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USE OF PETRI NETS TO MODEL DETERIORATION ON CIVIL ENGINEERING INFRASTRUCTURES

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Background and Motivation

The aging of the infrastructures together with the scarce budgets available to maintenance and rehabilitation actions as well as the increase of awareness of the concept of sustainability are increasing the effort to develop decision support tools in order to maximize the investments done in the past.

Less focus to the design and construction of new infrastructures

vs.

More emphasis on the maintenance and rehabilitation of existing infrastructures

The experience gained over the years showed that the uncertainly associated with the deterioration process has to be explicitly included in the models, since the complexity of the phenomena involved and the little information available make it impossible to model the deterioration with high precision.

Markov Chains (MC) are the most commonly used stochastic technique to predict deterioration in different fields of civil engineering. However, the simplicity of the exponential distribution can result in a gross approximation of the system characteristics. To overcome this limitation, models based on Petri Nets (PN) can be useful.

Petri Nets

A PN is a mathematical and graphical tool, suitable for the description of relationships between the parts of a system or of flow activities in complex systems.

It is composed by three fundamental types of components:

- ***Places (circles)*** represent possible states of the system;
- ***Transitions (rectangles)*** are events or actions which cause the change of state;
- ***Arc (arrows)*** connects a place with a transition or vice-versa;

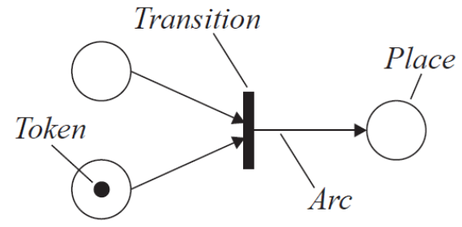


Figure 1: Example of a Petri net

Each place has the ability to store a varying number of **small dots (tokens)**. The distribution of the tokens on the places represent the present state of the system.

Transition together with the tokens are the responsible by the evolving of the system, from one state to another. Transitions govern the movements of the tokens between places.

Petri net deterioration model

The deterioration process can be modelled with PN through a linear sequence of places and stochastic timed transitions (Figure 2). Each place represents a condition state of the classification system adapted and each transition defines the movement between condition states. The sojourn time in each condition state is randomly computed from a probability distribution.

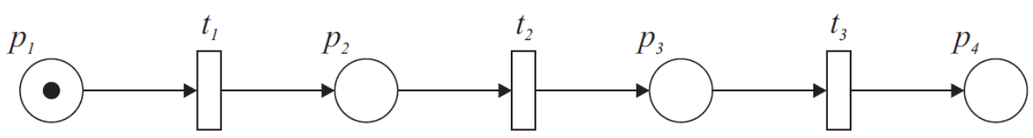
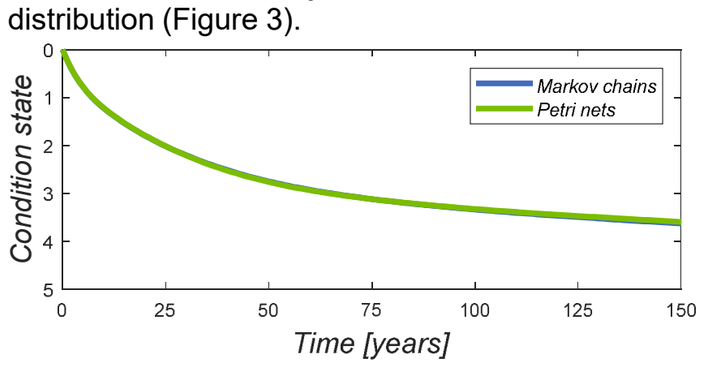


Figure 2: Petri net scheme of the deterioration model

Validation PN deterioration model

Since MC are widely used to evaluate the deterioration process over time and taking into account the isomorphism between MC and stochastic PN, in a first phase it is assumed that the sojourn time in PN deterioration model follows an exponential distribution (Figure 3).



Model	Likelihood
Markov chains	394.38
Petri nets	392.36

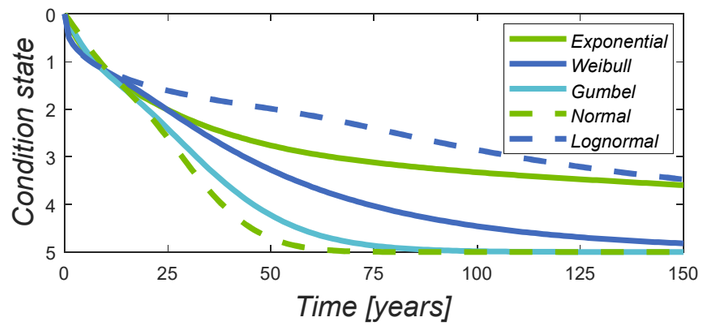
Table 1: Likelihood values for both models

Figure 3: Mean condition profile over time for both models

- The two curves are practically overlapping. However, the Petri nets show a better agreement with the historic data than Markov chains (smallest likelihood value);
- Historical data from pre-stressed concrete deck located in Portugal was used to validate the PN deterioration model.

Probabilistic analysis

In PN deterioration model, in addition to the Exponential distribution, four distributions were studied: Weibull, Gumbel, Normal, and Lognormal (Figure 4).



Distribution	Likelihood
Exponential	392.36
Weibull	361.58
Gumbel	407.18
Normal	425.34
Lognormal	363.17

Table 2: Likelihood values for all distributions

Figure 4: Mean condition profile over time for all distributions

- Exponential and Lognormal do not describe adequately the transition between more advanced deterioration states due to the low number of elements in the database;
- Gumbel and Normal present the worst results in terms of likelihood and relative errors;
- Weibull shows a smallest likelihood value and a better fit to the historical data.

Petri net maintenance model

The maintenance model has, as a starting point, the Petri net deterioration model, and in addition, the inspection and maintenance processes are also included (Figure 5).

Inspection process

The introduction of the inspection process aims to simulate in a more adequate way the procedures that exists in reality. I.e., the condition of a system is not continuously know, it must be detected. Its true condition is only revealed after a major inspection. The exposure of the true condition will enable the most appropriate maintenance work to be request for existing anomalies with the appropriate priority.

The part of Petri net that is responsible for the inspection process is formed by the places $p_5 - p_{10}$ and the transitions $t_4 - t_9$.

Maintenance process

The maintenance process includes all information related with the maintenance strategies, such as: the type of maintenance that should be made in each condition state defined in the performance scale and its impact on the structure. In each condition state there are, always, three options: do nothing, preventive, or corrective maintenance.

The part of Petri net that is responsible for the maintenance process is formed by the places $p_{11} - p_{22}$ and the transitions $t_{10} - t_{25}$.

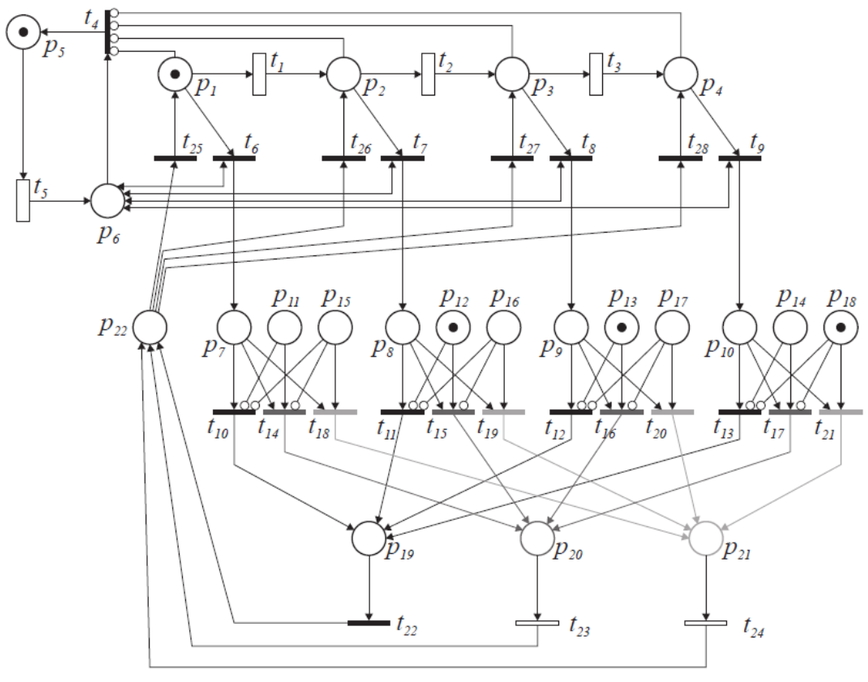


Figure 5: Petri net scheme of the maintenance model

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