APPROACHES TO IMPROVE SAFETY AND RECOVER LOST PRODUCTIVITIES IN VERTICAL SHAFT SINKING BY MAKING USE OF INDUSTRIAL ENGINEERING AND RISK DRIVEN 3-D MODELLING TECHNIQUES

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1. Synopsis

Over several decades in Southern Africa the advance rates when sinking vertical shafts have declined significantly. The upside has been a substantial improvement in shaft bottom conditions and a commensurately improved safety performance, with an increasing number of shafts being sunk without fatalities and disabling injuries.

This paper briefly reviews historical sinking rates and matches changed sinking productivity to the introduction of new sinking methods that have been adopted to eliminate/mitigate safety risks.

Meeting the challenge of returning to historical advance rates whilst progressing in the quest for zero harm by utilizing three dimensional animated computer modelling is described. Making use of commercial modelling software makes it easier to evaluate different methods, sequencing, in shaft barrel ergonomics, and stage and shaft bottom layouts before procuring project plant and equipment. Benefits accrue not only in better communicating methods and configurations for detailed planning and design, but also during crew training. The traditional engineering "as-built" drawing practice has been extended to the concept of an "as executed" sinking model which seeks to capture operational experience and learning for future best practice.

The paper concludes with some of the organizational culture challenges being overcome as this non traditional approach to shaft sinking optimization is being introduced.

2. Introduction

Vertical shaft sinking practices throughout the world have evolved over the last century, with preferred methodologies in different countries being driven by local physical environments, source and culture of management and labour, legislative requirements, adoption of new technologies, geology and miners' appetite for risk. What was an acceptable sinking shaft bottom environment eighty years ago is no longer acceptable today.

The elements contributing to what constitutes superior "value add" in a shaft sinking project extends increasingly beyond a low financial cost and rapid sink. Nevertheless early access to an ore body achieved through rapid sinking and equipping rates will undoubtedly remain a high priority for investors.

What we have seen in South Africa in the last decade is a deterioration in productivity as encapsulated by extended project durations from start of pre-sink to equipped shaft commissioning, frequently attributed to having adopted safer technologies and methodologies in the face of a growing shortage of skills.

Often it is noticeable that the tools we use are used inappropriately and are contra beneficial, for example how often do we see people palm a calculator to do simple mental arithmetic and even get the answers wrong with too many or too few zeros! In a similar vein it is the author's contention that we are often using inappropriate tools to optimize sinking in the twenty first century.

The art of shaft sinking with its changing set of values is becoming an increasingly complex integration of methods and technologies, involving a host of interfaces and is moving beyond the skill of the traditional Master Sinker to assimilate all into a well oiled machine that delivers the project. All shaft sinking requires great cooperative effort. Large crews and many disciplines work together to complete specific tasks and hand over to other crews. The tools of industrial engineering including ergonomics, process management, materials management, and system simulation and analysis offer an opportunity to assist the new generation Project Manager to bring back lost sinking advance rates.

2.1. Southern African perspective

This paper focuses on shaft sinking performance in Southern Africa as drawn from experiences of the oldest African specialized hard rock mine development and shaft sinking contractor, with a shaft sinking pedigree going back to the contract in the mid 1950's for the preliminary works, diversion tunnel and first coffer dam at Kariba. The crew formed the nucleus for the team that sunk the Prain shafts at Mufulira and then the first shafts sunk on contract in South Africa at Carolusberg. Since then approximately 70km of vertical shafts have been sunk by the author's company.

The Southern African sinking market of past and present can be characterized as one of large diameter relatively deep shafts, concrete lining being a concurrent non critical activity and equipping carried out after the barrel has been completed, many sunk through significant water bearing and methane carrying structures, with the work undertaken by teams with large migrant labour complements of relatively semi-skilled personnel, managed and supervised by a very small pool of specialists who have moved between the companies that have the work.

Commercial arrangements which have an impact on relationships between the parties on a sinking project, sometimes inclusive of an independent engineering, procurement, contract management party (EPCM Project House), have in recent times migrated from the open tender fixed price re-measurable contracts of the past to negotiated cost reimbursable agreements with pain gain mechanisms which seek to distribute the risk to the party best equipped to deal with it.

3. The zero harm imperative

Production performance being accorded a higher priority than a safe outcome is a legacy of the past, when historians recorded a shaft bottom fatality on average for every 100 metres sunk. Every object falling down a sinking shaft, usually something that has been dropped by a person, knocked loose through equipment and materials handling or barrel wall scaling from rock stresses is a potential fatality and consequently a driver to mechanize the operations. It is no longer socially acceptable or justifiable that shaft sinking be carried out at the expense of human health or injury. Inculcation of safe behaviours and striving for zero harm to people and the environment is now a core value within the mining industry, part of the social license to operate and equally an imperative amongst professional sinking contractors.

The sinking industry has risen to the challenge and now shafts are being sunk fatality free and more recently even lost time injury free through proactive risk management, however at the cost of reduced sinking productivity. The challenge remains to better succeed in meeting a zero harm aspiration, yet at the same time recovering sinking production rates which have been lost.

4. Historical perspective – advances in productivity – a view on the impact of the skilled master sinker

A journey through the Association of Mine Managers of South Africa Papers and Discussions from 1931 to present was undertaken in preparation for this paper to gain a perspective on how shaft sinking productivity has changed with time. The papers openly share knowledge and reflect a pioneering spirit of achievement with new sinking records being reported on and broken regularly. This information was compiled with more recent private company records since published information has been increasingly scarce in the last three decades, possibly due to the increasingly competitive nature of the industry.

Figure 1 records “average” sink rate and highest monthly sink rate against year of barrel completion, “average” because the figures exclude the pre-sink but are inclusive of variable factors. Examples of these differences are number of and depth of holes drilled for pre-emptive shaft bottom cover, the extent of cementation that was necessary, whether or not a surface or underground headgear, the number of stations excavated and volume of rock mined in off shaft development, ground quality and shaft diameter.

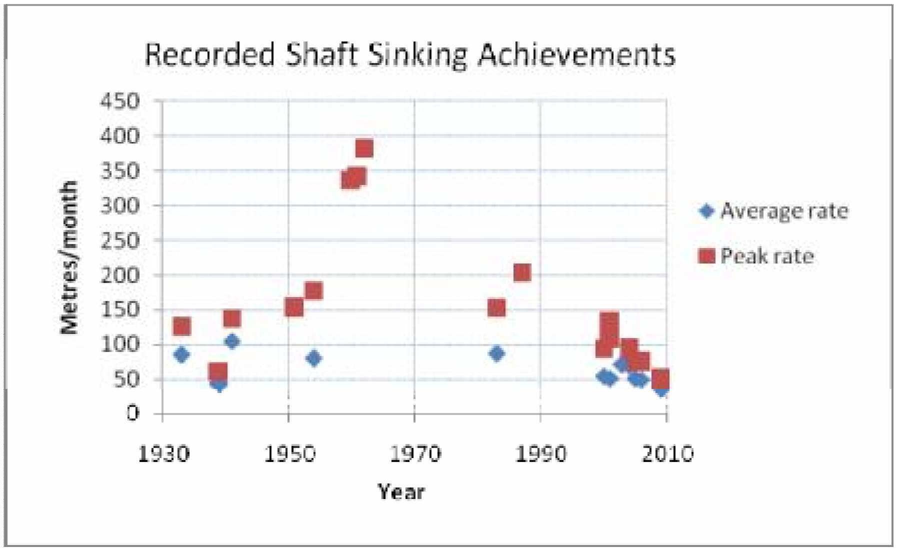

Figure 1: Historically achieved sinking rates

The periods during which those exceptional performances and of late declining sink rates were achieved can be interestingly matched to the introduction of new or alternative technologies and buoyancy of mineral and precious metal prices, which drive shaft sinking activity.

Sources of increases in productivity were reported to be in summary:

1950's

- Introduction of pneumatically operated Cactus grabs at Vlakfontein[1] moving from hand lashing
- Use of lining shutter with a curb ring[2] (soffit base) with scribing planks, rather than long shutters in the critical path

1970's

- Introduction of a pneumatic jumbo to replace hand held drilling in the shaft bottom

2000's

- Introduction of full shaft bottom sidewall cladding

5. A changing environment in which productivity will have to be improved

The way in which a shaft is sunk is strongly influenced by both geotechnical and prevailing local social and political conditions, all within a legislative framework which differs from country to country. Those bold enough to transplant a completely un-acclimatized sinking recipe from one country to another, for instance in the past from Canada to South Africa, have faced insurmountable challenges and met with extremely costly failure. Nevertheless for long term survival contractors and the client body must not be put off and embrace the challenge, learn from their international peers and strive to be more innovative and entrepreneurial.

Risk mitigation requires more than an intuitive understanding of the nature and character of the tangible forces which influence change in our project environment. It requires an understanding of the human psyche and how it responds to the environment. Having decided to change the next step is to identify those key issues to be addressed in the action plan. Three of which are considered relevant to this paper.

5.1. Legislation

Promulgation of the Mine Health and Safety Act in 1996, significantly changed the environment in which mining and shaft sinking contractors operated, with a shift from a prescriptive set of regulations to tripartite responsibility and a self assessed risk discipline. It further introduced a manufacturers and suppliers duty for health and safety (Section 21) which has impacted on engineering change control management on the sinking site. A much greater discipline is required when making operation changes to designs of sinking equipment to eliminate delays and requires a greater involvement of subject matter discipline experts.

Recently the firm stance taken by the Department of Mineral and Energy of issuing “Section 54” instructions to stop the work after a serious incident or accident has had a severe impact on productivity. In a drive utilizing punitive means to achieve a year on year reduction of fatalities of 20% and draft legislation to increase “Section 55” penalties the effect has been for holders of legal appointments to place additional focus on legislative compliance. A significantly greater emphasis on compliance issues, and providing supporting paper trails, is stretching the already overloaded limited operational skills away from direct supervision of the job where they can have the greatest impact on ensuring safe outcomes and productivity.

5.2. Employment of EPCM managers on sinking projects

The introduction of EPCM managers in the 1990’s marked a second change in the sinking environment. The specialist skills within the EPCM houses had the potential to improve project delivery through greater supervision of the contractor in response to declining mining house project capacity. Significantly along with the EPCM managers came Quantity Surveyors with their specialist skills in contract administration, which in turn resulted in sinking contractors skilling up further to match the new administrative regime.

The question needs to be asked whether or not the potential value creation through this evolutionary adaptation has been successful, in particular in the last 5 years of dire skills shortages when EPCM providers found themselves having to strip out knowledgeable operational project personnel to staff their organizations, thereby depleting the teams doing the actual work. The very nature of hourly charged out and reimbursed work allowed EPCM service providers to draw hard operational skills because contracting companies were locked into salary and wage levels determined at the time of tender which could not easily be raised to match lucrative offers. One must also challenge how sustainable this approach is as generally those with the aptitude to get the sinking done are less effective in fulfilling an oversight role.

Deployment of for example one Master Sinker within an EPCM provider to provide oversight of another sinking the shaft with his team introduces a potentially counterproductive risk, especially when the sinking methodology being used differs from the EPCM sinker's experience. How the client responds when safety or production is challenged has a significant impact on relationships and team work which in turn has either beneficial or detrimental impacts on the project team culture, inter party climate and sinking performance.

Matching of personnel with sufficient analytical knowledge and competence within the project team from the client, EPCM provider and contractor is essential to realise the full potential of industrial engineering approaches in these tri-party arrangements.

5.3. Industry capacity – availability of core sinking teams and autocratic leadership.

The number of sinking projects fluctuates dramatically with time depending on commodity cycles and most recently availability of project finance. As alluded to in the introductory remarks, core to a successful sinking project in the past was a dominant knowledgeable leader with his close-knit team who understood the work and in particular what needed to be done to keep up the job momentum and rhythm. Contracting companies jealously guarded their handpicked teams and through good and bad times endeavoured to hold them together.

It is no coincidence that sinking records have all been achieved when there have been many projects in progress.

Currently we find in South Africa that the Master Sinker and his team of the past is becoming extinct; the market of the late 1990's was unable to ensure the survival of enough core teams to meet even the current demand (only six African shafts in barrel excavation at the time of writing). An absolute priority for sinking contractors is to capture the specialist knowledge in a way that new entrants are able to benefit from past learning, whether in training programs, standards, technical papers, archives or otherwise.

6. The source of productivity in sinking

The credo[3] of one of South Africa's sinking leaders, Alastair Douglas, was, "The fewer the movements the shorter the cycle" and "If you are not lashing, you are not sinking". Another wisdom from Canadian pioneer Jim Redpath[4] hinged on two rules, the first being "Make sure the first months performance achieves expectations", and the second "Run a smooth delay-free operation". The source for productivity optimization is clear.

6.1. Building blocks in a South African sinking cycle

Fundamental to analysing and modelling sinking cycles is an understanding of the elements making up the process. The description which follows is generic with relevance to most projects illustrating the number and complexity of the variables.

6.1.1 Cleaning

Hand held shovel cleaning of blast rock was universally carried out with the workers wearing sheet metal "faka-nyawo" boot protectors prior to the introduction of mechanized means using Eimco 630 crawler mounted over throw loaders, cactus grabs and in some instances bucket excavators. Loading rates for hand lashing in the confined space was of the order of 40 tons/hour. Final cleanup of the shaft bottom in preparation for drilling is by hoeing with compressed air, shovel and cactus cleaning.

Pneumatically actuated cactus grab cleaning introduced in the 1950's at instantaneous rates of up to 180 tons/hour was a technological breakthrough for bulk removal, with the grabs suspended from turret type pneumatically powered slewing and hoisting mechanisms. Currently one contractor is conducting a trial with a more energy efficient and quieter electrically driven unit.

Cactus units are capable of grabbing large rocks, which makes fragmentation control and handing of large sloughed off rocks less onerous than when cleaning manually. Large rocks in the bottom, especially if they have to be blasted can significantly reduce sinking productivity.

There is a degree of flexibility in being able to move and position the stage during cleaning with both hand and cactus methodologies, although grab lashing does confine the stage within the length of the grab suspension rope, a consideration when evaluating cycle elements for optimal use of time and concurrency of other activities such as concrete lining.

6.1.1.1 Shaft depth and diameter influences

In every sinking shaft there is a depth at which the rate of loading into the kibbles exceeds the capacity to hoist the rock. The constraint can be modified by altering loading rate, modifying kibble capacity, and changing winding speed, tipping time in the headgear, and delay time when approaching bank and stage.

Intersection of water and the necessity to pump or bail (hoist the water out of the shaft bottom with the kibbles) can impact significantly on overall cleaning rates. The best time to do this is often a point of contention.

Ideally the methods design engineer selects the largest possible kibbles within winder capacity and shaft diameter to achieve maximum cleaning rates. Kibble aspect ratio (height to diameter) is important for shaft bottom stability so that it does not topple over on an uneven bottom thereby becoming a safety risk. The author's company has adopted a maximum ratio of 1,5:1 unless there are exceptional circumstances and a solution has been found to the toppling risk.

In smaller diameters where Eimco 630 or hand loading is the chosen method the maximum rim height is restricted through the ability of the lashers to heave rock into the kibble.

Increasingly off shaft barrel construction and development is carried out concurrently using a temporary service winder while the main barrel is sunk deeper. This has the consequence of having to install additional column capacity to ventilate the multiple ends. Space on the stage decks is at a premium on smaller shaft cross sections with diameters of less than 7 metres, and the area taken up by additional or large diameter ventilation columns really challenges the designer.

When laying out the stage decks there needs to be an optimization between working space for the stage hands (ergonomic solutions favouring safe outcomes), space for as large a diameter kibble(s) as possible to travel freely through the decks to shaft bottom, space to clear the cactus grab lashing unit mechanics and space to clear the installed ventilation columns in the event that the stage has to be brought to surface in an emergency. Positioning of all of these items for maximum cleaning rates and then also to link them to service column and rope positions, and tipping configurations in the headgear as well as integrate the methodology for final shaft furnishing can be likened to building a 5000 piece jigsaw puzzle.

6.1.2 Support, Drilling & Charging

In order to sink deeper after the blast rock has been removed from the shaft it is necessary to drill, charge up and once again blast.

Until the sinking industry has progressed to fully mechanised blind sinking, where the technologies exist but have yet to be integrated into viable business case processes, people will continue to work on the bottom and be exposed to risk. Effective temporary ground support of the newly exposed shaft barrel before the permanent concrete lining has been cast becomes the most important task for the team.

Long round drilling technology was trialled at the South Deeps Project[3] to double the face advance from 3 to 6 metres, with an objective of halving the number of drilling and charging set ups. Potentially also every second time-consuming blow-over activity could be eliminated (blow-over typically accounting for 30% of the total cleaning time). Whilst the 6 metre advance was achieved together with a more productive cleaning cycle all gains were lost during support work to ensure a safe sidewall. The cleaning had to be stopped half way through to make sure that the sidewall could be accessed safely to install split-sets and mesh cladding.

Early literature from South Africa records that short rounds were drilled, coupled with matched hand held cleaning rates to maintain 8 hour cycles, blast to blast. The face was allowed to advance well ahead of the permanent lining, which was then carried out over an extended length as a critical activity, with the shutter carried off of the broken muck pile.

Sinkers in Southern Africa have adopted the approach of carrying out the permanent monolithic concrete lining as an activity concurrent with drilling, thereby taking it off of the sinking critical path. Only casting of the bottom "kerb" ring, with its soffit support which supports the barrel concrete above it, is planned as a critical activity for safety reasons.

As a consequence of this approach it is critical to have precisely the correct stage deck spacing to ensure that time wasting stage movement is limited as far as possible and that at the same time stage hands have adequate and safe access for sidewall barring, concrete shutter handling and setting, followed by concrete dressing after stripping.

6.2 Project culture

An increasing planning risk is that those involved with the design and engineering of sinking equipment and specification of tendered productivities and scheduling underestimate the impact of the culture of the team on site when planning sinking working. Those who provide the information have gained the knowledge from a previous operating environment and in particular one where sinking skills were readily available. The planning approaches to achieving productivity in this new environment need to integrate the proven past with the unproven future, an ideal opportunity for the type of tools available when applying industrial engineering techniques.

The mix of skills, experience and competence of the sinking team and project leadership are undoubtedly the most critical success factor for safe highly productive sinking. In the past much of the day to day sinking know-how was been passed on through journeyman/apprentice type relationships. The new era of qualification and certification has changed this, requiring substantial investments by some of the contractors to capture the knowledge "on paper" beyond the traditional engineering drawings and working procedures for the benefit of the less experienced.

Along with the journeyman/apprentice paternalistic learning environment came nepotism, where for example team leaders were sent back from their hostels to their home towns to find new recruits. Certain villages in Lesotho were renowned for their source of tough shaft bottom men, with several generations in individual families having worked on sinking shafts. Family associations and patriarchal behaviours extended up the management structures.

Many of these employment practices are no longer acceptable, have been legislated against and a source of attention amongst the unions. Additionally the drive to employ from local communities to foster the development of local communities are all changes which have had a negative impact on sinking project performance.

The challenge for future sinking project managers is to create and maintain a new sinking ethos, characterized by:

- Strong, visible, hands on leadership; the Master Sinker and Engineer must have all of the information at their finger tips all of the time on what is happening in the shaft barrel. To do this they will have to be down at the face at least every blast cycle, and more frequently when there are delays.
- A passion for meeting the planned cycle, analysing deviations and continuous improvement
- Shift handover between teams at formal handover sessions to ensure continuity in communication
- Strong discipline on the way we do things around here – no deviations from standard practice unless agreed through a formal team approach. A culture of sticking to the rules and ostracising those who deviate
- Transparency of daily performance and team reward on an understood unified equitable basis
- Intensive induction and introduction of new team members before they are allowed to work
- A passion to listen to team members
- Have a genuine concern for ones fellow team member and that each person's views are worthy of consideration.
- A workforce culture of flexibility to be at work when the work needs to be done, traditionally known as working call out cycles. This was easily managed in the past with hostels close to the project.

6.3 Technology

Any discussion on improving shaft sinking safety and sinking rates must include technological opportunities and how these come about, taking into account that the mining industry, contractors and clients alike, is notoriously slow to adopt alternative/newer technologies probably because of the dire consequences of failure when working underground.

Frequently in post tender clarifications project clients call for the sinker's innovative pedigree to be presented reflecting an inherent desire to do things safer, faster and at a lower cost. Generally the sinking contractor is willing to pursue new technology, but is wary of doing it at his risk as most of the commercial benefit when successful is for the client. The client view is that the sinking contractor has a new string to his competitive bow and should therefore carry some of the cost and risk. The counter to this is that with an increasingly free flow of intellectual property in the industry, driven by safety and client desire for ownership, the advantage is extremely short lived.

Nevertheless some contractors and some clients continue to innovate forming various types of partnership for short term competitive advantage and sustainability of the industry as a whole and innovation does occur albeit slowly. Extensive pre-use validation is imperative; when a new idea is introduced and it is unsuccessful on a project it is challenging to find a champion to pursue development on that specific project because of the production pressure.

A far greater drive to introduce technological change comes from market driven imperatives, such as increasing intolerance of harm to persons, changed legislation, shortages of specialist skills, equipment obsolescence as for example in the case of lashing unit air motors mentioned earlier and suppliers fading from the market place, need for energy and environmental conservation, greater diameter and deeper shafts and also unwillingness of people to be engaged in hard manual work.

The innovation process is frequently initiated when the question is asked, “How can it be different?” Technological innovation to improve sinking productivity as opposed to, for instance, innovation in the management of people lends itself to industrial engineering methodologies, several examples from one company being given below

6.3.1 Reduction of shaft bottom personnel during drilling.

Any falling object in a shaft barrel is a potential fatality, with the difference between a near miss incident and fatality measured in centimetres. The introduction of a pneumatic sling down shaft jumbo in the 1970’s at the Vaal Reefs Number 10 shaft reduced the number of persons from a normal 1 per square metre to 1 per 5 square metres. Trials continue with an electro hydraulic sling down jumbo (EHDR) capable of drilling sidewall support reduces the number down initially to 1 person per 10 square metres with the goal of 1 person per 15 square metres.

6.3.2 Drilling speed and shaft bottom noise reduction to preserve hearing.

The EHDR mentioned above is fitted with Atlas Copco 1838 drifters of nominal output power of 20 kW. Conventional pneumatic jumbos are fitted with Seco 140 units of nominal power of 13 kW. Substantially improved drill penetration rates and noise reduction have been measured, also with considerable potential to improve on the long-hole cover drilling times. 20kW drifters drilling side wall support in place of hand held Seco 25 machines offers the potential for huge productivity increases in the support element of the cycle.

6.3.3 Temporary support alternatives

Some years ago on the Karee 4 twin shaft project the author’s employer standardised on the use of expanded metal sheeting pinned to the sidewall with split sets to prevent injury from side wall scaling. The risk of injury from a rock falling from the sidewall was eliminated, the down side dropping the monthly sinking rate by 9% to an average 78 m/month. The application of thin skin liners has subsequently been unsuccessfully tried but was not without merit. Further work will be done in future projects with different materials and different placing equipment. Application rates are impressive, but were bedevilled by sensitivity to operator control.

6.3.4 Charging

Water gel cartridge explosives with caped fuse and electric starter, detonating cord trunk lines and non electric shock tube detonation have been standard practice in recent times. Time studies have shown the potential of bulk explosive loading, although more work needs to be done to work out optimal loading sequences. Nevertheless confidence is building in pumpable explosives as the reliability of emulsion charging equipment improves. Reduction of over break and crew acceptance are the last barriers to crack before widespread implementation.

7 Industrial engineering applied to in-barrel methodology

Up until this point in the paper the rationale has been to provide a view of issues and challenges which have influenced productivities in current sinking practice. Some aspects which offer opportunity to add additional value to project execution through industrial engineering approaches have been given a primary focus.

The second objective has been to explain the level and degree of the complexity and multiple process linkages that are involved in engineering and planning sinking methodologies; also the relevance of having a humanistic view as skill levels and emotions are at play and cannot be ignored. Too frequently the author has seen subject matter experts in their fields provide intensively and diligently worked through answers, but neglect to think laterally about what they are proposing, put themselves in the shoes of the crew and especially talk their language. In these circumstances the power of teamwork is diluted and considerable value lost.

By further using industrial engineering tools we have the opportunity to bridge some of these gaps in adapting to our changing environment. The next section of the paper discusses some aspects in the development of animated models to achieve and capture best practice, making use for illustrative purposes of a specific example where the technique is being used.

7.1 Sinking engineering – the current scenario

Every shaft sinking project is unique and standardization of activities and detailed engineering a utopian situation. Notwithstanding uniqueness similarities between projects abound, and generic methodologies are suitable for primary engineering, cycle planning, resourcing, scheduling and estimate preparation, but are inadequate to execute any specific project. Consequently a secondary rigorous detailing process is needed once a contract is awarded.

Invariably the window of opportunity to optimize the sinking process design and detailed engineering is constrained by the few weeks available to establish site, assemble the crews, plant up, carry out the pre-sink and prepare for the main sink in earnest. During this time the Project Manager and his on site team are fully occupied with day to day activities, limiting their availability to participate in detail engineering and productivity optimization.

The real optimization happens once the main works have started, leaving little opportunity to do little more than fine tune tendered methods and make small engineering changes. By way of example, how frequently have we seen the Master Sinker arrive at the fabricator to pass out the stage and then a host of last minute modifications having to be made to suit his requirements before delivery? The reality does not stop there. Once the stage is suspended in the shaft and the stage hands have had their input, further changes are required! Change the Master Sinker on the project and a whole new set of ideas is introduced, inevitably resulting yet further changes. Introduce a new technology or sequence associated with the stage, for example a new kerb ring design, without adequate understanding and team buy-in, and the stage is at risk for further on-site detail re-engineering as symptoms of problems are dealt with, some beneficially others incorrectly as the real problems have been missed.

Invariably by the time the shaft is complete yet further detail changes have been made as the team picks up other shortfalls hindering either safety or productivity. Any fundamental errors in the primary engineering, for example unsuitable stage deck spacing, may have to be tolerated for the project duration.

To the passive observer it may seem strange that all of the stage detail has not been resolved prior to manufacture, which is an objective for every project. There are a host of contributing reasons such as limited time, non availability of the key persons at the right time, misunderstood designs, unsuitable/inexperienced design, incomplete designs, personal preference based on past yet not appropriate experience, arrogance, loss of previous learning and poor communication.

In order to obviate this situation the sinking contractor endeavours to involve the proposed project team members early in the tender process to engineer in those aspects which from experience contribute to an optimal solution for the project. Outputs from this process have typically been:

- Method statements with associated risk assessments
- Typical baseline sinking cycle (see figure 1 as an example)
- General arrangement drawings (see figure 2 as an example) and methodology sketches.
- Project organogram and resource schedule
- Project program
- Plant and equipment lists
- Priced bills of quantities
- Proposed commercial conditions

This information pack becomes the starting point for detail engineering once a contract has been won, a successful past approach.

More recently due in part to the factors discussed in paragraph five of this paper allied to a critical shortage of sinking experience, the foundation information to start the construction has been found to be lacking in the detail, primarily because of a lack of experience of the implementation team. Of increasing importance are user friendly knowledge bank processes which allow site project personnel easy accesses to the company centralized knowledge repository, whereas previously the skills were predominantly only held within the site team members memories.

The idea of a detailed animated three dimensional shaft sinking simulation was hatched as a new engineering tool to mitigate both planning and implementation risks. Real time simulations are generated and used in the industry for mine planning, for example in packages such as Mine 2-4 D and MineServe and three dimensional design drafting is well established in the component manufacturing industry. Why not integrate the two applications to sink a shaft on a computer screen BEFORE construction begins and iron out all the wrinkles?

BASE CYCLE	
ACTIVITY	HOURS
RE ENTRY	0.50
LOWER STAGE	0.33
BAR SAFE	0.50
LASH	4.59
BLOW OVER	0.86
STEADY & SET-UP JUMBO	0.50
DRILL ROUND	2.39
CHARGE UP	0.88
RAISE STAGE	0.33
CLEAR # AND BLAST	0.17
EFFECT OF STATUTORY EXAMINATIONS	0.22
SUB TOTAL	11.27
COVER DRILLING	2.00
SUPPORT	0.93
ALLOW FOR KERB	2.00
TOTAL HOURS PER ROUND	16.20
ADVANCE PER ROUND	3.00
ADVANCE PER DAY	4.44
ADVANCE PER MONTH :	111.08
ROUNDS PER MONTH	37.03

Figure 1: Typical baseline sinking cycle

7.2 3-D stage modelling – an example of the potential benefits to be gained

The heart of the sinking process remains with lashing; however delay and incident/accident analysis on a current twin shaft sinking project pinpointed the stage as the area where the greatest value could be added through building a 3–D real time model. The model is continuously in development as greater levels of detail are being added. Modeller costs have been challenged, appear high as a direct overhead, but in the context of saving a lost blast or preventing an accident remain insignificant for the overall project.

Funding to do the modelling work becomes a contentious issue for organizational leadership to debate; few clients will be interested in paying directly to have the as executed model and so it becomes an overhead cost coming directly from the company bottom line. Whether or not to invest in such an approach is a medium term company sustainability issue, one that builds value in the brand.

A greater emphasis on using industrial engineering tools, and especially animated modelling, greatly expands the sinking contractor's ability to re-engineer methodologies and answer "what if?" questions. Firstly does the current culture within the organization have faith in the tools and have sufficient understanding to supply the necessary inputs, and when used are the limitations held in the right perspective? Secondly, and more importantly will the organization adopt and imbed the tools into daily operations, in which case there can be tremendous benefit and the processes will be sustainable, or will they sit on the fringes and be accorded the status of secondary assistance for problem solving when the "old ways" fail. If the answers indicate significant changes to the way we do things, will the organizational culture accept this?

Focusing for the moment as an example only on the stage, already the process of animated model building has proved to be beneficial in a number of areas:

7.2.1 Visualization

Traditionally stage drawings have been two dimensional, with horizontal sections taken at each deck level, (Figure 2). Visualization of the assembled stage, in three dimensions, (Figure 3 & 4), is not an issue to the experienced draughtsperson, designer and engineer, who have a spatial aptitude, however poses a real challenge to the majority of other persons. The ability to show the stage in any orientation in three dimensions greatly improves communication between designers and end users

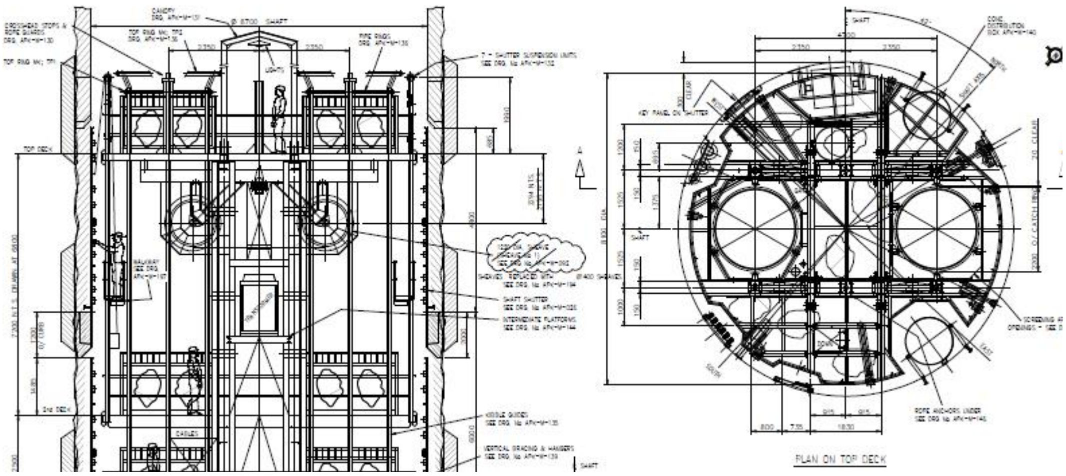

Figure 2: An extract from a traditional 2-D drawing as used to configure and engineer a sinking stage

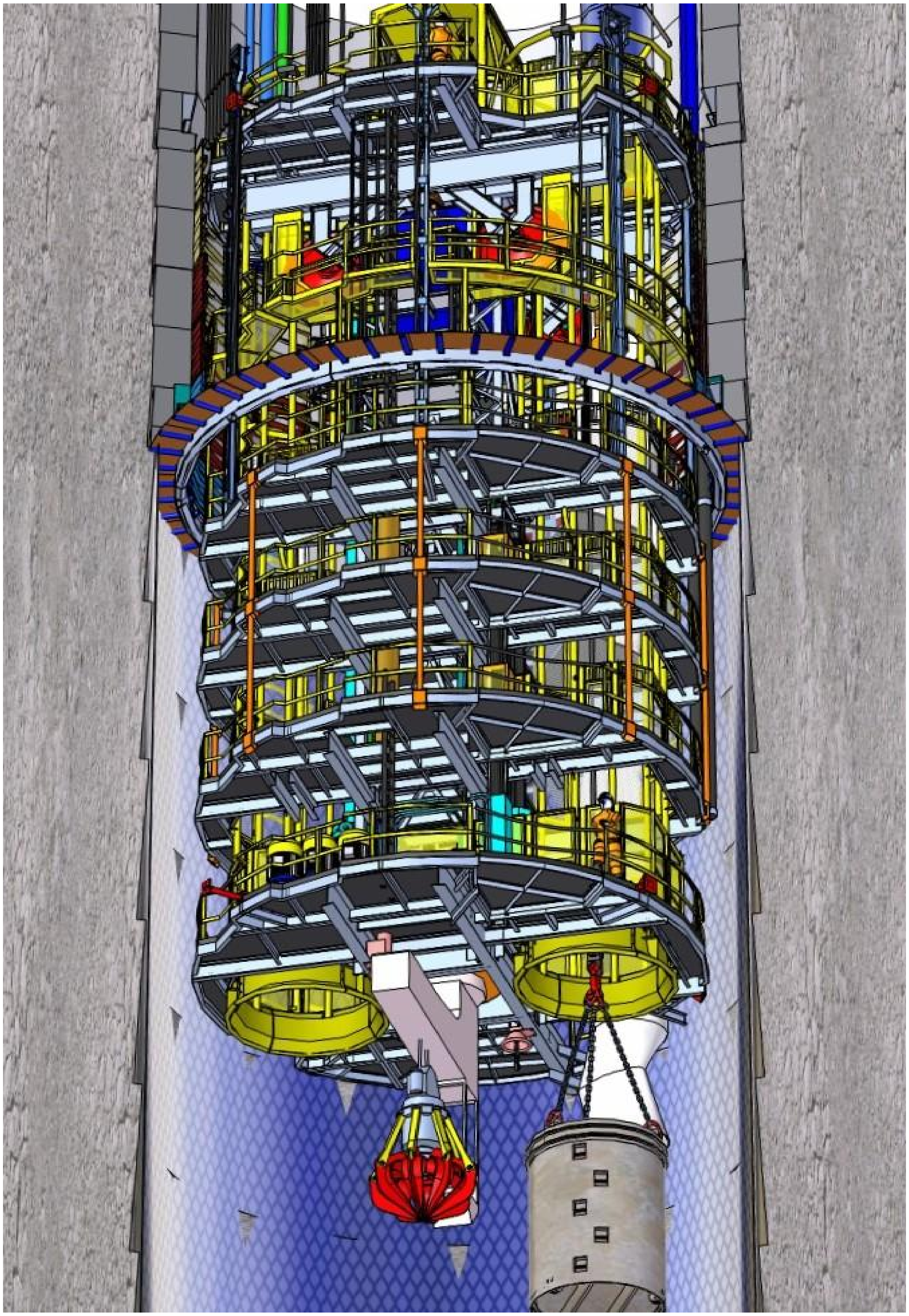

Figure 3: A screen shot from 3-D stage animation.

7.2.2 Holistic visualization of assembled elements

Building on improved visualization is the integration of many different functional elements into one view. For instance on the stage it is a lot easier to simulate the positioning of the flexible concrete elephant hose as it passes between decks when accessing the filler ring

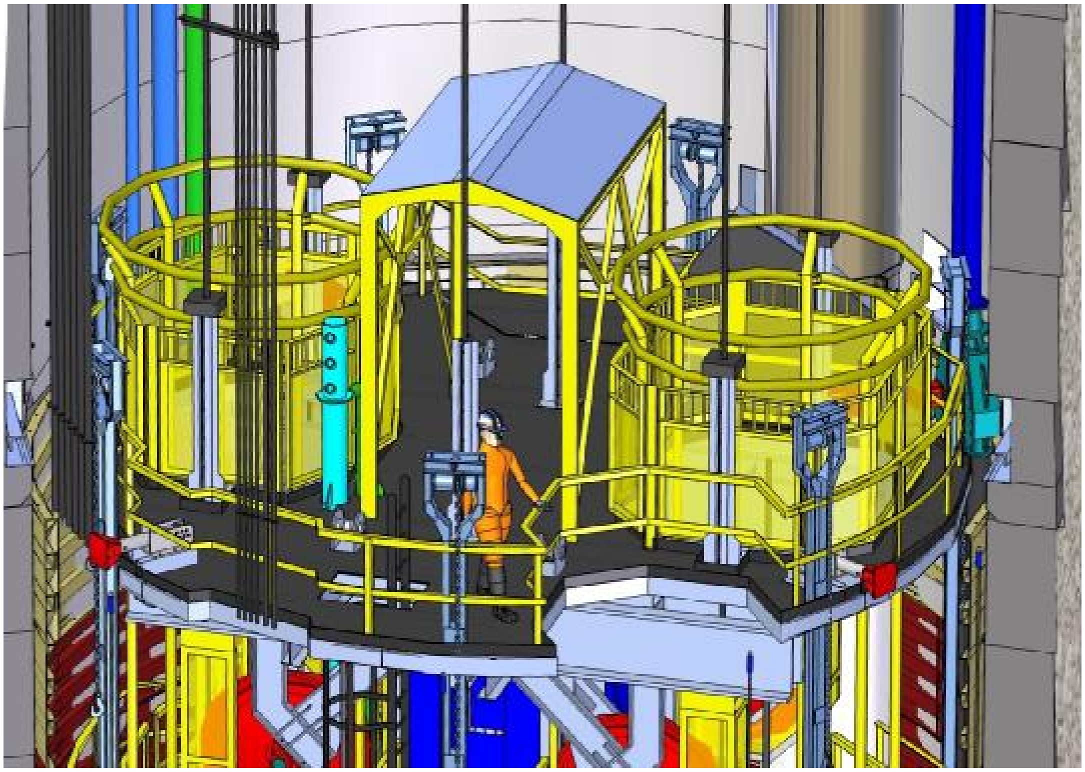

Figure 4: Zoom in to the 3-D model with a change of orientation, illustrating the level of detail that can be engineered, for example for ergonomic discussion

7.2.3 Clash detection

Traditionally stage drawings focus on the stage structural and screening elements and are prepared primarily to provide construction details to the fabricator, who is normally unfamiliar with stage furnishing. Frequently the fabricator is charged with the responsibility of shop detailing as he knows his manufacturing processes and capability, thereby lowering the risk of fabrication defects. Drawing a fully furnished stage in 2-D is a time consuming challenge and of limited value. 3-D drawing is ideally suited to clash detection and optimal positioning of components, providing that previously unobtainable single holistic view of all interfaces.

7.2.4 Man – equipment interface design

Conceptually the stage is a platform to protect and support equipment and people. As we mechanize sinking methods stage complexity increases and the space for the stagehands becomes more confined. (This situation is no more evident than in recent stage/Galloway designs emanating from Canada, where hydraulic drill rigs and their power packs and transformers are additionally nested in the structure, together with Cryderman muckers, rather than carried below). Safe ergonomically designed access for maintenance, side wall barring, and concreting activities is becoming increasingly challenging, especially without the use of 3-D visualization.

7.2.5 Change management

3-D visualization is well suited to the "what if" scenario when optimizing or re-engineering the stage. The real benefit here is that the modeller can change orientations, configurations, layouts, placements, and sizes in front of the Master Sinker and his team providing a completely understandable animated image of the consequences. Too often on site stage modification is carried out to find solutions to deemed problems, which later turn out to be the symptoms of a problems rather than the problems themselves. 3-D visualization eliminates many of these well meaning, but inadequately thought through changes.

7.2.6 Sequencing optimization

Having assembled all of the activities which happen on a stage and animated them into a fully furnished stage in the shaft, including personnel movement, further interrogation of what happens if activities are re-sequenced can be investigated without any impact on the actual shaft operation. For example the question may be asked should service pipes and ventilation column be extended concurrently with setting of the kerb ring, or should this be done when lowering the barrel formwork? Will extra men be required, or should the service pipe couplings be made on the second rather than the top deck of the stage? How much time will be saved? Questions such as these can be answered by the Master Sinker and his crew after work-shopping for an hour or two with the modeller, rather than having to trial the techniques in the barrel.

7.3 Training

The building of the 3-D stage model can and is being extended to other areas to improve productivity, such as drill rig boom sequencing to minimize time wasting boom movements. Modelling mining sequences in station cutting affords yet another of many opportunities to have a virtual dress rehearsal before the main act.

Simulation is a well known technique to fast track initial training, having a long history in aviation, and has more recently been introduced into the mining industry for haul truck, LHD, and drill rig operators. The visual nature of animated 3-D models in the context of shaft sinking greatly aids in familiarizing the crews with their activities, and in particular assist in showing team members how all the activities are integrated. Each man is able to have a helicopter view to see how his work contributes to the work of others and how changing sequences impacts on the whole cycle.

When coupled to carrying out actual work in shaft barrel mock-ups where physical conditions are experienced the novice sinker has a very good idea of how the job will be executed before the site is established, with the crew not only assessed capable, but also competent.

7.4 Knowledge capture – "as built" towards "model as executed"

Improvements for safety reasons and optimizations for productivity enhancement will occur throughout a sinking project despite the best of method selection, procedures, design and draughting, risk assessment, manufacturing and installation in any of the sinking processes.

The learning has traditionally been captured by those on the project and then filed in the company knowledgebase in the form of closed out accident reports, project reports, diligently used formal non conformance and engineering change management documentation, together with daily site production records, all pre-requisites to comply with ISO 9001. Engineering "as built" drawings, to which future reference can be made, can be useful in the design office for the next designs when correctly managed, particularly in an era where "copy – paste" is prevalent amongst draughtsmen working under pressure.

Developing the concept of "as built" to one of "modelled as executed" using time based 3-D models opens up a wealth of opportunity to capture the learning from a project in a hitherto new format which integrates much information in a way not previously possible.

What is required is to take the 3-D model prepared at planning stage and update it with actual changes as well as time measurements taken from in barrel activity studies and incorporate these for improvement. This should form part of a continuous improvement program and not recommended to only do the work at the end of the project as project team and crew priorities, from where the rich information emanates, are focussed on commissioning, punch listing, site disestablishment and positioning themselves for the next contract.

This work should become a regular activity throughout the sinking duration.

8 Organizational culture changes for the new environment

A view of a business is that it is a goal directed risk management process. The sinking organization's appetite for risk and individual's desire to change behaviour, with the over arching shareholder business performance imperatives will dictate how rapidly sinking productivity will be recovered.

Pro-actively changing decades of a well imbedded shaft sinking organization's culture in what has until the last few years been a relatively unchanging industry environment to a radically different scenario requires a leadership team prepared to embrace the challenge and accept industrial engineering methodology has an important contributory role

Recognition and acceptance of inexperience of sinking crews industry wide must be acknowledged internally and by the client body whilst building a culture of the right relationships and interaction between sinking team members and specialist industrial engineering staff. Prior to site establishment there needs to be sufficient time available in project programs to prepare the models and develop understanding of importance of the tools amongst the project team and crew so that they can make use of them productively. The industry practice of pushing for an early start in recruiting for experience from those who have been on earlier sinking projects when there is insufficient capacity within the organization will not be effective as new skill sets have to be learned.

Productivity improvement through an autocratic management style, whereby the leader almost unilaterally decided when and how change would happen is outmoded and no longer proving to be successful – engagement with each and every team member in a contributory manner has never been more crucial. The team members therefore need to understand the benefit and be involved at their level of understanding in building and maintaining the animated models throughout the life of the project.

Complementary to achieving change in the environment of sinking experience and skills shortages are well understood and applied systems, systems to evaluate the risks created through change, systems to monitor the implementation, measure improvement and systems to feed back learning for further process improvement. This requires project team members with an aptitude for systems and the discipline to stick to them, deviating only after following structured thought processes. Uninformed or emotional decision making on the spur of the moment and "maak 'n plan" or "free engineering" are inappropriate behaviours.

8.2 Future organization culture changes – a view driven by potential outcomes of sinking re-engineering

A vision for the not too distant future to when animated modelling in sinking is well entrenched amongst project team members also requires ingenuity to comply with legislative requirements which are restrictive to the organizational structure of a project team (Mine Manager, Mine Overseer, Engineer appointments) and further organizational culture shifts:

- The future Master Sinker will rely less on his accumulated hands on technical mining skills, these will be provided by supporting specialists, such as blasting engineers, drill masters, mechanical and electrical technicians. He will be a leader of men with exceptional motivational, team building and organizing abilities who understands the sinking cycle and adherence to its discipline. He may not necessarily be an experienced Mine Overseer, but will be skilled in day to day risk assessment practice.
- The project team will have a senior on-site methods engineer who has analytical ability to continuously review productivity and give the in barrel crew feedback on performance, as well as engineer productivity improvements.
- The Site/Project Manager will have a high competence in all aspects of project management and be commercially astute.
- The Site Engineer will focus on maintenance engineering, with any re-engineering carried out by specialist off site engineers
- Remuneration and bonus structures will have been accepted that attract senior yet hands on multi-skilled in barrel crew who are required to work in a much more mechanized sinking environment. Full time in barrel crew take home pay will often exceed that of their managers
- Artisans generally working without assistants.
- Mining and Engineering Foremen are working Foremen

Will the shaft sinking industry be able to make this paradigm shift?

The time is ripe for a new generation of fresh open minded young mining engineers currently waiting in the wings to take sinking responsibility, with the mining industry under severe cash flow stress, without a short term solution for the severe shortage of experienced sinking skills and those remaining rapidly moving towards retirement. Match their energy and potential and their understanding of systems and industrial engineering tools with the older experienced leaders of men and accelerated beneficial change will happen!

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