پانزدهمین سمینار احتمال
و فرآیندهای تصادفی
۸ و ۹ شهریور ۱۴۰۴
دانشگاه کردستان

15th Seminar On Probability and Stochastic Processes
August 30-31, 2025
University of Kurdistan

انجمن آمار ایران

Application of statistical models in designing a system to save animal lives

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Abstract

These days, one of the most common causes of animal deaths is road accidents. For this reason, it is essential to equip vehicles with a system for identifying and recognizing animals. Using statistical models, it is possible to identify animal behavior patterns and also assess risks, which will lead to improved resource management and relief efforts. In this article, an attempt has been made to explain how road accidents can be reduced by using an early warning system to prevent accidents, using statistical models such as Markov chains and reliability parameters. This system can help in quick and effective decision-making by analyzing data and predicting critical situations.

Keywords: Stress-Strength Parameter, Markov Process, Reliability, Warning System.
Mathematics Subject Classification (2020): 62N05, 60Jxx.

1 Introduction

Environmental protection plays an important role in the lives of future generations. Natural and unnatural factors have caused a decrease in the animal population. Road accidents are one of these factors that can be controlled and reduced. Intelligent and advanced systems are one of the ways in which road accidents can be reduced. Statistical models have played an important role in optimizing systems in various fields. For example, you can see Lebreton and *et al.* (1993), Festing (2004), Festing (2006) and Williams and *et al.* (2020). In this article, a system has been designed that can save the lives of some animals and, using simple examples, the importance and application of statistical models in optimizing such systems has been shown.

2 System Design

We want to design a system that warns the driver before an accident. Therefore, this system should consist of four parts:
1. Motion sensors: Detecting animal body heat in the dark or in adverse weather conditions

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2. Smart cameras: Image processing to detect the type of animal and its direction of movement,
3. Warning system: Send audio/visual alerts to the driver,
4. Emergency braking: Automatic braking activation if the driver does not react.
Systems that are designed from parts like the system above usually face various errors and risks, some of which are mentioned below:
1- Sensor error in detecting animals,
2- Delay in sending the warning,
3- Camera failure.
4- System hardware failure

3 System reliability

One of the most important points in designing various systems is that the system must have high reliability. Suppose that the random variable X represents the lifetime of a system. The reliability of a system is represented by $R(t)$ and is defined as follows

$$R(t) = P(X > t) \qquad t > 0 \tag{1}$$

Using the formula (1), the reliability of many systems can be easily calculated. But in sensitive cases, its reliability must be increased by considering all the possible risks that a system may face. Therefore, we will use several methods to increase the reliability of the system.

3.1 Reliability for hardware components

For the hardware components of the system, a stress-strength reliability model can be used, considering the stresses imposed on the system and the system capacity. Suppose that the stresses imposed on the system, for example, the number of processing requests per second, are represented by a random variable X and the strength of the system, for example, the server processing power, is represented by a random variable Y. In this case, stress-strength reliability is equal to

$$R = P(Y > X) \tag{2}$$

Calculating the formula (2) is simple in most cases, and in cases where the calculation of the formula is complex or several different stresses enter the system, it can be easily calculated using nonparametric methods.

3.2 Probability of complete failure

Calculating the probability of the system reaching a complete failure state is another issue that must be examined to increase the reliability of the system. To calculate this probability, we need to examine the system's operating process and its states. For most systems, the system operating states can be considered as follows:
a) Operational: The system is healty.
b) Partial failure: Some sensors have failed or the alarm system has been muted.
c) Complete failure: The system is inoperable.
The best way to examine the transition between states and determine the probability of reaching a complete system failure is to model the system performance using processes such as Markov, semi-Markov, or a renewal process.

Example 3.1. *Suppose that the transition between system states can be represented by a Markov process with a transition probability matrix P as follows. In this case, by obtaining the stationary distribution of the process, the probability of the system reaching a complete failure*

can be calculated.

$$P = \begin{bmatrix} 0.94 & 0.0.4 & 0.02 \\ 0.33 & 0.60 & 0.07 \\ 0 & 0 & 1 \end{bmatrix}$$

By solving the Markov equations $\pi = \pi P$ *where* $\pi = (\pi_1, \pi_2, \pi_3)$*, the long-term probability of each state is given by:*

$$\pi_1 = 0.80, \quad \pi_2 = 0.15, \quad \pi_3 = 0.05$$

That is, the system is operational 80 percent of the time, has a partial failure 15 percent of the time, and a complete failure 5 percent of the time.

3.3 System Availability

In this process, system availability is the percentage of time the system is in a or b. Assuming the conditions of Example 1 are met, then

$$Availability = \pi_1 + \pi_2 = 0.80 + 0.15 = 0.95$$

With 95 percent communication capability, this system can reduce animal collisions by up to 80 percent. By improving the Markov model and adding layers of redundancy, higher accuracy can be achieved.

3.4 Equipment Lifetime Prediction

The system designed in section 2 consists of different parts that have different functions and different structures. Therefore, it is better to calculate a separate reliability function for each. One of the best reliability models for predicting the lifetime of equipment is the Weibull reliability function model, which is as follows:

$$R(t) = e^{-(t/\alpha)^{\beta}} \tag{3}$$

Where α is the scale parameter (characteristic life) and β is the shape parameter (failure rate). The Weibull model is a suitable model for predicting the time to replace sensors before failure.

Example 3.2. *Suppose that for the system discussed in Section 1, we have the following conditions:*
a) The sensors have an exponential lifetime with a failure rate of 0.002.
b) The stress applied to the camera system has a $Weibull(2, 1.5)$ *distribution and its resistance has a* $Weibull(2.5, 2)$ *distribution.*
c) The lifetime of the warning system has a $Weibull(50, 1.8)$ *distribution.*
d) The stress applied to the brake system has a $N(50, 10)$ *distribution and its resistance has a* $N(65, 8)$ *distribution.*
Figure 1 shows the reliability of such a system. Since the order of the steps in this system is serial, the reliability of the sum is less than the reliability of the parts.

3.5 Using spares

In some parts of systam, such as the animal detection part where sensors are used, it is better to use several sensors in parallel due to their high sensitivity, thereby increasing the reliability of the system.

Example 3.3. *Suppose we have three sensors with a reliability of* 0.9 *placed in parallel. In this case, the total reliability is*

$$R_{total} = 1 - (1 - 0.9)^3 = 0.999$$

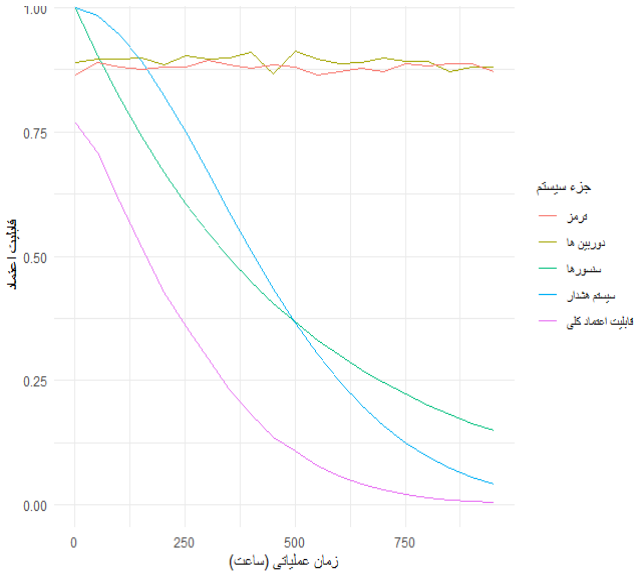


Figure 1: Comparing total reliability with component reliability.

3.6 Reduce recognition error

Use machine learning to reduce recognition error. For example, use the YOLO algorithm to recognize animals in images. Collect thousands of images of animals in different conditions. Test the system in different conditions.

4 Improving sensor performance

Here, we present a Markov model for modeling animal behavior, movement patterns, and environmental hazards to improve sensor performance. For this model to function properly, in addition to vehicle sensors, sensors need to be placed where animal populations are high and the likelihood of them crossing the road is high. For example, electronic signs should be placed on the side of the road that indicate the possibility of animals crossing or flashing lights should be placed on the side of the road to scare the animal away.
The Markov chain states for improving sensor operation are defined as follows:
1- Safe state: the animal is away from the road.
2- Possible danger state: the animal is near the road.
3- High danger state - the animal is on the road.
4. Accident state

Example 4.1. *Suppose that the transition matrix in a Markov chain is as follows:*

$$\begin{pmatrix} 0.7 & 0.3 & 0 & 0 \\ 0.2 & 0.5 & 0.3 & 0 \\ 0.1 & 0.2 & 0.6 & 0.1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Then the probability that an animal will be in the forest or away from the road after five transition steps when it is in step zero is 0.04.

By monitoring the current state of the animal, the system calculates the probability of being in a danger state, and if the probability of danger is higher than a certain level, an alarm is activated. For example, if the Markov model predicts that deer will move towards the road with a probability of over 75 percent, warning lights for drivers will be activated.

4.1 Hazard Rate Function

Another way to improve sensor performance is to use hazard functions to model the probability of an accident at different time intervals. If the hazard probability exceeds a certain threshold, the warning system is activated. Suppose we have data that includes the time until the animals reach the road (Time-to-Event) and whether an accident occurred or not (Censored Data). Models such as the Cox Proportional Hazards model or the Weibull distribution can be used to predict the hazard.

Example 4.2. *suppose that the vector* $(5, 10, 3, 8, 12, 7, 15, 20, 4, 6)$ *represents the time until an accident occurs or does not occur, and the vector* $(1, 0, 1, 1, 0, 1, 0, 1, 1, 0)$ *represents the occurrence or non-occurrence of an accident. Figure 1 shows a simulation in R for the cumulative hazard function graph for animal collisions. Also, the probability of an accident occurring in less than 7 minutes is* 0.4.

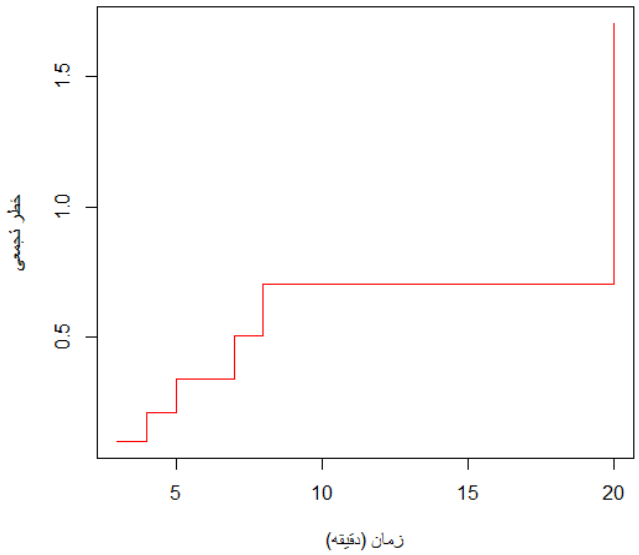


Figure 2: Write the caption here.

4.2 Checking the presence of danger at a specific time

The number of accidents varies due to the variable number of cars and animals at different times. For this reason, the probability of the presence of danger at a specific hour or day should also be checked.

Example 4.3. *Suppose that the number of animals near the road at a specific time and place can be represented by* $Pois(5)$. *Suppose that the number of cars moving on the road near these animals is between 10 and 100. Suppose that the probability of an accident is equal to* $\frac{Numberofcars*Numberofanimals}{1000}$ *and if this probability is above* 0.7, *the warning system is turned on. Figure 2 shows the risk graph over time for thirty consecutive days.*

If the number of animals and cars is updated, using this method, dangerous days are identified and the driver is warned on that day to be more careful.

5 Conclusion

Statistical models are applicable and efficient in almost any field. In this paper, we have shown that statistical models can be used to design highly reliable animal rescue systems. The

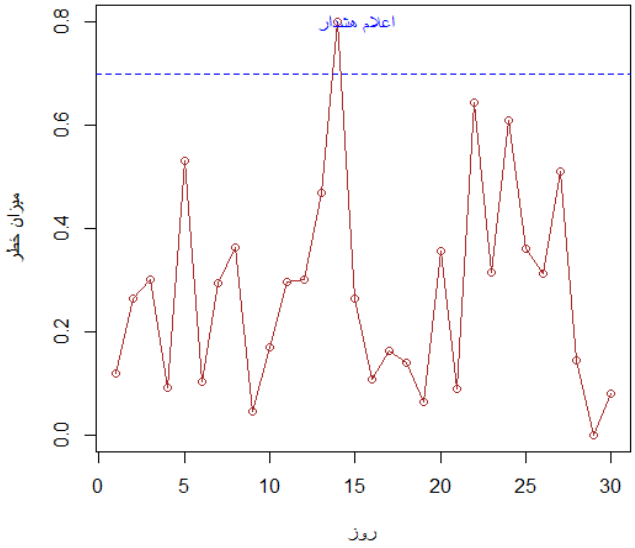


Figure 3: Write the caption here.

application of different reliability methods such as 1 and 2 was shown in different sections. We also showed that statistical models such as Markov and Weibull can be used to predict failures. Of course, the mentioned method is expensive and one of the main problems that makes vehicle manufacturers reluctant to design such systems is its high cost.

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