Assessment of level of service for urban signalized intersections in India

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Significant work on level of service (LOS) has been conducted around the globe over the last two decades. However, till date, no guidelines exist for LOS of signalized intersections in India. The present study attempts to introduce LOS criteria for signalized intersection under mixed traffic condition. Thirteen intersections from four different cities of India were chosen for this study. Delay at intersections (which is the backbone for deriving LOS) is estimated using the area estimation method (according to *HCM 2010*). Clustering technique (to be specific, *K*-mean clustering) has been used to classify six clusters of delay corresponding to six different LOS and arrive at a LOS criteria. Silhouette method has been employed to validate the proposed delay clusters. The silhouette indices obtained justify the proposed delay ranges corresponding to the clusters and indicate the possible implementation of the proposed LOS for rating the performance of signalized intersections of India.

Keywords: Area estimation method, LOS, *K*-mean clustering, signalized intersection, user perception survey.

LEVEL of service (LOS) indicates the qualitative measure describing the operational conditions within a traffic stream and their perception by motorists and passengers. When an intersection is carrying a traffic equal in volume to its capacity under ideal roadway and traffic conditions, the operating conditions become extremely poor. Speed drops down and the delay and frequency of stops mount up. The service which an intersection offers to the road users can vary under different volumes of traffic. The *US Highway Capacity Manual* (*HCM*)[1] introduced the concept of LOS, which denotes the level of satisfaction one can derive from a road under different operating characteristics and traffic volumes. *HCM 2010* has defined six different levels of service, LOS A (free flow) to LOS F (forced or break down flow) and their respective criteria for signalized intersections based on traffic conditions of USA[2]. The traffic conditions in developing countries like India are exclusively different from those in the US or the Europe. Heterogeneity and poor lane discipline are the prime traffic characteristics of developing countries. Therefore, categorization of Indian signalized intersections, based on *HCM*[2] LOS ranges, is not realistic. It requires different LOS criteria for signal controlled intersections in developing countries like India based on existing traffic conditions. LOS at a signal controlled intersection is generally measured in terms of delay caused to an individual vehicle. This parameter has been accepted globally and the same is used in the present study also.

Several researchers have worked on the assessment of LOS at signalized intersections[3–7]. Safety and delay-based LOS (LOS A–F) criteria was proposed for signalized intersections[8]. It was observed that *HCM*[2] proposed delay based LOS criterion is probably not a good surrogate from safety point of view of a signalized intersection. Later on, a fuzzy neural network-based approach was developed to predict LOS based on user perception survey[9]. Moreover, accepted delay time was introduced for different LOS by studying the willingness of motorcycle rider and car drivers[7]. During the last thirty years, a number of researchers have adopted user perception survey technique and come up with various LOS ranges of signalized intersections in different countries. Various parameters were taken into consideration while carrying out the user perception survey[3,5–10]. Average delay time, mean waiting time, stopped delay time, intersection design, signal timing, conflict points, safety index and turning movements are few of them, among which average delay time was the prime parameter.

The user perception survey is a time-consuming process with lot of difficulties and error. Dealing with the road users, convincing them to answer all the required questions and at last proposing LOS ranges based on all the chosen parameters are really complex and need sufficient manpower. Moreover, most drivers cannot discriminate well between small variations in average waiting times. This difference may lead to an unavoidable error. For example, there is a chance that LOS A indicates delay up to 25 sec and LOS B starts with a delay of 26 sec. Therefore, an accurate examination of average waiting time is necessary while dealing with LOS criteria. To save the time and minimize these errors, analytical techniques such as clustering analysis have been adopted for defining LOS ranges at signal controlled intersections.

Six LOS boundaries were proposed based on fuzzy clustering and user perceived delay at signalized intersections[4]. *K*-mean clustering method was used to propose six LOS ranges for urban arterials of India based on volume capacity ratio[11]. Adding to this, LOS ranges were proposed for Indian urban arterials, based on the percentage speed reduction of the vehicles with the help of *K*-mean clustering technique[12]. Similarly, hierarchical agglomerative clustering technique was used on average travel speed of the vehicles, to define LOS criteria of urban streets in India[13]. In all these studies, clustering approach has been adopted for proposing LOS ranges on urban arterials and urban streets. Apart from this, fuzzy

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clustering technique was also used for LOS categorization of signalized intersections in USA. However, the clustering approach is not yet used in India for proposing LOS ranges at signalized intersections. Moreover, the LOS range is not yet proposed for signalized intersections in India. User perception is not always the best method to classify the data in different ranges. It is true in the case of LOS where different road users perceive the delay differently based on value of their time. A delay of 25 sec for a car user may be quite substantial and may be reasonable for a motorized two-wheeler rider. Therefore, clustering analysis technique is opted in this study for more accurate assessment of LOS. The objective of the present study is to focus on the assessment of LOS criteria for urban signalized intersections of India using *K*-mean clustering.

Video graphic technique was used for data collection. Thirteen signalized intersections in four different cities of India namely Delhi, Patiala, Chandigarh and Punch Kula were chosen. All intersections were four arm, provided with channelized left turning lane (for left hand drive conditions) and no influence of bus stops, parking or other side frictions. One approach was selected at each intersection. The approach width and cycle length for each approach are shown in Table 1. Two cameras were used; one upstream and another downstream of the approach to record both arrival and departure rate of the vehicles on that particular approach. Both morning (10 a.m.–1 a.m.) and evening peak hours (2 p.m.–5 p.m.) were considered for data collection. A longitudinal trap was made on selected approaches as shown in Figure 1 from the stop line to the end of the queue. The end of the queue was decided by visually monitoring a number of randomly selected cycles.

The video data were played in the laboratory to extract the desired information. Vehicles were classified into five categories namely two-wheelers, three wheelers, big car, small car and heavy vehicles. The arrival and departure of vehicles, traffic volume and capacity-related information

Table 1. Details of signalized intersections chosen for the study

Intersection number	City	Approach width (m)	Cycle length (sec)	Number of observed cycles
1	Delhi	10.2	170	50
2	Delhi	10.2	170	45
3	Patiala	7.3	110	50
4	Patiala	7.3	110	60
5	Patiala	8.0	120	40
6	Chandigarh	12.1	120	49
7	Chandigarh	7.7	120	60
8	Chandigarh	10.0	135	45
9	Chandigarh	14.6	130	40
10	Chandigarh	13.6	150	50
11	Punch Kula	8.9	100	50
12	Punch Kula	9.1	100	40
13	Punch Kula	9.1	100	45

were extracted for all the cycles in terms of number of vehicles. Data were extracted for every 5 seconds interval. The moment a vehicle enters into the trap is considered as its entry time. Similarly, the moment the vehicle completely crosses the stop line is taken as exit time of that vehicle. Later on, the number of vehicles entered and exited from the trap is considered for queue length estimation. Total number of vehicles in the queue is taken as the summation of number of vehicles already present in the queue and the number of vehicles arrived during five seconds interval, minus the number of vehicles that had crossed the stop line during that time interval[2].

Delay to a vehicle is the extra time required at the intersection while crossing a road. When vehicles travel through an intersection there can be two types of situation. One, the total number of vehicles entered into the intersection during a particular cycle are able to cross the stop line before completion of their first green, known as under-saturated cycle. Two, total number of vehicles entered into the intersection cannot cross the intersection during first green. The queue at such intersections builds up and the cycle is called over-saturated cycle. While travelling through an intersection, the major part of the delay experienced is mainly due to the waiting time. A vehicle has to wait for a long time at intersections mainly in two conditions; first, when a vehicle enters the intersection approach during the red phase of the cycle and secondly, when the vehicle is following a long queue of vehicles in front. Waiting of a vehicle during red phase can be avoided if it is possible to reach the intersection during green phase. But there is no assurance that no queue will exist during green time also. Therefore, it is a conventional method to measure delay at a signalized intersection by plotting queue length of a particular cycle against the total cycle time. *HCM 2010* suggests that the total delay of an under-saturated cycle can be measured by plotting a trapezoid or a triangle among queue length of a cycle and cycle time[2]. The area of the triangle or trapezoid represents the total delay associated with that cycle. The present study has adopted the same method.

All the vehicles present in the queue are able to cross the stop line before completion of the cycle (Figure 2). Therefore, the area estimation concept can be used in this case. The total area under the curve is the delay experienced by the vehicles present on that particular cycle. It is observed that the curve between queue length and cycle length is not straight. Therefore, the curve was assumed straight (as per cut and fill method) to make the area measurement easy. The total area was then divided into a number of suitable triangles and trapezoids for better estimation of the delay.

In the case of oversaturated cycles, the total delay experienced by the vehicles includes uniform delay, random delay and overflow delay which is mainly because of those vehicles which cannot cross the stop line during their first green. It is to be noted that uniform and random

Figure 1. Trap from (***a***) stop line to (***b***) end of the queue at intersection approaches (Chandigarh Sector 46 C chowk).

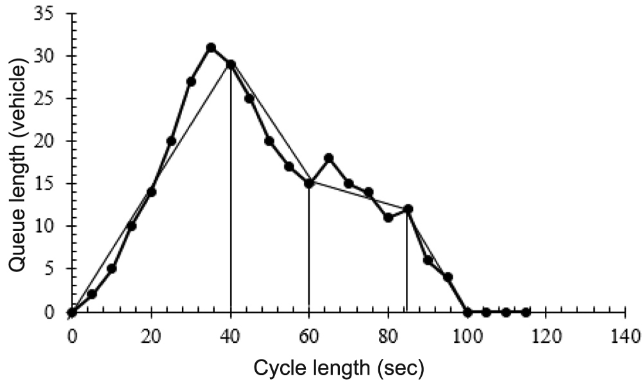

Figure 2. Delay measurement of under-saturated cycle using area estimation method.

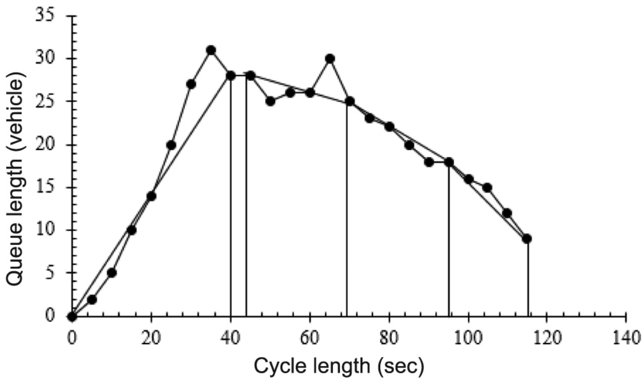

Figure 3. Delay measurement of over-saturated cycle using area estimation method.

delay components of an oversaturated cycle can be estimated using area estimation method.

Figure 3 shows that the area under the curve is not the overall delay of that particular cycle. The area indicates delay due to uniform and random arrival of vehicles. Some of the vehicles remain in queue after the end of their first green. These vehicles have to wait till their second green time initiates. The delay occurred due to these excess vehicles is known as overflow delay. However, to make delay estimation simple, total uniform and random delay was estimated by measuring the area under the curve of Figure 3 and overflow delay component was estimated using Webster's overflow delay model (eq. (1))

$$\text{TOD} = \frac{1}{2}T((v/c)-1), \tag{1}$$

where TOD = total overflow delay of a cycle (sec), T the cycle length (sec) and v/c is the volume capacity ratio.

K-mean clustering is one of the most popular clustering algorithms to classify a large number of data sets into a number of groups. This approach was employed in this study to classify all the measured delay data sets of 13 signalized intersections into 6 groups. Each group corresponds to a different level of service. Delay was classified into 6 clusters. Silhouette method was then employed to validate the clustering approach. If validation of clustering is not successful, then the number of groups would be varied and results of each case will be validated until optimum number of clusters are found.

The *K*-mean clustering process followed the following the steps: (1) Total number of clusters (*K*) was decided, among which estimated delay values would be divided; (2) Delay data sets were randomly distributed among *K* number of clusters; (3) Centre of each cluster was estimated as the mean of cluster members; (4) Euclidian distances were measured between each data point and the centre of all the clusters. The distances show how a delay data point is close to the center of the cluster; (5) If any delay data point was found to be closer to the centre of another class than its current one, then the data point was shifted to that particular cluster; (6) Clusters containing newly added data points were developed. The procedure from step 3 to step 6 was repeated successively until maximum number of iterations were reached.

The measured delay values at all the thirteen signalized intersections were taken together and the procedure explained above was repeated up to 100 iterations to obtain the range of clusters. Table 2 shows the range of delay for six different LOS classes. These ranges are different from those given in *HCM 2010* (ref. 2).

Several researchers studied the LOS criteria of signalized intersections and proposed different delay ranges for different countries. Many of them have adopted user perception survey and fuzzy clustering and came up with some delay ranges. However, we preferred *K*-mean clustering over the user perception survey for more accuracy and less time consumption. Delay ranges proposed in this study for signalized intersections of India are different from other countries. A comparison of proposed delay ranges for different LOS criteria has been done with the existing delay values proposed by *HCM 2010* (ref. 2) and Fang *et al.*[4] (Table 3).

The delay ranges shown in Table 3 imply that HCM 2010 (ref. 2) and Fang *et al.*[4] proposed almost similar delay values for LOS A to LOS F. This is mainly because the study area was in Pennsylvania, located in the Northern and Mid-Atlantic regions of the United States. Therefore, the traffic and driver characteristics are similar in these two studies. However, traffic in India is of mixed nature with extremely poor lane discipline. Small-sized vehicles like motorized two-wheeler can easily move in a zig-zag manner and reach near the stop line of the intersection during the red phase when a long queue is standing behind. However, heavy vehicles and cars cannot follow the same and ultimately face more delay, thereby increasing the average delay of the vehicles while crossing the intersection stop line. Apart from this, signals at intersections in India are pretimed rather than fully actuated signal as observed in US and the Europe. Therefore, green and red phase of a cycle do not change according to the demand in the approach. Further, no separate lanes exist for right turning vehicles, bicycles and buses. Therefore, the delay ranges for different LOS are large as compared to those given in US HCM[2].

It is necessary to study how good the cluster members are fitted within the proposed ranges. Validation has been done to check quality of the clusters. Dunn's index and Silhouette index are two validity indices which are generally used for validation purpose. Dunn's index gives accurate results but the validation procedure is too complex and more time consuming. However, the main drawback of silhouette index is that it cannot be used effectively for higher dimensional spaces. The present study does not need delay ranges with high decimal spaces. Therefore, the silhouette method was adopted for validating the proposed clusters. Silhouette method was proposed by Rousseeuw in 1987. It is a graphical representation indicating how well every data point fits into a cluster. Silhouette index for ith member can be expressed as given in eq. (2)

$$S(i) = \frac{b(i) - a(i)}{\max\{a(i), b(i)\}}, \tag{2}$$

where $a(i)$ is the nearest distance between ith member and other members of the same cluster, $b(i)$ the nearest distance between ith member and members of nearest neighbouring clusters. It is obvious that $-1 \leq S(i) \leq 1$.

Silhouette value of all the members of a particular cluster is presented together in the form of a band. The height of the band shows the total number of members in the cluster. Silhouette width is the average of silhouette index of all the members present in a cluster. Silhouette coefficient is the weighted average of all silhouette widths for the complete data set. Table 4 shows the quality of clustered data corresponding to the ranges of silhouette co-efficient[14].

Figure 4 shows the silhouette plot of K-mean clustering among silhouette index and level of service. Silhouette index was estimated using eq. (2). Silhouette width of each cluster and silhouette co-efficient were estimated

Table 2. Proposed LOS ranges for signalized intersections

LOS	Delay ranges (sec/vehicle)
A	≤10
B	10–45
C	45–65
D	65–100
E	100–135
F	>135

Table 3. Comparison of proposed LOS ranges of India with the existing ones

LOS	Proposed delay ranges (sec/vehicle)	*HCM 2010*[2] delay ranges (sec/vehicle)	Delay ranges by Fang *et al.*[4] (sec/vehicle)
A	≤10	≤10	0–12
B	10–45	>10–20	12–25
C	45–65	>20–35	25–38
D	65–100	>35–55	38–56
E	100–135	>55–80	56–90
F	>135	>80	> 90

Table 4. Silhouette co-efficient ranges for quality of clusters[14]

Range of silhouette co-efficient	Interpretation
0.71–1.0	A strong structure has been found
0.51–0.70	A reasonable structure has been found
0.26–0.50	The structure is weak and could be artificial
< 0.25	No substantial structure has been found

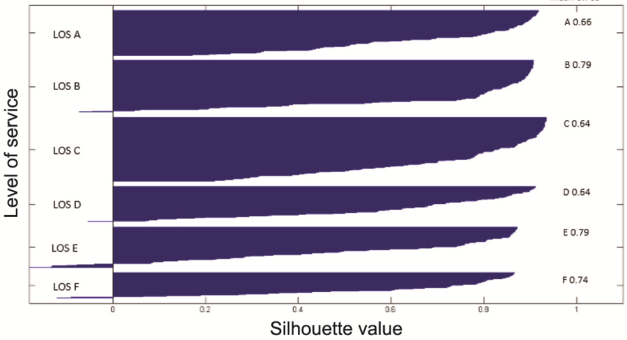

Figure 4. Silhouette plot of K-mean clustering.

taking average of silhouette indices and silhouette width respectively. Silhouette co-efficient was 0.709 (Figure 4) which indicates a strong structure. Therefore, six LOS are proposed, accompanied by significant delay ranges as mentioned in Table 2.

Six LOS as explained below are proposed at signal controlled intersections under mixed traffic conditions in India.

LOS A: Low volume and small queue length. Maximum vehicles enter into the intersection, almost at the end of the red phase or starting of the green phase. So, the vehicles that enter into the intersection do not need to wait much to get their turn to cross the stop line. Moreover, the length of green phase is sufficient according to the volume. Because of that, all the vehicles entered into the intersection are able to cross the stop line during their first green. Adding to this, vehicles arriving during green phase can cross the stop line without stopping in between. Drivers experience minimum delay (≤10 sec) and enjoy freedom of movement without any congestion in between.

LOS B: Volume of incoming vehicles and queue length start increasing. Vehicles enter into the intersection randomly in the form of platoon throughout the cycle and all the entered vehicles are able to cross the stop line during their first green. Not all the vehicles are able to cross the intersection without stopping, only those reaching the intersection at the middle of the green phase time can cross without stopping. Time of green phase is sufficient for all the vehicles to cross the stop line. Delay time is acceptable (10–45 sec) and drivers have reasonable freedom of movement as volume increases but congestion is yet to start.

LOS C: Volume is high and long queue exists starting from red phase to end of the green phase. Arrival of vehicle is random and in form of platoons throughout the cycle. All the entered vehicles are able to cross the stop line just before the green phase ends. The length of green phase is exactly equal to the time required to cross the arrival volume. Delay is somewhat acceptable (45–65 sec). No vehicle can cross the intersection without stopping. Driver's freedom of movement starts restricting, congestion initiates because of high volume and long queue.

LOS D: Volume is higher than LOS C and queue length keeps on increasing. All the vehicles entered into the intersection are not able to cross the stop line during their first green. Some vehicles left in queue have to wait till next green phase for their turn to cross the stop line. Length of green phase is not sufficient for all the vehicles to cross the stop line. Delay is more (65–100 sec) but can be tolerated for short period of time. Drivers experience congestion and freedom of movement is somewhat restricted.

LOS E: Volume is equal or near the capacity of intersection. Vehicles enter into the intersection in the form of big platoon especially at the staring of red phase and at the end of green phase. Therefore, they have to wait more time to cross the stop line. Moreover, all the vehicles that enter into the intersection are not able to cross the stop line during their first green. A good proportion of vehicles have to wait till next or next to next green phase to cross the intersection. Delay keeps on mounting, reaching unacceptable (100–135 sec) delay. Length of green phase is very short for all the arrived vehicles to cross the intersection. Vehicles get a very less space for movement because of high traffic volume and a long queue. As a result, congested condition is experienced by the driver and freedom of movement gets restricted.

LOS F: Volume is more than the capacity of intersection. A very big queue builds up at the intersection. A very good number of vehicles in queue, enter into the intersection especially at the end of the green phase. Length of green phase is insufficient to let all the arrived vehicles to cross the stop line sometimes even during their second green phase. Only few vehicles cross the stop line during their first green. Because of excess volume and longer queue, congestion increases. Delay is higher (>135 sec). A no movement congested situation is experienced specially by the vehicles that get space at the middle and end of the queue.

LOS is the qualitative measure of satisfaction that one can derive from the existing roadway and traffic conditions. The LOS of an intersection is generally measured in terms of total delay to an individual vehicle. The total delay of a cycle is the area between queue length and total cycle length. Therefore, the present study suggests measurement of delay at a signalized intersection using triangular area estimation method. In case of under saturated cycles, delay estimation using triangular or trapezoidal method is feasible as no queue is left over at the end of the cycle. However, in over-saturated cycles, all vehicles that entered into the intersection are not able to cross the stop line during their first green. Overflowing vehicles are required to wait for their second green. Therefore, the area between queue length and cycle time is not the total delay of all the vehicles of over an saturated cycle. In addition to this, the delay of overflow vehicles needs to be measured separately. For this purpose, Webster's overflow delay model was used in this study. The delay ranges for different LOS are proposed at signalized intersections of India where traffic is heterogeneous in nature and poor lane discipline is maintained. *K*-mean clustering algorithm is used to classify the large delay data sets into number of clusters and six clusters are proposed. Silhouette method was implemented to validate the proposed clusters. Silhouette co-efficient indicates that a strong cluster has been formed. The study will be helpful for the road users to easily identify the performance of intersections and rate it into various groups depending on the amount of delay experienced while traversing through the same. It will also guide the traffic management agencies to design the signals with a targeted LOS.

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Xylooligosaccharides production from tobacco stalk xylan using edible acid

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In the present study, a process was developed to hydrolyse xylan from tobacco stalks into xylooligosaccharides (XOS) by applying tartaric acid, an edible acid. The tobacco stalks contained approximately hemicelluloses (16.99%), cellulose (50.8%) and lignin (15.6%). Use of 8% KOH or NaOH under overnight incubation resulted in almost complete recovery of xylan from the tobacco stalks. Application of 1 M tartaric acid at 90°C hydrolysed xylan into XOS and the highest (0.357 mg/ml) yield of XOS was recorded after 120 minutes. Hence, prebiotic XOS could be produced from the tobacco stalk xylan by applying tartaric acid.

Keywords: Edible acid, tobacco stalk, xylan, xylooligosaccharides.

LIGNOCELLULOSIC wastes are generated from different crop production systems. These are considered as an abundant carbon-neutral renewable reservoir of the earth that can be utilized for the production of multiple value-added products for various industrial applications such as food, feed, pharmaceutical, polymer, fuel, etc. Currently, there is global attention for utilizing agricultural wastes as raw materials for producing numerous valuable products, including prebiotics. According to an estimate[1], the cost of lignocellulosic biomass was approximately US$ 23 per tonne compared to the crude oil price of US$ 50. Despite that, efficient bio-refining processes for translating agricultural waste into value-added products are lacking[2]. Amongst the list of agricultural wastes, tobacco (*Nicotiana tabacum*) stalks occupy significant niche because they are grown in almost 4.3 million hectares of agricultural land distributed among 124 countries. After harvesting of leaves, the stalks are generally incorporated in the soil or burned in field as they carry meagre economic significance[3]. The tobacco stalk is primarily composed of cellulose and lignin in addition to hemicelluloses. Therefore, partitioning of biomolecules from the tobacco stalks is noteworthy in the direction of environmental protection as well as effective utilization of agricultural wastes. Xylan represents a significant fraction of hemicelluloses present in the tobacco stalks. Therefore, it can be used for the production of numerous finer molecules, including prebiotic xylooligosaccharides (XOS).

In current days, prebiotics attracted the attention of global researchers for health and well being as its principle of action relies on 'prevention is better than cure'. Out of the several classes of prebiotics, XOS is presumed to be an emerging one which possesses several beneficial roles. It selectively stimulates the growth of beneficial gut bacteria, produces short-chain volatile fatty acids, boosts immunity, enhances mineral absorption and lowers blood cholesterol, colonic pH and pro-carcinogenic enzymes in hind gut[4]. Additionally, XOS also alleviates the symptoms of diabetes, cancer, stress, etc.[4–6]. The production of XOS is environmentally caring because it generates value-added products from the abundantly available agricultural wastes unsuitable for human consumption. Xylan is the precursor for XOS. The main backbone of xylan is formed by xylose monomers, linked by β-1,4-xylosidic bonds and often replaced with arabinose or acetyl or methyl groups[7].

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