Evaluation of the Effect of Access Point Density on the Safety of Primary Roads. A Case Study

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ABSTRACT

This paper investigates the nuanced exploration of access point density's influence on accident frequency, specifically focusing on primary roads in Malaysia. The analysis is multifaceted, considering geographic variations, land use patterns, and the density of access points per km. This investigation scrutinizes the direct relationship between the number of access points per km and the corresponding accident frequency. A critical threshold value for access point density is identified, revealing its consequential impact on average accident frequency. The observed direct proportionality between access point density and accident frequency is a pivotal discovery. Moreover, the role of land use parameters emerges as a key determinant in understanding how accident frequency varies with access point density, particularly on specific road types. This establishes eight access points per km as a potential threshold value for ensuring optimal access point density within a road network. In summary, this study provides insights into the intricate dynamics of access point density and its consequential impact on road safety. The identified threshold value and the recognition of the role of land use contribute valuable perspectives for informed decision-making in road network planning and management.

Keywords-crash frequency; road geometry; land use; unsignalized intersection; access point per kilometer

I. INTRODUCTION

Access commonly refers to the provision of a path through which a vehicle can enter or exit a road or street. Formally an Access Point (AP) in a transportation network includes driveways, street connections [1, 2], and unsignalized intersections. As per their functionality, there is no significant difference between an AP and an unsignalized intersection but the former can be referred to as a facility that provides access to minor-streets, side-streets, and private driveways from a building to a major road [3], while the latter is primarily referred to as a facility that occurs when two roads meet each other, with one road classified as the minor and the other as the major. Unsignalized intersections can be three-legged or T-junctions and four-legged or crossroads, whereas APs are mostly T-junctions. A driveway can be further divided into several types, such as major, minor, commercial, residential, and industrial/institutional [3]. These driveway types are parts of every road network and development schemes, therefore, evaluation of their contribution to the safety of the road network is necessary. It is a known fact in the field of transportation engineering that access and mobility are inversely proportional to each other. An increase in access will decrease the mobility and vice versa, as shown in Figure 1. The increase in access, on the other hand, increases the exposure to risk, because the addition of any AP adds to the number of merging and diverging movements through traffic [4]. Thus, the AP density, measured in terms of the number of APs per km, affects the safety of highways and streets. It has been reported [5] that an increase of one AP per km will increase the number of accidents by 4% for a given volume on a particular road. There is a positive association of AP density with the accident rate per million vehicle mile travel [6].

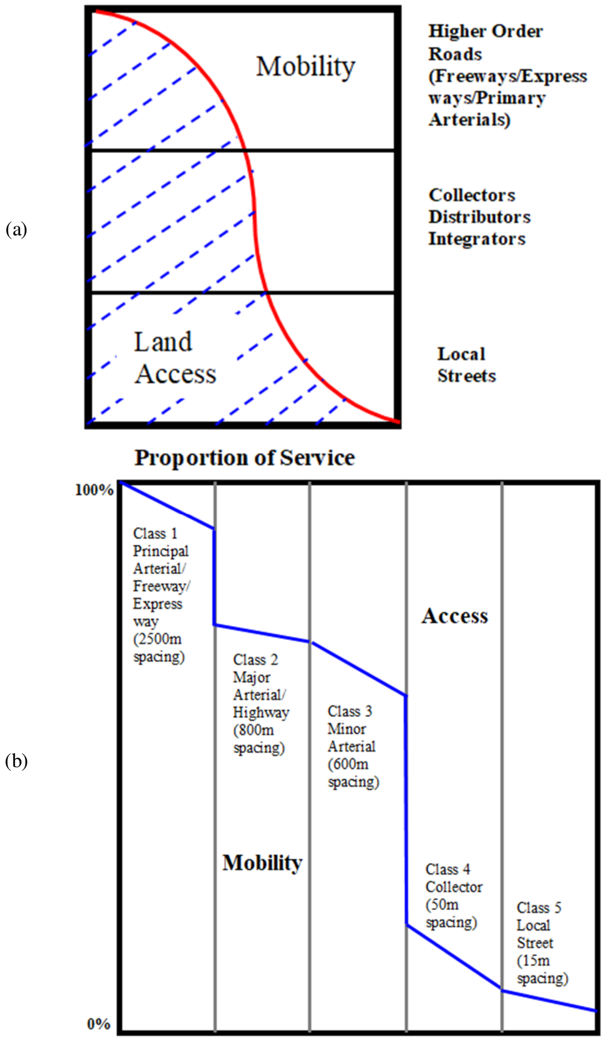

Fig. 1. (a) Effect of mobility and accessibility on highway classification, (b) mobility versus accessibility in highway classification.

The importance given to the APs or unsignalized intersection density per km in the literature and their contribution in decreasing road safety provided the motivation for this study. This paper aims to explore the effect of AP density on the accident frequency at primary roads in Malaysia. The roads which fall under the federal government are termed as primary roads [7] and can be classified as arterial roads. This paper presents the results of the field survey conducted on 28 roads in Penang, Malaysia. Geometric parameters like the width of major and minor roads, the length of the entire major road, the number of intersection legs, lane marking, and shoulder width, control parameters like stop signs/line or no control at all, and social parameters like land use pertinent to the APs on the roads under consideration, were monitored. The effect of the number of APs per km on the number of accidents was analyzed. A threshold value for the AP density was determined and its impact on the average accident frequency is presented.

II. LITERATURE REVIEW

The literature on road safety management and APs reveals a comprehensive understanding of the factors influencing accident frequency, particularly in the context of AP density. Several studies contribute valuable insights into the geometric and functional design of APs, shedding light on their impact on safety. Authors in [8] conducted a comprehensive study on the management of uncontrolled APs, emphasizing the importance of considering design criteria and risk factors associated with these road network elements. The research focused on APs without traffic control features, such as traffic lights or stop signs, highlighting safety issues related to their location, design, and visibility. By analyzing the geometric and functional design of uncontrolled accesses, the study aimed to provide insights into defining more adequate design criteria for improving safety. Authors in [9] delved into the association between driveway land use and safety performance on rural highways, particularly in the context of county roads in Michigan. While prior research had explored the safety impacts of driveway density, this study extended the focus to examine the effects of different classifications of driveway land utilization. The findings indicated that commercial driveways had a more pronounced effect on crash occurrence compared to other land use types, contributing valuable insights into the nuanced relationship between land use, driveway density, and road safety. Authors in [10] evaluated the safety impacts of access management techniques in Utah, addressing the growing traffic volumes and congestion on arterial streets. The study employed a geographic information system (GIS)-enabled data almanac to assess crash data and identify high crash locations. Although the study did not uniformly observe reduced crash rates, it highlighted safety improvements, particularly in eliminating the severity of collisions. The findings emphasized the need to consider a range of safety outcomes beyond simple crash rates when evaluating access management techniques. Authors in [11] focused on the effect of midblock APs on traffic accidents on state highways in New Jersey. Through statistical analysis, the study identified access density as a contributing factor to accidents, emphasizing that while it was a significant factor, it was not the sole determinant. The research provided valuable insights into the distribution of accidents along state highways, distinguishing between section accidents and those occurring at signalized intersections. Authors in [12] expanded the focus beyond access management characteristics, examining the relationships between various physical characteristics of arterial roadways and safety. This research brought attention to the positive relationship between specific access management-related characteristics and increased crash rates and severity. Additionally, it highlighted the role of land use in influencing the safety of arterial roadways, particularly the association between adjacent commercial land use and higher crash rates. The impact of access density on the number of crashes at commercial roadways, considering various access management techniques was explored in [13]. The study, conducted in Oregon, involved a comprehensive analysis of crash incidence per mile in relation to access density. The results indicated a correlation between crashes and access density, suggesting that factors, such as average daily traffic and number of lanes may also influence the number of segment crashes per mile. Authors in [14] presented a quantitative framework for evaluating highway access safety programs, emphasizing the importance of performance metrics and a decision-aiding framework. The framework applied multicriteria analysis and cost-benefit analysis with parameter uncertainties, offering a systematic approach to assess the relative needs at existing APs. This research demonstrated the applicability of the framework across large corridor networks and diverse time horizons. Authors in [15] investigated the effect of access-point density on traffic crashes on a rural two-lane highway, specifically the Ahar-Tabriz Highway. The study, conducted through a case study approach, provided valuable insights into the relationship between AP density, spacing, geometric features, and crash rates. The results indicated a direct correlation between AP density and accident rates, emphasizing the role of AP specifications in highway safety.

III. STUDY AREA AND DATA COLLECTION

The state of Penang, Malaysia, chosen as the study area for this research, represents a compelling and dynamic case study for the evaluation of the effect of AP density on the safety of primary roads. Nestled on the northwest coast of Peninsular Malaysia, Penang is a state comprising the island of Penang and a portion of the mainland known as Seberang Perai. Penang presents a dynamic and diverse landscape that encompasses both urban and rural types of environment. The region offers a unique blend of economic vitality and cultural diversity. The arterial roads of Penang Island weave through densely populated cities, catering to a spectrum of economic activities, while Seberang Perai introduces elements of rural landscapes into the road network. With a mix of commercial hubs, industrial zones, and agricultural areas, Penang's road network reflects its economic significance and multicultural population. The interconnected highways serve not only as conduits for urban commuters, but also as vital links for rural communities. As Penang undergoes rapid urbanization and economic growth, the study seeks to delve into the safety implications of AP density, examining the ways the varied road network influences safety across urban and rural contexts. This dynamic study area is poised to provide valuable insights into the interplay between AP density and road safety, contributing to local policy considerations and also offering lessons of broader significance in the context of global urban development and transportation challenges.

The methodology formulated for the field data collection was simple and required minimal equipment and manpower. Regarding the survey, only a safety vest, a measuring wheel and a set of noting pad and pens were needed. A single person can easily conduct the survey of a particular roadway during normal working hours. The procedure comprised the following steps:

- Identifying the survey location using Google Maps.
- Taking screenshots of the survey location from the beginning to the end of the road.
- Arranging the screenshots according to their sequence.
- Start the survey from the beginning of the road by walking. Spot any unsignalized intersection that comes first on the way. Mark its position on the map and give it a serial number for identification.
- Measuring the widths of the minor and major roads as shown in Figure 2.

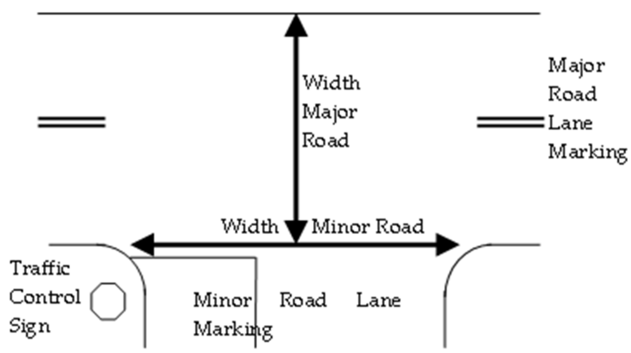

Fig. 2. Widths of the minor and major roads.

The survey was carried out between May and July 2013. A total of 28 roads were surveyed in the state of Penang, Malaysia. Table I displays a list of the parameters used in this study on the roads under consideration. As mentioned above, the state of Penang consists of two different geographical parts. One is located on the west side of Peninsular Malaysia and is a part of the mainland, while the other is an island. The parts have different topography, land use, sociology, and economy. Therefore, the roads surveyed were divided based on their location and a comparative analysis of all the parameters collected was performed with respect to geographical location. The names and lengths of the roadways are presented in Table II.

TABLE I. PARAMETER LIST

Parameter type	Parameter
Geometric	Width of major roads
	Width of minor roads
	Length of the entire major road
	Number of legs of intersection
	Shoulder width
Control	Stop sign/line
	Lane marking
Social	Land use: city, town or rural area

A. Descriptive Analysis

The data collected for this study consisted of two parts. The first part was related to the number of APs or unsignalized intersections on a particular road and the geometry of each AP. These data were acquired through field surveys as explained above. The second part comprised the accident data which were acquired from the Malaysian Institute of Road Safety Research (MIROS). The data consisted of the total number of accidents that occurred along each road for a period of six years, from 2006 to 2011. Descriptive analysis of the data was performed and the effect of various parameters, such as geographical boundaries, land use, number of APs per km on the frequency of road accidents were analyzed. The descriptive statistics of the accident data acquired from MIROS and geometric parameters obtained through field survey, are presented in Table III.

TABLE II. NAME AND LENGTH OF SURVEYED ROADS WITH RESPECT TO GEOGRAPHICAL LOCATION

S. No.	Name of Road	Road length (km)
	Island	
1	Lebuhraya Thean Teik	3.1
2	Jalan Paya Terubong	8.4
3	Jalan Persiaran Gurney	1.9
4	Jalan Cantonment	1.1
5	Jalan Air Itam	0.9
6	Jalan Padang Tembak	1
7	Jalan Burma	3.6
8	Jalan Jelotong	2.3
9	Jalan Bukit Gambir	5.6
10	Jalan Sri Tan Hi Ewe Lim	1.2
11	Jalan Tanjung Bungah	2.6
12	Jalan Batu Gantung	0.8
13	Jalan Penaga Z0372	0.55
14	Jalan Sultan Azlan Shah	11.5
	Mainland	
1	Jalan Raja Uda	4.1
2	Jalan Bagan Ajam	0.75
3	Jalan Pongsu Seribu	2.7
4	Jalan Besar Nibong Tebal	0.65
5	Lorong Mak Mandin 5	1.2
6	Jalan Bagan Lalang	2
7	Jalan Pengkalan Macang	0.07
8	KM22 Jalan Besar Simpang Ampat	0.16
9	Jalan Bertam 1, Kepala Batas	0.75
10	Jalan Dua Kepala Batas	1.1
11	Jalan Merbau Kudung	0.15
12	Jalan Telaga Air	0.8
13	Jalan Padang Bengali	4.7
14	Jalan Penaga P001	4.3

TABLE III. DESCRIPTIVE STATISTICS OF THE ACCIDENT AND FIELD SURVEY DATA

	Mean	Min	Max	SD
Number of accidents	8.71	2	31	7.57
APs per km	9.58	3	43	7.77
Average road width (m)	10.54	6.6	14.7	2.05
Average AP width (m)	13.61	10.1	21.4	2.69
Average shoulder width (m)	0.98	0	3.75	0.94

IV. RESULTS AND DISCUSSION

Access commonly refers to the provision of a path through which a vehicle can enter or exit a road or street. Formally an AP in a transportation network includes driveways, street connections, minor unsignalized T-intersections [22]. This section provides a discussion about the effect of the geographical distribution on the geometry of APs, the effect of land use followed by the effect of AP density on accidents. A threshold for the number of APs per km was determined and the way it influences the average accident frequency was examined.

A. Effect of Geography on Geometric Parameters

The geometry of an AP plays an important role in the severity and frequency of accidents that occur on a particular road. In this study, each road encompassed several APs, thus, the geometric characteristics of all the APs on each road were averaged. Table IV provides a quick reference to their values. Since the socio-economic, demographical, and geographical conditions of the mainland and island were different, the geometric characteristics of their access points also varied.

TABLE IV. GEOMETRIC PARAMETERS WITH RESPECT TO GEOGRAPHICAL LOCATION

Parameter	Mainland	Island
Average length of road (km)	1.67	3.18
Average major road width (m)	10.92	10.16
Average minor road width (m)	12.74	14.48
Average number of 3-leg APs	11.57	19.36
Average number of 4-leg APs	1.36	1.64
Average number of APs with double line lane marking	4.86	6.86
Average number of APs with single line lane marking	5.36	4.29
Average left shoulder width (m)	1.06	1.05
Average right shoulder width (m)	1.12	0.78
Average number of accidents	8.50	8.93

The average lengths of the roads on the island were greater than those on the mainland as they encompassed a larger area and connected several points stretched along the road. Higher widths of major roads were observed on mainland, which depicts that land acquisition is more difficult on the island due to its higher land value. For the same reason, the shoulder widths of the APs along the major roads were more on the mainland. Contrary to major roads, the widths of minor roads were greater on the island, which indicates that the minor roads of the APs on the island are required to cater for more traffic as compared to the mainland. Both the average numbers of 3-leg unsignalized intersections or APs as well as 4-leg unsignalized intersections were higher on the island. Consequently, it can be inferred that the density of APs in general is higher on the island. The effect of the density of unsignalized intersection/AP per km is discussed in detail in the subsequent section. The primary purpose of lane markings provided along the middle of the road is to separate the traffic that moves in opposite directions, but they also serve as a surrogate measure for traffic volume. Double line lane markings are usually provided on roads that have a higher volume while single line lane markings are provided on roads that have a comparatively lower volume. This could be the probable reason why the average numbers of

APs with double line lane markings on the major road were higher on the island. Similarly, the average numbers of APs with single line lane markings on the major road were higher on the mainland. The effects of all the geometric parameters discussed above explain the reason behind the higher frequency of accidents observed on the APs located in the island.

B. Effect of Land Use

Various types of land use generate different magnitudes of trip [16], which can affect crash frequency. Thus, the risk of accident due to APs that lie on major roads situated in different locations can be attributed to their land use. Variation in land use in turn causes variation in the density of APs per km. This is evident in [17], where it was reported that the Department of Transportation in the state of Minnesota in USA uses area type, similar to land use type, as one of its selection criteria for spacing between APs [18]. Therefore, locations which are composed of a greater percentage of high trip land use may experience a higher crash frequency. Figure 3 shows the distribution of land use in the two geographical boundaries of Penang state. The results of the survey indicated that the part that was located in the island was more urbanized and had a higher percentage of cities and towns while areas that can be classified as small towns were only 7% with no presence of rural land use at all. Dissimilarly, the part which was in the mainland was less urbanized and had a higher percentage of small towns and rural land use. Therefore, the higher frequency of accidents observed on the APs in the island, as mentioned in Table II, can be attributed to the high number of merging and weaving maneuvers that take place due to a greater number of trips generated because of the greater percentage of urbanized land use. This result is in accordance with the findings in [19].

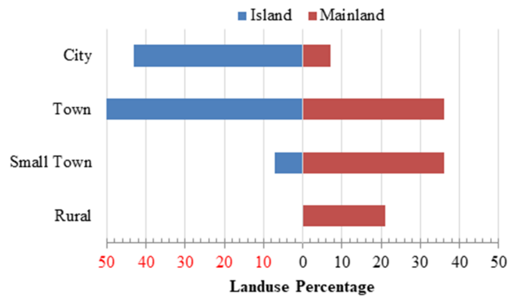

Fig. 3. Distribution of land use with respect to the geographical location.

C. Effect of Unsignalized Intersection/Access Point Density

There was a remarkable difference between the density of APs in the island and the mainland. The average number of unsignalized intersections/APs observed on each road in the island were 1.7 times higher than in the mainland. Figure 4 depicts a comparison between the AP density and the accident frequency. These values were obtained by dividing the total number of APs observed on all the roads surveyed in each part of the state with the total number of the roads in each part. Thus, they do not represent the density in terms of Aps per km. It can be seen that the increase in the number of unsignalized intersections or APs raises with the number of accidents.

D. Access Point Density Threshold

The density of APs per km was calculated by dividing the total number of unsignalized intersections observed on each road with the total length of the road. The general density of APs per km for the entire state was found to be 9.6, which is close to the findings of [20], in which relevant data were provided and the calculated value was 8.55. The accidents were further grouped with respect to the number of APs per km and the respected cumulative frequency percentage curve was plotted. From this curve, the value of the number of Aps per km that accounted for 50% of the cumulative accidents was found, as illustrated in Figure 5. This is called the 50th percentile value and is a common statistical parameter related to grouped data. It bisects the data into two categories with respect to the independent variable and helps further examination by evaluating the relationship of the dependent variable with each category. The graph indicated that an AP density of 7.1 to 8 per km is critical in relation to the accident frequency. The 50th percentile value of APs per kilometer lied between 7.1 to 8, so, the threshold value of 8 APs per km was chosen and a further analysis with respect to accident frequency was performed.

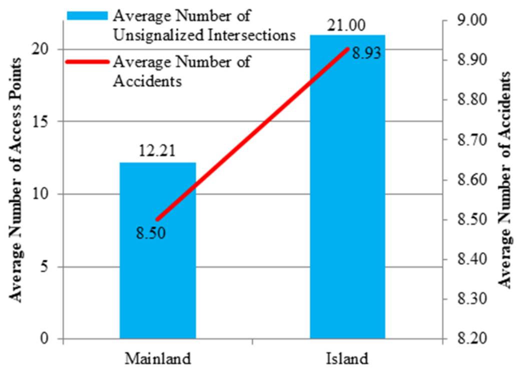

Fig. 4. Average number of APs and accidents with respect to the geographical location.

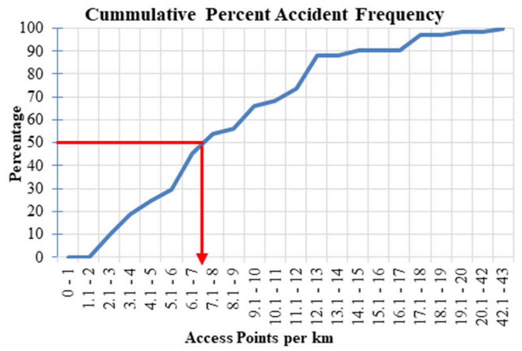

Fig. 5. AP density threshold.

E. Access Point Density Threshold and Average Accident Frequency

The threshold value of 8 APs per km was found from the analysis of the cumulative percentage of the number of accidents. Therefore, the data regarding the number of accidents on each road were grouped into two categories. The first group involved the roads that had less than 8 APs/km and the second group covered the roads that had at least 8 APs/km, as portrayed in Figure 6. Their respective average accident frequency was calculated by dividing the total number of accidents observed on all roads in each group with the total number of roads. The overall analysis of the concentration of unsignalized intersections or Aps/km of all the 28 surveyed roads, indicated that accident frequency was directly proportional to the concentration of APs. This is a very important finding, which is also evident from the results reported in other studies and the conclusions drawn from them [17, 21, 22]. Authors in [23] disclosed a decrease in the risk of accidents with the increase in AP density, but accepted that this result is not conformal with other studies [24] in which a positive association was found. It has been documented [24] that higher AP densities and the presence of bus stops tend to increase the risk of severe crashes. Incorporating the effect of speed, authors in [17] announced that the spacing between APs should be 45.72 m for roads having speed limit of 56 km/hr, as applied by the DOTs of Georgia, West Virginia, and New Jersey. This equals a density of 22 AP/km. In the same study, it was recorded that the spacing between APs should be 109.72 m for roads having speed limit of 72 km/hr, as applied by the DOTs of Minnesota and Texas. This equals a density of 9 APs/km.

It should be noted that AP density is one parameter that affects the frequency of accidents along various classes of roads. The literature indicates that apart from this parameter, other factors that affect accident occurrence are over-speeding, negligent driving, alcohol intake, and violation of traffic laws [25, 26, 27]. As a result, these factors are required to be explored in combination with the AP density.

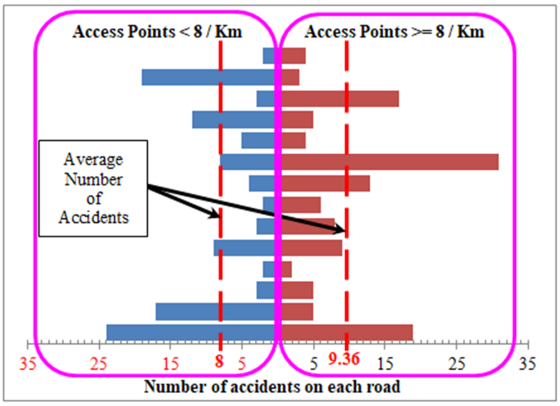

Fig. 6. Average number of accidents with respect to AP density per km.

V. CONCLUSION

In conclusion, this study underscores the direct proportional relationship between access point density and accident frequency. A value of eight access points per kilometer has been identified as the threshold after which an increase in accident frequency can be expected on primary roads. Land use, particularly in areas generating high traffic, further amplifies this impact. It is recommended that road design and management strategies consider limiting access points, especially in regions with commercial, educational, industrial, or high-density residential land use. At the micro level, the findings reveal that, on an individual road basis, the number of accidents does not exhibit a clear relationship with access point density. However, at the macro level, a positive association emerges when comparing roads with fewer than 8 access points per kilometer to those with 8 or more. This macro-level insight aligns with the findings in the literature, supporting the notion that access point density values exceeding 8 can compromise road safety. Moving forward, it is crucial for future investigations to incorporate additional microscopic traffic parameters, such as spot speed and spacing between vehicles. Acknowledging this study limitations, further research is anticipated to refine the understanding of the intricate relationship between access point density and accident frequency, providing valuable insights for road safety, design, and urban planning.

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