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Abstract

Astronomical site selection is extremely challenging. Unmanned technologies represent critical trends and viable solutions. We present a relatively straightforward method for planning high-reliability site selection that extends the interval between site deployment and return visits for maintenance through unmanned site verification. First, we redefine the reliability of a site selection deployment using the parameter of “trusty time” , which indicates the required return time and can be relatively straightforward to estimate. This redefinition frames the reliability parameter as a Bayesian probability that can be obtained through estimation in addition to testing, thereby significantly simplifying the evaluation of each device’ s reliability. We then employ the block diagram tools in MATLAB Simulink software to construct structural diagrams, connecting each component through relationships including parallel, series, redundant protection, and other configurations. This enables calculation of the overall reliability value during the design or planning phase of site selection. We applied this concept and method to an actual site selection project in Lenghu, Qinghai Province, China. Field implementation demonstrates its effectiveness and simplicity.

Full Text

Preamble

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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 is an exceptionally challenging endeavor, and unmanned technologies represent crucial trends and solutions. We present a relatively straightforward method for planning high-reliability site selection that can extend the interval from initial deployment to maintenance visits through unmanned site confirmation. First, we redefine site selection deployment reliability using the parameter of “trusty time,” which indicates when a return visit becomes necessary and can be estimated with relative ease. This redefinition frames the reliability parameter as a Bayesian probability that can be obtained through estimation rather than solely through testing, substantially simplifying the evaluation of each device’ s reliability. We then employ block diagram tools in Matlab Simulink software to construct structural diagrams and link components through parallel, serial, protection, and other relationships. This enables calculation of the overall reliability value during the site selection design or planning phase. We applied this concept and method to an actual site selection project in Lenghu, Qinghai Province, China, and the survey practice demonstrates its effectiveness and simplicity.

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

1. Introduction

Traditional astronomical site selection is extremely difficult, particularly as modern observatories increasingly trend toward high-altitude, remote, and desolate locations. Although unmanned technologies enable automatic device deployment and remote data acquisition, unintended device failures frequently necessitate return visits. Consequently, astronomical site selection remains expensive and exhausting.

Systems engineering (SE) provides a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system (NASA 2019) and is commonly employed to ensure product quality. Since L. Von Bertalanffy’ s foundational work on systems theory, SE has evolved from Text-Based Systems Engineering (TBSE) to Model-Based Systems Engineering (MBSE) (Chen & Lu 2022). While successful in fields such as aeronautics and astronautics, SE functions primarily as a verification or management tool within quality standards like ISO 9000 rather than as a practical design tool. Moreover, the extensive documentation requirements can exhaust designers planning site selection projects.

Given the difficulty of site selection and the challenges of site access, we naturally gravitate toward unmanned solutions. Most devices for verifying site quality now have unmanned alternatives, yet we remain compelled to visit sites frequently, partly because we lack evaluation of the entire site’ s reliability. Site surveys require numerous diverse devices from different manufacturers with varying accessories, most of which undergo no site-specific testing. Obtaining precise reliability parameters such as Mean Time To Failure (MTTF) and Mean Time Between Failure (MTBF) proves exceptionally difficult.

How, then, can we confirm the unmanned quality of an observatory during its site selection phase? How can we plan or design a site selection—including determining what to monitor, which monitoring devices to deploy, and how to implement the monitoring—relatively easily while maximizing the interval between visits? In this paper, we develop a relatively simple method to evaluate or plan site selection as a complete system using SE theory (both traditional TBSE and modern MBSE). Section 2 introduces our methodology, describing how we estimate reliability by incorporating Bayesian probability to simplify concepts and how we adapt this for site selection by defining device blocks and their relationships. Section 3 applies this method to a survey plan in Lenghu, Qinghai Province. Section 4 verifies the method’ s effectiveness, Section 5 discusses its implications, and we conclude with final remarks.

2.1. Definition of Trusty Time TT

Drawing from systems engineering and reliability engineering theory, we can define site selection reliability as a system parameter. The reliability, R, can be defined as:

$$R = e^{-1/t}$$

where t is the trusty time. The term 1/t resembles the failure probability definition in traditional reliability engineering (Kailash & Michael 2014). Note that this definition differs from conventional engineering, which typically uses experimentally determined MTTF. Our approach employs an estimated value, making the equation suitable for site selection systems. This definition also applies to every individual device.

Reliability R evaluates site selection trustworthiness, reflecting our confidence in unattended operation. If derived entirely from experiments, it represents a traditional probability; if determined by human confidence (from the designer, leader, or survey executor), it becomes a Bayesian probability. In this paper, we can consider each device’ s reliability not only through certification but also through intuition, or even a combination of experimental data and subjective assessment. Thus, it constitutes a Bayesian probability. Unlike traditional SE, where reliability values must be obtained experimentally, we can acquire them much more easily. Although not entirely experimentally derived, this approach remains valuable for planning and design. Traditional SE' s requirement for experimental determination of every parameter makes reliability analysis prohibitively difficult to complete.

The trusty time (TT) t represents the duration we can rely on a device or device system, similar to MTTF and MTBF. We define its unit as days, indicating how many days we can leave the devices or site unattended and when we should return for maintenance. Unlike MTTF and MTBF, TT can derive from human estimation rather than experiments alone.

Because experimental determination is unnecessary, estimation becomes sufficiently practical to complete the reliability work. TT reflects human confidence like reliability R, making it a Bayesian estimation as well. Given its similar mathematical form to traditional metrics, we believe TT is proportional to MTTF or MTBF, allowing its use in probability calculations.

TT can be estimated more easily than MTBF during site design or planning, or upon completing deployment before departure. It is also more intuitive and applicable in site selection practice than MTBF and can be treated as constant. In traditional SE (Kailash & Michael 2014), the hazard rate varies over time, resembling a bathtub curve shown as the red line in Figure 1. Consequently, reliability varies with the hazard rate, depicted as the blue line in Figure 1.

Regardless of how reliability varies temporally, we can regard it as constant during site survey system estimation, shown as the green line in Figure 1. We can also modify and update it throughout the site selection process. This simplification makes estimation practical while still preventing major errors.

All component TTs can be reconsidered when leaving the site, which is why we can simplify them as constants. Their values depend on the evaluation moment.

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

$$t = \frac{-1}{\ln(R)}$$

Thus, after calculating the entire system, we obtain the intuitive parameter TT, which indicates when we must return rather than providing only a probability value.

2.2. Estimate TT by MTBF and Confidence

TT can be derived from MTBF, which represents the mean time between failures —an arithmetic average of time-to-failure. MTBF corresponds to the time when 50% of failures have occurred, providing 50% confidence in the device.

When estimating TT, we similarly identify a time when we have C confidence in the device. Here, C (confidence degree) represents our confidence level, equivalent to the probability of failure-free operation. At time TT, 1 - C failures will have occurred. For example, if C = 90%, 10% of failures will have occurred by time TT.

Assuming failures follow an exponential distribution, we can identify the time corresponding to any failure ratio from the area under the probability density curve. This yields the relationship between TT and MTBF, illustrated in Figure 2 [Figure 2: see original paper].

We derive the relationship equation between TT and MTBF as Equation (3):

$$t = \mathrm{MTBF} \times \frac{\ln(C)}{\ln(0.5)}$$

where confidence degree C is the confidence level with the device, also representing the probability of proper operation without failure. We list various C values in Table 1 for convenient TT estimation across different confidence levels and to enable unified evaluation.

In this paper, we use C = 90% as the default for TT estimation.

2.3. Estimate TT by Past Performance

For a single device that has operated for an extended period without failure, we can estimate MTBF as if failure occurred at that moment, representing the lower MTBF limit. For instance, a device used for one full year can be considered to have an MTBF of 1 year. Its TT would be 55 days when C = 90%, simply calculated as 365 days multiplied by 0.152 according to Equation (3) and Table 1.

As site selection progresses, we can determine MTBF if the device fails or establish the MTBF lower limit if it does not. We can then predict its MTBF and consequently its TT at that moment.

2.4. Calculate TT by Relationship Among Components

A system' s reliability comprising many components is determined by those components' reliabilities and their relationships. Components exhibit various relationships: serial, parallel, protection, and others.

For serial relationships, system reliability is:

$$R_{\text{serial}} = r_1 \times r_2 \times r_3 \times \dots$$

where r_1, r_2, r_3···are component reliabilities.

For parallel relationships, system reliability is:

$$R_{\text{parallel}} = 1 - (1 - r_1) \times (1 - r_2) \times (1 - r_3) \times ...$$

If device A is protected by auxiliary facility device B, such as an enclosure, the device’ s reliability changes based on device B’ s presence. With device B, reliability is r_1; without it, r_0. We term this a protection relationship, expressed in Equation (6):

$$R = \begin{cases} r_1 & \text{if device B exists} \\ r_0 & \text{if device B does not exist} \end{cases}$$

where r_0 and r_1 are specific reliability values under different conditions. Note that reliability in this paper represents trust in the device rather than an intrinsic characteristic. Under different conditions, trust in a device varies, manifested through different TT values and different reliabilities. This differs from traditional reliability theory, where reliability is an experimentally tested characteristic.

2.5. Component Block

When planning an observatory, we create a structure diagram—a fundamental task in scheme design. This diagram can be drawn on paper and should not ordinarily be omitted.

From an MBSE perspective, or using MBSE tools, we also draw the structure diagram on a computer. In a digital environment, we can place component blocks on a sheet and define their relationships through connecting lines. To create a calculable structure diagram, we use the Matlab Simulink software package. While Matlab Simulink includes an MBSE tool called Matlab Composer, programming it is not straightforward, so we simply use basic Simulink blocks to define our structure diagrams.

In Simulink, we define each device or facility as a block. A typical block is shown in Figure 3 [Figure 3: see original paper], featuring five inputs and one output.

The input port S_{in} represents serial relationships. When an upstream device’ s reliability enters this port, the block calculates serial reliability using Equation (4). The input ports P_{in} represent parallel relationships, with three such ports (P_{in1}, P_{in2}, P_{in3}) in the block. When upstream devices’ reliabilities enter these ports, the block calculates parallel reliability using Equation (5).

The P_{in} port can be empty, which defaults to 0 (triggering a warning in the Diagnostic Viewer, which is inconsequential). When more than three parallel devices exist, we can easily add ports by modifying the block’ s code.

The input port t represents the device' s TT, which is transformed to reliability R within the block. It can be linked to a constant block.

The output port R_{out} transmits the final reliability from the block, calculated by the block' s program shown in Listing 1, which synthesizes Equations (4), (5), and (6).

The code length is modest, making block construction straightforward and easy to duplicate for other devices' blocks.

Listing 1: Typical codes of a reliability block

```
function R = fcn (S_{in},P_{in1}, P_{in2}, P_{in3}, t)
    R = S_{in} * (1 - (1-P_{in1})*(1-P_{in2})*(1-P_{in3})) * exp(-1/t);
end
```

From the typical block in Figure 3, we can derive various block types to streamline the design sheet, some of which are shown in Figure 4 [Figure 4: see original paper]. In Figure 4, Device_P has S_{in} set to 1, Device_S has P_{ins} set to 1, and Device_0 has both S_{in} and P_{ins} set to 1, making the block parameters appear compact.

2.6. Structure Diagram

Using these blocks, we can define a site selection' s structure diagram or device layout. Figure 5 [Figure 5: see original paper] illustrates a Differential Image Motion Monitor (DIMM) telescope system diagram. The system comprises three components: a solar panel, a battery set, and a DIMM telescope. Both the solar panel and batteries have expected lifespans of one year, but the unenclosed DIMM telescope cannot be left unattended for more than one day.

Their reliability relationships are determined as follows: since any component failure necessitates a site visit, the three components share serial reliability relationships. The solar panel supports the batteries and DIMM, while the batteries support the DIMM, creating parallel relationships between the solar panel and batteries for the DIMM, and between the solar panel and batteries (though no other device parallels the solar panel). We represent these relationships through the linkages shown in Figure 5.

Running this diagram in the Matlab Simulink environment yields a final system reliability R of 0.958. This can be transformed to trusty time t using the R→t block programmed according to Equation (2), outputting a TT value of 0.9922 days—slightly less than one day. This aligns with intuitive judgment.

With the structure diagram, we can analyze the site selection system. For example, we can examine the overall TT range by varying each component' s TT input, study each component's sensitivity to the whole system, and naturally optimize the site selection by modifying the structure diagram.

2.7. Scheme Comparison and Optimization

As shown in Figure 6 [Figure 6: see original paper], we developed two alternative schemes to optimize the configuration from Figure 5, performed through simple copy, paste, and modify operations in the computer environment.

In scheme (a), we add an enclosure to shelter the DIMM telescope system. Consequently, the DIMM telescope system' s TT depends on computer stability rather than weather conditions. Assuming the new TT value is 180 days and the enclosure' s TT is also 180 days, running the Simulink diagram yields a system TT of 51.74 days.

In scheme (b), we increase the DIMM telescope' s IP (Ingress Protection) waterproofing grade, improving its TT to 180 days (similar to scheme (a), as TT is now determined by computer stability). This yields a new TT of 72.61 days.

This simulation suggests that, from an unmanned operation perspective, waterproofing the DIMM telescope is superior to covering it with an enclosure.

3. Application

3.1. Site Selection in Lenghu

The National Astronomical Observatories, Chinese Academy of Sciences (NAOC) is conducting a radio site selection survey in the Lenghu area of Qinghai Province to identify locations suitable for radio astronomical observatories. As a general survey project, its objective is to explore as many qualified sites as possible—an important goal since astronomical sites are increasingly regarded as important strategic resources worldwide.

The Lenghu area offers numerous advantages for radio astronomy. Notably, an excellent optical astronomical site already exists on Mount Saishiten' s summit (Deng et al. 2021; Yang et al. 2024). The sparse human population generates minimal radio frequency (RF) interference from economic or life activities, which is highly beneficial for radio astronomical observations. The area' s distance from major cities and industries ensures low electromagnetic pollution. The high altitude and extremely dry air significantly reduce high-frequency radio signal attenuation, making conditions ideal for such observations.

Undoubtedly, the site selection work is exceptionally challenging. The radio site selection covers approximately 18,000 square kilometers. Unlike optical site selection, which typically focuses on Mount Saishiten' s summit, radio sites can be located on both mountains and plateaus. To select the best site, we must monitor numerous locations, but the desert terrain makes site access very difficult. Consequently, minimizing staff visits is crucial. We employed unmanned technologies to address these challenges, particularly the method described in Section 2, during the initial planning phase to reduce human visitation.

3.2. Structure Diagram of Lenghu’ s Site Survey

We designed the site selection and created the structure diagram shown in Figure 7 [Figure 7: see original paper]. The site comprises solar panels, batteries, an inverter, a transformer, a computer, a self-made device, a spectrum analyzer, and an antenna. The batteries, computer, spectrum analyzer, and self-made device are housed in a cabin. Their blocks are defined in Figure 7, with relationships established through inter-block linkages.

Table 2 lists the TT values for the Lenghu site selection’ s main components, along with their evaluation basis. All reliability parameters were estimated carefully and conservatively to the best of our abilities.

Table 2. TT of Main Components

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

Some devices’ TTs can be estimated solely by intuition. Since all parameters depend on the designer’ s confidence, the results reflect only that confidence and may not represent the system’ s true reliability, but they provide valuable references.

Some devices’ TTs can be estimated from warranty periods. Typically, warranty periods are set at MTBF/10, corresponding to approximately 90% reliability, so they can be regarded directly as TT. For example, solar panels with a 10-year warranty are estimated to have a TT of 10×365 days.

Other devices’ TTs can be estimated from MTBF. Since obtaining exact MTBF values for specific device types is difficult, we reference similar or general devices through internet sources. For instance, the ThinkPad computer brand we used has an MTBF of 500,000 hours, which transforms to a TT of 316 days when multiplied by 0.152 according to Equation (3) and Table 1. A typical spectrum analyzer has an MTBF of 10,000 hours, yielding a TT of 63 days. However, our Agilent spectrum analyzer is a qualified, long-lasting device that feels as stable as our computer, so we estimate its TT as ranging from 63 to 316 days.

With these parameter estimations, we obtain a system TT ranging from 30 days (when spectrum TT is 63 days) to 50 days (when spectrum TT is 316 days).

4. Verification

Based on the structure diagram and simulations, we deployed the site selection system on a Mount Saishiten hillside near NAOC’ s Lenghu site, shown in Figure

8 [Figure 8: see original paper].

Given the scheme' s TT of 30–50 days, indicating the site should be visited every 30–50 days, we decided on a monthly visitation schedule. With a confidence degree C of 90%, this frequency should encounter no problems approximately 9 times out of 10.

The system has operated smoothly without on-site failures for over six months. Thus far, we have observed no conflicts between simulation and actual site selection practice.

5. Discussion and Conclusion

We proposed a design method for on-site monitoring in radio astronomical observatory site selection, grounded in traditional TBSE, MBSE, and reliability theories. This method helps estimate and extend maintenance revisit intervals.

The method has been applied to radio astronomical site selection in the Lenghu area, demonstrating its effectiveness and simplicity. During design and optimization, the method compels repeated scheme consideration. By examining each component, their combinations, and the automatically calculated whole-system reliability, we ensure the final site selection' s quality to the best of our ability.

The method may extend to other astronomical site selections and even general astronomical observatories. While suitable for unmanned purposes, it still requires practical testing. Actual site selections are highly complex and cannot be solved by a single method alone. This approach depends on device automation —a trend and focus of device manufacturers that may provide future solutions. Its ultimate success will rely on future developments in site selection device automation technologies. As device automation advances, the overall difficulty of site selection will decrease.

In practice, occasional unexpected issues such as thunderstorms and strong winds occur completely irregularly, presenting challenges we must address. Furthermore, the initial device deployment phase remains difficult, requiring substantial human resources. Addressing these difficulties to solve the fundamental challenges of site selection represents our next research step.

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Note: Figure translations are in progress. See original paper for figures.

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