A HOUSEHOLD LOSS MODEL FOR DEBRIS FLOW

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ABSTRACT

This study proposed a debris flow loss model using the data from a survey conducted by the National Center for Disaster Reduction (NCDR) (2005). The sample was focus on debris flow victim list provided by the social welfare department in Taiwan. In total, 241 victims were recruited, all of which were the main financial supporter in their household. A set of standardized questionnaires containing information with regards to demographic background, financial damages, disaster experiences as well as risk perception were filled in by all the participants.

In the proposed model, a set of vulnerability indices for debris flow loss were used. They are the total area covered by the debris flow, the height of debris flow coverage, the experience with the disaster, house type-pure residence, the number of people per household, the community disaster preparedness, and construction type-RC materials. The result of the regression model showed that, all the variables included were statistically significant. The coverage area, the height of debris flow coverage, the number of past disasters, the number of people per household and construction type-RC materials were positively associated with financial loss. Furthermore, the results also showed that higher community readiness may lead to less financial loss and higher total financial loss is observed among participants using their house as a business setting.

Key Words：Debris flow, Landslide, Loss assessment, Vulnerability analysis

INTRODUCTION

From the aspect of the past history of disasters, whenever Taiwan, which is located in a fracture zone, suffers from serious typhoon or downpour events, serious slopeland sediment disasters follow, with heavy casualties and financial losses. Especially under the circumstances in which climate variation is hard to predict, the influences of typhoons or downpours would be higher than usual. Typhoon Toraji struck Taiwan in August, 2001. The downpours it brought caused debris flows and landslides in several places in Taiwan, with a total of 129 casualties, 299 houses collapsed, and 85 houses half-collapsed. Typhoon Aere struck Taiwan in 2004, bringing heavy downpours in the north, east-north, central, and south of Taiwan successively. The rain led to serious sloping field disaster in Taoshan Village, Wufeng Township, Hsinchu County with more than 20 casualties and more than 20 houses

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being buried by debris debris flows. Both Typhoon Kalmaegi and Typhoon Sinlaku struck Taiwan in 2008 with heavy downpours which over a-hundred-year return period, causing serious disasters in south Taiwan with 200 houses collapsed and half-collapsed. Typhoon Morakot struck Taiwan in 2009 with heavy downpours which over two-hundred-years return period, causing over 600 deaths. The most serious disaster happened in Xiaolin Villiage, Kaohsiung County. The number of deaths in this village is over 400. And over 100 buildings collapsed. In order to solve this kind of problem and to reduce the impact of slopeland sediment disasters in the future, the risk management of disasters becomes very important.
Generally speaking, complete risk management is done with three phases. Phase one is to understand hazard potential. Phase two is to understand impacts and influences disasters may bring. The third phase is to come up with corresponding solutions. Every phase is very important and essential. However, there have been many researches or actual cases related to hazard potential. In comparison, influences disasters may bring and corresponding solutions need to be explored more. Currently, solutions are usually proposed according to roughly estimated impact or range of influences. Only very few of them are proposed after assessing actual loss within range of influences. Therefore, some strategies may be costly because assessments of impacts are not precise, resulting inefficient execution. Thus, this study focuses on evaluation of loss, especially for the households with more serious damages, in order to improve the preciseness of risk assessment.

REFERENCE

There are many researches on debris flow risk assessment or hazard assessment such as Hürlimann, Marcel and Copons, Ramon *et al.* (2006) present a multidisciplinary procedure including geomorphologic and geologic analysis, scenario simulation, hazard assessment, hazard mitigation to evaluate the debris flow hazard at a local scale.

Chen, Chien-chih and Tseng, Chih-Yuan et al (2007) propose the method of minimum entropy analysis (MEA) to assess debris flow hazard. They apply this method to a dataset of debris-flow occurrences in Taiwan and successfully identify three relevant variables, i.e. the hydrological form factor, landslide area, and number of landslides, to the occurrence of observed debris-flow events by the 1996 Typhoon Herb. Others used numerical method to simulate the hazard area of debris flow, such as Laigle and Marchi (2000), Liu K.F. and Huang M.C.(2006), Gwo-Fong Lin etc.(2006) and so on..

Those literatures discuss the range of affected area and the degree of danger for that area, rarely on the loss assessment of exposure. Only few researches such as Pasuto, Alessandro and Soldati, Mauro (2004) made use of an integrated approach including historical, geomorphologic, geostructural, meteorological and forest-management aspects. They study took into account the increased frequency and magnitude of recent events and considering the location of roads and buildings in the accumulation area, the risk conditions were analyzed in order to identify a risk zonation and to propose mitigation measures.

H. Staffler, E. Berger and A. Zischg (2006) used empirical and physical models to calculate the hazard area, and use the results to estimate the probable maximum loss of building, which including the number of residential persons and its monetary value.

Liu and Li *et al.* (2009) utilizes economic concepts to propose a reasonable estimation of the hazard damage and the cost of proposed mitigation measures. The proposed method is composed of four steps, namely, delineating the area of the disaster with different return periods, itemizing the land use within those area, calculating the hazard lose using official values and computing the expected probable maximum loss with a probability distribution.

But except Liu and Li *et al.* (2009), other literatures adopt an engineering point of view to deal with the value-wise discussion. In the engineering research field, the losses were usually classified into direct loss, indirect loss, tangible loss, intangible loss.（White, 1945; Parker, Green and Thompson, 1987; UN, 2002）However, the definition of engineering classification for losses was indeterminate, and confused the opportunity cost with financial cost; the capital stock with capital flow. (Van der veen and Logtmeijer,2005). For example, most researches regard building loss as direct loss, but if the building is damaged and unavailable to live, the repair cost or the building value decrease is regarded as direct loss, the moving cost and the expense for temporary living elsewhere are usually regarded as indirect costs.

In order to avoid the above pitfalls and make the concepts of economic cost clearer and more appropriate for estimating the damage, Shaw *et al.* (2005) and Shaw *et al.* (2007) redefine and reclassify the natural disaster damage based on welfare economics. He defined the damage in relation to a specific type of damaged capital as the minimum compensating payment that is necessary to make the owner of the damaged capital or the user of the flow of services from that capital indifferent between the original situation and the new situation. The damaged capitals can be separated into three categories including natural capital, man-made capital and human capital. After considering the time effect of the natural disaster damage and its restoration, He defined the damage as follows:

$$\text{Disaster damage} = \left(\begin{array}{l}\text{Lost value of service}\\ \text{flows from the date}\\ \text{of the disaster until}\\ \text{the date of the}\\ \text{decision to restore}\\ \text{the damaged capital}\end{array}\right) + \left(\begin{array}{l}\text{1.Lost value of service flows from}\\ \quad\text{the date of the decision to restore}\\ \quad\text{the damaged capital until an}\\ \quad\text{indefinite future,}\\ \text{2.The cost of restoration plus the}\\ \quad\text{lost value of services during the}\\ \quad\text{period of restoration,}\\ \text{3.The cost of replacement plus the}\\ \quad\text{lost value of services during the}\\ \quad\text{period of replacement}\end{array}\right) \quad (1)$$

From equation (1), it can be found that, in the aspect of service flow of economics, the definition of loss is very clear. It rarely causes confusion. Therefore, in this study, the method proposed by Shaw *et al.* (2005) and Shaw *et al.* (2007) was applied.

Building a household loss model for slopeland sediment disasters victim households

Data from the survey of slopeland sediment disasters

In 2004, Typhoon Mindulle and Typhoon Aere had struck Taiwan one after another, bringing heavy downpours in the north, northeast, middle, and south of Taiwan, causing serious slopeland sediment disasters and several landslide roads. The most serious damages were debris flows and landslides in Taoshan Village, Wufeng Township, Hsinchu County and the in the mountains in central Taiwan. According to the statistics from the typhoon database of the Central Weather Bureau, 48 people died in these two typhoon events. 26 were missing, and many houses collapsed. The loss of agriculture, forestry, fishing, and animal husbandry was over 10 billion dollars. Thus, in 2005, the subjects of the questionnaire survey conducted by the National Science and Technology Center for Disaster Reduction were the main disaster areas in north (Hsinchu County) and central (Taichung County and Nantou County) Taiwan (table 3.1). There are 261 valid samples (241 samples of households with actual loss) with 95% confidence interval and the sampling error is approximately 5.7%. The estimation method for different types of household losses is listed in table 3.1.

Table 3.1. Information from 2004 slopeland sediment disasters survey

Item	Content
Survey Duration	2005/3/1~2005/4/15
Typhoon Event	Typhoon Mindulle (2004/7/1~2) Typhoon Aere (2004/8/25) 911 Flash Flood Event (2004/9/11)
Survey Range	(1) Jianshi Township, Hsinchu County: Yixing Village, Yufeng Village, Xiuluan Village, Jiale Village, Meihua Village, Jinping Village, and Xinle Village. (2) Wufeng Township, Hsinchu County: Taoshan Villiage (3)Heping Township, Taichung County: Lishan Village, Daguan Village, Ziyou Village, Tianlun Village, Nanshi Village, Zhongkeng Village, and Boai Village (4) Ren-ai Township, Nantou County: Datong Village , Nanfeng Village , Cuihua Village , and Qinai Village
Survey Method	Household interviews (261 valid questionnaires, 241 questionnaires with actual loss)

In the past, when estimating losses in engineering research field, opportunity cost is usually not considered. The estimates are only from the tangible loss. But according to the definition of loss in economics, complete loss shall be estimated with the concept of opportunity cost (H.C. Li, 2008, *et al.*). In table 3.2, the estimation method of loss includes human capital and man-made capital. Besides real money loss, the loss of opportunity cost is also considered.

Table 3.2. Items of household losses from slopeland sediment disasters

<table>
<tr><th>Capital</th><th>Loss</th><th colspan="2">Loss content</th><th>Estimation</th></tr>
<tr><td rowspan="3">Human capital</td><td rowspan="3">Human capital loss</td><td colspan="2">Absent labor hours from employment</td><td>Opportunity cost</td></tr>
<tr><td rowspan="2">Water Borne Disease or sickness caused by disaster</td><td>Medical expense</td><td>Restoration cost</td></tr>
<tr><td>Salary decrease during sickness</td><td>Opportunity cost</td></tr>
<tr><td rowspan="2">Man-made capital</td><td rowspan="2">House loss</td><td colspan="2">Repair expense for structural damage</td><td>Restoration cost</td></tr>
<tr><td colspan="2">Temporary living expense</td><td>Replacement</td></tr>
</table>

				cost
		Cleanness or repair cost for decoration, electricity and plumbing etc.	Salary loss causing by self cleanness or repair	Opportunity cost
			Cleanness or repair cost for hiring workers	Restoration cost
	Furniture loss	Repair or replace cost for damaged furniture and electric appliances		Restoration or replacement cost
	Vehicle loss	Repair or replace cost for damaged vehicles		Restoration or replacement cost
	Public loss	Shared cost of damaged public man-made capital		Restoration or replacement cost
Total Loss = Human capital loss + House loss＋Furniture loss＋Vehicle loss＋Public service loss + others				

Structure of Model Assessment

The household loss model for debris flow disasters victim households is built according to risk assessment framework. The three important factors of risk assessment framework are hazard, exposure, and vulnerability (Hsin-Chi Li, et al, 2009). However, exposure can be combined with vulnerability and discussed together. Because exposure means possible damage and range of disasters, and vulnerability is quality and capacity of systems fighting disasters. The relationship between exposure and vulnerability is like that between quantity and quality. They are two sides of the same thing (figure 1). Therefore, from figure 1, we can see that the factors which should be taken into account for the loss model include hazard, exposure, and vulnerability.

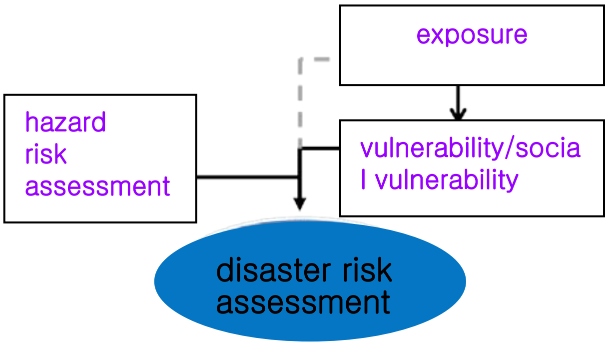

Fig. 1. Risk assessment framework

Model Building

At last, by referencing the data from the questionnaire survey and estimation of loss, and discarding outliers, the household loss function for landslide victim households (equation 2). The significances of the factors are listed in table 3.3. The first field is the independent variables of the model. The second one is the coefficients of those variables. The third one is the significances of the variables (p-values). When a p-value is less than 0.05 (with significance level of 95%), it means the corresponding variable is can significantly explain the loss. The smaller a p-value gets, the higher the significant level would be, and the better the ability to explain the loss.

$$
\begin{aligned}
\text{LN(Total loss)} = \ & 9.36 + 0.603\ \text{LN(Height of debris flow coverage)} \\
& + 0.736\text{LN (Square measure being covered by debris flow)} \\
& + 0.092\ \text{(Number of members per household)} \\
& + 0.210\ \text{(Disaster experience having been through)} \\
& - 1.015\text{(House type—Pure residence)} \\
& - 0.231\ \text{(Community disaster preparedness)} \\
& + 0.451\text{(Construction type – RC material)}
\end{aligned} \quad (2)
$$

Table 3.3. Analysis significances of factors

Independent Variables of the Model	Coefficient	Significance (p-value)
(Constant)	9.360	.000
Log height of debris flow coverage (m)	.603	.000
Log square measure being covered by debris flow (m^2)	.736	.000
Number of members per household	.092	.009
Disaster experience having been through	.210	.001
House type- Pure residence	-1.015	.000
Community disaster preparedness	-.231	.000
Construction type – RC material	.451	.010

In equation (2), “height of debris flow coverage (m)” and “square measure being covered by debris flow (m^2)” are factors of “hazard”. The higher the height of debris flow coverage and the larger the square measure being covered by debris flow, the more the loss would be. Because these two variables are log values and their coefficients are significant, it means the marginal utility is diminishing. When the values of the height of debris flow coverage and the square measure being covered by debris flow are over certain cut points, their influences on loss would diminish. “Number of members per household” is a factor of “exposure”. The more people in a household, the more the loss would be.

”Disaster experience having been through”, “house type (pure residence)”, “community disaster preparedness” and “construction type (RC material)” are the factors of “vulnerability”. The larger numbers of disaster experience having been through, the more the loss would be. The main reason is that if the chance of recurrence of debris flow is high, with the stability of the slope toe or slope being destroyed or without proper renovation, same tragic might happen again. Therefore, areas with large “disaster experience having been through” are disaster-prone areas. If residents of those areas do not move, the loss would go higher as the number goes higher. The relationship between “house type (pure residence)” and loss is negative, which means if the house type is pure residence, then the loss would be less. The main reason is that, in this study, households were categorized into “pure residence” and “non pure residence (including residential-commercial use and pure commercial use), and the loss of stores is higher due to the goods in stock. That’s why the loss of the households as residences is generally less. The relationship between “community disaster preparedness” and loss is negative. In a community, if the disaster preparedness work (including prevention constructions, conservation of water and soil, early warning for community and residents, evacuation, etc.) is complete, the loss would be less. In the questionnaire, there are also questions about individual disaster preparedness. Although it’s related to disaster preparedness, its influence on loss is not significant. The result shows that the focus of the disaster preparedness work for debris flow disasters is on community disaster preparedness. The last one is “construction type (RC material)”, representing whether a house is made of RC or not. The result shows that cost of restoring RC houses is rather high, which means the loss of those households is rather high. The relationship between this variable and loss is positive. All the factors mentioned above have significant influences on loss (with significance level of 95%. For “height of debris flow coverage”, “square measure being covered by debris flow”, “number of members per household”, “house type (pure residence)”, and “community disaster preparedness”, the significance level is 99%).

The other factors in this questionnaire analysis are not adopted for their insignificance, except for “number of children under 12” being discarded for it is highly related to “number of members per household” and “individual disaster preparedness” being discarded for being related to community disaster preparedness. In addition, in many documents, it is mentioned that “income per household” is an important factor for loss. However, this study does not have the same conclusion[4]. According to the result of the questionnaire analysis, “income per household” is positively and significantly related to “construction type” (households with high income can afford solider materials). The variable which can significantly explain more variation of loss was chosen. Therefore “income per household” was discarded.

Finally, the explanation power of this model is 55.0% (Adjusted R^2 =0.536). As a social science survey model, this power is outstanding (Generally, Adjusted R^2 > 0.3 is good enough.).

Model Testing

There are many tests which can be applied to a regression model. They can be divided into three categories. The first type is used to test a regression model’s significance. The second one is the test for collinearity. The third is Residual analysis.

F test

The significance of a regression model’s explanation power is generally tested by F-test. The theory behind F-test is to use the ratio of variation between groups to variation within groups. This ration is the so-called F value. The larger F-value is, the more scattered the means of groups would be. If the F-value exceeds the cut-point, it can be concluded that the null hypothesis (H_0: Factors have no influence on the dependent variable) shall be rejected. And

[4] According to the experiences from previous surveys, victim households are usually conservative when they are asked about their household income. Analysis result would not be able to reflect the truth because of this reason.

the alternative hypothesis (H_1: Factors have influence on the dependent variable) shall be accepted.

The F-value of the regression model from equation (2) is 39.979, which is higher than the cut-point of 99% significance level, as shown in table 4.1. The result shows that the means of groups are significantly different. Therefore the null hypothesis shall be rejected, which means this model can significantly explain the variation of loss.

Table 4.1. Result of the F-test

Item	Sum of Squares	df	Mean Square	F	Sig.
Regression	336.181	7	48.026	39.979	.000(a)
Residual	275.095	229	1.201		
Total	611.276	236			

Collinearity test

If some variables are collinear in a model, regression coefficients would be influenced and the error would be larger. Therefore, it is necessary to check the collinearity before building a model. There are two types of collinearity test: one is to test the collinearity of independent variables and other variables, the other is to test the overall collinearity of the regression model.

Testing the collinearity of independent variables and other variables

The theory behind the test of certain independent variable's collinearity with other variable is to evaluate with tolerance or variance inflation factor (VIF). The range of tolerance is from 0 to 1. Larger values represent smaller collinear problems. Generally, if tolerance is smaller than 0.6, then there is a collinear problem. VIF is the inverse of tolerance. It would be better if VIF is close to 1. If VIF is larger than 1.6, then there is a collinear problem.

The test results show that all the variables in equation (2) have tolerance values larger than 0.6, and most of them are larger than 0.9. And their VIF values are all smaller than 1.6. Thus, the collinearity problem for this model between independent variables and other variables is rather small.

Table 4.2. Diagnosis of collinearity between independent variables

Independent Variable of the Model	Tolerance	VIF
(Constant)		
Log height of debris flow coverage (m)	.813	1.230
Log square measure being covered by debris flow (m^2)	.703	1.423
Disaster experience having been through	.963	1.038
House type- Pure residence	.926	1.080
Number of members per household	.950	1.053
Community disaster preparedness	.919	1.088
Construction type – RC material	.844	1.185

Testing the overall collinearity of the regression model

Then it's the test of the overall collinearity of the regression model. The diagnose of overall collinearity of the regression model can be done through eigenvalue (λ) and conditional index (CI). Generally, high eigenvalues mean minor collinearity, while high CI values mean serious collinearity (Belsley, 1991). When CI is lower than 30, collinearity is minor. When CI is between 30 and 100, collinearity is from moderate to serious. When CI is over 100, collinearity is very serious (Belsley, 1991; Belsley, Kuh & Welsch, 1980). Conditional number (CN) is the square root of the largest eigenvalue divided by the smallest one. The value in the last row of CI (table 4.3) is CN. CN reflect the degree of the influences on a regression model.

The result in table 4.3 shows that the CIs for all dimensions are less than 30. And the CN for this model is 22.853, which is less than 30. This means the collinearity of this model is minor. Thus, the predictions made with this model are not significantly influenced by colliearity.

Table 4.3. Diagnose of overall collinearity of the regression model

Model Dimension	Eigenvalue (λ)	Conditional Index (CI)
1	5.798	1.000
2	1.031	2.372
3	.634	3.024
4	.194	5.467
5	.182	5.641
6	.094	7.856
7	.056	10.150
8	.011	22.853 (CN)

Residual analysis

The so-called residuals are the differences between "real values" and "estimates by models". Generally speaking, the conditions must be met so that we can use residual analysis to check if a regression model fits are: residuals must follow normal distribution and residuals must be independent of each other. If these conditions are not met, this method can not be applied for the model.

Normality Test

The method used to tech normality is very simple. It can be done with a bar chart of residual to decide whether it follows normal distribution. If the chart shows a bell-like shape, we can preliminarily decide that the condition of normal distribution is satisfied.

Figure 4.2 is the bar chart of the residual for this model. The bell-shaped line is normal distribution. From the figure, we can see that the shape of the bars is like a bell with the trend similar to the normal distribution line. Thus, judged from this figure, the regression model built in this study passed the normal test. The condition is met.

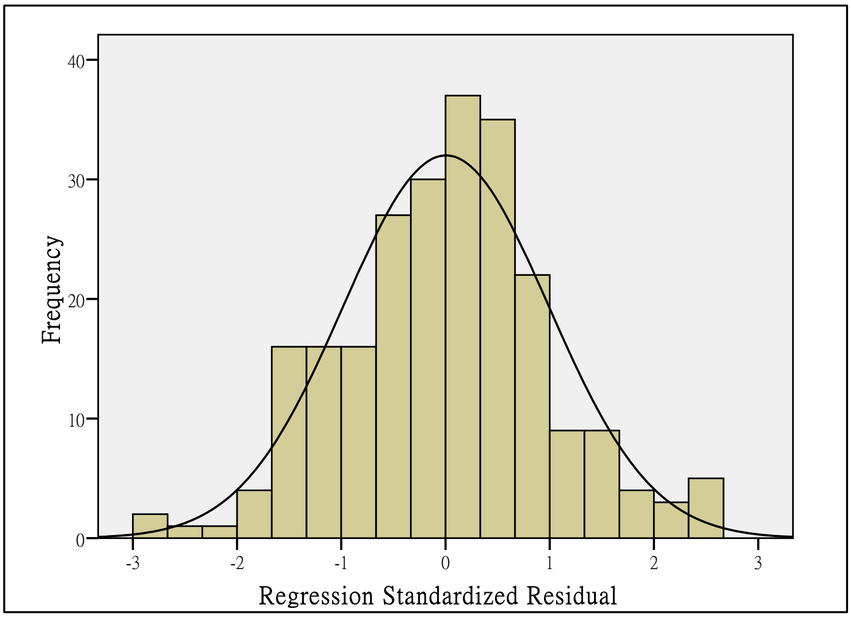

Fig. 4.2 Standardized residult bar chart

Independence test

Durbin-Watson test is an independence test generally adopted (Durbin, J., and Watson, G. S, 1950&1951) with the value called DW value. It is used to check the independency between residuals. If the residuals are not independent of each other, this situation is called autocorrelation of residuals, which means previous observed values are related to later observed values. And one of the conditions is not met. The range of DW value is from 0 to 4, the cut point is 2, which means if the value is less than 2, the residual is positively autocorrelated while larger than 2 represents negatively autocorrelated. Therefore, if residuals are independent, the corresponding DW value should be close to 2.

After applying Durbin-Watson test, the DW value derived is 1.807, which is close to 2. Thus, we can be sure that the regression model built in this study passed the normal test. The condition is met.

CONCLUSION

Our study based on the framework of risk and used the data of on-site survey to build a regression loss model of debris flow. In the proposed model, a set of hazard, exposure and vulnerability indices for debris flow loss were used. They are the total area covered by the debris flow, the height of debris flow coverage, the experience with the disaster, house type-pure residence, the number of people per household, the community disaster preparedness, and construction type-RC materials. The result of the regression model showed that, all the variables included were statistically significant.

Furthermore, by examination we learned that this mode have a good explanation of the loss, and consistent hypothesis of regression method. Therefore this result had proven this model is available to calculate the household loss of landslide disaster.

Last, through the analysis result we found that personal preparedness is not significant. Only through community preparedness can effective reduce the loss. Although it is hard to change the house type in the hazard-prone area, it is possible to strengthen the work of community preparedness for reducing the loss. In case of new or rebuilt houses there are technical possibilities for the design and construction of debrisflow-proof buildings. And from the study we know the Number of household people is the significant factor of loss; therefore, if we can reduce the numbers, the loss also can be reduced. For example, we can evacuate the residents who live in the hazard-prone area before the disasters happen. Or a possibility to reduce future losses is to restrict the development of new housing lots in areas endangered by debris flow.

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