Didactic of Teaching Failure Analysis and Logistic Planning Software

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Abstract: The possibility to develop reliability analyses and simulations for the logistics of warehouses for industrial companies resulted in an increase of their safety and reliability since the development of such process. The applicability of the failure mode and effects analysis (FMEA) has been taught for many years to the students of the Italian universities in order to prepare the future engineers to face, in the most efficient ways, the problems in the industrial field. The university of Genoa has contributed to future studies by developing a new software called TARAS, specifically dedicated to the failure analysis of mechanical systems and complex plants. This software has been designed to model the operation of a complex system aiming at determining the integral parameters for availability, reliability, and failure probability. The logistic planning is meanwhile taught during both bachelor's and master's courses of mechanical engineering. The knowledge acquired on simulation software is part of the essential competences that industrial engineers should acquire nowadays. In the past years, simulation software have been taught and actively applied to several case scenarios, making the students of our university and of foreign partner's universities aware of the various application of these technologies. When describing the case regarding the teaching of TARAS, this has been proposed also to the bachelor's students of the environmental safety department of Bauman Moscow State Technical University during the yearly seminar on Environmental Monitoring and Industrial Safety. With this study we want to show the efficiency of such software for industrial applications and how these can be effectively taught to students.

Keywords:

I. Introduction

It is extremely important nowadays to employ the available technology in the industrial field to predict certain factors, such as costs, availability, and maintenance time. The possibility of employing simulation tools for failure analysis is a particularly important opportunity on which industries rely on.

The department of mechanical engineering of the university of Genoa decided to contribute to future risk analyses with its own software for failure analysis, TARAS. A detailed description of the software will be given in this article. The reliability of this software has been consolidated during the years by many studies and test cases (1, 4, 9, 10).

Other software used by the University of Genoa to introduce modelling and simulation to the engineering students have been Anylogic and Anylogistix. The Anylogic company developed two simulation software extremely useful in many industries, among which supply chain design, risk assessment, picking optimization and logistics planning. The efficacy of the software is proven by the many companies that decided to entrust Anylogic for the reliability assessment. For our study is particular relevant the presence of many case studies on the employment of Anylogic and Anylogistix for industrial purposes (5-8).

These software have been shown to the students of mechanical engineering of the university of Genoa. For the case of TARAS only, the professors of our department presented the software to the bachelor's students of the Bauman Moscow State Technical University. For the students of the industrial safety department, the seminars of Industrial Monitoring resulted in being as much interesting and captivating as for the Italian students. The feedback received from all the students is appreciated and gives us solid ground to consider TARAS as a value for future industrial engineers. During the first semester of the academic year 2021/2022, the department of mechanical engineering of the university of Genoa approved the teaching of the simulation software Anylogic implemented with Autostore for logistic planning.

To all the courses where the application of these simulation software were proposed (principles of production and industrial safety engineering, industrial plants for energy, supply chain resiliency and manutenzione e sicurezza degli impianti industriali), the students of mechanical engineering, management engineering and safety engineering responded well to a dynamic teaching. A proactive attitude, particular attention during the lessons and the modification of a proposed simulation as final assignment, gave us the necessary feedback to consider the learning of how to simulate and work with an autonomous environment successfully.

Not always engineering students receive a proper and clear education on how to develop FMEA and FMECA processes and how to prepare valid models for simulation. Given the positive results with both Italian and international students, with this article we want to describe these two understandable approaches for failure analysis and logistic planning, the reliability of such methods and their potential for industrial applications.

The structure of the article is the following: a literature review of the software used by the university of Genoa; the presentation of examples and practical applications that were done during the courses of industrial and mechanical engineering; and the personal opinions of the full professors and associate professors involved in these lectures.

LITERATURE REVIEW

Failure analysis is a very relevant step in the safety analysis of industrial plants, especially when critical elements are employed, and plant managers need to keep under control the evolution of the single elements. The processes and the devices that can be found within an industrial plant, can then be analysed with FMEA and FMECA methodologies, allowing operators to have concrete ideas on what is the reliability of the elements under study. At the University of Genoa, it is extremely important that students would know which tools they can use and which can be learnt to develop FMEA and FMECA analyses, for basic studies to more complex ones.

TARAS has been developed as a Montecarlo simulator where each component contains within itself other elements [1, 2, 3, 4]. The complexity and amount of these so-called "sub-components" is given by the degree of complexity desired for the analysis. The software is programmed to define two types of entities which will define the degree of precision:

- Physical nodes;
- Logical nodes.

The first ones are used to define the self-standing components which are characterised by a failure rate λ_i, and the second ones are used when the failure rate depends on the failure rate of the sub-components. The software works with the definition of status variables (S_i) indicating the status of a component, 1 if available or 0 if unavailable. The process comprehends the comparison with the failure rate of each component with an associated random number, extracted from a range between 0 and 1. If the failure rate results bigger than the random number, then the components is considered unavailable. The process with which TARAS work is by time steps, which can be translated in one hour of operation each. The algorithm works in the following way:

- Analysis of each node, from the root to all the branches, of the operational tree;
- Calculate a value of the components equivalent time;
- Proceed with the next time step and repeat the process.

These steps allow the localisation of eventual failures of components, which, in the worst case, would propagate along the tree, determining the failure of the whole system, the so-called "top event".

The input needed by TARAS are

- the set of parameters characterising the failure/maintenance features of each component;
- their failure rates, which can be time dependent values, mathematical formulas, or constant values;
- the possible failure modes of each component, identified by a value β (between 0 and 1 and where the sum of every β referred to every component has to be 1) and characterised by one mean time to repair (MTTR) for each component;
- and the scheduled maintenance.

Other software widely used for failure analysis are AnyLogic and AnyLogistix. These multi-agent modelling and simulation software combine the three paradigms of simulation: agent-based modelling, system dynamics modelling and discrete event modelling. These software work by steps:

- creation of an agent;
- definition of the state changes;
- establishing the links between the agents

Because we do not have only a single basic element (the agent), multi-agent simulation models allow to simulate the behaviour and interaction between these elements (5-8). It is possible to draw the state diagrams for each agent, allowing to track the failure source and locating the fault which can be used for a great variety of areas, from pharmaceutical to education and from energy systems to the industrial field.

PRACTICAL APPLICATIONS

The examples that we are bringing to the attention of the readers are three practical applications proposed by the lecturers of the mechanical engineering department of the University of Genoa

A. TARAS

The exercise lectures regarding the teaching of TARAS are organised in teaching the principles on how FMEA and FMECA analysis work. TARAS allows to model the system using a hierarchy of components, assemblies and sub-assemblies expressed by an operational tree, whose root is represented by the system itself and whose leaves are represented by the elementary components. The operational tree is intended as the scheme of the logical interconnections, existing among the different components, on which the system correct operation depends. The proposed example regards the development of a system defined by an industrial plant where combustion vapors of CH_4 are turned into liquid phase by cooling under pressure (fig. 1).

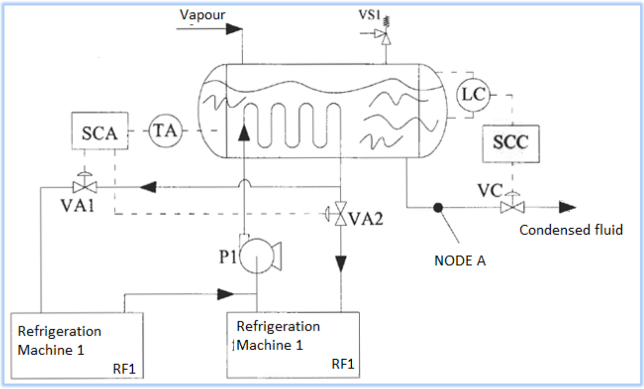

Fig. 1. Scheme of the TARAS exercise.

From this picture, the students are guided to define the operational tree of the system after defining the conditions which are needed for the condenser to be supplied from above by a smart control centre (SCC) which analyses the level of fluid within the condenser by the measuring system LC and keeps this value constant by the control valve VC. The cooling is guaranteed by the two identical refrigeration machines which work in parallel thanks to the pump P1 and the control centre SCA. The SCA analyses the temperature of the condensed vapour through the TA meter and regulates the quantity of cooling fluid which is divided between the two refrigeration machines. This is done to ensure that, in case of failure of one of the two machines, the other one can guarantee the cooling of the condenser. We then have a safety vent valve VS1 applied to the condenser to lower the eventual too high pressure. The optimal operation tree that the students are guided to build is represented in Figure 2.

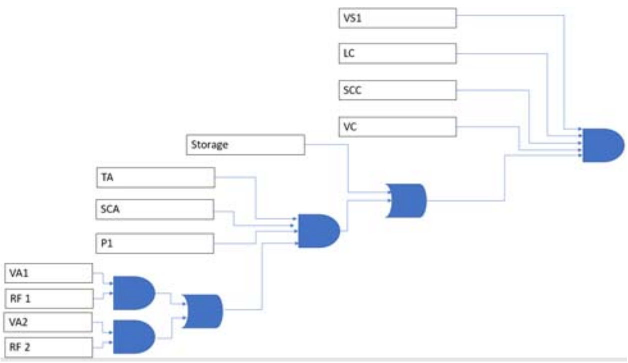

Fig. 2. Operational tree of the TARAS exercise

The students are in this way helped understanding the difference between physical and logical nodes, in this case the pump component and the internals part of the pump (the motor, the shaft, the bearings and the rotor). In case of a more complex system, it would be possible to establish redundancy relations. These can be set for the logical nodes through a *k/n* parameter, where k represents the number of sub-components that need to be working over the n total number of sub-components for an optimal functioning. After the definition of the failure rates, the failure modes and the scheduled maintenance, w attribute them at each level of the operational tree.

Among the elements that we can see in the operational tree, th storage component appears that was not in the proposed scheme in Figure 1. This component contains a feeder and a reservoir, which are in charge of feeding the line and of the delay of the line itself.

The graphical user interface (GUI) of TARAS was designed to be user friendly. After the definition of a new scenario, we need to define each component that is in the system with all the characteristics that we mentioned before (Figure 3).

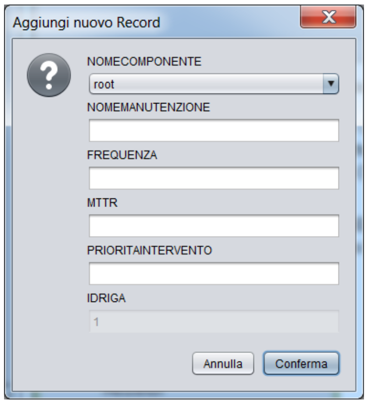

Fig. 3. Component characteristics.

At this point it is possible to run the simulation and obtain the result of the simulation for how many time steps are necessary.

B. *AnyLogic*

The exercise with AnyLogic proposed to the students of principles of production and industrial safety engineering and industrial plants for energy is structured with the learning and explanation about the real applications of this software, followed by a guided exercise that the students have to understand, implement and explain during the final exam part. To the students is explained the importance of the quantitative decision-making process. The relevance of knowing how to develop and present a simulation is since the beginning of the course explained: the importance of 3D representations, the clarity of the production line, the total throughput per day and the equipment employed. Because simulation is a tool used to study a model representing the real world (or at least that part of the real world that is under examination), the first thing that students should understand is the type of simulation which will be necessary: if a discrete event simulation (DES), system dynamics (SD) or an agent-based modelling (ABM). The students understand the importance of evaluating different scenarios of the same simulation (or better, with the same “core logic”). By running multiple simulations at the same time keeping the core logic intact, the students are able to evaluate how the key performance indexes (KPI) change. Within the framework of the industry 4.0, the students are asked to understand and implement a simulation model with AutoStore^{TM} to create a full automated warehouse. What we want the students to achieve is to understand the relevance of the application of these type of studies. In this case we would have a storage unit which would have a storage capacity equal to four times more for the same storage facility but not automated.

With the tools that the university is given, the students will be able to define the model, properly designing the system for future presentations and understanding how the components work (Figure 4).

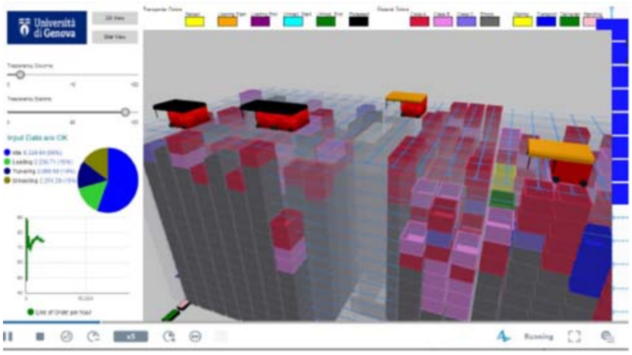

Fig. 4. Design for the AnyLogic assignement

At the end of the course, the students are introduced to other real applications previously developed by our department, starting from the study of virtual reality employed in industrial systems (quote glasses article) going to biggr projects regarding the new terminal San Giorgio of the port of Genoa (quote our article).

CONCLUSIONS

This article was proposed to be a review of the didactics employed at the University of Genoa for the teaching of simulation and modelling procedures to the students of mechanical engineering, management engineering and safety engineering. The software taught and explained have been:

- TARAS, a software developed by the department of mechanical, energetic, management and transport engineering for FMEA and FMECA analyssi
- Anylogic and Anylogistix, multimethod simulation and modelling software developed by the Anylogic company.

With practical applications, proposed examples and final evaluations through assignments, the students acquired and consolidated the knowledge regarding simulation and modelling software and how the real world can be represented. To these lectures, also the lecturers were able to keep the classes motivated and focused with examples and practical applications, showing how these course may already be effective to properly form the future generations of engineers.

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AUTHOR COMMENTS:

- The Literature Review section could benefit from adding a couple paragraphs about FMEA and FMECA, how they are often taught in schools and more innovative approaches that leverage on technology, such as AnyLogic, AnyLogistix, and the one presented in the paper.

- Page 2 Section "Practical Applications". Starting the section with an introduction to the 3 practical applications as well as the software used would be very useful to understand the connection, if any, between these 3 applications

- Have you considered the pedagogical implications of implementing these practical applications? In terms of teaching methods, learning methods, learning space, etc. Perhaps this could be achieved by dividing each subjection within "Practical Applications" into learning activities, expected learning outcomes, and learning assessment.

- The article mentions the effectiveness of the use of practical applications in class. It would be interesting to expand on what is meant by "effectiveness" and what makes these applications to be "better" than traditional lectures.