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# Total Project Planning: Integration of Task Analysis, Safety Analysis and Optimisation Techniques

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# Total project planning: Integration of task analysis, safety analysis and optimisation techniques

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ABSTRACT

Safe and successful completion of complex projects in industrial environments requires careful planning and collaboration of different stakeholders. This paper presents the integration of three methods (task analysis, safety analysis, and project optimisation) to apply a holistic approach to complex project planning. The attributes and limitations of the separate elements are discussed, and a case study applying the integrated methodology is presented. The results from the case studies indicate that significant benefits in terms of time, cost and safety can be achieved through the application of the integrated methodology.

## 1. Introduction

The safe and successful completion of maintenance and overhaul procedures is dependent upon the collaboration of different departments and individuals, the clear planning of the work, and the availability of the required resources. For complex or rarely performed procedures, the competence and knowledge needed for planning and mitigating the risks associated with the project may be spread across different parts of the organisation. However, accessing and utilising this knowledge is critical for de-risking major projects and investments. Major projects, for example the delivery of the London Olympic Park, are increasingly placing value on the ability of suppliers and contractors to deliver projects with the highest levels of safety (Shiplee et al., 2011) and the criticality of safe performance of maintenance procedures is illustrated by major accidents such as Piper Alpha, Clapham Rail Disaster, and Texas Oil Refinery. However, Badri et al. (2012) state that project management is often deficient in integrating safety risks. In a study of 183 process industry major accidents, Okoh and Haugen (2014) found that 44% had a link to maintenance and of these, deficient planning/scheduling/fault diagnosis were a cause in 69%. Maintenance is also a factor in 15–20% of all occupational health and safety accidents, and 10–15% of all fatal accidents (OSHA, 2011). The need for safer maintenance must also be balanced with the business requirements for time and cost effective completion of maintenance activities.

Previous research has focussed on identifying safety hazards as part of the project planning process, and has had some success in integrating the safety analysis with 4D models used to communicate and engage with project stakeholders (e.g. Benjaoran and Bhokha, 2010; Gerbec et al., 2016a). This paper extends such work by also incorporating uncertainty modelling using the Monte Carlo technique, giving stakeholders the ability to assess the impact of different resourcing choices on the project timescales and risk. This paper presents a methodology for the elicitation of the information required to fully plan a maintenance activity, assessing both safety and efficiency goals, using a participatory approach that harnesses the existing knowledge in the organisation and engages key stakeholders in planning activities to help ensure safe and timely completion of activities. The results of a case study application of a maintenance overhaul procedure in an electricity generating station are also presented. The approach was developed under the scope of the TOSCA (Total Operations for Safety Critical Activities) project, which developed a set of principles, processes and tools to support Total Safety Management (TSM; Kontogiannis et al., 2016). TOSCA proposes the development of a Common Operational Picture supported by four safety pillars: commitment in action, understanding risks and hazards, managing/treating risks, and

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learning from experience. The methodology presented in this paper contributes to commitment in action, through the use of participatory approaches, and understanding risks and hazards.

The methodology consists of three strands:

- A participatory workshop to produce a detailed task analysis of the works, providing a basis for the plan;
- A participatory risk assessment based on the task analysis, to identify risks and plan appropriate mitigations;
- A Monte Carlo simulation based on the task analysis, to provide a cost-benefit analysis of the use of additional resources.

The participatory approach is designed to engage stakeholders from across the organisation in the planning, and ultimately the successful completion, of the maintenance project. This approach draws strongly on the area of Participatory Ergonomics, an approach concerning "the involvement of people in planning and controlling a significant amount of their own work activities, with sufficient knowledge and power to influence both processes and outcomes in order to achieve desirable goals" (Wilson, 1995, p. 1071). Kuorinka (1997) describes the role of all those with first-hand experience of the problem in question to work together towards problem solving, i.e. the participation of stakeholders. The benefits of a participatory approach are improved design solutions incorporating the accumulated knowledge and experience of the stakeholders, and improved acceptance of the solutions (Gyi et al., 2015). Typically, Participatory Ergonomics approaches tackle issues in the everyday operations of an organisation, such as production lines, using a wide variety of methods (Nagamachi, 1995). However, Kuorinka (1997) suggests that complex industrial processes may also benefit from participatory approaches, particularly considering they are typically not well represented by the procedural standards. In terms of safety management, participatory ergonomics approaches have been widely applied with the objective of preventing musculoskeletal disorders (Yazdani et al., 2015) but may also be effective in creating a strong safety culture (Rocha et al., 2015). The participation of the workers in identifying hazards and developing mitigations helps to engage workers in safety, while increasing the realism of the safety assessment and the practicality of the mitigation measures.

The data collection and analysis is based on bottom up estimation techniques (PMI, 2013) captured in a tabular task analysis that is subsequently used as the basis of the risk assessment. Task analysis is the human factors equivalent of a functional analysis in systems engineering, where task analysis identifies and examines the tasks performed by human operators when interacting with the system (Kirwan and Ainsworth, 1992). As in a functional analysis, decomposition of higher-level functions adds more detail and allows system objectives to be allocated to lower-level functions. Task analysis methods are widely used by human factors professionals for a variety of purposes, including risk assessment of human activities and tasks within a system (Kirwan, 1998). Common task analysis representations include Hierarchical Task Analysis (HTA; Annett and Duncan, 1967), Link Analysis (Chapanis, 1996), Operational Sequence Diagrams (Kirwan and Ainsworth, 1992), Cognitive Task Analysis (CTA; Stanton et al., 2005) as well as more general process and flow-chart techniques. The data for these representations are usually captured through observations, analysis of documentation, and/or interviews. Tabular task analysis captures the data in a sequential list of tasks, broken down into sub-tasks as necessary.

The completed task analysis can be used to structure a risk assessment, where hazards can be identified and analysed for each task documented in the task analysis. Hazard identification is based on screening issues according to five types (offering prompts specific for the domain) to identify possible issues connected with each step of the task analysis using a structured workshop format. This approach is similar to a HAZOP study (Kletz, 2006) in which each part of a plant is examined in turn, but in this approach the nodes are individual (sub)tasks instead of parts of a plant. The approach can be referred to as Task HAZID (Leva et al., 2012; Demichela et al., 2014; Gerbec et al., 2016a). The identification of hazards can be accompanied with a semi-quantitative risk category estimation in order to separate between safety and productivity issues. This involves assigning the consequence classes on a scale (e.g. 1–5), and similarly assigning their likelihood of occurrence, while risk values are simply provided by multiplying both. The method allows the hazards associated with each task to be identified in the form of possible deviations from the correct execution of the task. The consequences and likelihood of each deviation is explored, and finally mitigations identified where appropriate.

Finally, a Monte Carlo optimisation based on discrete event simulation can be used to examine the possible impact of different resource configurations. Discrete-event simulation 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). Discrete-event processes must include predetermined starting and ending points, and a list of discrete events that occur in between these points. The task analysis is ideally suited to providing these points. Discrete-event simulation is commonly used to monitor or predict procedures and processes in various industries, such as manufacturing. The final aim of a simulation is to define a precise scheduling of the listed tasks, considering all known external and internal constraints characterizing the whole activity to be organized. In order to provide a highly reliable plan of the tasks, the simulation should take into account a number of variables to consistently adhere to reality. Uncertainties may be generated from the inability to precisely predict the duration of each task due to external constraints, lack of knowledge, and the possibility of known or unknown issues arising during the project. The participatory approach helps to elicit as much information as possible about the task sequence, expected durations, and possible issues (including safety concerns) and thereby reduce the uncertainty. Especially when the activity is characterized by high level of internal and/or external constraints, it is of extreme importance to include the uncertainty affecting the hypothesis used to introduce those constraints in the simulation. In the present case study, the main constraints refer to the mutual conditioning of some subtasks (i.e. one task cannot be performed unless another one is already complete), availability of resources (e.g. people and tools) and the time of some external events necessary for accomplishing the procedure in safe conditions (i.e. time of tides). In this sense, Monte Carlo (MC) method has been identified as a suitable tool to run a discrete-event simulation under uncertainty since it allows the computation of a mean value and a variance of the given quantity under investigation. This quantity is governed by a known phenomenon depending on a set of variables characterized by a level of uncertainty (i.e. the input variables are introduced as a set of mean values and a related variances or in form of Probability Density Function, instead of a set of definite values). MC computes a set of estimations of the final quantity based on different values of input variables generated according their Probability Density Function. Consequently, the final output of the simulation will be an average of the quantity under investigation and a related variance depending on the variance of the input variables. In this specific case, the exploitation of MC is very advantageous for estimating the final planning of an activity taking into account the uncertainty declared by the stakeholders about the duration of each task. Indeed, the application of the Monte Carlo optimisation gives a more nuanced result from the analysis than is possible through the task and safety analysis. It allows dif-

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ferent options to be tested and the expected impact on the project plan to be evaluated.

## 2. Integrated methodology

The proposed methodology is illustrated in Fig. 1. The initial participatory workshop uses a first version of the project plan (if available) to structure the workshop and elicit detail on the tasks to be performed from beginning to end from all participants. The outputs of the workshop are used to construct a detailed task analysis, forming the basis of the updated plan. This is then used to structure a second participatory workshop, identifying the key risks for each phase of the work and generating mitigation actions in collaboration with the participants. A further update of the plan is made after this workshop to make any adjustments required as part of the mitigations. This second version of the plan is then used to support the Monte Carlo analysis, which can be used to identify critical activities and examine the impact of varying resource levels.

The plan may be held in whatever format is most acceptable to the particular organisation (e.g. Microsoft Project, Microsoft Excel, Teamwork, Project Place, etc.). Table 1 describes the main inputs, attendees, and outputs for the three main phases of the methodology. The workshops require representatives from all stakeholder groups, particularly any different operational or maintenance departments who will have to coordinate to complete the works. It may also be useful to have representatives from any other maintenance projects scheduled to occur during the same timeframe.

The methodology described here was tested in a case study of a cold water system overhaul in an electricity generation station. The description of that case study and its results are discussed in the next section.

## 3. Case study: Cold water system overhaul

The developed methodology was trialled within an electricity-generating organisation in Ireland. The organisation regularly undertakes maintenance and overhaul procedures during unit outages at their generating stations. These complex works have significant safety, productivity, and ultimately financial consequences if not successfully completed; however, detailed project management is difficult due to lack of firm planning data, variation in the work undertaken in each overhaul, the different departments involved in the works, time pressures associated with normal running of the plant, and the focus of engineering teams on technical planning.

For this case study, the overhaul of a cold water system during two overlapping unit outages was considered. The planned works involved the replacement of two valves and the inspection and repair of the busmain. The work must be undertaken during the outage of two of the three generating units, so that reduced cooling water flow is required for the overall station, enabling the isolation

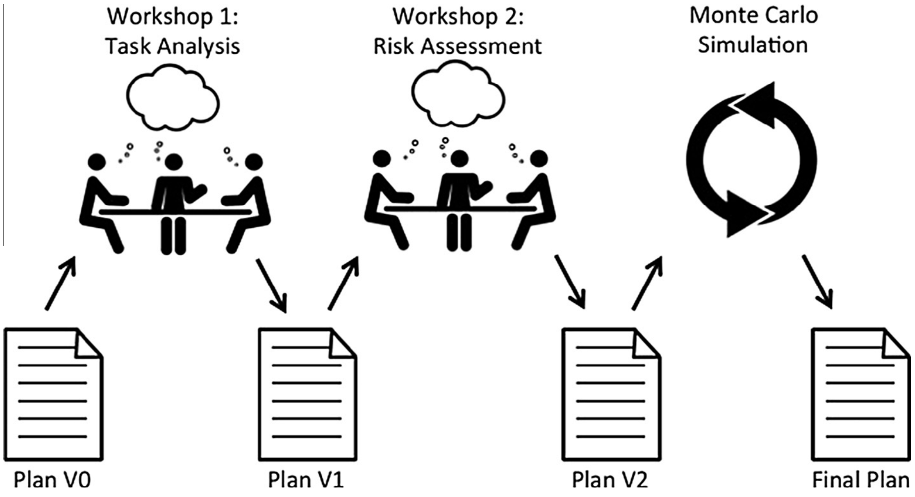

**Fig. 1.** Participatory planning methodology.

**Table 1**
Inputs and Outputs.

| | Inputs | Attendees | Outputs |
|---|---|---|---|
| Workshop 1 | Maintenance goals<br>Plan V0<br>Estimated resources<br>Known constraints<br>Schematics of the system | Project manager<br>Operations rep<br>Maintenance manager<br>Maintenance staff<br>Contractor rep<br>Facilitator | Task analysis<br>Plan V1<br>List of issues |
| Workshop 2 | Plan V1<br>Safety analysis framework<br>List of issues | Project manager<br>Operations rep<br>Maintenance manager<br>Maintenance staff<br>Contractor rep<br>Facilitator | Plan V2<br>Safety analysis<br>List of mitigations |
| Monte Carlo | Plan V1 and Plan V2<br>List of issues | Project manager | Final Plan |

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of the necessary parts of the cold water cooling system. The outage of both units was initially planned for 5 days, leaving a short time window in which to complete the work, and significant losses to the plant would be incurred through lost revenues if start-up were delayed. The time pressure associated with the works also increases the likelihood of errors that may impact both safe and timely completion of the work. The aim of this case study was to provide a project plan for the overhaul procedure, based on the participatory approach to engage all stakeholders and integrate that plan with a risk assessment of the works covering safety, cost and time. The resulting plan should account for individual tasks, consider access to and use of resources, and identify the main risks, in terms of operational delays and process safety, capable of undermining the successful outcome of the project.

The first participatory workshop was held approximately 2.5 months prior to the planned start date of the works. This workshop detailed the task analysis and also documented any risks and mitigations that emerged in the course of the discussion, although these were not the focus of this workshop. Additional one-to-one meetings were held with key stakeholders over the following months to clarify some remaining points and the plan was documented in the form of the task analysis and Gantt and PERT charts. The second workshop was held one month prior to the works to finalise the risk assessment. The Monte Carlo simulation was finalised approximately two weeks ahead of the works start date.

The initial workshop was designed to engage key stakeholders and elicit the information needed for detailed planning. A basic scale model of the CW system was used to structure the discussion (Fig. 2). Participants were asked to use small figurines and toy cranes to represent the progression of the tasks on the model. Each participant was assigned one or more roles. This structured and immersive approach helped to elicit and document each task needing to be completed during the works.

A full list of tasks, from when the second unit shut down through to handing back of the CW system to operations, was elicited in the workshop and annotated with actors, tools and equipment and expected durations against each. Upper and lower limits of the expected durations were also noted for the future optimisation. The data collected from the workshop was structured in an Excel based tabular task analysis, highlighting questions for further analysis and resolution. These were addressed offline in discussion with key stakeholders.

This process resulted in a detailed plan for the works, which was represented in both PERT and Gantt Charts. This plan was used as the basis for a hazard identification (Task HAZID) workshop with the same group of stakeholders considering likely hazards as a prompt to identify all the possible risks associated with each task so as to verify if any additional countermeasures may be necessary.

The Task HAZID study again involved 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 five main guide categories of issues types used were:

- Logistical hazards: lack of resources (manpower, cranes, equipment,) unavailability of required parts, damage of required parts and or equipment, space constrains/improper provision for access ways and laydown areas, undetected faults.
- Mechanical hazards: moving parts and materials High pressure fluids Fragment & liquid metal projection, FODs left in after repairs, noise, vibrations, Improper weight support, quality of welds, etc.
- Automation hazards: mis-calibration, undetected faults, etc.
- Process Safety hazards: dangerous substances, hot surfaces, loss of containment, fire, ATEX, interlocks being disabled and not reset.
- Electrical hazards: improper isolation, faulty connections, inadequate parts and fittings, arc flash.
- Other hazards: human performance, ergonomics and mechanical lift supports, confined spaces, external weather conditions or microclimate considerations, etc.

In the case study presented here, the Task HAZID and risk categorization was carried out in a simple spreadsheet template, 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 template streamlines the analysis and simplifies the documentation of the analysis itself. The impact of each identified risk was considered in terms of Cost, Time, and Safety and rated according to its perceived likelihood and severity, using the following scales (Tables 2 and 3).

The risk matrix (Table 4) was used to calculate the overall risk score, by cross-referencing the assessed likelihood and severity. The red indicates high risks that must be addressed with actions to reduce the risk. Amber risks should be reduced if practical, while green risks can be accepted, although any further risk reduction measures that can be implemented easily and cost-effectively should still be considered. This risk matrix, as well as the severity and frequency tables used, was aligned with those used more widely for safety management within the organisation.

Finally, an Excel-based Monte Carlo simulation was run on the basis of the task outline, the estimated durations and the required

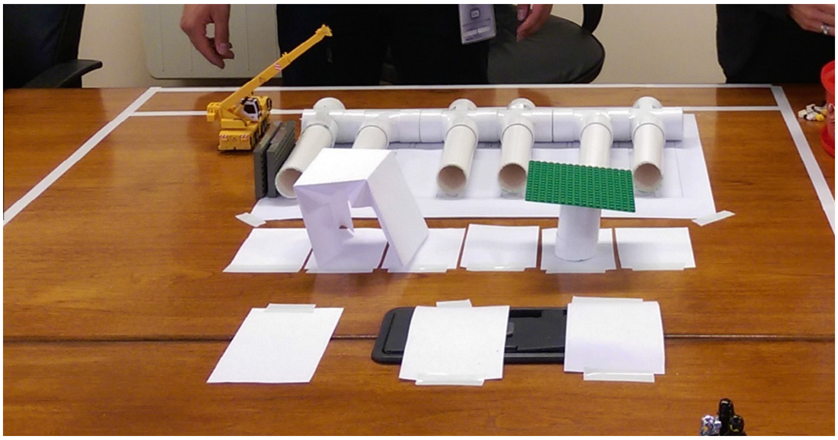


**Fig. 2.** Scale model of CW system.

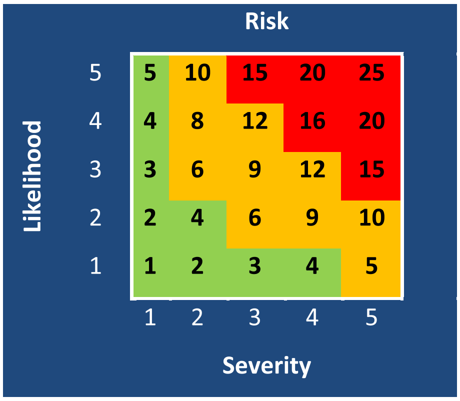
**Table 2**
Likelihood table.

| Likelihood | | | |
|---|---|---|---|
| Rating | Name | Description | Quantification |
| 1 | Unlikely | Could happen but never heard of in the industry | <$10^{-6}$ ev/yr |
| 2 | Remote | Has occurred in the industry | $10^{-6}$–$10^{-4}$ ev/yr |
| 3 | Possible | Has occurred in the company | $10^{-4}$–$10^{-1}$ ev/yr |
| 4 | Probable | Has occurred several times a year in the company | $10^{-1}$–1 ev/yr |
| 5 | Frequent | Has occurred several times a year in the location | >1 ev/yr |

**Table 3**
Severity table.

| | Consequences | | |
|---|---|---|---|
| | Safety | Cost | Time |
| 1 | Minor injury | <10 k € | <3 h delay |
| 2 | 1–2 day LTA | >10 k € | <8 h delay |
| 3 | Serious injury | >50 k € | <24 h delay |
| 4 | 1 fatality, permanent incapacity | >200 k € | <1 week delay |
| 5 | Multiple fatalities | >1 M € | >1 week delay |

**Table 4**
Risk matrix.



Risk

| Likelihood | | | | | |
|---|---|---|---|---|---|
| 5 | 5 | 10 | 15 | 20 | 25 |
| 4 | 4 | 8 | 12 | 16 | 20 |
| 3 | 3 | 6 | 9 | 12 | 15 |
| 2 | 2 | 4 | 6 | 9 | 10 |
| 1 | 1 | 2 | 3 | 4 | 5 |
| | 1 | 2 | 3 | 4 | 5 |

Severity

availability of resources, using a triangular distribution to describe the expected, upper and lower durations. Where upper and lower limits had been captured during the workshop, these were used; otherwise upper and lower limits were defined as 1.1 and 0.9 of the expected duration respectively.

### *3.1. Results*

The workshop broke the works down into eight distinct phases of the revamping procedure:

Z. Preparation;
A. River Isolation;
B. Draining and preparation of the coldwater pipework;
C. Removal of the valves (1/2 NRV and CW1/2 isolation valve);
D. Inspection and repairs;
E. Installation of the new valves;
F. Commissioning;
G. Removal of river isolation.

The PERT chart of the project is shown in Fig. 3.

Under this current plan, the project was expected to be completed at 2330 on Tuesday 11th August, or 87.5 h (3 days, 15.5 h) after the estimated start time of 0800 on Saturday 8th August following the planned outage of two of the three power generation units in the station. The critical path is shown in red.

The PERT includes scheduled break times for those activities scheduled to fall at break time. These are shown in blue in the duration boxes. The plan is slowed by the need to wait for resources on three occasions:

1. C3: Only one crane is available and this is needed simultaneously to lift and hold both valves during their removal (C2, C3). Therefore, the removal of one valve will have to wait for the crane to become available. In the PERT, this valve is the NRV, putting the remaining activities involving the NRV on the critical path. If the NRV is instead removed first, the remaining Isolation valve tasks will instead be on the critical path.
2. D4: The repair teams work only dayshifts, but to complete the repair of the Isolation valve flange face would require working through the night. A wait time of 12 h has been added to account for this time.
3. D5: Again, the repair team is not available to start work at 2330 (the scheduled removal time of the NRV) and this task must wait to begin at 0800.

Fig. 4 shows a Gantt chart summarising the overall procedure stages and duration.

The risk assessment based on the detailed plan identified 10 green risks and 18 amber risks. The green risks were deemed to be sufficiently well mitigated and were not further analysed. Examples of amber risks included:

- A delay in the operational isolation (Likelihood: 3, Severity: 3; Risk = 9). The operations team are likely to have a high workload after the unit comes off load and may not be able to provide the isolation in the required timeframe, causing a delay to the work. A dedicated operator, and clear planning of the works were the recommended control measures for this risk.
- Diver injury (L: 2, S: 4; R = 8). The cleaning of the shutes is a high-risk activity, and there is the possibility of an injury to the divers. The recruitment of an experienced diving team and careful monitoring of their planning and risk assessment should mitigate this risk.
- High winds prevent crane use (L: 3, S: 2; R = 6). High winds may prevent the crane from dropping the river isolation gates into place, causing a short delay to the works until the winds die down. The only possible mitigation is to check weather conditions in advance of the works to determine the possible impact and whether to continue.
- Damage to existing pipework around the valve being removed (L: 3, S: 3; Risk = 9). The removal of the large valves using the crane holds the potential to damage the remaining pipework. Procedures for the careful removal of the valves were developed to manage this risk.
- Lifting hooks unable to hold valve weight (L: 2, S: 3; R = 6). The lifting hooks may have become degraded over the course of time and may not be able to take the full weight of the valves.

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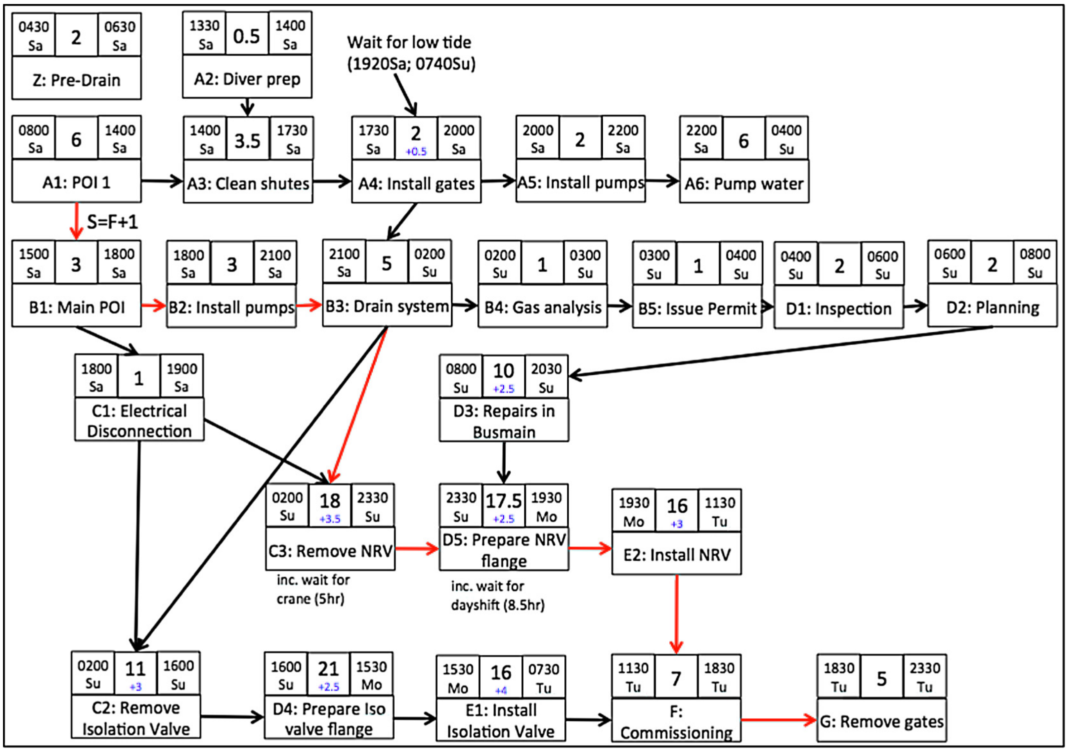

**Fig. 3.** PERT diagram.

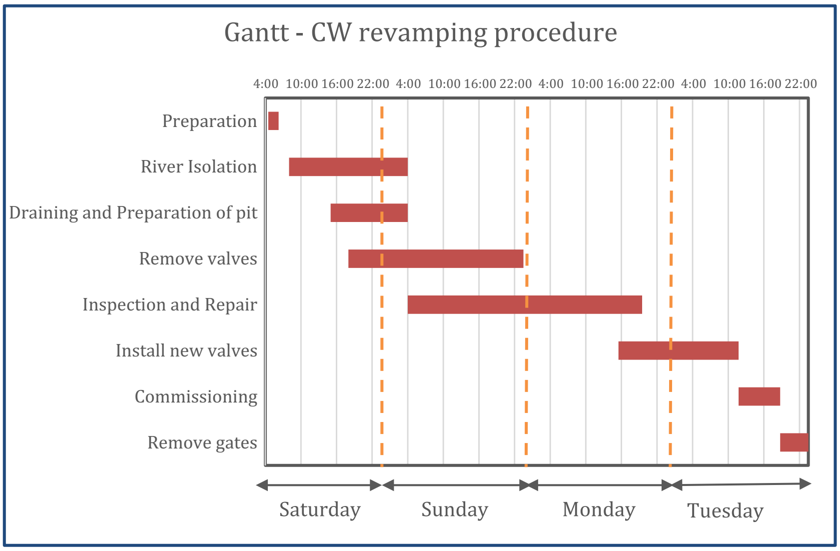

**Fig. 4.** Gantt for overall operations.

Inspection of the lifting hooks prior to the works is recommended and the use of a sling around the body of the valve.

- Inhalation of toxic gas formed during cureing (L: 2, S: 3; Risk = 6). A toxic atmosphere may form in the pipes during the cureing phase of the repair works. Force ventilation should be installed to mitigate this risk;
- Injury of operator during blasting operations (L: 2, S: 3; R = 6). Operator PPE should be available and in use to prevent injury.

A Monte Carlo simulation of the planned works was run, using the expected, maximum and minimum values for each task as collected in the initial workshop and follow up visits. The simulation used had two main constraints on its realism. First, break times cannot be accounted for in the current simulation. This was dealt with by adding 3 h to every 24 h of the final expected time. Second, the simulation assumes all resources are available 24 h, so cannot account for the repair teams only being available during the dayshift. Nevertheless, the simulation provided some useful results.

Averaging over 20 runs, the simulation expects the work to be completed at 2240 on Tuesday 11 August. This is very close to the expected time as calculated in the PERT, and suggests that the simulation is reasonably accurate despite the constraints.

If a second crane were to be used, the averaged result of the simulation suggests that the time required for completion could

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decrease by 7 h, anticipating the return to operation to 1530 on Tuesday 11 August. The use of the third repair team makes little difference on its own, but the use of three repair teams and a second crane makes the completion time a full 12 h earlier, at 1000 on Tuesday 11 August.

### 3.2. Validation

The approach was validated against the actual works as completed. The primary objective of the study was to de-risk the project by identifying the tasks, resources, and risks in detail and ensuring the necessary measures were in place to maximise the probability of safe and successful project completion.

The main criterion was satisfied, in that the project was successfully completed during the outage. However, this is not sufficient to validate the method and additional analysis of the planned versus actual project completion was performed to this end. Feedback was also collected from key stakeholders.

#### 3.2.1. Duration comparison

The work was calculated to take approximately 4 days (3 days, 15.5 h), but in actuality took 7 days. The change in overall timescale was ascribed to additional time becoming available for the outage, due to overrunning of other planned works, allowing the schedule to be relaxed. Key differences were a delay to the start of Phase B, not working 24 h shifts, and not running major tasks in parallel. Table 5 describes the expected duration for each phase of works, compared with the actual duration (not including breaks) and Figs. 5 and 6 describe the overall timeline of the planned and actual works respectively. The actual duration of the works exactly matched the expected duration, although this was likely a coincidence given the variation in individual tasks.

**Table 5**
Expected vs. actual task durations.

| Task | Expected duration | Actual duration |
|---|---|---|
| A. River isolation | 19.5 h (12.5–26 h) | 13.5 h |
| B. Prep of pit | 13 h (11–16 h) | 8 h |
| C. Remove valves | 11 h (6–15.5 h) | 12 h |
| D. Inspection and repair | 14 h (12–31 h) | 19 h |
| E. Installing new valves | 13 h (6.5–16.5 h) | 13 h |
| F. Commissioning | 7 h (5.5–11 h) | 9 h |
| G. Remove gates | 2.5 h (2–5 h) | 5.5 h |
| Totals | 80 h (56–121 h) | 80 h |

The majority of tasks were within the expected timeframe, with most tasks generally at the lower end of the expected duration. Phase B (Prep of pit) was the only phase completed more quickly than the lower expected duration. This was due to a considerably faster drainage time of water from the pit than anticipated. However, the durations in Table 5 do not include an 18 h delay to the start of the tasks, due to the need to wait for an isolation from operations. Phase C was completed in a time very close to the expected duration, however several of the tasks in Phase C had been planned in parallel, but were completed in series. The actual tasks of removing the individual valves were completed in a time closer to the lower expected limit (i.e. 5–6 h actual duration per valve; expected durations were 8–10 h, with a lower limit of 5 h and upper limit of 13.5 h). Phase D, Inspection and Repair, took longer than the expected duration, although still within the set limits. This was due to the completion of tasks in series that had been planned in parallel. Similarly with Phase E, installation of new valves, although the planned and actual durations are similar, in fact the tasks were completed close to the lower time estimate, but were completed in series rather than parallel, as had been planned. Phase F, Commissioning, took slightly longer than the expected duration, due to the removal of the isolation. Finally, Phase G, Remove Gates, exceeded the upper expected duration. This was due to longer than expected times to remove the pumps from the system and to equalise water pressure with the river.

A final note on the accuracy of the estimation method is to compare the bottom-up estimate used to an initial top-down estimate prepared by the project leader. This estimated the works to take 11 days, a vast overestimation in comparison with the eventual bottom-up estimation, and an overestimation even compared to the relaxed pace of the actual project completion. While this 11 day estimate was an initial estimate and may reflect lack of accuracy at that point, it is also likely that the detailed decomposition facilitated a more accurate analysis of the final duration. This is interesting in the context of Besner and Hobbs (2004) finding that top-down estimating is more widely used the bottom-up estimating.

Overall, the durations were within tolerance, and the planned procedure provided a good estimate of the actual performance.

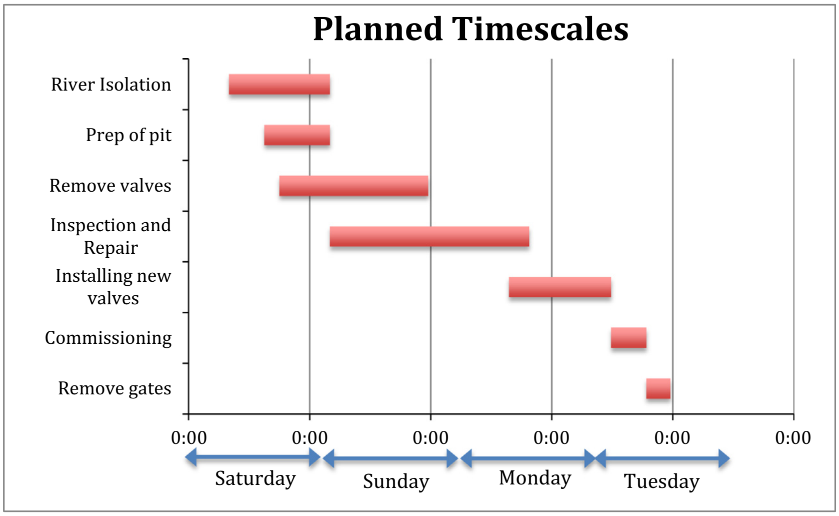

**Fig. 5.** Planned timescales.

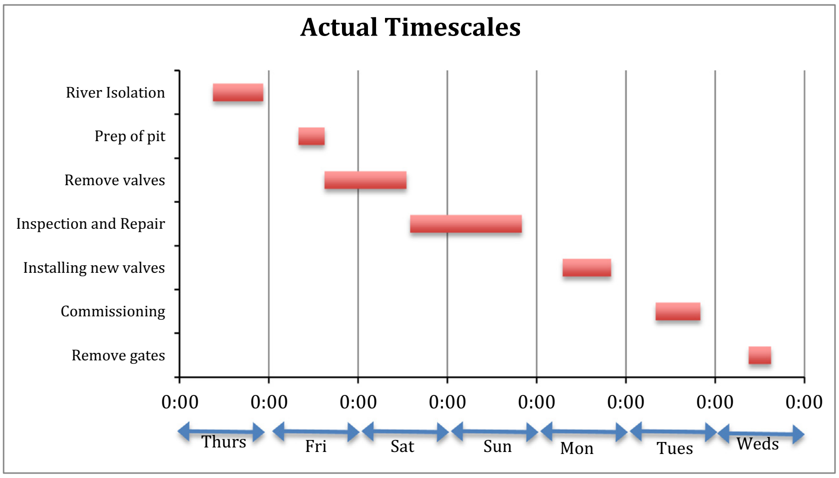

**Fig. 6.** Actual timescales.

*3.2.2. Risk analysis*

The risk analysis carried out in the Task HAZID workshop identified 18 amber risks to the works. Additional risks were identified and mitigated during the initial task analysis, and in fact this approach is more integrated and appeared to offer a more natural way for stakeholders to consider the possible deviations and controls as they developed the plan. However, a drawback of the risk assessment based on the detailed task analysis was the fixation of stakeholders on individual deviations, rather than global risks to the project. These were under-represented, and key risks which did later manifest, such as the delay to the outage start time and the overrunning of another project during the outage (which in fact had positive consequences on the project), were not identified. The risk analysis aspect of the approach therefore needs to be reconsidered, with perhaps a brainstorming session before or after the completion of the task analysis to identify wider risks to the project as well as risks to individual tasks within the project.

*3.2.3. Cost benefit analysis*

The planning and optimisation work conducted for the case study is estimated at 1 project manager (engineer) month of effort (i.e. 20 days), with a gross salary of €5000. This includes the time of the various stakeholders (project manager, four engineers, operations supervisor, technician) for two workshops and an additional 6 days of effort by the project manager to analyse the data and generate the plan.

In contrast, an overrun of one day is estimated at €250,000 in lost earnings for the station and the analysis helped ensure that the work could be completed within the available time window. The risks identified to the project calculated the potential risk exposure of up to €102,035, based on a multiplication of the frequency and severity scores determined in the risk workshop. The cost benefit analysis therefore clearly demonstrates the value of the pre-planning and analysis work in de-risking the project.

*3.2.4. Feedback*

Key stakeholders gave very positive feedback on the approach, with comments including:

> *"I firmly believe that the attention to detail highlighted in your submissions prior to the project helped us to complete the work safely and without delay"*
>
> *"Input made a huge difference and the CW was one of the jobs during our recent outage that had a very successful outcome"*

Specific benefits of the approach were:

- Early engagement and motivation of stakeholders across the plant, ensuring tasks and activities were clear and achievable during the works;
- Clear planning that identified pre-work and resources required to de-risk the works;
- Confidence on what was possible in the time window available, enabling re-planning decisions to be made smoothly during the outage when required.

## 4. Discussion and conclusions

This paper has presented a methodology for the integration of safety analysis with project planning for maintenance procedures. The need for such a methodology is clearly demonstrated by the high number of process and occupational safety accidents occurring during maintenance activities, and the contribution of poor planning to those accidents (Okoh and Haugen, 2014). The approach presented here aims to engage key stakeholders through participatory workshops, to capture their knowledge and expertise in developing a plan and to promote coordination between different stakeholder groups. Capturing the knowledge elicited in the workshops in a project plan allows the key issues to emerge and different options to be tested ahead of the works.

The case study presented in this paper represents a complex maintenance procedure involving several different stakeholder groups and operating under tight constraints. The workshop approach was very successful in engaging the plant personnel, and allowed key efficiency and safety risks to be identified, discussed, and mitigated ahead of the works. Although the eventual works did not follow the plan exactly, the clear documentation of the tasks and risks allowed the maintenance team to adapt to changing circumstances with confidence.

It was not possible to include all stakeholders in the workshops, in particular it was difficult to access contractor staff in this context and this is likely to be the case in many organisations. This limitation was overcome by documenting assumptions or questions for the contractor staff, and directing these queries to the relevant contractors after the workshops. However, it would have been preferable to better engage contractors directly in the whole planning procedure. Indeed, the inclusion of as many stakeholders as possible in the workshops is preferable since this will help to

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reduce uncertainties and assumptions, and result in more realistic results. A second limitation was the linear nature of the case study followed, which limited the potential benefits of the optimisation methods. Future research should consider less linear projects in order to demonstrate the additional benefits of optimisation. The MC analysis should also be improved to account for break patterns and to incorporate the risks identified.

Overall, the application of the integrated methodology in the case studies described in this paper has demonstrated the potential benefits in terms of increased safety, cost savings, and time savings. The individual methods described are all available to organisations at little or no additional cost, and the use of workshops with key stakeholders serves not only to elicit the necessary information for better project planning, but also to engage the stakeholders in the project, highlight the key risks and motivate stakeholders to work together to ensure project success. The approach was positively received and showed its ability to provide an accurate and detailed plan of proposed works. The methods used are a combination of tried and trusted project management, human factors, and risk assessment methods, but could easily be adopted to support more advanced risk analysis techniques, such as the Integrated Dynamic Decision Analysis (IDDA; Demichala and Camuncoli, 2014) or Bayesian Networks (e.g. Gerbec et al., in press). The combination and use of the methods in a participatory manner provides a stronger result with better engagement from key stakeholders, resulting in increased motivation for a successful project conclusion.

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## References

Annett, J., Duncan, K.D., 1967. Task analysis and training design. Occup. Psychol. 41, 211–221.

Badri, A., Gbodossou, A., Nadeua, S., 2012. Occupational health and safety risks: towards the integration into project management. Saf. Sci. 50, 190–198.

Benjaoran, V., Bhokha, S., 2010. An integrated safety management with construction management using 4D CAD model. Saf. Sci. 48, 395–403.

Besner, C., Hobbs, B., 2004. The Perceived Value and Potential Contribution of Project Management Practices to Project Success, 37(3). Project Management Institute.

Chapanis, A., 1996. Human Factors in Systems Engineering. John Wiley & Sons, New York.

Demichala, M., Camuncoli, G., 2014. Risk based decision making. Discussion on two methodological milestones. J. Loss Prev. Process Ind. 28 (1), 101–108.

Demichela, M., Pirani, R., Leva, M.C., 2014. Human factors analysis embedded in risk assessment of industrial machines: effects on the safety integrity level. Int. J. Perform. Eng. 10 (5), 487–496.

Gerbec, M., Balfe, N., Leva, M.C., Prast, S., Demichela, M., 2016a. Design of procedures for rare, new or complex processes: Part 1 – An iterative risk-based approach and case study. Saf. Sci.

Gerbec, M., Demichela, M., Baldissone, G., in press. Design of procedures for rare, new or complex processes: Part 2 – Comparative risk assessment and CEA of the case study. Saf. Sci. http://dx.doi.org/10.1016/j.ssci.2016.10.015 (submitted for publication).

Gyi, D., Shalloe, S., Wilson, J.R., 2015. Participatory ergonomics. In: Wilson, J.R., Sharples, S. (Eds.), Evaluation of Human Work. third ed. CRC Press, London.

Kirwan, B., 1998. Human error identification techniques for risk assessment of high risk systems – Part 1: Review and evaluation of techniques. Appl. Ergon. 29 (3), 157–177.

Kirwan, B., Ainsworth, L.K., 1992. A Guide to Task Analysis. Taylor & Francis, London.

Kletz, T., 2006. HAZOP and HAZAN, Identifying and Assessing Process Industry Hazards. The Institution of Chemical Engineers.

Kontogiannis, T., Leva, M.C., Balfe, N., 2016. Total safety management: principles, processes and methods. Saf. Sci. http://dx.doi.org/10.1016/j.ssci.2016.09.015 (submitted for publication).

Kuorinka, I., 1997. Tools and means of implementing participatory ergonomics. Int. J. Ind. Ergon. 19, 267–270.

Leva, M.C., Pirani, R., De Michela, M., Clancy, P., 2012. Human factors issues and the risk of high voltage equipment: are standards sufficient to ensure safety by design? Chem. Eng. Trans. 26.

Nagamachi, M., 1995. Requisites and practices of participatory ergonomics. Int. J. Ind. Ergon. 15, 371–377.

Okoh, P., Haugen, S., 2014. A study of maintenance-related major accident cases in the 21st century. Process Saf. Environ. Prot. 92 (4), 346–356.

OSHA, 2011. Healthy Workplaces: A European Campaign on Safe Maintenance. European Agency for Safety and Health at Work, Brussels.

PMI, 2013. A Guide to the Project Management Body of Knowledge (PMBOK). PMI, Pennsylvania.

Robinson, S., 2004. Simulation – The Practice of Model Development and Use. Wiley.

Rocha, R., Mollo, V., Daniellou, F., 2015. Work debate spaces: a tool for developing a participatory safety management. Appl. Ergon. 46, 107–114.

Shiplee, H., Waterman, L., Furniss, K., Seal, R., Jones, J., 2011. Delivering London 2012: health and safety. In: Proceedings of the Institution of Civil Engineers – Civil Engineering, 164(5), pp. 46–54.

Stanton, N.A., Salmon, P.M., Walker, G.H., Baber, C., Jenkins, D.P., 2005. Human Factors Methods: A Practical Guide to Engineering and Design. Ashgate, Aldershot, UK.

Wilson, J.R., 1995. Ergonomics and participation. In: Wilson, J.R., Corlett, E.N. (Eds.), Evaluation of Human Work: A Practical Ergonomics Methodology. second and revised ed. Taylor and Francis, London, UK.

Yazdani, A., Neumann, W.P., Imbeau, D., Bigelow, P., Pagell, M., Theberge, N., Hilbrecht, M., Wells, R., 2015. How compatible are participatory ergonomics programs with occupational health and safety management systems? Scand. J. Work Environ. Health 41 (2), 111–123.

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