

IMPACT OF MOTORCYCLES AND SHOULDER WIDTH ON TWO-LANE HIGHWAY CAPACITY IN THAILAND USING TRAFFIC MICRO-SIMULATION MODEL

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ABSTRACT: The effect of motorcycle and shoulder width on two-lane highway capacity using a traffic micro-simulation model was investigated, together with other effect factors, which are heavy vehicles and access points. Four sections of a two-lane highway that have different shoulder widths were selected for the study. Under prevailing conditions, a two-lane highway with a shoulder width of fewer than 1.5 meters will cause a motorcycle to interfere with the carriageway and other impact factors that make capacity significantly less than HCM2010 calculation. The analysis of the base conditions model determined that the maximum capacity of a two-lane highway with a shoulder width of 2.0 meters was 1979 passenger car/hour/direction. Two-lane highways with shoulder widths of 1.5, 1.0 and 0.5 meters recorded maximum capacity at 1914, 1860 and 1789 passenger car/hour/direction, respectively, with all results higher than the HCM 2010 calculation. Model equations for capacity estimation were developed using multiple linear regression analysis derived from the relationships between capacity, shoulder width, and other affecting factors. Results can be used as guidelines for the future capacity assessment of two-lane highways in Thailand.

Keywords: Capacity, Two-Lane Highway, Traffic Micro-simulation model, Motorcycle, Shoulder width

1. INTRODUCTION

Highway capacity is one of the most important applications of traffic theory, with the analysis and design of transportation facilities leading to competent decision-making to improve road networks. The United States Highway Capacity Manual (US-HCM) has been a worldwide reference for transport and traffic engineering. However, this was developed specifically for the United States and may not be relevant in other countries which have unique traffic characteristics. The behavior and characteristics of traffic in some areas which illustrate the difference from HCM conditions such as "Heterogeneous Traffic" or "Mixed Traffic Conditions" [1,2], traffic formation of "Virtual Lanes" by vehicles and many "Slow Moving Vehicles" in the traffic stream [3], etc.

Some nations have attempted to modify the US-HCM and develop highway capacity manuals specifically suited to their individual requirements as the Swedish Capacity Manual, Korea Capacity Manual (KHCM), Indonesian Highway Capacity Manual (I-HCM), Indian Highway Capacity Manual (Indo-HCM), German Highway Capacity Manual (HBS) and China Highway Capacity Manual (CHCM) [4-9]. Likewise, Thailand is a country where, in general, there are differences in

the variety of behavior and other factors that affect highway capacity [10,11] Therefore, Thailand may consider the development of a highway capacity estimation method that is designed especially for Thai's highways.

Another most important factor contributing to the estimation of the capacity of the two-lane highways in Thailand that is different from the usual HCM conditions is the behavior of motorcycles. [12] noted that the HCM mentions motorcycles; however, in the United States, motorcycles are a small percentage of the number of registered vehicles and "are not included in the total". Therefore, motorcycles are not included in any of the HCM methodologies there [13].

However, the driving behavior of motorcycles in Thailand is directly related to the width of the road shoulder. This is because the shoulder has the main function of providing access for motorcycle usage, which comprises more than 30% of the traffic stream on some routes [14]. Therefore, a narrow shoulder is a limitation on the safety of the motorcycle, so, as a result, the driver must use the main carriageway to ride, which thereby reduces the flow rate of the traffic stream. Two-lane highways account for more than two-thirds of the national highway network and many have no

standard 2.5 meters shoulder width. [15] calculated the mean operating space required for a single motorcyclist riding at an average speed of 60 km/hr with a flow rate of 1200 mc/hr/ln as 1.3 m. [16] recommended configuring a Shared Motorcycle Lane of 1.5 m width and an Exclusive Motorcycle Lane of 1.5 to 2.0 m width. This is consistent with the riding behavior in Thailand, where motorcyclists can ride safely without restrictions when the shoulder is at least 1.5 m wide, and a shoulder width of more than 1.5 m does not affect road capacity (Fig. 1).



(a) 0.5 m. shoulder width



(b) 1.0 m. shoulder width



(c) 1.5 m. shoulder width

Fig. 1 Influence of motorcycles and shoulder width on two-lane highway capacity in Thailand

As a result, this study focuses on the estimation of capacity for two-lane highways as carried out by using a traffic micro-simulation model. Regarding motorcycle behavior and shoulder width, these are two of the characteristics for Thai two-lane highways that significantly affected capacity, together with other effect factors as heavy vehicles and access-points. The Maximum Capacity, as both a base estimation and with prevailing conditions, was identified and the mathematical equations models were presented in order to estimate the capacity of the two-lane highways.

2. METHODOLOGY

This study is a part of the study on the application of the traffic micro-simulation model to analyze the capacity of the highways in Thailand. The micro-simulation model is often used in the indirect empirical methods of roadway capacity estimation [17] that reduces the

limitations of the survey and the complex phenomena that are difficult to analyze with mathematical techniques [18]. In this article, present the estimation of the two-lane highways, the sections were selected with different shoulder widths. Micro-simulation model is developed by imitating driving behavior in each section, which has been surveyed and the collection of relevant traffic data. Then calibrate and validate the model before applying it to the capacity estimation, the methodology of this study are presented in Fig. 2

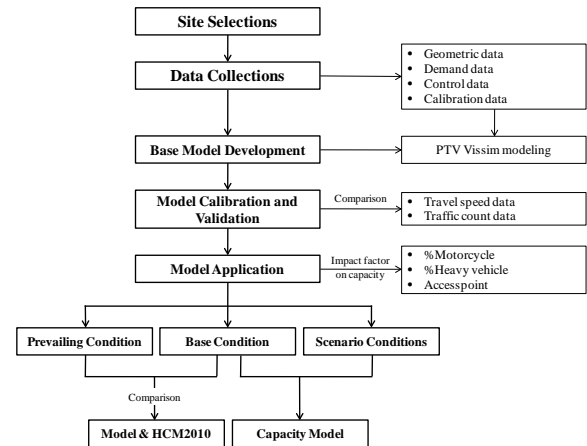


Fig. 2 Research methodology flowchart

2.1 Site Selection and Data Collection

Generally, criterion of site selection followed the HCM 2010 base condition [19] represent the prevailing conditions of two-lane highways in Thailand as follows:

- In good condition in traffic operations.
- No influence of any intersections.
- A 7.0 m carriageway width (3.5 m per lane) in accordance with the standard of the Department of Highways, and the highest traffic volume [20].

Moreover, there are two key factors to be concerned in investigating of two-lane highway capacity in Thailand are shoulder width and motorcycle affecting driver behavior. Based on these conditions, these patterns are divided into four types of cross-sectional designs for traffic operations and services relating to existing road networks in Thailand as shown in Table 1 and Fig. 3.

Table 1 Selected sections of two-lane highways

Section no.	Highway no.	Lane width (m.)	Shoulder width (m.)
1	2040		2.0
2	2046	3.5	1.5
3	228		1.0

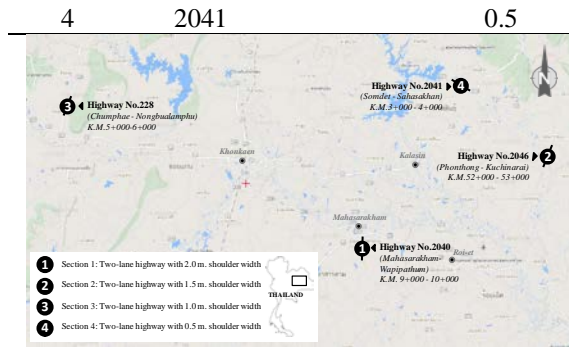


Fig. 3 Selected sections of two-lane highways

Once site locations of four types of cross-sectional highway, it is then to collect required four groups data including (1) Geometric data: lane width, shoulder width, median width, median type, and aerial photos, (2) Demand data: entry volume and traffic composition, (3) Control data as the speed limits, and (4) Calibration data: spot speed (free flow speed and turning speed), travel speed, traffic count, and time gap. The entry volume was measured at two intervals of 1 hour 30 minutes each during the morning and evening peak hours. Vehicles were divided into six types including motorcycle (MC), passenger cars (PC), light and medium buses (MB), medium trucks (MT), heavy buses (HB), and heavy trucks (HT). However, in the analysis, there are only three groups of vehicles that were analyzed: MC, PC, and HV. HV is defined as heavy vehicles that have more than four tires in contact with the pavement [19], inclusive of MB, MT, HB and HT.

Free-flow speed (FFS) are part of the spot speed survey, followed the desired distributions in the micro-simulation model as a significant variable that affected the capacity [21]. Radar speed gun surveys were conducted during non-peak hours by vehicle type and traffic lane (Table 2).

Time gap is defined in the car following model as the minimum time a driver will maintain while following another vehicle. In case of high volumes this distance becomes the value which has a determining influence on capacity [21,22]. Video data were collected and used in the calibration of the micro-simulation model. According to the survey, the section 1 of selected two-lanes highway recorded a few shorter average time gap than the others section. Due to the physical characteristics that contribute to higher speed and the driver's perception of safety, the average time gaps are 1.32, 1.39, 1.41 and 1.47 seconds for the section 1, 2, 3 and 4, respectively.

Table 2 The free-flow speed data

Section no.	Vehicle Type	Free-Flow Speed (km/hr)			
		V ₁₅	V ₅₀	V ₈₅	V _{avg}
1 (Two-lane with 2.0 m. shouder width)	MC	43.0	53.0	73.0	55.8
	PC	70.0	81.5	90.6	81.4
	MB	53.4	59.0	63.0	58.4
	MT	53.0	62.0	72.2	62.1
	HB	69.8	75.0	78.6	74.6
	HT	57.2	62.0	68.8	62.7
2 (Two-lane with 1.5 m. shouder width)	MC	37.0	52.0	65.2	65.7
	PC	64.9	78.0	87.0	77.3
	MB	50.0	55.0	59.8	54.3
	MT	47.9	56.5	65.2	56.7
	HB	70.4	75.5	78.0	74.8
	HT	50.7	58.5	64.8	58.5
3 (Two-lane with 1.0 m. shouder width)	MC	39.9	52.5	68.0	65.7
	PC	63.0	77.0	87.0	76.6
	MB	48.0	54.0	65.1	55.8
	MT	52.4	57.0	62.0	57.6
	HB	59.1	63.0	66.8	62.2
	HT	49.0	55.0	66.0	57.2
4 (Two-lane with 0.5 m. shouder width)	MC	36.9	50.0	63.0	63.9
	PC	66.0	77.0	86.7	76.5
	MB	48.7	54.5	57.7	54.2
	MT	50.0	55.5	57.7	54.0
	HB	58.4	60.0	62.7	60.3
	HT	50.3	55.0	68.1	57.6

2.2 Micro-Simulation Model

2.2.1 Base Model Development

PTV Vissim software was applied to develop a traffic micro-simulation model divided into five steps as (1) Base data for simulation, (2) Traffic networks, (3) Evaluation and configuration, (4) Simulation, and (5) Error checking.

2.2.2 Model Calibration and Validation

Calibration and validation were improved by adjusting the model parameters to maximize the ability to reproduce local driver behavior and traffic performance characteristics from the field survey. Traffic volume and travel speed were used as measures of consistency between the model and local conditions. The criteria for calibration and validation targets were based on the DMRB and other acceptable standards [23].

2.2.3 Model Application

The traffic micro-simulation model was applied as a tool to estimate two-lane highways' capacity for each shoulder width, considering various factors including the different proportions of motorcycles (0%, 10%, 20% and 30%), different proportions of heavy vehicles (0%, 5%,

15% and 25%) and number of access-points per km (0, 2, 4 and 6). The design turning volume on an access-point is based on survey, with turning volume being 5% of the total two-direction traffic volume in each model. In this study, the modeled of a two-lane highway was estimated assuming that the directional split was 50:50.

2.3 Capacity Estimation

The results of this estimation of the capacity of the two-lane highways are the main topic of this study. The capacity will reflect the driving behavior and physical characteristics of the highways, and this data can be used to analyze, design and conduct the planning of transportation and traffic systems for two-lane highways in Thailand more effectively. In this capacity estimation, a calibrated and validated micro-simulation model is used, speed data was estimated under different traffic volumes by increasing the flow rate in increments of 200 veh/hr/direction from an initial value up to highway capacity. When the simulated volume reached capacity level, increments in the input traffic volumes did not equate to increase in the exit volume and resulted in a decrease in the rate of traffic flow [24]. Highway capacity estimation was performed using speed-volume relationships by plotting speed on the graph ordinate and volume on the abscissa. The micro-simulation model replicated the traffic flow over the possible range of influencing variables, and traffic capacity was estimated on the basis of the simulation results [25]. Estimated capacity on the carriageway included only traffic flow of passenger cars and heavy vehicles, not motorcycles, but their impact in disrupting mainstream traffic and reducing capacity was taken into account. In this study, the conditions were tested using a traffic micro-simulation model divided into 3 groups, as shown in Table 3.

3. RESULTS AND DISCUSSION

3.1 Estimation of Capacity under Prevailing Condition

Estimation of two-lane highway capacity under prevailing condition done by the model base on the survey state by remaining survey data. The results will be used in comparison with HCM2010 method to evaluate the applicability for two-lane highway in Thailand as shown in Table 4. Base on the result for each two-lane highway section, the capacity results were significantly different from the HCM2010 method (two-way capacity well in excess of the 3,200 pc/hr.

Table 3 Test conditions for the Traffic micro-simulation model

Condition Model	Description	Factors		
		M	H	A
Prevailing Conditions	Model for the representative section based on physical characteristics and actual field survey data	✓	✓	✓
Base Conditions	Model for ideal conditions set with no effect by the impact factors	✗	✗	✗
Scenario Conditions	Model for each scenario with varying factors affecting capacity	✓	✓	✓

Note:

*M = Motorcycle, H = Heavy Vehicle and A = Access-point

** ✓ = Include in the model

✗ = Not include in the model

This results are consistent with previous studies in Thailand, which have the capacity is less than HCM about 18.9 % [10]. This difference was caused by the shoulder width and other factors having the capability to disturb traffic flow. It can be seen that models with a shoulder width of less than 1.5 meters will cause a motorcycle to interfere with the carriageway and other impact factors that make capacity significantly less than HCM2010. Shoulder widths wider than 1.5 meters will allow motorcycles to be less influential, despite any impact caused by access-points or heavy vehicles as the observed data, and afford greater capacity than HCM.

Table 4 Capacity estimation for different cross-sections of two-lane highways under the prevailing condition compared with the HCM 2010 calculation

Section no.	Capacity (Veh/hr)		Diff. (%)
	Micro-Simulation	HCM2010	
1	3103	2563	21.1%
2	3026	3188	-5.1%
3	1756	2544	-31.0%
4	1857	2672	-30.5%

3.2 Estimation of Capacity under Base Condition

The base conditions model was developed utilizing the driving behavior and physical road characteristics from the prevailing conditions model. This model was set to ideal conditions,

with relevant factors that affect the capacity set assuming no access points and with all vehicles as passenger cars (no heavy vehicles or motorcycles in the traffic stream). The results from base conditions will be used to present the maximum capacity for each section then compared with HCM2010 method. The two-lane highways with a shoulder width of 2.0 m (Section 1) gave maximum capacity at 1979 pc/hr/dir. Two-lane highways with shoulder width 1.5, 1.0 and 0.5 meters (Section 2-4) recorded 1914, 1860 and 1789 pc/hr/dir, respectively. However, all results were higher than the HCM 2010 calculation at 80.5 km/hr of free flow speed (for the range of 76.4-84.5 km/hr FFS) by 5.2%-16.4% because Thai's highway characteristics and traffic conditions are different from HCM2010 parameters (Fig. 4). With wider shoulder widths, the traffic stream on the carriageway proceeded with no disturbance from motorcycles which traveled on the shoulder without restrictions. The traffic stream on the carriageway could travel faster with greater capacity. The results are consistent with previous studies, which have the capacity as 2000 pc/hr/dir is more than HCM about 17.6 % [26].

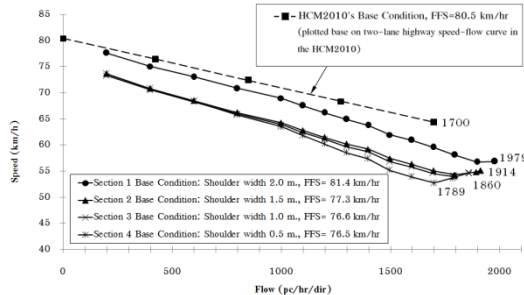


Fig. 4 Speed-flow curve under base condition

Under the base conditions, it was apparent that vehicles tended to use a lower speed when driving on a highway with narrower shoulders. Thus, the physical conditions of the shoulders play an important role in the capacity of a two-lane highway. The effect of shoulder width was presented as the nonlinear equation $C = -6S^2 + 139.8S + 1722$, ($R^2 = 0.998$), where C is the capacity for two-lane highways (pc/hr/ln) and S is the shoulder width (in the range of 0.5-2.0 m). A plot of highway capacity against shoulder width is shown in Fig. 5.

3.3 Estimation of Capacity under Scenario Conditions

The scenario conditions models are further developed by the base model for each section with varying factors affecting capacity, including

motorcycles, heavy vehicles and access-point. The results can show the effect of each factor on capacity and lead to the model equation for capacity estimation.

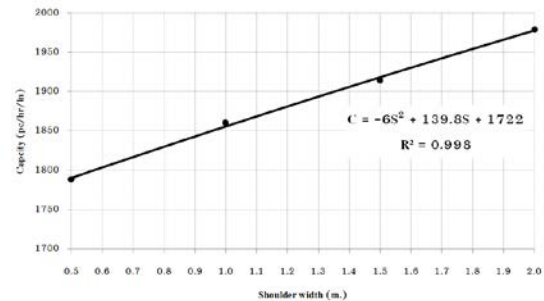


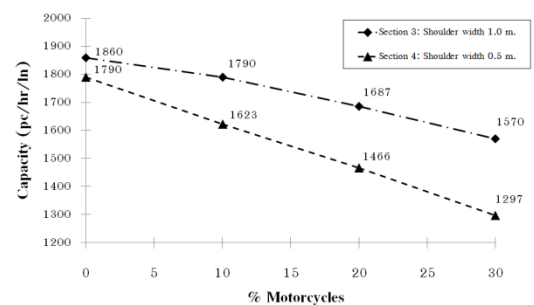
Fig. 5 Relationship between two-lane highway capacity and shoulder width

3.3.1 Impact of Factors on Capacity

The impact of factors on the capacity of each section of two-lane highways, as determined by the relationship between speed and traffic volume (speed-flow curve), was estimated by the micro-simulation model as follows:

- **Impact of Motorcycle on Capacity**

Results for two-lane highway capacity at 0% to 25% of motorcycle proportion on traffic flow for highways in Sections 3 and 4 showed a decrease of 15.6% and 27.5%, respectively, compared to the base condition. Reduced capacity was due to the inadequate shoulder width for safe motorcycle driving, causing the motorcycles to intrude onto the main carriageway and interact with the vehicles resulting in both speed and traffic volume reduction (Fig. 6).



Note: Two-lane highways on section 1 and 2 were assumed as unaffected by Motorcycle

Fig. 6 Impact of Motorcycle on capacity

- **Impact of Heavy vehicles on Capacity**

The impact of heavy vehicles on traffic flow at 0% to 25% resulted in a decrease in the capacity of all sections. There was a relatively stable trend, whereby a 0.3%-0.5% decrease in the proportion of heavy vehicles resulted in a 1% increase from

the base condition. Heavy vehicles required more space between vehicles in the traffic stream and this caused both speed and capacity reduction (Fig. 7).

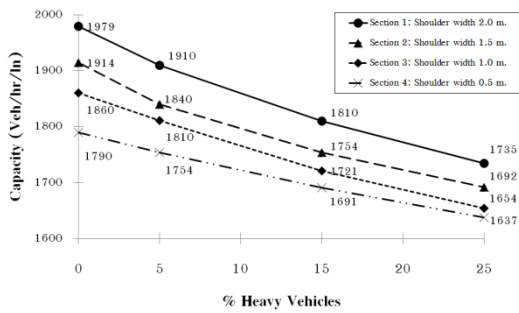


Fig. 7 Impact of heavy vehicles on the capacity

• **Impact of Access-Point on Capacity**

The impact of access-points was significant on two-lane highway capacities for all sections and reduced traffic flow by 30%-40% compared with the base condition. Access points involved turning through the oncoming traffic, resulting in flow disruption and reduction in both speed and capacity (Fig. 8).

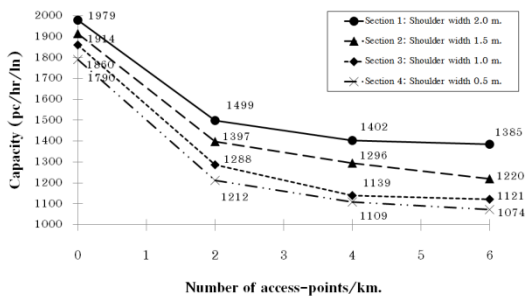


Fig. 8 Impact of access-points on capacity

It can be seen that the traffic micro-simulation model was used to develop the scenario conditions to analyze the effect of each factor on capacity under the terms of different shoulder widths, which were divided by sections of a two-lane highway. All factors resulted in reduced capacity on the highway to varying degrees. The results can be applied to capacity analysis in the case of individual factors and will be incorporated into the combination of all factors analysis to be developed as a capacity estimation model in subsequent topics.

3.3.2 Capacity Estimation Model

The relationships between capacity as a dependent variable and access-point, heavy vehicle, and motorcycle as independent variables were investigated. Simple regression analysis was used to check the correlation coefficient (r) between the independent variables, and non-collinear variables

are induced into the multiple linear regression models. The form of multiple linear regression models is shown in

$$Y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 \quad (1)$$

A multiple linear regression model was generated from the micro-simulation results which estimated two-lane highways' capacity on prevailing conditions as follows:

$$C_{Section1} = 1812.647 - 6.892H - 91.194A \quad (2)$$

$$C_{Section2} = 1746.990 - 6.599H - 98.563A \quad (3)$$

$$C_{Section3} = 1670.047 - 8.260M - 6.009H - 104.420A \quad (4)$$

$$C_{Section4} = 1529.699 - 12.738M - 5.312H - 81.145A \quad (5)$$

Where C is the capacity for each two-lane highway type (veh/hr/ln), M is the percentage of motorcycles in the traffic stream (in the range of 0-30%) H is the percentage of heavy vehicles in the traffic stream (in the range of 0-25%) and A is the number of access-points per kilometer (in the range of 0-6). From the statistical analysis of the model, the coefficients of determination (R²) at 0.772, 0.790, 0.797 and 0.812 reflected high goodness of fit. Significance at the 95% confidence level, with significance of the F statistic at <0.001. The coefficient of all the independent variables was also significantly different from zero at the 95% confidence level. The model provided a logical explanation for the effect of the factors on capacity. A negative sign indicated that as the effect of the factor as motorcycle, heavy vehicle, and access-point increased, the capacity decreased. The standardized coefficients (β) show the influence of each variable. The access-point was the most influential factor for two-lane highways of all sections. In the descending orders, the impact of proportion of motorcycle and heavy vehicle.

4. CONCLUSION

The application of a traffic micro-simulation model is a novel approach to estimate highway capacity. In addition to reducing the limitations of survey data, micro-simulation models can also effectively emulate local traffic conditions, resulting in more accurate highway capacity estimations. In this study, the traffic micro-simulation model was applied as a tool to estimate capacity on four sections of two-lane highways

when taking into account motorcycle behavior and shoulder-width as characteristics of Thai highways, which could significantly affect capacity, together with other effect factors as heavy vehicles and access-points.

The models for two-lane highways under prevailing conditions compared with the HCM approach showed significant differences. Two-lane highways with a shoulder width of fewer than 1.5 meters will cause motorcycles to interfere with the carriageway and other impact factors, causing less capacity than HCM2010. A wider shoulder of 1.5 meters will allow for less motorcycle impact, even when taking into account the impact of heavy vehicles and access points and result in greater capacity than HCM. The results under the base condition model demonstrated that two-lane highways with wider shoulder widths allowed for greater capacity and higher speeds.

The scenario conditions model presented amounts of the effect of the factor as motorcycle, heavy vehicle and access-point increased, the capacity decreased. The access-point was the most influential factor for two-lane highways of all sections. Capacity estimation model was developed that can serve as a guideline for transport and traffic operation, and improve design and planning on the two-lane highways are based on the standard of Thailand's Department of Highways (DOH) with assumptions of the level terrain. Research should be extended with comprehensive field data obtained from various factors and other geometrics that fall under the responsibility of different departments.

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