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SYSTEM OF NON-DESTRUCTIVE TESTING

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ABSTRACT

In this paper the initial analysis of NDT laboratory is presented by means of agent-based modelling. For the purpose of analysis, laboratory is taken into account as a complex system consisting of three agents; equipment, personnel and specimens. Interaction between the agents is circular. In that sense, the agents are mutually interconnected in a way that one agent simultaneously interacts with others.

According to the interactions specific for NDT laboratories, the response of total testing time is presented considering various number of laboratory personnel while each operator has different skills and ability. Agent personnel has to perform testing of specimens. Since the complexity of specimens is quite diverse the specimens are represented as an agent. Additionally, during the whole time sequence of testing a certain specimen, operator is using NDT equipment relevant for the testing method, while the particular time of usage of the equipment can be shorter than the whole testing time. Availability of the equipment is therefore another agent. The evaluated outcome is the total testing time.

Presented results are obtained carrying out a simulation by means of multi-agent modelling and simulation tool named "ENTORAMA". Finally, the overall laboratory's performance is given in the respect of the number and structure of the laboratory personnel.

KEY WORDS

non-destructive testing, personnel, equipment, laboratory, agent-based model

CLASSIFICATION

JEL: C65, L15

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INTRODUCTION

The structuring of activities in testing laboratories is important contribution to the overall quality management. There is permanent need to test whether the adopted structuring is optimal in a given working environment. However, methods used in that task, prevalently experiments or mental models, are not sufficient to provide the clear solution to the problem.

Nowadays quality assurance requires to determining which technique should be used, and when and where it will be applied. It is necessary to implement an appropriate technique if one wants to ensure an adequate result with the adequate level of assurance. Thus, non-destructive testing (NDT) has taken the responsibility, as a part of preventive technologies, for detecting discontinuities and predictions of further improvements in industrial production. It is also an unavoidable mean to verify and detect possible discontinuity within in-service inspection of plants, materials and structures, thus preventing accidents that could have major negative impact on environment [1, 2].

Moreover, the non-destructive testing techniques are used to assess the integrity of the components or structures throughout their designed life-time. To summarise, the main contribution of non-destructive testing is to provide confidence in obtained results to customers [3, 4].

For initial discussion, a model of laboratory is emphasised as a crucial next step in improving the structuring of activities in testing laboratories. The model represents a NDT laboratory in an idealistic case where the personnel are reduced. Only characteristic of personnel that is represented is their ability and competence, no other attributes are included. Further upgrade is provided for implementation all disability of indicated elements.

In this article, the agent based simulation model is performed in order to research behaviour of complex organisation that is representing as laboratory for non-destructive testing. In accordance with formulated relations between agents it is demonstrated how the outcomes depend on actions between entities and how the system efficiency is changed with personnel's characteristics. Because of the flexibility of the agent based modelling, it is useful to find out which of part has significant contribution in systems ability and which of part contribute the lowest influence. Following that, the system can be improved and the expected quality assurance level can be reached.

MODEL

A laboratory is a representation of a complex system. Therefore, a reliable model of a laboratory will include elements of a complex system description. In this model, we extract several elements of a typical NDT laboratory, and relate them mutually with specific relations, bringing about summarily representation of laboratory as a complex system.

We model the dynamics of these elements in a given working environment using an agent based model approach [5, 6]. In our approach, the laboratory consists of the following elements: equipment, personnel, specimens and procedure.

Equipment is essential in organising all other activities in chain of complex system. It does not mean that expensive contemporary equipment will produce better result. The material facilities determine all other activities in procedure to detect presumably discontinuity. To provide systems' quality, the equipment should be calibrated and certified and it is necessary to do proof and evidence of their accuracy and uncertainty. Periodic calibration, that is required and determined by codes and therefore implemented in system, is essential condition in estimation measurement uncertainty that is prescribed to device. It is also unavoidable part of equipment to have a reference block to ensure traceability and to provide systems' adequacy [4, 7].

In our approach equipment is an agent consisting of all items like instruments, probes, reference blocks and material means for enabling the personnel to perform operations as are prescribed in written testing procedures. In this approach there are five different NDT methods with different equipments. Thus, the equipment is distinct for visual testing (VT), liquid penetrant testing (PT), magnetic particle testing (MT), ultrasonic testing (UT) and radiography testing (RT). The variables of the equipment are current number of personnel that share the same equipment and maximum number of personnel that can share the same equipment. How the equipment will be shared depends on method and handling time. Thereby some of equipment can be used by several operators in one time scale. One of them is penetrant testing (PT) with testing time around 30 minutes whereof the equipment is used only 5 minutes. Visual and ultrasonic methods have just testing time whereas the equipment is used all the time with duration of 30 minutes for visual testing and 60 minutes for ultrasonic testing. Testing time to complete the magnetic method is around 10 minutes what include 5 minutes for equipment using and finally the on-site radiography method need 90 minutes for testing where only 10 minutes the equipment is used. The method that is applied on one specimen depend on its complexity, but regardless on complexity, minimal number of testing method for one specimen is two. In that sense and in accordance with most technical codes of practice, the method that is always applied is visual testing and is specified with 100 % applicability. Estimated testing probability for application of volume method and surface method is 70 %. The volume method refers on ultrasonic testing and radiography testing where each applicability is 35 %. Surface method includes magnetic testing and penetrant testing with same applicability of 35 %.

Next essential condition for functioning of every type of a system is personnel. There is major need for continually improvement personnel' skills within the meaning of continuous training [2-4]. The personnel should be well motivated because their satisfaction can have positive influence on system. The NDT method that can be applied depends on components' characteristics as well as on the physical characteristics and properties of the material. It means that staff should know how to perform testing correctly without skipping any part of procedure. If the method is adequately performed then possibly existing discontinuity will be detected.

In this paper personnel is agent which represent people performing regular NDT operations of a laboratory, i.e. examinations and measurements, receiving the samples and conduct prescribed testing, writing records and reports, ensuring that results are accurate, reliable and timely. They provide crucial information for detecting and evaluating discontinuity and defect concerning acceptance criteria given by relevant codes or standards.

The variables of the personnel are characteristic of experience, understanding codes and standards and number of hours that is spent in testing.. According to their operating ability and testing experience, the personnel are divided into two categories, A and B. Personnel in A category are less competitive with lower level of skills. The opposite is B category including the personnel with better abilities and competences. In further discussion the personnel categories will be attributed values 1,5 for category A and 1 for category B.

Specimens that are under testing should be carrying on properly. The laboratory has the responsibility to provide adequate storage for all specimens that comes into laboratory. It is important to send back the specimens in unmodified state as this testing is non-destructive. If the customer does not have any particular request for testing method, the personnel will decide and choose which of the test method will be applied and performed according to relevant technical specification.

Specimen is an agent that is sent to the laboratory which has to detect possible discontinuity. The variables of the specimens are specimen complexity and discontinuity presence. In

general specimens have discontinuity but it does not mean that it is defect. The specimens' complexity is quantified as continual variable between 1 and 2. The most complex specimens will be quantified with number 2 opposite to 1 which regard on the simplest one. Some testing will be carried out outside the laboratory since the most complex specimens require on-site inspection. In that testing condition the operator with better ability will perform testing faster and more accurate achieving the same level of testing reliability as operator with lower ability. Some of specimens will not have any discontinuity and so neither defect. But this issue is not emphasizing like separately variable in this concept. Total number of specimens in laboratory is divided in appropriate ratio between category A and B.

The written NDT procedure should ensure high level of detection probability what is in correlation with reliability of results. Specific steps for every method are defined and finding of any significant discontinuity is ensured. For laboratory quality system it is important how the records and documentation are carried on and are they in accordance with codes and references. In our model of simulation procedure is not taken as a particular agent but it is implemented in agent personnel concerning personnel's competence and technical knowledge with reference to performing testing.

Environment is element that will not have noteworthy influence on test results if the conditions are under control. Effect of environment is excluded from observed laboratory here representing complex system.

INTERACTIONS

In our laboratory model, interaction between the agents is circular. In that sense, the agents are mutually interconnected in a way that one agent is simultaneously in interaction with other two. In other words, it is by no means straightforward to monitor interaction between just a two of agents' types (Figure 1.).

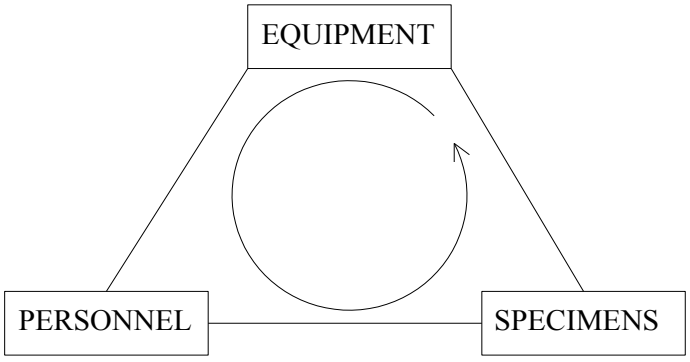

Figure 1. Circular interaction.

In the model, agents interact in the following way: personnel interact with equipment in a way that time of using equipment depends on quickness of personnel and method that is applied. Personnel can start with testing only when the equipment is available. Some of the equipment can be used by several persons what depends of method that is performed. Therefore for each method there exist both the associated time for using equipment and the total time for testing. In that way, total time for testing whole specimen is maximally reduced whereas the equipment after using by one person is forwarded to another. It is obvious that testing time also depends on personnel skills, competences, knowledge and their adequacy. But this testing time is more noted in interaction between specimens and personnel. Regarding the specimens' complexity it is clear that an operator with more testing experience

and proficiency will perform testing faster opposite to operator with less ability. As it was emphasised before, this system is circular, thus an indirect interaction of equipment and specimen is left. Their interaction is evident in time that is longer if the specimen is more complex. Therefore, for their testing it is necessary to perform several methods what extends total testing time. Some of the specimens need to be tested by more, e.g. 4 to 5 different methods. None of the specimen requests only one testing method, i.e. the minimum number of methods applied to a specimen is two.

SIMULATION OF COMPLEX SYSTEM

As a point of reference, at first we develop the ideal case in which there are no restrictions on equipment availability. In that case all personnel would have their own equipment for testing. They will perform testing on a specimen chosen randomly. Duration of testing is calculated using following expressions:

$$T_i = \sum t_M p_M \cdot p_i \cdot s_i , \tag{1}$$

$$s_i = \frac{\sum_j s_{i,j}}{\sum_j 1}, \; s_{i,j} \in \{1;2\}, \tag{2}$$

$$T_0 = \sum_i T_i , \tag{3}$$

in which t_M is the average time for testing specimen with given method, p_M the probability for utilising a given method, the index I denotes a personnel's category while {j} denotes a set of specimens with different complexity, T_i is the average testing time performed by one person on average specimen s' complexity, P_i personnel adequacy (skills, competences, capability, knowledge), s_i is pecimens' complexity and T_0 the total testing time.

Expressions (1-3) form set for ideal case where testing time depends on specimens' complexity and personnel adequacy. Average time for testing one specimen is attributed for every method. It is determined as an average time needed for testing that is performed on one specimen with ordinary complexity by personnel of sufficient competence and skills.

Beside presented ideal case the simulation for a real case laboratory has been performed. For a single laboratory with different number of personnel that are allocated into category A and B we performed simulation in the following way: for each ratio of personnel in categories A and B, the simulation is repeated 100 times, and as a result we took the average value of these simulations. The result of the simulation is duration of testing time where specimens' complexity, personnel adequacy and testing method are varied. Duration of that time is given by the following equation:

$$T_\Sigma = \sum_i T_i + \Delta , \tag{4}$$

in which T_Σ is the testing time obtained by simulation and Δ denotes duration of higher order effects which measures the influence of combinations of elements.

The results that are obtained from expression (4) refer to a real case in which the personnel and their operating time depend on equipment ability.

RESULTS

Outcomes of the model are time duration of testing performed by personnel with different capability and competence. Time duration of testing is consequence of specimen's complexity

and of personnel capability and competence. Personnel that perform testing randomly take the specimen. Personnel with less skills and competence will perform testing longer, with enlarged possibility for mistake. Their testing time and time of equipments using will be longer and their behaviour will have larger influence on system. So, in this approach the personnel have the biggest influence on system especially on testing time and system efficiency.

Restrictive element in laboratory system is number of equipment and its operative time. The time needed to perform each method is quantified with minutes. Some of the equipment can be consecutively used by several persons during the simultaneous testing cycle what depend on method that is performed.

Total testing time that is given by expression (3) is set for the ideal case which is independent as regards personnel number in laboratory. For each ratio of categories A and B (personnel adequacy), testing time needed to perform testing will be the same regardless to total number of personnel in laboratory. This is expected effect as there is no factor affecting personnel interaction since each operator possesses own equipment. Consequently the same results will be obtained for any combination of personnel in categories A and B. In Figure 2 the dependence of total testing time on percent of personnel from category “A” (thus also with personnel from category “B”) is shown. If the laboratory has 40 % personnel from category “A”, than 60% personnel will be from category “B”.

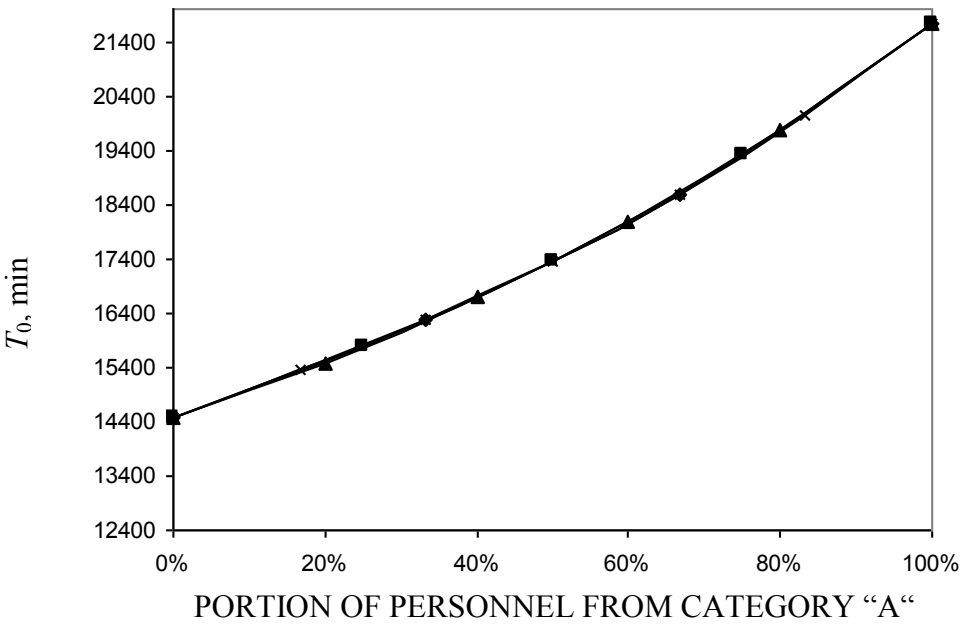

Figure 2. Testing time in ideal case.

In the model, four different cases are simulated where "case" implies laboratory with certain number of personnel allocated in categories A and B. The simulation is run for four laboratories equipped with personnel consisting of 3, 4, 5 and 6 operators in total.

The obtained simulation results reveal that laboratory with more operators will consume greater total testing time rather than laboratories that have less operators while. Respectfully corresponding curves for different laboratories are shown in Figure 3. In that sense total testing time does not mean longer period of testing for the reason that total testing time could be distributed to more personnel that will finally result with shorter period of testing.

As is shown in Figure 3, for a particular laboratory the total testing time appears longer in comparison with testing time in ideal case. It is due to the fact that there are more operators sharing the available equipment.

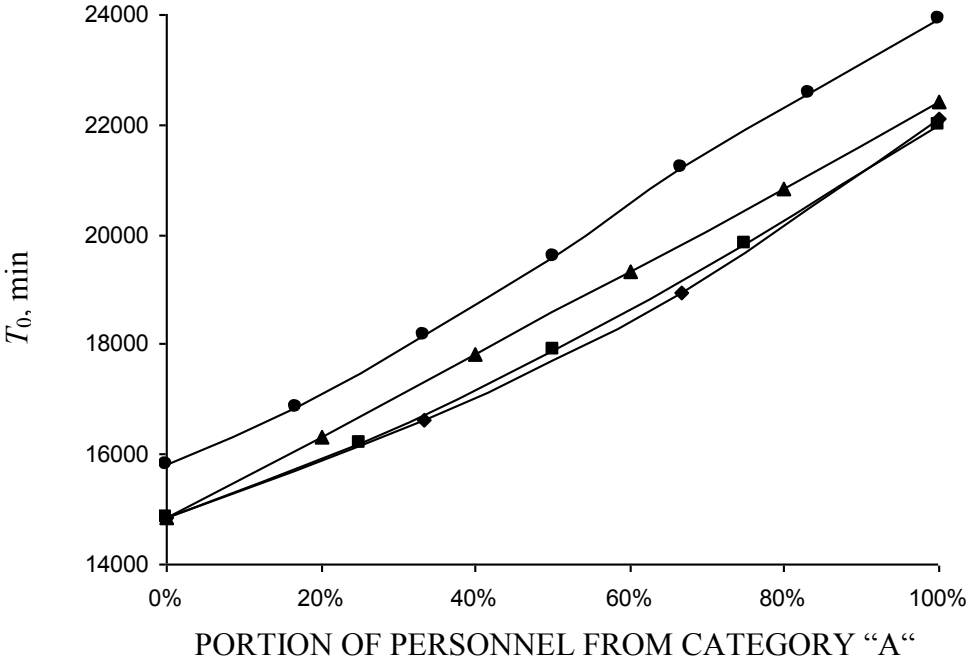

Figure 3. Testing time obtained by simulation.

CONCLUSIONS

In this article we presented initial results regarding the influence of the number and structure of the laboratory personnel on the overall laboratory's performance. We differentiated between the ideal and realistic case. In the former, the total time needed to process a given specimen set is solely sum of times which individual operators need for testing of randomly attributed specimen. In the later case, total time is duration of processing as given in the simulation using the agent based model of the laboratory. The difference between two respective times is caused by impossibility for sharing the equipment. In ideal case personnel have their own equipment without need for sharing them what is not situation in realistic case. If the laboratory has larger number of personnel, difference will be larger. Larger number of personnel is resulting in increasing waiting time for equipment availability what is actually inefficient time generating additional costs for laboratory. In the simulation we introduced time needed to perform testing. For a given set of specimens the distribution of required testing methods was prescribed in accordance with the common practice.

By means of presented simulation and developed model of laboratory structure and processes the laboratory management has a convenient tool for analysis, review, planning and improvement of laboratory resources. Simulation and model also provide indicators as a measure for improvements of quality system and economic benefits.

Simulation results revealed that further research must be focused more in detail on the interaction between available laboratory testing equipment and corresponding number of personnel with different testing abilities.

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SAŽETAK

U radu se laboratorij analizira kao kompleksni sustav s tri vrste agenata: opreme, osoblja i uzoraka. Međudjelovanje između agenata je cirkularno. Na taj način, agenti su međusobno povezani tako da svaka vrsta istovremeno međudjeluje s ostale dvije vrste. Prema njihovom međudjelovanju, određeno je kako vrijeme ispitivanja uzoraka ovisi o ukupnom broju osoblja različitih vještina i sposobnosti. Agent osoblje provodi ispitivanja na uzorcima različite složenosti. Značajno pitanje u svakom laboratoriju je oprema. Ako osoblje mora dijeliti istu opremu, ukupno će trajanje ispitivanja biti veće nego u laboratoriju u kojemu svatko od osoblja posjeduje potrebnu opremu. U tom slučaju će trajanje ispitivanje biti najkraće, što je u radu označeno kao "idealni slučaj". Idealni slučaj se uspoređuje s realističnim slučajevima koji su razrađeni koristeći modeliranje pomoću agenata i programski paket *Entorama*. Na taj način izdvojen je utjecaj broja i strukture laboratorijskog osoblja na ukupno djelovanje laboratorija.

KLJUČNE RIJEČI

Nerazorna ispitivanja, osoblje, oprema, laboratorij, modeliranje pomoću agenata