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Introduction to Human Error Investigation and Remedy in Oil & Gas Industry

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Abstract

It is proved that most of industrial accidents are related to some kind of human failure, sometimes with catastrophic consequences. The estimation of human error is a contributory factor for many industrial accident occurrences. The present paper refers to human error probability in industrial activities. The paper intends to make a literature revision referring important concepts about human behavior and human reliability. It is fundamental to identify tasks, actions or activities that depend on human behavior or even determine the conditions that influence human error and thus increasing risk. With this target, the most important methods, techniques and tools to assess human failure (error) are referred showing their potential applicability. Secondly, the paper proposes the approach that gives an insight on training quality, with a dedicated focus on virtual reality training, based on which suitable corrective measure can be adopted to decrease human error. Pioneering organizations are using Virtual Reality (VR) to improve productivity and quality of the operations. By combining the strengths of humans and machines, VR will dramatically increase value creation for the organization. The effectiveness of the VR-based training process depends directly on the quality of the prepared training material and on the quality of the prepared virtual training environment, which directly improves learning curve of the trainee. Virtual training is a promising solution to bypass the limitations of hardware training and especially to test and secure production processes in a safe environment. O&G has remarkable interest in applying VR/AR techniques in training, maintenance, operation.

Keywords: Human Reliability, Maintenance, Training, Virtual Reality, Safety

1. Introduction

In Oil&Gas (O&G) sector, "Safety first" has become a general validity motto in every subfield such as O&G Engineering, Operation and Maintenance. In an outdated approach, safety and quality measures should be balanced with productivity measures. Nowadays, safety and quality are no more alternative to productivity. Safety, quality and productivity must go together and conciliate with each other in a win-win approach (see Figure 1).

O&G projects and activities deeply rely on people and human activities involving several types of issues: technical, financial, managerial and most of all organizational ones.

O&G field is inherently hazardous and critical because of several reasons:

- activities involve hazardous substances and plants are often located in severe environments;
- activities are completed in tight schedules;
- costs, direct and indirect (opportunity/time cost) are always very high;
- plants require h24 operation and continuous maintenance;
- maintenance is performed during plant operation phase;
- activities, from design to operation, from maintenance to decommissioning, require

simultaneous and coordinated intervention of several people.

From all these considerations, it follows that in O&G both safety and productivity are deeply depending on human performance.

Improving human reliability and reducing human error in O&G results as a major impact strategy to achieve the win-win approach of increasing safety and productivity at the same time.

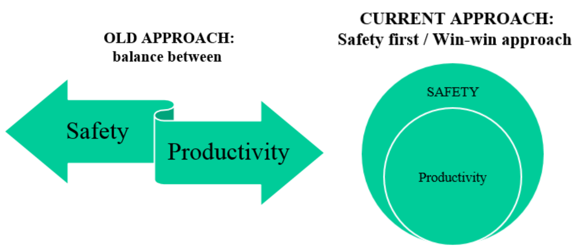

Figure 1. Approach evolution

The main contribution of the paper is twofold:

(i) Introducing the specialist to the "human error and remedy" theme by means of a literature summary of

a. human error and reliability, both in general and in maintenance in particular,

b. virtual reality in maintenance and in training quality;

(ii) Adding to the picture the particular research experience of an O&G Company, namely Eni.

The present work starts with Human error, reliability and methods to assess human failure. So far O&G sector has not been given as much attention as aviation and nuclear sectors, traditionally considered highest risk sectors. The literature summary goes on with Human Error in Maintenance, with a brief parenthesis on training, and then application of Virtual Reality in Maintenance and in Training.

In the final part of the summary, two promising research fields are referenced: collaborative virtual environments and web-based multimedia maintenance manuals.

The present work ends exposing ENI involvement in the VR/AR field - proving O&G industry general interest - and stating possible future scenarios in O&G.

Abbreviations

AI	Artificial intelligence
AR	Augmented Reality
ASEP	Accident Sequence Evaluation Program
ATHEANA	A Technique for Human Event Analysis
CAVE	Cave Automatic Virtual Environment
CPS	Cyber-Physical Systems
CREAM	Cognitive Reliability and Error Analysis Method
DHM	Digital Human Modeling
GVT	Generic Virtual Training
HEART	Human Error Assessment and Reduction Technique
HEM	Human Error in Maintenance
HEPs	Human Error Probabilities
HF	Human Failure
HMD	Head Mounted Displays (e.g. Google Glass)
HR	Human Reliability
HRA	Human Reliability Analysis
HUD	Head-Up Display
IoT	Internet of Things
KPI	Key Performance Indicator
LARTE	Live Augmented Reality Training Experience
LDCM	Learning and Forgetting Curves Model
ML	Machine learning
NPP	NuclearPower Plant
O&G	Oil&Gas
PDA	Personal Digital Assistant
PSFs	Performance Shaping Factors
SAR	Spatial Augmented Reality
SPAR-H	Standardized Plant Analysis Risk - Human
THERP	Technique for Human Error Rate Prediction
UI	User Interface
VBT	Virtual-Based Training
VR	Virtual Reality

2. Literature Summary

2.1. Human Error and reliability

Most of industrial accidents are related to some kind of human failure. Human reliability analysis (HRA) is one of the most difficult issues with risk analysis (Sobrals, 2018).

Reliability can be defined as the probability to perform correctly a task at given condition for a given time.

Reliability for humans is more complex.

Pallerosi (2008) as cited in Sobrals (2018) mentions a more complete definition of human reliability: it is the probability of a person not to fail on the accomplishment of a required task (action), when demanded, in a give period of time, under adequate environmental conditions and with available resources to perform it.

Human Failure (HF) can be classified in Errors (with subtypes Slip/Mistake) or Transgression (with subtypes deliberate / unintentional). Most common type of failure is error (Figure 2).

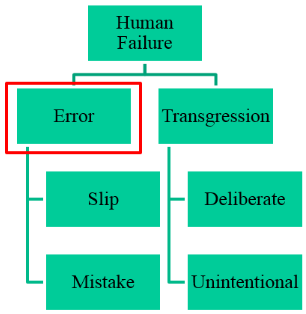

Figure 2. Human Failure Classification (Pallerosi, 2008). Error is the most common type or human failure

Another suitable classification distinguishes omissions (omission of the entire task / omission of a single step in the task) and commissions (selection, sequence, time, qualitative).

2.2. Methods to assess Human Failure (Error)

The most important methods to assess human failure (error) are the following:

1. Technique for Human Error Rate Prediction (THERP) by Swain: diagnoses probability of occurrence of human error. It comes from nuclear applications but it is general.
2. Accident Sequence Evaluation Program (ASEP): 1987 by Swain, for nuclear only. A method that could estimate human error probabilities (HEPs) and response times for tasks during normal operating conditions and post-accident conditions.
3. Human Error Assessment and Reduction Technique (HEART), by Williams, UK 1985, simple and quick method to quantify risk related to human error and give suggestions on how to reduce it. Centered on human operator rather than technical process, it has general applicability.
4. Standardized Plant Analysis Risk - Human (SPAR-H), Idaho National Laboratory, US 1994, mostly for Nuclear, probabilistic model to assess human reliability in NPPs. Contributory factors and a rating based on their combinations.
5. Cognitive reliability and Error Analysis Method (CREAM) by Hollnagel in 90s (paper in 1998). It is a bidirectional method, based on distinction between competence and control. Method classifies errors into causes (genotypes) and effects (phenotypes).
6. A technique for Human Event Analysis (ATHEANA) is assessment technique that provides a useful structure for understanding and improving human performance in operational events. It attempts to identify the probability of a situation that can trigger unsecure or unsafe action in plant personnel.
7. The Simulator for Human Error Probability Analysis (SHERPA) model (Di Pasquale, Miranda, Iannone, Riemma, 2015) exploits traditional HRA methods in order to model human behaviour and predicts the error probability for a given scenario in every kind of industrial system without being resource intensive or time consuming. Human reliability is estimated as function of the performed task, the Performance Shaping Factors (PSF) and also, that is an innovation, the time worked.

SHERPA also provides the possibility of determining the optimal configuration of breaks during shift maximizing productivity, which, in this case, is intended as production capacity.

The methodology uses assessments of an economic nature.

The SHERPA model quantifies human error probability in any work situation and in every context – quantification that today is hardly possible given the lack of tools.

The SHERPA model can be effectively used to evaluate changes in human error probability when changes occur in influencing factors considered.

2.3. Human Error and Maintenance

Human factor plays an inevitable role in maintenance activities and the occurrence of human errors impacts on system reliability and safety, equipment performance and economic results. Human Error in Maintenance (HEM) is significant because different error types occur during the maintenance process with non-negligible effects on the system.

In (Di Pasquale, Franciosi, Iannone, Malfettone, Miranda) is presented a literature review concerning HEM with the aim of investigating, through a critical analysis, the current HEM state-of-the-art in industrial systems and highlighting the research and practice gaps.

Di Pasquale et al. systematically investigated the relationship between human performance and maintenance activities.

A total of 63 studies were analysed. A classification of works in terms of types and typical human errors in maintenance, error contributing factors, maintenance policies and methodologies for human error analysis, maintenance error consequences and industrial sectors was made.

High-risk sectors, like nuclear power plant or aviation, have strongly taken into account human error in maintenance activities, whereas in manufacturing systems HEM has not received the amount of attention that it deserves (Figure 3).

Work environment, organization and individual features turn out as the major contributors to human error and quality of the performance of a maintainer.

The analysis of contributing factors is often performed in high-risk industries (aviation, NPP), by accident reports analysis, since accidents and incidents are the main evident consequence of human error.

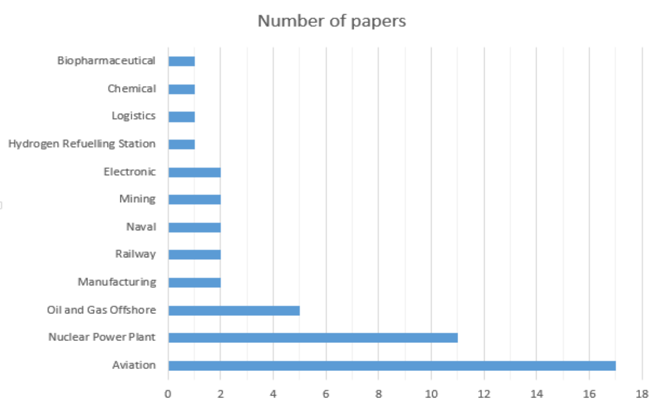

Figure 3. Number of papers per field

As a research opportunity, it must be pointed out that to date only the safety issue has been deeply investigated, differently than other HEM consequences, due to its relevance in high-risk industries where the majority of studies were conducted. Instead, the HEM impacts on system availability and reliability (e.g. frequency of maintenance intervention or length of intervention time) and the HE economic and environmental consequences have been superficially considered.

Sheikhalishahi, Pintelon, Azadeh, (2016) consider human factors in maintenance, reviewing 78 articles.

Three major categories for human factors are identified and considered:

- human error/reliability calculation,
- workplace design/macro-ergonomics
- human resource management (Figure 4).

Review has shown that research has mainly focused on human errors calculation models and methods; social and organizational factors have received increasing attention in recent years, but still studies of physical and mental stress, normal work, cultures of maintenance have been scarce.

In addition, most of the studies are focused on reliability-centered industries including aviation, nuclear power plant and chemical processing (73%), since in this type of industries, reliability and specifically human error is the main concern.

Table 1. Classification for human factors in maintenance

Category	Factors
Human error/reliability calculation	• Quantitative/qualitative methods for calculating human error/reliability • Contributing factors
Workplace design/macro-ergonomics	• Organization/environment • Work/workplace conditions
Human resource management	• Workforce planning • Performance assessment • Training/knowledge management • Performance shaping factors

Future direction in this area would be investigating human factors from long-term cost, availability, and ergonomics points of view in a wide range of industries.

Another important aspect of human factors in maintenance is maintainability, which should be taken into account from the design phase of equipment and organizations. This would reduce maintenance workload and downtime, fatigue and work injuries, probability of human error, and will improve workplace environment and employee satisfaction.

Comprehensive studies in the area of crew resource management, operator allocation and personnel recruitment are very rare.

According to the literature, fatigue, knowledge and experience, and coordination and communication are amongst the most important human factors related to the maintenance.

Thus, human resource management and scheduling could be an interesting area for future studies. Finally, other future directions in this area would be to develop human error models for different types of error (slips of action, mistaken assumption etc.), error prediction and recognition tools and technologies, intelligent decision aid system.

2.4. Training

Training can be defined as the process in which an intelligent resource, either human or artificial, systematically acquires some desired knowledge and skills, becoming, at the end of the process, "expert" and able to perform a task or a series of tasks, such as those required by a particular job.

Learning curve is a curve relating learning (knowledge/skills level/productivity/error rate) as a function of time/experience (number of hours worked/ number of cases experienced by the subject).

Di Pasquale, Miranda, Iannone, Riemma, (2015b) address the impact of the learning and forgetting processes on the system performance during the working activities in combination with the human error quantification.

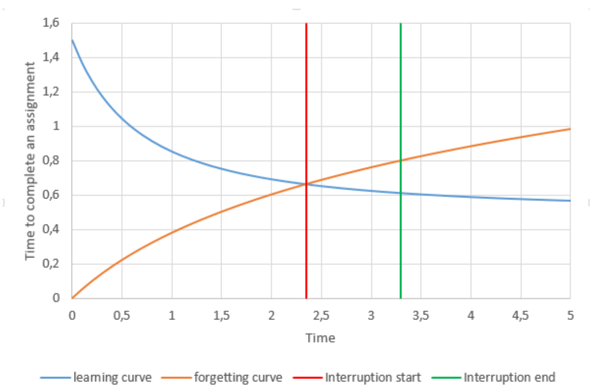

Figure 5. Learning and forgetting curve

The Learning and Forgetting Curves Model (LFCM) was implemented as a new module in the SHERPA simulator (see Di Pasquale et al. 2015a), developed for the human error assessment.

The LFCM module assumes, according to the literature, that human performance improves with the increase in cumulative production, leading to a progressive reduction of the processing times (Figure 5). On the contrary, the performance deteriorates when learning sessions are separated by rest breaks that cause knowledge depreciation or forgetting. Di Pasquale et al. (2015b) provide a different model to measure the system performance when the learning and forgetting processes are present, considering at the same time the productivity and the error probability.

2.5. Virtual Reality and Maintenance

Pioneering organizations are using Virtual Reality (VR) and Augmented Reality (AR) to improve productivity and quality of the operations.

Augmented reality (AR) is a key technology for the development of smart manufacturing. One of the main advantages of AR is that it can help workers to accomplish several tasks, making it possible the shift from mass production to mass customization.

However, for industrial scenario application, the question about which display solutions fit better the industrial constraints remains open. Based on the literature overview, laboratory experiments, and feedbacks from industrial companies, Uva, Gattullo, Manghisi, Spagnulo, Cascella, Fiorentino, (2018) studied the use of spatial augmented reality (SAR).

Their work presents the evaluation of the effectiveness of conveying technical instructions with this SAR prototype as compared to paper manual. An experiment with 16 participants to measure user task performance (completion times and error rates) and to collect subjective evaluation was made (the experience of operators, as well as the learning effect due to the repetition of a procedure at different times, or the possible fatigue of operators using SAR was neglected). Technical information were projected on a motorbike engine during a seven-task maintenance procedure. SAR turned out to be more effective for difficult tasks than for simple ones and that the main advantage of SAR is related more to the reduction of error rates than to completion times.

SAR presentation mode, well accepted by the operator, is significantly better than paper presentation in completion times (reduction of 20.3% in overall completion time) and error rates (83.3% fewer errors with the SAR mode). That perfectly complies with the fact that industry, O&G included, always considers overriding the reduction of the errors made by the operators and optional (nice to have) the reduction of times.

Result of this paper is important because it is in line with the objectives of Industry 4.0 and supports the role of AR as a key technology for a smart factory.

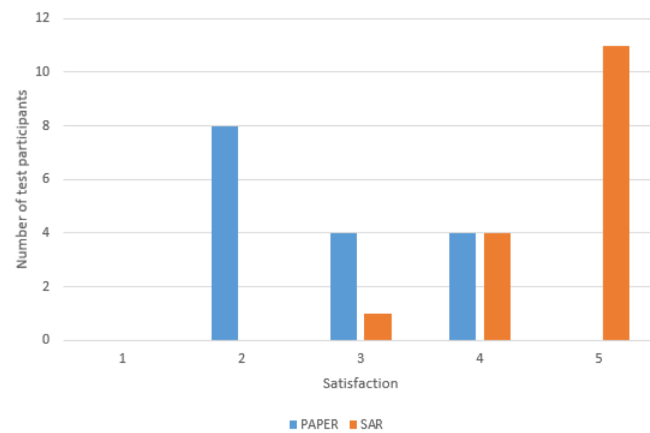

Figure 6. SAR vs paper manual comparison results

A current challenge in industrial systems, such as E-maintenance, responsible for gathering all maintenance-related data in a single system, is how to display information to users. This same challenge is present when considering new devices for visualization, such as Head Mounted Displays - HMD (e.g. Google Glass). Advanced interfaces such as Augmented Reality (AR) and Head-Up Display (HUD) provide a means to display this information for users.

However, there is still a lack of theoretical design studies (studies that do not consider current technologies limitations) of Augmented Reality and HUD.

Another problem in industrial scenarios is motivation, especially considering repetitive procedural works. Therefore, Oliveira, Caetano, Botega and Borges de Araujo, (2006) present and discuss a high fidelity theoretical prototype of an interface for maintenance, that uses Gamification techniques to motivate the user, and AR and HUD to display information in a HMD device.

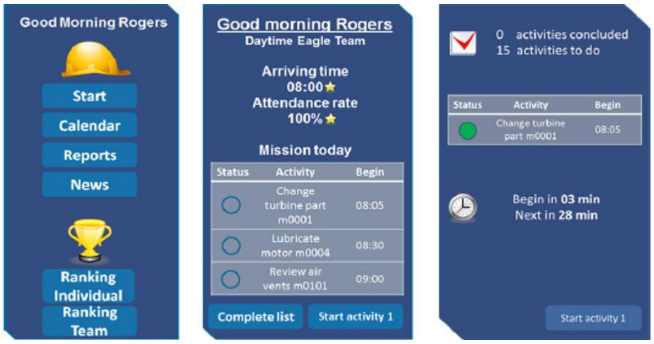

Figure 7. Gamification approach - interface

The User Interface (UI) prototype proposed by the study (Figure 7) has several goals.

The first goal is to demonstrate how Gamification can be used in a maintenance context, both in input data and presentation output. This prototype explored the user performance indicator, also known as Key Performance Indicator (KPI).

Another goal is to explore a HUD-like interface for access complex data and information in maintenance.

The third goal is to propose different forms of AR in maintenance, considering technologies aggregated by the E-Maintenance system. An example of technology is the Internet of Things (IoT).

The fourth goal is to explore procedure and risk awareness of the maintenance activities in a UI. Several AR interfaces for maintenance were proposed in literature, but always focusing on procedure, while the prototype in this paper also focuses on awareness of risks during the task.

The fifth goal is to explore a team awareness interface. The improvement of team situation awareness is an important research in industry, especially to avoid accidents.

In future projects, this prototype will be evaluated with usability heuristics and user testing in a simulated virtual environment.

2.6. Virtual Reality Training

Ferrise, Caruso, Bordegoni, (2013) describe an application based on Virtual and Augmented Reality (and Virtual Prototypes) technologies specifically developed to support maintenance operations of industrial products (Figure 8). Two scenarios have been proposed.

In the first scenario, an operator learns how to perform a maintenance operation in a multimodal Virtual Reality environment that mixes a traditional instruction manual with the simulation, based on visual and haptic technologies, of the maintenance training task.

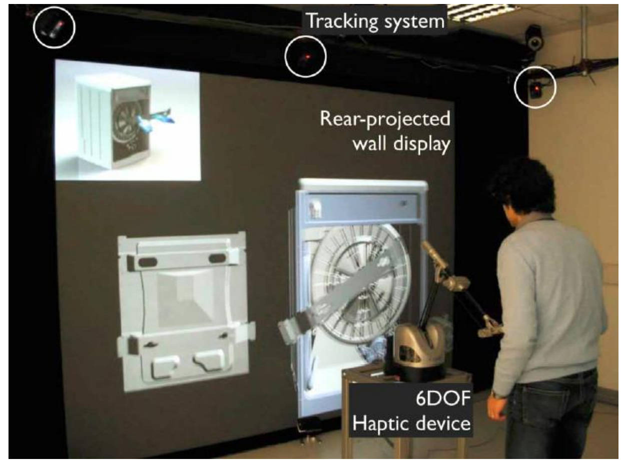

Figure 8. hardware setup: rear-wall projector and optical tracking system

In the second scenario, a skilled user operating in a similar multimodal Virtual Reality environment - but with the training features disabled (manual and order of tasks) - can remotely train another operator who sees the instructions about how the operations should be correctly performed, which are superimposed onto the real product. The approach has been tested on a case study consisting of a washing machine.

Limits and potentialities of the use of Virtual and Augmented Reality technologies for training operators for product maintenance are discussed. The proposed system (the case study consisting of a washing machine) helps companies improve the efficiency of the maintenance activity of their products during their lifecycle.

The work performed a user study measuring ease of use, intuitiveness, learning curve and goal achievement.

Already after a few trials, even users that had never used haptic devices before, were able to use the application and complete the task. Also the efficiency of the training system is good. Testers' suggestions were toward the improvement the communication from the skilled to the remote operator.

In perspective, the use of the environment can affect both the quality and costs of maintenance services. In fact, operators will have the possibility of practicing through continuous training, also learning how to cope with very rare situations. Furthermore, companies will be able to cut the costs related to the travelling of skilled operators and to reduce the intervention time.

The experiential training performed in virtual environments is a powerful alternative to classic video training explanations.

Borsci, Lawson, Jha, Burges and Salanitri, (2016) explored the virtual training for service operators in one of the most competitive and complex industrial fields, automotive.

Sixty participants were randomly assigned to one of the following three training experiences to learn a car service procedure:

1. observational training through video instruction;
2. an experiential virtual training and trial in a CAVE (Cave Automatic Virtual Environment);
3. an experiential virtual training and trial through a portable 3D interactive table.

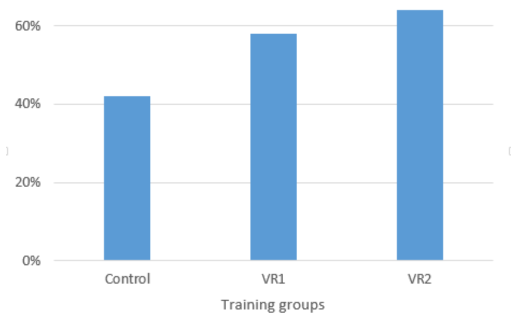

Figure 9. Score of participants (divided in Control, VR1 and VR2 groups)

Results (Figure 9) show that virtual trained participants, due to the possibility to interact with components and experience a procedure in a 3D training application, such as the LARTE-VBT, (Live Augmented Reality Training Experience project – Virtual Based Training) after the training can remember significantly better the correct execution of the steps compared to videotrained trainees.

Virtual training experienced through a portable device such as the interactive table can be as effective as training performed in a CAVE.

This suggests the possibility for automotive industries to invest in advanced portable hardware (i.e. portable and relatively cheap devices compared to a full CAVE system) to deliver effectively long distance programs of training for car service operators placed all over the world.

Recent statistics on causes of aviation accidents and incidents demonstrate that to increase air-transportation safety, we must reduce human errors' impact on operations. The main advantages in using computer-based systems to train or support technicians are that computers do not forget and that they can help humans clearly understand facts. Such features can help reduce errors due to procedure violations, misinterpretation of facts, or insufficient training.

AR is a promising technology to build advanced interfaces using interactive and wearable visualization systems to implement new methods to display documentation as digital data and graphical databases.

De Crescenzio, Fantini, Persiani, Di Stefano, Azzari and Salti, (2011) developed a prototype system that incorporates four main requirements for efficiency:

- it is user-centered;
- it implements markerless camera pose estimation;
- it provides an efficient authoring procedure;
- it keeps interaction simple and easy.

The participants understood well how to use the prototype and appreciated its implementation (figure 10).

Performed to requested operations ratio of 1,2 was obtained.

The case study indicated that this system is strongly application oriented, demonstrating AR's potential and overcoming some skepticism about AR.

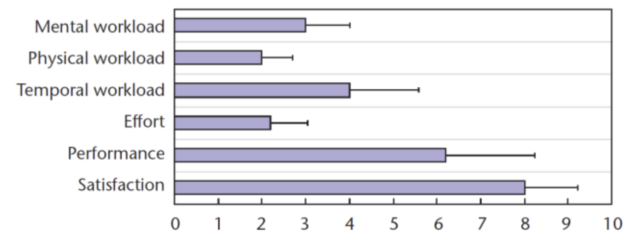

Figure 10. Participants rate of the prototype system

The study of Shamsuzzoha, Toshev, Tuan, Kankaanpaa and Helo, (2019) evaluates the use of VR platforms, which is an integrated part of the digital factory for an industrial training and maintenance system.

The research work was mostly concentrated to apply the virtual reality technique in industrial maintenance without considering the accompanied cost analysis.

The digital factory-based VR platform provides an intuitive and immersive human–computer interface, which can be an efficient tool for industrial training and maintenance services.

An application case on virtual reality technique in a power plant operations and maintenance is demonstrated within the scope of this research, which developed a digital factory model in virtual reality environment (Figure 11) and tested the capacity of virtual training and maintenance of industrial systems.

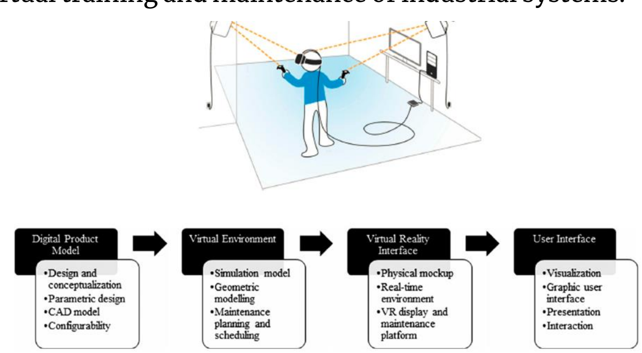

Figure 11. VR-based maintenance environment

The virtual reality platform, which is an integral part of the digital factory concept for industrial maintenance tasks, is complex activities that require specific knowledge and procedure.

Maintenance works are complicated, risky and expensive as well. Therefore, it would be a good idea for the industrial firms to finding ways to train more efficiently engineers to perform maintenance tasks.

The digital factory offers virtual maintenance system, which can be helpful for the engineer\technician to acquire sufficient knowledge and expertise before conducting the real-life maintenance works.

The time for maintenance operations is often restricted due to external circumstances. When conducted with inexperienced operators, additional uncertainties can arise and in case of a delay, high follow-up costs emerge. By using VR, operators may practice their skills in advance.

Schroeder, Friedewald, Kahlefendt, Lödding, (2017) analyze the training content and describe which parts of a generic operating cycle have the potential to be supported by VR as training technology.

The generic operating cycle is analyzed and the trainable parts for VR are determined. These are especially cognitive and motor skills up to the level of applying respectively manipulation. Subsequently, the paper derives a concept with the three training phases, preparation, execution and evaluation.

The paper describes the resulting information flow and the expected benefits of each phase. At last, it proves the feasibility of the concept by presenting a basic prototype.

Advantages of virtual reality training are ready acceptability of the method by the users, good efficiency in training, improvement in maintenance quality reduction in duration and cost of maintenance.

A key topic for the effectiveness of a virtual reality training experience, and for the success of these kinds of applications in the industrial field, is the subjective perception that the final end users (i.e., operators, managers, professionals, trainers) have during the training about the usability of the tool, and how much they believe that the virtual training is trustable and comparable to the real one.

2.7. The frontier

In the last part of the present work, two papers having particular subjects are selected.

Collaborative virtual environments and web-based multimedia maintenance manuals are treated.

The paper of Gerbaud and Arnaldi, (2008) describes a system used in the context of virtual training on collaborative maintenance procedures where the focus is on the learning of the industrial procedure rather than technical gestures. In existing collaborative virtual environments for training, the distribution of scenario actions among actors is fixed: only one role can be associated with a given scenario action. In this paper, a proposal to overcome this limitation and to add a mechanism to deal with this new flexibility is presented. This mechanism is able to select, dynamically, the best actor for an action, based on various criteria, and to propose a distribution of actions among actors (Figure 12). We also propose to add collaborative profiles to virtual humans to guide them in order to select the next action to perform, possibly following the distribution suggestion. Trainees and virtual humans can then adapt their activities while respecting the reference procedure.

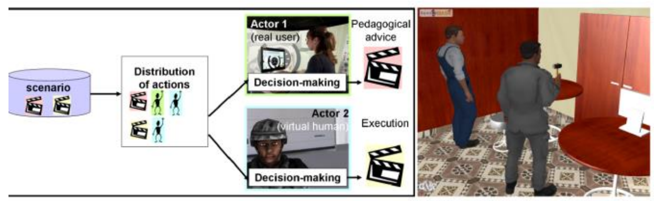

Figure 12. Real users and virtual humans share the scenario and collaborate

The mechanism presented requires to add minimal specifications in the scenario language used, to add a module of action distribution that communicates with the scenario and to add decision-making modules to each actor.

These modifications have been integrated into the General Virtual Training (GVT) project in order to validate the potential of our mechanism. It is also obtained a benefit from the collaborative profile to adapt a trainee's partners to his level of knowledge: we can provide novice trainees with partners who tend to help them while challenging expert trainees with trouble-making partners. The execution context of the procedure in order to evaluate whether the trainee has sufficient knowledge about the procedure to be able to adapt his way of performing it can also be changed.

It is also possible to use the application not to train people but to build a new procedure incrementally: by letting virtual humans perform it and observing the changes introduced while changing some elements of the context (number of people, location of tools, etc). Indeed, the observation of virtual humans adapting to unexpected situations, the problems they have to cope with or simply the division of work could help perfecting a procedure (change the expected distribution of tasks, the number of people required, the roles required, etc.).

Di Gironimo, Mozzillo and Tarallo, (2013) focus on a structured methodology that uses VR and digital human modeling (DHM) to study maintenance procedures of industrial products. VR technologies help to highlight the most critical aspects of maintenance operations, while DHM tools allow detailing working sequences.

Data coming from these analyses are then used to draw up a multimedia maintenance manual based on digital video animations, audio comments, explanatory images and written recommendations (Figure 13). Information is available to maintenance personnel directly on the working site through portable electronic devices. Furthermore, web-based multimedia manuals can be updated on-line and help to shorten learning time and maintenance costs and downtimes improving at the same time the quality of working.

The same technology could be extended to any assembly task as well as any industrial process involving human workers. Web-based manuals potentially may give better support to workers than a paper guide. Operators can look through the most updated version of the maintenance sequences and procedures by means of portable electronic devices (PDAs, tablet PCs, etc.) connected with a remote data repository.

A still open issue is time needed to draw up the multimedia manual and to develop simulations using digital humans.

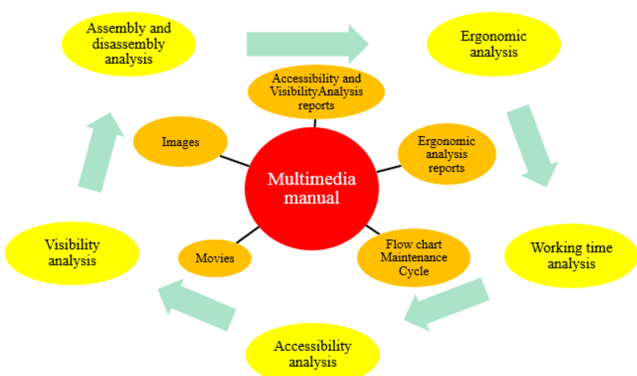

Figure 13. Multimedia manual information flow

3. ENI Experience

We conclude the paper with a reference to O&G activities, namely Eni experience in Virtual and Augmented Reality.

Some applications of 3D immersive virtualization have been developed over the last couple of years.

Many devices have been tested for visualization (like standard 2D monitors, stereoscopic view using stereo glasses, and immersive 3D using HTC Vive Virtual reality helmet) and interaction (HTC controllers, ManusVR: gloves for hand/finger tracking, Leap Motion: camera for hand/finger tracking).

Active objects have been inserted in the 3D model, being capable to be queried by the virtual player (the "avatar"). These objects, configured in a suitable database, provide various types of data and are used for specific operations during the training sessions.

Specific functionalities have been included as well:

- some HSE cases replicating really occurred incidents;
- historical data. For instance from real wells, historical data can be played-back, producing both drilling rig equipment motion (for string battery management) and well data display on virtual interfaces inside the virtual rig consoles.

Simultaneous multiusers have been included. For instance, in case of training sessions, each trainee tests particular operations and the trainer supervises it, starts various events, runs HSE events, modifies ambient conditions (time of day, weather) or operative conditions (alarms, fire/gas release), monitors the execution of "missions" by the trainees.

The potentialities of Virtual and Augmented reality in Oil and Gas field are still not completely expressed. Eni and EniProgetti are continuing to invest in those technologies. We envisage an implementation journey that can follow several and correlated steps.

In the short term, VR and AR promise to overcome traditional training methods and improve support to the operators in both normal operations and emergency scenario, leading to an improved safety of people and plants.

In the medium term, virtualized environment can be used as a decision making tool. Thanks to the always closer to the simulations of real plants, Company would set-up and plan the operations and, by comparison with the real behavior of the plants, optimize the control configuration to get best results, safety and production wise.

Looking some more years ahead, O&G plants will be remotely operated by the virtualized console or by drones or robots thanks to the future AI and ML algorithms.

4. Conclusions

Most of industrial accidents are related to some kind of human failure. Probability of human error is influenced by ability, training, experience, personal correctness and aging.

The most important methods to assess human failure (error) are from NPP field, but some methods are general.

Work environment, organization and individual features turn out as the major contributors to human error and quality of the performance of a maintainer.

According to the literature, fatigue, knowledge and experience, and coordination and communication are amongst the most important human factors related to the maintenance.

Augmented reality (AR) is a key technology for the development of smart manufacturing.

Virtual trained participants to studies, due to the possibility to interact with components and experience a procedure in a 3D training application, such as the LARTE-VBT, after the training can remember significantly better the correct execution of the steps compared to videotrained trainees.

SAR presentation mode is significantly better than paper presentation in completion times (reduction of 20.3% in overall completion time) and error rates (83.3% fewer errors with the SAR mode)

SAR can be used for both training new maintenance operators and assisting operators in ordinary maintenance. Gamification can be used in a maintenance context, both in input data and presentation output to motivate the user.

A skilled user operating in a similar multimodal Virtual Reality environment can remotely train another operator who sees the instructions about the correct operation performed.

In collaborative maintenance procedures, the focus is on the learning of the industrial procedure rather than technical gestures. This mechanism is able to dynamically select the best actor for an action.

It is also possible to use the application to build a new procedure incrementally.

Portable and relatively cheap devices can be used for long-distance training activities with the same effectiveness compared to a full CAVE system.

VR technologies help to highlight the most critical aspects of maintenance operations, while DHM tools allow detailing working sequences.

Data coming from these analyses are then used to draw up a multimedia maintenance manual based on digital video animations, audio comments, explanatory images and written recommendations.

Web-based multimedia manuals can be updated on-line and help to shorten learning time and maintenance costs and downtimes.

A still open issue is time needed to draw up the multimedia manual and to develop simulations using digital humans.

To date only the safety issue has been deeply investigated, due to its relevance in high-risk industries. Instead, the HEM impacts on economic and environmental consequences have been superficially considered.

Future direction would be investigating human factors from long-term cost, availability and ergonomics points of view in a wide range of industries.

Human resource management and scheduling could be an interesting area for future studies.

Other future directions in this area would be to develop human error models for different types of error (slips of action, mistaken assumption etc.), error prediction and recognition tools and technologies, intelligent decision aid system.

Eni, along with its engineering arm EniProgetti, is strictly following the diffusion and evolution of the Virtual and Augmented Reality applications. Some projects are ongoing to experience the benefits and potentialities of such applications in the O&G sector (Figure 14).

Eni interest proves the interest of O&G industry in VR/AR for training, in maintenance but also in operation (becoming more and more automatic) and in general in all human based activities that are core parts of the Energy business.

In the short term, in O&G VR and AR will improve safety of people and plants.

In the medium term, virtualized environment will optimize safety and productivity at the same time

In the long term, O&G plants will be remotely operated by the virtualized console or by drones or robots.

Figure 14. VR in Drilling Operation Training

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