IS ONE INSPECTION ENOUGH TO ESTIMATE DURABILITY IN BUILDINGS? A SIMULATION STUDY.

Carles Serrat[1]

Abstract

Decisions about intervention in existing buildings are generally based on information gathered from inspections, as a systematic tool for the identification of some injury in buildings. In this sense, in order to carry out an efficient preventive task and maintenance, knowledge of the evolution of injuries and their distribution are essential. However, this information, unfortunately, does not exist and there are few studies that describe the lifecycle of constructive elements in play; so we must use durability estimators based on inspections. The main problem of this methodology is the high variability of the resulting estimator. The goal of this research is to present a simulation study that aims to analyze this accuracy and allows the design of an efficient inspection plan.

Key words

Censored data, Durability, Maintenance, Nonparametric estimator, Simulation, Survival analysis.

1 INTRODUCTION TO THE METHODOLOGY AND MOTIVATION RESEARCH

Buergel-Goodwin *et al.* (2005) [2] proposed the interest of the use of survival distributions for monitoring and maintenance of buildings. Recently, Serrat *et al.* (2009) [8] presented a methodology for inspection and analysis for the study of the time to injury on the façade. Concerning the methodology of inspection, Serrat *et al.* (2009) [8] proposed a systematic inspection of façade elements aimed at the detection of risk factors based on the characterization of the buildings, the building parts and elements that compose the façades and its materials, the most recurrent injuries that may affect the façades, the severity of these injuries, and finally, its magnitude. Data coming from one inspection are known as current status data and are characterized by the effect of the censorship (Gómez and Canela, 1994 [3]; Meeker and Escobar, 1998 [7]; Kleinbaum and Klein, 2010 [5]) due to the fact that it is not possible to observe the exact (failure or injury) times of interest. As regards the methodology of analysis, durability was estimated with a nonparametric estimator (Turnbull, 1976 [9]) that takes into account the censorship mechanism in the data, takes advantage of all the available information, and extends the estimator Kaplan-Meier (1958) [4].

[1] Carles Serrat, M.Sc. PhD, School of Building Construction of Barcelona, UPC – BarcelonaTECH, Av. Doctor Marañón, 44-50, 08028-Barcelona, Spain (carles.serrat@upc.edu)

A high proportion of censorship in the data generates a high variability in the resulting estimators and the investigator may wonder, for a given time, how far the proposed estimator is from the true value of durability. It is obvious that a schedule of successive inspections improves the quality of data (although still being 100% censored) and reduces the negative impact of censorship in the precision of the estimators. And the question is: how often should we inspect the building for an efficient estimation of durability? In this regard, the objective of this research is the study via simulation of what should be an efficient inspections schedule that minimizes the effect of censorship.

2 DESIGN OF THE SIMULATION

Different scenarios for the simulation are design taking into account: a) the true failure distribution (family of probability distributions, shape, and scale), b) the number of buildings subject to inspection and c) the inspection mechanism (number of inspections performed on the same building and its distribution across time). This configuration gives rise to more than 4500 scenarios that allows us to study models under assumptions that include a great variability of distributions of risk and inspection strategies. Estimated durability function is calculated for each scenario and its goodness of fit is measured and this allows the study of the efficiency of the resulting estimators.

2.1 Family of probability distribution

As regards the functions of density to be considered, it is important to take into account different behavior patterns for the risk function, and consequently for the durability function. In this sense we have considered Weibull distributions for modeling monotonous risk (increasing, constant or decreasing over time), Lognormal distributions in the case of a cushioned risk function or distributions to enable bathtube shaped risk functions like a Weibull-Exponential-Weibull combination, the Gamma-Weibull family (also known as Generalized Gamma) and the Weibull with resilience family. Details about these density functions can be found in Marshall and Olkin (2007) [6].

Table 1 shows the selected configuration parameters for each distribution and the resulting 78 distributional scenarios. This setting models different patterns of durability in the 150 years observation window that we are considering. Figures 1 to 4 illustrate the durability function and the risk function that we are modeling. Results for the Weibull with resilience family are similar to the obtained for the Gamma-Weibull family.

2.2 Sample size

Sample size, n, has been setup at the values n = 100, n = 400, n = 1600 and n = 6400, in order to check which sample size is large enough to correct the negative effect of censorship in the data on the resulting estimator data.

2.3 Inspections scheduling

Concerning the scheduling of the inspections for each distribution and sample size two strategies of inspection has been considered, depending on the number of inspections and the interval between them, namely:

a) from 1 to 5 inspections with an interval equal to the fifth part of the interquartile range
b) from 1 to 10 inspections with an interval equal to one tenth of the interquartile range.

Tab. 1) Distributional scenarios for the simulation

Family	Parameters	Values	# scenarios
Weibull	α (*shape*)	$\alpha = 0.5, 1, 1.5, 2, 3, 4$	**6**
	β (*scale*)	$\beta = 50$	
Lognormal	μ (*location*)	$\mu = 1, 2, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5$	**30**
	σ (*scale*)	$\sigma = 0.5, 1, 2$	
Bathtube			
Weibull-Exponential-Weibull.	α_1 (*shapeWeibull*$_1$)	$\alpha_1 = 0,5$	**24**
	a (*origin*)	$a = 5$	
	b (*end*)	$b = 10, 25$	
	β (*scale*)	$\beta = 10, 25, 50, 100$	
	α_2 (*shapeWeibull*$_2$)	$\alpha_2 = 1.5, 2, 3$	
Generalized Gamma	α (*shapeWeibull*)	$\alpha = 1.5, 2, 3$	**9**
	β (*scale*)	$\beta = 125$	
	ν (*shape Gamma*)	$\nu = 0.1, 0.2, 0.3$	
Weibull with resilience	α (*shapeWeibull*)	$\alpha = 1.5, 2, 3$	**9**
	β (*scale*)	$\beta = 125$	
	η (*resilience*)	$\eta = 0.1, 0.2, 0.3$	
		Total	**78**

In all cases the time of initial inspection is generated with an uniform distribution between 0 and the true distribution 99.9 percentile. This approach generates 15 different inspection mechanisms for each simulated dataset.

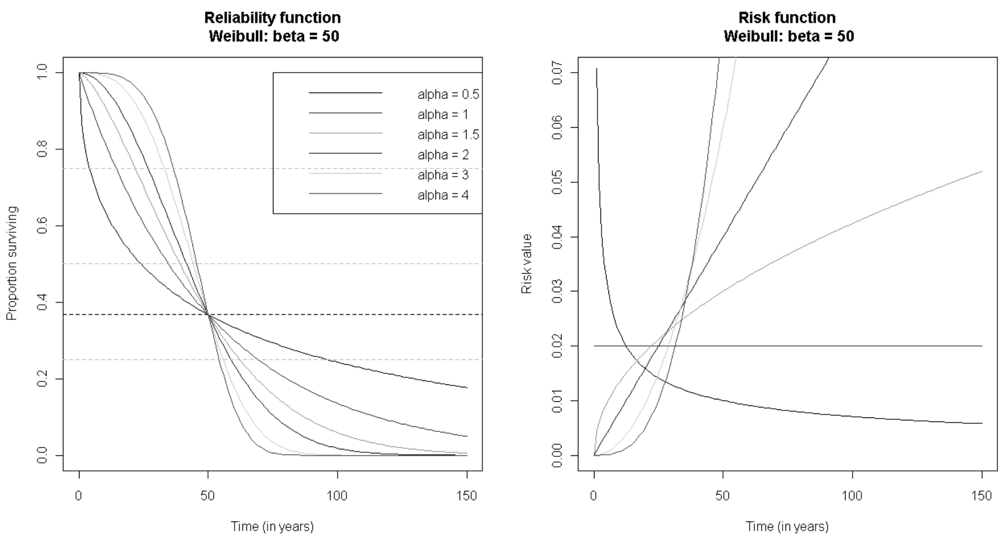

Fig. 1) Durability function and risk function for selected parameters of the Weibull distribution

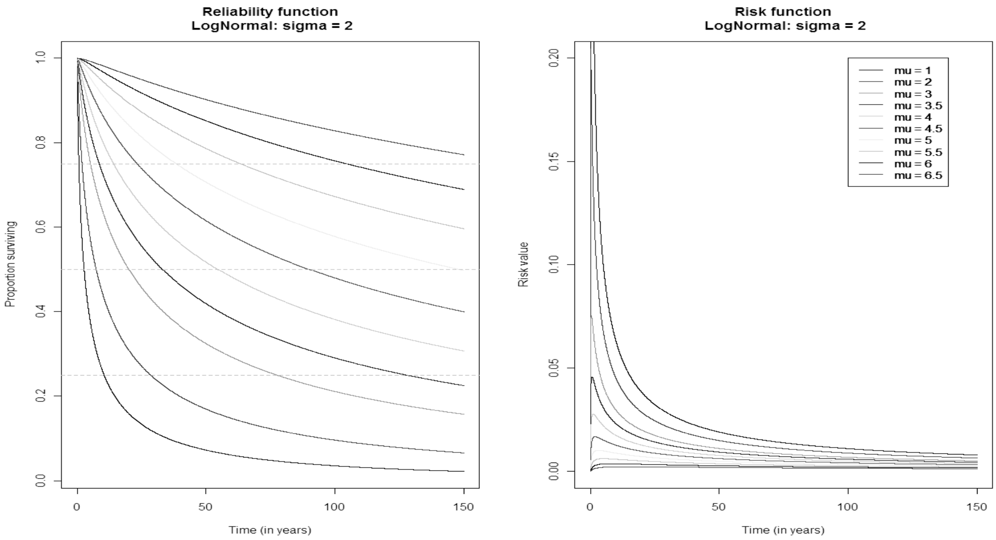

Fig. 2) Durability function and risk function for selected parameters of the Lognormal distribution

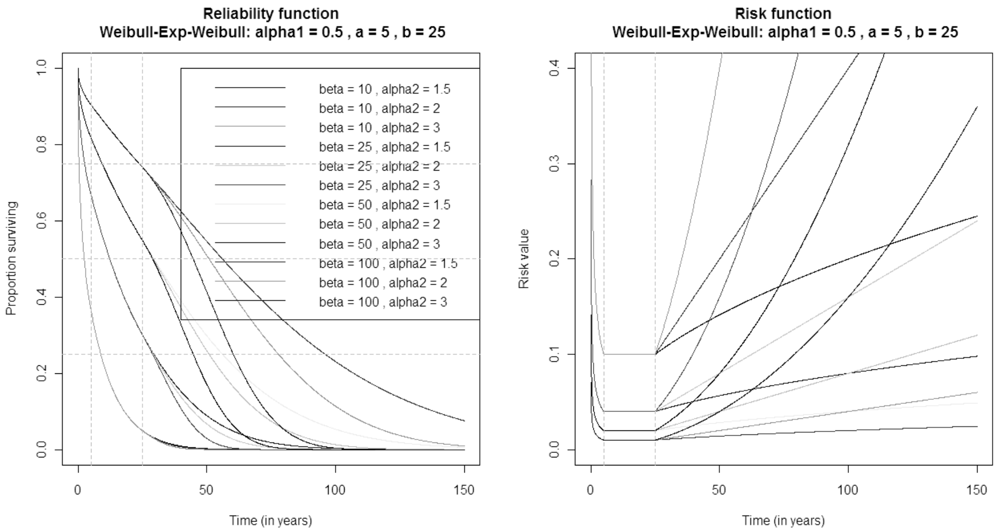

Fig. 3) Durability function and risk function for selected parameters of the Weibull-Exponential-Weibull distribution

2.4 Resulting scenarios

With the above-mentioned settings in the previous sections the number of scenarios to simulate is $78 \cdot 4 \cdot 15 = 4680$.

2.5 Number of replicas of simulation and goodness of fit measurement

For each of 4680 simulation scenarios 1000 replicas of simulation are run and evaluated. Evaluation of the goodness of fit of each of the replicas is measured in a timely manner in the 10th, 25th, 50th and 75th true percentiles (a priori known after choosing the true distribution) and, in a overall way, by the resulting percentage of left, right and interval censorship, by the supremum of the residuals in the observation window. More specifically, in each quantile we measure: bias, 95% confidence interval, coverage and half-amplitude. The summary statistics of the replicas of each scenario are:

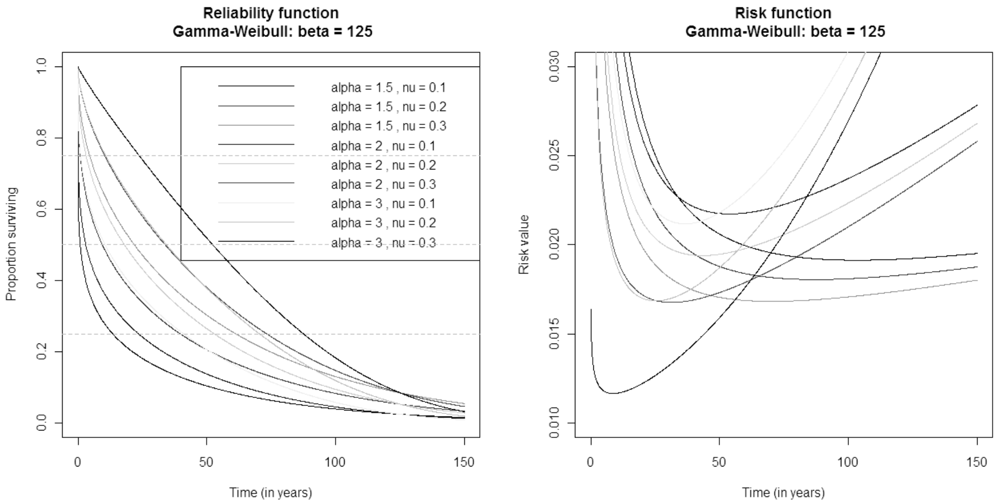

Fig. 4) Durability function and risk function for selected parameters of the Generalized Gamma (Gamma-Weibull) distribution

a) In each quantile: the mean bias, the mean square error (MSE=variance + bias^2), mean coverage and the mean half-amplitude.
b) Globally, mean of censorship, maximum of the suprema and the mean and the standard deviation of the distribution of the points where supreme is reached.

2.6 Simulation scheme

Figure 5 illustrates the flow diagram of the generation of the replicas, and the data and the results that we obtain.

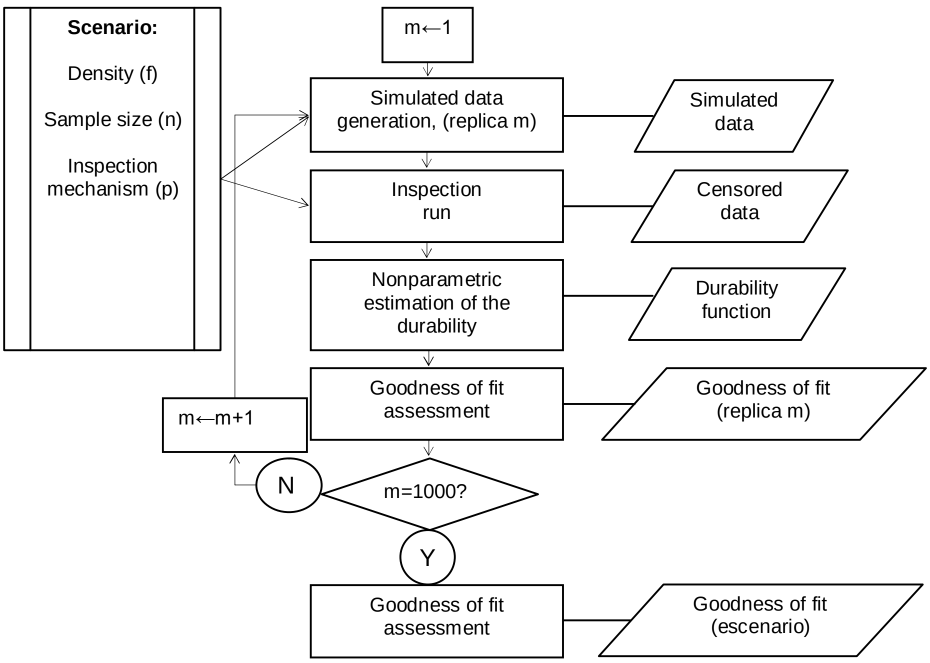

Fig. 5) Flow diagram of the simulation

2.7 Implementation and analysis of the results

All procedures for the simulation have been developed in S-PLUS ® Insightful ® (Braun and Murdoch, 2008 [1]).

The interpretation of the results is derived from the comparison of the summary statistics obtained at the end of each scenario. At each quantile, mean bias reduction, mean square error reduction, mean coverage close to (or higher than) the nominal value (95%) and half-amplitude reduction of the confidence interval will be recommended. Globally, maximum of the suprema (and its distribution) represents an upper bound for permissible errors and allows the investigator to globally assess the goodness of fit. On the other hand, efficient estimators can be chosen by evaluating the ratio of the respective MSE.

3 CONCLUSION AND FUTURE RESEARCH

One useful tool for the design of inspection programmes in heritage built has been proposed, in order to get efficient estimators for the durability function. The major advantage of this methodology is its independence from the type of injury or event of interest we are considering, although it clearly depends on the underlying distribution of the data.

In order to help the decision-making system, a potential extension of this methodology could incorporate the associated cost of the inspection strategy. This would allow to assess the price of the improvement in the quality of information obtained from successive inspections.

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