USING THE HAZOP METHOD TO CONDUCT A RISK ASSESSMENT ON THE DISMANTLING OF LARGE INDUSTRIAL MACHINES AND ASSOCIATED STRUCTURES: A CASE STUDY

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ABSTRACT

This paper presents a method that can be used to conduct a safety risk assessment prior to the dismantling of large bulk materials handling machines. The method was developed during a dismantling project that involved the decommissioning and dismantling of two shiploaders and two stacker reclaimers that had been in operation for more than 40 years. The HAZOP risk assessment method was selected as a suitable risk assessment method. A research gap related to the availability of suitable HAZOP guide words for the safe dismantling of these machines was identified early in this project. The research method included (i) confirming the appropriateness of the HAZOP risk assessment method for this application; (ii) the development and testing of a context-specific set of guide words, with input from the Australian Standard AS2601-2001: The demolition of structures; (iii) applying these guide words to the dismantling HAZOP for the shiploaders; (iv) incorporating lessons learned into the guide words and process for the HAZOP for the stacker reclaimers; and (vii) presenting a proposed set of guide words. The proposed set of guide words may be practically applied in any dismantling project that involves large outdoor machines where the dismantling process includes a significant amount of rigging and lifting.

Key words: safety risk assessment; materials handling machines; HAZOP; dismantling; demolition, AS2601-2001

1. **INTRODUCTION**

Demolition is one of the most dangerous types of construction activity, due to the uncertainty involved in structures that may have been weakened either by normal operation (wear and tear) or by natural forces (floods, corrosion at sea level) (Kuhl, 2017). The South African Occupational Health and Safety Act (1993) and Construction Regulations (2014) define the term 'demolition' as any method to dismantle, wreck, break, pull down, or knock down a structure, or part thereof, by way of manual labour, machinery, or the use of explosives. These structures include fixed plant, and not just civil structures (Occupational Health and Safety Act (1993) and Construction Regulations (2014)). In the context of this paper, 'demolition' refers to the dismantling and removal of parts related to two 41-year-old 600-ton shiploaders and two stacker reclaimers located at the Richards Bay Coal Terminal in South Africa.

When confronted with having to conduct a risk assessment on the process of dismantling these machines as part of the case study research presented in this paper, no clear answers to the next two questions were immediately apparent:

1. What appropriate risk assessment tools and methods are available that can be used to conduct a risk assessment on the process of dismantling the machines? The answer to this question is important, since it indicates whether the HAZOP method is an appropriate method to do a risk assessment on the safe dismantling of large industrial machines and associated structures.
2. How is the selected approach applied during the risk assessment? This answer shows how the dismantling process and the guide words were developed and applied during a high-risk dismantling project. The process went through three iterations of guide words (an initial set that was used on the shiploaders, a revised set that was used on the stacker reclaimers, and the final set) and also presented some lessons learned, which are discussed later in this paper.

These two questions mainly arose due to the relative rarity of dismantling projects of this nature in industry – mainly because of the long lifespan and high initial capital cost of such machines.

The paper starts by presenting the project context and the research objectives: (i) an overview of the project owner; (ii) the machines that needed to be dismantled; and (iii) the objectives of the dismantling research project. A literature review then presents (i) the history of the HAZOP method; (ii) its strengths and weaknesses; and (iii) arguments in its favor as an appropriate method for identifying hazards during the dismantling and decommissioning of the machines.

A research gap was identified during the literature review, since a suitable set of guide words that could be used to conduct a HAZOP study on the dismantling of large materials handling machines could not be found.

The research method includes a detailed discussion on how the research was conducted for the dismantling of the shiploaders and stacker reclaimers. The shiploader dismantling HAZOP is discussed in terms of (i) drafting and reviewing the dismantling work method statement; (ii) the development of an appropriate risk assessment process and of HAZOP guide words; and (iii) lessons learned during the HAZOP workshop. The stacker reclaimer dismantling is then discussed in terms of (i) a short process overview and (ii) lessons learned.

The results section proposes an approach that may be employed in conducting a HAZOP on similar installations, using the proposed set of guide words. Some advantages and potential shortfalls of the approach are also discussed. The paper concludes with a short discussion of the research questions and related results.

2. PROJECT BACKGROUND: CONTEXT AND OBJECTIVES FOR THE CASE STUDY

Richards Bay Coal Terminal (RBCT) is one of the five largest coal terminals in the world, and is the largest coal terminal in Africa. The terminal was launched in 1976 with an original capacity of 12 million tons per annum, and has since grown to a 24-hour/365-days-a-year terminal with a design capacity of 91 million tons per annum. The terminal occupies a 276-hectare site, and has a 2.2 km quay length with six berths and four shiploaders. It also has a stockyard capacity of 8.2 million tons. This translates to more than 900 ships loaded annually (Richards Bay Coal Terminal, 2016). In 2015, RBCT embarked on a three-year machine replacement programme, during which two rail-mounted shiploaders and two rail-mounted stacker reclaimers were to be replaced by higher-capacity machines. Incoming coal arrives via rail at RBCT, and incoming wagons are tipped, after which a conveyor network transports the coal to a specific stockpile where a stacker reclaimer is used to stack the coal. Should some of the coal need to be exported, the same stacker reclaimer reclaims the coal, and it is then transported via a conveyor network and loaded into the ship's hold with a shiploader.

The original machines were commissioned in 1976, and thus were reaching the end of their operational lifespans (Murphy, 2017). As part of this machine replacement programme, the two existing shiploaders and the stacker reclaimers needed to be dismantled and removed from the quay and the stockyard respectively. Two of the machines appear in Figure 1.

Figure 1: Stacker reclaimer and shiploader

Table 1*:* Machines - size and weight

As part of the case study, the dismantling project had the following objectives (Sandvik Mining South Africa, 2017):

- Safe and secure dismantling of the two shiploaders and their associated parts and components. This was complicated, since the dismantling of these machines took place on the quay wall, near the two new shiploaders, which were in full production.
- Safe and secure dismantling of the two stacker reclaimers and their associated parts and components. The dismantling of these machines took place in the coal stockyard: the old machines were moved to the end of their respective rails while the newly commissioned stacker reclaimer was in production on the same rails.
- Minimum work time above and next to live conveyors. This was critical to limiting the exposure of conveyors to potential damage during the dismantling project.
- Minimum interruption to RBCT operations. This was especially important, as the shiploaders were dismantled from November to December – traditionally the busiest time of the year at RBCT.
- Assurance of the maximum benefit of sold scrap metal, accurate material control, and mass verification of the removed components had to be ensured.
- Compliance with all environmental legislation. This included avoiding hydrocarbon spills on the quay wall, into the sea, and in the stockyard.
- No damage to RBCT property.
- Completion of the dismantling projects according to the contractual agreements in respect of schedule and quality.

The two dismantling projects took place six months apart: the shiploaders were completed in December 2017, and the stacker reclaimers in September 2018. The contracts for dismantling all four machines were awarded to the same contractor who was responsible for the design, fabrication, and commissioning of the four new machines. Risk assessments on the safe dismantling of the old machines were required, and a literature review had to be conducted to determine the most appropriate risk assessment method for the dismantling project.

3. LITERATURE REVIEW

The first part of the literature review provides some history and attributes of the HAZOP method, while the second part discusses why HAZOP was selected as an appropriate method for conducting a risk assessment on the safe dismantling of the shiploaders and stacker reclaimers.

3.1 History and attributes of the HAZOP method

Hazard analysis involves the identification of hazards at a facility and evaluating possible scenarios that might lead to unwanted consequences (Gould et al., 2000). In this regard, the HAZOP (HAZard and OPerability) study method was developed in the 1960s by Imperial Chemical Industries (ICI) during the examination of the designs of a phenol plant. It evolved from the application of the critical examination study method to the design of the plant to identify any design deficiencies and deviations. The critical examination method is a recognised method for examining activities and generating alternatives by asking questions such as “Was it achieved?”, “What else could be achieved?”, “What should be achieved?”, “How is it achieved?”, etc. (Kletz, 1997). The first open literature publication on HAZOP was a paper by Herbert Lawley in 1974 (Lawley, 1974). In 1977 the Chemical Industries Association published a guide to hazard and operability studies (Crawley and Tyler, 2015), and the term ‘HAZOP’ was first used by Kletz in 1983. An international standard – ISO61882:2001 (Hazard and operability studies) was published in 2001 and updated in 2016.

3.1.1 HAZOP method

The HAZOP method is qualitative in nature, and is based on the use of guide words that examines the ways in which the design intention or operating conditions might not be achieved at each step in a design, process, procedure, or system (South African Bureau of Standards, 2014). It works by applying a set of guide words (such as NO, MORE, LESS OF) together with process parameters (such as PRESSURE, TEMPERATURE, FLOW) on elements/parts (also called ‘nodes’) of a system to identify deviations from the design intent (South African Bureau of Standards, 2014). As an example, when considering FLOW as a process variable. as indicated in Table 3, the guide words MORE OF and LESS OF might lead to meaningful process variable deviations.

The study is co*ncluded when all the guide words have been applied to all the nodes of the design, process, procedure, or system. Treatment plans for the deviations are also identified and then managed according to the principles described in ISO31000:2009. The process itself is described in more detail by the British Standards Institute (2001), the Center for Chemical Process Safety (2008), Crawley and Tyler (2015), and the South African Bureau of Standards (2014).

3.1.2 **Strengths and weaknesses of HAZOP**

The strengths and weaknesses of HAZOP have been documented by South African Bureau of Standards (2014), Crawley and Tyler (2015), Gossman (2009), Rimkevicius et al. (2015), and Schlechter (1995). HAZOP's strengths include that (i) it is simple, systematic, thorough, structured brainstorming; (ii) it is attended by a multidisciplinary team with real-life operational experience; (iii) it generates discussion, solutions, and treatment plans; (iv) it is applicable on a wide range of systems, processes, and procedures; (v) it allows for the causes and consequences of human error; (vi) it creates a written record of the process; (vii) is recognised and able to receive regulator acceptance; and (viii) it may be used at varying times during the life cycle. The latter may start during process development and continue through to the closure of the plant, and may include the hazard assessment of any modifications proposed during its operational life span.

The method also has some weaknesses. They include that (i) it may be very time-consuming and therefore expensive; (ii) it requires a high level of system, process, and procedure documentation; (iii) the workshop discussions may be too focused, and so could miss issues with fundamental assumptions and wider or external issues; (iv) the process relies heavily on the expertise of the designers, who may find it difficult to be sufficiently objective to spot shortfalls in their designs; (v) inadequate terms of reference or a poor definition of the study's scope may cause difficulties; and (vi) it focuses on single events rather than on combinations of possible events. The focus on guide words that allows it to overlook some hazards that are not related to a guide word, and the need to have a trained facilitator, are also seen as limitations. The most important weakness in the context of this research project was that, based on the literature review, no context-specific guide words could be identified; and so they had to be developed.

3.1.3 **Use of HAZOP in related contexts**

When reviewing risk identification methods related to decommissioning and dismantling in the process industry, four trends emerged. The first was that some authors (Bridges (2008), Safe Work Australia (2016), Standards Australia (2001)) either excluded HAZOP from their research, or indicated that HAZOP was not typically used during the decommissioning phase (Center for Chemical Process Safety (2008)). The second set of authors, such as Crawley and Tyler (2015), ISHECON (2006), and Rasmussen and Whetton (1997), proposed alternative methods. The most comprehensive list of alternatives was found in the paper by Tixier et al. (2002), who presented a list of 61 alternatives to the HAZOP method. Tixier et al. (2002), together with the British Standards Institute (2001) and Gould et al. (2000), indicated that HAZOP is suitable, but did not present any guide words.

The last group of authors added various sets of guide words as part of their research, as presented in Table 2. This research tended to be related to dismantling in the process or nuclear industries, with guide words aligned to those industry requirements.

Table 2: Literature overview on dismantling and decommissioning HAZOP

3.2 **Selecting HAZOP as an appropriate method for dismantling and decommissioning risk assessments**

When a risk consultant is confronted, on short notice, with the task of conducting a risk assessment on the safe dismantling of stacker reclaimers and shiploaders, the question about which method should be used is the first of many obstacles that need to overcome. Several methods exist, such as brainstorming, structured or semi-structured interviews, the Delphi method, HAZOP, root cause analysis, and business impact analysis. The selection of a suitable method should take into consideration the following constraints:

- The time available to prepare for the workshop.
- The availability of a suitable workshop facilitator.
- The availability of project information, such as detailed work method statements.
- The experience of the workshop participants.
- Client requirements, in that the workshop output has to be in the form of a list of actions / errors, such as a simple qualitative risk register containing the risk name, risk event, risk causes, treatment plans, treatment plan owners, and due dates.

American Society of Safety Engineers (2011) and Schlechter (1995) proposed various methods that may be employed to selected an appropriate risk identification method. The selected method should be justifiable and appropriate to the project context. The criteria include the following:

- The complexity of the problem.
- The extent of the available resources in terms of time, level of expertise, data requirements, and cost.
- The available documentation that may be used in the assessment and that could contribute to the client's objectives.
- Whether the method selected is required to provide a quantitative output.

The main reason that HAZOP was selected was its strengths, which were described earlier.

The method also has some weaknesses. The workshops may be very time-consuming, which also contributes to high costs. This was overcome by extensive preparation discussions between the risk consultant, the dismantling contractor, and the engineering consultant. Another weakness is the requirement of a high level of system, process, and procedure documentation, terms of reference, and study scope. Since the dismantling process was safety-related, and the documents had already been prepared after extensive discussions between the dismantling consultant and the engineering consultant, this was not an issue. Some weaknesses had to be accepted, including that (i) the HAZOP method focuses on single events rather than combinations of possible events, and that (ii) it may overlook some hazards not related to the guide words used in the study. The most important weakness was that, based on the literature review, no context-specific guide words could be identified, and therefore these had to be developed.

4. RESEARCH METHODOLOGY

This section addresses the second research question: "How is the selected approach applied during the risk assessment?" It also presents the method used to develop a set of guide words.

4.1 Study design and participants

The process that was followed to apply HAZOP in the dismantling of the machines in the case study is described in the next flow diagram, which shows the tasks for (i) the dismantling contractor (which included their rigging and lifting contractor); (ii) the engineering consultant for finite element analysis (FEA); (iii) the project owner; and (iv) the risk consultant.

The process to develop the guide words took place in two phases. During Phase 1, the guide words were developed and used in a HAZOP for the dismantling of the shiploaders, and the lessons learned were documented. This process of developing guide words is part of the planning phase of a HAZOP study, in line with ISO61882:2001 (British Standards Institute, 2001). During Phase 2, the refined guide words and the workshop process were used for the stacker reclaimer dismantling HAZOP. This process appears in Figure 2.

Figure 2: Case study process overview

4.2 Phase 1: Shiploader dismantling

This part of the process in the case study had seven main steps: (i) preparing the dismantling work method statement; (ii) reviewing the draft work method statement; (iii) issuing the work method statement to the risk consultant; (iv) developing the process for the HAZOP workshop; (iv) conducting the HAZOP workshop; (vi) physically dismantling the shiploaders; and (vii) documenting the lessons learned.

4.2.1 **Step 1: Preparing the dismantling work method statement**

Several meetings and discussions took place between the dismantling contractor and the engineering consultant, during which the work method statements were drafted and completed. During these meetings, the dismantling sequence was discussed in relation to structural integrity, and adjusted accordingly. The dismantling contractor would show where a specific part of the structure would be cut, after which the engineering consultant would recommend adding certain supports and/or moving the cut to a different place. In general, the sequence was not changed, but the dismantling process was made safer (Van Zyl, 2018).

The main activities of the dismantling phase of the project were split into (i) site preparation work, (ii) dismantling, and (iii) scrap removal.

The site preparation work included tasks that had to be executed prior to the physical dismantling work, and incorporated activities that needed to be supported and carried out by others. The main tasks included the following:

- Residual or spillage: Shiploader and tripper car were washed down by RBCT and handed over for dismantling.
- Mechanical component recovery: Items to be recovered for later use were agreed with RBCT and marked before handover.
- RBCT structural supports: Some structural supports that were previously used for maintenance and related activities were surveyed to determine their availability and condition for use.
- Positioning: RBCT had to move the machines to the dismantling area and disconnect any trailing cables. The shuttle was then locked into storm lock position, and wheel brackets/wedges were attached to the longitudinal travel wheels. Boom trestles were then installed.
- De-energizing of shiploader: Once the belt had been cut and the tripper car had been retracted into the bypass position, the shiploader was de-energised and the generator removed.
- Oil and grease draining: A list of hazardous chemical substances (transmission oil, hydraulic oil, lubrication grease, transformer oil) was drawn up, and the oil and grease were drained where practically possible.

The dismantling phase included all tasks and efforts that were required to dismantle the shiploader and tripper car safely and securely. The individual dismantling steps were described in a work method statement document that was developed by the dismantling contractors. This work method statement represented the most logical and practical dismantling sequence, and was based on the reverse sequence in which the shiploader was originally assembled in 1976. For the dismantling work, the following 10 main steps were identified by the dismantling contractor, based on the configuration of the shiploader and on a logical and safe dismantling sequence: (i) tripper car, (ii) cable reel structure, (iii) bridge tail and bypass trolley, (iv) mast and ropes, (v) boom, (vi) shuttle, (vii) e-house, (viii) bridge structure, (ix) sea side leg, and (x) land side leg. For each of the 10 dismantling steps, the tasks contained both (i) preparatory work and (ii) rigging and lifting.

Scrap removal involved defining the traffic management plan, ensuring that transportation and lifting equipment was available at the off-site dismantling facility.

4.2.2 Step 2: Reviewing the draft dismantling work method statement

After the dismantling contractor and their rigging and lifting contractor had prepared the dismantling work method statement, the work method statements were issued to the project owner. A workshop was held between these parties and the project owner, during which the work method statement was approved by the project owner.

4.2.3 Step 3: Issue work method statement to risk consultant

After the workshop in which the dismantling work method statement was reviewed and approved, it was forwarded to the risk consultant to prepare for the HAZOP workshop.

4.2.4 Step 4: Develop HAZOP workshop process, nodes, and guide words

The 10 steps in the dismantling process described above were then used as the ‘nodes’, as described in ISO61882:2001 (British Standards Institute, 2001). The risk consultant then categorised the nodes into (i) site preparation, (ii) dismantling work, and (iii) scrap removal. Given that the 10 individual dismantling steps each contained (i) preparatory work and (ii) rigging and lifting, a total of 39 study nodes were identified, as shown in Table 4.

Table 4: Shiploader nodes

ISO61882:2001 (British Standards Institute, 2001) recommends that the study leader – in this case study, the risk consultant – propose an initial list of guide words, and that these guide words should be tested against the system that will be assessed to confirm their adequacy. Since the available guide words, as described in the literature review, were found to be inappropriate for the dismantling of large bulk materials handling machines, a unique set of guide words had to be created.

The risk consultant took the project objectives and the project phases into consideration, and reviewed the following documents: (i) the shiploader dismantling work method statement; (ii) the *Australian Standard AS2601: The demolition of structures* (Standards Australia, 2001); (iii) *the Demolition work code of practice* (Safe Work Australia, 2016); (iv) *Demolition – What you need to do* (HSE Executive, 2017); and (v) the *South African Occupational Health and Safety Act 85 of 1993 and Construction Regulations* (2014). During this review, positive answers to the question, "Can this be turned into a guide word and assist in identifying a context specific risk?" was used to identify 26 guide words.

Guide words related to the legal aspects of dismantling were excluded, since it was assumed that the work method statements that would meet all legal requirements – e.g., lifting and rigging equipment, competency of personnel conducting the rigging and lifting, welding and associated activities, and personal protection equipment – were covered in separate risk assessments.

Guide words were identified for each of the phases – i.e., (i) site preparation, (ii) demolition – lift preparation, (iii) demolition – rigging & lifting, and (iv) removal of scrap.

Table 3 below contains the guide words, their sources, and the specific paragraphs from each guide word were taken. It should be noted that, of this set of guide words, 15 were derived directly from headings in the AS2601 standard.

Table 3: Shiploader guide words

4.2.5 **Step 5: HAZOP workshop and lessons learned**

The guide words were applied during the HAZOP workshop, and 34 hazards were identified. Since this was the first time that the project team had conducted a dismantling workshop, a short discussion on lessons learned took place after the workshop. These lessons are discussed here in terms of what worked well and what could be improved ahead of the stacker reclaimer dismantling workshop.

4.2.5.1 Positive aspects

The participants had the appropriate technical, safety, maintenance, lifting, and construction experience, and were well-prepared. The list of participants included representatives of the dismantling contractor, the engineering consultant for FEA, and the project owner. Since various preparatory meetings had taken place between the dismantling contractor, the rigging and lifting contractor, the engineering consultant, and the project owner, only minor sequence issues were identified in the dismantling work method statement. The workshop proved to be a good communication tool. In some instances, minor sequencing issues were sorted out and roles and responsibilities were clarified.

A previously verified finite element model provided accurate COG (center of gravity) and masses of the different structural components, and allowed for the structural evaluation of each component with regard to the lifting/dismantling method. Suitable safety factors were introduced to provide for any unknown structural mass changes. The engineering consultant assisted the dismantling contractor in answering the question, “Once the component is cut, how will it react?” to ensure that the appropriate treatment plans were implemented to prevent the uncontrolled movement of components. The treatment plans included the optimal position for cutting, as well as the most appropriate rigging points.

The fact that the guide words were broken down into the various project phases made the workshop shorter, in that it reduced the number of guide word/study node combinations from a potential total of 1 066 to only 370.

4.2.5.2 Improvements required

The Health and Safety guide words (noise and vibration) were raised many times, and could have been covered in the site preparation phase. Some issues were also experienced with the new guide words. The first of these were that the term ‘adjacent structures’ should have been expanded to ‘adjacent structures / clashes / pinch points’. The guide word ‘fixed moving parts’ should also have been included, as it relates to parts that are attached with hinges and other connecting methods. The prevention of these risks included bracing movable parts during the lift preparation phase.

During the workshop, the issue of moving COG was mentioned several times. This related to a COG being defined before a component was cut up or separated from another part of the shiploader. To provide for these types of risk, the COG guide word should have been changed to ‘centre of gravity / moving center of gravity’. This would have helped in identifying the safest lifting positions.

It was also found that the consequences to hazard did not work well as guide words – i.e., the guide word ‘controlled movement’. These types of guide words were removed from the list. Another process issue was that, during the workshop, the various steps were not fully discussed, and process diagrams were not shown at the beginning of each of the 10 process steps during the workshop. By showing these steps, some issues related to understanding of the process could have been clarified. The dismantling contractor also noted that, had the HAZOP been conducted earlier, rework on the already completed lifting plans and related work method statements could have been avoided, and the cost estimates of lifting equipment could have been more accurate.

4.2.6 Step 6: Dismantling the shiploaders

Dismantling the shiploaders was completed ahead of schedule with no safety incidents and without any unacceptable operational interruptions. Some issues were encountered during this process that required a change in the guide words used. There was water in the shuttle of the shiploader that had to be drained before the lift. This risk was not identified during the HAZOP workshop, and a guide word relating to ‘moving COG’ was added to the list. An example of this that had to be treated was that wheel stoppers on the tripper car had to be installed. These stoppers had to be installed before the drives (with integrated brakes) were removed to prevent free-running structures. The guide word ‘tandem lift’ was replaced by ‘stored energy’ during the workshop after a discussion on counterweights on the stacker reclaimer itself and on tensioning weights on the conveyors that would be affected by the dismantling of the stacker reclaimers.

4.2.7 Step 7: Incorporating lessons learned

The risk consultant updated the guide words based on the lessons learned during the actual shiploader dismantling.

4.3 Phase 2: Dismantling of stacker reclaimers

The process followed for the dismantling of the stacker reclaimers (Figure 2) differed so little from the corresponding steps for the shiploaders that no further discussion of these steps is required. The completion of the dismantling of the stacker reclaimers was delayed, but with no safety incidents or any unacceptable operational interruptions.

As with the dismantling of the shiploaders, some issues were encountered that were used to improve the guide words. Unexpected heavy winter rainfall delayed site establishment by three days, since additional ground preparation work had to be completed to ensure the stability of the supporting trestles for the stacker reclaimer loading boom and counterweight structures. Although the loading boom was lowered and laid down on four trestles, its front end lifted 0.5m, mainly due to delays in completing ground preparation for the installation of the trestle supporting the counterweight. The original set of guide words provided for asking for level ground, but did not provide for the ground preparation requirements for lifting components weighing up to 230 tons. The guide word ‘ground preparation’ was changed to ‘ground preparation (level & weight)’.

The components were much heavier and had different measurements than shown on the latest available drawings. The tripper car drawing indicated a total weight of 99 tons; but when it was lifted, the crane scales indicated an additional weight of 45 tons. The reason for this remains unsolved, but could be attributed either to the tandem lift process or to additional mass on the structure. The latter is questionable, since the same cranes were used for single lifts that were accurately estimated by the FEA process. Some of the box sections had trapped water inside them, mainly due to water ingress into closed boxed sections due to long years of service or to blocked drainage points. To treat this, suspect box sections could have been identified during the preparation phase, and large drainage holes should have been drilled in time. To lower the 230-ton counterweight, a special frame had to be fabricated due to risks related to the structural integrity of the counterweight box. Since the counterweight was 15 m off the ground and difficult to access, the latest available drawings for the counterweight structure were used during the fabrication of the frame. However, the counterweight had bulged due to age, and the frame didn't fit and had to be reworked, which delayed some of the work. 3D laser scanning could have been used to obtain more accurate dimensions. To make provision for similar hazards, a new guide word 'measurements' was added.

5. RESEARCH OUTCOMES

5.1 Proposed process

Based on the lessons learned during the dismantling of the shiploaders and stacker reclaimers, the proposed process for conducting a risk assessment on the dismantling of large industrial machines and associated structures appears in Figure 3. The process is relatively simple: there are only five steps, each with clearly defined roles for the dismantling contractor, the engineering consultant, the project owner, and the risk consultant. The process assumes that an FEA is available, but it can be conducted without it – although this would bring some added risk. A list of sub-tasks was also provided (Table). These steps may be applied to any similar dismantling project, since the steps followed in this type of dismantling project are generic.

Figure 3: Proposed process

Table 6: Detailed description of process steps

5.2 Proposed process and guide words

After two iterations, the research methodology produced a list of 26 guide words, spread across four dismantling project phases. Each of these guide words could be linked to a potential hazard and appropriate risk, as described in Table 7. This list of proposed guide words makes no claim to being definitive or complete, since ISO61882:2001 requires that guide words be reviewed before each HAZOP. It does, however, provide a starting point for risk consultants and practitioners wishing to do similar studies.

5.3 **Proposed set of guide words, and examples from risk assessment**

Table 8 contains the updated list of guide words, along with some examples of risk events and the associated hazards. The research methodology also confirmed some of the strengths and weaknesses of the HAZOP method, as discussed previously. The methodology was relatively simple, systematic, and thorough, but it was time-consuming. It should also be noted that no significant safety incidents occurred during the dismantling of either the shiploaders or the stacker reclaimers. The work done by the dismantling consultant, the engineering consultant, and the project owner before the workshops also confirmed the need for a high level of process and system documentation.

Table 7: Updated guide words, and examples of risk assessment

6. **DISCUSSION & CONTRIBUTION**

This discussion relates to the HAZOP process itself, as well as to other more general project management issues arising from the dismantling project.

6.1 **The implementation of the HAZOP method and developed guide words**

The proposed process (Table 6), the guide words, and the list of risks (Table 7) should provide project owners, dismantling contractors, and risk practitioners with a starting point should any of these require similar risk assessments for comparable dismantling projects. In addition, the risks identified in Table 7 may be used as a checklist in their own right, as a quick way of doing a risk assessment on similar projects.

Since the process is generic, and since ISO61882:2001 requires that guide words be reviewed before each HAZOP, it is fair to conclude that the process may be applied not only to the dismantling of large industrial machines, but also to any demolition project that may require some form of lifting and rigging. This may include moving machines such as ship-to-shore cranes and large mining excavators, as well as non-movable plant and equipment. The process may also be conducted for the safe erection of machines and plant that may require any form of lifting and rigging.

At the conclusion of the workshops, some comparison could be drawn between the traditional HAZOP and the dismantling HAZOP presented here. The main differences related to (i) the element or node, (ii) the guide words, and (iii) the process parameters, as given in Table :

Table 8: Differences between a normal process HAZOP and a dismantling HAZOP

6.2 **Project management of the dismantling project**

Various lessons about improving the guide words have already been discussed in sections 4.2 and 4.3. During the process, some other lessons were noted too; and it is the authors' opinion that these are worth mentioning, since they contributed to other objectives of the dismantling project. These lessons refer to (i) the key success factors for the safe completion of the dismantling of the shiploaders and stacker reclaimers; (ii) the sources of the guide words; (iii) improvements in method statements and procedures; and (iv) issues related to scrap handling.

Various key success factors for the dismantling project could be identified. The project team consisted of suitable team members who were appropriately experienced (technical, safety, maintenance, lifting, and construction), aware of the project context, and well-prepared for the workshop and the planned work. The list of participants for this project included representation by the dismantling contractor, the engineering consultant for FEA, and the project owner. It is also important that the workshop participants be representative of all the stakeholders involved in the process. Since the project took place in a live production environment, the participation of representatives from the project owner's operations team was valuable.

Collaborative planning meetings took place between all the stakeholders. Planning and preparation meetings between the dismantling contractor, the rigging and lifting contractor, the engineering consultant, and the project owner took place before the workshops. The work method statement was created by the dismantling contractor in conjunction with the engineering consultant. This contributed to risk identification workshops that were time- and cost-effective, that focused on identifying hazards, and that did not aim to define the dismantling process itself.

From the start of the project, the dismantling sequence and steps were designed to incorporate safety. An example of this was that, since the stacker reclaimers' counterweights weighed in excess of 220 tons, jacking systems were designed and installed instead of using tandem lifts.

An experienced and well-prepared workshop facilitator / risk consultant also supported the time- and cost-effective execution of risk workshops. The risk consultant was instrumental in identifying HAZOP as an appropriate method and in defining the initial set of guide words.

The availability of finite element models provided accurate COG and masses of the different structural components, and allowed for the structural evaluation of each component in the lifting/dismantling method.

At the end of the stacker reclaimer workshop, the register for the shiploader dismantling was used as a double-check and a completeness check to ensure that risks that appeared on the shiploader were not excluded from the stacker reclaimers. Although the machines were technically very different, the dismantling process was very similar.

The research showed that guide words may be identified during a literature review of appropriate standards and good practice documents. In this regard, Australian Standard AS2601: The demolition of structures played a significant role in creating the initial list of guide words. It might also be useful to note that, of the initial guide words, 15 were derived directly from headings in the AS2601 standard.

It was noted by several of the workshop participants that, had the HAZOP workshop been conducted earlier in the process, its recommendations could have been incorporated into the detailed work method statements, thus avoiding extra work.

Various issues related to scrap handling and removal from the site were noted. It was wrongly assumed that the counterweight itself was made up of concrete only. When it was dismantled, various pieces of metal were found to be embedded in the concrete. This delayed the scrapping of the counterweight, as suitable equipment wasn't available on-site to cut all the metal pieces. This was a safety risk, since injuries due the inappropriate use of equipment have been widely described.

The planning process for handling and storing salvaged components should have included more detail about the handling and long-term storage of large salvaged components, such as the E-houses. There was some uncertainty regarding where to store large components and who should carry the cost for the lifting and transport of these components. In addition to this, the contract with the demolition contractor was based on the scrap price of steel only and should have made provision for the pricing of cement, steel and the copper found in the stay cables.

7. CONCLUSION

In the context of having to safely dismantling 40-year-old shiploaders and stacker reclaimers, two research questions were answered in this paper. The first related to the identification of an appropriate method that could be used to identify safety hazards during the dismantling of the machines. A literature review revealed that the HAZOP method had previously been applied during dismantling processes, with specific reference to nuclear power and chemical process plants. However, this review failed to produce a list of suitable guide words that could be applied during a HAZOP study of the safe demolition of large materials handling machines.

The second research question related to the development of suitable guide words and the application of the HAZOP method to the various steps of the dismantling process. Guide words were developed using the project’s work method statements, as well as existing standards such as AS2601: The demolition of structures. The latter was of particular importance, as it emphasized the usefulness of interrogating existing standards to establish guide words for contexts when they cannot be found during a literature review.

Some might argue that the use of the headings from AS2601 is an extended use of existing tools and that, as described and implemented, this does not fill any research gap. This argument is countered by the absence of any mention of HAZOP studies or guide words in AS2601, as well as the identification of suitable guide words during the literature review.

Since the research project went through three iterations of guide word development, and since the dismantling project was completed without serious incidents, the guide words constitute a baseline that may be used in HAZOP studies of a similar nature. The proposed set of guide words may therefore be practically applied to any dismantling project that involves large outdoor machines and where the dismantling process includes a significant amount of rigging and lifting.

Of equal importance is the recording of lessons learned during the project management part of the dismantling project. This again emphasizes the importance of the collaborative approach that was followed during the planning and execution phases of the project. Complex demolition projects like this cannot be delivered without a well-managed project team that must consist of appropriately experienced technical, safety, maintenance, lifting, and construction management personnel. The project owner’s insistence that risk management – and not mere compliance – form part of the planning and decision-making contributed significantly to the success of this project, as the appropriate implementation of risk management in projects should do.

8. ACKNOWLEDGEMENTS

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9. DATA AVAILABILITY STATEMENT

Some or all of the data, models, or code generated or used during the study are proprietary or confidential in nature, and may only be provided with restrictions. The guide words described in this research were used in HAZOP studies to create HAZOP risk registers, which included risk sources, risk events, treatment plans, treatment plan due dates, risk rankings, and task owners. These original HAZOP risk registers are available, subject to restrictions that would apply to the names of the task owners, the risk ranking, and treatment plan due dates.

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TABLES

Table 1: Machines - size and weight

Machine	Weight (tons)	Highest component to be dismantled	Heaviest component to be removed
Shiploader	589.59	Winch break hydraulic system (18m above ground level).	Bridge structure (190 tons).
Stacker reclaimer	587.52	Cabin luffing cylinder (15.5m above ground level).	Counterweight box (220.9 tons).

Table 2: Literature overview on Dismantling and Decommissioning HAZOP

Title and Author	Comment	Guide Words
HAZOP: Guidelines to best practice for the process and chemical industries, Crawley and Tyler (2015).	• Mentions a HAZOP 7 – Demolition / Abandonment. • Study takes place before final shut down. • Addresses issues such as cleaning methods and standards, size reduction, recovery and recycle of working inventories, recycle of equipment, safe disposal of nonrecyclable materials/equipment, and location of potentially harmful/toxic materials in the equipment or soil. • Guide words for the dismantling of process plants.	1. Density (Higher/lower) 2. Molecular weight (Higher/lower) 3. Pressure ratio (Higher/lower) 4. Power demand (Higher/lower) 5. Gamma (Higher) 6. Noise (Higher) 7. Debris (Some/more of) 8. Contamination (Oxygen/ inserts - source of/disposal of)Process contaminants (As well as) 9. Water (Consequences of/formation of) 10. Cleanliness (More/less) 11. Pressure (Over/under) 12. Load/stress (Higher) 13. Other (Projectiles: more/less/velocity) 14. Other (Ice/mass balance/static load)
Decommissioning hazards for process plants (Cameron and Raman, 2005)	• Hazard identification is conducted on a developed decommissioning plan, with well-defined steps. • Additional Guide Words should be brainstormed for the occasion. • Guide words relate to process plants.	1. Draining/Purging 2. Chemicals 3. Sampling 4. Simultaneous operations 5. Electrical Hazards 6. Third party management Waste disposal 7. Mechanical handling 8. Underground tanks and pipes 9. Environmental 10. Regulatory
HAZOP application for the nuclear power plants decommissioning projects (Rimkevicius et al., 2015)	• Focus is on application of HAZOP technique for identification of the hazards due to the dismantling and decontamination activities at the Ignalina nuclear power plant in Lithuania. • Guide words relate to the dismantling of nuclear power plants.	1. External dose 2. Internal dose 3. Shielding 4. Containment 5. Ventilation 6. Fire 7. Explosion and overpressure 8. Chemical reaction 9. Maintainability 10. Remote handling 11. Operator error 12. Loss of services: power, steam, water, compressed air 13. Effluents: gaseous, liquids Wastes 14. Corrosion and erosion 15. Associated facilities 16. Extreme weather, wind, temperature, flooding 17. Seismic 18. Toxicity 19. Dropped loads, impacts 20. Conventional hazards 21. Access 22. Environmental impact 23. Control and instrumentation 24. Communications 25. Domino effects
Hazop guide line procedure (WorleyParsons, 2006)	• Guide words used to assess impact of new equipment on old equipment. • Guide words relate to phosphate plants and related infrastructure.	1. General comments 2. Relief devices 3. Safety instrumented systems 4. Instrumentation Sampling/analysis 5. Downstream effects 6. Upstream effects 7. Miscellaneous

Table 3: HAZOP process parameters and Guide Words (Crawley and Tyler, 2015)

Parameter	Guide words that can give a meaningful combination
Flow	None; more of; less of; reverse; elsewhere; as well as
Temperature	Higher; lower
Pressure	Higher; lower; reverse
Level	Higher; lower; none
Mixing	Higher; lower; none
Reaction	Higher (rate of); lower (rate of); none; reverse; as well as/other than; part of
Phase	Other; reverse; as well as
Composition	Part of; as well as; other than
Communication	None; part of; more of; less of; other; as well as

Table 4: Shiploader Nodes

Step	Node	Description	
Site Preparation	1.	Component recovery: Component salvage.	
	2.	De-energizing of SL 1&2: De-energized and generator removal.	
	3.	Oil and grease draining: Liquids drained.	
		Preparation	Rigging and Lifting
Step 1: Tripper car	4.	Cut towing bar.	
	5.	Remove tail section idlers.	
	6.		Lower tripper car.
Step 2: Cable reel	7.	Disconnect trailing cable	
	8.	Coil trailing cable.	
	9.		Remove cable reel.
Step 3: Bridge tail and bypass trolley	10.	Remove idler rolls.	
	11.	Lift counterweight and remove conveyor belt.	
	12.	Lower counterweight.	
	13.	Bridge tail structure cut and lowered.	
Step 4: Mast, rear and front ropes	14.	Position lifting crane.	
	15.		Disengage winch brakes.
	16.		Bundle rear ropes and cut.
	17.		Release comealongs.
	18.		Bundle front ropes and cut.
	19.		Release comealongs.
	20.		Cut mast and release to ground.
Step 5: Boom	21.	Remove shuttle conveyor.	
	22.	Remove gravity take-up ballast.	
	23.	Remove operator's cabin and lower to ground.	
	24.		Remove mast pins.
	25.		Install boom lifting spreader beams.
Step 6: Shuttle	26.	Cut shuttle uplifting device and lower to ground.	
	27.	Secure bogies.	
	40.		Lift shuttle.
Step 7: E-house	28.	Cut in and outgoing cables.	
	29.		Remove E-house and lower to ground.
Step 8: Bridge structure	30.	Install temporary diagonals and supports.	
	31.	Remove access, platforms, and stairs.	
	32.		Remove and lower bridge structure
	41.	Cutting of legs	
Step 9: Seaside leg	33.	Remove drive units.	
	34.	Secure bogies.	
	35.		Rig and lower seaside leg.
Step 10: Land side leg	36.	Remove drive units.	
	37.	Secure bogies.	
	38.		Rig and lower seaside leg.
Removal of scrap	39.	Removal of Scrap	

Table 5: Shiploader Guide Words

Phase	Guide word	Guide word description	Source: Australian Standard AS2601	Source: Demolition Work: Code of Practice	Source: Demolition – What you need to do	Source: Occupational Health & Safety Act (South Africa)
Site preparation	1. Connected services	Connected services (above and below ground), i.e. supply of gas, water, sewerage, telecommunications, hydraulics pressure mains, electricity, chemicals, fuel and refrigerant in pipes or lines).	1.7.2.5 Heading	2.1	Yes. Heading	14 (4) (e)
	2. Electrical equipment	Electrical shock.	1.5.2.8 Heading	4.8	Yes	14 (4) (e)
	3. Exclusion zone / Falling objects	Exclusion zones protect workers undertaking demolition and prevents unauthorised personnel entering work areas.	1.3.8 Heading	2.3	Yes. Heading	14 (4) (h)
	4. Ground preparation	Ground preparation (cranes and other lifting equipment).	3.4.3.2	3.	No	14 (4) (a)
	5. Public access	Public access & Exclusion zones.	1.5.1 Heading	4.3	No	None
Demolition - Lift Preparation	6. Confined spaces	Confined spaces.	1.5.2.3 Heading	3.4	No	14 (4) (g)
	7. Debris removal	Removal of debris (larger than rubble, i.e. >keg).	1.3.4 Heading	4.6 Heading	Yes	14 (6)
	8. Fire	Fire (flammable, combustible materials, welding, cutting).	1.5.2.5 Heading	4.9 Heading	Yes. Heading	None
	9. Hazardous chemicals and materials	Hazardous chemicals and materials (asbestos, Lead, PCBs, Synthetic mineral fibers).	1.3.10 Heading	4.2 Heading	Yes. Heading	None
	10. Human access and exit	Worker safe access and exit.	1.7.1.1 Heading	3.3	No	14 (4) (g)
	11. Machine access and exit	Cranes safe access and exit.	1.7.1.1 Heading	3.3	No	14 (4) (g)
	12. Noise & vibration	Related to injuries caused by excessive noise and vibration.	1.7.2.3 Heading	2.1	Yes. Heading	None
	13. Powered mobile plant	Powered mobile plant (site access, moving during project).	None	4.5 heading	Yes. Heading	None
	14. Sequence	Dismantling sequence.	3.4.1.1 Heading	5.	Yes	None
	15. Temporary structures	Temporary structures (platforms, ladders, bracing, support structures, electrical installations powered mobile plant).	From Work Method Statements, discussions with Demolition Contractor			

Phase	Guide word	Guide word description	Source: Australian Standard AS2601	Source: Demolition Work: Code of Practice	Source: Demolition – What you need to do	Source: Occupational Health & Safety Act (South Africa)
Demolition: Rigging & Lifting	16. Adjacent structures	Proximity of adjacent structures, clashes and pinch points.	1.7.1 Heading	3.5 heading	None	14 (4) (d)
	17. Centre of Gravity	Position of Center of Gravity.	From work method statements, discussions with demolition contractor			
	18. Fixed moving parts	Parts which are attached to other components, but which might still move around hinges.	From work method statements, discussions with demolition contractor			
	19. Controlled movement	Lifting of demolished components.	From work method statements, discussions with demolition contractor			
	20. Falling objects	Falling (objects, from one level to another, workplace layout).	1.3.8 Heading	2.3	Yes. Heading	14 (4) (h)
	21. Structural integrity / Distortion	Structural integrity (sequence of demolishing, bracing).	From work method statements, discussions with demolition contractor			
	22. Tandem Lift	Tandem lift – this was specifically included as RBCT has a policy on avoiding tandem lifts due to the risks involved.	Included, from client requirements			
	23. Weather	Weather (wind speed, wind speed for partially demolished structures, rain).	3.1.7 Heading	2.2	None.	None.
	24. Weight	Lifting of materials and equipment.	3.4.1.3	4.5	None.	None.
Removal of Scrap	25. Moving vehicles	Traffic management	2.3	Appendix B	Yes. Heading	None.
	26. Transportation of components	Transportation of components (size, shape, weight, center of gravity)	From work method statements, discussions with demolition contractor			

Table 6: Detailed description of process steps

Process Step	Comments
Step 1: Prepare dismantling work method statement.	Preparation for dismantling • These are tasks and efforts which shall and have to be executed prior to the physical dismantling work and incorporate activities which need to be supported and carried out by others: • Residual or spillage: Machines washed down before handover. • Mechanical component recovery: Agree on list of items which need to be recovered and where they must be stored. • Structural supports: If required, determine availability and condition of structural supports. • Positioning: Move machines to dismantling area and secure with wheel blocks or other suitable method. Also ensure that other movable parts of the machine (if any) are appropriately secured. • De-energizing of machine: All electrical supply as well as batteries are removed. • Oil and grease draining: Identify list of components which might contain oil, grease and gasses and remove as per acceptable safety procedure.
	Dismantling • These are all tasks and efforts which are predominantly related and necessary to dismantle safely & securely the Shiploader and Tripper Car in pieces. • Define dismantling sequence and separate each of the steps into a Preparatory work and Rigging phase. • For Preparatory work, establish Engineering Mass calculations for each step in the dismantling sequence. • For Rigging and Lifting, review lifting plans.
	Removal of Scrap • This involves defining the traffic management plan, ensuring that transportation and lifting equipment is available at the off-site dismantling facility
Step 2: Review work method statement with project owner and other stakeholders	• Use verified FEA models with accurate COG and masses for the different structural components to evaluate structural integrity of each component with regards to the lifting/dismantling method. Suitable safety factors should be introduced to provide for any unknown structural mass changes. • Ask the question "Once the component is cut, how would it react?" to ensure that the appropriate treatment plans are implemented to safeguard that no uncontrolled movement takes place.
Step 3: Review and agree nodes and guide words	• Based on the approved Work Method Statement, the Risk Consultant would use the set of Guide Words, review them as appropriate, and assign suitable guide words for (i) site preparation, (ii) demolition - lift preparation, (iii) demolition: rigging & lifting as well as (iv) removal of scrap.
Step 4: Conduct HAZOP workshop	• As per normal good practice. • Ensure that the participants (dismantling contractor, rigging and lifting contractor, engineering consultant for FEA, and the project owner) are appropriately experienced (technical, safety, maintenance, lifting, construction experience) and well prepared.
Step 5: Complete and issue report and risk register.	• As per normal good practice. • Ensure that treatment plans for identified during the HAZOP are implemented.

Table 7: Updated Guide Words and examples of risk assessment

Phase	Guide word	Meaning	Examples from risk assessment		
			Risk event	Hazard	Consequence
Site preparation	1. Connected services	Connected services (above and below ground), i.e. supply of gas, water, sewerage, telecommunications, hydraulics pressure mains, electricity, chemicals, fuel and refrigerant in pipes or lines).	There is a risk of hydrocarbon spills.	• Residual oil in the machines.	• Environmental non-compliance. • Marine spillages.
	2. Electrical equipment	Electrical shock.	There is a risk of electrical shock from UPS.	• UPS is not disconnected.	• Electrical shock. • Fatalities.
	3. Exclusion zone / Falling objects	Exclusion zones protect workers and infrastructure below overhead work.	There is a risk that the exclusion zone is not properly marked / secured.	• Unauthorised access to exclusion zone. • Exclusion zone not marked or clearly marked. • Traffic management plan not adhered to.	• Injuries and fatalities due to falling objects.
	4. Ground preparation (level & weight)	Ground preparation: levelling and ground bearing capacity (cranes and other lifting equipment).	There is a risk of crane collapse due to uneven ground surface on quay.	• Uneven ground / surface for working level of crane - between seaside and land side.	• Damages to property and equipment. • Injuries and fatalities.
	5. Public access	Public access & exclusion zones.	There is a security risk due to the planned removal of a part of the fence between quay side and RBCT.	• Gap in the fence access and removal of the crane.	• Damages to property / theft • Injuries and fatalities.
	6. Scrap storage	Planning for laydown areas for scrap storage and cutting.	There is a risk that the project site will be	• Traffic flow, operational impact.	• Damages to property. • Injuries and

Phase	Guide word	Meaning	Examples from risk assessment		
			Risk event	Hazard	Consequence
			congested due to stored scrap.		fatalities.
	7. Debris removal	Removal of debris (larger than rubble, i.e. >50kg).	There is a risk that greasy bearing balls (25 kg) might fall from heights when they are removed from the slew bearing.	• Grease on bearing balls. • Bearing balls are going to be removed by hand.	• Injuries and fatalities. Falling bearing balls.
	8. Fire	Fire (flammable, combustible materials, welding, cutting).	There is a risk of fires due to hot work (cutting).	• Hot works. • Insufficient supervision. • Hot work permit system not followed.	• Damages to property, Burns. • Fatalities.
Demolition - Lift Preparation	9. Hazardous chemicals and materials	Hazardous chemicals and materials (asbestos, Lead, PCBs, Synthetic mineral fibers).	There is a risk that the fire detection system is still pressurised.	• System in place, not checked before dismantling.	• Injuries and fatalities. • Uncontrolled release of CO_2 gas.
	10. Human access and exit	Worker safe access and exit.	There is a risk that the towing bar might fall after cutting.	• Towing bar between tripper car and Shiploader not secured before cut.	• Injuries and fatalities. • Uncontrolled movement.
	11. Machine access and exit	Cranes safe access and exit	There is a risk that the scaffolding is not taking the height of loaded conveyors into consideration.	• Coal height not taken into consideration when scaffolding is erected.	• Operational Impact. • Damages to conveyors.
	12. Powered mobile plant	Powered mobile plant (site access, moving during project).	There is a risk that mobile cranes can clash with existing structures.	• Visibility. • Congested site.	• Damages to property. • Injuries and fatalities.

Phase	Guide word	Meaning	Examples from risk assessment		
			Risk event	Hazard	Consequence
Demolition - Lift Preparation	13. Sequence	Demolition sequence.	There is a risk that the disk brakes cannot be disengaged manually.	• Disc brakes are operated hydraulically. Power is off. • Brakes need to be manually disengaged.	• Injuries and fatalities. • Cables cannot be cut, they are under tension.
	14. Measurements	Accuracy of existing drawings (dimensions and weights)	There is a risk that the cranes cannot lift the components safely because they are heavier than expected/indicated on drawings.	• Cranes cannot lift components safely.	• Damages to property. • Injuries and fatalities.
	15. Trapped Water	Trapped water in the machines due to rain, blocked drainage points.	There is a risk that large box sections are filled with water which might make lifts unsafe.	• Moving water inside box sections.	• Damages to property. • Injuries and fatalities.
	16. Temporary structures	Temporary structures (platforms, ladders, bracing, support structures, electrical installations powered mobile plant).	There is a risk that the temporary structures are not sufficient to carry the weight of the legs of the Shiploader after the bridge has been removed.	• Inadequate detail design of legs.	• Damages to property. • Injuries and fatalities due to structures collapsing. • Uncontrolled movements. • Operational impact

Phase	Guide word	Meaning	Examples from risk assessment		
			Risk event	Hazard	Consequence
Demolition: Rigging & Lifting	17. Adjacent structures / Clashes / Pinch Points	Proximity of adjacent structures, clashes, and pinch points.	There is a risk that conveyor 50 and 52 might be damaged during the lift.	• Lift plan not followed. Uncontrolled movement. • Large wind area.	• Damages to property. • Injuries and fatalities. • Operational Impact.
Demolition: Rigging & Lifting	18. Centre of Gravity / Moving Centre of Gravity	Position of Center of Gravity.	COG unknown.	• Current configuration makes COG unknown.	• Uncontrolled movement.
Demolition: Rigging & Lifting	19. Fixed moving parts	Parts which are attached to other components, but which might still move around hinges.	There is a risk that the cut line between the between the counterweight and the boom is cut in the wrong direction.	• Cut line between counterweight and frame too small.	• Rework. • Injuries and fatalities.
Demolition: Rigging & Lifting	20. Structural integrity / distortion	Structural integrity (sequence of demolishing, bracing).	There is a risk that the lifting beams and support structure of the E-house is not strong enough to support on 4 points during lifting.	• Structure is 41 years old and there might be corrosion which is worse than anticipated.	• Damages to property. • Injuries and fatalities. • Uncontrolled movements.
Demolition: Rigging & Lifting	21. Stored energy	Energy stored in components which might be released during the dismantling process.	There is a risk that the tensioning mechanism on the conveyor belt is not secured.	• Conveyor belt under tension, needs to be released before work can start.	• Damages to property. • Injuries and fatalities.
Demolition: Rigging & Lifting	22. Weather	Weather (wind speed, wind speed for partially demolished structures, rain).	There is a risk that severe weather might cause parts of the dismantled structure to collapse.	• Severe weather. • Weakened structure. • Components not secure.	• Damages to property • Uncontrolled movement.

Phase	Guide word	Meaning	Examples from risk assessment		
			Risk event	Hazard	Consequence
Demolition: Rigging & Lifting	23. Weight	Lifting of materials and equipment.	There is a risk that the temporary unsecured protection canopies over the conveyors are blown away.	• Canopies not secured, moved by wind.	• Damages to property. • Injuries and fatalities. • Operational Impact.
Removal of Scrap	24. Processing of scrap	Safe processing of scrap (cutting, stacking, storing, environmental spills).	There is a risk of injuries during the cutting of scrap.	• Sharp edges of cut material. • Cutting equipment.	• Injuries and fatalities.
	25. Moving vehicles	Traffic management.	There is a risk of traffic accidents.	• Speeding. • Drivers not used to drive on a quay wall.	• Injuries and fatalities.
	26. Transportation of components	Transportation of components (size, shape, weight, COG).	There is a risk of components falling of trucks.	• Unsecured components.	• Damages to vehicles. • Traffic accidents

Table 8: Difference between a normal Process HAZOP and a Dismantling HAZOP

Attribute	HAZOP	Dismantling HAZOP
Element or node	Element constituent of a part which serves to identify the **part's** essential features.	Element constituent of a part which serves to identify the **process step's** essential features.
Guide word -	Word or phrase which expresses and defines a specific type of deviation from an **element's** design intent.	Word or phrase which expresses and defines a specific type of deviation from a **process element's** design intent.
Process Parameters	Same process parameters applied to each node. • Pressure • Temperature • Flow etc.	Dismantling related process parameters related to the following phases of the dismantling project, i.e. • Site Preparation phase • Connected services • Electrical equipment • Exclusion zone / Falling

LIST OF FIGURES

Figure 1: Stacker reclaimer and shiploader

Figure 2: Case Study Process Overview

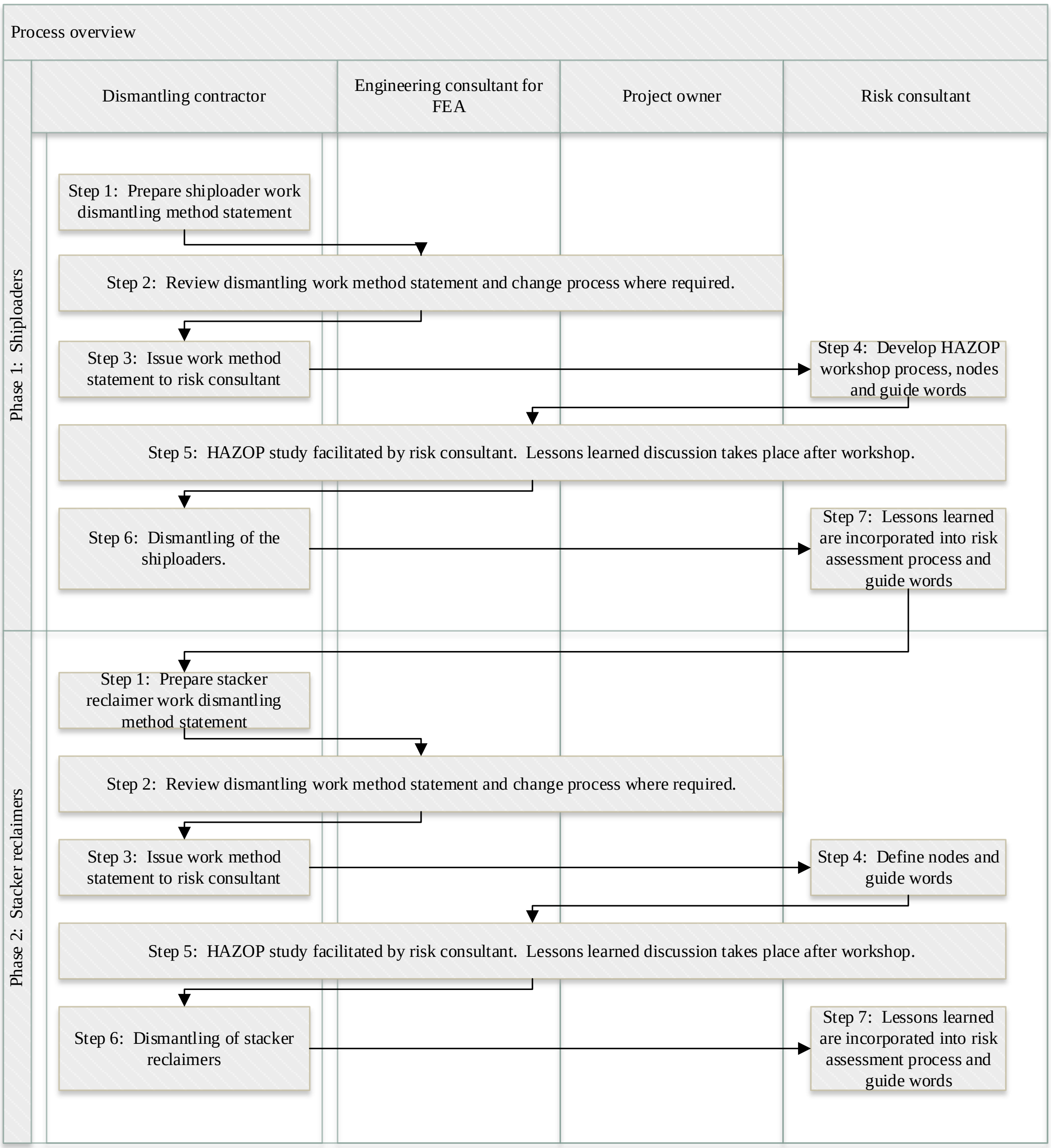

Figure 3: Proposed Process