Project management, and the design of shaft-sinking projects

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Synopsis

Change is endemic in our society. Future change will be accelerated by an explosion in technology, communication, and political thought. To meet these challenges, rapid structural changes have been taking place in mining organizations both here and abroad. The management of shaft-sinking projects is a case in point. Shaft sinking is a seminal element in the sustained well-being of a deep-level mining venture. Its accomplishment is fraught with risk, involves a high level of capital expenditure, and is a precursor to profitable mining investment. The purpose of this paper is to present a concise and practical picture of the concepts, methods, and techniques of professional project management as applied to shaft-sinking projects.

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Introduction

Traditionally, shaft-sinking projects have been managed by conventional operational techniques, and have often involved large cost and time overruns. This paper proposes that the project-management system has a better chance of success. The characteristics, techniques, and application of project management are examined. Experience gained on numerous shaft-sinking projects has increased confidence in the efficacy of the project-management concept.

Shaft sinking in South Africa is as old as the mining industry itself[1]. For over one hundred years, mining houses have been involved in the sinking of shafts. Each mining house developed expertise and skills of its own that were jealously guarded and protected. Shaft-sinking crews were paid premium salaries and acquired a certain amount of exclusivity. They exploited the arcane nature of the profession to gain somewhat of a *prima donna* status. Their management styles were dictatorial and based on the command-and-control principle.

In boom times this was acceptable but, when the economic pinch came, corporate management looked at alternative methods of sinking their shafts. A specialist contracting industry began to evolve, firstly from within the various mining houses and under their financial and managerial control, but later on these companies acquired independence, although there are still some notable exceptions. However, in spite of the growing competition among the contracting companies, cost and time overruns persisted. Mining houses continued to develop design expertise, but management systems were sadly neglected. Shaft sinking was often relegated to a minor role, being treated as an adjunct to the operational management function.

The increasing economic pressure in the industry virtually forced a new approach to the management of shaft-sinking operations. Various forms of organizational structure were, and still are being, experimented with. The partial project-management systems implemented by some mining houses were less than successful.

Astute corporate executives, under constant pressure of changing and challenging economic constraints, are re-evaluating their mission statements, and in many cases are becoming more sharply focused in what their business activity should be. 'What are we actually required to produce?' is the question that is being asked. Activities that are not in the main stream are being pruned and, under the severe strain of capital budgeting requirements, they have started looking for better and more cost-effective ways of creating and expanding their production facilities.

In addition, organizations now operate in an environment that is even more turbulent than before. The growing demands of international competition, increasingly sophisticated customers, unprecedented short lead times, and uncertainty in the environment require levels of performance, adaptability, flexibility, and speed of innovation that only a few years ago would not have seemed possible.

Executives have realized that, to meet these new demands, the creation of new facilities cannot be treated as an adjunct to the operations function. Operational managers are dedicated to production, and very rarely have either the specialized skills required to manage projects or the necessary time to allocate to these projects. This has induced corporate executives to search for new methods to improve their organizational effectiveness. The project-management system is an obvious and viable alternative. Project management is an advanced and specialized branch of management. Virtually every organization in the free world has come to recognize its tremendous value, and is using project management in one form or another.

The Project Management Institute (PMI)[2] defines a project as 'any undertaking with a defined starting point and defined objective by which completion is identified'. Project management is defined as 'the art of directing and co-ordinating human and material resources throughout the life of a project by using modern management techniques to achieve pre-determined objectives of scope, quality, time and cost and participant satisfaction'.

Project management achieves its success by creating an environment that is flexible, responsive, and goal-oriented. The work flow is multidirectional, and not merely vertical as in a functional organization. This promotes communication and co-operation between top management, the various functional departments, and the project office.

The question now arises as to why a group of professionals cannot simply be assembled and adapt the skills they have developed through the years to accomplish a project successfully. After all, these professionals may have a record of exemplary performance in the operations field. The answer lies in the fact that project management is not simply an assemblage of skills and techniques, sophisticated computer programs, and technical proficiency. Project management is a whole new culture that is designed for quick response, being based on a flat organizational structure and total integration across functional disciplines. Integration is central to the discipline of project management. If undertakings are to be completed successfully, the individual disciplines can no longer take a parochial approach and be managed on a superior–subordinate basis.

Often, groupings of workers adopting conventional management procedures do not cope well with project work. It is difficult to diffuse responsibility for cost and performance in a rapidly changing situation. Specialized units strive to perpetuate their own interests and privileges, rather than advance the project focus. Strong interfunctional bonds do not usually exist in conventional management structures.

Project management is a process rather than the application of specialized techniques. Technology is a necessary and essential part of project management, but without a system to tie all the entities of the project together it will end up in a mélange of confusion.

Perhaps the most compelling reason for the adoption of project management is its emphasis on the human side of management. It powers the way for the performance of the necessary project tasks by creating an objective problem-solving atmosphere. The effectiveness of the approach relies on the principle that all project problems can be solved by people.

The acid test for any management system is the degree by which it increases the owner's wealth. Measured against this criterion, the organizational form of project management is superior to any of the conventional management forms. The sections that follow describe characteristics and techniques of project management as applied to shaft-sinking projects.

The Organizational Structure

The form of organizational structure selected to complete a project is the single most important contributor to the successful outcome of the project. There are numerous forms and combinations of structures to choose from. This can be a problem for the corporate executive who has to make the final choice. Many factors have to be considered before a final choice of structure is made. From a corporate point of view the following factors are important:

- corporate culture
- mission statement
- available skills, technology, and experience
- the external environment
- politics
- size of project
- time frame
- organizational effectiveness
- corporate partners.

Research, technical writing, and discussion on the subject of organizational structure are prolific. Many diverse opinions have come to the fore, but experienced practitioners all agree on the fundamentals. A project organization should be

- simple
- flat in structure
- unbureaucratic
- flexible
- decentralized
- small and mobile
- clearly defined
- equipped with managers, right down the line, capable of delegation and personal accountability proportional to their responsibility
- organic and adaptive with a high rate of response
- highly integrated across the functional boundaries.

There are numerous alternatives across the continuum of project-management organizational structures. Youker[3] has compiled a neat diagram to demonstrate this relationship between the functional on the one hand, the matrix in the middle, and the pure project type on the other hand (Figure 1).

Characteristics of Organizational Forms[4,5]

Pure Functional

This is the traditional organizational structure, which works well for routine tasks where the environment is stable and where there is a high level of repetition. Such a mechanistic structure is often necessary to achieve co-ordination in manufacturing, assembly, and production lines.

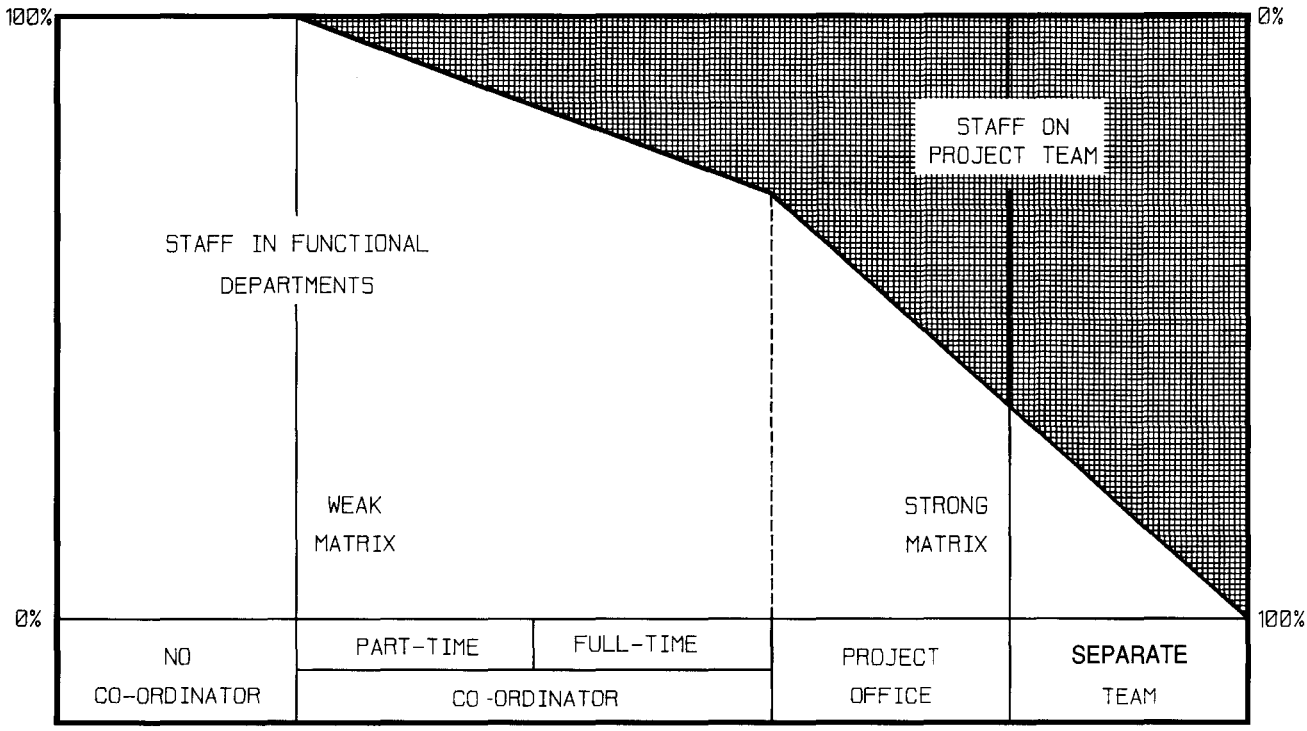

Figure 1—Organizational continuum[3]

Unfortunately, the impregnable boundaries that often arise around the different functions force long lines of communication up and down the pyramid formed by the vertical chain of command.

Pure Project Organization

From a pure project point of view, this is the ideal organizational structure. People and resources are allocated completely to the project team for the duration of the project, and the project manager has full line-management authority over them. Functional departments may very well develop within this format, but the project manager has full control. Complete integration of all departments and other stake-holders is simplified by the fact that there is a single superior in close proximity to any conflict centre.

This type of organization is possible only in companies specializing in project management, or where the parent company runs a full-blown projects division.

The Matrix Project Organization

In an effort to optimize the extremes of the continuum of organizational structures, the US Defence Department conceived the concept of matrix management (Figure 2). This format is ideally suited to project-driven companies running multiple projects. It is also used by the traditionally functional organization for achieving small projects through specially dedicated task forces. The matrix form has tended to predominate in in-house project organizations and is almost always used in joint-venture types of contracts.

The matrix organization combines the vertical hierarchical structure with a superimposed lateral or horizontal structure of project management. Implicit in this arrangement is the dual subordination of team members where the vertical functional lines meet the horizontal project lines.

Although it is a very flexible format, the matrix organization can become complex, and has a high potential for conflict because of the dual subordination inherent in this arrangement. A matrix or project manager is appointed to manage and integrate work and people on a project, but the functional groups are retained intact with technical authority over the specializations.

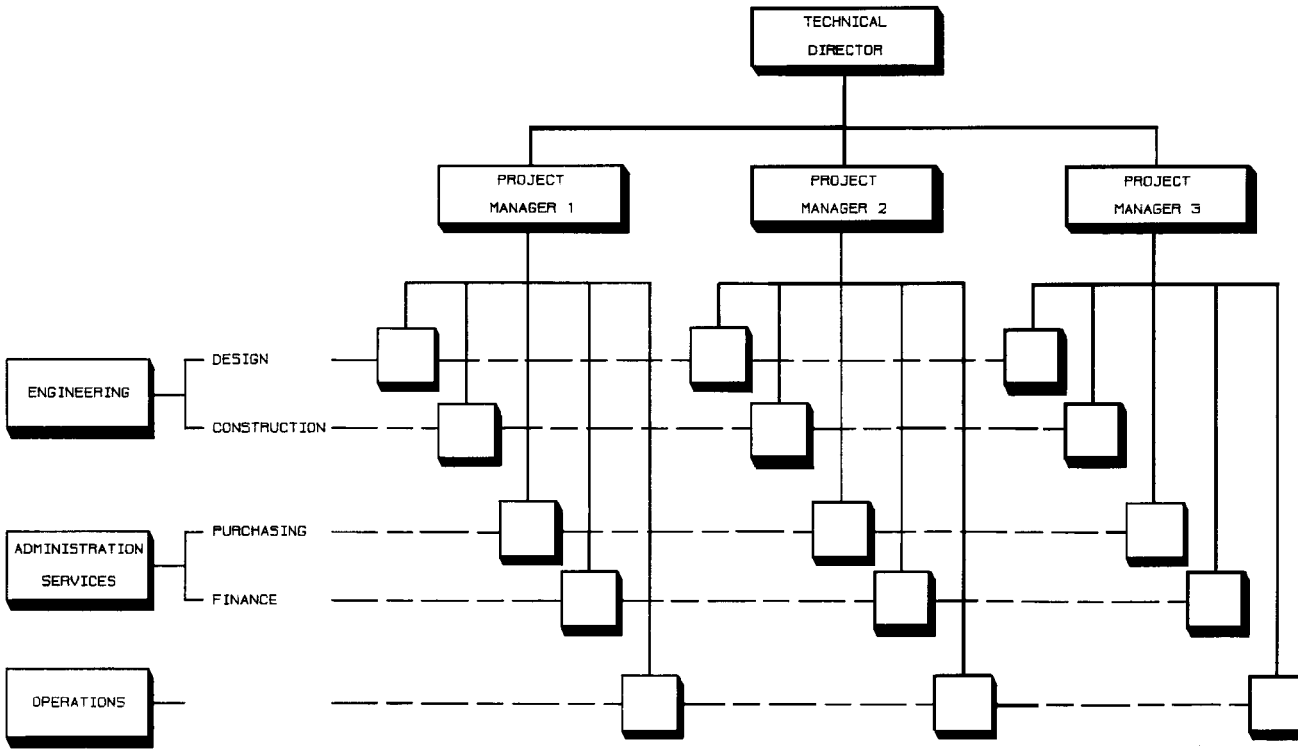

Figure 2—The project-related matrix

Organizational Structure for a Shaft-sinking Project

Shaft-sinking projects, depending on the scope, often qualify for mega-project status. The scope might include the shaft, shaft steel, rock passes, tips, station development, station steel, and loading stations, with the concomitant infrastructure, pump stations, refrigeration, and ventilation. The surface infrastructure comprises winders, headgears, electrical distribution, transport of ore, waste dumps, disposal of mine water, rail-sidings stores, workshops, offices, change houses, personnel control facilities, etc.

The preferred project structure will therefore tend strongly towards the pure project organization or, at the very least, to the strong matrix type of structure.

A manifestation of the project world is the large number of project specialists who act as independents and go from one project to another. Very often they follow a particular project manager from project to project. This may be the result of the strong emphasis on team building; the high level of adrenalin generated on projects; or interest, excitement, or personal gain. The spin-off is that experienced project personnel are more readily available (depending on market conditions), and the deployment of personnel is relatively easy.

A typical organizational structure for a particular shaft-sinking project is shown in Figure 3. The flexibility of the structure allows resourcing strictly in accordance with the requirements of the different lifecycles of the project. This ensures optimal use of manpower throughout the life of the project.

Functions of the Shaft-sinking Project Team

A description of the organizational structure in a shaft-sinking project team would not be complete without a brief description of the responsibilities of the main members of the team.

Project Office Personnel

The Project Manager

- The first and most important function of the project manager is overall responsibility and accountability for the outcome of the project.
- As projects are of relatively short duration, the project manager must, in a minimum period, build a strong and integrated team from members with diverse backgrounds. Integration must take place across the total spectrum of stakeholders, including client, project sponsor, parent company, functional heads, contractors, and other involved parties.

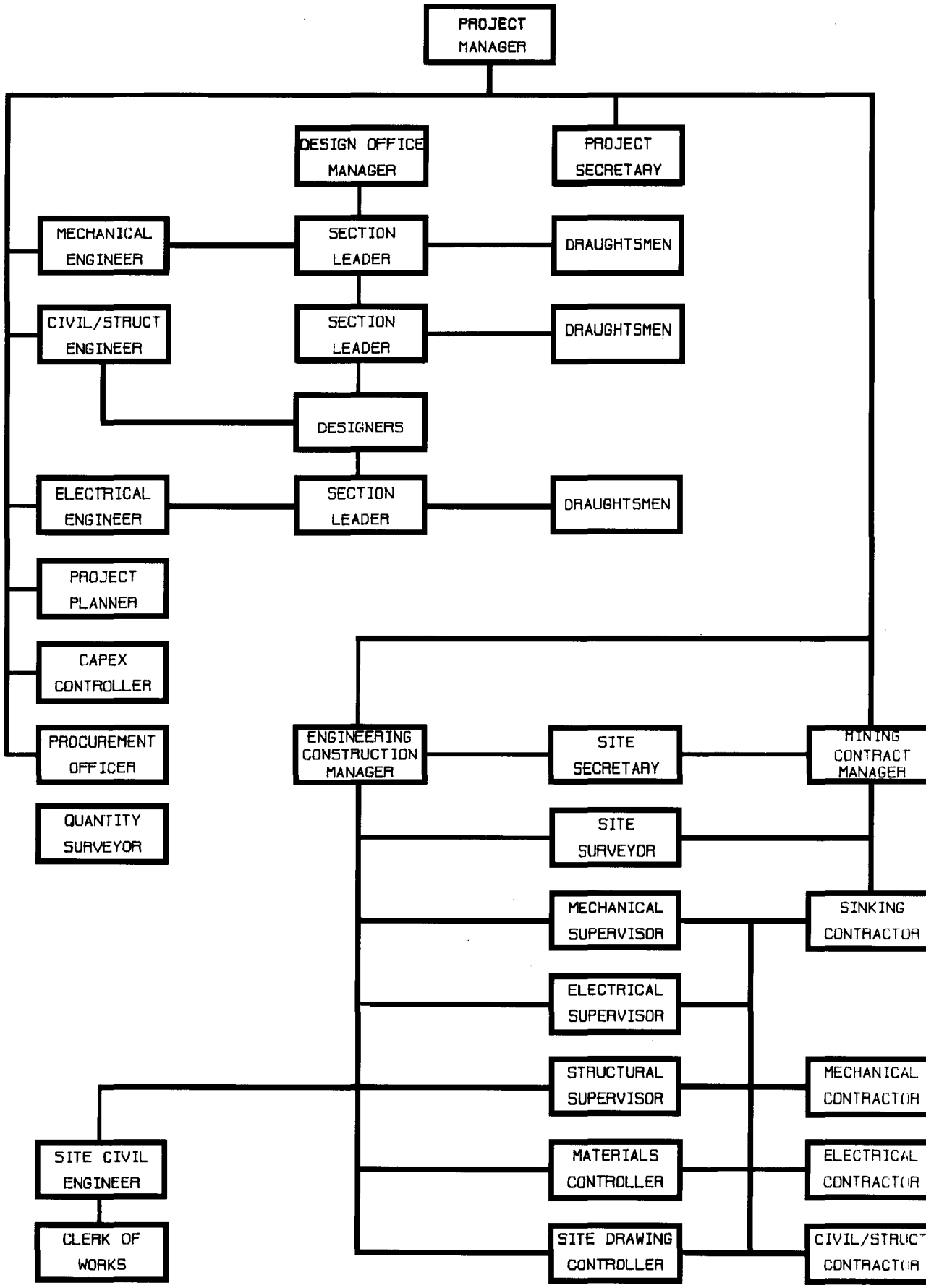

Figure 3—A typical project structure for a particular shaft project

- Planning is a continuous function of the project manager. In the volatile project environment, the scene is constantly changing, and programmes must be continuously adjusted in order to maintain the end date.
- The project manager must co-ordinate the efforts of all the team members and ensure that the project focus is maintained.
- Project management has a high potential for conflict. The management of this conflict is a high priority in the duties of a project manager.
- Comprehensive reports have to be produced periodically by the project manager to keep the client informed of progress and cost, as well as of variances in schedules and performance.
- The project manager is the focal communication point with both the internal and the external environments.

The Project Engineers

Project engineers in the disciplines of mechanical, civil/structural, electrical/instrumentation, and control engineering are assigned to the project to

- head the design teams
- write specifications
- set standards of quality and control those standards
- oversee the procurement activities
- administer the contracts from inception to completion
- ensure that the schedule, cost, and performance criteria are met
- commission and hand over equipment and plant to the client
- monitor budgets applicable to discipline and responsibility
- liaise in the construction
- control changes.

The Project Planner

Project planning is one of the key elements in the control function of a project. A project is a large, complex entity that is dynamic. The control of even a moderately sized project of 500 000 man-hours is a mammoth task. It is, however, critical to the success of a project that the project manager is made aware of changes in their interrelationships with other activities. This process is continuous throughout the life of a project.

The project planner must monitor the schedules from the contractors who are active on the project on a weekly basis. He must keep the project manager informed of the present and future implications of deviations. He and the team are responsible for replanning in order to maintain the end date of the project.

It is essential that control analysis is not limited to the recording of historical events. The trend today is to use future-directed, earned-value performance analysis. This requires the adoption of sophisticated software packages that can be linked into an integrated project-management information system (IPMIS).

The project planner thus has a role that pervades the total project from budget preparation, through design, contract placement, procurement, field execution, and commissioning.

The Design-office Manager

The engineering activity is clearly a vital part of the project-management effort. All inputs and ideas from stakeholders find expression in the design, which is the core of the engineering process. If the design fulfils the requirements of the client (market) and makes a profit for the parent company (project office), then the whole system is sustainable and may even grow.

- The design-office manager is responsible for systematically producing a workable design from the input of the project engineers. Such a design must be produced within the budgeted hours, and must be constructable and functional.
- The general discipline, allocation of work, organization, and control of the design office are the responsibilities of the design-office manager.
- The design-office manager maintains discipline over the total design function. The engineer must produce a formal design specification complete with calculations to support his proposal. The designer/draughtsman must turn it into a workable piece of equipment, and the constructor must be able to build it using his normal resources.
- Design review meetings must be called at regular intervals so that all interested parties have the opportunity of voicing their opinions timeously.
- The design-office manager must adhere strictly to time schedules.

Field Personnel

The Construction Manager

The construction manager has overall responsibility for constructing the required facilities and for the safety of all the personnel on the site. He is responsible for managing and integrating contractors and sub-contractors, and for handing over all the installed equipment and related documentation to the client as specified by the contract. He represents the project manager on the construction site.

The special duties of the construction manager are as follows:

- assist mine management as a subordinate engineer in terms of regulation 2.13.3.1 (*Minerals Act* no 50:1991)
- maintain project procedures in accordance with the laid-down standards
- report on site progress and other activities at the weekly progress meetings
- take corrective action to maintain safety, schedule, and performance within the limits of the laid-down project procedures
- maintain regular contact with the project engineers in respect of contractor performance
- ensure that all the contractors are working to the latest drawings, and inform the project engineers of all change proposals in the field operations.

The Contracts/Mining Engineer

The special duties of the contracts/mining engineer are as follows:

- assist mine management as a subordinate manager in respect of regulation 2.6.1 (*Minerals Act* no. 50:1991)
- control the shaft-sinking contractor in accordance with the contract-prime function
- provide liaison between the project manager, the sinking contractor, and the mine management in respect of safety, performance, and the requirements of the Minerals Act
- arbitrate with the contractor on contract variations in respect of standing time, extension of time, additional support, overbreak, etc., and report these to the civil/structural project engineer
- assist the quantity surveyor and the civil/structural engineer in the preparation of the monthly certificate
- ensure that the sinking contractor works to authorized methodologies
- authorize the contractual resources required by the sinking contractor
- keep a daily log of all events, including the sinking schedule, occurring on the shaft
- ensure that the sinking contractor works to the agreed quality levels.

The Materials Controller

The function of the materials controller embraces the receipt, classification, storage, retrieval, and issue of materials to the contractors in the right quantities at the right time for the right work package.

- He is responsible for the implementation of a well-planned comprehensive materials-management system early in the project. This system must be linked to the IPMIS so that the early-warning and tracking systems are totally compatible.
- He must have close-co-operation with the project engineers, purchasing officers, and accounts department.
- Engineers will certify invoices only against waybills or delivery notes signed by the materials controller.
- A requirement of the IPMIS is that all the receipt and issue details are altered without delay. This will ensure that inventory levels remain up to date, and that material items can be retrieved with the minimum of effort.
- A special system must be developed for the disposal of scrap and, for best results, should be integrated with the established mine system.
- The total materials-control system should be audited by an independent auditor at intervals not exceeding six months.

Supportive Roles

In addition to these core members of the project team, there are a number of functions that support the team on a part-time or a full-time basis for a specific part of the project lifecycle. These resources can be obtained either through the functional departments within the parent company or from specialist consultants outside the firm.

These functions include but are not limited to

- soil-survey consultants
- geotechnical engineers
- project accountants
- quantity surveyors
- land surveyors
- winder consultants
- procurement officers
- quality-assurance officers.

It is vital that the support groups should be involved in the project work as early as possible. The motivation of these groups is particularly difficult because they can easily become alienated, if not adversarial.

The support groups should make time and cost estimates of their tasks for approval by the project team. These estimates may differ from the initial estimates made by the project team and, in that case, adjustments should be made until mutual agreement is reached. Meaningful commitments should be obtained in writing from the support groups. The support teams must be integrated into the main project team at every possible opportunity. They should attend all meetings where their input may be necessary, or where the information disseminated is useful to them. They should also be listed on the inter-office memo-circulation list.

Changing to a Project-management Structure

In the change from a classical structure to a project-management organizational format, the transition must be carefully managed in order to secure its success.

Dr L.J. Smalley[6] has identified five phases in the lifecycle of the transition process.

- *Phase 1: Conception and planning (measured in months)*. Outside consultants are used to train the executives, who are usually not familiar with the total implications of converting to a matrix or any other type of structure. The line managers should be involved right at the outset.
- *Phase 2: Line management involvement (measured in weeks)*. Line-management support is indispensable to the entire operation. The danger of organizational instability is greatest in this phase.
- *Phase 3: Conversion (measured in weeks)*. In this phase, the final design of the new organizational form has to be completed. Employees have to be introduced to the new structure. Leaders and followers are identified in this phase, and all the participants' roles are clarified.
- *Phase 4: Employee involvement.* Management must convince employees that the restructuring is in their best interest. An effective way to do this is by means of training. It is emphasized that the brute force approach will not work.
- *Phase 5: Maturity (measured in years)*. This phase consists in the development and refinement of a cost-control system. In a project structure, costs are controlled horizontally as opposed to the vertical mode of the classical structure. The search for supporting software and the development of sophisticated tools and techniques normally start during this phase. A follow-up of the employee training is also required.

Formal Relationship between Employer and Project Team

The project manager represents the employer in any dealings with the contractor. He is therefore a party to any contract existing between the contractor and the employer. A formal agreement should therefore also exist between the employer and the project manager. In some cases, their agreement is actual, in others apparent, and in yet others partly actual and partly apparent. The agreement may be structured formally on the basis of a managing contractor, or to provide professional services as an engineer, an 'engineer' being defined in the General Conditions of Contract of the Institute of Civil Engineers. Nonetheless, the project manager has a professional, ethical, and legal obligation to conduct the contract in terms of the law and in the best interests of all the parties concerned.

The management system should therefore be formally structured and committed to writing wherever possible. In consequence, the parol evidence rule is of particular relevance in this respect. This is a rule evolved by the courts, which holds that, where there is a clear and unambiguous written agreement between the parties, this will be deemed to be the only and exclusive record of their agreement. Neither party will be permitted to allege that the terms of the written agreement bearing his signature are not the true terms, or that he signed the document believing it to contain other terms or to mean something else (Du Plessis & Nel, 1952, (1) SA 515 (A)).

The project manager must work to establish a special relationship with the client. After all, the client is the supreme authority (he is the employer). In the final analysis, it is the client who pays the bills and must therefore be satisfied. It would be short-sighted in the extreme for the project manager to seek shelter under the law when a conflict arises between the project team and the client's representatives. The project manager must adjust his management style to complement that of the client. An apathetic client may expect the project manager to take the initiative, and to act with bold and rapid strokes. On the other hand, an aggressive client who takes a hands-on approach may cause the project manager to shift towards a more participative stance, requiring extensive prior discussion of proposed decisions with interested client personnel. The project's success is strongly dependent on the project manager's ability to conciliate project-management philosophies with the client.

The client's ability to oversee a project, to establish policies, to indicate controls, to provide specifications, and to participate in major project decisions is a fundamental factor in a project's success. This is of particular importance early in the lifecycle of the project, and preferably during the conceptual design phase. Belated changes in philosophy at the development and execution phase could be disastrous.

When the client is perceived as a group of individuals each with distinct personal, professional, and project objectives, then client relations tend to be harmonious and productive. If the relations are open, easy, and straightforward, positive results will be forthcoming. If the relations are strained, extended client involvement will create obstacles to the progress of the project.

Formal Project Documents and Activities

Work is initiated on a formal and structured basis. It is essential that the project team understand clearly what the client has in mind. To avoid any confusion and conflict, the use of the following documents promotes clarity and control.

Statement of Work (SOW)

The SOW is the most important document in the hierarchy of work. It is that portion of the contract that explicitly enumerates what the contracting organization will deliver to the client. The SOW contains the client's requirements and obligations, a specific work authorization, specific measurable and attainable goals, a list of all deliverables, and a project schedule and budget. Thus, the SOW includes a plan for performance in terms of cost, time, and quality, as well as listing every activity that must be performed and every result that must be obtained. The SOW includes a comprehensive linear responsibility matrix, which must be drawn up at this stage. This linear responsibility chart must identify the participants and the degree to which an activity will be performed or a decision made. The function of the linear responsibility chart[4] is to define, in unambiguous terms, the responsibilities of the client and of the project team.

This chart will obviously be further developed during the project lifecycle but it must be in place from the outset at the conceptual phase. An example is shown in Figure 4.

Organisation Work breakdown structure		Project Manager	Mechanical Engineer	Civil Engineer	Structural Engineer	Electrical Engineer	Mining Engineer	Quantity Surveyor	Cost Engineer	Planning Manager	Procurement Manager	Drawing Office Manager	Client Representative	Security Manager	Ceo/Rockmechanics Manager	Environmental Manager	Quality Manager
Area code	Description																
301	Cross section		P				S			S		S					
301	Longitudinal section		P				S			S		S					
300	Rope layouts		P									S					
100	Surface layouts		S	P						S		S					
301	Station layouts						P			S		S			S		
300	Headgear GA		S		P							S					
300	Tipping arrangement		P		S							S					
300	Arresting devices		P		S							S					
300	Bank doors		P		S							S					
100	Signalling					P						S					
100	Grid Co-ordinates											S	P				
301	Piping services		P							S		S					
100	Batch plant			P								S					
–	Emergency procedure						P								S		
100	Security arrangements													P			
300	Headgear structural steel				P							S					
–	Headgear contract				P			S	S		S						
300	Headgear civils			P						S		S					
–	Project reports	P															

Figure 4—Linear responsibility chart

Work Breakdown Structure (WBS)

The WBS is a convenient method for the division of the engineering project into tractable, small work packages, tasks, or activities (Figure 5). Essentially, it is a methodology of project organization, planning, and control based on deliverables, rather than simply on tasks or activities of proper organization.

The WBS is critical to the whole planning process because it provides the framework from which

- the total programme can be described as a summation of sub-divided elements
- planning can be performed
- costs and budgets can be established
- time, cost, and performance can be tracked
- objectives can be linked to company resources in an objective manner
- schedules and status-reporting procedures can be established
- network construction and control planning can be initiated
- responsibility assignments for each element can be established.

The WBS is intended to ensure that all the required engineering activities are logically identified, coded, and related. The methodology of the WBS approach is the most effective way of structuring and integrating a project, its organization, and its systems. It provides a basis for the modern and advanced approach to structured project management.

The more work packages in a project, the smaller and cheaper each work package becomes. However, the more work packages, the more money and time are spent in arranging for these to be properly interfaced with one another and managed. Conversely, if there is only one large work package, there is no interfacing cost, but the task itself is large and expensive. This is where the astute and experienced engineer can demonstrate his prowess. The larger the packages, the fewer the interfaces, the fewer the schedule activities, and the less intensive the site control. One large work package also deflects more of the risk onto the contractor. The engineer must always be sensitive to the market situation and size his packages accordingly.

There is an inverse exponential relationship between the WBS levels and the activities to be scheduled, and therefore also between the cost and the control of scheduling.

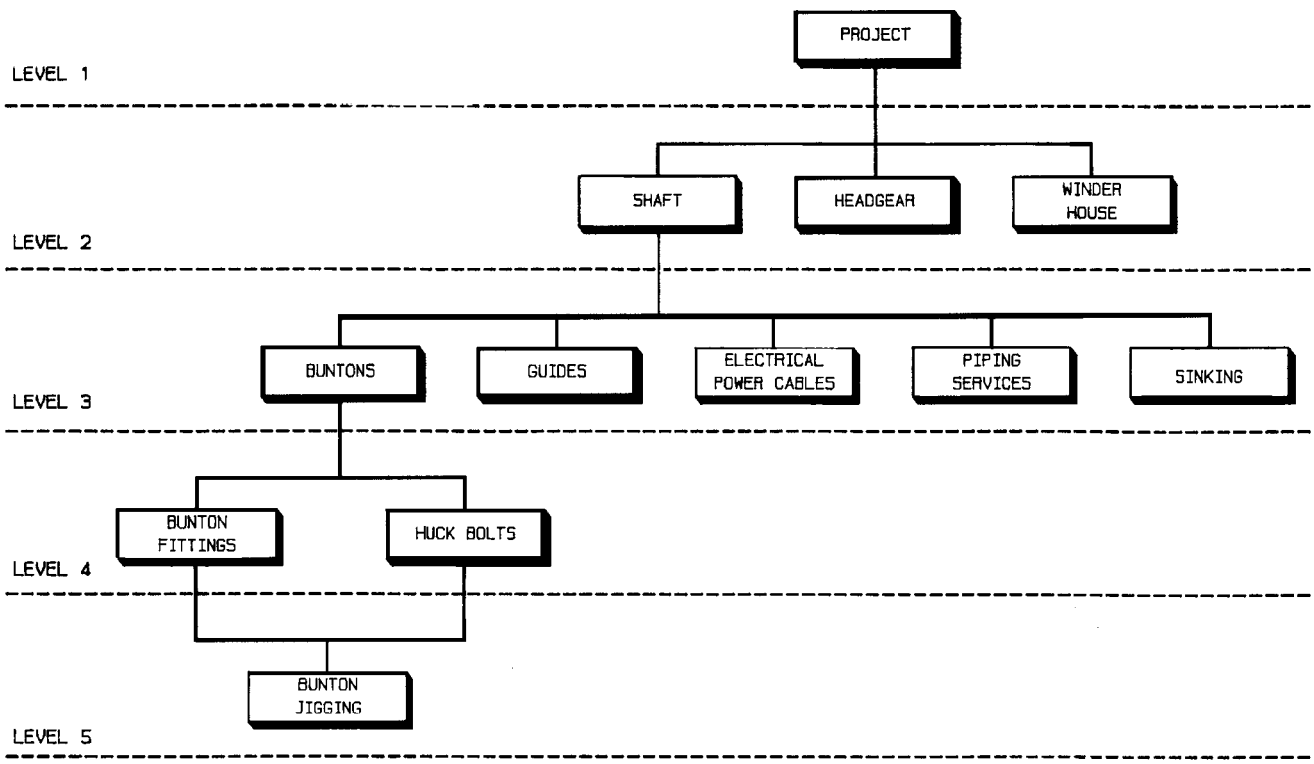

Figure 5—Work-breakdown structure for a typical shaft-task element

Data Sheets

Work packages form the input to the drawing office by way of a data sheet. The data sheet provides the design-office manager with

- all the technical input for the accomplishment of the task
- all reference drawings
- all manufacturer's drawings and data, including dimensions
- scheduling information
- preliminary sketches.

The data sheet is initiated by the engineer for the discipline concerned, initialled by the planner, and authorized by the project manager. The addressee is the design-office manager, who will check the data sheet for completeness and then allocate it to the relevant draughtsmen. Copies are sent to the engineer for each discipline, and the original is filed by the design-office manager.

Project Specification

Project definition is the process that defines the three project objectives of time, cost, and performance before any work starts. The project specification[7] is the document that contains the technical and commercial elements of the project definition. Starting from the first client enquiry to the contractor, and following through the various technical and commercial discussions between the parties involved in the establishment of a contract, a large volume of data is amassed for any project of significant size. This information must be recorded faithfully. Its interpretation has to be clear and uniformly appreciated by both the client and the contractor. Most importantly, this information has to be communicated through the project manager to all participants to ensure that the project is carried out in the manner intended by the client.

A full and comprehensive list of specifications must be identified by the engineer at the initiation of a contact. Each specification must be relevant to the work as anticipated, and each change must be formally approved by all the project stakeholders.

Change-of-scope Documents

Change control is a vital aspect of the overall cost-control system of a project. The engineer for that particular discipline must ensure that his current design is congruent with the WBS. Any changes must be recorded through variation or change-of-scope documents. This must also be done for concept changes, even when no actual cost variances have been generated. In this context, the project-management and design-cost components are often overlooked.

The practice of funding from undeclared surpluses and savings should not be tolerated since this can result in major unexplained variances. Each and every deviation from the WBS must be carefully recorded and processed, and all undeclared surpluses and savings should be under the sole control of the project manager.

Design changes can emanate from many areas: flawed designs, changes in client requirements, updated information from external sources, new legislation, new safety requirements, and internal instructions from senior management. All must be documented, and must be subjected to consideration and review in the same systematic manner as the original documentation. In addition to the aspect of quality, these reviews have to take into account the likely effect of each proposed change on the cost and progress of the project. Formal procedures for controlling the engineering changes will ensure that the client is consulted where it is relevant.

Distribution of the Documentation

Procedures must be established for the distribution of the documentation so that the recipients are accurately identified. More importantly, the procedures used must be based upon the principle of *needs.* Involvement by those have have no need to be involved not only creates confusion, but also adds considerably to the circulation time and, consequently, to the project schedule. Inevitably, such an overloaded list becomes inoperable and obsolete. The project manager must select the recipients, and only those who are essential for inclusion on the list must be considered. An example of such a distribution list is shown in Figure 6.

Design

The process of design is at the core of any engineering practice. Design is the function of creating a technical plan to solve a problem. It involves much more than calculations on a computer and lines on a drawing. It also involves careful planning for safety, technical feasibility, economic viability, constructability, and ease of maintenance. The design problem-solving process requires inventiveness, analysis, and decision-making.

PROJECT DRAWING COMMENT CO-ORDINATION MATRIX		Client (Division)	Client (Mine)	Project Manager	Civil/Structural Engineer	Mechanical Engineer	Mining Engineer	Instrument Engineer	Electrical Engineer	Drawing Office Manager
Process	Process flow diagrams	X	X	X	X	X	X	X	X	X
	Design criteria	X	X	X	X	X	X	X	X	X
	P & ID's	X	X	X	X	X	X	X	X	X
Engineering	Mechanical equipment list	O		X		X	X	X	X	X
	Instrumentation equipment list	N		X		X	X	X		X
	Electrical equipment list			X		X	X	X		X
	General spec enquiry			X	X	X	X	X	X	
	Civil spec enquiry	R		X	X					
	Structural spec enquiry	E		X	X					
	Mechanical spec enquiry	Q		X		X				
	Piping spec enquiry	U		X		X				
	Mining spec enquiry	E		X	X		X			
	Instrumentation spec enquiry	S		X				X		
	Electrical spec	T		X					X	
Civil	Concrete arrangements	X	X	X	X	X	X	X	X	X
	Reinforcing details									
Struct	Steelwork arrangements	X	X	X	X	X	X	X	X	X
	Shop details									
Mech	General arrangements	X	X	X	X	X	X	X	X	X
	Details			X		X				X
	Data sheets									
Piping	Piping arrangements	X	X	X	X	X	X	X	X	X
	Pipe supports and details			X	X	X				X
	Isometrics, MTO lists and data sheets									
Mining	Mining arrangements	X	X	X	X	X	X	X	X	X
	Details			X			X			X
Instr	General arrangements			X	X	X	X	X	X	X
	Loop diagrams, schedules and diagrams									
	Data sheets									
Elect	General arrangements			X	X	X	X	X	X	X
	Cable schedules, routing and schedules									

Figure 6—Distribution of documentation

Changes in Design

Design and change control is managed in accordance with the ISO 9000 series of standards. The main objective is to ensure that the design of the product results in its specified requirements being met. The design inputs and outputs must be agreed on between the main parties. The outputs should include criteria of conformance, and must be demonstrated in the verification process. Design also requires the creation of an organization with appropriate technical interfaces and a documentation and control system.

A design change affects the total execution process of a project. All the stakeholders are involved. Documents have to be updated, affecting the cost schedules, planning schedules, procedural schedules, manpower schedules, quality plans, and project specifications. A structured control and document-revision system must therefore be maintained.

Design Phases

In accordance with Asimon's[8] morphology of design, the following phases of a design project can be considered.

Phase I: feasibility study. The aim of this phase is to validate the need for the project, establish the line of thinking, produce a number of possible solutions, and validate the solutions on the basis of physical realizability and financial feasibility. This stage is also called the conceptual stage.

Phase II: preliminary design. From the useful solution developed in Phase I, the parameters are quantified so as to establish an optimal solution. Only order-of-magnitude estimates of design performance and costs are established.

Phase III: detailed design. The purpose of this phase is to develop a complete engineering description of a tested and producible design. A detailed design includes manufacturing drawings with all parts dimensioned, toleranced, and specified. These drawings are often produced by project-design offices, but this practice is not recommended since it can be counterproductive in respect of both cost and time. Manufacturers and fabricators have their own methods and procedures that are congruent with their fabricating facilities, and they must be allowed to produce these final designs. The project team must review these detailed drawings carefully against the specifications and preliminary designs.

Design Reviews

A fundamental part of design management is the design review. The project manager must call for design audits on all the major plant items that can have a material effect on the outcome of the project. The engineer selected to do the audit should have a status at least equal to that of the engineer responsible for the original design. It is preferable for an external design review to be carried out by a party not connected with the project.

Reviews amount to a detailed design audit, adherence to the contract, and an account of previous studies. Both the timing and the cost of the reviews should be built into the project schedule and budget.

Internal design reviews are called at weekly intervals by the design-office manager. The main purpose of these reviews is to involve all the disciplines at an early stage of the design process. At this early phase of the design process, the cost of a design change is minimal compared with a change made later on. The final quality of a product is determined to a large extent by the effort that goes into the design. It is therefore of the utmost importance that the design team should be totally committed towards quality from the start. This motivation should be reinforced at every design-review meeting.

The Shaft-sinking Contract

Background

The contractual arrangements between the parties involved, i.e. between employer, engineer, and contractor, will have a significant influence on the success of a project. Prime objectives must be to prepare the contract documentation, and to administer the contract so as to minimize the risk of litigation arising from ill-considered and imprecise allocation of risk and consequent uncertainty.

As Max W. Abrahamson[9] says, 'The Engineer is under a duty to have a reasonable working knowledge of the law relating to his job — e.g. to comply with statutes and by-laws; to advise on the causes which should be in the construction contract, but not on the details of draughting; to look for and make reasonable enquiries from his client as to private and public rights which may affect the works; to acquaint himself within a reasonable time of major changes in the law, by legislation or decisions of the court'.

An excellent, comprehensive, and penetrative work on construction law is that by P.C. Loots[10], which is practical, easy to understand, and intended for the professional engaged in contracts. Nonetheless, an engineer can never assume the role of a legal practitioner, and the final draft would always be prepared by a lawyer with experience and training in engineering contract law.

Basis of the Engineering Contract

Under common law, a contract can be described in simplistic terms as an obligation to keep a promise. Both the law of obligation and the law of contracts enjoy prominence in legal and commercial affairs.

The simple obligation involves a legal relationship between two persons: one is bound to perform and is called the debtor; the other is entitled to performance and is called the creditor. The basic characteristic of the obligation is that the debtor can be forced directly or indirectly to comply. The debt cannot be reclaimed if performed in accordance with the law. From the creditor's point of view, the obligation involves the idea of a right that is sometimes obscured by the dominant concept of a duty.

Often, common law will not be satisfactory to the parties for the performance of their particular obligations, and they will make their own particular rules that will expand the rules of common law. A case in point is the engineering and construction law from which the different conditions of contract arose. The most prominent of these are the Conditions of the British Institution of Civil Engineers (ICE). These conditions have stood the test of time, and are the foundations on which most engineering contracts in the free world are based. Many variations of these conditions have been attempted, but any change must be made with the greatest circumspection since the court's interpretation is not always exactly determinable. Only the doctrine of precedent can make the law certain and, when a clause has not been tested in the courts and a decision reached, such a clause remains uncertain.

The ICE Conditions are supported by a large body of law emanating from the law of precedent. With the growth of the construction industry in South Africa, it became necessary to adapt the ICE Conditions to South African conditions, particularly in relation to Roman–Dutch Law as it is applied in the Republic of South Africa. The rules known as the General Conditions of Contract were prepared under the auspices of, and recommended by, the South African Institution of Civil Engineers, the South African Association of Consulting Engineers, and the South African Federation of Civil Engineering Contractors. Certain mining houses have further developed these conditions specifically for use in shaft sinking, raiseboring, and development works.

The Association of Mining Contractors' Standard Conditions of Tender have not found general favour among the mining houses. Different forms of contract are available, and the selection of a particular type of contract is of vital importance to the employer and the contractor.

The employer, by appointing a contractor, transfers some of the risk of the successful outcome of a project to the contractor. At the same time, the employer loses some of his control over the project to the contractor. Together with the transference of risk goes the flexibility that the employer has in the execution of the project. It is therefore obvious that the employer must devote sufficient time and resources to the determination of a contract strategy that satisfies his objectives. Peter Thompson[11] illustrates this graphically, as shown in Figure 7.

The employer's risk and flexibility are minimal under a *lump-sum* contract. This type of contract presupposes that the design is complete, all the specifications and drawings have been completed, and the total works have been accurately defined. No variations are anticipated throughout the construction period.

At the other extreme is the *cost plus percentage fee*. This type of contract is used when the requirements of the employer are vague, or when it is desirable for the design to proceed concurrently with construction. In other words, when the contract is executed on a fast-track basis, the employer is directly involved in the management of the contract and the financial risk to the contractor is reduced.

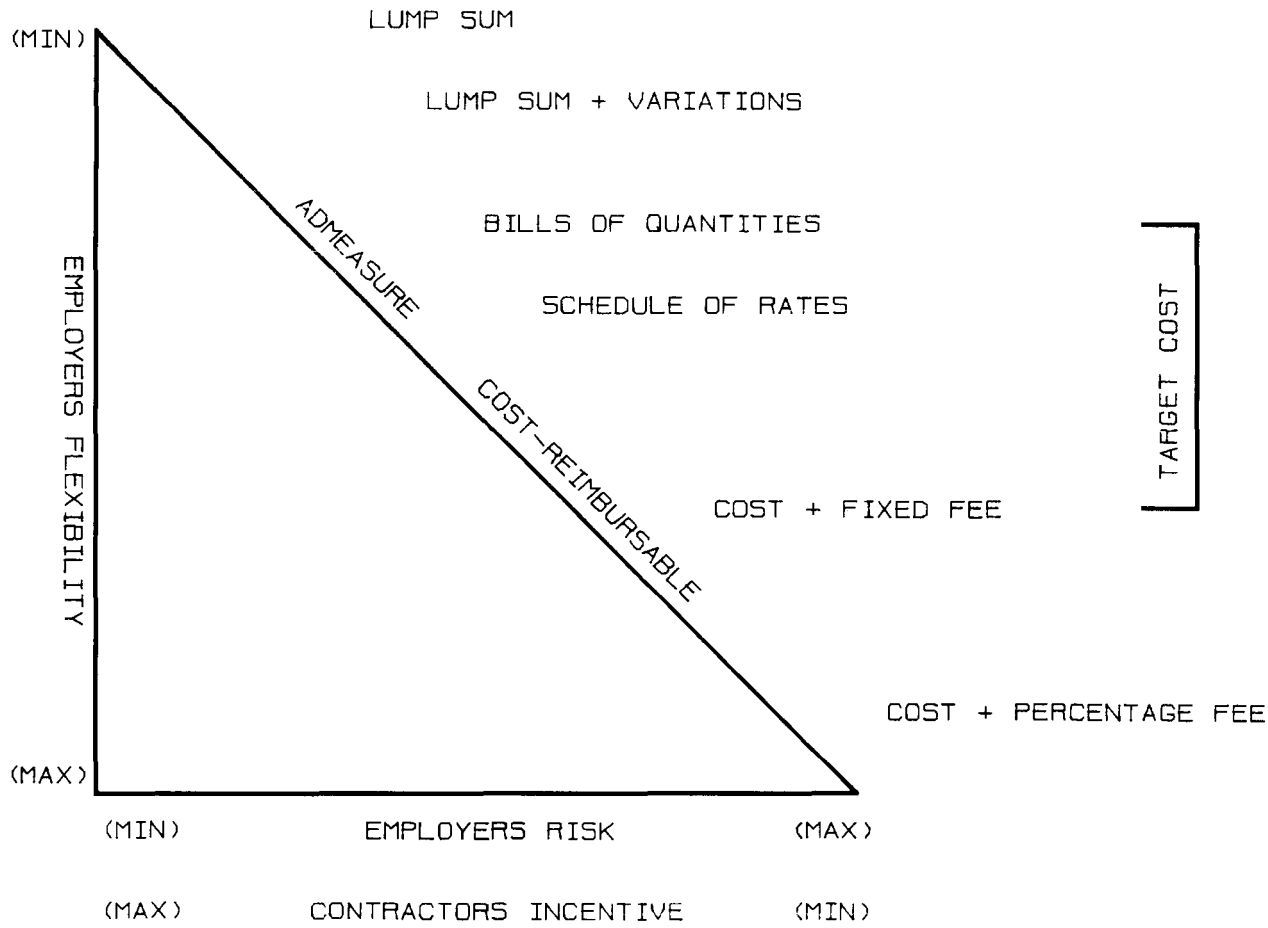

Figure 7—Contract formats[11]

Between these two extremes, in ascending order of risk to the employer, are contracts involving *bills of quantities* and *schedules of rates*. Both forms are based on re-measurement of the contract works. The difference is that, under the bills of quantities form, each composite item of work is supplied at the rate quoted provided that a re-measurement of the quantities does not vary by more than an agreed percentage from the bills of quantities; under the schedule-of-rates form, the rates apply and the full extent of the work remains unquantified.

The nature of shaft sinking is such that change is inevitable during the contract because of ground conditions, water inflow, or change of employer requirement. It is therefore prudent to select a form of contract based on the re-measurement of the contract works and risk-sharing in the most equitable manner.

History has proved that unquantifiable risk can be transferred only at a premium. The employer is in a better position to carry and underwrite this type of risk. On the other hand, every effort must be made to transfer the quantifiable risk to the contractor, and there is no better way of doing this than by full disclosure of all the project variables and an open, competitive tender. Experience has shown that at least 40 to 50 per cent of the engineering must be done if a confidence level approaching 90 per cent is to be attached to a variation of approximately 10 per cent of the tender value and schedule.

The final document is the base line in the consideration of variations. The more managerial input into the document, the lower the conflict level between the contractor and the engineer. Also, administration of the contract will flow more easily, resulting in greater potential for the final success of the project.

Terms of the Contract

The contract document should have the following sections.

- General conditions of contract
- Special conditions of contract

- Technical information containing the project specification, schedule of responsibilities, schedule of drawings, and geotechnical information
- Schedule of quantities
- Form of tender, with annexure and *pro forma* forms
- Applicable standard specifications.

The following principal points should be contained within the conditions of contract.

- The insurance of the contract works, SASRIA, public-liability insurance, and removal of lateral or other support should be covered by the mine company's principal-controlled insurance policy. However, the first amounts payable or deductibles are to be paid by the contractor in respect of each and every claim. The contractor should be responsible for arranging insurance for workmen's compensation, common-law employer's liability, contractor's plant and equipment, off-site manufacturing, MVA, and balance of third party.
- The contractor must provide a surety bond to the value of 10 per cent of the contract sum. This bond is released upon fulfilment of all the contractor's obligations under the contract.
- Retention is held to the value of 10 per cent of the amount due up to a limit of 3 per cent of the contract price.
- The maintenance period is twelve months. Within this period the contractor must make good any defects. If defects are not made good, the company can arrange for the work to be carried out at the contractor's expense.
- The contract is subject to escalation. The escalation formula with co-efficients is closely examined at the tender-adjudication stage, and provisional factors are applied in a determination of whether the co-efficients are competitive.
- All the work is carried out in accordance with the mine's safety requirements. Should the engineer consider that the works are being carried out in an unsafe manner, he has the right to suspend the works.
- The company has an option to terminate the contract at any time. The contractor is paid for the work already carried out, together with proven costs.
- The company may also terminate the contract due to default by the contractor.
- Geotechnical information is provided in the form of borehole logs. The contractor is entitled to payment for incompetent ground only if the actual ground conditions differ from those indicated by the borehole logs.
- The permanent headgear, winder house, and winders must be available for the main sink. Water and power are provided free of charge to the contractor.

The contractor is also required to submit the following information:

- a detailed programme for the proposed work
- a comprehensive method statement
- histograms showing plant utilization and labour
- proposal for the contract-management structure.

The contractor may also submit alternative proposals that he considers to be technically or financially superior to the proposal asked for in the enquiry.

Administration of the Contract[12]

The following reports and procedures make up the administration of a shaft-sinking contract.

Daily Sinking Reports

Daily sinking reports record the work achieved against the work planned, and include all the safety statistics and the delays, both unavoidable and those attributable to slippage by the contractor. These reports, authorized by the contracts/mining engineer, are of fundamental value in determining the payment certificates and contract progress, and generally monitoring the performance.

Payment Certificates

Payment certificates are prepared at the monthly certificate meeting by the quantity surveyors. The certificate is based on measurements supplied by the contractor and approved by the contract/mining engineer and the project's quantity surveyor. Only completed work is considered for inclusion in the monthly certificate, i.e. payment for performance.

Claims

Where a measurement or item cannot be agreed upon at the certificate meeting, the contractor is required to lodge a claim in writing. The claim is then evaluated in terms of the provisions of the contract. One calendar month is allowed for resolving a claim.

Contract Meetings

A meeting chaired by the project manager is held on a monthly basis to record and resolve all contractual matters pertaining to the project. All correspondence, claims, payment certificates, and progress are recorded and actioned when required.

Change control

No work is actioned or performed, or any costs incurred, that are not part of the order placed on the contractor. During the execution of the contract, it may become necessary to change or vary the scope as defined in the contract. Various avenues are available depending on the nature of the variation or change.

- *Order Amendments.* An order is amended to include any additional work required. Such work is budgeted for, but does not form part of the initial scope of the contract.
- *Changes of Scope.* Where an amendment to the contract is required and there is no allocation of funds in the budget, a change or variation of scope is initiated and, once approved, the order on the contractor is amended.
- *Requests for Site Variations.* Where minor work outside the scope of the contract needs to be done immediately, site variation requests (SVRs) are made to prevent unsafe site conditions arising or continuing, or to prevent an overall delay in the project's progress where such a delay has resulted from factors beyond the control of the contractor. The contracts/mining engineer may authorize work of this nature up to a value of R10 000 only.

Potential Claims

Experience shows that claims related to standing times or extensions of time often result in protracted negotiations. An endeavour is therefore made to define the situation very clearly. Cycle times are broken down into the smallest elements so that a change can be defined more easily.

The evaluation of a claim involves a determination of whether the delay incurred is

- beyond the reasonable control of the contractor
- unavoidable after the contractor has taken all reasonable measures to avoid or reduce the delay
- the cause of a major disruption or total stoppage in the regular progress of the works.

The special conditions of contract defines *standing time* as 'a period of time, measured in hours, when the contractor's normal operational cycle is affected by causes beyond his reasonable control and results in total stoppage or major disruption to the *regular progress* of the works'. The special conditions also specify when payment is to be authorized for standing time. Payment is made *at cost,* i.e. standing-time rates should not attract a profit element. The payments for standing time are exclusive of preliminary and general costs. Standing-time claims will attract an extension-of-time cost only if the activity under consideration falls on the critical path of the schedule. There should be no incentive on the part of the contractor to wilfully cause standing time if his standing-time rates do not attract a profit element. It would be more cost-effective for the contractor to perform the work.

An extension-of-time claim applies when additional work or influences, such as changes to work methods that were not part of the original contract, are undertaken by the contractor. The extension of time is primarily there to compensate the contractor for the additional preliminary and general costs that are incurred as a result of being on site. The escalation costs that apply to an extension-of-time cost are high since these costs are incurred at the end of the contract period.

Project Control

General Control

Control has a pejorative connotation that implies power, domination, and authority. It is associated with action and, more explicitly, corrective action arising from the output of the monitoring function. Variances are identified, and the control system provides the means to correct the variance. It is therefore axiomatic that there is a base plan against which performance can be measured. Project control is the process in which deviation between the actual performance and the planned performance in the areas of cost, time, and quality is reduced.

The planning and control cycle is a structured, closed-loop flow of information from the launching of the plan to the monitoring of progress and adjustment of the plan in accordance with the feedback. Time is of the essence. It is essential for effective project control that performance is measured while there is still time to correct the action. Corrective action is comparatively cheap early in the life of the project, but it may be prohibitively expensive at a later stage.

In the dynamic shaft-sinking environment, traditional, manual-based procedures are not adequate for the measurement of project progress, evaluation of performance, and implementation of control actions. Computers provide the capabilities for the acquisition of a large amount of data, measurement of the data, and presentation of a formal analysis in a consistent and timely manner. A further enhancement is the use of expert systems and real-time data-entry and analysis techniques that enable project managers to keep track of small and large shaft-sinking projects.

The breakdown structure of the work is seminal to the planning process. Functional tasks, emanating from the sub-projects and deliverable items in the WBS, are identified, classified, and fed into the planning process. The WBS offers team members a means of visualizing the entire project in a meaningful way. They can then think through all the elements of the project. This helps to avoid omissions and clarifies the scope of the work assigned to each project leader. The final output of the WBS in the form of the work packages that provide the input to the planning process. To be useful for control purposes, functional tasks should be of relatively short duration and small cost compared with the duration and cost of the total project.

An important part of the project planning effort is the identification of the major interface events to be managed by the project manager. Such interface events must be incorporated into the detailed project plans and schedules.

Schedule Planning

There are basically two levels of schedule planning: the project level, and the task level. The project-level schedules integrate all tasks, interfaces, and milestones, and the task-level schedules cover all the key activities that must be carried out to complete the task as defined in the statement of work.

The scheduling of a shaft-sinking project includes five main techniques, which are known as milestone scheduling, Gantt chart, critical-path method (CPM), programme evaluation and review technique (PERT), and precedence network (PCD).

Milestone Scheduling

Milestone schedules are clearly list-defined, achievable goals that may require approval before further work is done (Figure 8). These milestones may be established on specific requests from the client, but the key to their helpful use is selectivity: they must be used sparingly and with circumspection to avoid turning milestones into pebbles over which people are always stumbling. Milestones with attendant schedule and budget measures emphasize the key points of a project. Nonetheless, milestones do not clarify the activity and task interdependencies. Such interdependencies are best explained by one of the many forms of network diagrams, most notably PERT, CPM, and PCD. Each method has its particular field of application, although there is a growing tendency towards precedence networking.

PERT

PERT is a networking system used when there is great uncertainty about the duration of activities. To arrive at a most likely time, it employs probability theory based on best, most likely, or worst times as determined by independent observers. Assuming that activity durations follow a beta distribution, one can compute the probability of completing a project in a given time. This method is particularly useful when one has to forecast durations for sinking through ground of unknown conditions. Because it requires a lot of computational effort to make three-time estimates, and to calculate the expected time and standard deviations, it is expedient to use a computer in networking with PERT.

CPM

CPM is the workhorse of the mining industry. Only one time estimate is used, and it is therefore a deterministic method. A critical path is produced. This is an aggregation of the activities on a sequential path that has the longest duration. The method is simple, and can easily be updated and tracked. It is used mainly for overall planning in the concept or definition phase of a project.

PCD

Precedence diagramming, also known as lead–lag networking, is a direct off-shoot of the CPM network-scheduling technique. In some cases, mutually dependent activities can be partially performed in parallel instead of serially. In such situations, it is possible to have start and finishing time restrictions that permit activities to overlap, or restrictions that require activities to disjoint.

ACTIVITY DESCRIPTION	APPROVED C.B.E. PLAN		APPROVED CONTROL PLAN		ACTUAL/ FORECAST PLAN		REMARKS
	START	FINISH	START	FINISH	START	FINISH	
14 LEVEL DEVELOPMENT	01-Jan-91	14-Feb-91	25-Mar-91	19-Jun-91	11-May-91	15-Jun-91	Completed
MAIN SINK & LINE TO 15 LEVEL	15-Feb-91	02-Mar-91	20-Jun-91	20-Jul-91	17-Jun-91	17-Jun-91	Completed
15 LEVEL DEVELOPMENT	03-Mar-91	13-Apr-91	22-Sep-91	03-Sep-91	18-Jul-91	02-Oct-91	Completed
MAIN SINK & LINE TO 16 LEVEL	14-Apr-91	28-Apr-91	04-Sep-91	27-Sep-91	03-Oct-91	28-Oct-91	Completed
16 LEVEL DEVELOPMENT	29-Apr-91	14-Jun-91	28-Sep-91	19-Nov-91	29-Oct-91	30-Dec-91	Completed
VENT HOLE REAMING			09-Feb-91	16-Mar-91	09-Feb-91	02-Apr-92	Completed
MAIN SINK & LINE TO 17 LEVEL	15-Jun-91	01-Jul-91	20-Nov-91	10-Dec-91	31-Dec-91	25-Jan-92	Completed
17 LEVEL & SILOS DEVELOPMENT	02-Jul-91	21-Aug-91	11-Dec-91	30-Apr-92	26-Jan-92	11-Jun-92	Completed
PUMP CHAMBER CONSTRUCTION			01-May-92	14-May-92	12-Jun-92	19-Jun-92	Completed
SINK TO, EXCAVATE & LINE LOADING BOX	22-Aug-91	20-Sep-91	15-May-92	23-Jun-92	20-Jun-92	23-Jul-92	Completed
MAIN SINK & LINE TO SHAFT BOTTOM	21-Sep-91	02-Oct-91	24-Jun-92	31-Jul-92	24-Jul-92	05-Sep-92	Completed
SHAFT BOTTOM DEVELOPMENT/CONSTRUCTION	03-Oct-91	16-Nov-91	01-Aug-92	19-Aug-92	25-Aug-92	19-Sep-92	Completed
STRIP SHAFT	18-Nov-91	14-Dec-91	20-Aug-92	26-Sep-92	19-Sep-92	13-Nov-92	37 Days (GFC slippage)
MODIFY HEADGEAR, COLLAR & STAGE	17-Dec-91	02-Jan-92	20-Sep-92	21-Oct-92	14-Nov-92	07-Dec-92	
EQUIP BARREL & STATIONS	03-Jan-92	13-May-92	29-Aug-92	02-Mar-93	08-Dec-92	30-Apr-93	
VENT HOLE EQUIPPING	31-Jul-92	15-Oct-92	29-Aug-92	19-Apr-93	07-Aug-92	18-May-93	In progress
EQUIP LOADING BOX & SPILLAGE WINZE	14-May-92	05-Jun-92	03-Mar-93	12-Apr-93	03-May-93	12-Jun-93	
INSTALL AIR/WATER & P.A. STATIONS			22-Aug-92	24-Sep-92	28-Sep-92	06-Oct-93	In progress
INSTALL CONVEYANCES/COMMISSION SHAFT	06-Jun-92	31-Jul-92	13-Apr-93	24-Apr-93	14-Jun-93	01-Jul-93	
POST COMMISSIONING							
ROCK PASS SYSTEM	01-Aug-92		02-Mar-93	03-Aug-93	24-May-94	22-Nov-93	
PUMP STATION		22-May-92	02-Mar-93	16-Sep-93	24-May-93	06-Dec-93	

NOTE: ADJUSTMENT FOR APPROVED DELAYS & C.O.S. TO DATE:- 179.4 DAYS

FORECAST COMMISSIONING DATE BASED ON HISTORY ONLY:- 20 APRIL 1993

VENT HOLE EQUIPPING NOW SCHEDULED FOR COMPLETION DURING SINKING OPERATIONS

P.A. STATIONS NOW TO BE POSITIONED DURING STRIPPING OPERATIONS

SILO EXCAVATION AND CONSTRUCTION AS WELL AS CONVEYOR CONSTRUCTION NOW BEING COMPLETED DURING SINKING OPERATIONS.

Figure 8—A milestone schedule[12]

This system is extremely simple since there are no dummy activities to be considered within the network diagram. Like CPM, it is used mainly for overall planning in the concept or definition phase of a project.

Gantt Chart

During the execution phase for day-to-day control, special-purpose charts such as Gantt charts are used to represent the network schedule. A Gantt chart enables the planner to deal with calendar-time constraints, resource availability, specified start and finishing dates, sub-contractor reliability, prescribed work periods, and other project restrictions. Contractors and sub-contractors are given the basic format of the chart, and are expected to present an updated version of the chart at weekly progress meetings.

Cost/Schedule Analysis

For effective management, it is imperative that accurate and speedy feedback is obtained on which to base decisions. Experience has shown that control of the physical progress and schedules separately from that of cost usually results in chaos. The integrated and structured approach of a management cost-and-control system ensures than an orderly and reliable system of cost analysis is maintained.

Variance analysis, based on three variables (budgeted, actual, and earned value), is a quick and informative way for the analysis of project performance. The three variables are defined as follows[13].

- *Budgeted cost for work scheduled (BCWS)* is the amount of cost for scheduled work to be accomplished, plus the amount of level of effort or apportioned effort scheduled to be accomplished, within a given time period.
- *Budgeted cost for work performed (BCWP)* is the budgeted amount of cost for completed work, plus budgets for level of effort or apportioned effort activity completed within a given time period. This is sometimes referred to as the 'earned value'.
- *Actual cost for work performed (ACWP)* is the amount reported as actually expended in completing the work accomplished within a given time period.

The variance in the budgeting and schedule systems must be compared because the cost variance compares deviations only from the budget, and does not provide a measure of comparison between the work scheduled and the work accomplished.

Project/Cost Integration

Curves of project/cost integration (Figure 9) display these concepts visually. The BCWP, BCWS, and ACWP curves depict some measure of cumulative progress on the vertical axis against time on the horizontal axis. Together, they provide a valuable insight into the status of a project. They also provide a graphic picture of how the project has been brought to this status. Trends can be forecast on the basis that

- performance to time will now be maintained
- performance improves because of the learning-curve effect
- performance decreases after time now.

It should be noted that forecasting would be more accurate if it were based on the tangential rate of progress, because future progress is more likely to occur at the current actual rate of progress than at the planned BCWS slope.

Although the scheduling variance provides a comparison between the planned and the actual performance, it does not include costs.

The two primary items of measurement are

- discrete elements of work with a definable schedule and tangible results
- the level of effort, which alludes to those items that are intangible and therefore not easily measured, such as project support and project control.

Variance Methodology

Variance methodology can be explained by the following relationships:

BCWP

BCWS ACWP

Schedule (Variance) Cost

or schedule variance (SV) is: SV = BCWP – BCWS

A negative variance indicates a behind-schedule condition

and cost variance (CV): CV = BCWP – ACWP

A negative variance indicates a cost over-run condition.

Variances can be made non-dimensional when the ratios are expressed as percentages. Thus,

$$\text{Schedule variance, } \% = \frac{SV}{BCWS} \times 100$$

$$\text{Cost variance, } \% = \frac{CV}{BCWP} \times 100.$$

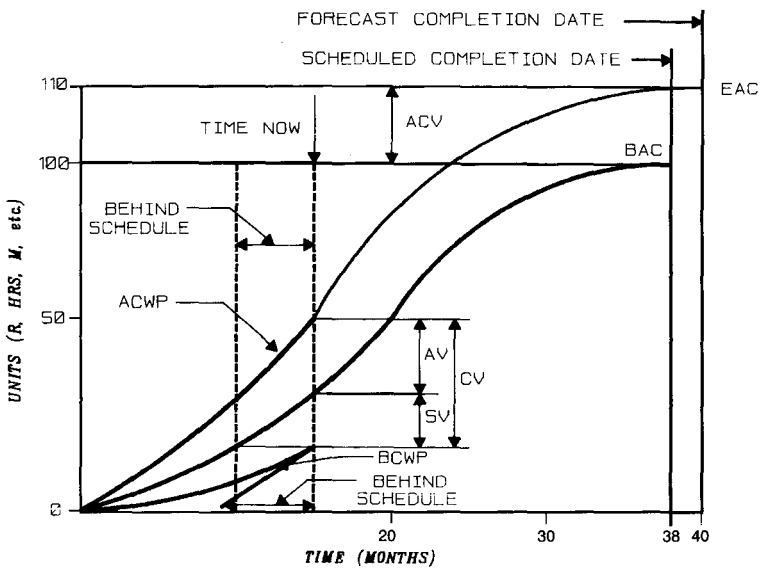

Figure 9—A project cost-schedule progress report

Threshold levels are allocated to critical items so that timeous corrective action can be taken. Performance indices can be developed to give a magnitude significance to variances. For example, a cost variance of R10 000 on one work package with a BCWP of R1 000 000 is not as important as a cost variance of R10 000 on a work package of R100 000:

$$\text{Cost performance index} = \frac{BCWP}{ACWP}$$

$$\text{Schedule performance index} = \frac{BCWP}{BCWS}.$$

A performance index of 1 represents the performance as planned, an index performance of less than 1 represents a poorer performance than planned, and an index greater than 1 represents a better performance than planned.

Cost forecasting is a vital element of the cost-analysis process. Senior management is always interested in projected cash flows, viability of the projects, and final cost of the project or parts of it.

A simple method of extrapolation of performance to date is used. In this way, one can analyse each cost account and higher-level accounts, including the cost of the project as a whole, by dividing the budget for the remaining work to be carried out by the CPI and adding it to the actual cost of the work performed:

Performance to date (CPI)

$$CPI = \frac{BCWP}{\text{ACWP}}$$

Budgeted cost for the remaining work = BAC–BCWP

$$\text{Estimate to complete } (ETC) = \frac{BAC-BCWP}{CPI},$$

where BAC is the budget at completion.

Forecast cost at completion *(EAC) = ACWP + ETC.*

Admittedly, there are many factors to be taken into account, but the extrapolative forecast is a good starting point, and any change in it must be justified. The schedule and test variances, coupled with the schedule and cost-performance indices, give sensitive and reliable indicators of the progress achieved against the plan and the budget. The system also automatically produces forecasts of final costs for parts of the project as a whole.

Quality Control

'High quality is the key to pride, productivity and profitability.' This declaration, taken from the American Society for Quality Control's Manifesto, elevates quality to a strategic business imperative essential to product and process leadership. Quality pervades the total project, and it demands a continuous improvement process. It is therefore necessary, not only to control conformance to standards, but to continually improve standards along with the process capability.

Statistical process control (SPC) techniques are used in the analysis of each facet of a project. The first objective is to ensure that the process is in control, i.e. that elements causing inconsistencies have been eliminated. Once the specific variation has been removed, common variation can be tackled. This process capability is now compared with the specifications, and the necessary adjustments are made.

A typical example is the sinking operation shown in Figure 10 and Table I. The duration of the activities is closely monitored and analysed statistically.

Project Reporting

One of the prime functions of a project manager is to keep the client informed of all the important aspects of the project. Indeed, it is the client's right to know how his money is being spent, how his objectives are being pursued, and how he could influence the project towards his desired goals.

Different clients have different requirements, and it is in the project manager's interest to study his client's particular needs, wants, and dislikes, and then to structure his reporting system accordingly. Much depends on the project manager's relationship with the client. For the project manager to understand the client's view of the relationship, he must deal with him effectively on a day-to-day basis. A successful project manager must sometimes modify his own management style to conform to the expectations of the client. Nonetheless, a project manager must always maintain his credibility, honesty, and dignity: he must serve without being servile.

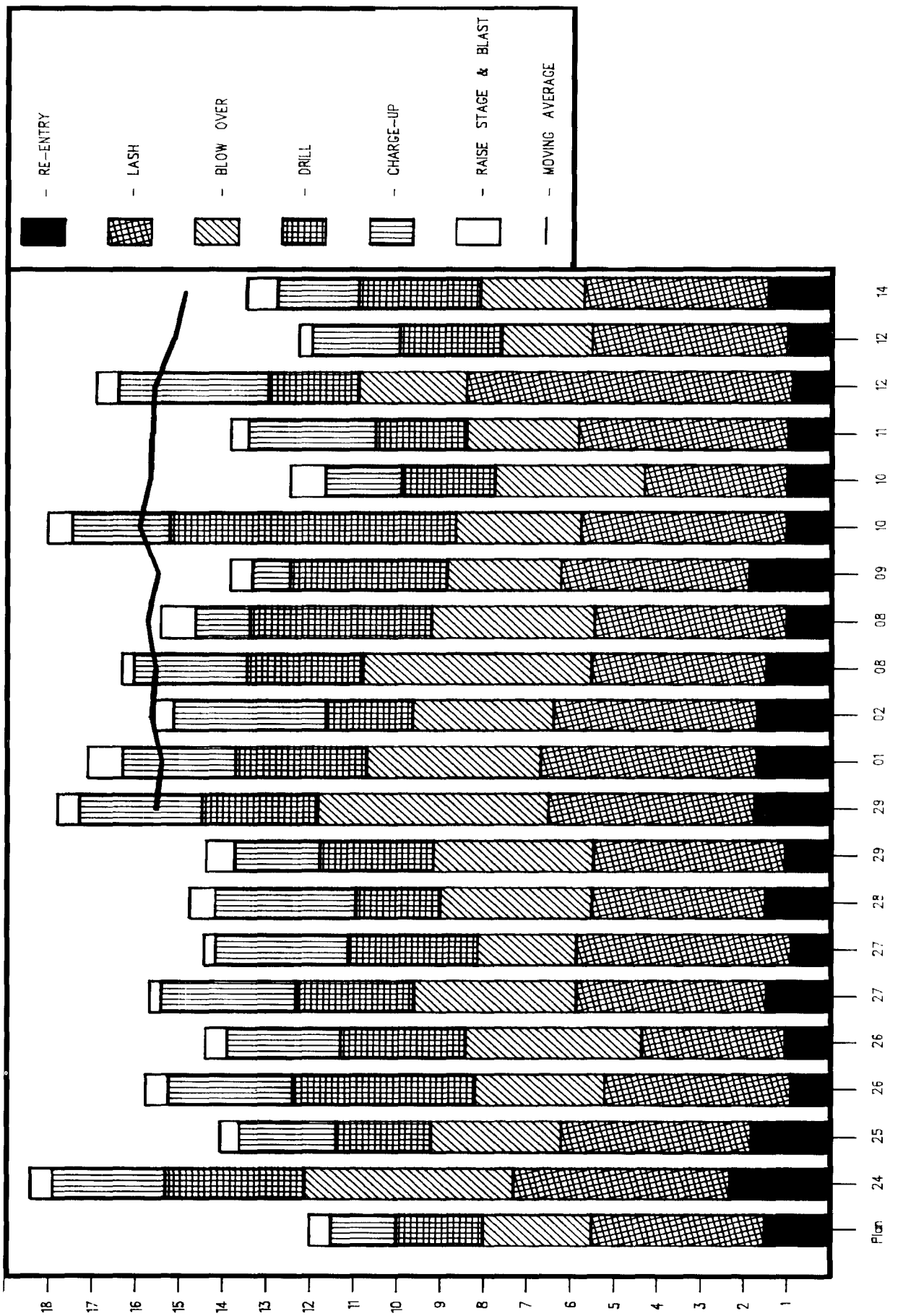

Figure 10—Histogram showing the duration of operations in the sinking operation

Table I

Duration of shaft-sinking operations (in hours)

Date	Re-entry	Lash	Blow over	Drill	Charge-up	Raise stage and blast	Total-cycle time	Moving average
Plan	1,50	4,00	2,50	2,00	1,50	,50	12,00	
24 May 1993	2,33	5,00	4,90	3,12	2,63	,50	18,48	
25 May 1993	1,90	4,28	2,92	2,33	2,33	,37	14,13	
26 May 1993	,95	4,33	3,83	3,25	2,83	,62	15,81	
26 May 1993	1,05	3,33	3,92	2,90	2,77	,33	14,30	
27 May 1993	1,60	4,33	3,67	2,67	3,17	,30	15,69	
27 May 1993	,87	5,00	2,22	3,00	3,00	,33	14,42	
28 May 1993	1,50	4,00	3,50	1,88	3,25	,47	14,60	
29 May 1993	1,12	4,38	3,58	2,75	1,67	,72	14,42	
29 May 1993	1,75	4,83	5,17	2,75	2,75	,50	17,75	15,51
01 June 1993	1,63	5,00	4,00	3,00	2,83	,83	17,29	15,38
02 June 1993	1,67	4,67	3,42	2,00	3,33	,42	15,51	15,53
08 June 1993	1,42	4,25	5,17	2,75	2,42	,25	16,26	15,58
08 June 1993	1,08	4,42	3,67	4,17	1,42	,57	15,33	15,70
09 June 1993	1,92	4,33	2,67	3,67	1,67	,50	14,76	15,59
10 June 1993	1,17	4,67	2,92	6,42	2,33	,53	18,04	15,99
10 June 1993	1,05	4,25	2,58	2,08	1,75	,83	12,54	15,77
11 June 1993	1,00	4,83	2,58	2,25	2,75	,42	13,83	15,70
12 June 1993	,83	7,50	2,50	2,17	3,42	,55	16,97	15,61
12 June 1993	1,03	4,25	2,42	2,25	2,00	,33	12,28	15,06
14 June 1993	1,33	4,42	2,33	2,83	1,92	,67	13,50	14,83
Standard	,39	,75	,88	,96	,56	,16	1,78	
Mean	1,36	4,60	3,40	2,91	2,52	,50	14,83	
Absolute	,14	,60	,90	,91	1,02	,00	2,83	
Percentage	9,34	15,09	35,94	45,48	68,13	,40	23,62	

The project manager should not be afraid of the Persian syndrome (the messenger who brings the bad tidings is shot!). Projects cannot always run without deviations from the goal. It is impossible to accurately predict the future, no matter how hard one tries. What is important, however, is to take corrective action without delay. The client must be informed timeously. He must be involved in the solution of problems, and must always be presented with two or three alternatives so that he makes the final choice. This will deepen the client's involvement and understanding of the project. The surest way to avoid client 'meddling' is to keep the client informed and involved. A reporting system will go a long way towards marketing a project since the merits of a project are not self-evident to everyone. If the project is not understood, valued, or supported, the reporting has not been effective.

The main reporting tools are the project manager's monthly report, the weekly status report, and the daily site report.

The Project Manager's Monthly Report

The project manager's monthly report forms the main point of discussion at the monthly project review. The report must be clear, concise and to the point, and without padding or embellishment.

The report should open with a brief executive summary. Although brief, it must contain all the essential facts, progress, cost and time variances, safety aspects, and personnel changes. As a busy executive will not have time to study the full report, judicious use must be made of pictorial presentations such as histograms, charts, schedules, achievement graphs, variance graphs, and tabulations. In fact, the output from the project-management control system should be presented in pictorial form.

This should be followed by a technical section under each discipline giving the technical and design progress. This section will be of interest to the client's technical staff since it will enable them to track the project and monitor compliance with their specifications.

Weekly Status Report and Daily Site Report

The weekly status report gives a brief review of the progress, safety, and major variances during the preceding week.

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The daily site report is produced to keep mine management informed of safety aspects, breaches of the Minerals Act, and major changes such as ground conditions and abnormal ingress of water. Care must be exercised. Where the duration of an activity was longer than the reporting period, considerable confusion can result when a person unskilled in scheduling estimates percentage completions. For this reason, such reporting should be done only from the project office by a skilled project planner.

The Close-out

The close-out is a very important part of a project manager's job. In a way, the project team is engineering their own demise. For this and other reasons, projects have a tendency to run on after the scheduled completion dates. A poorly structured close-out plan can mean the difference between the success and failure of a project. It should be remembered that the race is often won or lost in the home straight. At some point, the project must come to an end. In the close-out phase, the following should take place.

- All the work packages must be handed over formally to the client. The client must be satisfied with all the deliverables.
- All the contractual arrangements have to be concluded. All the orders and contracts must be settled, and the retentions must be in place. A comprehensive list of all the contracts must be handed to the client.
- All the surplus material must be returned to the rightful owners, e.g. client, project office, or contractors.
- All the project files must be up-to-date and handed over to the client.
- All the functional departments must be notified formally that the project has closed, and that no further expenditure can be made against the project.
- A post-completion evaluation must be made and included in the close-out report.

The evaluation should

- list and explain all the variances both negative and positive
- identify the mistakes
- determine their impact
- determine how they can be avoided on future projects
- suggest appropriate changes and improvements in project management and in functional policies and procedures.

Challenges for the Future

There is a Chinese proverb that says 'Prophecy is extremely difficult, especially if it concerns the future'. The future is fickle, and to predict it is folly. Great intellects who succumbed to this temptation have rued the day. At best, current trends can be considered, and a number of shifts in strategy will become apparent immediately.

Firstly, a dramatic flattening of the corporate pyramid is evident. Hierarchical layers have been reduced, bringing top executives closer to the market — the work face. Dis-economies of scale set in at much lower levels of capacity than before. Corporate staff have been reduced in ratios of up to 20:1 in some extreme cases[14]. This is particularly true of mergers, where in many cases the combined staff have been reduced to a level below those of either company before the merger. There is a strong move towards decentralization and smaller groups.

Secondly, product lifecycles have shrunk considerably. New and better products are continuously displacing 'older' products, and profit margins have consequently also shrunk. Hence, the competitive spirit has been raised to an all-time high. What was adequate yesterday may be rejected by the market today. The net effect is to decrease lead times to the lowest levels ever.

Thirdly, there have been dramatic improvements and advances in the microprocessor field, and in computers as a whole. The tremendous strides taken in the software market have brought top-level executives closer to the operational areas. Another effect is the greater flexibility in the requirements of system integration. Members of a project team can now very easily operate out of centres that are remote from one another.

Fourthly, there has been an increasing sophistication on the part of the work force, and hence the concomitant increasing interest in the human element of management.

What does this all mean for project management as a whole, and what is its application to shaft-sinking practices? There is no doubt that the highly volatile business environment demands a greater flexibility, faster shifting of focus, and quicker response time. We have entered the age of the ephemeral. Competition will be based more and more on flexible management, ability, and technological sophistication. Devolution of power and authority down towards smaller groups means that the system is moving closer to the project-management form of organizational structure.

Tom Peters[15] goes even further. He says, 'most of tomorrow's work will be done in project configurations. Functional staffs will all but disappear, and maybe not "all but". The professional service firm is the best possible model for future survival.'

It is of paramount importance that our shaft-sinking techniques and managerial practices be changed and improved. Smaller teams, greater decentralization, and technical innovation are the factors that will need close scrutiny. If this does not take place, we shall lose our position in terms of global competitiveness. The world has shrunk, and it is not inconceivable that teams from outside our borders will be sinking shafts in this country!

These ideas will become more focused and made more acute by the current worldwide economic downturn. When the upturn comes, our house had better be in order if we want to be part of the new prosperity.

Conclusion

This paper has examined some systems, tools, and techniques of project management in respect of shaft-sinking projects. These techniques are not dissimilar to those of other disciplines of business economics. What is different is the thread of integration that ties it all together. Project management cannot be treated piecemeal —there has to be a system's approach. The total picture must be looked at to make it successful.

Inter-relationships and interaction among the elements of management are central to the effective operation of project management. When deviations occur, swift decisions and quick actions are required to keep the project on track. Project management is a process designed to manage change. It does this by a total integration of functions, technologies, and the client. In the final analysis, the success of a project is how the client perceives the outcome of the project. The triad of cost, time, and quality remain important, but they are subordinate to the client's preceptions of the project.

The project-management organizational format may not be flawless. Most organizational formats will work if the participants want them to work. However, project management has all the elements required by the new world of exciting change. Organized business using sophisticated electronic facilities is moving in the direction of smaller, more autonomous groups. This is a fertile environment for the growth of project management. ◆

Merger of Departments

The Departments of Chemical and Metallurgical Engineering at the University of Stellenbosch decided recently, after thorough discussions among all the members of staff and the university management, to amalgamate and become one department. This was approved by the University Council, and the new department will come into effect on 1st July 1994, and will be called the Department of Chemical Engineering.

The staff of the new department will consist of Professors J.S.J. van Deventer, F.L.D. Cloete, and L. Lorenzen; Doctors S.M. Bradshaw, and J.H. Knoetze; and Mr C. Nel; as well as three new members who have yet to be appointed. Professor G.S. Harrison retired at the end of 1993, and Professor N.J. Louw, who founded the Department, is retiring in September 1994. The combined department recently elected Professor J.S.J. van Deventer, currently Head of the Department of Metallurgical Engineering, as Chairman of the new Department of Chemical Engineering from 1st July, 1994.

The two degrees offered by the new Department of Chemical Engineering (Chemical Engineering and Chemical Engineering—Mineral Processing) were accredited by the British Institution of Chemical Engineers (IChemE) for the next five years after a visit by the accreditation team from the IChemE in 1993. The accreditation is important since it indicates that the courses offered by the Department meet internationally recognized standards.

Also, in August 1993, the two Departments (i.e. Chemical and Metallurgical Engineering) were accredited by the Engineering Council of South Africa for a further five years.