport, emit no pollution, use renewable energy, emphasize use of labor rather than capital for mobility, and are well suited for short trips in most cities regardless of income, offering an alternative to motorized transport for many short trips. Thus, they are appropriate elements in strategies dealing with poverty alleviation, air pollution, management of traffic problems and motorization, and the social and economic dimensions of structural adjustment. NMVs have a most important role to play as a complementary mode to public transportation.

While most of the Sri Lankans are not so poor to afford the subsidized public transport costs, cycling is dominant in many areas outside Colombo. Bicycle population is dominant especially in North Central, North and East provinces. But no separate bicycle facilities are provided in these remote areas. This is explained by Michael Raplogle stating: In many low income Asian cities where NMVs predominate, there has been little need to create a separate cycle network because large numbers of NMVs define their own legitimacy to right-of-way. However, as motorization increases, or as traffic congestion worsens, it becomes increasingly important to develop modal separation in high traffic flow corridors. This is particularly vital in mixed traffic cities where NMV use is declining due to competition from growing motorized traffic.

2.2 Types of Bicycle Facilities

Bicycle facilities are incorporated into the traditional highway design in various magnitudes. They can be bicycle lanes running in the both sides of a highway, which are demarcated by lane marking, or separate bicycle paths. Four types of bicycle facilities are given in the Highway Design Manual [2006:1000-2] categorizes the bicycle facilities into four major groups.

2.2.1 Shared Roadway (No Bikeway Designation)
In some instances, entire street systems may be fully adequate for safe and efficient bicycle travel and signing and pavement marking for bicycle use may be unnecessary. In other cases, prior to designation as a bikeway, routes may need improvements for bicycle travel. Many rural

highways are used by touring bicyclists for intercity and recreational travel. It might be inappropriate to designate the highways as bikeways because of the limited use and the lack of continuity with other bike routes. However, the development and maintenance of 1.2 m paved roadway shoulders with a standard 100 mm edge line can significantly improve the safety and convenience for bicyclists and motorists along such routes.

2.2.2 Class I Bikeway (Bike Path)

Generally, bike paths should be used to serve corridors not served by streets and highways or where wide right of way exists, permitting such facilities to be constructed away from the influence of parallel streets. Bike paths should offer opportunities not provided by the road system. They can either provide a recreational opportunity, or in some instances, can serve as direct high-speed commute routes if cross flow by motor vehicles and pedestrian conflicts can be minimized. The most common applications are along rivers, ocean fronts, canals, utility right of way, abandoned railroad right of way, within college campuses, or within and between parks. There may also be situations where such facilities can be provided as part of planned developments. Another common application of Class I facilities is to close gaps to bicycle travel caused by construction of freeways or because of the existence of natural barriers (rivers, mountains, etc.).

2.2.3 Class II Bikeway (Bike Lane)

Bike lanes are established along streets in corridors where there is significant bicycle demand, and where there are distinct needs that can be served by them. The purpose should be to improve conditions for bicyclists in the corridors. Bike lanes are intended to delineate the right of way assigned to bicyclists and motorists and to provide for more predictable movements by constructing bike lanes is to better accommodate bicyclists through corridors where insufficient room exists for safe bicycling on existing streets. This can be accomplished by reducing the number of lanes, reducing lane width, or prohibiting parking on given streets in order to delineate bike lanes. In addition, other things can be done on bike lane streets to improve the situation for bicyclists, that might not be possible on all streets (e.g., improvements to the surface, augmented sweeping programs, special signal facilities, etc.). Generally, pavement markings alone will not measurably enhance bicycling.

If bicycle travel is to be controlled by delineation, special efforts should be made to assure that high levels of service are provided with these lanes.

2.2.4 Class III Bikeway (Bike Route).

Bike routes are shared facilities which serve either to:

(a) Provide continuity to other bicycle facilities (usually Class II bikeways); or
(b) Designate preferred routes through high demand corridors.

As with bike lanes, designation of bike routes should indicate to bicyclists that there are particular advantages to using these routes as compared with alternative routes. This means that responsible agencies have taken actions to assure that these routes are suitable as shared routes and will be maintained in a manner consistent with the needs of bicyclists. Normally, bike routes are shared with motor vehicles.

The use of sidewalks as Class III bikeways is strongly discouraged.

It is emphasized that the designation of bikeways as Class I, II and III should not be construed as a hierarchy of bikeways; that one is better than the other. Each class of bikeway has its appropriate application.

In selecting the proper facility, an overriding concern is to assure that the proposed facility will not encourage or require bicyclists or motorists to operate in a manner that is inconsistent with the rules of the road.

An important consideration in selecting the type of facility is continuity. Alternating segments of Class I and Class II (or Class III) bikeways along a route are generally incompatible, as street crossings by bicyclists are required when the route changes character. Also, wrong-way bicycle travel will occur on the street beyond the ends of bike paths because of the inconvenience of having to cross the street.

In this research, only the Bike Lanes are considered for the analysis as it is the one introduced to Sri Lankan highways for the time being.

2.3 Pros of Bicycle Facilities

Winnipeng City [3] defines cons of bicycle lanes as follows. Bike lanes help define road space, decrease the stress level of bicyclists riding in traffic, encourage bicyclists to ride in the correct direction of travel, and signal motorists that cyclists have a right to the road. Bike lanes help to better organize the flow of traffic and reduce the chance that motorists will stray into cyclists' path of travel. Bicyclists have stated their preference for marked on-street bicycle lanes in numerous surveys. In addition, several real-time studies (where cyclists of varying abilities and backgrounds ride and assess actual routes and street conditions) have found that cyclists are more comfortable and assess a street as having a better level of service for them where there are marked bike lanes present.

In summary, bike lanes do the following:

- support and encourage bicycling as a means of transportation;
- help define road space;
- promote a more orderly flow of traffic;
- encourage bicyclists to ride in the correct direction, with the flow of traffic;
- give bicyclists a clear place to be so they are not tempted to ride on the sidewalk;
- remind motorists to look for cyclists when turning or opening car doors;
- signal motorists that cyclists have a right to the road;
- reduce the chance that motorists will stray into cyclists' path of travel;
- make it less likely that passing motorists swerve toward opposing traffic;
- decrease the stress level of bicyclists riding in traffic.

2.4 Width of Bicycle Lanes

Road Development Authority recently incorporated Bicycle Lanes and Bicycle Paths into their design strategy. The general bicycle lane width maintained by Road Development Authority is 1.5m for bicycle lanes.

Toronto draft bicycle design guidelines [4] recommends following widths for bicycle lanes.

Where curbs are present, the bicycle lane width, the distance from the face of the curb to the centre of the lane line, should be between 1.5 metres and 2.0 metres. On paved shoulders without curbs, the bicycle lane width, the distance from the edge of the pavement to the centre of the lane line, should be between 1.2 metres and 1.7 metres. A wide bicycle lane (1.8 to 2.0 metres where curbs are present; 1.5 to 1.7 metres without curbs) is recommended under one or more of the following conditions:

- where lateral obstructions, such as utility poles, are within 300 mm of the edge of curb;
- where the bike lane is on a bridge or underpass;
- where the posted speed limit is 60 km/h or greater;
- where the adjacent traffic lane is 3.6 m or greater;
- where the bike lane is between two traffic lanes;
- or all contra-flow bicycle lanes.

Where on-street parking is permitted, the preferred combined width of the parking zone and bicycle lane is 4.2 metres. The minimum combined width is 3.8 metres.

2.5 Intersection Treatment

Bicycle lanes should be a component of a network of bicycle lanes that maintains the integrity of the system. Toronto Draft Bicycle Lane Design Guidelines [4] proposes following lane marking in non signalized intersections.

The bike lane striping is discontinued across the leg of the intersecting street. If the approach with the bike lane features a stop line and crosswalks, the bike lane continues all the way to the stop line with, in most cases, the final 15 metres demarcated by a broken white line. The two exceptions are:

- where a nearside bus stop is present, the broken line begins 20 metres from the stop line; and,
- where right turns are not permitted, the solid line continues all the way to the stop line.

The solid lane line should resume immediately downstream of the farside crosswalk. The diamond and bicycle logo pavement marking should be placed within the first 15 meters of the lane.

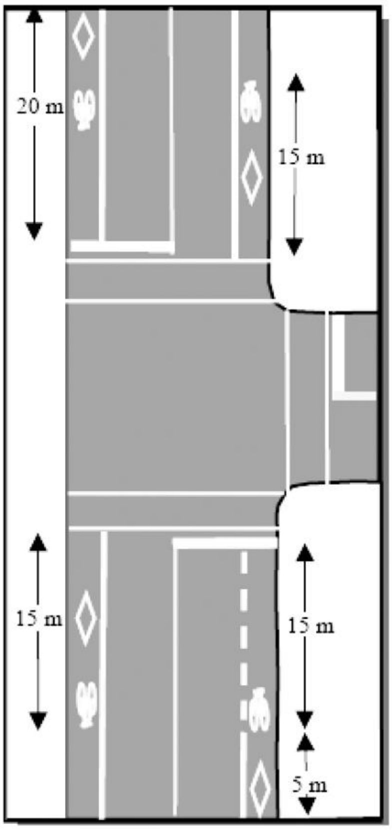

Figure 1. Typical dimensions for an intersection treatment (non-signalized - four ways)

2.6 Crashing with Car Door Opening

On street parking is either allowed or illegally enjoyed in many of the urban highways in Sri Lanka. In places where the on street parking is allowed, the bicyclist is at risk the crashing with suddenly swung open doors of the cars. Maryland SHA Bicycle and Pedestrian Design Guidelines [5] describe this situation as follows.

In locations where bike lanes are adjacent to on-street parking, consideration should be given to the possibility that bicyclists may crash into car doors that are suddenly swung open. This type of crash is typically more likely in locations with higher parking turnover, such as main streets, streets near restaurants and retail, etc. This is not typically a concern on residential streets. Bicyclists encountering an opened door must either stop short of the door, swerve into an adjacent travel lane or risk riding into the open door or being struck by the opening door. This act is commonly referred to as "dooring" by bicyclists. Bicyclists have been injured and killed due to dooring events.

To mitigate or reduce the possibility of a dooring event a number of communities have experimented with various pavement markings, regulatory signs, and or warning signs to prevent dooring incidents. The following mitigation measures have been analyzed in locations with high parking turnover, and 7 or 8 foot parking lanes adjacent to bicycle lanes; or locations with a history of dooring accidents or complaints of dooring "close calls." SHA may consider using these measures on urban streets with frequent on-street parking turnover, on an experimental basis.

2.6.1 Dooring Warning Sign

This sign can be located adjacent to existing parking regulation signs to increase theirvisibility to motorists. An example of a dooring warning sign is shown in below Figure 2.

Figure 2. A typical door warning sign

2.6.2 Modified Bicycle Lane Marking

Based upon a study performed in San Francisco, CA, marking the door zone with extension lines as shown in Figure 2.3 may encourage bicyclists to ride towards the left side of the bicycle lane outside of the door zone. Engineering judgment should be utilized to determine the frequency of placement of the door zone extension lines. Consideration may also be given to utilizing a smaller bicycle lane symbol and arrow which would be placed on the extreme left side of bicycle lane.

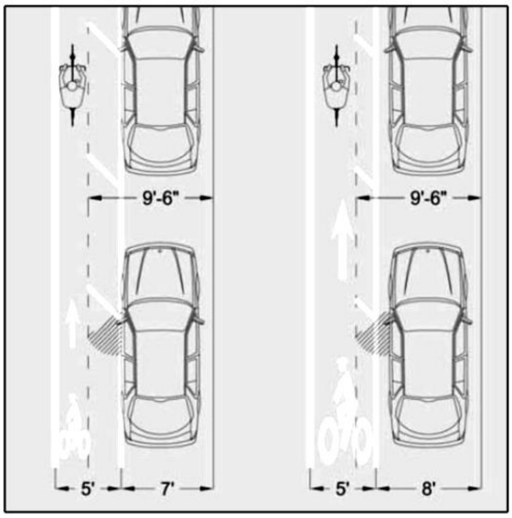

Figure 3. Modified bicycle lane marking with door zone

3 EXPERIMENTAL DETAILS

3.1 Method of Data Collection

Data were collected by the opinion surveys conducted in town areas where a bicycle lane would be beneficial. Questionnaire forms were prepared as this regard.

3.2 Groups for Opinion Surveys

Following 4 groups were selected to collect data.

- General public - Any conclusion for the integration of a new facility to a highway should incooperate the public opinion. Therefore the views of general public were extracted in an opinion survey. This survey was conducted in Malabe Town.
- School Children - School children are a potential group that can use bicycles. So an opinion survey was conducted at Boys' Model School, Malabe.
- University Students - University Students are another potential group that can use bicycles. So an opinion survey was conducted at Sri Lanka Institute of Information Technology by among the second year engineering students.
- Bicyclists - These are the people who really use bicycles for their day to day activities. Their contribution to this study cannot be overlooked at any rate. So an opinion survey was conducted with them in Malabe-Kaduwela Road.

4. DISCUSSION

4.1 Failure of the Bicycle as a Transport Mode in Sri Lanka

Long ago, one may be familiar with the bicyclists who had the dominance of our national road network. This is not the case with the recent development. This notion can be justified with the survey data collected in this research. No wonder none of the persons questioned in the category of general public responded affirmatively for their bicycle usage. While the data spectrum collected would not represent the total picture of the country's transport profile, it may be argued that the data collected were from Malabe where moderate income earning people reside. So it may be suggested that the bicycle is no more the common man's vehicle in this country, at least in the highly urbanized west. This is further consolidated with the fact that according to the survey, none of the school children use bicycle as a transport mode. In SLIIT none use the bicycle. This is a clear indication that supports the previous argument that bicycle is not used as a common transport mode among the moderate income group of this country.

In University of Moratuwa, mere 6% and in University of Colombo mere 10% of the students questioned used the bicycle as a transport mode to travel to the university. The indication given in both universities is tangible to note that the share of the bicycle as a transport mode is very low compared to other transport modes such as public transport which was used by 72% of the general public and 60% of the school children. This clearly shows that despite various strategies used by road agencies to promote the bicycle usage, the bicycle has failed as a transport

4.2 Reasons for the Failure of the Bicycle

An astounding reality that was revealed from this research was the fact that while the bicycle usage was that much low among various groups, the bicycle possession was substantial, accounting to 83% among general public, 69% among school children, 44% among SLIIT, 38% among University of Moratuwa students and 32% among University of Colombo students. The question emerges here as to why the bicycle usage is such low while a fair number of people owned the bicycle. It may be argued that there should be a problem in our road system.

The failure of the bicycle as a common transport mode can be affiliated to various factors such as poor road condition, no facilities for the bicyclists, long distances, no safe parking, sweating and social stigma to name a few. Sweating was the major problem for school children and SLIIT students accounting to 62% and 40% respectively, while the two universities considered had their fair share. This is noted as a crucial factor in this research as Sri Lanka being a tropical country should focus its attention on these issues before investing heaps of money for the implementation of bicycle lanes. Social stigma played the least influential factor among educated masses i.e. SLIIT and the both universities while it was high among the school children where class differences as a shadow of the colonial past still haunted. It was further noted that many were reluctant to use the bicycle as a transport mode due to the long distance that they had to cycle. This was 38% among school children, 49% among SLIIT students, 29% among University of Moratuwa students and 25% among University of Colombo students. Parking was a major issue for the school children among whom 46% admitted that as a problem. This is true as the school in question did not have a safe parking place for the bicycles. This problem was not significant among students of SLIIT and both Universities where safe parking places actually existed.

4.3 Potential of a Bicycle Population

It may be argued with caution that there is a potential bicycle population in this country who really considered bicycling is convenient even in the current road network. That was 42% among bicyclists, 50% among school children and 34% among SLIIT students, while University of Moratuwa and University of Colombo held it to be 41% and 42%. The reasons for this notion could be many, among which short distance, traffic congestion, lack of doorstep transport, economy, lack of sufficient public transport and physical exercise were assessed. Short distance was the major factor for selecting the bicycle among almost all the groups. This gives a clear indication that people are ready to use the bicycle for short distances under improved road condition. Economy and physical exercise were other two major factors. A very important finding here was that bicycle was used as there was no public transport for the door step. It may be argued here that this stresses the need of improving byroads along with the national road network so the bicycles can be used effectively by those who are under privileged to have doorstep transport.

4.4 Ups and Downs for the Bicyclists in the Current Road System

Now it may be suggested that there is a potential bicycle population who would use the bicycle provided their expectations are met in the road network. A major factor those who were questioned mentioned for the convenience of the bicyclists was the separate bicycle lane. This was as high as 94% among school children. The next important point was the wide roads, which was admitted by 65% of the bicyclists and 72% of school children. May be the wide roads could reduce the negative effects of motorized traffic to the bicycles. Built up shoulders and good road surfaces did not have that much weight compared to the other factors.

The problems that prevented this potential bicycle population from actually taking a bicycle and riding on the road were numerous. Heavy congestion and poor driver discipline were the major factors according to the survey. Bicyclists' affirmative response was as high as 79% for heavy congestion while the SLIIT students' affirmative response was as high as 89% for safety. Lack of an exclusive bicycle lane apart from the road and lack of priority while considerable, did not have that of weight compared to the other factors.

4.5 New Proposals to Encourage Bicycles

Now the problem is shortened to the fact that while the presence of bicycles in our road network is minimal, there is a potential bicycle user population who do not actually takes a bicycle and rides owing to the various problems of the current road network. This research may not be able to address all of them, such as traffic congestion which requires major strategic planning and policy decisions to mitigate the effects. Four options were put forward for the assessment i.e. Exclusive bicycle lane, Separate bicycle lane, Raised bicycle lane and green shelter. Exclusive bicycle lane was preferred by many, accounting to 46% of school children, 50% of SLIIT students, 46% of University of Moratuwa students and 49% of University of Colombo students. Raised bicycle lane was the second best choice accounting to 21% of school children, 42% of SLIIT students, 37% of University of Moratuwa students and 36% of University of Colombo students. Separate bicycle lane was the least preferred. Green shelter had its fair share of preference accounting to 35% of school children, 26% of SLIIT students, 32% of University of Moratuwa students and 24% of University of Colombo students.

4.6 Lane Width

From the literature review, following lane widths may be suggested.

- Where curbs are present, the bicycle lane width, the distance from the face of the curb to the centre of the lane line, should be between 1.5 metres and 2.0 metres.
- On paved shoulders without curbs, the bicycle lane width, the distance from the edge of the pavement to the centre of the lane line, should be between 1.2 metres and 1.7 metres.
- A wide bicycle lane (1.8 to 2.0 metres where curbs are present; 1.5 to 1.7 metres without curbs) is recommended under one or more of the following conditions:
  - where lateral obstructions, such as utility poles, are within 300 mm of the edge of curb;
  - where the bike lane is on a bridge or underpass;
  - where the posted speed limit is 60 km/h or greater;
  - where the adjacent traffic lane is 3.6 m or greater;
  - where the bike lane is between two traffic lanes;
  - -for all contra-flow bicycle lanes.

4.7 Intersection Treatment

It was observed in our intersections the ad hoc bicycle lanes vanish due to the space constraints, without being a part of an integrated bicycle lane network. So it is suggested that a proper intersection treatment system such as that of Toronto or Chicago as given in the literature review be adopted. In this research, it is proposed to adapt to a lane marking system as shown below.

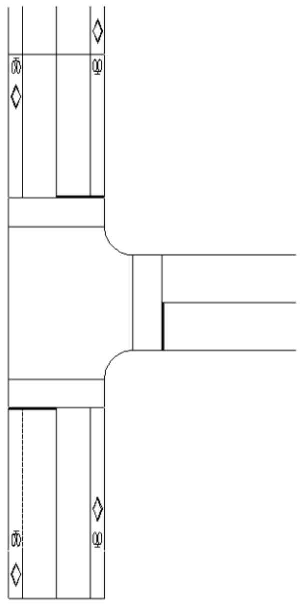

Figure 3. Lane Marking Suitable for a 3 way Intersection

This basic system can be improved to include 4 way intersections, roundabouts, signalized intersections etc. as the need arises.

4.8 Dooring Warning System

It is suggested that the warning symbol and the modified lane marking given in the literature review be adopted where the parking is allowed with the bicycle lane.

4.9 Necessity of Bicycle Parking Places

Majority of the school children accounting to be 46% admitted their inability to use the bicycle due to the fact there is no safe parking in the school. So the bicycle parking is a major issue in this country where proper bicycle parking facilities are not provided. Therefore, Alexandria government's bicycle parking technique is proposed.

4.10 By road Improvements

15% of the school children, 20% of the SLIIT students, 21% of the University of Moratuwa students and 4% of the University of Colombo students wanted to bicycle as they did not have the doorstep transport. So this is a clear indication that people use the bicycle to come to the main road hence the by roads should also be improved to cyclable condition along with the major road improvements.

4.11 Measures to Increase Bicycling Share

The suggestions of the people who were surveyed were assessed to increase the bicycling share of the transport system and highest demand was the concession on prices. This needs further investigation by means of a separate research.

The second highly demanded requirement was to provide more facilities for the bicyclists such as continuation of the bicycle lane etc. Parking shed had their fair share of demand while that for the giving priority for bicyclists was comparatively high. Bicycle registration system had the least demand of all.

5. CONCLUSION & RECOMMENDATIONS

It was explained in the discussion that there is still a fair demand for the bicycle but the common people are reluctant to use this economical transport mode due to various problems. Following recommendations can be made with regard to the literature review and data analysis.

- Where curbs are present, the bicycle lane width, the distance from the face of the curb to the centre of the lane line, should be between 1.5 metres and 2.0 metres.
- On paved shoulders without curbs, the bicycle lane width, the distance from the edge of the pavement to the centre of the lane line, should be between 1.2 metres and 1.7 metres.
- A wide bicycle lane (1.8 to 2.0 metres where curbs are present; 1.5 to 1.7 metres without curbs) is recommended under one or more of the following conditions:
    - where lateral obstructions, such as utility poles, are within 300 mm of the edge of curb;
    - where the bike lane is on a bridge or underpass;
    - where the posted speed limit is 60 km/h or greater;
    - where the adjacent traffic lane is 3.6 m or greater;
    - where the bike lane is between two traffic lanes;
    - -for all contra-flow bicycle lanes.
- Intersection treatment should be carried out as per the standards used in developed countries as given in this research.
- Dooring warning system should be implemented appropriately where parking is allowed with bicycle lanes.
- Proper bicycle parking places should be provided where a potential bicycle population is expected such as schools and universities.
- By road improvements should be carried out along with the main road improvements to facilitate the bicyclists use the road.
- Raised bicycle lanes, separated from the motorized way should be provided

wherever possible.

- Green shelter should be provided for the bicycle lanes so the sweating would be minimized.
- Since the convenient bicycling distance varies, it is proposed that at least 4km bicycle lane should be provided surrounding the institutions like universities where a potential bicycle usage is anticipated, in case the whole road is not provided with a bicycle lane.

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STABILIZATION OF EXPANSIVE CLAY SOIL USING BUTON ROCK ASPHALT THE OTHER UTILIZATION OF BUTON ROCK ASPHALT

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Abstract: Subgrade is the lowest layer of the pavement that must eventually support all the loads that come onto the pavement structure. Therefore, it is essential to make sure that the layer is stable and has sufficient shearing strength to withstand the traffic induced stresses without excessive deformation. If the subgrade soil is poor, sufficient shearing strength, then it must be stabilized to improve its properties. In this paper Buton Rock Asphalt (BRA) was studied to stabilize the expansive clay subgrade soil of Semarang-Purwodadi road in North-East Central Java Province of Indonesia. Amount of 2%, 4%, 6%, and 8% of BRA by weight of soil were added. As comparison or control, natural sand in amount of 5 to 25% in increments of 5% by weight of soil was also added. Laboratory works show that BRA can improve bearing capacity of soil far higher than the natural sand resulted. By adding 8% by weight of soil, BRA can improve bearing capacity of those of expansive clay soil, measure by using CBR, from the value of CBR 1.6% to 5.97% or increase 373%, while 20% of sand only increasing the CBR of soil become 3.90% or increase 244%. Increasing of CBR by adding BRA is in linear line with the line equiation $y = 51.54x + 2.126$. This mean if the percentage of BRA also 20% the CBR value of BRA-stabilized soil is 12.43% and suitable as well as very good for subgrade material.

Keywords: Buton Rock Asphalt, Stabilizer, Expansive soil, Improve, Bearing Capacity, Strength.

1. INTRODUCTION

Soil is one of nature's most abundant construction materials. Almost all construction is built with or upon soil. Found from Aggrebind.com/wp-content/…./10/Soil-Stabilization-from Caterpilar.pdf. Introduction to Soil Stabilization (2010), when unsuitable construction conditions are encountered, the following four options can be selected to be conducted: (1) Find a new construction site; (2) Redesign the structure so it can be constructed on the poor soil; (3) Remove the poor soil and replace it with good soil; (4) Improve the engineering properties of the site soil. Option (4) is being used more often today and is expected to dramatically increase in the future.

Improving on-site (in-situ) soil's engineering properties is referred to as either "soil modification" or "soil stabilization" The term of "modification" implies a minor change in the properties of soil, while stabilization means that the engineering properties of the soil have been changed enough to allow field construction to take place.

There are two primary methods of soil stabilization used today:, namely mechanical and chemical or additive method. The most common form of "mechanical" soil stabilization is compaction of soil, while the addition of cement, lime, bituminous, or other agents is referred to as a "chemical" or "additive" method of soil stabilization.

There are two basic types additives used during chemical soil stabilization: mechanical additives and chemical additives. Mechanical additives such as soil cement mechanically alter the soil by adding a quantity of material that has the engineering characteristics to upgrade the load-bearing capacity of the existing soil. Chemical additives such as lime chemically alter the soil itself, thereby improving the load-bearing capacity of the soil.

Buton Rock Asphalt (BRA), the natural asphalt discovered in Buton island located in South-East of Sulawesi Island of Indonesia, that consider as the new soil stabilizer was studied to use as soil stabilizer and will be described in this paper (Buton Asphalt Indonesia, Co. Ltd. 2006). How much the influence of BRA in improving the properties of soil as soil additive will be described in this paper, and will compare with sand, the other natural material that have been used as soil stabilizer.

2. OBJECTIVE OF THE RESEARCH

The objective of this paper is to promote the suitability of BRA in providing sufficient strength to the expansive subgrade soil, in order suitable to be used as good subgrade.

3. BUTON ROCK ASPHALT (BRA)

BRA is the natural asphalt discovered in Buton Island located in South-East Sulawesi. The areas in Buton Island which have much deposit of rock asphalt are Lawele, Kabungka, Waisnu, Wariti, and Epe. From those five areas, Lawele and Kabungka have much rock asphalt. Natural rock asphalt is found firstly in 1926 by Hetzel, a Dutch geologist. Survey conducted by Ministry of Energy and Mineral Resources Republic of Indonesia show that deposit of natural rock asphalt are estimated around 650 to 700 million tones (Buton Asphalt Indonesia, Co. Ltd. 2006). Deposit of rock asphalt can only be found in 1 to 1.5 meter depth from the land surface as shown in the Figure 1, and bitumen content in the rock asphalt range about 10 to 40%. Since the first time are discovered and mined, still only 3.4 million tons of rock asphalt has been explored.

For this research, BRA was supplied by Buton Aspal Indonesia (BAI) Co. Ltd. in form of coarse grain and was packed in bag contains 25kg per bag (Figure 2). BAI Co. Ltd. takes BRA from Lawelle quarry. Gradation of BRA and it other properties were shown in Table 1.

Figure 1. Rock asphalt in Lawelle quarry of Buton Island

Figure 2. BRA in bag (left) and coarse grains of BRA (right)

Table 1. Gradation and Properties of BRA (Buton Indonesia Co. Ltd. 2006)

No.	Test	Test Method	Result	Specification	Unit
1	Gradation	ASTM C 136			
	Sieve No. 16		100		% passing
	Sieve No. 30		54.02		% passing
	Sieve No. 50		16.97		% passing
	Sieve No. 100		3.75		% passing
	Sieve No. 200		1.82		% passing
2	Bitumen content	ASTM D 1856	22.52	18 – 22	%
3	Solubility in C2HCL3	ASTM D 2042	18.72	Minimum 18	-
4	Specific gravity	ASTM D 854	1.976	1.70 – 1.90	-
5	Flash point	ASTM D 9272	232	Minimum 230	0C
6	Water content	ASTM D 1461	0.81	Maximum 1	%
7	Volatile content by distillation	ASTM D 402	0.20	-	%

4. RESEARCH METHODOLOGY

This research was conducted in the Geotechnical Laboratory, Faculty of Engineering, Universitas Islam Sultan Agung (UNISSULA) of Semarang, Indonesia. Soil to be stabilized is expansive clay soil take from the subgrade of Semarang-Purwodadi road, the 64 km length of provincial road located in North-East Central Java Province of Indonesia.

To be able to get the correct conclusion that BRA is suitable for soil stabilizer, sand, another natural material was also used to stabilize the same soil. The improvement of strength and properties of soil after adding with stabilizer material was determined by using Atterberg Limit, California Bearing Ratio, and Direct Shear Test tests.

The amount of 2 to 8% in increments of 2% of BRA and 5 to 25% in increments of 5% of natural sand by weight of soil were added.

5. LABORATORY EXPERIMENTS

5.1 Expansive soil

Laboratory works was commenced with Atterberg Limit test for original soil, which the result is given in Table 2, and shows that Plasticity Index (PI) value is 33.9% is categorized high, and the soil can be classified as expansive clay.

Table 2. The results of Atterberg Limit tests for the expansive soil

Test	Result
Liquid Limit (LL)	75.9%
Plastic Limit (PL)	42%
Plasticity Index (PI) = LL – PL	= (75.9 – 42)% = 33.9%

5.2 Soil - BRA and soil-sand stabilization

Laboratory works of Soil–BRA stabilization was commenced by activating bitumen that contain in the BRA in order to be able to blend with soil. Activated bitumen in the BRA was conducted by adding bunker oil. Bunker oil is, used ship lubricating oil, adds to the BRA, mixed and then keeps in the shady place for 48 hours. After 48 hours, bitumen in the BRA will melt, and the particles of BRA become soft. As have been mentioned, amount of 2, 4, 6, and 8% of this melt and soft BRA then were added to the soil used as additive or stabilizer.

Laboratory test of the mix of soil-BRA and soil-sand were also commenced with Atterberg Limit test, and followed with CBR and Direct Shear test.

6. RESULT AND ANALYSIS

6.1 Soil-BRA Stabilization

6.1.1 Atterberg Limit

The Atterberg test results were given in Table 3 and Figure 3 show that the values of Plasticity Index (PI) lower with increasing of BRA content in the soil. These results correspond to the hypothesis that the lower of PI value, the less potential of soil to become expansive. This means that the more BRA adding, the less expansive of the soil. Decreasing of PI value is caused by decreasing of pores in the soil.

Table 3. Plasticity Index (PI) of soil-BRA

% of Buton-NRA	LL	PL	PI
0%	75.9	42	33.9
2%	71	39	32
4%	69	38	32
6%	69	4	25
8%	68	44	24

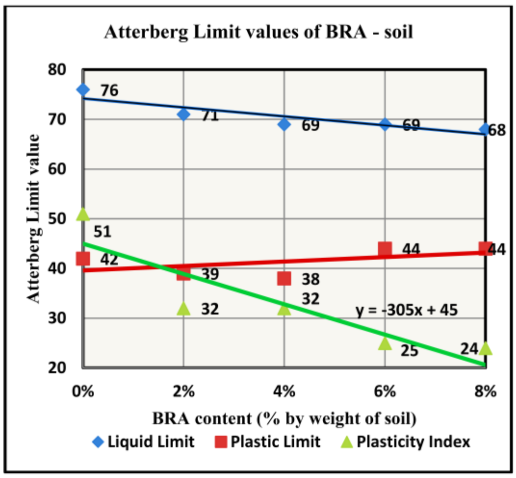

Figure 3. Atterberg values of soil-BRA

6.1.2 California Bearing Ratio (CBR) test

The results of CBR test for BRA stabilize expansive soil were given in Table 4 and shown statistically in Figure 4. The hypothesis said that the more BRA content, the higher the CBR value is. Regression model give coefficient of determination, R-square, R2 = 0.9662 and coefficient of correlation R = 0.9830. Those values of regression model show that between BRA content and CBR have strong correlation, and the contribution of BRA to CBR value is above 90%, and can be concluded that the CBR value of Soil-BRA is fit with the hypothesis.

CBR values of BRA stabilized soil also have linear line with line equation y = 51.45x + 2.126. This mean, if the BRA content adds to 20%, the CBR value will become 12.43%, suitable and very good for subgrade material.

Table 4. CBR value of soil-BRA

% BRA	CBR (%)
0%	1.6
2%	3.5
4%	4.8
6%	5.05
8%	5.97

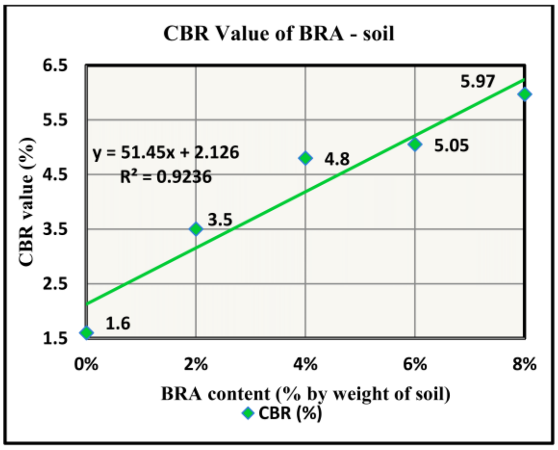

Figure 4. CBR value of soil-BRA

6.1.3 Direct shear test

The results of direct shear test of BRA stabilized soil given in Table 5 and graphically show in Figure 5 and Figure 6 both for cohesion value and angle of internal friction Ø value respectively. Attention should be paid to this direct shear test results. Normally, the higher value of cohesion of soil, the lower value of Ø is. However, soil-stabilized with BRA show the different result, where the higher cohesion also the higher angle of internal friction Ø. This result can be explained as follows: when BRA was added to the soil and thoroughly blend, the particles of soil will be bind by melt bitumen of BRA because the mix of soil-BRA becomes cohesive. Nevertheless, this cohesion is false cohesion, since the rocks particles contain in BRA make the particles of BRA – soil mixtures are clotted, hard, and make it like granular material. That is why the angle of internal friction Ø higher if the BRA content high.

Table 5. Cohesion and angle of internal friction of soil-BRA

% of BRA	Cohesion (c) (kg/cm^2)	Angle of internal friction Ø
0%	0.49	14
2%	0.31	37
4%	0.40	41
6%	0.51	43
8%	0.73	46

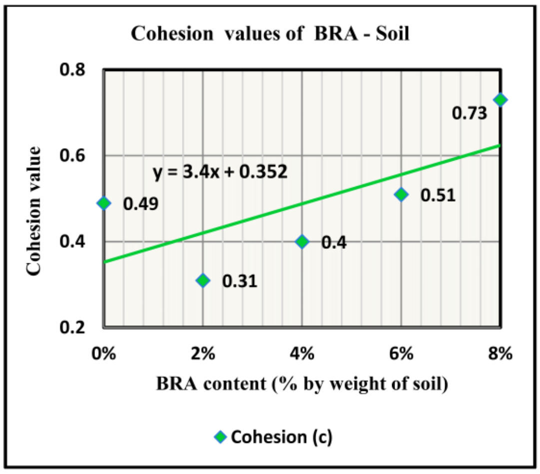

Figure 5. Cohesion value of soil-BRA

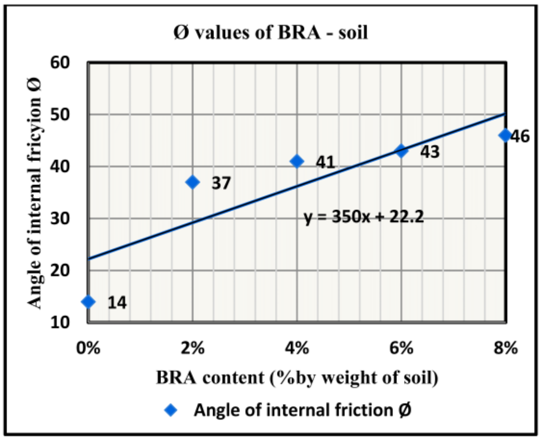

Figure 6. Angle of internal friction of soil-BRA

6.2 Soil-Sand Stabilization

6.2.1 Atterberg Limit

Similar to the soil-BRA, Plasticity Index (PI) lower with increasing of sand content in the soil. The Atterberg test results of soil-sand were given in Table 6 and Figure 7 also show that the values of PI decrease with increasing of percentage of sand content. These results correspond to the hypothesis that the lower of PI value, the less potential of soil to become expansive. This means that the more sand adding, the less expansive of the soil. Decreasing of PI value is caused by decreasing of pores in the soil.

Table 6. Plasticity Index (PI) of soil-sand

% of BRA	LL	PL	PI
0%	75.9	42	33.9
5%	72	46.3	25.7
10%	71	33.31	37.9
15%	60	31.79	28.21
20%	59	29.15	29.85
25%	52	28.18	23.82

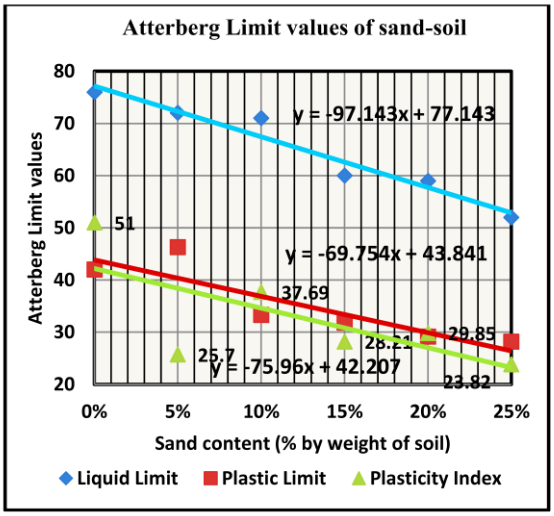

Figure 7. Atterberg Limit value of soil-sand

6.2.2 California Bearing Ratio (CBR) test

The results of CBR test for sand stabilize expansive soil shown statistically in Table 7 and Figure 8. The hypothesis said that the more stabilizer content, the higher the CBR value is. Regression model give coefficient of determination, R-square, R2 = 0.8527 and coefficient of correlation R = 0.9234. Those values of regression model show that between sand content and CBR have strong correlation, and the contribution of sand to CBR value is 85%, and can be concluded that the CBR value is fit with the hypothesis.

Table 7. CBR value of soil-sand

% BRA	CBR (%)
0%	1.6
5%	2.7
10%	2.95
15%	3.58
20%	3.9
25%	4.92

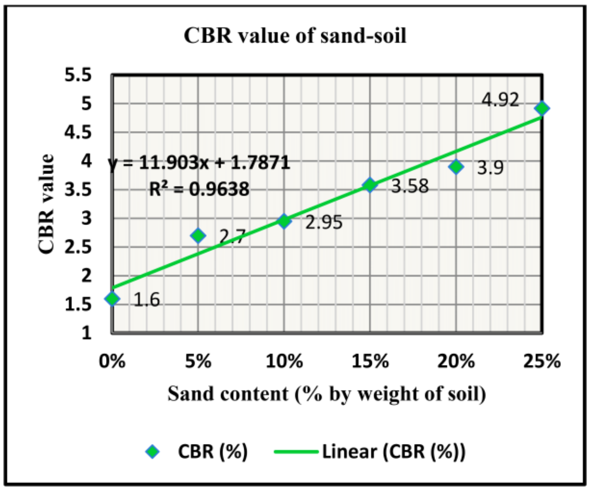

Figure 8. CBR value of sand stabilized soil

6.2.3 Direct shear test

The results of direct shear test for sand stabilized soil given in Table 8 and Figure 9 as well as Figure 10 both for cohesion value and angle of internal friction Ø respectively. The results show the normal value where the higher cohesion value, the lower angle of internal friction Ø. Original soil (0% sand content) have cohesion value 0.49 kg/cm2 and angle of internal friction Ø = 14°. The more sand content, the lower cohesion value and the higher Ø value is, since sand is naturally cohesion less material.

Table 8. Cohesion and angle of internal friction of soil-sand

% of BRA	Cohesion (c) (kg/cm^2)	Angle of internal friction Ø
0%	0.49	14
5%	0.31	15
10%	0.29	16
15%	0.27	17
20%	0.24	20
25%	0.20	24

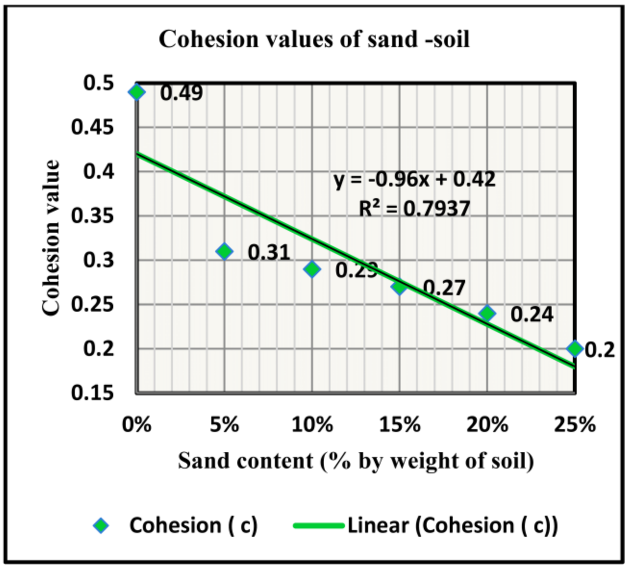

Figure 9. Cohesion values of sand stabilized soil

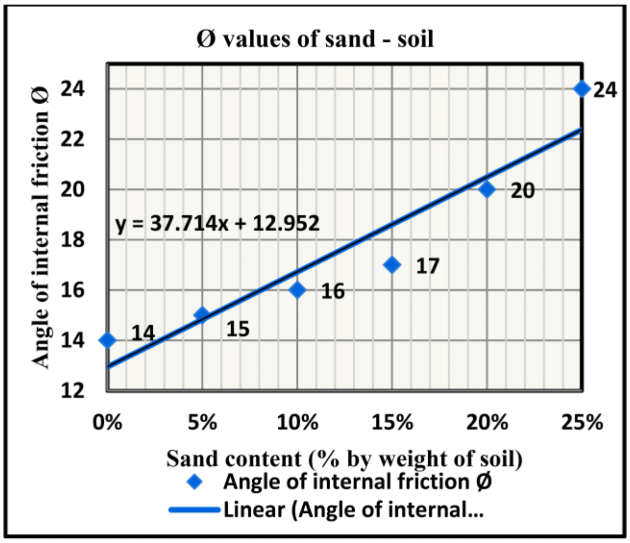

Figure 10. Angle of Internal Friction Ø values of sand stabilized soil

7. CONCLUSIONS

From the entire test results of those two soil stabilizer, the conclusions can be drawn as follows:

- Plasticity Index (PI). With 8% of BRA content in the soil, soil-BRA have PI value 24 similar to the 25% of sand content in the soil-sand where PI value is 23.82 ~ 24. Since the PI have linear value, where the higher stabilizer content, the lower of PI value, and the lower of PI, the less expansive of soil, therefore the higher of BRA content, the less expansive of the soil-BRA will be.
- BRA increase CBR of expansive clay soil significantly and according to AASHTO soil classification categorized as good material for subgrade pavement.
- The cohesion value of soil-BRA high with the higher of BRA content. But this condition cannot be concluded that soil become more cohesive if the BRA is added. As has been explained above and referring to the conclusion point 1 above as well as the angle of internal friction value, the cohesion value of soil-BRA is false value. When bitumen in the BRA become dry, the particles of BRA become clotted and hard, the soil-BRA become a granular material and not cohesive.
- Angle of internal friction Ø. Ø value show that the soil is not cohesive, the higher Ø value, and the less cohesive of soil. The results of the research show that the higher BRA, the higher of the Ø value.

8. SUGGESTIONS AND RECOMMENDATIONS

From the above test results and conclusions, the author considered to recommends and suggests using BRA to stabilize expansive subgrade soil of the entire road pavement, flexible or rigid, because:

- Many road pavement structures deteriorate early because there was no strengthening of subgrade soil.
- BRA has naturally ready and low cost because not require industrial process compare to cement, lime or petroleum asphalt.
- More than 600 hundred million deposit of BRA still have not explored yet.
- Using other methods which have been used to strengthen subgrade soil, like geotextile was proved not succeeding.

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