TU1406
COST ACTION

eBook of the 2nd Workshop Meeting

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Opening Note from the Chair

Prof. Jose Matos

COST Action TU1406 aims to address the European economic and societal needs by standardizing the condition assessment and maintenance level of roadway bridges. Currently, bridge quality control plans vary from country to country and, in some cases, within the same country. This therefore urges the establishment of a European guideline to surpass the lack of a standard methodology to assess bridge condition and to define quality control plans for roadway bridges.

Such a guideline will comprise specific recommendations for assessing performance indicators as well as for the definition of performance goals, bringing together different stakeholders (e.g. universities, institutes, operators, consultants and owners) from various scientific disciplines (e.g. on-site testing, visual inspection, structural engineering, sustainability, etc.) in order to establish a common trans-national language.

COST Action TU1406 Workshops aim to facilitate the exchange of ideas and experiences between active researchers and practitioners as well as to stimulate discussions on new and emerging issues in line with the conference topics. This second Workshop addresses the WG1, performance indicators, WG2, performance goals, and WG3, establishment of a Quality Control plan, developments. The main outcome, given in this eBook, is really important, not only for those directly involved in this Action, but also for the whole bridge engineering community.

COST TU1406 Action Presentation

Jose C. Matos
Chair COST Action TU1406

Note from the Vice Chair

Prof. Joan R. Casas

The working group meetings and 2nd Workshop of COST Action TU1406 in Belgrade has seen the continuation of the work developed within WG1 and the first working sessions for WG2 and WG3. The state-of-the-art and the different approaches along Europe on the performance indicators used by the different owners and operators to meet the quality expectations of the users is close to its completion. A huge amount of information has been collected and the posterior processing will become a relevant input for the rest of the WG´s. Also the collecting of research performance indicators was presented. This will serve as the basis for the proposal of new indicators that will allow a more optimized definition of future quality control plans for highway bridges.

An important number of papers were also presented during the Workshop related to all WG´s. The key-note presentations explaining the experience from previous COST actions, on sustainability indicators and pavement performance indicators, will be very helpful for the Action in seeking the best methodology and approaches to gather the most relevant and representative data from the large data base that is in our hands by now.

Lively discussions after the presentations and in the WG´s meetings has made possible to get and agreement and deliver a clear route map among the different WG conforming the Action on how and what to focus in the coming years, looking at their specific goals and close interactions and avoiding overlapping of activities. In summary, looking to the success of this second workshop, and the future activities planned, we may be confident on the achievement of the required standardization of the quality specifications for highway bridges in Europe.

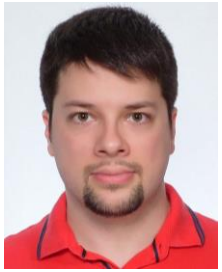
Joan R. Casas
Vice-Chair COST Action TU1406

Note from the Local Organizers

Prof. Rade Hajdin

As the Work Group 3 Leader and a member of the Local Organizing committee, it has been a pleasure to host the 2nd Workshop of the COST TU1406 Action in Belgrade, Serbia. The principal aim of the COST Action is to facilitate the identification of maintenance needs within the roadway bridge management process. The main output of the action are adequate quality control plans for bridges which comprise performance indicators. The value of this Action therefore lies beyond its obvious academic merit, delivering a framework which is at this point in time urgently needed in bridge management by practitioners worldwide. Apart from the main goal of the meeting which is presenting of the results of WG1 - the survey on performance indicators, the kickoff meetings of WG2 and WG3 here take place.

Prof. Snežana Mašović



Prof. Nikola Tanasić

The COST Action TU1406 comprises members from nearly all European Countries, as well as countries outside Europe. Wide participation is an important feature of these actions, whose scope is to form a European research area across borders and interlink high-quality research and practice communities in Europe and worldwide. The location of the last conference at the end of the first year of the action is well chosen. The Serbian capital - Belgrade (Beograd) is situated in South-Eastern Europe, on the Balkan Peninsula, at the confluence of the Sava and Danube rivers. It has been always on the crossroads of many cultures and nations. Today, it is the capital of Serbian education, science, economy and culture. Here located are the most significant works of architecture, monuments, cultural treasures and numerous archaeological sites from prehistory to today.

With these words: It is a pleasure to welcome the WG Meetings and the second Workshop of the COST TU1406 Action in Belgrade !

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WG MEETINGS & WORKSHOP

An overview of Key Performance Indicators across Europe and Overseas
The main findings from WG1 and other contributions from WG2 and WG3

FORECASTING OF PERFORMANCE INDICATORS

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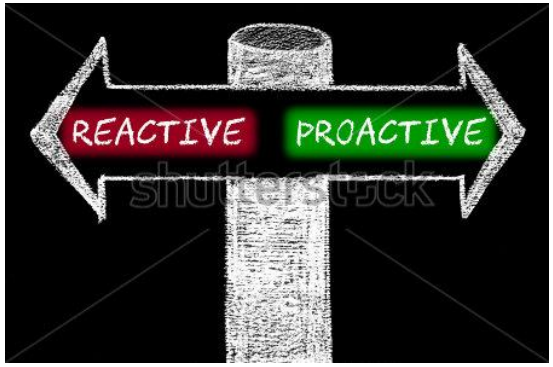
link to paper

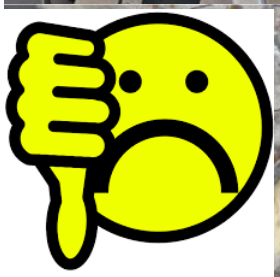
INTRODUCTION

- To assure that bridge structure meets all performance requirements (performance goals) many different performance indicators are introduced.
- A performance indicator is a parameter that quantitatively describes a specific performance aspect.
- Thus, such indicators are measurable, testable and computable, i.e. they can be derived from the conditions of the structure and the environment.
- This performance indicators might be represented in a qualitative discrete scale.
- Condition rating – condition state
  takes an integer value

BRIDGE MANAGEMENT



WHAT?



Redirection of the budget towards great investments in infrastructure reduces funds for maintenance.

WHEN?


IT SEEMS LIKE YOU JUST CAN'T TRUST ANYTHING ANYMORE


DO IT NOW
DO IT LATER


VOTING
GOP
Bennett Chattanooga Times Free Press


RISK
SAFETY


BRÜCKENARBEITEN!

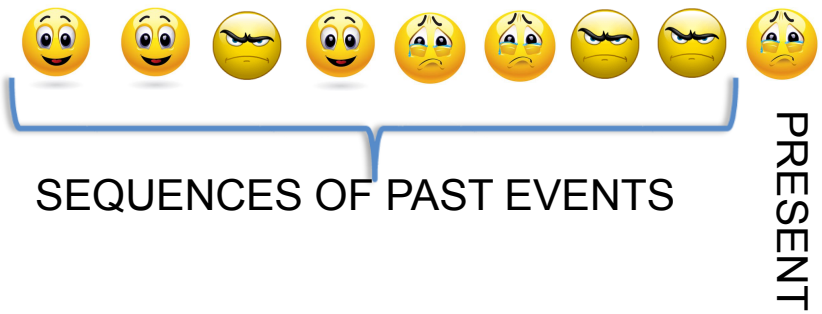
PREDICT THE FUTURE !?

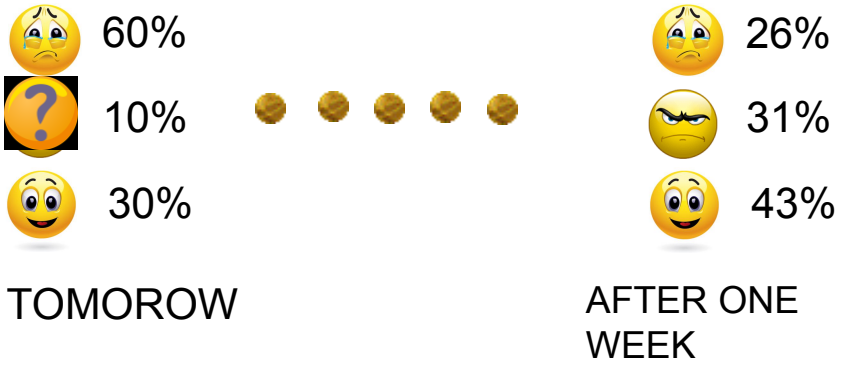
To predict future performance it is essential to explore how something has “behaved” in a similar set of circumstances.

There might be something in the past that will predict the future – but the right questions are to be asked.

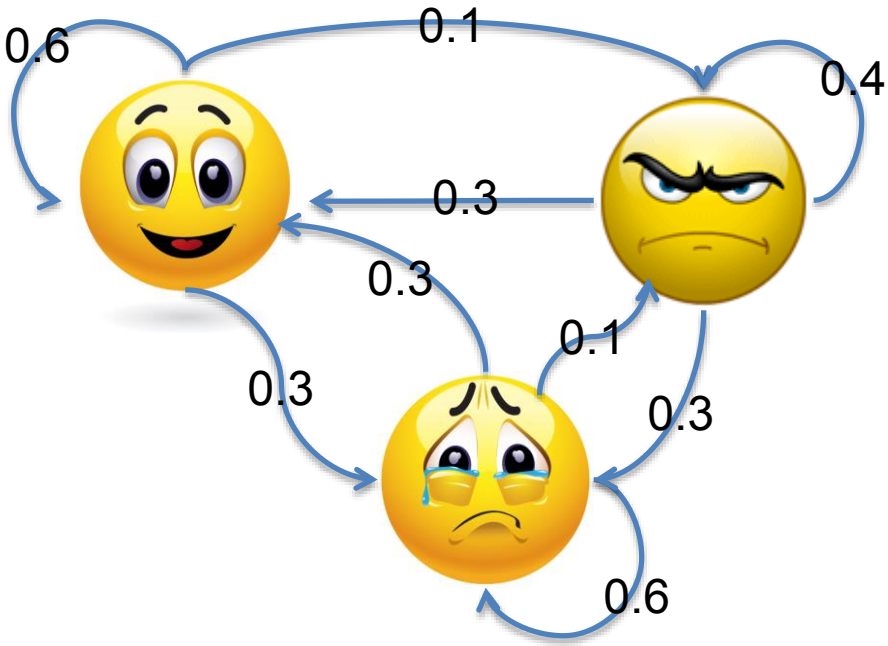
LOOK INTO THE PAST

FORECASTING WITH MARKOV CHAIN

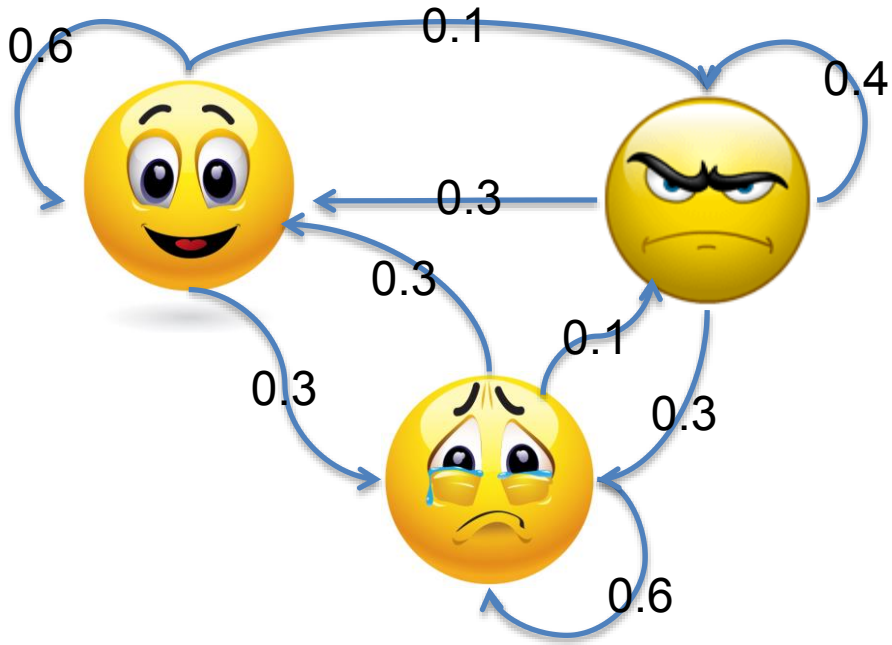


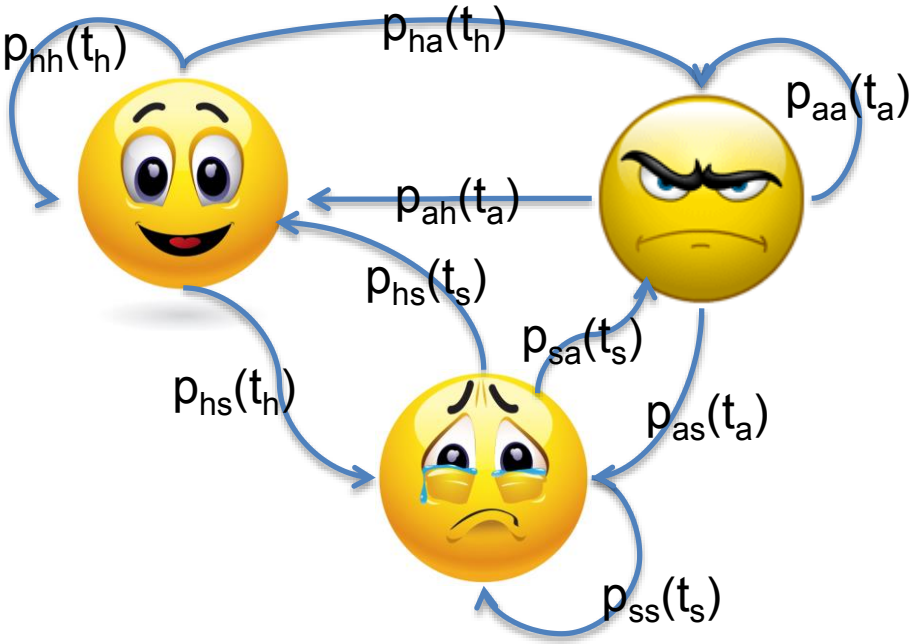


CONCEPT OF STATES AND STATE TRANZITIONS



MARKOV AND SEMI MARKOV MODEL



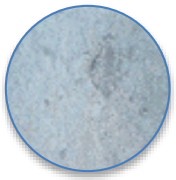


MARKOV MODEL FOR AGEING STRUCURE

- Aging is the one way process

Absorbing state

- Deterioration of the structures is somewhat similar



NO VISUAL SIGN

VISABLE STAINS

DELAMINATION & SOME SPALLING

SERVE SPALLING STEEL EXPOSED

REBAR SECTION LOSS

SURVIVAL IN THE STATE

- Complementary cumulative distribution function of random variable T_i i.e. $(p(T_i>t)=S_i(t)$) is called the survival function of T_i (survival in state i).
- Memoryless property (Markovian property) in discrete case (unit time step) gives:

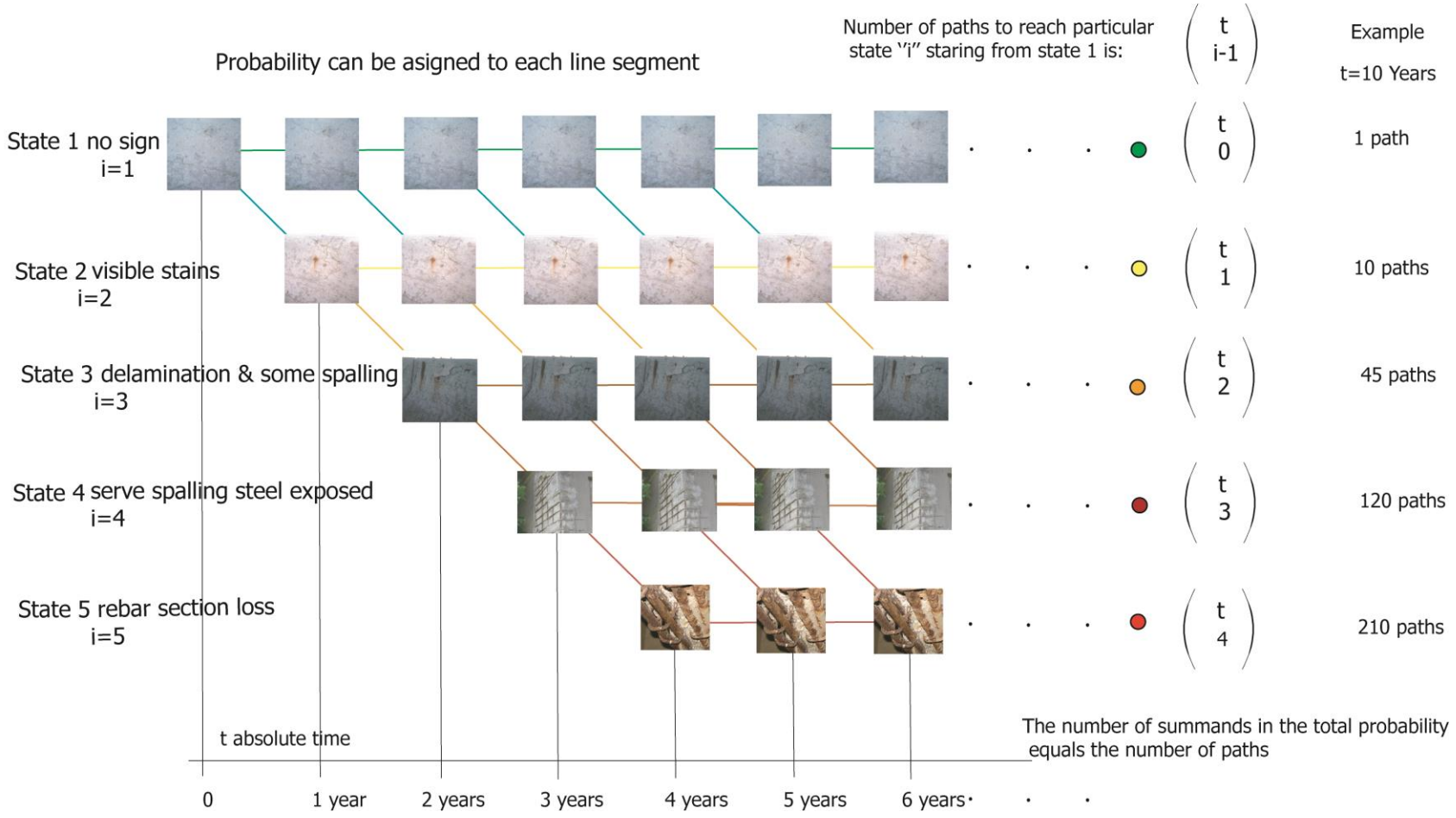
$$S_i(k) = 1 - F_i(k) = p_{ii}^{\,k}$$

- If sojourn time in state *i* follows Weibull distribution than survival function in state *i* us given by:

$$S_i(k) = e^{-(k/\mu_i)^{\beta_i}}$$

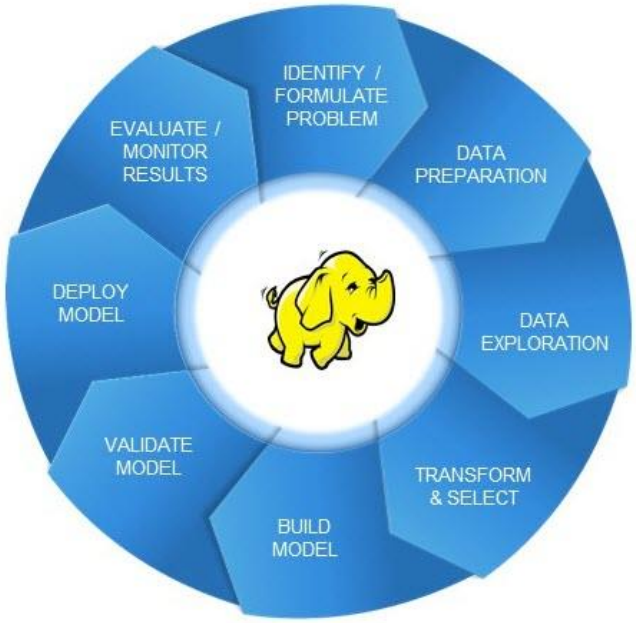
- The longer an element has been at a particular condition, it seems that is more likely it will transit to a lower condition in the next instant, i.e. $\beta_i > 1$

EVENT TREE


Probability can be asigned to each line segment
Number of paths to reach particular state "i" staring from state 1 is:
$\binom{t}{i-1}$
Example
t=10 Years
State 1 no sign
i=1
$\binom{t}{0}$
1 path
State 2 visible stains
i=2
$\binom{t}{1}$
10 paths
State 3 delamination & some spalling
i=3
$\binom{t}{2}$
45 paths
State 4 serve spalling steel exposed
i=4
$\binom{t}{3}$
120 paths
State 5 rebar section loss
i=5
$\binom{t}{4}$
210 paths
t absolute time
0
1 year
2 years
3 years
4 years
5 years
6 years
The number of summands in the total probability equals the number of paths

DATA

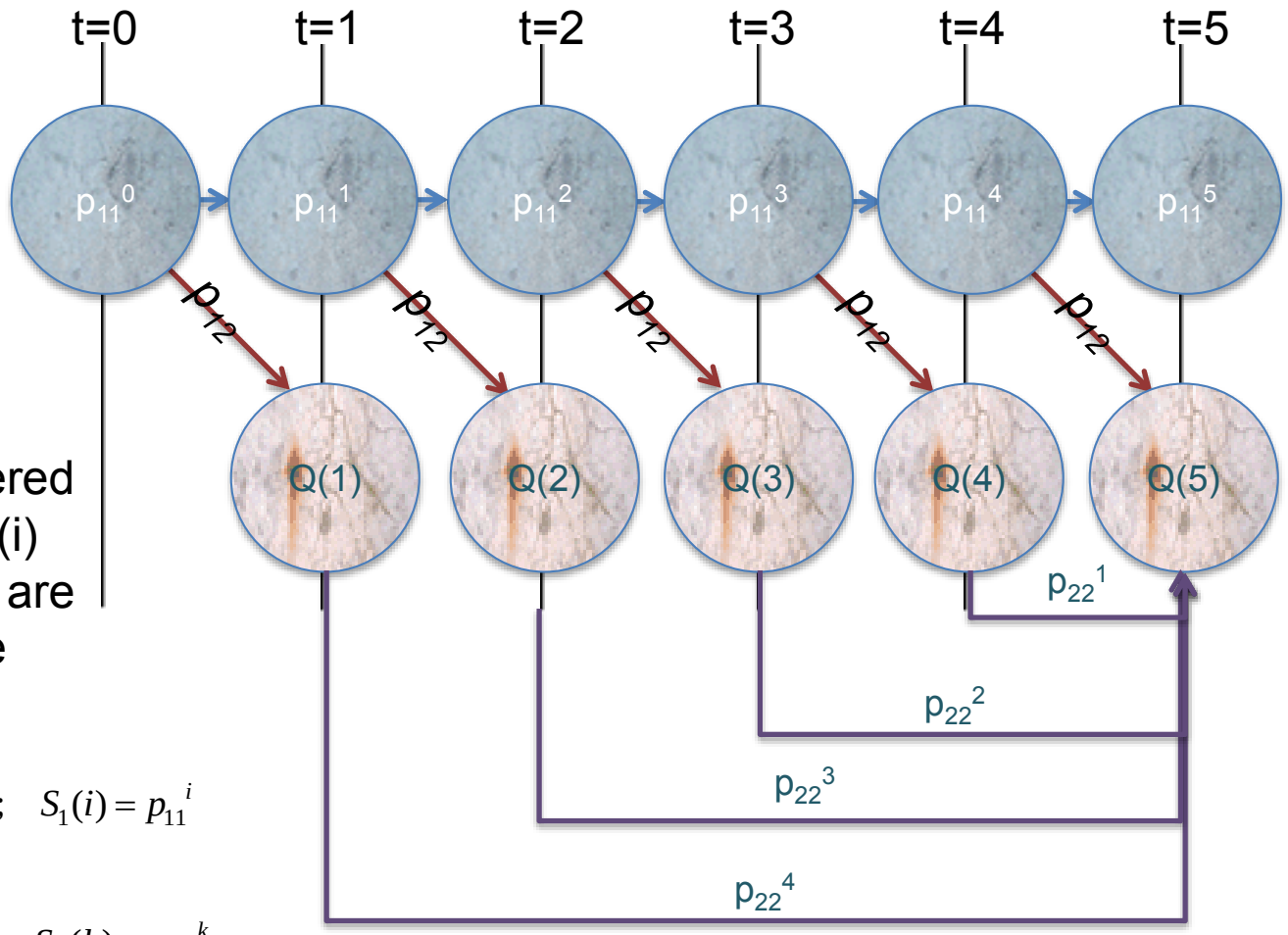
- Model is data driven
- Databases
- Quantity and quality of the data
- Visual inspection
- Visual inspection - Subjective data
- Data filtering – (possibility of manipulation)!
- Use the historical data to estimate transition probabilities ($p_{i,i+1}$), employing statistics.
- Does the model fit to the data?
- Is the process stationary ?
- Does $p_{i,i+1}$ depends on the sojourn time?
- Abundance of data for transition from the best (state 1) to the second best (state 2) indicates that **it does**.
- How to model sojourn time?
- Random variable τ_i sojourn time in state *i*.
- Practical problem – determination of sojourn time distribution.



MARKOV PROPERTY (MEMORYLESS)

Quantities that ''survived''

Quantities that entered subsequent state q(i)
Quantities that that are in subsequent state Q(i)

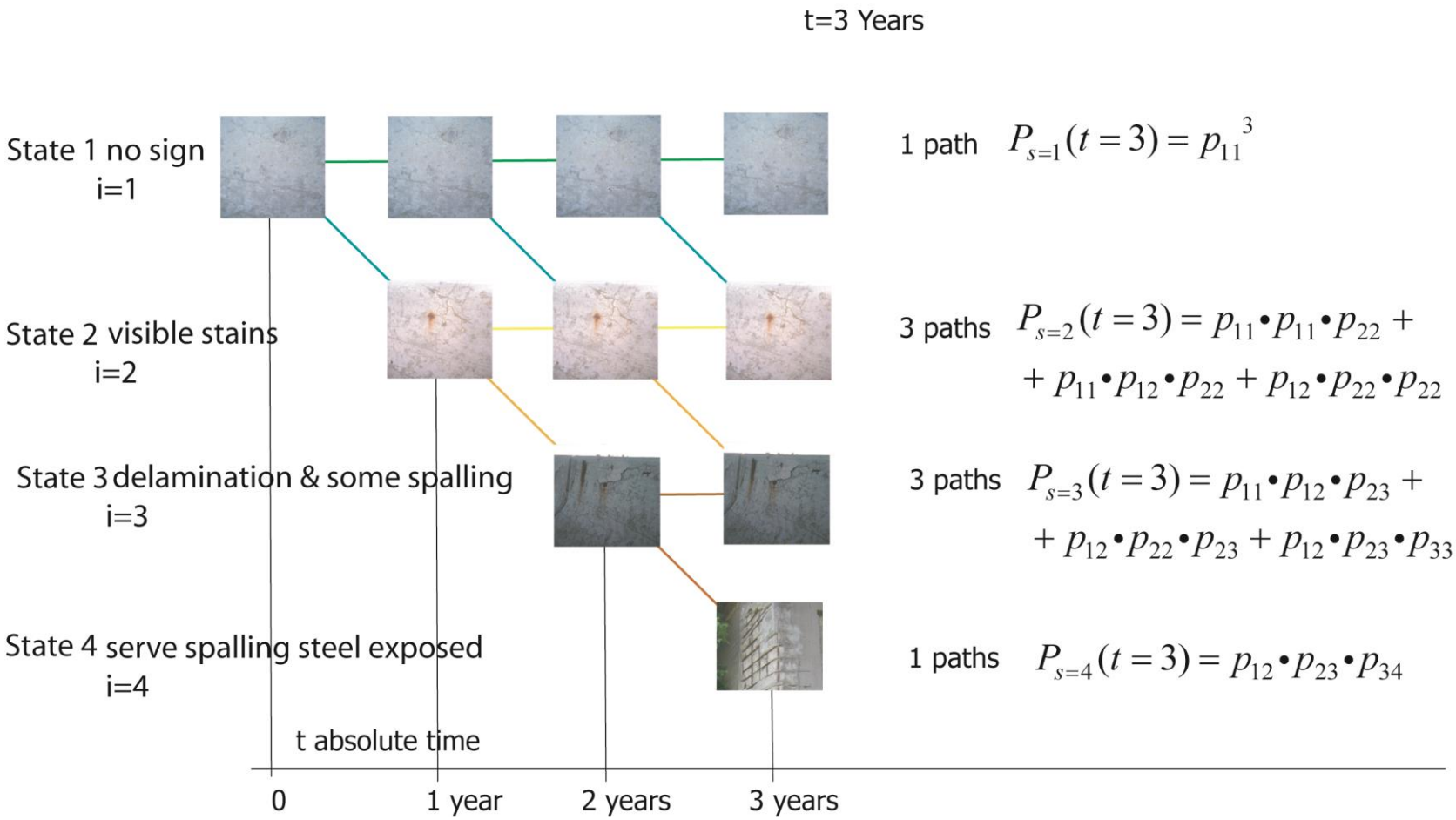


$$p_{11}(i) = p_{11};\ \ i = 1,2,3...n;\quad S_1(i) = {p_{11}}^i$$

$$p_{1,2}(i) = 1 - p_{11} = q_2$$

$$Q_2(i) = \sum_{j=1}^{i} (1 - p_{11}) {p_{22}}^{i-j};\ \ S_2(k) = {p_{22}}^k$$

EVENT TREE - CORROSON



1 path $P_{s=1}(t=3) = p_{11}^{\ 3}$

3 paths $P_{s=2}(t=3) = p_{11} \bullet p_{11} \bullet p_{22} + p_{11} \bullet p_{12} \bullet p_{22} + p_{12} \bullet p_{22} \bullet p_{22}$

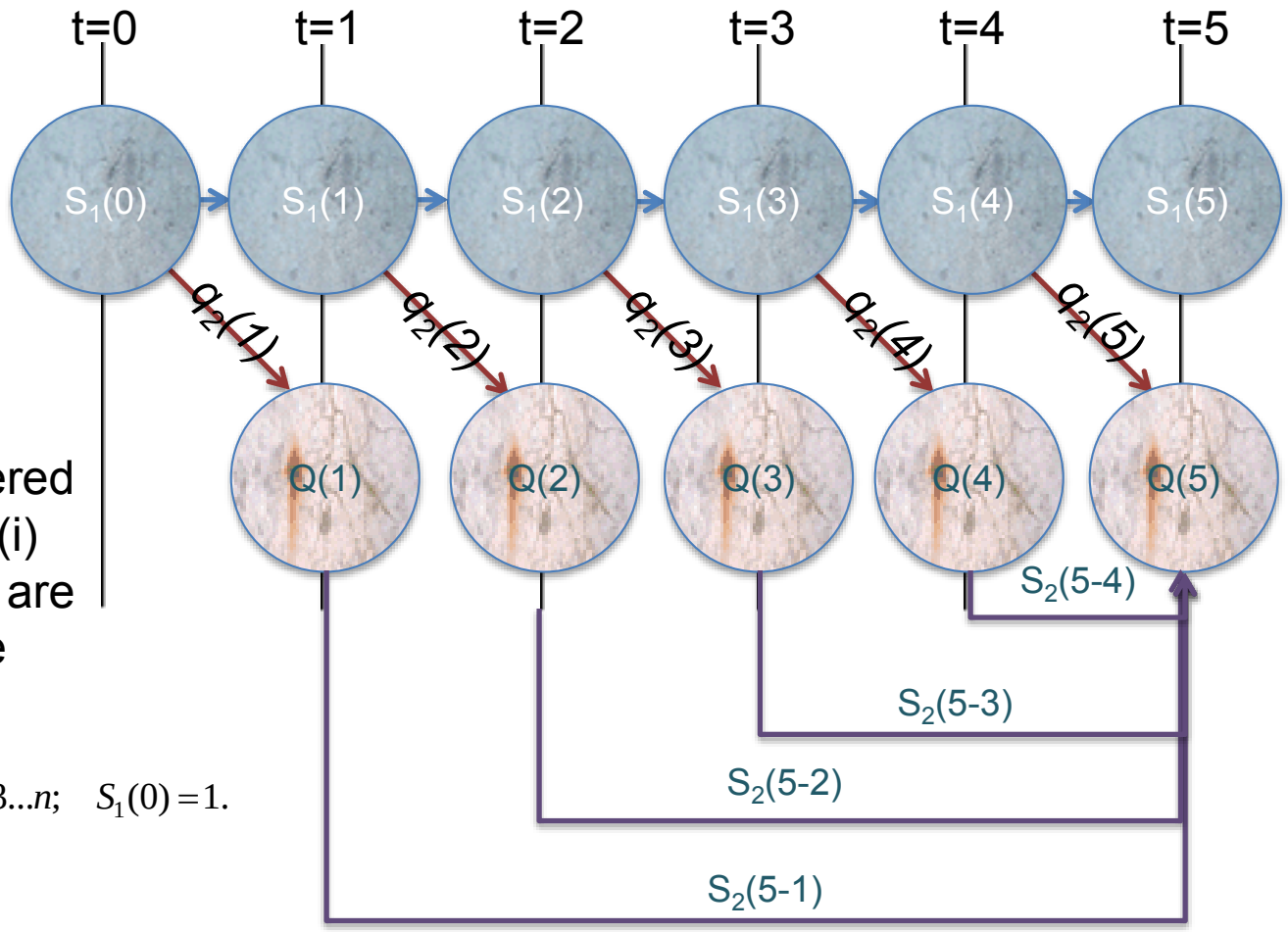
3 paths $P_{s=3}(t=3) = p_{11} \bullet p_{12} \bullet p_{23} + p_{12} \bullet p_{22} \bullet p_{23} + p_{12} \bullet p_{23} \bullet p_{33}$

1 paths $P_{s=4}(t=3) = p_{12} \bullet p_{23} \bullet p_{34}$

MODEL OF THE SEMI MARKOV PROCESS

Quantities that ''survived''

Quantities that entered subsequent state q(i)
Quantities that that are in subsequent state Q(i)



$$p_{11}(i) = \frac{S_1(i)}{S_1(i-1)}; \quad i = 1,2,3...n; \quad S_1(0) = 1.$$

$$p_{1,2}(i) = 1 - p_{11}(i) = q_2(i)$$

$$Q_2(i) = \sum_{j=1}^{i} q_2(j) \square S_2(i-j); \qquad S_2(0) = 1.$$

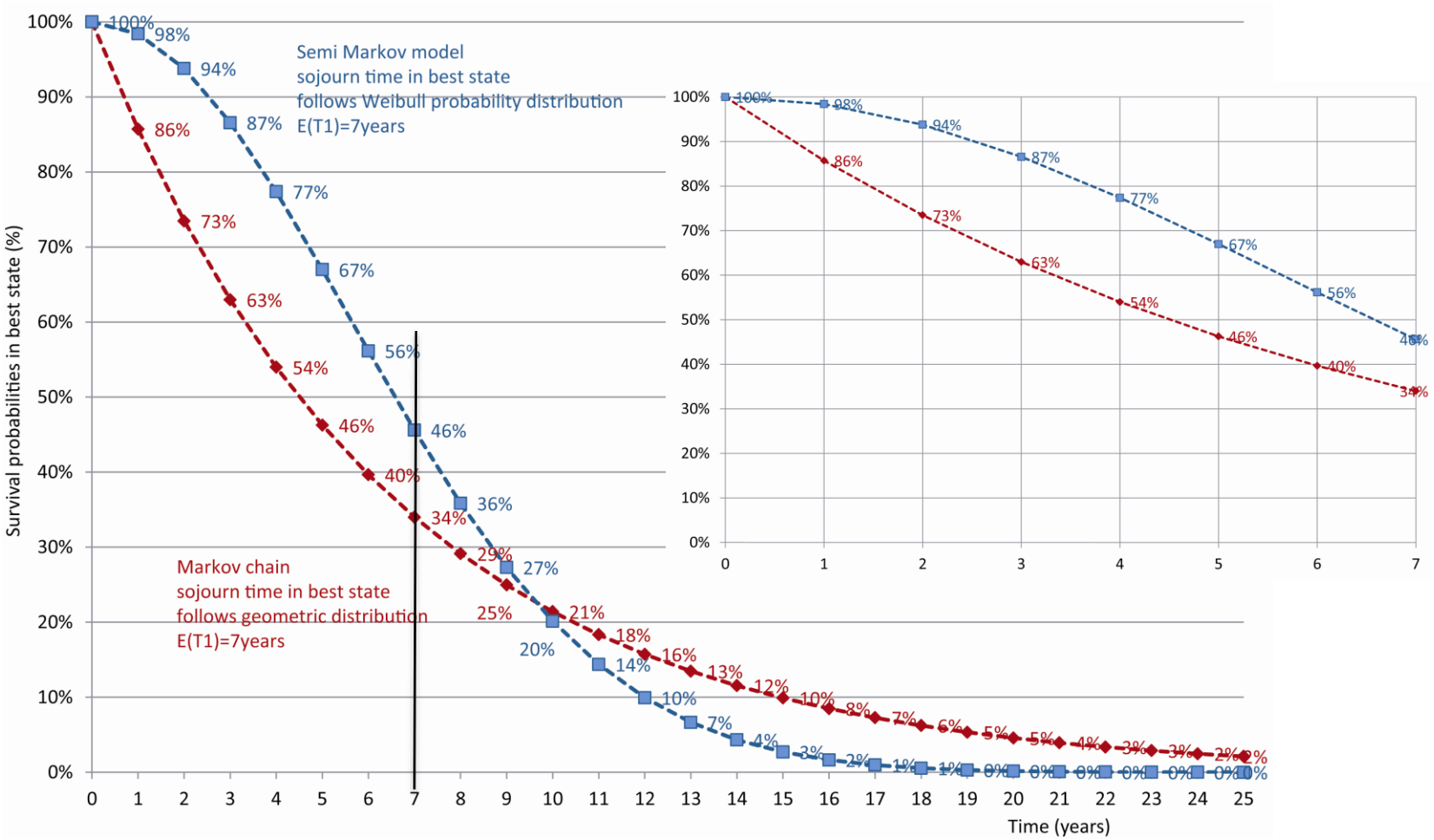
Expected time to transition between the corrosion states

Panel of experts

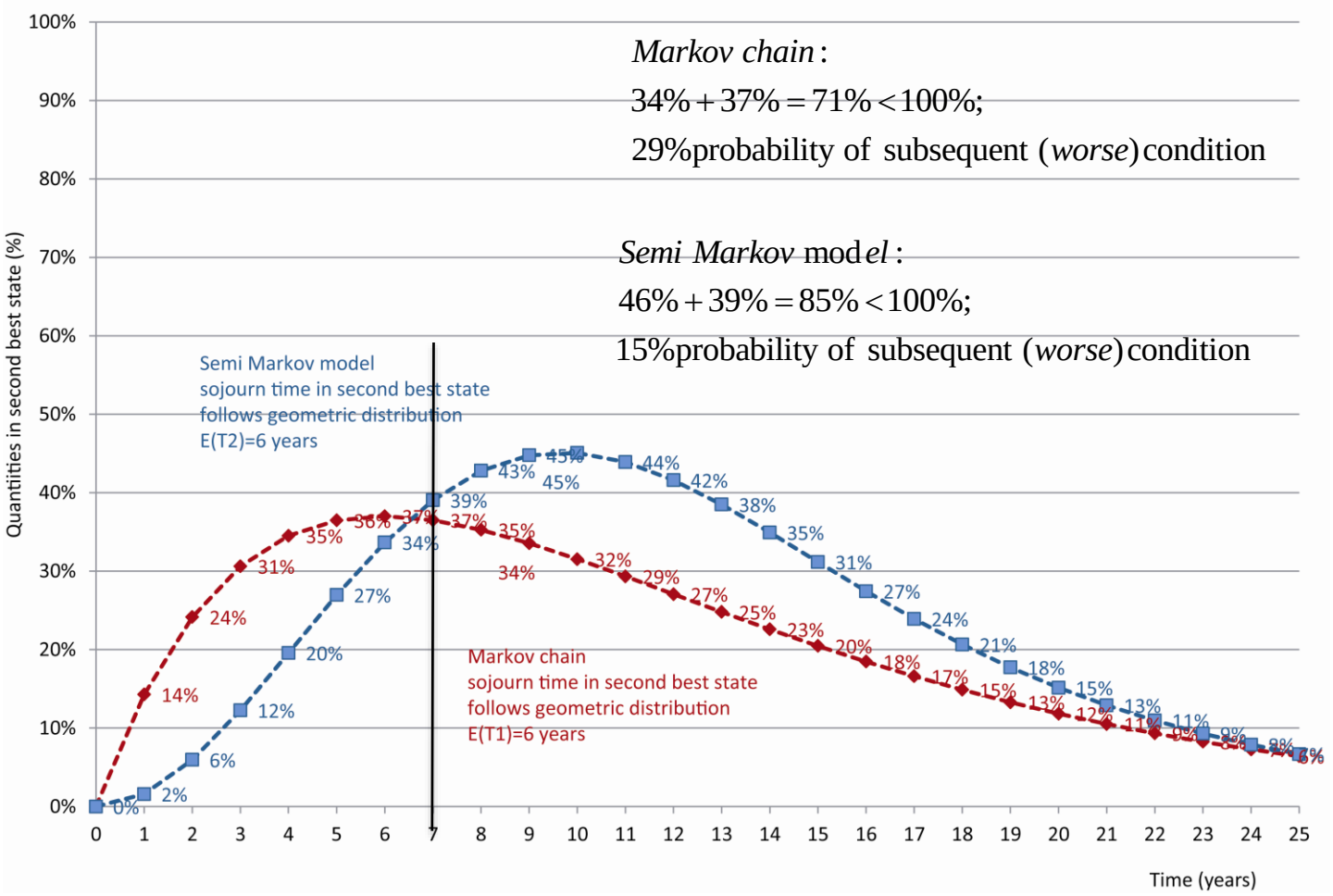
$E_t(S_i)$	S_i
7 years	
6 years	
5 years	
2.5 years	

Expected time to reach failure state 20.5 years.

COMPARISONS – NUMERICAL EXAMPLE

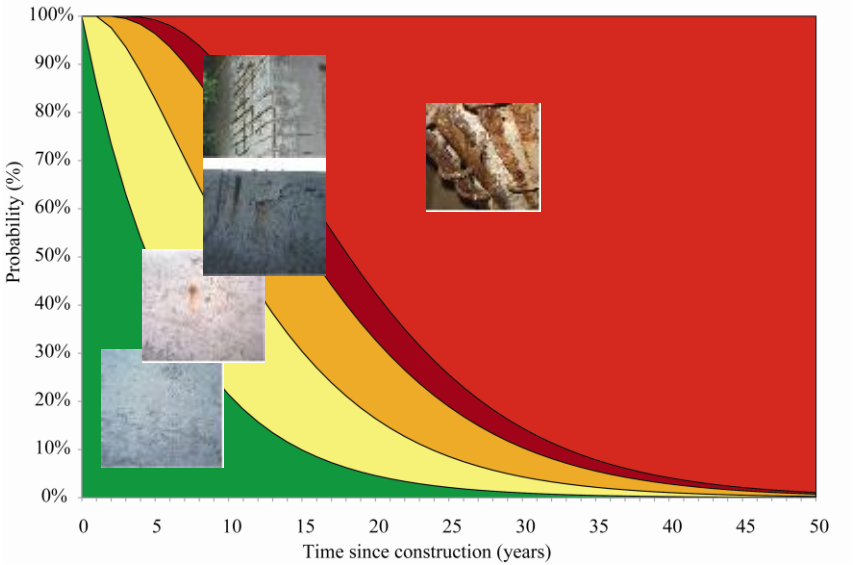


QUANTITIES IN SECOND BEST STATE

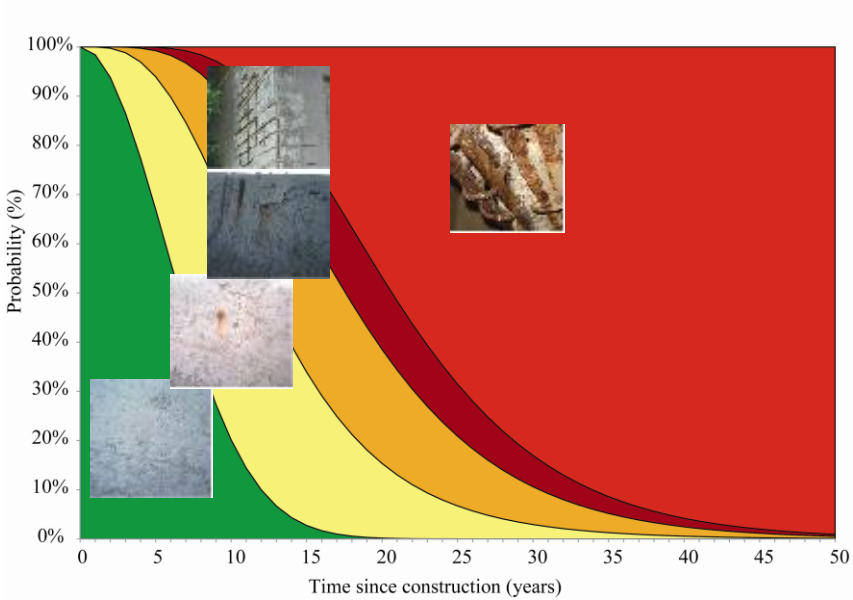


FRACTIONAL DISTRIBUTION OF CONDITION

Markov chain

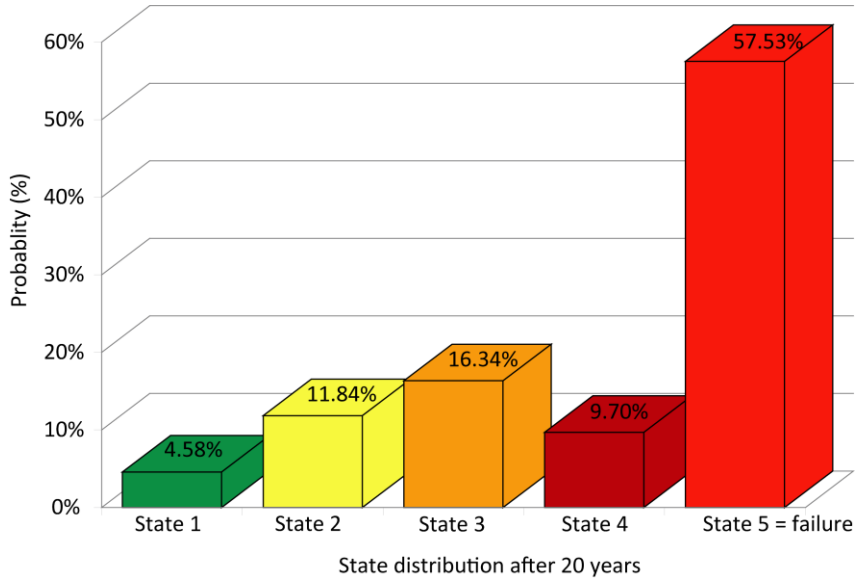


Semi Markov model

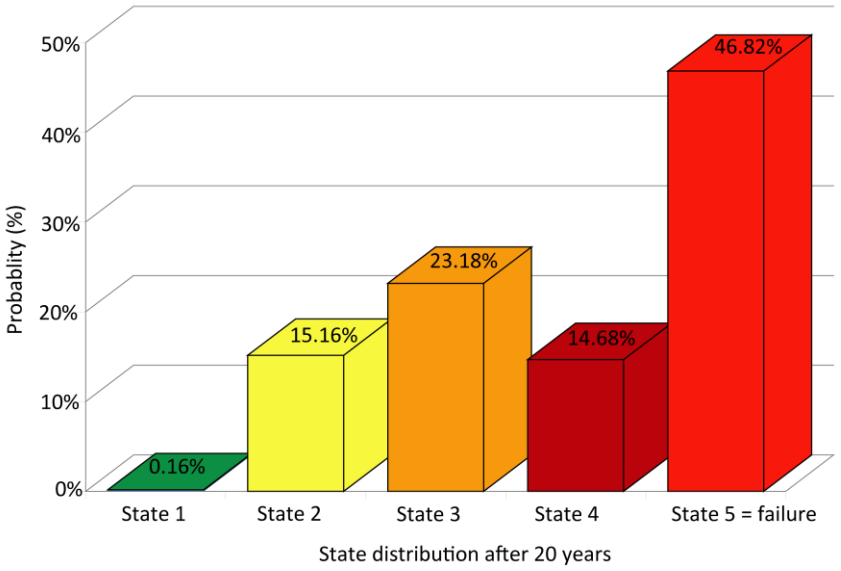


CONDITION DISTRIBUTION AFTER 20 YEARS

Markov chain



Semi Markov model



CONCLUSIONS

- Stochastic model is proposed for forecasting performance indicators.
- Two types of Markov processes can be employed:
  - Markov chain model;
  - Semi Markov model.
- Transition probabilities estimations:
  - Experts judgements,
  - Historical data,
  - Simulations of mechanical process of deterioration using developed analytical models.
- Semi Markov model seem more appropriate from a physical point of view, but:
  - hampered estimation of sojourn time distribution;
  - absence of the memoryless property poses severe mathematical complexity for short-time horizon optimization.