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Methodology Study for Planning On-site Monitoring for Radio Astronomical Site Selection from Unmanned Aspects

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Abstract

Astronomical site selection work is very hard. Unmanned technologies are important trends and solutions. We present a relatively easy method to plan a high reliability site selection which can extend the time from site deployment to returning for maintaining by unmanned confirming the site. First, we redefine the reliability of a site selection deployment with the parameter of the trusty time, which means when we must return, and which can be relatively easy for estimating. The redefinition makes the reliability parameter as a Bayesian probability, and can be obtained by estimating besides testing, which makes the evaluation of each device's reliability much easier. Then we use block diagram tools in the Matlab Simulink software to construct structure diagram, and to link each component with relations of parallel, serial, protection, and so on. This makes the whole reliability value can be calculated at the time when we design or plan a site selection. We applied this concept and method in an actual site selection in Lenghu, Qinghai Province, China. The survey practice reveals its effectiveness and simpleness.

Key words: Astronomical Instrumentation, Methods and Techniques – site testing – methods: analytical

1. Introduction

Traditional astronomical site selections are very hard, especially due to the fact that modern astronomical observatories are trending to the high altitude, long distances, and deserted places nowadays. Though unmanned technologies can make people deploy automatic devices on the site, and get data remotely, unmeant device failures still often force people back to the site. Astronomical site selections are still expensive and exhausting.

Systems engineering (SE) is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system (NASA 2019). It is often used to ensure quality of a product. Since the beginning of the system theory by L. Von. Bertalanffy, SE has developed from Text Based System Engineering (TBSE) to Model Based System Engineering (MBSE) (Chen & Lu 2022). It has been succeeded in many fields such as aeronautics and astronautics, etc., however, it is more a verification or management tool in the quality standards such as ISO 9000 instead of a design tool in practice. Furthermore, there is much work belonging to these SE works, which makes it not so popular in other industries that are relatively not so sophisticated, such as a site selection. Piles of documents might make the designer exhausted in planning a site selection.

Because of the hardness of the site selection and the difficulty to reach the site, we tend to make the site unmanned. Nowadays, most devices to verify the quality of a site have unmanned alternatives. But, we are still forced to visit the site frequently, one reason may be that we have no evaluation on the reliability of the whole site. There are so many devices needed in the site survey, but they are much different, not made by one company, and need different accessories. Most of these devices have no test on the site. It is too hard to get exact parameters about reliability, such as Mean Time To Failure (MTTF), Mean Time Between Failure (MTBF), etc.

So, how can we confirm the unmanned quality of an observatory at its site selection phase? Or how to plan or design a site selection—including planning what to monitor, what monitoring devices to deploy, how to deploy and implement the monitoring, etc.—rather easily and can maximize the period from one visit to next visit as well?

In this paper, we develop a relatively simple method to evaluate or plan a site selection as a whole system by the theory of SE (both traditional TBSE and modern MBSE). In Section 2, we introduce the concept of this method, describe how we estimate the reliability by introducing Bayesian probability to simplify the conceptions, and how we make it suitable for the site selection by defining device blocks and their relationships in the system structure diagram. In Section 3, we use it in a site plan for a survey in Lenghu, Qinghai province, China. In Section 4, we verify the effects of the method. In Section 5, we discuss the method and draw a conclusion.

2. Concept

2.1. Definition of Trusty Time TT

Referred to the theory of system engineering and reliability engineering, we can define the reliability of a site selection as a system. The reliability, R, can be defined as:

$$R = 1 - 1/t \tag{1}$$

where t is the trusty time. The item $1/t$ looks simply as same as the failure probability defined in the traditional reliability engineering (Kailash & Michael 2014). Note that the definition of t is different from that in the traditional reliability engineering which usually uses MTTF by test, it is an estimated value, which makes the equation suitable for site selection systems. This definition is also suitable for every single device.

The reliability R is used to evaluate the reliability of a site selection. It reflects the degree we can trust them working without human visiting. If it totally comes from experiments, it is a traditional probability. If it can be decided by a human's confidence (Designer, Leader, or Executor of a site survey), it will be a Bayesian probability. In this paper, for each device, we can not only consider or estimate it by the certification of the device, but also we can consider it by feeling, even a combination on both experiments and feelings. So it is a Bayesian probability. Contrast to that reliability value must be obtained by experiments in traditional SE, we can get it much easily. Though not coming from experiment entirely, it is still good for planning and designing. It is too hard to get every parameter by experiments in traditional SE, which makes the reliability work too difficult to finish.

The trusty time (TT) t is the time we can rely on the device or devices system. It is similar to the MTTF, MTBF, etc. We define its unit as days. It means how many days we can leave the devices or the site, and means when we feel we should return to the site. Different from the MTTF and MTBF, TT can come from people's estimation instead of experiments only. Because it does not have to be determined by experiments, it can make the estimation work easy enough for finish the reliability work. It reflects people's confidence like the reliability R. So it is a Bayesian estimation as well. For the same shape of the equation as traditions, we believe TT is in ratio to MTTF or MTBF, we can use it in calculations in probability theories.

TT can be estimated relatively easier than MTBF when we design or plan the site, or when we finish the deployment of the site and ready to leave. It is also easier for understanding and applying in the site selection practice than MTBF. It could be a constant. In traditional SE (Kailash & Michael 2014), the hazard rate is varying in time, it looks like a bathtub, shown as the red line in Figure 1. For the relationship between hazard rate and the reliability, we will see that the reliability will vary following the variation of the hazard rate, shown as the blue line in Figure 1.

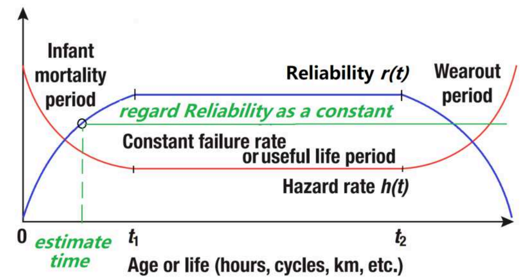

Figure 1. Idealed bathtub curve of hazard rate and reliability.

No matter how reliability varies with time, it can be regarded as a constant at the time when we estimate the site survey system, shown as the green line in Figure 1. We can also modify and update it along the process of the site selection. This makes the estimation work easy enough to be finished, and still can prevent big mistakes from happening. Every TT of all the components can be reconsidered when people leave the site. This is why we can simplify them as constants. Their values depend on the time when we consider.

From Equation (1), we can derive Equation (2) to transform R to t.

$$t = 1/(1 - R) \tag{2}$$

So after the calculation of the whole system, we can get a rather intuitive parameter—TT. It can show when we must return, instead of only a probability parameter.

2.2. Estimate TT by MTBF and Confidence

TT can be derived from MTBF. MTBF means the mean time between failures, which is an arithmetic average of the time to failure. So MTBF is the time when there are 50% failures happening. At the time of MTBF, we can have 50% confidence to that device.

Meanwhile, when we estimate the TT, it is also a time when we have C confidence with the device. Here C, confidence degree, is how much confidence we have with that device. It is also the probability of no failures. At the time TT, there will be 1 - C failures happening. For example, if $C = 90\%$, at the time TT, there will be 10% failures have occurred.

We suppose that the failures happen with an exponential distribution. So when we draw a probability density distribution chart, we can point the time of how much ratio failures have happened from that ratio of the failure area to the whole area. Then we get the relationship between TT and MTBF, which is shown in Figure 2.

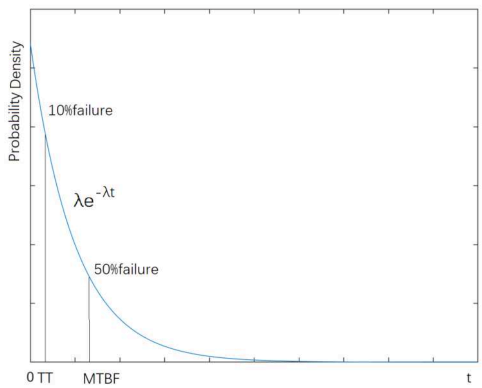

Figure 2. TT and MTBF.

We can derive a relationship equation between TT and MTBF as Equation (3).

$$\mathrm{TT} = \frac{lnC}{ln0.5}\mathrm{MTBF} \tag{3}$$

in which, the confidence degree C is the degree of the confidence with the device. It is also the probability of well working and no failure. We list many Cs here in Table 1, for the convenience for estimating TT for different confidences, and for making them unifying together.

In this paper, we use $C = 90\%$ to estimate TT by default.

2.3. Estimate TT by Past Performance

For a single device that has applied for a long time and has not failed, we can estimate MTBF as if it had failed just at that moment. It is the lower limit of the MTBF. For example, if a device has been used for a whole year, we can regard its MTBF as 1 yr. Its TT is 55 days when $C = 90\%$, simply using 365 days multiply 0.152 according to Equation (3) and Table 1.

With the progress of a site selection going on, we can get the MTBF if the device fails, or know the lower limit of the MTBF if the device does not fail. We can predict its MTBF at that moment, and so we can predict its TT by the MTBF then.

2.4. Calculate TT by Relationship Among Components

The reliability of a system that consists of many components is determined by the reliabilities of these components and their relations. There are many kinds of relationships among these components, such as parallel, serial, protection, and so on.

If the relationship is serial, the reliability of the system is:

$$R = r_1 r_2 r_3 ... \tag{4}$$

where r_1, r_2, r_3... are the reliabilities of each component.

If the relationship is parallel, the reliability of the system is:

$$R = 1 - (1 - r_1)(1 - r_2)(1 - r_3)... \tag{5}$$

Table 1
Ratios between MTBF to TT with Different Cs

C	$\ln C/\ln 0.5$	Meaning
99.99%	0.000144	Perfectly safe
99.9%	0.00144	
99%	0.0145	
98%	0.0291	
95%	0.0740	
90%	0.152	TT adopted in this paper
85%	0.234	
80%	0.322	
75%	0.415	
70%	0.515	
65%	0.621	
60%	0.737	
55%	0.862	
50%	1	MTBF, Half Reliability

Besides, if a device can be protected by an auxiliary facility device A, such as an enclosure, the reliability of this device can be changed with the existence of the device A. When there is device A, it is r_1, while if there is no device A, it is r_0. We name this condition as protection relation. It can be shown in Equation (6).

$$r = \begin{cases} r(A) = r_1, & \text{if device A exists} \\ r(\bar{A}) = r_0, & \text{if device A does not exist} \end{cases} \tag{6}$$

in which, r_0, r_1 are specific reliability values in the different conditions. Note that the reliability in this paper is the trust to the device instead of an inner character. In deferent conditions, the trust to a device is different. It is shown in different TT, and is shown in different reliabilities as well. This is different from traditional reliability theory in which reliability is a character tested by experiments.

2.5. Component Block

When we plan an observatory, we will draw a structure diagram, which is a fundamental work in the scheme design. The structure diagram could be drawn on a sheet of paper, and ordinarily it should not be omitted.

From the view of MBSE, or by MBSE tools, we will draw the structure diagram on a computer as well. In a computer, we can put component parts in a sheet, and define their relations by linking them with lines. In order to draw a structure

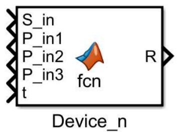

Figure 3. Typical reliability block of a device.

diagram which can calculate parameters, here, we use a software package named as Matlab Simulink. There is a MBSE tool in the Matlab Simulink software named Matlab Composer. Since it is not easy to program, we simply use basic Simulink blocks here to define the structure diagrams in the Matlab Simulink.

In Simulink, we define each device or facility as a block. A typical one is shown in Figure 3, in which there are five inputs, and one output.

The input port S_in represents serial relationships. When the upper device's reliability goes into this port, the block will calculate the reliability as the serial algorithm with Equation (4).

The input port P_in represents parallel relationships. Here, there are P_in1, P_in2, and P_in3 in the block. When the upper devices' reliabilities go into this port, the block will calculate the reliability with the parallel algorithm with Equation (5). The P_in port can be void, which will be regarded as 0 by default (there will be a warning in the Diagnostic Viewer, but it does not matter). When there are more than three parallel devices, we can easily append ports for the device block by appending codes in the block.

The input port t is TT of this device. It will be transformed to reliability R in the block. It can be linked with a constant block.

The output port R outflows the final reliability out of this block. It is calculated by the program of the block shown in Listing 1, which is synthesized by Equations (4), (5), and (6). We can see the length of the codes is not too long. It is easy to build the block, and easy to be duplicated to make other devices' blocks.

Listing 1: Typical codes of a reliability block

```
function R = fcn (S_in,P_in1, P_in2, P_in3, t)
R_this=1-1/t/24;
P=(1-(1-P_in1)*(1-P_in2)*(1-P_in3)))* R_this;
R = S_in * P;
```

From the typical block shown in Figure 3, we can derive many kinds of blocks, which will make the design sheet smart. Some of them are shown in Figure 4.

In Figure 4, the Device_P is a block where S_in is 1, the Device_S is a block where P_ins are 1, and the Device_0 is a block with both S_in and P_ins being 1. They embody the parameters in the block to be looked compact.

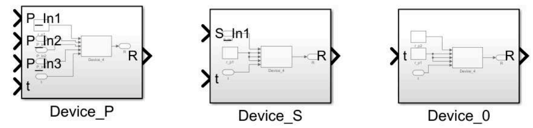

Figure 4. Kinds of derived blocks.

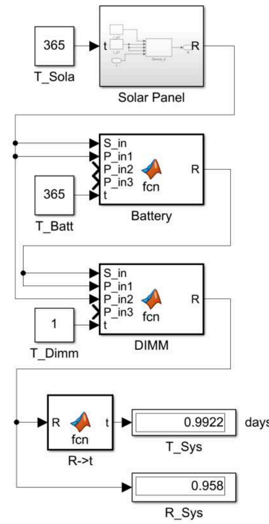

Figure 5. Typical structure diagram.

2.6. Structure Diagram

With these blocks, we can define structure diagram of a site selection, or the devices layout of the site. Figure 5 shows a diagram about a Differential Image Motion Monitor (DIMM) telescope system. There are three components of the system: a solar panel, a set of batteries, and a DIMM telescope. Both the solar panel and the batteries can be expected to be used for 1 yr, but for the DIMM telescope, since there is no enclosure protected, we cannot leave it over a day.

Their reliability relationship is decided as follows: For no matter which component fails, we must return to the site, so these three components are in serial reliability relations together. The solar panel supports the batteries and the DIMM, and the batteries support the DIMM, so the solar panel and the batteries are parallel for the DIMM, and the solar panel is parallel for the batteries, though there is no other device to be parallelled with the solar panel. We draw these relationships as the linkages shown in Figure 5.

We run this diagram in Matlab Simulink environment, and see the final R of the system is 0.958. It can be transformed to the trusty time t by the block R->t, which is a program according by Equation (2). The output TT value is 0.9922 day, which is slightly less than 1 day. We can see that it is fit for people's instinctive judgement.

With the structure diagram, we can study the site selection. For example, we can study the range of the whole site selection system's TT by change the TT input of each

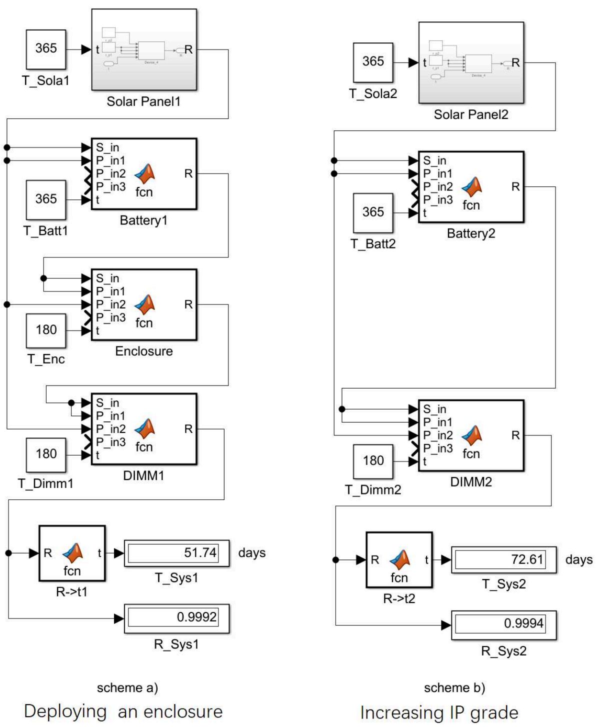

Figure 6. Schemes' comparison and optimization.

component. We can study the sensitivity of each component for the whole system. Naturally, we can optimize the site selection by changing the structure diagram.

2.7. Scheme Comparison and Optimization

Shown in Figure 6, we make two alternative schemes to optimize the scheme shown in Figure 5. The work is performed by the actions of copying, pasting, and modifying in computers.

In scheme (a), we append an enclosure to shelter the DIMM telescope system. So the TT *t* of the DIMM telescope system will depend on the stability of the computer instead of the weather. We suppose that the new TT's value is 180 days. The enclosure is a complex device, we also suppose its trusty time TT as 180 days. Then we get the system's trusty time *t* by running the diagram in the Simulink. It outputs 51.74 days.

In scheme (b), we increase the DIMM telescope's IP (Ingress Protection) grade, that is, waterproof grade, to make it waterproof. Then we can suppose that its trusty time improves to 180 days, since TT is also decided by the stability of the computer similar in scheme (a). Then we can get a new trusty time. We can see that the new TT of scheme (b) is increased to 72.61 days.

The simulation above suggests us: from the view point of the unmanned duty, making the DIMM telescope waterproof is better than covering it with an enclosure.

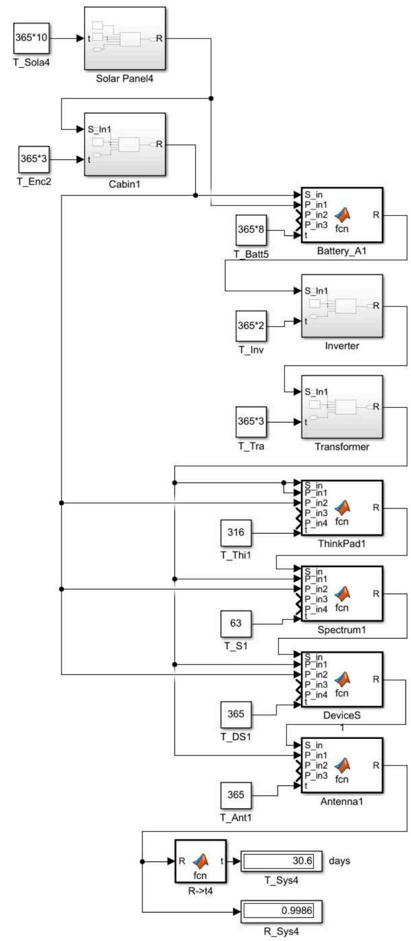

Figure 7. Radio site survey in Lenghu.

3. Application

3.1. Site Selection in Lenghu

The Radio Site Selection in Lenghu Area is being conducted by National Astronomical Observatories, Chinese Academy of Sciences (NAOC). It will survey the whole area of Lenghu, Qinghai province, to find places suitable for radio astronomical observatories. As a general survey project, the aim of this site selection is to explore as many qualified places as possible. It is important since astronomical sites have been regarded as important strategic resources of the world.

There are many merits of Lenghu area for radio astronomy; besides, there has been an excellent optical astronomical site (Deng et al. 2021, Yang et al. 2024) on the summit of the Mount Saishiten, Lenghu. There are only a few people there, so there is less interference on the radio frequency (RF) yielded by the people's economic or life activity, which is very good for radio astronomical observations. The Lenghu area is far from big cities and industries, so there is less electro-magnetic pollution. The altitude here is very high, and the air

Table 2
TT of Main Components

Items	MTBF (in hr)	TT (in days)	Basis
Solar Panels		10×365	evaluated, 10 yr guarantee by vendor
Cabin		3×365	evaluated
Battery		8×365	evaluated, 8 yr guarantee by vendor
Inverter		2×365	evaluated, 2 yr guarantee by vendor
Transformer		3×365	evaluated
Computer	500,000	316	MTBF of ThinkPad $\times$ 0.152
Spectrum	10,000	>63, up to 316	MTBF of Agilent $\times$ 0.152; Its reliability was felt similar to the ThinkPad
Self-made Device		365	evaluated by the maker
Antenna		365	evaluated, there is movable head

here is very dry, which is very beneficial for high frequency radio observations. Good air condition and low water vapor content are very helpful for decreasing the high frequency radio signal attenuation.

No doubt the site selection work here is very hard. The radio site selection in Lenghu area will cover so large an area up to about 18 k square kilometers. Different from the optical site selection which is often focused on the summit of the Mount Saishiten, a radio site could be both mountain and plateau area. To select the best site, we should monitor more places. For the desert there, the traffic to the site is bad. It is very difficult to get there.

So it is very important to relieve the staff from frequently visiting the site. We tried to employ the kinds of unmanned technology to solve these difficulties, especially the method described in Section 2 at the beginning of site selection planning phase for decreasing human visiting.

3.2. Structure Diagram of Lenghu's Site Survey

We design the site selection and draw the structure diagram shown in Figure 7. The site is constructed by a set of solar panels, batteries, an inverter, a transformer, a computer, a self-made device, a spectrum, and an antenna. The devices including the batteries, the inverter, the transformer, the computer, the spectrum and the self-made device, are in a cabin. Their blocks are defined in Figure 7, and their relationships are defined by the linkages among these blocks.

TTs of the main components in Lenghu site selection are listed in Table 2.

The evaluation basis is also listed in Table 2. All reliability parameters are estimated carefully and conservatively to the best of our abilities:

Figure 8. Radio site survey in Lenghu.

All devices' TTs can be estimated only by feeling. Notice that all parameters are decided by the designer's confidence, so the result only reflects the designer's confidence. It may not be the truth of the system, but can be references.

Some devices' TTs can be estimated by the warranty period. Normally, the warranty period is decided by MTBF/10, which is a possibility of about 90%. So it can be regarded as TT directly. For example, the solar panel, whose warranty time is 10 yr. So we estimate that its TT is 10×365 days.

Some device's TTs can be estimated in according to MTBF. For it is difficult to get the exact MTBF of that exact type of device, we refer to similar or general devices by web pages on the Internet. For example, the MTBF of a Thinkpad, which is the computer brand we used, is 500,000 hr. We can transform MTBF to TT with multiply 0.152 which is 316 days. The MTBF of a normal spectrum is 10,000 hr, and we estimate that TT of the spectrum is 63 days. But the spectrum we employed is an Aglient device which is qualified and can be used for a long time. We feel it very stable just like the computer we used. So we estimate its TT as a range from 63 to 316 days.

With these parameter estimations, we finally get the TT of the system which is from 30 days (when TT of the spectrum is 63 days) to 50 days (when TT of the spectrum is 316 days).

4. Verification

With the structure diagram and its simulations, we finally deployed the site selection on a hillside in the Mount Saishiten, near the Lenghu site of NAOC. The site's photo is shown in Figure 8.

Since the TT of that scheme is $30 \sim 50$ days, which means that the site should be visited once per $30 \sim 50$ days, we decided that the site should have been visited once per month. The confidence degree C we used is 90%, so it means that there will be no problem about 9 times out of 10 times with this visit frequency.

It has been running smoothly without any failure on site for more than half years since then. So far, we have not seen any conflict between the simulation and the site selection practice.

5. Conclusion and Discussion

We proposed a design method for an on-site monitoring for a radio astronomical observatory site selection, based on the traditional TBSE, the MBSE, and the reliability theories. It can help to estimate and extend the time period of revisiting for maintenance.

The method has been applied in the radio astronomical site selection in the Lenghu area, which reveals the effectiveness and simpleness.

In the process of the design and optimization with this method, we can be urged to consider the scheme repeatedly. By considering and studying each component, their combinations, and the reliability of the whole system calculated automatically, the quality of the final site selection will be ensured to our best.

The method may be extended to other astronomical site selections even to general astronomical observatories, for unmanned purposes, but it still needs test of practice. The actual site selections are very complex, so it must be difficult to be solved only by one single method. This method is based on the automation of each device, which is the trend and endeavor of device manufacturers. This may be a future solution. Whether or not it is a success will also rely on the future development of the site selection devices' automation technologies. With the development of the automation of devices for site selections, the hardness would be decreasing wholly.

In the practice of site selection, occasionally unexpected issues may happen, such as thunder, strong winds, etc. They happen totally irregularly, which is also a problem we have to face. Further more, another hard period of site selections is the deployments of devices in the very beginning which need lots of human powers. How to deal with those difficulties to solve the hardness of site selections is our next step study.

Acknowledgments

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