# THE USE OF SURVIVAL ANALYSIS TECHNIQUES IN BUILDING MAINTENANCE

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### Abstract

We want, on one hand, to introduce survival analysis techniques for being used in building maintenance and, on the other hand, to apply this methodology for analyzing a large building stock in order to obtain information for maintenance strategies and/or prevention policies.

For the time being, building follow-up is based on inspections. Data coming from building inspections are always censored, due to the fact that, at each inspection time, the event of interest is already happened, or not yet. After the analysis of this type of data, durability and hazard functions are derived. The possibilities of this proposal will be illustrated with the analysis of all the buildings façades in Hospitalet de Llobregat, the second most important city in population in Catalonia (Spain).



### Key words

Building durability, Building maintenance, Building management, Censored data, Survival analysis, Time to failure


## 1 INTRODUCTION

The management of the building maintenance is reaching a huge impact around the world, especially in recent decades, with the incorporation of tools to automate the tracking information and potential follow-up. From the social point of view it is illogical to leave without controlling the building stock. Moreover, if we take into account the high cost that the non-maintenance of buildings in appropriate good service conditions represents.

The study that we present has the main goal of establishing policies based on criteria of maintenance by creating director plans that allow to define in which way we have to act on the built heritage; no matter if the actions are at macro or micro urban level. This will allow to establish more consistent decisions in accordance with the findings of analytical reliable studies.

## 2 ANALYSIS METHODOLOGY

For the inspection process we have classified the buildings, the building elements that make up the façades and their materials, the injuries that may affect the façades, the gravity of the injuries and, finally, their magnitude. In this section we will introduce basic definitions in durability, the censorship mechanism issue and the non-parametric approach that we will use for the statistical analysis. Some basic references on reliability/survival analysis are the books by Meeker and Escobar (1998) [5], Klein and Moeschberger (1997) [4] and Gómez and Canela (1994) [3], among many others.

### 2.1 Fundamental concepts in survival analysis

*Definition 1: We will understand by failure the event of interest in which we are concerned about.*

Let T be the time from the beginning of the follow-up (time zero) until the failure (the event of interest) happens. T is a random variable and we are interested in its distribution, in order to compute probabilities under its density $f(t)$ or to obtain statistics like, for instance, the quantiles of the distribution. This will allow us to estimate the time until a proportion of damaged buildings in the

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population or, in the reverse sense, the proportion of damaged buildings at certain time for a particular injury.

*Definition 2: The durability function for the random variable T is the complement to one of the distribution function of T:*

$$R(t) = 1 - F(t) = 1 - P(T \le t) = P(T > t) \quad (1)$$

In other words, $R(t)$ is the probability of the failure would happen beyond *t*, *i.e.* the probability that the element would survive at the moment *t* (with respect to the failure that we would be considering).

*Definition 3: The mean time to failure (also known as MTTF or mean life of the element) is the expectation of the random variable T.*

$$MTTF = E(T). \quad (2)$$

### 2.2. About the censorship mechanism

If *T* is the true time of interest until the failure and $C_1$ denotes an inspection time, what happens at time $C_1$ is that, with probability one, $T < C_1$ or $T > C_1$. So, as a consequence, for each subject we do not observe the exact realization of *T*, but only a part of the information. Fig. 1 illustrates the different possibilities. In this work we only consider one inspection time, so we only deal with left censored or right censored observations.

Concerning to the censorship mechanism it is important to assume the non-informative hypothesis, in the sense that the censoring time *C* is independent on the random variable of interest *T*. In general, when *C* is defined by design the non-informative hypothesis can be assumed.

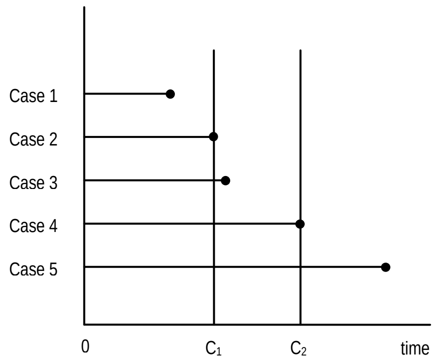


Fig. 1: Illustration of the censorship mechanism: a) At time $C_1$, case 1 is left censored, case 2 is exact observation and cases 3, 4 and 5 are right censored observations. b) With a second inspection time $C_2$, case 1 is left censored, cases 2 and 4 are exact observations, case 3 is interval censored and case 5 is right censored.

### 2.3 A non-parametric approach

Since there are no references on the distributions that failure times in the different injuries and elements follow, we will estimate the durability function in a non-parametric way. That is, our estimates will be only based on the data and we will not suppose any hypothetical (and non-testable) distributions family for the unknown density $f$ of *T*. Turnbull (1976), in [6], developed an estimator for interval censored data based on an iterative algorithm that maximizes the non-parametric likelihood function

$$L = \prod_{i \in O} \left( F(o_i) - F(o_i^-) \right) \prod_{i \in R} \left( 1 - F(r_i) \right) \prod_{i \in L} F(l_i) \prod_{i \in I} \left( F(r_i) - F(l_i) \right), \quad (3)$$

where *O*, *R*, *L* and *I* are, respectively, the subsets of exact, right-censored, left-censored and interval-censored observations.

### 2.4 Implementation of the analysis methodology

We have developed all the durability analysis methodology in S-PLUS®, by Insightful®. A library, containing routines and procedures for obtaining estimates for the failure probabilities, the durability functions and summary statistics tables, has been implemented.

# 3 ILLUSTRATION

L'Hospitalet has 266,973 inhabitants (Institute of Statistics of the city, 31th December 2008, [1,2]). It is the second city of Catalonia in population and is among the twenty most populated cities in Spain. The municipality covers an area of 12.5 square kilometres between the towns of Barcelona, Esplugues, Cornellà and El Prat. Successive inspection processes carried out around the entire city between 2001 and 2004 reported a total of 10150 inspections.

| Number at risk | % of censoring | | Estimated % of injuries Initial | | Final | | Years until a % of cumulative injuries | | | | Cumulative % of injuries across the years | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Left | Right | Years | % | Years | % | 10% | 25% | 50% | 75% | 10 | 25 | 50 | 100 |
| 2960 | 12.4 | 87.6 | 4.7 | 2.8 | 106.1 | 84.3 | 32.6 | 80.7 | 95.1 | 99.2 | 5.2 | 8.3 | 16.4 | 79.8 |
| 2960 | 5.3 | 94.7 | 9.5 | 1.6 | 106.1 | 74.7 | 75.7 | 89.5 | 98.4 | -- | 1.6 | 3.0 | 7.9 | 66.9 |
| 2960 | 0.1 | 99.9 | 37.8 | 0.2 | 106.1 | 22.8 | 89.7 | -- | -- | -- | 0.1 | 0.2 | 0.2 | 22.8 |

Table 1: Numerical results of the graphical analysis in Fig. 2

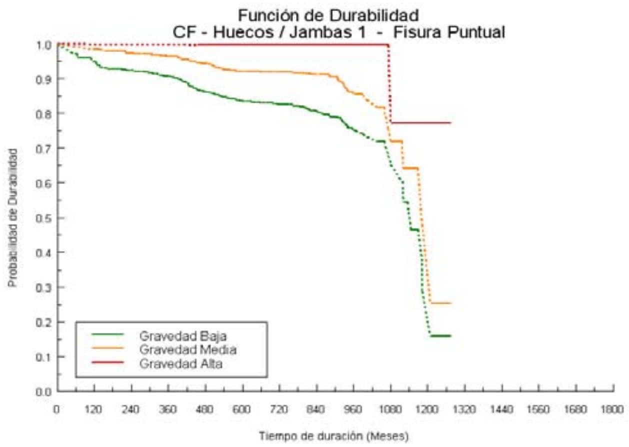


Fig. 2: Durability and hazard functions for punctual fissure on the jambs (by gravity level)

With the aim of illustrating the capacities of our proposal, in this section here we present a small sample of the graphical and numerical results from the analysis by gravity. From the durability function in Fig. 2 and Table 1 we can see, among other conclusions, that after 10 years, a 5.2% of the jambs will suffer a low grave punctual fissure (and a 1.6% or 0.1% a medium grave or high grave punctual fissure, respectively)

# 4 DISCUSSION AND FUTURE WORK

We have introduced our proposal to use survival techniques in building maintenance. As a probabilistic technique it allows to estimate the failure distributions for all injuries in which we may be interested. Moreover, we can test for those characteristics which play (or not) a significant role in the deteriorating process. We would like to remark two aspects in which we are working now. Firstly, the relevance of programming a more accurate inspection schedule. Secondly, the interest of adjusting the resulting distributions to the covariates of interest. It is obvious that both approaches will make the building maintenance strategy more efficient.

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