Can Modern Roundabouts Improve Level of Service and Reduce Vehicular Emission? A Comparitive Analysis

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Abstract— Steady growth of traffic over the years has put environmental stress on urban centers in various forms particularly causing poor air quality. Urban air quality is generally poor at traffic intersections due to variations in idle timing and vehicles' speeds as they approach and leave. Modern roundabouts can reduce the idle time of vehicles resulting in reduced air pollution. The primary objective and focus of this research was to study the impact of modern roundabouts on vehicular emissions as well as provision of level of service compared to signalized and unsignalized intersections. Twelve existing intersections were selected from the center of Bangkok, Thailand, with respect to traffic volumes, percentage of heavy vehicles, geometry of the intersection and vehicle speeds. Traffic operation of the intersections was videotaped and traffic data was extracted from the tapes. Analysis was conducted using 3.2 Version of Signalized and Unsignalized Intersection Design and Research Aid (SIDRA) software. The results obtained from the real data collected from existing intersections were recorded. Secondly, the same data set was entered to the software while the types of intersections were converted to modern roundabouts and the results were recorded. The two results were compared in terms of the total amount of four measures of effectiveness (MOEs) namely Carbon Dioxide (CO2), Carbon Monoxide (CO), Nitrogen Oxide (NOX) and Hydrocarbons (HCs) in (Kg/h). The findings from the study illustrated a significant reduction in total amount of the MOEs after conversion of currently operating intersections to modern roundabouts. Similarly, the level of service, average delays and vehicle speeds were also considerably improved.

Index Terms— Modern Roundabouts, Emission Reduction, Level of Serivce, Delay, Improvement, Comparison, Signalized Intersections

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Intersections are considered to be the most critical, congested and unsafe parts of highways; where some may call them hotspots of crashes. Likewise, driving within intersection is one of the most complex and confusing conditions encountered by the drivers. Intersections in general are divided into various types in terms of operations, number of segments and requirements of several types of roads. But mostly used types may be classified as 3-Way, 4-Way, 5-Way, 6-Way and a circular type called roundabout.

Roundabout is a type of intersections or in other words circular junctions which circulates traffic around a circle called Central Island requiring drivers to yield and give priority to vehicles already inside the circulatory roadway. Compared to conventional intersections; modern roundabouts are counted to be safer, more convenient and environmentally friendly and may provide higher level of service. From early 1990s the interest in adoption of roundabouts has been rising in United States, which is inspired by their success in other countries of the world such as Europe, Australia and UK [1]. In 2005, France was leading with an approximate number of 25,000 roundabouts countrywide with an annual growth rate of 1000 roundabouts per year [2]. On the other hand, United States takes account of approximately 1,000 roundabouts operating in number of US Cities [3].

The safety aspect of roundabouts has attracted immense interest among the experts and researchers and had been a motive to extensive researches in various countries. Roundabouts if properly designed can provide much safer movements compared to other types of intersections. Geometric design, deflection of Central Island in particular is one of the most affecting factors in improving the safety of roundabouts.

According to previous researches roundabouts are found to reduce the number of conflicts by 36% and reduce the severity of crashes by 76%. However, roundabouts are found to be less effective for cyclists and could increase the severity of crashes by 80% [4].

Recently, one of the basic concerns for planners and designers of all infrastructures particularly, those related to transportation engineering is their impacts on environment. Due to rapid trend of population growth and motorization, transportation engineers and planners are immensely challenged by the negative impacts of transport systems on the air quality of mega cities around the globe [5], [6]. Increased number of vehicles over the years is believed as one of the main contributors to increased amount of air pollution. Strictly speaking, emission rates and production severity may differ due to characteristics of traffic, number of intersections on a highway segment, types of vehicles etc. [7]. For instance if we consider a particular vehicle, its size, weight, age of vehicle, and maintenance will highly affect the amount of emission produced by the vehicle [8]. Likewise, the type and quality of fuel/gas will also affect the amount of vehicular emissions [9].

With reference to the amount of delay, vehicles are found to produce more emissions at intersections. This has encouraged the professionals in providing more environmentally friendly alternatives to the conventional intersections. Modern roundabouts are found relatively effective as one of the main functions of roundabout is the reduction of delay and queuing time, resulting in reduction of vehicular emission and fuel consumption putting a positive impact on environment. As intersections require stops at red phases it generates longer delays coming with more fuel consumption and consequently results in increased emissions, while roundabouts commonly have shorter delays and idle timings. However, at some circumstances such as the increase of traffic or congested highways; emission production of roundabouts may increase due to extreme delays, larger queues and increased number of speed cycles for approaching traffic [10].

2 Survey and Methodology

2.1 Data Collection

The main objective of this study is to compare the performance of roundabouts to other types of signalized and unsignalized intersections by considering their environmental impacts and overall level of service. Twelve intersections were selected at the center of Bangkok for collection of data and analysis of the level of service provided by each intersection and the amount of emission produced. The intersections were selected with respect to:

- Cruise Speed,
- Traffic Volumes,
- Portion of Heavy Vehicles, and
- Geometry of Intersection.

Though, there are multiple parameters which may affect amount of emitting pollution; yet in this study the above mentioned parameters were given the priority while selecting the samples.

To ensure accuracy of the data; the data was collected in two phases:

a) Phase I: Video Data Collection: Video cameras were placed at suitable points of every intersection to video tape the movement of the traffic entering and exiting the intersections. This method ensures the quality of the data as accuracy of counting the traffic while entering, exiting and circulating are recorded at each leg of the facility is high and can also be accessed, reviewed and retrieved later on at any time needed. Besides, the possibilities of missing the speedy cars and committing other mistakes are significantly reduced [11].

b) Phase II: Visual Data Collection: After recording the videos the second phase was to collect the data visually from the videotapes. All the videos were reviewed and studied visually to extract the traffic volumes and turning movements for the analysis. Meanwhile, the vehicles were classified into two groups of Heavy Vehicles and Light Vehicles [11].

2.2 Analysis Method

The model selected for the analysis is a 3.2 version of Signalized and Unsignalized Intersection Design and Research Aid (SIDRA). This Australian package has some advantages with respect to the analysis of intersection controls and performances. The calculations carried by SIDRA emphasize the consistency of capacity and performance analysis methods for roundabouts, sign-controlled, and signalized intersections through the use of integrated modeling framework. Another strength of SIDRA is that it is based on the U.S. Highway Capacity Manual as well as Australian Road Research Board research results. SIDRA uses a four-mode elemental model for estimating fuel consumption, operating cost and pollutant emissions for all types of traffic facilities. This helps with estimation of air quality, energy and cost implications of alternative intersection design. For this purpose, a unique vehicle drive-cycle model (acceleration, deceleration, idling, and cruise) is used.

The Australian package of aaSIDRA requires huge input data which requires enormous use of personnel and equipment to obtain more accurate data. A brief description of required data is provided in Table 1.

TABLE 1
INPUTS REQUIRED TO RUN aaSIDRA

No	Input Group	Specifications/ Detail
1	Geometry Group	• Intersection geometry. • Roundabout geometry. • Lanes. • Approaches. • Medians.
2	Movement Group	• Movement description. • Definitions and path data. • Movement data. • Priorities. • Opposing movements and opposed turns. • Traffic volumes.
3	Traffic Signal Group	• Phase times. • Phasing data. • Priorities. • Green, red and yellow timings.
4	Vehicle Classification	• Portion of heavy and light vehicles for each intersection.

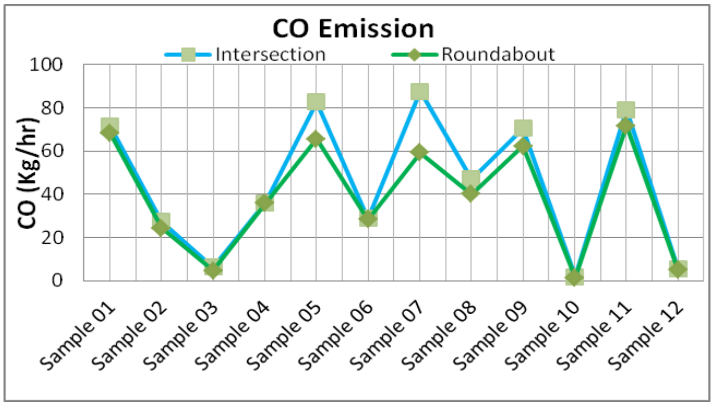
3 Results and Discussion

After collecting accurate data from the video tapes the required input data was entered to software and the results were obtained and further analyzed. At the first stage the real type of intersection along with all real data was entered and analyzed. Secondly, the type of the intersection was changed to modern roundabout while all other input data was kept unchanged and the software was run again. The objective of changing only type of intersection was to check if all traffic characteristics remain unchanged and only intersection is converted to roundabout what will be the impact on amount of emissions, LOS, overall delays and operating speeds.

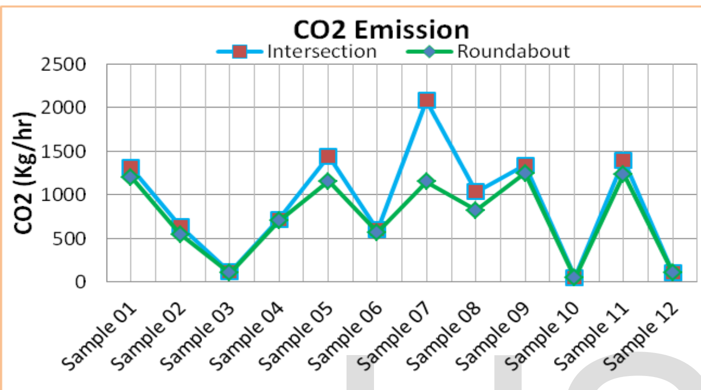
The software produces number of Measures of Effectiveness (MOEs) where for emissions four MOEs were selected from the output tables namely CO2, CO, NOX and Hydro Carbons (HCs).

3.1 Vehicular Emission

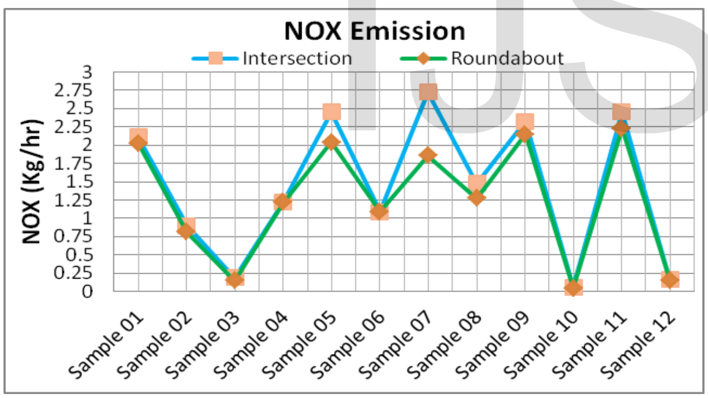
Figure 1(a,b,c and d) shows the amount of all four types of emissions produced by existing signalized and unsignalized intersections based on real traffic data as well as the amount of the emission expected to be generated if the intersection is converted to a modern roundabout.



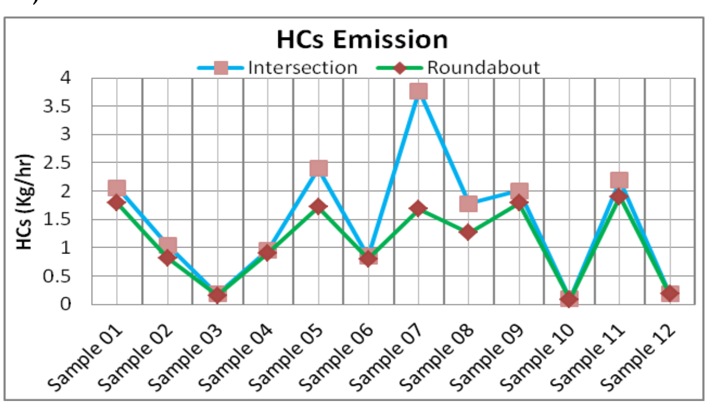
a)



b)



c)



d)

Fig 1(a, b, c, d), Comparison of emission production

TABLE 2
SUMMARIZED RESULTS OF EMISSION REDUCTION

Type of Emission	Total Amount by all Inter-sections	Total Amount by all Round-abouts	Percent Reduced (%)	Reduc-tion in Kg/h
CO2	10840.3	8885.2	18.035	1955.1
CO	544.39	466.69	14.273	77.7
NOX	17.174	15.047	12.385	2.127
HCs	17.495	13.084	25.213	4.411

As shown in Table 2, the results of converting intersections to modern roundabouts show considerable reduction in amount of all selected pollutions, which indicates the effectiveness of modern roundabouts in reducing vehicular emissions.

3.2 Intersection Delay

In general, traffic delays and queues are key performance measures used for determination of intersections' Level of Service (LOS) or over all changes in operational performance. Vehicle delays intensely affect the overall performance and LOS of the intersections. The interaction between delays and emission production is also very strong. If vehicles are to face longer queues and delays; it directly increases the rate of emissions produced. Besides, if the delays are longer the acceleration and deceleration rates stay unstable which can raise the amount of emissions. One of the main reasons for reduced amount of emission at roundabouts is the smaller time of delays. Our analysis showed that after converting intersections to roundabouts, the amount of delays was considerably reduced. Table 3 is designated for further details.

TABLE 3
COMPARISON OF TOTAL DELAY

Site	Delay by Intersections (S/Veh.)	Delay by Roundabouts (S/Veh.)	Dif-fer-ence	Reduction (%)
01	35.6	4.8	30.8	86.517
02	54.9	4.2	50.7	92.350
03	13.7	2.6	11.1	81.022
04	17.6	5.3	12.3	69.886
05	64.3	5.6	58.7	91.291
06	9.6	3.4	6.2	64.583
07	220.6	9.1	211.5	95.875
08	72.9	6.7	66.2	90.809
09	20.3	5.1	15.2	74.877
10	19	1.68	17.32	91.158
11	33.1	22.9	10.2	30.816
12	2.7	0.8	1.9	70.370
All	**564.3**	**72.18**	**492.12**	.

It is apparent from Table 3 that if all sampled intersections are converted to modern roundabouts, the total delays will immensely drop. Numerically can be written that the delays will be lessened as much as 492.12 Sec/Vehicle or by 87.209% of the total amount which proves the effectiveness of roundabouts over other types of conventional intersections.

3.3 Speed

Vehicle speeds also play an important role in production of vehicular emissions. Likely, the overall performance of an intersection can also be judged with reference to operating speeds at intersections. In this study attention was paid to select intersections with varying speeds and study weather converting the intersections to modern roundabouts affect the average travel speeds; and meanwhile to check the impact of speed on vehicular emissions.

Table 4 shows the results for travel speeds of existing intersections and estimated speeds of modern roundabouts. As can be observed from the table, converting the intersections to modern roundabouts will considerably increase the travel speeds. Though there is an increase in all samples, yet the increment is not distributed normally and differs with discrete characteristics of intersections. At this point the geometries of the intersections play an essential role; total number of lanes, lane widths, negotiation distances of the intersections and some other geometric parameters are drastically affecting elements. Based on the results shown below; if all 12 existing intersections are converted to modern roundabouts, the overall speed will be increased by 20.895%. This percentage is calculated by considering the total growth and rise in speeds for all intersections and does not represent individual intersections.

TABLE 4
COMPARISON OF SPEEDS

Site	Speed by Intersections (Km/h)	Speed by Roundabouts (Km/h)	Difference	Increment (%)
01	26.1	32.6	6.5	19.939
02	21.6	30.2	8.6	28.477
03	28	32	4	12.500
04	38	42.7	4.7	11.007
05	24.6	38.6	14	36.269
06	46.3	49.4	3.1	6.275
07	11.9	34.7	22.8	65.706
08	21.7	34.8	13.1	37.644
09	38	43.5	5.5	12.644
10	7.3	7.2	-0.1	-1.389
11	31.8	34.4	2.6	7.558
12	28	28.6	0.6	2.098
Total Increment in percentage				20.895

3.4 Overall Level of Service (LOS)

Level of service of an intersection is a parameter which explains the overall performance of an intersection. If the level of service for an intersection is low, this will mean that all other elements such as travel speed, delays, emissions etc. will be in poor operational status.

The impact of level of service on emission production is very vital and significant. The results from our study showed a very strong relation between the level of service and quantity of all types of emissions. In our sample set some intersections accommodate high number of traffic with higher level of service which resulted in lower amount of emissions. On the other hand, we have intersections with smaller traffic volumes but worse level of service and the results explained that however the traffic is smaller still the emissions are much higher compared to other intersections. Though, it is certain that level of service plays deep role in creation of vehicular emissions, yet we cannot ignore the role of traffic volume as well. The traffic volumes also cause an increase in emissions since the number of vehicle increases, but compared to level of service this influence is much smaller.

One of most important and positive aspect of modern roundabout is provision of best level of service. In our study the levels of service for sampled intersections differ. Some intersections have good Level of service while others have weaker level of service. Yet after their conversion to modern roundabouts the level of services for all intersections has notably changed and improved.

TABLE 5
IMPROVEMENT OF OVERALL LOS

Site	Original LOS	LOS after conversion
01	D	A
02	D	A
03	B	A
04	B	A
05	E	A
06	A	A
07	F	A
08	E	A
09	C	A
10	C	A
11	C	C
12	A	A

Table 5 proves the efficiency of roundabouts in providing better level of service. The conversion of exiting intersections to modern roundabouts amazingly improved their level of services. Thus conversions of sampled intersections to modern roundabouts are rated positively with consideration of their impact on environment. An overall summary of analysis is presented in Table 6.

TABLE 6
OVERALL RESULTS OF ANALYSIS

Type	Total Demand Flows (Veh/hr)	% Heavy Vehicle	Level of Service	Average Delay (S/Veh)	Average Speed (Km/h)	Emission (Kg/h)			
						CO_2	CO	NOX	HCS
Intersection	3932	8.2	D	35.6	26.1	1310.6	71.49	2.112	2.06
Roundabout	3933	8.2	A	4.8	32.6	1200.9	68.08	2.029	1.788
Intersection	1952	6.7	D	54.9	21.6	638.2	27.32	0.9	1.042
Roundabout	1952	6.7	A	4.2	30.2	545.6	24.41	0.815	0.821
Intersection	725	6.2	B	13.7	28	112.2	6.26	0.187	0.179
Roundabout	725	6.2	A	2.6	32	101.3	4.67	0.148	0.152
Intersection	2234	15.1	B	17.6	38	718	36.05	1.228	0.954
Roundabout	2234	15.1	A	5.3	42.7	698.8	35.81	1.22	0.905
Intersection	4124	6.3	E	64.3	24.6	1446	82.59	2.455	2.4
Roundabout	4124	6.3	A	5.6	38.6	1155.4	65.65	2.037	1.72
Intersection	2227	6.9	A	9.6	46.3	597.4	28.82	1.09	0.84
Roundabout	2227	6.9	A	3.4	49.4	568.4	28.25	1.088	0.801
Intersection	4067	8.6	F	220.6	11.9	2082.5	87.58	2.724	3.773
Roundabout	4067	8.6	A	9.1	34.7	1152.6	59.33	1.857	1.685
Intersection	3234	3.9	E	72.9	21.7	1036.2	47.09	1.478	1.775
Roundabout	3234	3.9	A	6.7	34.8	819.3	40	1.274	1.264
Intersection	4870	7	C	20.3	38	1342.4	70.57	2.326	2.009
Roundabout	4870	7	A	5.1	43.5	1250.3	62.36	2.147	1.784
Intersection	542	9.2	C	19	7.3	49.1	1.89	0.059	0.09
Roundabout	542	9.2	B	1.68	7.2	47.2	1.29	0.046	0.086
Intersection	4513	6.4	C	33.1	31.8	1397.3	79.05	2.452	2.188
Roundabout	4513	6.4	C	22.9	34.4	1238.1	71.6	2.232	1.9
Intersection	569	0.4	A	2.7	28	110.4	5.68	0.163	0.185
Roundabout	569	0.4	A	0.8	28.6	107.3	5.24	0.154	0.178

TABLE 7
RESULTS OF REGRESSION ANALYSIS

Variables	Coefficients	Standard Error	t-Stat	P-value
CO				
Intercept	-8.470751262	4.90628509	-1.726510202	0.118331277
Traffic Volume	0.016114162	0.00114355	14.09135357	1.93873E-07
% Heavy Vehicles	0.43284945	0.530241248	0.816325496	0.435387373
NOX				
Intercept	-0.266510199	0.111722568	-2.38546432	0.040860068
Traffic Volume	0.000505654	2.60401E-05	19.41825968	1.17778E-08
% Heavy Vehicles	0.018422879	0.012074291	1.525793858	0.161403101
HCs				
Intercept	-0.117392255	0.089652882	-1.309408603	0.222835487
Traffic Volume	0.000432362	2.08962E-05	20.69095807	6.72787E-09
% Heavy Vehicles	0.002703545	0.009689134	0.279028509	0.786528614
CO2				
Intercept	-121.7229445	53.50384199	-2.275031847	0.048958621
Traffic Volume	0.290307397	0.012470596	23.2793524	2.37064E-09
% Heavy Vehicles	9.056826947	5.782367603	1.566283497	0.15172404

3.5 Regression Analysis

Commonly, Multiple Regression Analysis is used to evaluate the correlation between a dependent variable and one or a set of independent variables. In this study the regression is used to identify the relation of Traffic Volume and percentage of Heavy Vehicles with the total amount of emissions produced by a modern roundabout. The regression was conducted on each MOE separately and the results are presented in Table 7. The results of the multiple regression analysis conducted to evaluate how the traffic volume and percentage of heavy vehicles relates to the reduction of emissions (CO2, CO, NOX and HCs) when the intersection is changed to roundabout. The findings showed a very strong relationship between Traffic Volume and amount of all emissions produced by the imaginary roundabouts. On the contrary, the correlation between percentage of heavy vehicles and sum of emissions was not very significant.

3 CONCLUSION

The findings of this study showed a significant reduction of vehicular emissions after converting intersection to roundabouts. The results illustrated a decrease in amount of all selected MOEs in all sampled intersections. However, this reduction is considerably fluctuated and differs with distinct intersection. It was evident from the results that the emissions of some sites were significantly decreased after conversion of exiting intersection to modern roundabout, where others showed smaller reduction. This fluctuation is highly dependent on the overall condition and performance of the intersections such as the intersections with good level of services, per -fect geometry, nicely designed signal timings and reduced delays have small amount of emissions produced; and after converting to modern roundabouts the difference of emissions is smaller as well. While on the other hand, if the level of service and other mentioned characteristics of the intersection are poor, the intersection can generate huge amount of pollutants. On a similar basis, roundabouts were found to be very effective in provision of better level of service. When converted to modern roundabouts, the level of service of intersections drastically improveed which resulted in massive drop of emissions. On a total account it can be stated that if a current operating intersection has a good level of service and it is converted to modern roundabout the drop in rate of MOEs will be smaller and Vice Versa. The results showed that if all studied intersections are to be converted to modern roundabouts, it will result in a reduction of 18.035%, 14.273%, 12.385% and 25.213% in amounts of CO2, CO, NOX and Hydro Carbons respectively. Similarly, the findings demonstrate a huge drop in overall delays and a notable increase in operating speeds. The results showed that if all 12 selected intersections are to be converted to modern roundabouts; the delays on an average basis will be reduced by 87.209% and the average operating speeds will increase by 20.895%.

Overall, the results from the study demonstrated that modern roundabouts play an essential role in terms of emission reduction compared to ordinary signalized and unsignalized intersections. The reduction of emission in all intersections was found considerably high. Yet a fixed range cannot be determined for the reductions since the amount of emissions produced by specific intersections deeply depends on performance and other characteristics of the intersections. Level of service, geometry and design of signal phasing were found to be exceedingly affecting parameters. Consequently, it can be stated that conversion of signalized and unsignalized intersections to modern roundabouts, or installation of new roundabouts will significantly decrease the sum of pollutions produced by the traffic negotiating the intersections.

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