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# Application of Markov chains in the ergonomic design of an industrial ventilation system

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**Abstract.** This paper presents studies and simulations realized on an existing industrial ventilation system and a new one, in the design stage, in order to ensure correct working conditions, in terms of air quality. The study was made by a multidisciplinary team from the Faculty of Mechanics and Technology of the University of Pitesti. The participants at this experiment applied the Markov chains to determine the probability of degradation over time of the existing ventilation system and the new one to be designed. Thus, a system capable of ensuring the appropriate working conditions for an a priori determined period of time can be designed.
**Keywords:** ergonomic design, multidisciplinary team, working conditions

## Introduction

In an increasingly crowded and polluted world, the need for ventilation systems is no longer questioned by companies and entrepreneurs.
Ventilation means health, and air circulation achieved by ventilation systems designed by specialists to provide the performance required for each type of space cannot be replaced by opening the window [3, 4, 5].
An optimal ventilation system can improve your health and quality of life by improving the quality of the air you breathe both at home and in your work environment.
As we all know, ventilation systems are a necessity for both personal and industrial use, and their role is to ventilate, to move air, to replace toxic, harmful and hot air with clean air at the desired temperature. In large warehouses, where standards are required, the equipment is installed in a special room or on the roof of the building. This depends on the allocation of storage space to certain fire hazard categories.
For proper ventilation we need a system made of ventilation ducts to ensure the evacuation of toxic or polluted air and the entry of clean air [6].
The industrial ventilation system performs the following tasks:

- Maintains the optimum level of humidity and temperature,
- Provides fresh air to the warehouse staff.
- Removes harmful substances that allocate (or may allocate) stored goods,
- Eliminates foreign odours. This is important for the comfort and safety of staff and for the safety of products: some products may be "infused" with odours from other products.

Depending on the purpose, the types of industrial ventilation are classified as follows:

- Hygienic ventilation - by using in spaces with harmful air which, through mechanical ventilation is removed and replaced with clean air. This hygienic role of ventilation installations extends to any type of ventilation in any room, because over time bacteria and microbes accumulate that must be released through the ventilation ducts.

- Ventilation with a comfort role - offers comfort to the users of the space where they are implemented, by removing through the ventilation installation the odours, dust or agents that make the air difficult to breathe.
- Technological ventilation - is specific to industrial installations or equipment that need their own ventilation system for their own operation, for example pneumatic transport.
- Ventilation with a protective role - Ventilation systems in case of fire, offer protection in terms of preventing the spread of fire with the same speed but also by absorbing smoke in the ventilation ducts, reducing the risk of intoxication in case of fire
- Breakdown ventilation - The role of ventilation systems in the event of a breakdown is to act in rooms where instantaneous accumulations of explosive, flammable or toxic substances may occur due to accidents in the operation of the respective machinery or technological installations.

The proper method of industrial ventilation remains the responsibility of specialists. There are clear protocols in this regard, and the design of the industrial ventilation system will be done by professionals.

## THE Markov chains METHOD

Markov chains are well known for their multiple applications [1, 2, 7]. Can be said that they model systems or processes whose final state is not related to the initial state, but to the transition probabilities from a state *i* at time *t*, to a state *j* at time *t + 1* […].
If $\prod(t)$ it is the vector of state probabilities at time *t* and $\prod(t+1)$ it is the vector of state probabilities at time *t + 1*, each vector having *m* elements π (i, t), $i = \overline{1, m}$ , we can write that:

$$\prod(t+1) = P * \prod(t), \qquad (1)$$

where *P* is the matrix of transition probabilities:

$$P = \begin{Bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ . & . & . \\ . & . & . \\ p_{m1} & p_{m2} & p_{m3} \end{Bmatrix}, \qquad (2)$$

The matrix *P* can be the same for any time interval, in which case the process is stationary, or it can differ from one stage to another, in which case the process is unstable or non-stationary.
The non-stationary processes can be regular, when the transition from matrix *P(t)* to matrix *P(t+1)* is made according to a law that can be determined, respectively non-stationary processes can be irregular then changes in matrices of transition probabilities cannot be evaluated.
Stationary and non-stationary processes can be treated using Markov chains, the others having to be studied using forecasting methods.
In relation to the values of the elements of the matrix *P* at least 3 types of Markov chains (processes) can be defined:

- Processes whose final state vectors are independent of the initial state, called ergodic processes;
- Processes whose final state can be only one, called trap processes;
- Processes whose state vectors follow a periodic sequence, called periodic processes.

From a graphical point of view, a Markov process can be represented in the form of the figure 1, in which only 2 states and 4 stages are considered.

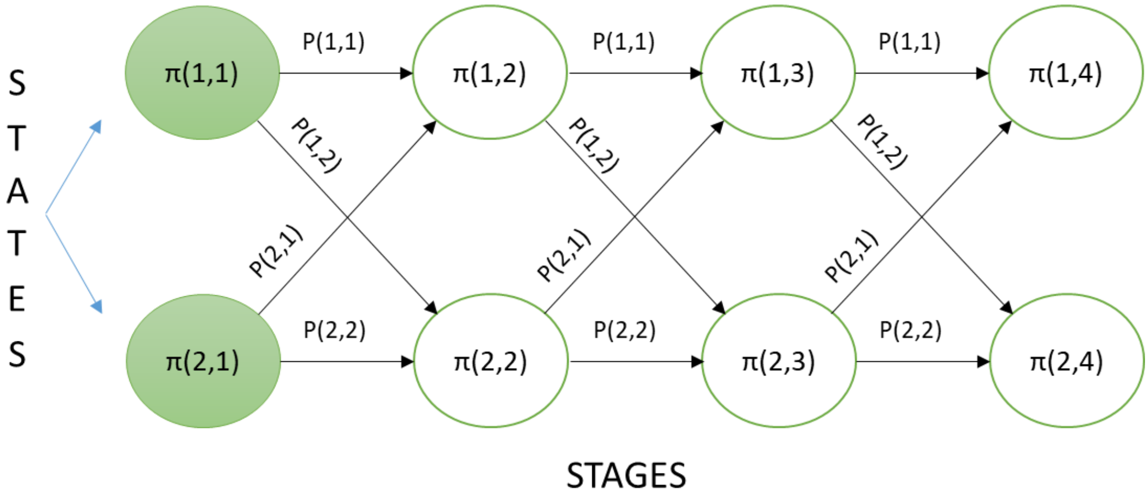


**Fig. 1.** A Markov chain

The equation that can be written based on the general relation of the figure is:

$$\pi(j,t+1) = \sum_{i=1}^{m} \pi(i,t) \times p(i,j), \quad (t = \overline{1,T}), \tag{3}$$

**The case study: an industrial ventilation system**

A case study was conducted and we noticed that the ventilation systems deteriorate over time.

**Fig. 2.** The industrial ventilation system

After the first year of operation, 11% of the system needs repair, and for the preventive maintenance of the system we use a probabilistic method of determining the interval for repair using the Markov method for ergodic processes.
The ergodic processes are characterized by the following properties:

$$|\pi(i,t+1) - \pi(i,t)| < |\pi(i,t) - \pi(i,t-1)|, \tag{4}$$

$$(i = \overline{1,m}\,; t = \overline{1,T}\,), \tag{5}$$

$$p(i,j) \neq p(i,k), \left(i = \overline{1,m}\,; j = \overline{1,m}\,; k \neq j; k = \overline{1,m}\,\right), \tag{6}$$

$$0 < p(i,j) < 1, (i = \overline{1,m}; j = \overline{1,m}) \,, \qquad (7)$$

Initially the system was fully functional, so:

$$\Pi(1) = (1 \quad 0)^T, \qquad (8)$$

As mentioned above, if after the first year of operation it is found that 11% of the ventilation system needs repair, therefore:

$$\Pi(2) = (0{,}89 \quad 0{,}11)^T, \qquad (9)$$

At the end of the second year it is found that 20% of the system needs repairs, then:

$$\Pi(3) = (0{,}8 \quad 0{,}2)^T, \qquad (10)$$

We set out to find out if after another 7 years the system will reach the level of 50% degradation in order to plan solutions. So let's start with the calculations needed to define the transition probability matrix:

$$\begin{aligned} &\pi\,(1{,}2) = 1{,}0 \times p\,(1{,}1) + 0 \times p\,(2{,}1) = 0{,}89 \\ &\pi\,(2{,}2) = 1{,}0 \times p\,(1{,}2) + 0 \times p\,(2{,}2) = 0{,}11 \\ &\ldots\ldots\ldots\ldots\ldots \\ &\pi\,(1{,}3) = 0{,}89 \times p\,(1{,}1) + 0{,}11 \times p\,(2{,}1) = 0{,}8 \\ &\pi\,(2{,}3) = 0{,}89 \times p\,(1{,}2) + 0{,}11 \times p\,(2{,}2) = 0{,}2 \end{aligned} \qquad (11)$$

the following system is formed:

$$\begin{aligned} &1{,}0 \times p\,(1{,}1) + 0 \times p\,(2{,}1) = 0{,}89 \\ &0{,}89 \times p\,(1{,}1) + 0{,}11 \times p\,(2{,}1) = 0{,}8 \end{aligned} \qquad (12)$$

resulting in: $p\,(1{,}1) = 0{,}89$ and $p\,(2{,}1) = 0{,}07182$, whence the difference will be obtained: $p\,(1{,}2) = 0{,}11$ and $p\,(2{,}2) = 0{,}92818$.

Thus, the matrix of transition probabilities will be:

$$P = \begin{pmatrix} 0{,}89 & 0{,}11 \\ 0{,}07182 & 0{,}92818 \end{pmatrix}, \qquad (13)$$

Since the matrix is known, the systems of equations needed to arrive at $\pi(2,\, t) \geq 0{,}5$ will be written:

$$\begin{aligned} &\pi\,(1{,}4) = 0{,}8\times0{,}89+0{,}2\times0{,}07182=0{,}72636 \\ &\pi\,(2{,}4) = 0{,}8\times0{,}11+0{,}2\times0{,}92818=0{,}27364 \end{aligned} \qquad (14)$$

$$\begin{aligned} &\pi\,(1{,}5) = 0{,}72636\times0{,}89+0{,}27364\times0{,}07182=0{,}66612 \\ &\pi\,(2{,}5) = 0{,}72636\times0{,}11+0{,}27364\times0{,}92818=0{,}33388 \end{aligned} \qquad (15)$$

$$\begin{aligned} &\pi\,(1{,}6) = 0{,}61682 \\ &\pi\,(2{,}6) = 0{,}38318 \end{aligned} \qquad (16)$$

$$\begin{aligned} &\pi\,(1{,}7) = 0{,}57649 \\ &\pi\,(2{,}7) = 0{,}42351 \end{aligned} \qquad (17)$$

$$\begin{aligned} &\pi\,(1{,}8) = 0{,}54349 \\ &\pi\,(2{,}8) = 0{,}45651 \end{aligned} \qquad (18)$$

$\pi(1,9) = 0{,}51649$
$\pi(2,9) = 0{,}48351$ (19)

$\pi(1,10) = 0{,}4944$
$\pi(2,10) = 0{,}5056$ (20)

The calculations show that in year *10 (3 + 7 = 10)*, *50,56%* of the ventilation system will be in a state of degradation, and the repairs will have to be planned for next year.
Taking into account this forecast of possible wear and tear of the ventilation system, we set out to plan an analysis plan for the implementation of a new ventilation system.
Following the analysis, it is found that the piping of the ventilation system is strongly affected by corrosion because it was made of materials that did not have a high resistance to chemical agents in the air. Thus, a new piping solution is proposed by replacing the old materials with new ones, which are much more resistant to corrosion.
It will be determined by applying the Markov method whether the new ventilation system will be more durable over time as follows:

$$\Pi(1) = (1 \quad 0)^T, \tag{21}$$

Given the corrosion behaviour of the new material, we can anticipate that the ventilation system will suffer a degradation of 9 % after the first year, and after the second year a degradation of 16 %:

$$\Pi(2) = (0{,}91 \quad 0{,}09)^{\mathrm{T}}, \tag{22}$$

$$\Pi(3) = (0{,}84 \quad 0{,}16)^{\mathrm{T}}, \tag{23}$$

In this case, the transition probability matrix will be:
$\pi(1,2) = 1{,}0 \times p(1,1) + 0 \times p(2,1) = 0{,}91$
$\pi(2,2) = 1{,}0 \times p(1,2) + 0 \times p(2,2) = 0{,}09$
. . . . . . . . . . . . . . . . . . .
$\pi(1,3) = 0{,}91 \times p(1,1) + 0{,}09 \times p(2,1) = 0{,}84$
$\pi(2,3) = 0{,}91 \times p(1,2) + 0{,}09 \times p(2,2) = 0{,}16$ (24)

the following system is formed:

$1{,}0 \times p(1,1) + 0 \times p(2,1) = 0{,}91$
$0{,}91 \times p(1,1) + 0{,}09 \times p(2,1) = 0{,}84$ (25)

Thus, the matrix of transition probabilities will be:

$$P = \begin{pmatrix} 0{,}91 & 0{,}09 \\ 0{,}13222 & 0{,}86778 \end{pmatrix}, \tag{26}$$

The systems of equations needed to arrive at $\pi(2, t) = \pi(2,10)$:

$\pi(1,4) = 0{,}785555556$
$\pi(2,4) = 0{,}214444444$ (27)
………………………………………………………………………………………………………
$\pi(1,10) = 0{,}637184684$
$\pi(2,10) = 0{,}362815316$ (28)

Also, an excel application to predict the degradation of the ventilation system was realized and used for the simulation, figure 3. Various scenarios can be simulated, depending on the design possibilities and the design constraints.

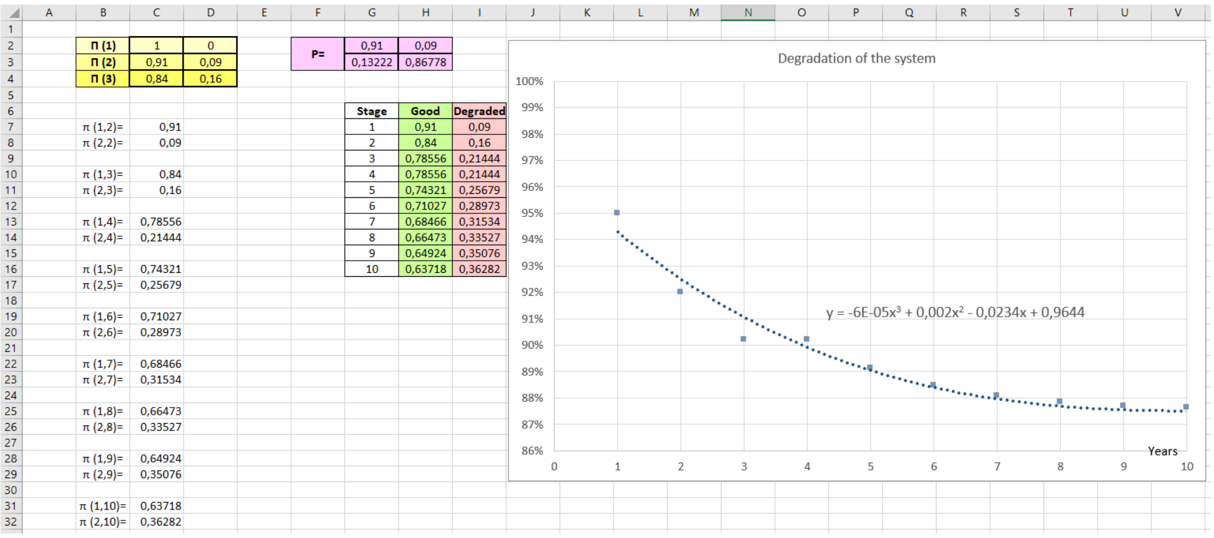


**Fig. 3.** Print screen of the excel application to predict the degradation of the ventilation system

## Conclusions

In this paper, a method for predicting the degradation of an industrial ventilation system using Markov chains was presented. Knowing the degree to which the system has deteriorated after the first and second year of use, it was possible to make a forecast on the degree of failure after 10 years and it was found that the system will degrade by 50%. After an analysis of the main causes leading to this degree of degradation of the ventilation system, it was found that the material from which its piping is made has a great influence.

In order to increase the durability for a new system, which is still in the design phase, it was proposed to replace the pipe material of the ventilation system with a more corrosion-resistant one and its degradation was simulated with the help of Markov chains. Thus, it was found that the degradation is lower in the second case.

We can recommend this method of forecasting to design specialists, being a useful tool in the design of various industrial installations, where there is a high level of noxious substances, thus ensuring appropriate working conditions.

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