Risk Assessment and Optimization for New or Novel Processes: Combining task analysis with 4D process simulation-framework and case study.

Maria Chiara Leva
Technological University Dublin, maria.leva@tudublin.ie

Marko Gerbec
Jozef Stefan Institute

Nora Balfe
Trinity College Dublin

Recommended Citation

Gerbec, M., Balfe, N. & Leva, M.C. (2015). Risk assessment and optimization for new or novel processes: combining task analysis with 4D process simulation-framework and case study. *ESREL 2015*, Zurich, Switzerland. doi.org/10.1201/b19094-54

Authors

Maria Chiara Leva, Marko Gerbec, Nora Balfe, and Micaela Demichela

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M. Gerbec
Jozef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia

N. Balfe, C. Leva
Centre for Innovative Human Systems, Trinity College Dublin, College Green, Dublin, Republic of Ireland

S. Prast
Celtic Oil, Borris, County Carlow, Ireland

M. Demichela
Politecnico di Torino, Dept. of Applied Science and Technique, Corso Duca degli Abruzzi, 24, 1029 Torino, Italy

ABSTRACT: This paper describes work undertaken as part of the TOSCA project to develop approaches integrating and enhancing safety, quality and productivity. The work reported here combines two existing approaches: task analysis and 4D process simulation to model tasks in a 3D environment, thus creating a 4D model. The 4D model is next used for safety analysis (e.g., ~~HAZOP~~ a structured Hazid study) and optimization (e.g., Pareto type). The approach is demonstrated on an industrial case study involving the planning of a infrequent cold water pressure testing of LPG storage tanks at a partner site. The results of the case study are presented and discussed. The plant management was provided with a detailed list of the main tasks (22), subtasks (115), specific risks identified (procedural delays, occupational safety and process safety) and 19 specific recommendations for safety and time optimization of the planned testing procedure. This information was warmly received by the plant management and field implementation of the procedure is planned for May 2015.

1 INTRODUCTION

This paper describes work undertaken as part of the EU FP 7 TOSCA (Total Operations Management for Safety Critical Activities) project (http://www.toscaproject.eu) to develop approaches for integrating and enhancing safety, quality and productivity. One of the areas of research to be tackled is Design and Planning for Safety, and within this an approach is being developed to assess the risks involved in complex changes, for example due to the introduction of new processes or procedures, or, as in the case study discussed in this paper, non-routine maintenance or inspection tasks. This methodology combines the human factors method of task analysis with 4D process simulation to model the system and identify areas for improvement, both in terms of process safety and efficiency. 4D Simulation is a method that brings together Discrete Event Simulation with a highly accurate 3D model of environment. The discrete event simulation is then run in the 3D model and the results collected and analysed. This paper will explain the overall approach, present its application within the TOSCA project's case study applied to the periodic inspection of pressurized vessels for liquefied petroleum gas (LPG) storage. The inspection procedure, made of complex manual procedures, is applied rather rarely (at least every five years according to the law, but can be substituted with less disturbing methods, so in reality full internal vessel inspections are done every 10+ years) thus affected to staff turnover, meaning that previous experience and procedures may not be available at the time of testing. In this paper we will also present case study results in terms of recommendations generated by this approach for the plant management for the coming full test procedure to be carried out.

2 APPROACH

The approach builds on using the principal methods such as Task Analysis (TA) in relation to 4D modelling and visualization of the operation under analysis. This renders a clear representation to the analysis team about the abstract details of the operation(s), next enabling them to apply the hazard identification methods, ~~(e.g., HAZOP),~~ qualitative risk categories ranking, as well as efficiency (e.g., in terms of resources needed, time, staffing, equipment, etc.). The overall approach is graphically presented in Figure 1 and suggests that decisions shall be taken after the optimization step – where recommendations from previous steps are compiled and assessed for the completeness and possibly about the tolerability of the residual risk levels. However, for example, in the case that the individual steps led to changes/additions to the list of tasks under considerations, the whole assessment shall undertake an additional update iteration. The details of the specific steps within the approach are given in the next subsections.

2.1 *Task analysis*

Task analysis is used to describe and evaluate the human interactions in a system. As such, it forms the basis of many human factors risk assessments. Task analysis has been defined as the analysis of how a task is accomplished, including a detailed description of both manual and mental activities, task and element durations, task frequency, task allocation, task complexity, environmental conditions, necessary clothing and equipment, and any other unique factors involved in or required for one or more people to perform a given task (Kirwan, 1992). Without these important representations of the socio-technical system, it would not be possible to correctly analyse the system and identify and evaluate all the relevant risks. Task analysis methods are widely used by human factors professionals outside of risk assessment and these methods are usually appropriate for supporting a risk assessment. Common task analysis representations include Hierarchical Task Analysis (HTA; Annett, 1967), Link Analysis (Chapanis, 1996), Operational Sequence Diagrams (Kirwan, 1992), Cognitive Task Analysis (CTA; Stanton, 2005) as well as methods used more widely outside the human factors domain such as Business Process Modelling (Aguilar-Saven, 2004). In this case, the Business Process Modelling approach was used as incorporated in the SCOPE software (Builes et al, 2014). SCOPE displays the task analysis in the form of a process map and further provides a template for the analysis team to conduct a hazard identification technique, ~~known as~~similar to HazOp, on the tasks. The information to feed the task analysis can be gathered from documentation (e.g. procedures) as well as individual experience. In the case of a rarely performed procedure, such as the case study presented here, the task analysis may be an iterative process that is refined as the procedure becomes clearer. The 4D modelling is a key tool in facilitating this improvement.

2.2 *4D modelling*

Simulation can be defined as the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed. This model represents the key characteristics or behaviours of the selected process (Banks, 2001). The model depicts the environment in which the process itself takes place, often in a 3D manner; the simulation depicts the operation of the process over the fourth dimension, time. This paper focuses on the use of discrete-event simulation, which models a process as a discrete sequence of well-defined events in time. Such events occur at a particular instance in time, marking a state change in the process (Robinson, 2004). Processes modelled in a discrete-event simulation must include predetermined starting and ending points, and a list of discrete events that occur in between these points. Discrete-event simulation is commonly used to monitor or predict procedures and processes in various industries, such as manufacturing.

Use of 4D simulation is beneficial as it employs the “learn by doing” principle and Park (2011) state

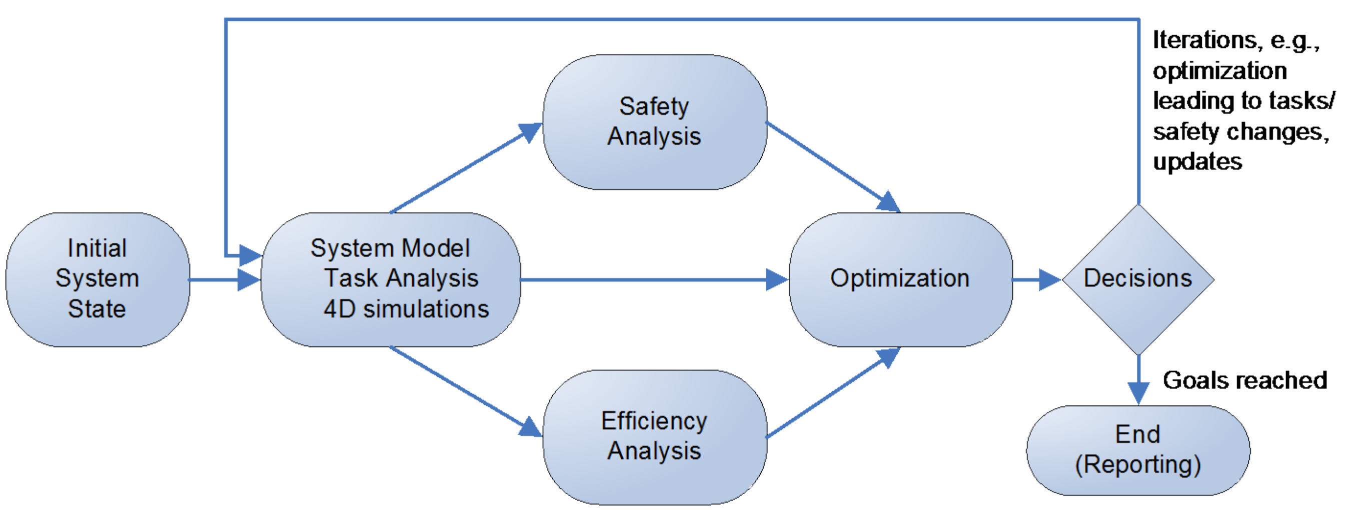

Figure 1: The graphical presentation of the proposed approach.

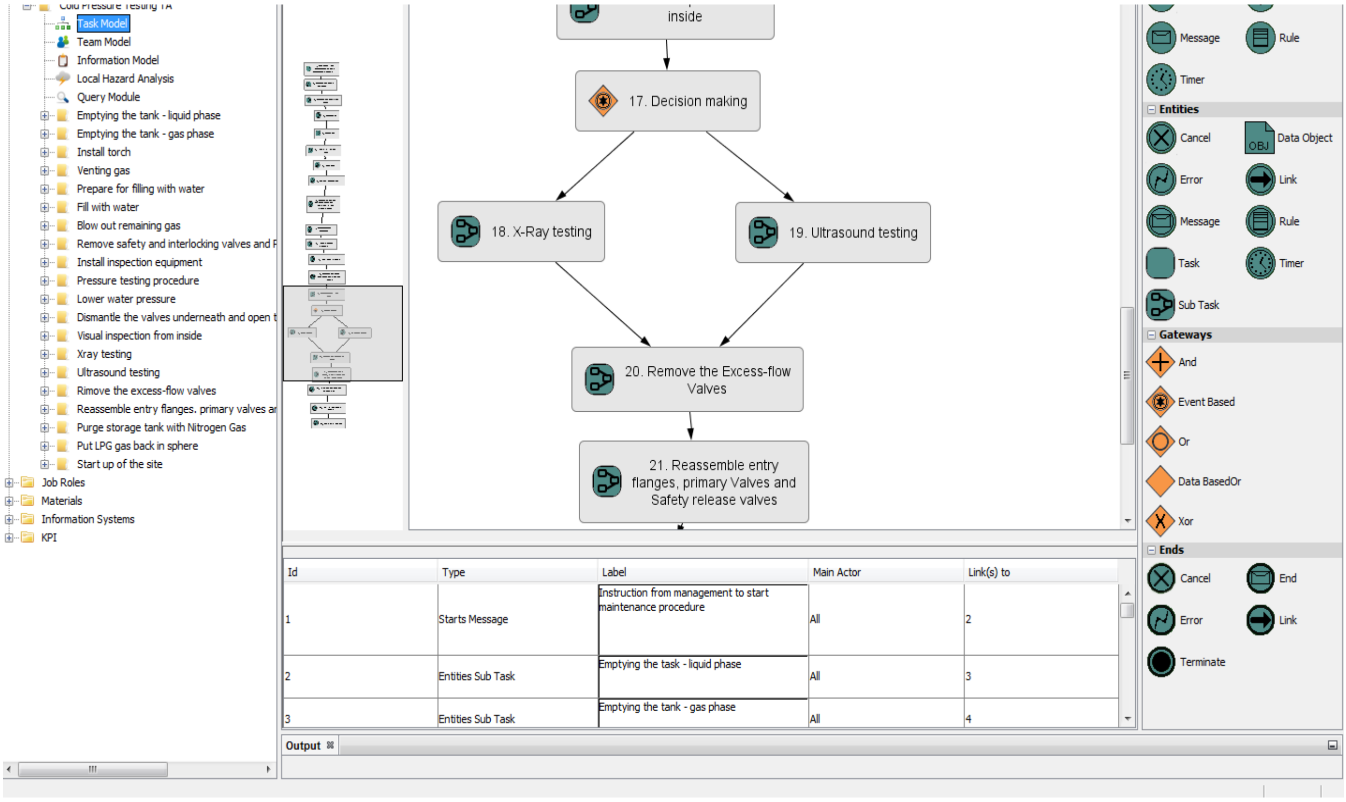

Figure 2: The SCOPE program interface during the task analysis of the case.

that the positive impact of 4D simulation on productivity and safety is proven in construction processes. This paper focuses on a case study which includes a process, distributed across the production site, that is undertaken quite infrequently. One of the key problems with improving processes on distributed sites is the difficulty in visualizing the process (Sacks, 2009) and Kang (2007) demonstrated that logical errors in construction schedules could be detected quicker and more reliably using 4D models as compared to 2D drawings. In this instance, a simulation would allow personnel to visualize and review the process virtually, identifying potential improvements as well as becoming better acquainted with it. It is often not possible to achieve this using the real environment due to lack of access opportunities, risk of damage to the plant, and risk of injuries to personnel. Using simulation to optimize, plan and prepare for infrequent, complex activities minimizes these risks during the actual operation.

2.3 *Safety Analysis*

The next step is ~~safety analysis of the detailed~~the hazard identification based on the tasks ~~for the hazards in the system~~analysis. This is based on using the task analysis outline as the basic functional analysis and ~~to~~ then perform a structured Hazard identification ~~perform a more broad~~ workshop similar to a HAZOP study (Kletz, 2006) where the nodes are ~~on~~ individual (sub)tasks instead of parts of a plant. The approach can be referred to as TASK HAZID (Leva et al 2012). The Hazid~~AZOP~~ study involve~~ds~~ a team workshop exercise with the team containing the appropriate expertise, including knowledge of the plant and the planned operation, safety analysis, and human factors knowledge. The identification of hazards was accompanied at the same time with a semi-quantitative risk category estimation in order to separate between safety and productivity issues. That involved assigning the consequence classes on a 1 to 5 point scale, and similarly assigning their likelihood of occurrence, while risk values were simply provided by multiplying both.

In the case study presented here, the TASK ~~HAZOP~~ HAZID and risk categorization was carried out in the SCOPE software (Builes et al, 2014) which facilitates an examination of each node in the task analysis, allowing each deviation to be documented and analysed. The capability of holding the full analysis in one software application streamlines the analysis and simplifies the documentation of the analysis itself.

2.4 *Optimization*

Following the safety analysis, the optimization process can be applied in two steps. The first is optimization of the 4D model and its (sub)tasks is performed with implementation and operating costs as the dependant variables. The optimization then done through an iterative method which tests each iterative arrangement over a statistically significant number of simulation runs. The result is a local optimization within the system based on cost. The second step applies to the results of the task analysis and the TASK HAZID ~~HAZOP~~ study, where the initial list of tasks is next refined and subjected to further optimization. We suggest that this optimization be done when hazards are already revealed (thus, e.g., after TASK HAZID) ~~HAZOP study)~~ and the team can concentrate on the further aspects, e.g., time duration of the main tasks, pertaining costs, etc. Finally a sensitivity analysis is done using a Pareto type optimization (Pareto, 1906) on a given system/activity aspect shall be applied and opportunities for further improvements searched for and documented.

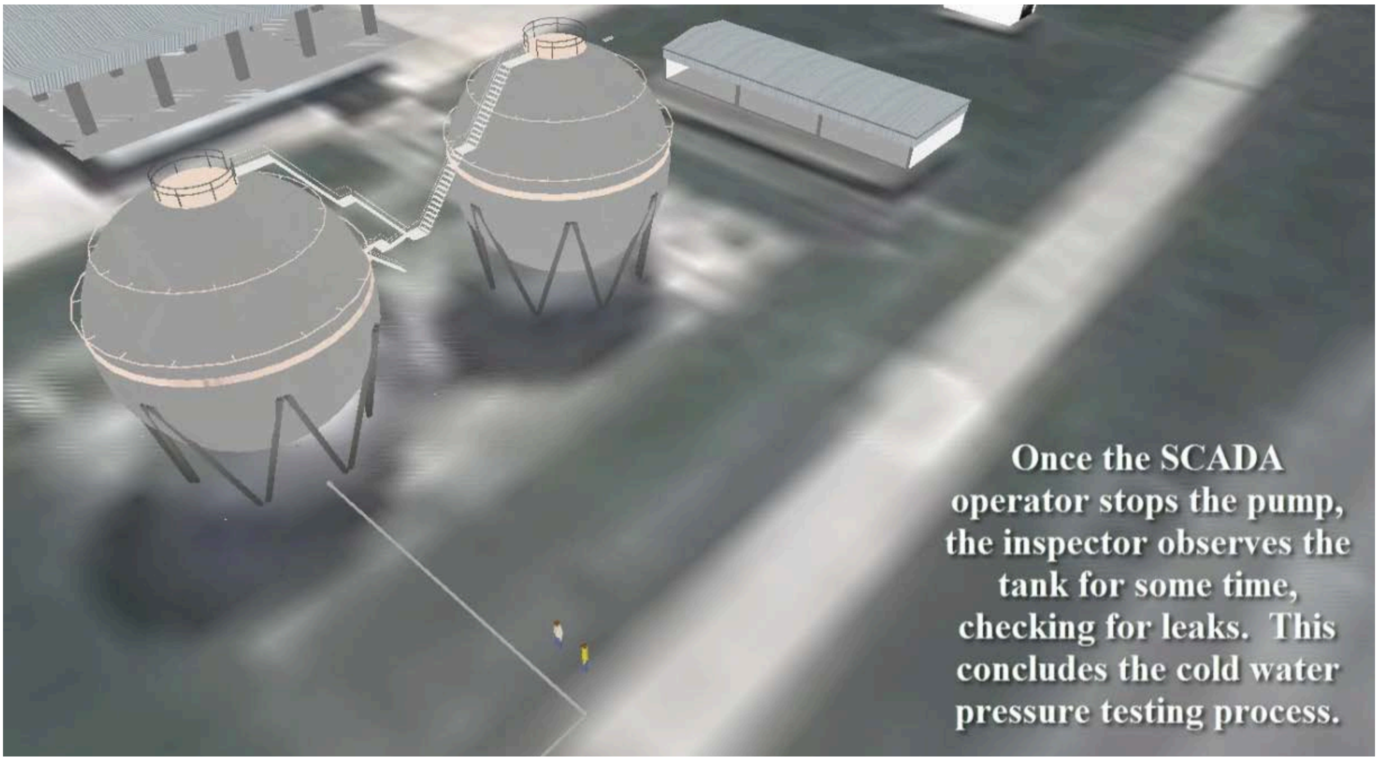

Figure 3: 4D simulation illustration from the case animation.

3 CASE STUDY – PROCESS AND RESULTS OBTAINED

The case study was completed at the company Plinarna Maribor d.o.o., LPG storage site located at Maribor, Slovenia (project partner). The periodic pressure vessel testing procedure consists of a number of steps. The pressure vessels considered are two 1000 m^3 volume spherical above ground storage tanks. The product stored (LPG) must be removed first before the vessel is prepared for pressurized water testing, emptying, internal visual inspection, ultra-sound and X-ray spot testing, and finally to be put back into operation. The individual steps are connected in a logical order but the details and criteria to proceed or not were not so clear at the start for the plant staff. The offer to analyse and re-develop the detailed procedure using the proposed approach outlined in earlier sections was accepted by the plant manager.

3.1 *Task analysis*

The task analysis was carried-out by the team and involving the site personnel. The task model was constructed in SCOPE software tool. The high level tasks and sub-tasks in the process were documented (Figure 2). The task analysis also captured actors, information, tools and duration of each envisaged task. During this step, 23 main tasks and 115 sub-tasks were identified.

3.2 *Creation of 3D visual and 4D model/simulation*

The site was first photographed extensively with a digital camera. Many pictures were taken from all possible angles of the buildings, equipment and layout of the site. Those pictures were then used to 3D models of the buildings and equipment at the site using photogrammetry software. Next, a high-resolution image of the site was taken from Google Earth. Finally, the 3D models of the buildings and equipment were placed on the high-resolution image to for a high accurate and easily recognizable 3D model of the entire site.

A 4D simulation was built using the 3D model of the site and the information from the task analysis. The behaviour of the individual tasks were modelled, including stochastic values for process and movement times. The simulation demonstrated the planned operation in order to allow the optimization of tasks and was annotated with information captured during the task analysis. Furthermore, the tool aided in documenting this complex testing procedure in advance and communicating the complex procedure to a variety of personnel. Figure 3 illustrates a screen capture from the simulation.

3.3 *Safety analysis*

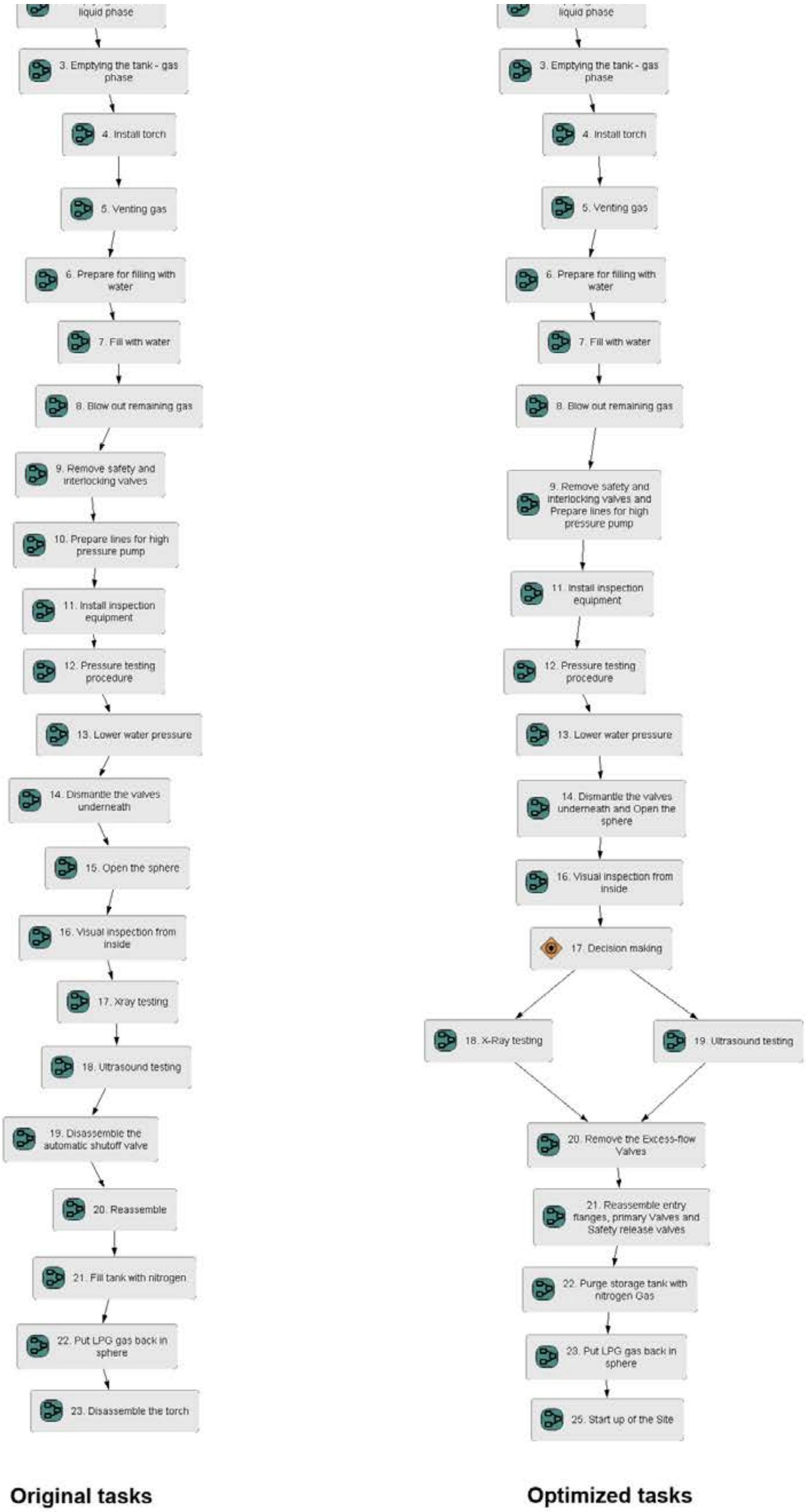

Figure 4: Task analysis diagrams for both the Original and the Optimized alternatives of the cold water pressure testing procedure.

Overall, the Task based ~~HAZOP~~ hazard identification study (TASK HAZID) operated as a central work point using both task analysis and 4D modelling as inputs and providing a list of recognized risks and additional safety measures as a main result. The team identified 26 potential deviations that could lead to ~~risks~~accidental scenarios. The TASK HAZID ~~HAZOP~~ study also suggested ~~that we can expect~~ three ~~different~~ main types of unwanted consequenc-

Table 1: Summary of recommendations from the ~~ HAZOP~~TASK HAZID study done over task analysis results.

#	Recommendation	Related tasks
1	Prepare a detailed written cold water testing procedure, following the tasks identified and implementing the specific recommendations given next. Suggested main topics: - General and specific planning of the testing (e.g., assurance of the contractors/equipment, list of all personnel (internal/external)), - Logic sequence of the tasks and sub-tasks, for each to consider validation criteria for completeness, as well as to mention anticipated hazards and required permitting. - Testing reporting - progress in time, persons involved - on suitable forms and check-lists, as well as to appoint approvals to next step(s).	All
2	Use of the torch with two pilot flames with thermal lock system - in order to assure reliable pilot flame	5, 23
3	Consider purging of the remaining LPG gas in the storage tank at level between 95 % and 100 % by nitrogen, from either car tanker with vaporizer, or from the bundled bottles. Prepare a detailed nitrogen purging protocol, related to recommendation 1.	7, 8, 22
4	Permanently monitoring of the tank water fill-in process; to assure adequate staffing and specific appointed person. Setting on the SCADA for an audible alarm at 98 % of full tank.	7, 22, 23
5	The measurement instruments used, are to be checked constantly during the test, related to strain gauges and movement of the tank observations. In case of the deviation(s) stop the procedure, thus the criteria must be defined prior the cold water testing starts. Note: additional task to be added to the previous task analysis to assure the mentioned equipment and contractors.	7
6	Plan the engagement of the contractors. Risk assessment of the operations and safety measures to be in place according to the national legislation on occupational health and safety, e.g., regarding work at height, falling objects/tools, work in closed spaces or potentially oxygen depleted atmosphere/flammable atmosphere, as well as common workplaces.	8, 16, 18, 20, 21
7	Consider in the procedure to check the water level before removing the valve at the end of task 8 (in order to assure low enough amount of the remaining gas inside tank).	8
8	In recommendation 1 consider also planning of the suitable crane with long enough arm to reach top of the sphere.	8, 21
9	While planning the high pressure water feed connection from the fire water system into the storage tank (considering the selected high pressure pump): - specify flexible hose rated for high enough pressure (30 bara) - validate with vendor/supplier, - as a back up plan for hose failure/leak, prepare in advance a fixed piping, or prepare sufficient fixed pipes and joints parts, to assemble connection on the spot.	9
10	Plan strict use of the validated and calibrated equipment (e.g., pressure and level measurements), validate also high pressure water specific rate, to be received from the contracted inspector.	12
11	Plan in a detail where to install blind flanges at the storage tank connections, in order to assure tightness at the connections during the high pressure test.	12
12	In recommendation 1 consider also correct sequence of actions to lower the water pressure in task 13 (13.3, related to the potential high pressure water jet, injuring the personnel).	13
13	Plan the electrical wiring and electrical installations to be installed only from the top opening, and not from the bottom opening, in order to prevent electrocution hazards, related to the potentially falling objects/tools for visual inspections, ultrasound testing and X-ray testing, expected to be done inside the storage tank.	16, 18, 20
14	Check with the insurance company about the liability coverage on cold water testing procedure, considering the own and the contracted personnel, as well as the equipment used/present.	All

es with increasing severity —~~ categories ~~following a ladder approach:

i. procedural risks (work delays); examples are too few fitter personnel at piping re-assembly, a ~~too short ~~crane arm too short to perform ~~for~~ PSVs removal ~~from ~~at the top of the spheresphere ~~top~~, as well as a possible low flowrate~~ water flow rate~~ ~~unknown in advance~~ for sphere fill-up.

ii. occupational safety risks; examples are personnel injuries due to LPG torch flame-off/on, work at height (sphere top), suffocation or electrocution hazards inside sphere, etc.

iii. process safety risks; examples are damages to equipment and/or personnel in juries/fatalities due to water ingress into compressor, tank sphere static overload with water (deteriorated legs), spheres damage by applying pressure above 25 bar, etc.

For the sake of brevity, the additional safety measures ~~are ~~were compiled as a list of recommendations to be incorporate into the detailed ~~toverall~~ ~~t~~esting procedure by the plant manager – reported in Table 1.

The TASK HAZID~~ HAZOP~~ study also rendered some additional tasks to be planned, possible re-scheduling of subtasks~~their optimal order changed~~,

Table 2: Summary of recommendation from the optimization step (considering top 5 out of 22 overall tasks (22.7%), related to 69 % of overall anticipated time needed.

#	Duration (h)	Main Task	Optimization opportunities	Duration (%) each	Duration (%) cumulative
1	72	16-Re-assemble entry flanges, primary valves and safety release valves (after previous completed)	a.) Evaluate alternative to apply more personnel at re-assembly task for entry flanges and SRVs, as overall man-hours needed should be the same, thus less time here. b.) Evaluate alternatives in organizing work on 8 h per day, against e.g., 24 ur-7 days per week basis, for whole testing procedure.	19.2	19.2
2	64	5-Fill with water	c.) Expected water flow rate into is unknown; plan and perform a small scale tank fill-up test using same conditions and equipment in order to get at least some estimate.	17.1	36.3
3	50	10-Lower water pressure	d.) Consider using larger pipework (over 2") and/or shorter pipework, in order to increase water flow out rate and save time here.	13.4	49.7
4	48	8-Install inspection equipment (this can be done from task 4 onward or more than likely during the filling with water)	e.) Assess and plan which tasks and sub-tasks can run in parallel, e.g., this one during water flow out sub-task.	12.8	62.5
5	24	12-Visual inspection from inside (this task can be performed after the valves underneath have been dismantled)	f.) Consider more inspection personnel to speed up the work.	6.4	69.0

or specific precautions to be added. In general, this led to the update of the task analysis and its report, leading us to the Original as well as Optimized versions of the report and related graphical diagrams from the SCOPE programme – both are simultaneously presented for comparative purposes on Figure 4. ~~The reader will note that some~~Some tasks were merged (e.g., 9 and 10 merged into a new 9) in order to emphasise closely connected sub-tasks, decisions were explicitly added (new task 17, old 17 became 18), some were added (final 25), thus leading to 22 top level tasks in the Optimized alternative.

3.4 *Optimization*

Having obtained the Optimized list of tasks to be pursued within the testing procedure, the assessment of the total duration done, being assessed to about 372 hours (15.6 days), considering 24 h per day and 7 days per week work. After consultations with the plant management, it was spotted that some tasks indeed need more time than others (not a surprise), and some could be accelerated using more resources (e.g., contracted personnel) while same man-hours product is needed. The general optimization approach was to perform a time Pareto style analysis, namely, sorting the main tasks in decreasing duration time (info collected in task analysis), and for those most lengthy ones to discuss the alternatives for shorten them. The results are presented in Table 2. We can note that top 5 main tasks out of total 22 (22.7 %) are related to cumulative 69 % of total time envisaged, being about 372 hours.

While not exactly following the proposed 80/20 Pareto rule, the similarity (69/23) provided additional insights about tasks that are worth of time optimization. In addition, for those tasks optimization opportunities were listed, and are to be added to the previous list in Table 1.

4 CONCLUSIONS

The approach to design and plan for safety ~~is~~ proposed in this paperr~~. It~~ consists of interconnected methods and tools used ~~to apply~~for task analysis, 4D simulations, ~~safety analysis~~hazard identification and optimization for ~~a complex, hard to visualize~~complex testing and or overhaul operations. The approach ahs been tested on a case study consisting on pressure testing of LPG tanks and it ~~case study use of the proposed approach appears to be a very good example of its use. The case study~~ provided 20 specific recommendations overall for the industrial partner's ~~management of~~on how to plan in detail ~~a rare and demanding~~this infrequent and demanding testing procedure. However, the approach could be easily ~~used or demonstrated on~~applied on ~~any~~ other safety or production critical operation, ~~above all,~~especially when the tasks are hard to visualize ad the human factors play a relevant role in it ~~procedures and human operation play a relevant role, as in the case under study and, more in general,~~(e.g. ~~for~~

batch processes~~ and operations~~). ~~The f~~Further work on this approach will involve its field verification against the actual ~~(the actual~~ testing procedure~~ is~~ planned ~~f~~to take place in~~or~~ May 2015. The verification will check whether the method missed on ~~) in terms "were~~ any important task~~s~~, or risk~~s~~ when comparing the actual activity with its ~~missed in the analysis/~~planning phase.~~?"~~ In addition, the authors ~~plan to~~are currently working on ~~perform~~ a probabilistic risk assessment ~~for~~ of the overall procedure ~~comparatively considering~~to compare the Original and the Optimized procedure ~~alternatives and link it with~~and use the data in a~~the~~ cost-benefit analysis of the risk mitigated against ~~avoided against~~ the costs of the ~~performing the~~ analysis and ~~careful procedure planning~~recommendations identified.

5 ACKNOWLEDGEMENT

The work presented in this paper was done in the scope of EU 7FP project TOSCA under grant agreement FP7-NMP-2012-SMALL-6-310201.

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