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Fundamentals of Construction Management

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Contents

Foreward

This book is based on a series of lecture notes used by the author for teaching the following subjects: Management of Building Projects (University of Lagos), Construction Management I & II (Caleb University, Lagos), and Construction Management (University of Cape Town) between 1996 and 2012. The book is also based on research undertaken and personal work experience of the author, and other contemporary construction management and management literature.

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1 Introduction

Construction provides:

- many of humanity's greatest achievements e.g. the pyramids at Egypt, Taj Mahal Salisbury cathedral, etc.
- shelter
- a basis for transportation system
- investment
- employment
- a significant contribution to a nation's economy

1.1 Common Sense, Perception, Illusion and Imagination

Construction practitioners by the nature of their work, pride themselves on their common sense and their ability to overcome obstacles. This is true to some extent because without ***practical ingenuity***, few projects would be successfully built.

Sometimes ***common sense*** leads to erroneous conclusions. As an illustration, consider the two building details in (a) and (b).

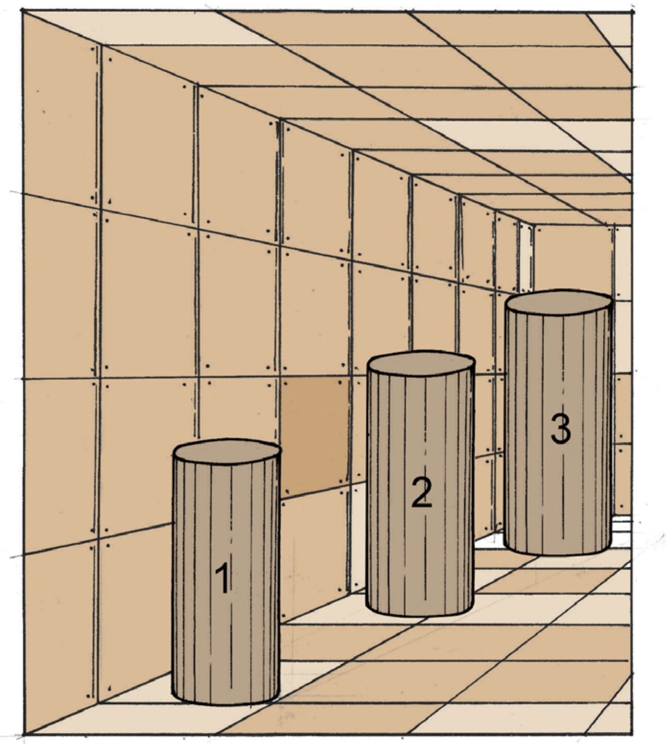

Figure 1 a: Building Details

- In Figure 1(a) which column is largest? Column 3?

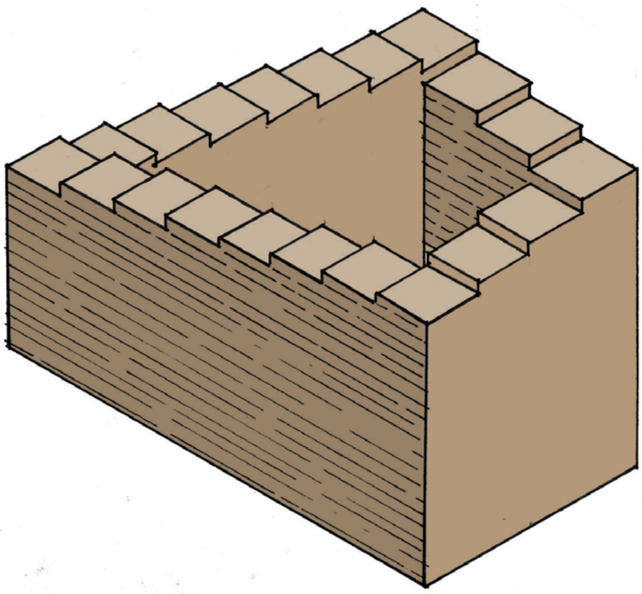

Figure 1 b: Building Details

- How would one design, quantify, bid or build the staircase shown in Figure 1(b)?

It can be argued that these figures are only visual illusions, similar to illusions of touch, temperature, time, and performance. These perceptual and cognitive illusions demonstrate an extremely important point. Many times, an individual's common sense – attitudes, values, preconceptions, and prejudices blinds him to obvious realities.

1.2 Definition of Key Terms Used in Management

The key terms used in management include:

Management	The **direction** and **supervision** of **resources** towards the achievement of a defined **goal** within a **time scale**. Controlling a business/industry (The description of management is not limited to one area or discipline – there are some aspects of management that are expected to be achieved, regardless of which discipline or area of management).
Theory of Management	This can be defined as the general principles of controlling a business/industry, tested and contrasted with practice.
Direction	Instructions about how to do something.
Supervision	To be in charge of a piece of work/labour and making sure that everything is done correctly, safely etc.
Resources	Something that is required in order to do work. They include: money equipment, people materials, information, skills, knowledge or any other item likely to be in limited supply.
Goal	A desired end. Something that you hope to achieve for example – quality of the building work.
Time Scale	The period of time that it takes for a project to happen or be completed.
Planning	• The act or process of setting out goals intended to be achieved, and what course of action should be used in achieving the goals; • Setting targets/time limits/course limits
Controlling	• Comparison of the actual performance of a process against the original plan; • It can also be defined as methods by which it is possible to establish and determine if work is being carried out as planned. A comparison is then made against the plan and variations are noted and analyzed; • There are three possible outcomes for each operation in construction work: - It either remains the same; - It is better; or - It is worse
Forecasting	Looking into the future to try and assess the possible trend of events, which are likely to influence the conditions of the working situation, so that steps may be taken to overcome any difficulties before or soon as they arise.
Motivating	• The reason why somebody does something that involves hard work and effort or the reason somebody behaves in a particular way; • An incentive or encouragement given to induce hard work, effort, and high productivity.
Coordinating	The act of making parts of something, groups of people etc. work together in an efficient and organized way. (Integrating)
Communicating	Act of exchanging information, news, ideas, feelings, thoughts etc. with other people. Making known your ideas, feelings, and thoughts etc. known to other people, so that they understand them.
Organizing	Arranging for something to happen or to be provided.

1.2.1 What is construction?

Construction is a series of **actions** undertaken by construction companies and consultants, which produces or alter buildings and infrastructure.

Construction actions can be described as a complex interplay of people, tools, equipment and materials, **coordinated** by **communication** and paid for with money. Construction actions include:

- design and management decisions;
- direct physical production of the facility on site;
- project close-out/final accounting; and
- rehabilitation and maintenance of existing facilities.

The sets of **actions**, which make up most construction projects, are so complex that there must be a sophisticated system of **coordination** to ensure the work is undertaken correctly. The actions which form any one construction project are extremely complex and diverse because:

- they take place in widely different locations; and
- may involve practically every technology yet devised by humans.

1.2.2 What is construction management?

Construction management is the practice of ensuring that construction actions are undertaken effectively and efficiently.

According to SACPCMP (2009), construction management is the management of the physical construction process within the built environment and includes the co-ordination, administration and management of resources. The Construction Manager is the one point of responsibility in this regard.

Fellows, Langford, Newcombe and Urry (2002), viewed construction management in two dimensions – the management of the business of construction and of projects. They highlight that in practice, the two dimensions rely on each other. This view is acknowledged by Radosavljevic and Bennett (2012) who posited that construction management is at the centre of both company and project management as shown in Figure 2.

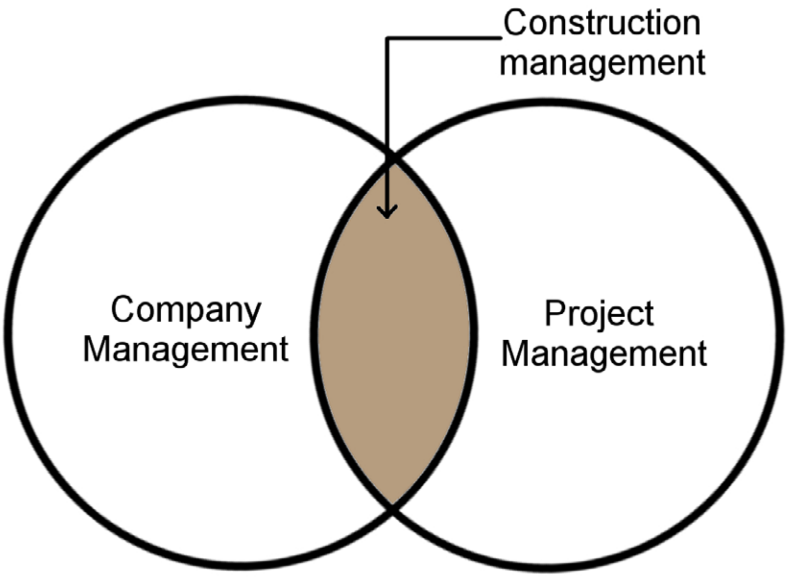

Figure 2: Construction Management at the centre of both Company and Project Management

1.2.3 Contractor vs. Construction Manager

The **contractor** means any person or legal entity entering into contract with the client for the execution of the works or part thereof (SACPCMP, 2009).

The **construction manager** can be said to be a professional who manages the building construction process – prepares production documents, involved with the day to day management of construction projects, have responsibility for supervising people and reports to the client and senior management.

1.3 The Objectives of Management

This is to ensure that productive efforts undertaken by a company/individual are efficient and effective:

- Less time taken
- Less waste (Lean principles)
- Economic use of resources
- Higher quality products
- More value
- Less accidents and fatalities
- Satisfaction of client/employer
- Products are sustainable e.g. green buildings, low impact design, and passive energy usage

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2 Theories Applicable To Construction Management

2.1 Schools Of Management/Management Theories

2.1.1 Main Schools of Management, their History and Development

Drucker (1996) argued that management is the function, which involves getting things done through other people. The practical implications of this definition however depend on each individual business and industry.

The contemporary conception of management would be considered at different periods because the varying phases over the course of time are none other than stages of the evolutionary process, which produced management, as it is known today.

1. The Industrial Revolution (Circa 1750 to 1850)

The early days of management as a subject for study were related to the latter half of the Industrial Revolution. This may be described as the period when mechanical power was introduced and applied to the production of goods, and the earliest efforts to improve management at this time were those concerned with technical issues of production, because the social conscience of the day did not enforce responsibility for personnel problems.

The pioneers in the field of management during this period included:

a) **James Watt (1736–1819)**: whose main interest centered on the efficient use of large variety of machinery. This entailed the elaboration of production management processes such as:
   - the layout of plant;
   - the flow of operations;
   - the planning of work schedules; and
   - other technical matters as the standardization of parts and the pre-fixing of dimensions.

   An inevitable consequence was an emphasis on the adequate training of skilled craftsmen to achieve production targets.

b) **Robert Owen (1771–1858)**: the pioneer of personnel management. Between 1800 and 1828, he successfully put into practice social reforms to remedy the evils that contemporary industry accepted as inevitable. Evils such as length of working day and lack of welfare scheme for workers.

c) **Charles Babbage (1791–1871)**: was among the first to advocate in relation to industrial problems, the fundamental thinking which preceded the formulation of the principles of management. His writings told little of the art of management as actually practiced in the early nineteenth century, but suggested the scientific or analytical approach to the problems of manufacturing.

2. Management Evolution (1850–date)

Important as the technical problems created by the introduction of machinery, were the social and organizational problems, which it brought in its train. Particularly, problems that had to be managed during this period arose out of the following prevailing conditions:

- The evolution of the Trade Union System and the means of negotiation in collective bargaining raised questions on the adequacy of wages and working conditions.
- Financial administration made necessary by the increasing demand for capital and the provision of finance for industry through the limited liability principle came into prominence.
- Towards the close of the nineteenth century, the main problems were beginning to concern the processes of marketing or distribution, to meet the emerging competition of growing industrial countries in Europe and elsewhere. In consequence, questions of the cost of production and of estimating prices at which the products of industry will be sold profitably were beginning to be of importance.

Some of the pioneers of management principles who are introduced in this section will also be further discussed and presented subsequently.

a) **Fredrick Winslow Taylor (1856–1915)**: the Father of Scientific Management, who researched into better methods of doing work. By detailed analytical experiments,

- he investigated problems of industrial organization such as relationship between a foreman and his work, and what constitutes a "fair day's work".
- he measured the efficiency of workers to determine if they justify what they earn. The Bonus System and functional incentive schemes were among the assumptions he was associated with.

b) **Henry Lawrence Gantt (1861–1919)**: His writings emphasized the human interest. He is remembered chiefly as the inventor of the Gantt chart for graphical planning. Gantt charts were employed on major infrastructure projects, and continue to be an independent tool in project and construction management.

c) **Frank Bunker Gilbreth (1868–1924)**: The pioneer of motion study. He researched chiefly into "the one best way to do work". In 1912, he introduced the science of micro motion study – the ultra small basic elements of body movements. Gilbreth discovered his vocation when as a young building contractor; he sought ways to make bricklaying faster and easier.

d) **Henri Fayol (1841–1925)**: He identified the processes that make up his every day practice as a chief executive. Namely: forecasting; planning; organizing; commanding; coordinating and controlling. He was the first to analyze and specifically lay down a set of management principles; and the firm advocate of the principle that management can, and should be taught.

e) **Elton Mayo (1880–1949)**: The founder of human relations movement and industrial sociology. He set out in 1954 to study the effects of lighting on output famously referred to as the **Hawthorne Studies**. The term gets its name from a factory called Hawthorne Works, where a series of experiments on factory workers was carried out between 1924 and 1932. At the end of the investigation, following changes in personnel, working conditions etc., it was found that:

   i. Human emotions could play havoc with the results of carefully planned and controlled scientific experiments;
   ii. Workers develop group attitudes, norms and values, so that they react to management not as individuals, but as members of a group.

iii. The physical ability of the worker is of little significance in comparison with social ability in determining the amount of work to be carried out.
iv. That non-economic reward has a significant role to play in motivating workers. It emerged that social factors play a significant role in determining worker productivity. Workers were not producing as much as they are reasonably physically capable of producing. They were producing amounts, which were socially acceptable to the group involved in carrying out the work.

The significant conclusion of his research is that none of the research findings gave the slightest substantiation of the theory that "the worker is primarily motivated by economic interest". The findings indicated that the efficiency of a wage incentive is so dependent on its relation to other factors that it is impossible to separate it as a thing in itself, having an independent effect.

As a result, the human relation theories were totally opposed to the findings of Taylor. Elton Mayo himself discounted the incentives of money stating that: "Man's desire to be continually associated with his fellow human beings is a strong human characteristic". The results obtained by Elton Mayo interpret management as the leadership of people and a social task of human beings among other human beings.

f) **Hans Remold**: His 1913 paper on Engineering Workshop Organization described and enlightened management principles and methods, based upon his firm. The company's organization structure was based upon functional specialization; a number of the younger staff were trained in management, whilst monthly balance sheets and returns facilitated the preparation of the annual stock-taking and yearly balance sheet within a few days. The company's procedures were efficient and he believed that "the working of an efficient system requires men of fact and power to lead".

g) **Abraham Maslow (1908–1970)**: He introduced the needs theory which was later developed **Hertzberg**. Maslow identified five set of goals, which he termed as basic needs, which if unsatisfied tend to produce tension in the individual. These needs are:

i. Physiological needs
ii. Safety needs of protection
iii. Love needs of association, affection and belonging
iv. Esteem needs of ego, self confidence, status and reputation
v. Self-actualization needs

The fundamentals of these theories rest on the basic principles that hierarchy is of importance – man has little regard for other things when there is thirst, hunger and homelessness and when these physiological needs are satisfied, he will be more concerned about of safety, love, self-esteem, etc. Therefore, a want satisfied, is no longer a want.

h) **Frederick Hertzberg (1923–2000)**: He further developed the study of needs and showed that Maslow only tackled half of the problem. Hertzberg's major work – **The Motivation to Work** – shows a systematic and realistic approach to analyzing the main motivators. His initial study of people in an organization was of 200 engineers and accountants and the analysis of the results showed two separate sets of factors causing workers dissatisfaction and satisfaction.

He found out that the only way to motivate employees is by giving them challenging work in which they can assume responsibility. Other distinct factors that satisfy other lower level needs are involved in job dissatisfaction. He identified five motivator factors that have the strongest influence on job **satisfaction** as:

- Achievement
- Recognition
- The work itself

- Responsibility
- Advancement/Promotion

Whilst the major factors identified to cause dissatisfaction were:

- Company policy and administration
- Supervision
- Salaries
- Interpersonal relations and
- Work conditions

The above factors have the ability to reduce a person's motivation if they are not satisfied. However, they could not increase a person's motivation if they are satisfied.

i) **Douglas McGregor (1906–1964)**: summarized the underlying assumption of scientific management and in turn incentive schemes about human nature and motivation in 1960, based on the pioneering work of **Fredrick Winslow Taylor**, in what he called **Theory X** approach to management. These assumptions are that:

   i. workers dislike work and avoid it if they can;
   ii. because of this dislike of work, they need to be controlled, directed, threatened and coerced with punishment in order to put them to work towards the organizational objectives;
   iii. workers like to be directed, like to avoid responsibilities, have little ambition and above all, want security of employment.

Based on the pioneering work of **Abraham Maslow**, **Douglas McGregor** developed also, the **Theory Y** approach to management. He assumed that:

   i. the expenditure of physical and mental effort in work is as natural as play or rest;
   ii. external control and threat of punishment are not the only means of bringing about efforts towards organization objectives. That man will exercise self-control in the service of the objective to which he is committed;
   iii. commitment to objectives is a function of reward associated with their achievement;
   iv. the average human being learns under proper condition, not only to accept, but to seek responsibility;
   v. the capacity to exercise a relatively high degree of imagination, ingenuity and creativity in the solution of organizational problems is widely not narrowly distributed in the population; and

vi. under the condition of modern industrial life, the intellectual potential of the average human being is partially utilized.

3. The Development of the Scientific Aspects of Management

A scientist proceeds by systematic reasoning and the scientific approach to the various aspects of management has developed those modern methods whereby, we try to substitute:

a) investigations and knowledge for individual judgment or opinions, when making **plans** and **decisions**;
b) intelligent and critical use of "tools" for hunch or instinct, in **practice**; and
c) fairness (justice) and trust in place of bias and suspicion, on the human side.

2.1.2 Principles of Management including the Seven Major Processes as outlined by Henri Fayol and Others

The principles of management can be discussed under the following headings:

1. **Productivity**: improving the necessary methods for an increase in the production of goods by the use of mechanical power

   The celebrated **James Watt**, of the steam-engine fame, became one of the earliest pioneers of such development in his Soho Foundry. The foundry was laid out in such a way that the flow of materials through the various processes was logically and thoughtfully arranged.

2. **Social Scientific aspect of Management**

   The growth of the trade union system in the mid-nineteenth century meant that considerable attention be given to wages and working conditions.

   The pioneers in personnel administration of which **Robert Owen** and **Charles Babbage** were by far the leading exponents, lived many generations before their principles including – length of working days and welfare schemes and the scientific/analytical approach to the problems of manufacturing, became generally accepted.

3. **Financial Accounting**

   The rapid expansion of industry meant that more attention had to be paid to the means of providing capital. With the principle of limited liability being accepted legally and commercially, there arose a need to assure those individuals providing the necessary capital that it was not being misused.

Attention therefore was given to proper financial accounting, maintenance of the appropriate books of account, and a periodical preparation of a balance sheet for the benefit of the interested parties.

4. **Planning, Motivation and Efficiency**

During the 1880s in the USA, the 'Father of Scientific Management' **Fredrick Winslow Taylor**, commenced his researches in the Midvale steel works, where he was a charge hand over lathe operators. Soon, with his colleagues **Lawrence Gantt** and **Frank Bunker Gilbreth**, he was to found a movement, which bore the title **Scientific Management**.

One of Taylor's main preoccupations was concerned with creating a mental revolution amongst both men and management in industry. He believed that both sides of industry were far too concerned with how the surplus moneys of the business were divided, when they should be more concerned with how to increase the extent of the surplus. As a means to increase the surplus, he advocated better **planning** and better **motivation** to work with a proper and adequate use of incentive and bonus system.

As well as being concerned with proposals for a mental revolution, Taylor and his associates Gantt and Gilbreth spent a considerable amount of time and effort on the elaboration of techniques such as:

- the specification of job responsibilities;
- time and motion study;
- planning schedules; and
- other tools to aid the adequate planning and control of production.

5. **Processes of Management**

   Henri Fayol produced a paper in France, the basis of which is still accepted today as describing the processes of management. Fayol was the General Manager of a large French iron and steel combine which had mining as well as metallurgical interests. In 1908, he presented a paper to one of the metallurgical societies in which he attempted to categorize the processes, which he understood to be involved in his day-to-day practice as a chief executive.

   The basis of his analysis was that a management process consisted of five areas – planning, organizing, commanding, coordinating and controlling. Fayol was the first person to advocate what at that time was considered to be a somewhat revolutionary thought, namely that management principles could and should be taught.

6. **Human Principles of Management**

   Simultaneously with Fayol's display of interest in the principles of management in France, **Mary Follett**, in the USA was working on the many social and industrial problems of the time. She presented a series of papers on the human principles of management.

   Other later pioneers in the field of human relation theories included – **Elton Mayo**, **Hans Remold**, **Abraham Maslow**, **Hertzberg** and **McGregor**, who developed theories of performance, organization, motivation, needs, satisfaction, threats and reward.

From the 1920s onwards, systematic study of the many branches of management has led to the propounding of a multitude of theories. Many textbooks have been written and research in universities and business schools has come to be accepted as one part of the training of competent managers. Furthermore, a body of knowledge has been built up concerning the principles of management.

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2.2 Systems Theory

Systems' thinking is an approach to viewing problems not as discrete events or situations with a single local solution, but rather as part of a greater set of conditions all of which have to be accounted for if an intervention is to work. Systems' thinking is a skill required of a construction manager due to the integrative nature of the construction activities that has to be managed on a project; the projects' complexity; and the uncertainties in the project environment. The construction manager is responsible for creating a new site organization from nothing; this involves developing processes, procedures, social relationships, and technical perspectives.

Ludwig von Bertalanffy, a Biologist, conceptualized General Systems Theory. He viewed that the principles of systems and sub-systems he observed in natural phenomenon could be abstracted and applied across different disciplines in the same way that mathematics has become universally applicable to most disciplines. General Systems Theory is like all sciences, grounded in a systematic search for laws about the universe. Systems theory can be categorized into five areas:

1. Order: regularity and randomness are preferred to lack of order or chaos;
2. Orderliness in the empirical world is interesting and attractive to the systems theorist;
3. There is order in the external or empirical world – laws about laws;
4. To establish order, quantification and mathematics are valuable aids; and
5. The search for order and law necessarily involves the quest for realities embedded in abstract laws.

2.2.1 Characteristics of General Systems Theory

The main characteristics of the General Systems Theory includes:

1. Inter-relationships – Every system theory needs to take into account the inter-relationships, inter-dependence, of objects and their attributes. Independent and unrelated elements cannot constitute a system.
2. Holism – the systems approach is not an analytical method of breaking things down into constituent parts to study in isolation. It is an approach to viewing things as a whole, accounting for their inter-relations and interactions.
3. Goal seeking – a system is assumed to be goal seeking because all systems embody components that interact. Interaction results in some goal or final state being reached or some equilibrium achieved.
4. Inputs and Outputs – all systems comprise of inputs that when transformed into outputs, enable the system to attain its goals. All systems produce outputs that are needed as inputs to other systems. In an open system, it is acknowledged that some of the inputs are from the systems environment.

5. Transformation process – All systems are transformers of inputs such as raw material, energy and information into a different form, which become the output e.g. a building.
6. Entropy – this is the process of transforming inputs from a more ordered to a less ordered state. Systems try to work against this by utilizing energy from their environment to convert inputs into more ordered states.
7. Regulation – interacting components of a system are regulated (managed) in some way, so that the system can achieve its goals (objectives). Objective setting is a form of regulation (control) and is embodied in human systems as the planning activity. A requirement for effective control is feedback. Regulation and control are areas considered by Cybernetics.
8. Hierarchy – Systems are generally complex and are composed of smaller sub-systems in a nested hierarchy. For example, a building is made up of the architectural, structural and mechanical and electrical sub-systems. The structure of systems has implications for its regulations because simple structures are more easily managed than complex ones, which have more interacting components. Projects with fewer construction activities are more easily managed than projects with interacting and dependent activities.
9. Differentiation – in complex systems, specialized units perform specialized functions. This differentiation of functions by components is a characteristic of all systems and enables the focal system to adapt to its environment. Differentiation, specialization, and division of labour are practically identical concepts.

10. Equi-finality – this simply means that open systems have equally valid alternate pathways to reach the same objective. In open systems, the final states are not constrained by the initial condition, but can be reached from different starting points and in different ways. In closed systems, a direct cause and effect relation can be found between its initial condition and its final state.

The most important types of systems for projects and project organizations are open systems. All living systems including social organizations such as business enterprises or projects are goal oriented.

2.2.2 The Process View of Systems

Systems typically have inputs and outputs and a transformation activity that converts the former into the latter. Inputs and outputs are therefore typically inert items that can be stored, seen or in some way inspected. This is a useful attribute for control because it is possible to review and confirm that a process has been completed and it is also possible to check the quality of the output by comparison against a standard.

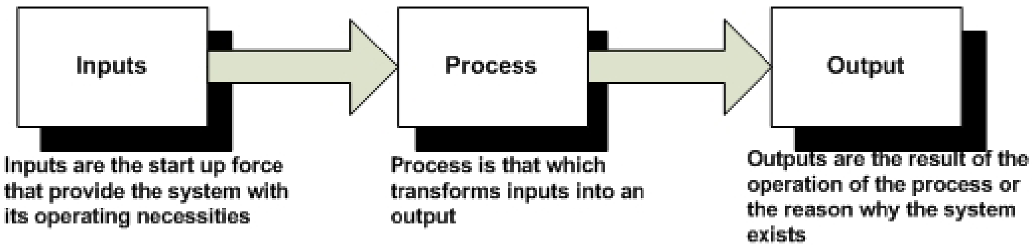


Figure 3: Process View of Systems

In management systems and many other systems, there is a feedback loop that examines the output against certain predetermined standard or 'goal' and if it is not acceptable, then further inputs are provided to the process until the desired state is reached.

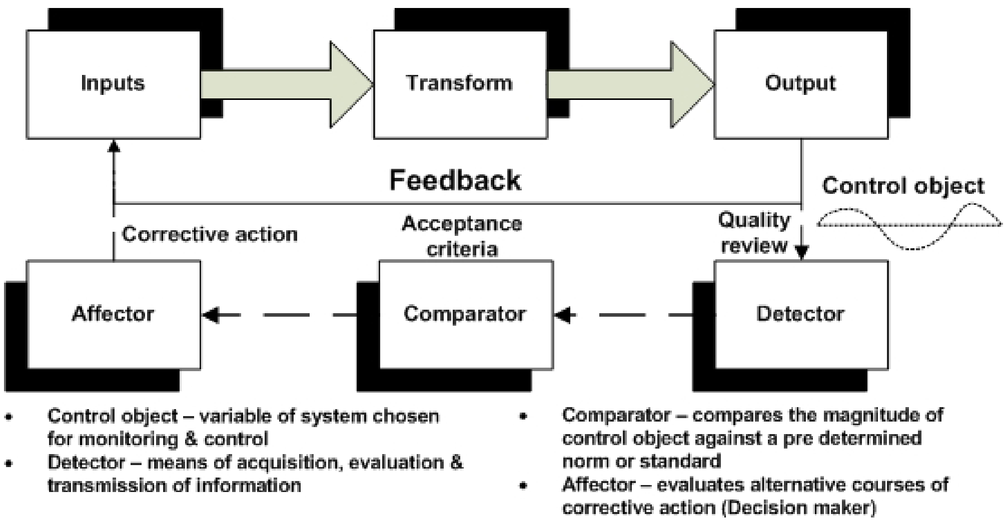


Figure 4: Process view of Control Systems

Figure 4 shows the relationship of the feedback loop to the primary system process. Each of the three elements, Detector, Comparator, and Affector is itself a complete process that can be represented as input-to-transform-to-output.

2.2.3 Bouldings' Classification of Systems

Boulding (1956) developed a classification of systems based on their complexity, which he arranged into a hierarchy of nine levels as follows:

1. Frameworks – these are static structures. At the most basic level, all systems are described in terms of their static relationships prior to moving to the dynamic aspects. Static structures can be described by function, position, structure, relationship and so on.
2. Clockworks – these are simple dynamic systems with predetermined movements such as the Solar System. Most systems that tend towards equilibrium are included at this level.
3. Cybernetics – these are goal-seeking systems that maintain equilibrium within certain limits but lack the ability to set or change a goal. Examples are thermostats.
4. Open systems – these are self-maintaining structures that rely on a throughput of material and energy. These systems are represented by unicellular life forms and are able to replicate themselves.
5. Genetic-societal – these are complex life forms that are unable to accept or act on information, but have some form of division of labour. Examples are plants.
6. Animals – these are systems with greater mobility and self-awareness. They have specialized information receptors to allow the structuring and storage of information.
7. Humans – humans are differentiated from animals by virtue of being aware of their self-awareness. This enables them to reflect on life and to plan for it.
8. Social organization – these are systems that assign people into roles. People are moulded by the roles they play and the history they are part of.
9. Transcendental – this is the level of the unknowable, things that escape us.

2.2.4 Complexity

In mathematical terms, complexity can best be understood in terms of probability. Mathematical complexity can be measured based on the probability that a system is in a particular state at a given time. In non-quantitative terms, it can be viewed as the quality or property of the system that is the outcome of the combined interaction of four main determinants:

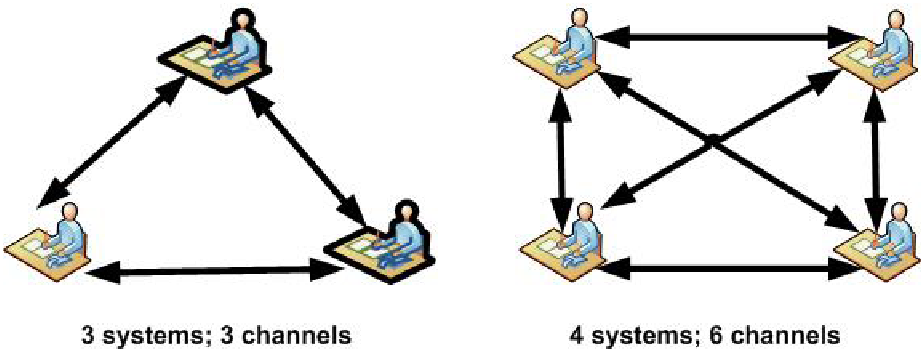
1. number of elements making up the system;
2. attributes of the elements making up the system;
3. number of interactions between the elements of the system
4. degree of organization inherent in the system (predetermined rules guiding interaction).

This implies that the larger a system, the more components it will have and thus, more connections will need to be maintained between the components (see Figure 5). As the system gets larger, the number of components may grow in a linear fashion but the number of connections will grow exponentially.

The formula that allows this complex relationship to be modeled (Davidson-Frame, 2002, p. 25) is as follows:

Channels of communication (Complexity) = $\frac{n(n-1)}{2}$;

Where: n is the number of systems.



Systems	Channels
3	3
4	6
5	10
6	15
7	21
8	28
9	36
10	45

Figure 5: Complexity: Systems and Channels of Communication

Size is another aspect of complexity because the human brain can only handle a maximum of seven to ten items of information simultaneously, so when the volume of information increases, the capacity of the brain to handle this information overload is reduced.

Complexity can also be viewed in terms of variety. Variety is defined as the number of possible states that the item being measured can have (Beer, 1994, p. 32). It therefore implies that for each channel of communication, the greater the variety of information it can carry, the more complex the project, situation or system is. Typically, channels of communication reduce the variety of information available about a system. A case in point is a telephone conversation where a team member is trying to describe a visual image. Increasing the number of communication channels increases the complexity of the information that has to be managed and absorbed at the receiving end, but it gives a more complete view of the situation.

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2.3 Theory Of Construction Management

Construction management is needed to ensure the specialist actions needed to produce modern buildings and all parts of the incredibly physical infrastructure can be undertaken efficiently and effectively. According to Radosavljevic and Bennett (2012):

- construction management is at the centre of both company and project management.
- only well-run construction companies can undertake construction projects efficiently and predictably.

A central assumption of the construction management theory is that projects need to be well managed and companies need to be equally well managed.

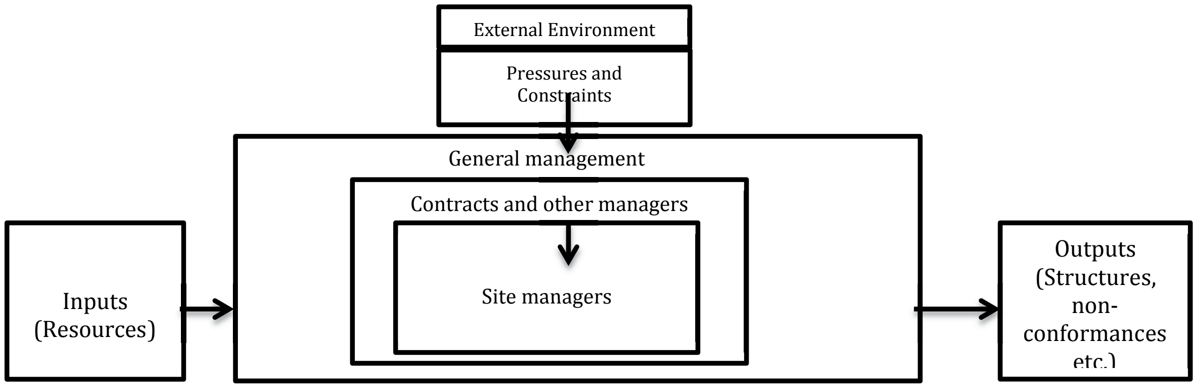


Figure 6: A Systems view of Managing Construction (Adopted from Smallwood, 2011).

2.3.1 Why a Theory of Construction Management is needed

Construction management involves challenges that result from the unique nature of construction projects, which are as follows:

1. Construction projects require a bewildering range of:
   a) Resources (4Ms)
   b) Specialization – knowledge and skills

2. Construction projects have features similar to the products and production processes, which characterize manufacturing and those, which characterize project-based industries.

3. The physical characteristics of construction projects are as a result of:
   a) many different technologies – sometimes depending on global networks of organizations;
   b) local industries;
   c) construction companies;
   d) building regulations and standards available locally and internationally.

4. Construction projects have:
   a) individual locations (no two sites are the same);
   b) complexity (a system with many parts);
   c) uncertainties (lots of risks)

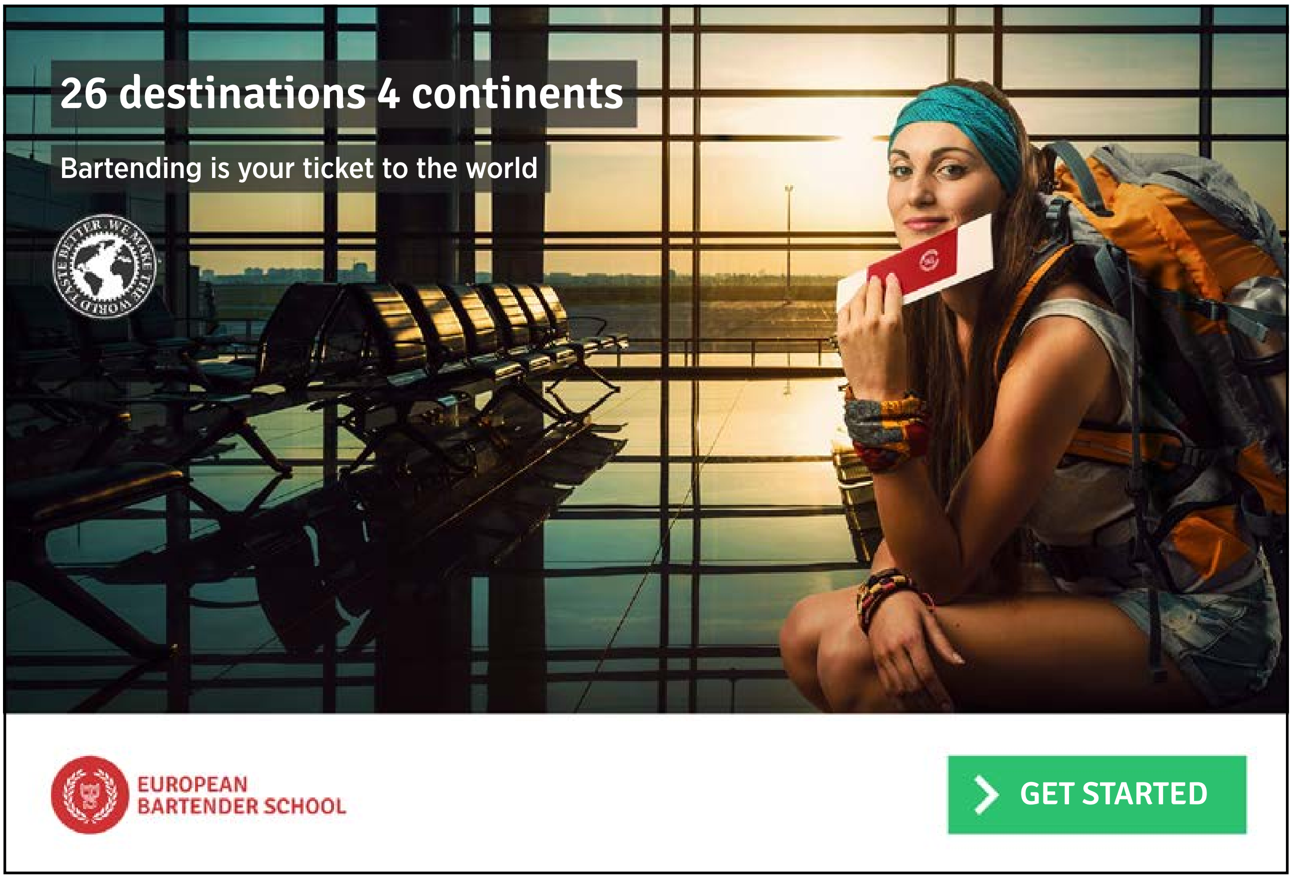
This combination of challenges is not comprehended by general management theories – which focus more on human management and production theories, which are rather straightforward, repetitive, predictable and uncomplicated. Secondly, a focus only on project management has limited construction's performance. The development and progress of the construction industry will depend on an understanding of project management to be combined with an equal focus on company management.

This section presents, and is heavily reliant on the theory of construction management proposed by Radosavljevic and Bennett (2012), which identify the actions that help construction projects' processes and companies to be efficient. Project and company management are treated as an integrated whole to take account of the major influence company managers have on projects, and the impact of project/construction managers on companies.

2.3.2 Efficient Construction Processes

Theory of construction management begins with the theory that construction management aims to enable construction to be undertaken efficiently and effectively within agreed objectives.

Efficiency can be described as meeting **agreed objectives**, or when used generally, it means performance within the power and resources available to a particular person or company.



Agreed objectives are the outcomes, which motivate those in construction. All construction stakeholders should explicitly agree to objectives and the measures used to manage actual performance.

2.3.3 Competent Construction Teams

The first and most obvious requirement in achieving the objective of construction management is to select competent teams to undertake all the essential construction actions.

Construction Teams can be described as formal group of individuals who work together on a permanent basis to undertake specialist construction, and the essential machines and equipment the team uses. Construction team members include:

- Designers
- Managers
- Building Team
- Manufacturers
- Production specialists
- Commissioning specialists

2.3.4 Types of Relationship Between Construction Team Members

There are two types of relationship shown in Figure 7, between construction teams:

1. **Boundary relationships:** wherein behaviour is guided by the teams' perception that they are parts of different organizations;
2. **Internal relationships:** wherein behaviour is guided by the teams' perception that they are parts of a joint organization.

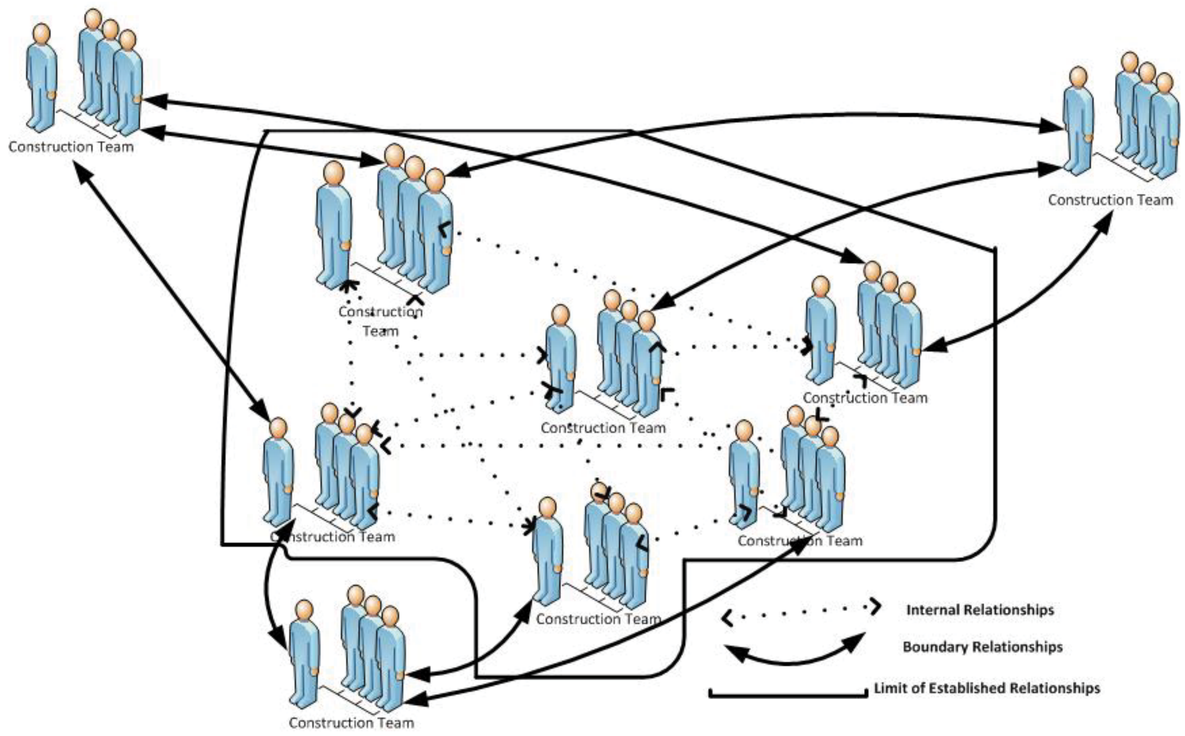


Figure 7: Relationships between construction teams
(Adopted from Radosavljevic and Bennett, 2012).

2.3.5 Quality of Relationships between Construction Team members

Figure 8 shows the quality of the relationship between the construction team members. It proposes that there is an inverse relationship between the time devoted to construction actions and the time devoted to interactions with other teams.

2.3.6 Barriers to Effective Relationships

The task of establishing effective relationships in a manner, which ensures construction is undertaken efficiently, is challenging because construction can create barriers, which restrict the most competent teams. Construction management therefore needs to devise strategies, which remove them or at least reduce their impact on efficiency. There are three factors in construction projects, which can lead to inherent difficulties in construction projects, which ultimately affects efficient construction processes. These are:

- Design
- Construction teams employed to undertake the project
- Environment which influences the project

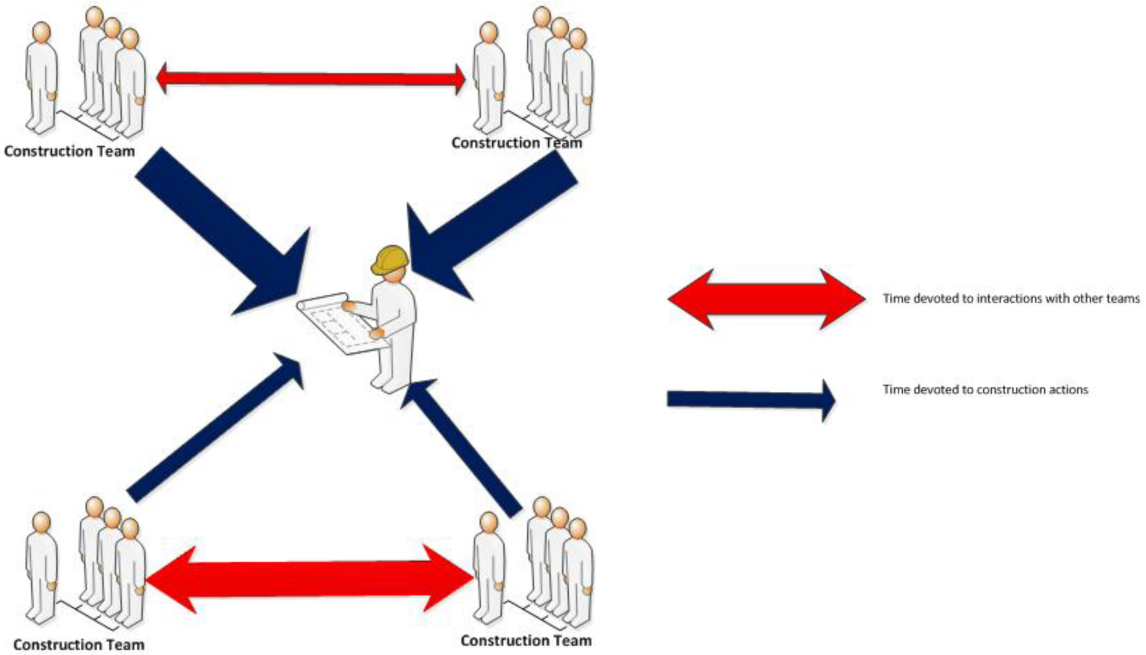


Figure 8: Quality of Relationships between construction teams
(Adopted from Radosavljevic and Bennett, 2012).

Design:

The design of a facility determines:

- the number of distinct technologies involved in its construction and how closely they are interrelated;
- this in turn influences the number of separate construction teams required to undertake the work and determines the need to establish relationships between them.

These two key characteristics – quality of relationships and number of interacting teams, directly influence the complexity of the construction project organization, which in turn contributes to the inherent difficulty it faces. Construction management strategies exist to mitigate the inherent difficulty actually faced by a project organization working with any given design. More advanced construction management strategies aim to influence the design in ways, which reduce inherent difficulty at source.

How does the design of a facility influence the number of construction teams involved in its construction and the interactions between them?

- Distinct technologies result from the application of knowledge and skills which provide the practical basis for individual construction teams;
- Any given set of technologies can be delivered by many different combination of construction team, which requires simple or complex interactions.

The level of complexity of the design is a major factor in determining inherent difficulty.

Construction Teams:

Variation in the construction teams' level of performance brings about complexity that impact on construction difficulty. The construction teams' influence on construction difficulty comes from undertaking their work at an inconsistent pace because construction teams' have good days and bad days thereby causing output to vary from day to day even when the surrounding conditions are similar. This inconsistency is measured in terms of variability around the norm. Secondly, the construction teams' involved in a construction project, undertake the required work to the level of efficiency established by the local construction industry and more importantly, their perceptions of what constitutes the key performance objectives often differ and this has a direct influence on the level of efficiency, which can be achieved.

Performance variability is a measure of the range of performance achieved by a construction team. The performance variability achieved by teams vary widely but typically ranges around a norm by + or – 50% or more. It is acknowledged that the **variability** of briefing, designing, planning and procurement actions is often greater than manufacturing, production and commissioning. Different unfortunate events within these construction actions cause variability, which is a source of complexity for construction project organizations and therefore of the inherent difficulty they face.

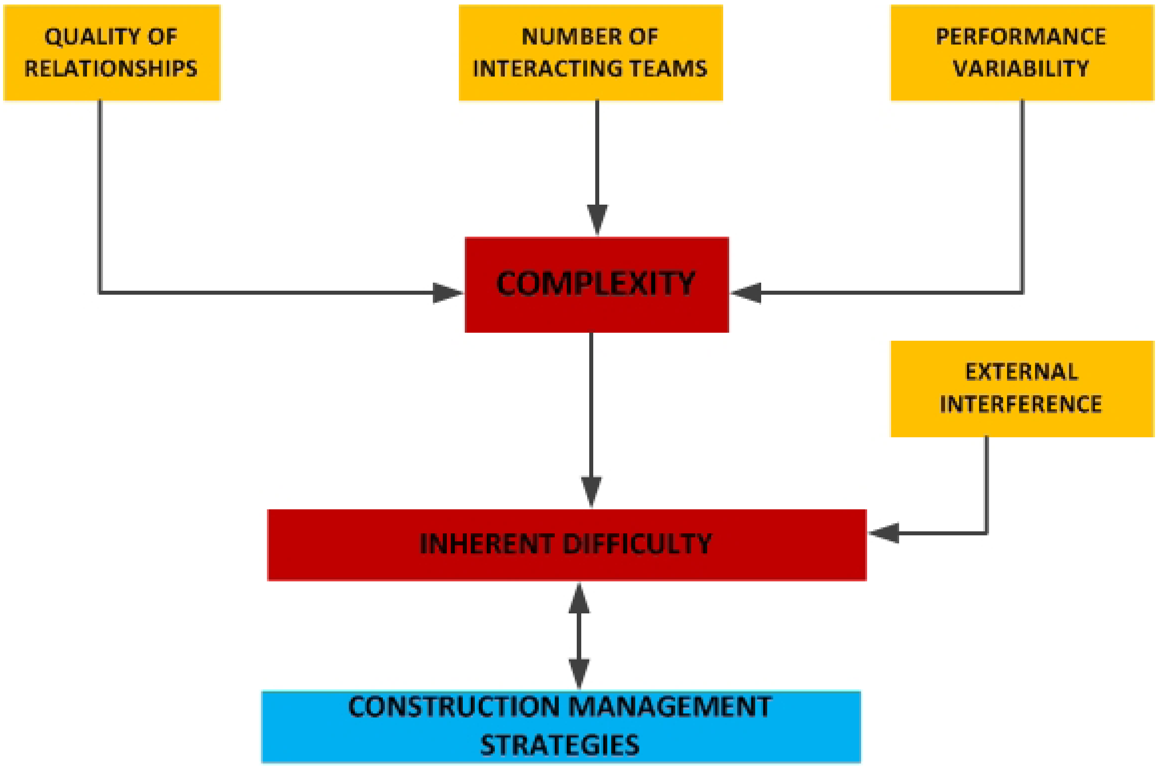


Figure 9: Inherent difficulty of construction projects
(Adopted from Radosavljevic and Bennett, 2012).

Figure 9 shows the component parts of inherent difficulty and suggests its direct influence on construction management strategies.

Construction Environments:

The fourth source of inherent difficulty is the impact of factors external to a construction project, which is outside the control of the construction project organization termed – **force majeure**. Factors of almost every imaginable type may interfere with the progress of a construction project. All construction projects are open to external risk that will interfere with progress.

Inherent Difficulty: is a measure of the complexity and external interference experienced by a construction project organization using traditional/local construction practice before any construction management strategy is applied.

External Interference: is a measure of the impact of factors external to a construction project. It is normally expressed as the percentage of time construction teams are delayed by external factors to the total project construction time. External interference is directly related to the occurrence and amount of delay.

Complexity: Complexity is a measure of the number of interacting construction teams involved in a construction project, the quality of the relationships between them and their performance variability. Complexity increases directly with the number of construction teams involved, inversely with the quality of relationships, and directly with performance variability.

2.3.7 Construction Management Strategies

The theory of construction management accepts that construction faces inherent difficulties that are unavoidable. Nevertheless, the theory is based on the rigorous view that the purpose of construction management is to reduce inherent difficulty. **Construction management strategy** is a coordinated set of decisions, which guide a construction project organization. The decisions aim to reduce the inherent difficulty of construction in ways, which increase the chances of agreed objectives, being achieved. This means in theory that there are sets of construction management **decisions**, which enable construction to be straightforward and certain.

In a straightforward construction project,

- a single organization exists which comprise all necessary construction teams to achieve the agreed objectives.
- only a very small proportion of specialist works would be outsourced – posing very little contractual risks.
- there is a single contractual relationship between the organization and the customer and very few other contractual relationships

The vast majority of relationships have been established during previous projects because the teams come from the same organization. It is important that relationships are not inhibited by contractual limitations.

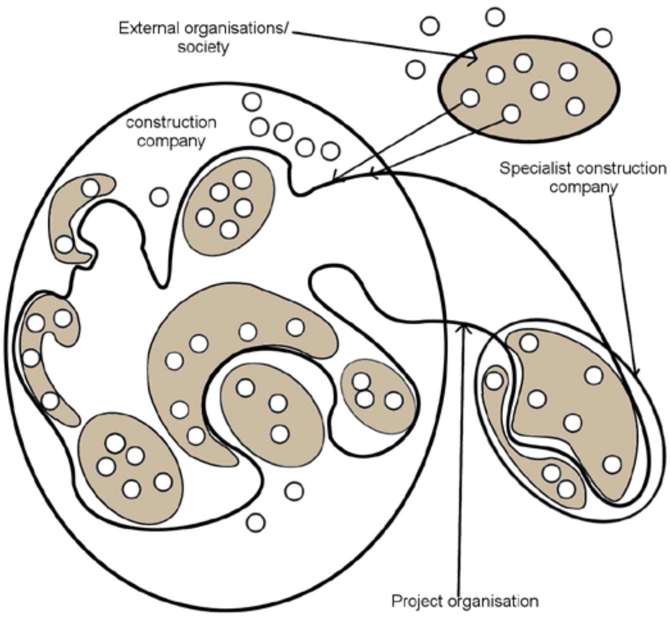


Figure 10: Example of a Straight Forward Construction Project
(Adopted from Radosavljevic and Bennett, 2012)

Indicators of Straight Forward Projects

- Clear and complete brief
- Single organization responsible for project
- Clear and complete design and plan
- **Competent teams with established internal relationships**
- Standard and readily available materials and components
- Efficient production and commissioning

Construction Management theory also provides propositions to guide construction away from difficult projects towards straightforward projects.

In a difficult construction project,

All actions rely solely on contractually determined boundary relationships within an ill-defined and constantly changing project organization.

Figure 11 illustrates construction companies comprising divisions, teams and internal relationships, which contribute to a construction project organization and in doing so, form a complex network comprising teams and relationships. In the worst-case scenario, the project organization is formed through **folding (F)**, which is a term borrowed from general Systems Theory. It refers to the formation of a higher order system from a collection of sub-systems without changing the quality of the relationship that exists in the subsystems. In relation to a project, this would correspond to forming a project organization where individual teams limit their relationships to contractual obligations and make no attempt to achieve positive synergy with other teams.

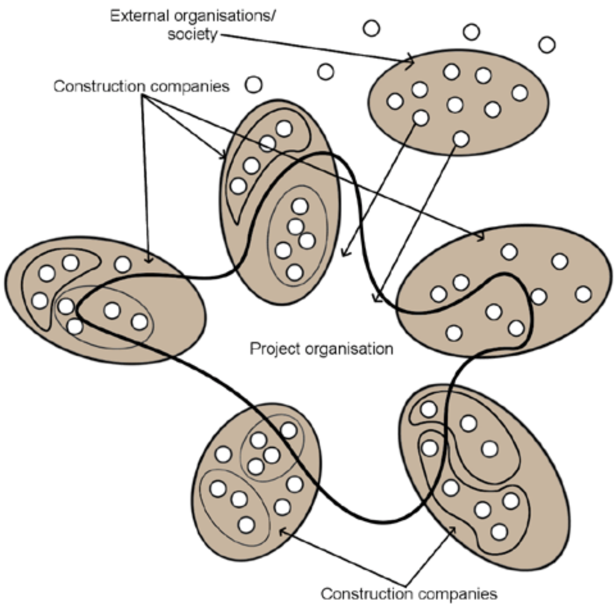


Figure 11: Example of a Worst Case Construction Project Network
(Adopted from Radosavljevic and Bennett, 2012)

2.3.8 Indicators of Difficult Construction Projects

- Vague and incomplete brief
- Complex and incomplete designs
- Technologies outside the competence of local companies
- Complex, contradictory and incomplete plans
- **Selection of numerous teams, which lack the required skills, knowledge and equipment**
- **Boundary relationships used to defend individual interests**
- Construction teams are forced into accepting tough unenforceable contracts which give rise to delays

- Manufacturing requires components and materials outside the competence of available manufacturing companies
- Production uses inappropriate skills, knowledge and equipment and faces constant changes to the design
- Commissioning delivers an incomplete facility which fall far short of the brief

Construction managers select from a range of strategies to enable them manage individual construction projects. In general terms, the choice is between doing nothing or being more proactive. The proactive strategies involve either:

- directly managing the inherent difficulty; or
- altering the factors which cause the inherent difficulty.

1. Accepting the inherent difficulty, which means doing nothing, is the **traditional approach**.
2. Managing the inherent difficulty can be achieved by use of different **procurement methods** including:
    a) Design and build;
    b) Management contracting; or
    c) Construction management

3. Altering the factors which cause inherent difficulty can be achieved by using relational procurement systems including:
   a) Partnering;
   b) An integrated approach; or
   c) Alliancing

Ultimately, construction managers apply proactive strategies by selecting actions, which mitigate the level of inherent difficulty, and then matching the actions of everyone involved to the resulting tasks. See Figure 12.

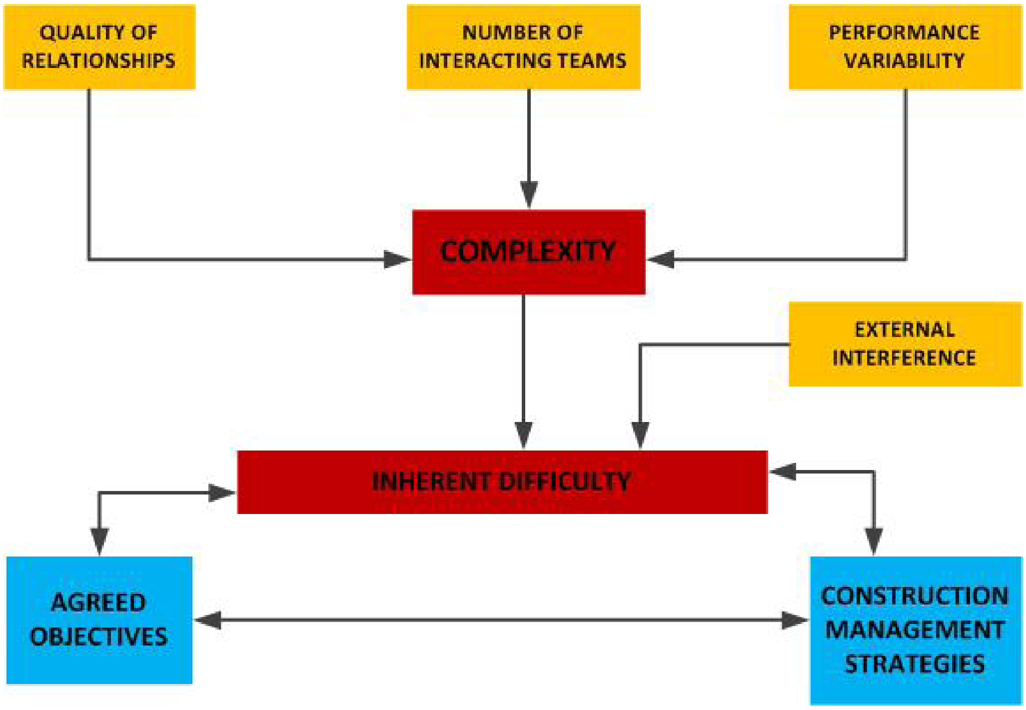
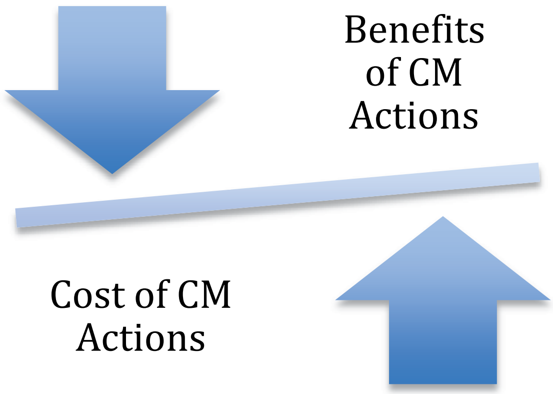


Figure 12: Basic concepts in theory of construction management
(Adopted from Radosavljevic and Bennett, 2012)

The **choice of an appropriate construction management strategy** is shaped by the fact that actions to mitigate inherent difficulty involve costs and benefits. These need to be balanced to determine an optimum set of management actions, which means the actions, which achieve the highest achievable level of efficiency. This results from balancing the costs of mitigating inherent difficulty with the benefits until a point is reached where the costs of further actions are unlikely to deliver commensurate benefits.



2.3.9 Construction Companies

Construction management strategies can be inherent in the work of the construction companies and the teams they source to form project organizations. Such well-established strategies are highly effective provided they are compatible with the projects undertaken. Other construction management strategies are devised for individual projects while others emerge on an ad hoc basis as projects proceed. Construction companies influence the efficiency of the teams they provide to undertake construction. The construction management theory proffered by Radosavljevic and Bennett (2012) provides the following propositions to guide this influence:

- Satisfy the requirements of local or specialised markets to ensure company's survival
- Develop teams with well developed skills and knowledge which match the requirements of projects
- Develop teams integrated by established relationships
- Improve the quality of support provided to teams by their companies
- Foster innovations which match the requirements of projects
- Ensure the use of effective information systems
- Establish values which run consistently throughout their organization
- Ensure their organization acts in ways which are intended and authorised
- Ensure communications are effective and result in common understandings
- Ensure transactions are agreed with minimum effort, accepted as fair, foster established relationships, and are acted on in the spirit in which they were agreed
- Ensure their organization forms established relationships with other organizations
- Ensure their organization collects, reviews and acts on feedback about the effects of its action on its objectives
- Ensure their organization collects, reviews and acts on feedback about the effects of established norms and procedures

2.3.10 Construction Teams

Construction teams form part of project organizations and construction companies as shown in Figure 13.

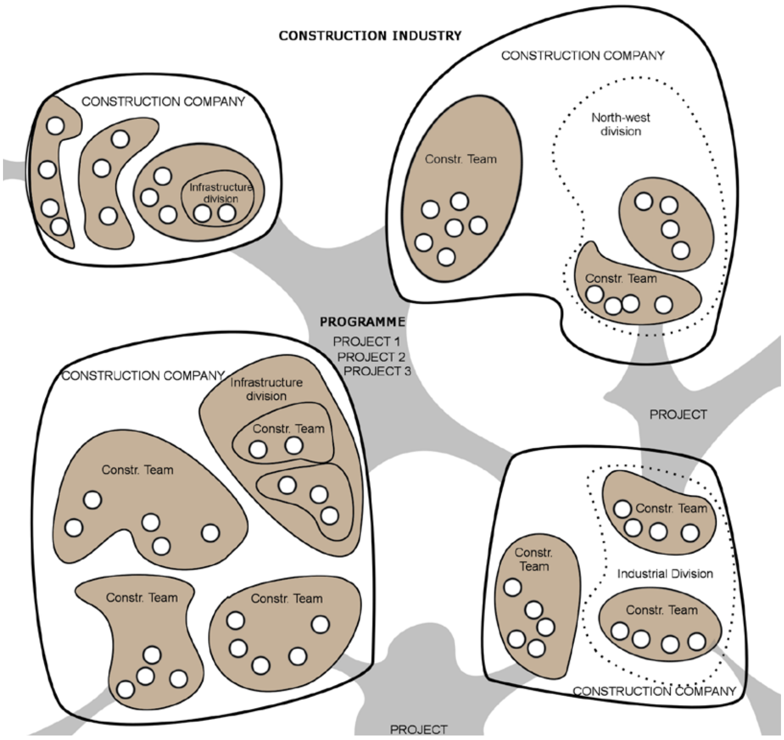


Figure 13: Construction organizations
(Adopted from Radosavljevic and Bennett, 2012)

Given competent construction teams, construction management is centrally concerned with ensuring the teams, which need to interact, establish effective relationships so as to reduce a project's inherent difficulty and making the project more straightforward. The following are selected construction management propositions posited by Radosavljevic and Bennett (2012), towards ensuring the teams, which need to interact and establish effective relationships:

1. Reduce the number of teams involved
2. Improve the quality of relationships
3. Reduce performance variability
4. Reduce external interference
5. Select teams competent in the technologies required by the project
6. Ensure teams accept the agreed objectives
7. Ensure teams are motivated to achieve agreed objectives
8. Foster accurate communications between teams
9. Minimise the effort needed to achieve accurate communications between teams

10. Minimise the length and intensity of negotiations over the transactions which bring teams into the project organization
11. Ensure teams regard the transactions as advantageous to themselves
12. Minimise the resources teams devote to improving the terms of the transactions which brought them into the project organization

References/Bibliography:

Radosavljevic, M. and Bennett, J. (2012) *Construction Management Strategies: A Theory of Construction Management*, Wiley-Blackwell: London.

Smallwood, J. (2011) Introductory Address at the NMMU Construction Management 40 Conference, Port Elizabeth, 27–29 November.

2.4 Operations Research Theory

Operational research (OR) has been defined by the Operational Society of the United Kingdom as: the application of the methods of science to complex problems arising in the direction and management of large systems of men, machines, materials and money in industry, business, government and defence. The distinctive approach is to develop a scientific model of the system, incorporating measurement of factors such as chance and risk, with which to predict and compare the outcomes of alternative decisions, strategies or controls. The purpose is to help management determine its policy and actions scientifically.

The focus of Operational research is to account for the use of all resources to produce an optimum overall situation for example, greatest profit, shortest time, maximum production, minimum of loss etc. It is a discipline that deals with the application of advanced analytical methods to help make better decisions. It is often considered to be a sub-field of mathematics. In life, there are always 2 + n paths: the one we choose and the others we did not choose. Operational research helps us to make informed, controlled, scientific and logical decisions in construction management. **Construction management strategy** is a coordinated set of decisions, which guide a construction project organization (Radosavljevic and Bennett, 2012).

Operational research uses a mathematical approach to problem solving and has evolved into a significant field of modeling and optimization techniques with specific emphasis on operational problems, particularly in manufacturing and logistic chains. The terms **management science** and **decision science** are sometimes used as more modern sounding synonyms to operational research. Operational research employs techniques from other mathematical sciences, such as linear programming, mathematical modeling, statistical analysis, mathematical optimization, queuing, econometric methods, data envelope analysis (DEA), neural networks, analytical hierarchy process, etc. to arrive at optimal or near-optimal solutions to complex decision-making problems.

2.4.1 Operational Research Techniques

The main operational research techniques/tools used in solving complex problems are described below:

1. Decision Theory

In one sense, operational research is about decisions. It is about decision rules, evaluating alternative decisions, optimizing decisions, predicting the outcome of decisions, helping to cope with uncertainty and risk, and sorting out the complexity of the situations in which decisions are frequently made so that management can swiftly exercise judgment on what is the best course of action in the circumstances.

A decision is a judgment; as such, it is concerned with imperfect information. If all the requisite information were available the result, or course of action, would be obvious (in fact, a decision may not be required) but this is rarely, if ever, the case, especially in connection with the construction industry where time periods are usually long and variables are numerous. A decision is the human element in the determination of a course of action and will, therefore, be governed not only by the information available and techniques used but also by the outlook of the individual.

A prime function of management is decision making. There is much subjectivity in decision-making but it is possible to introduce a measure of objectivity by the application of decision-making techniques such as decision analysis. The application of scientific decision-making techniques promotes consistency, thoroughness and objectivity even in the evaluation of unknowns.

Decision theory deals with the process of making decisions especially in conditions of uncertainty, when a number of alternative courses of action may have to be evaluated before a final decision is made. Decision theory analyzes:

- Types of decisions;
- Sets out ground rules for making decisions; and
- Develops decision-making methods using various kinds of models or procedures.

Types of Decisions

Decisions may be either:

- **Strategic** – long term dealing with wide issues affecting the whole or a major part of an organization; or
- **Tactical** – short term, dealing with operational issues, which, although they may affect the whole organization, are more likely to make an impact upon a particular function or department.

Decision Rules

- Clarification of decision rules: optimistic, pessimistic, opportunity cost or expected value. Decision-making is somehow like taking a risk it could be positive or negative but we try to take the right decision hence you need to have decision rules.
- Rules are guidelines – dos or don'ts
- Between two decisions take one with the:
    - Shortest duration
    - Lowest cost
    - Highest Quality
    - Safest Method

  These can be given weights to help as a guide in taking the best decision.

The Decision Theory Techniques available are:

1. **Means-end analysis:** to clarify a chain of objectives and identify a series of decision points;
2. **Decision matrix analysis:** to model relatively simple decisions under uncertainty and to make explicit the options open to the decision taker. The factors relevant to the decision, and the probable outcomes from a combination of each option with each factor as shown on the matrix. The form in which a decision matrix is constructed is shown in Figure 14.

		Mechanical Factors		
		F1- Ease/Methods of Use	F2- Size/Capacity	F3- Cost
Options-Time	**C1** – Before Deadline	011	012	013
	C2 – Just in Time	021	022	023
	C3 – Later than Deadline	031	032	033

Figure 14: A Decision Matrix

Figure 14 implies that if a decision maker wants low-budget equipment for example which can complete a task before the set deadline, then the probable outcome of the two options is 013.

3. **Decision trees** to assist in making decisions in uncertainty when there is a series of either/or choices. Decisions are often made in conditions where there are a number of alternative courses of action and when the outcomes of these actions are uncertain. Furthermore, earlier actions may affect subsequent actions and these likely effects need to be considered at the earlier stage.

   Decision trees are a means of setting out problems of this kind, which are characterized by the interaction between uncertainty and a series of 'either/or' decisions. They display the anatomy of sequential decision points, the implications of which lead to branches on the tree. Thus the consequences of future decisions can be traced back to assess their influence on the present decision.

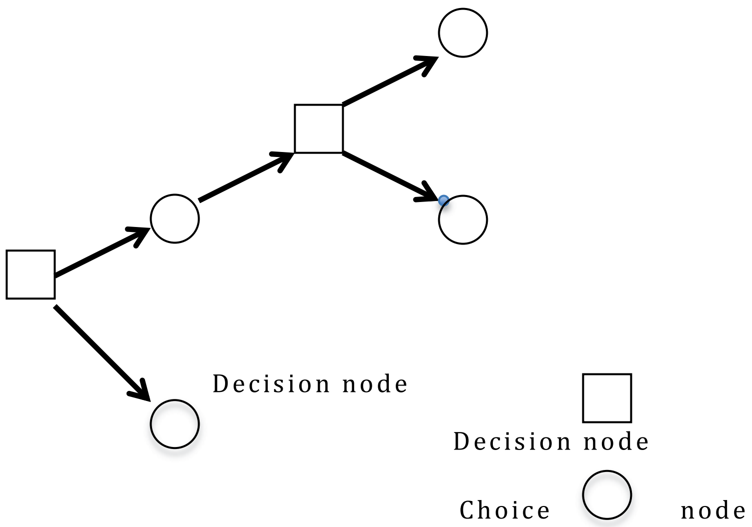


Figure 15: A Decision Tree Structure

Squares represent decisions you can make. The lines that come out of each square on its right show all the available distinct options that can be selected at that decision analysis point. Circles show various circumstances that have uncertain outcomes (For example, some types of events that may affect you on a given path). The lines that come out of each circle denote possible outcomes of that uncontrollable circumstance.

Exercise: Use a decision tree to trace the decisions you have taken since you woke up this morning and those you are still to take before going to bed at night. Write down above each such line in the decision tree your best guesses for probabilities (for example, “80%” or “0.8”) of those different outcomes. Each path that can be followed along the decision tree, from left to right, leads to some specific outcome. You need to describe those end results in terms of your main criteria for judging the results of your decisions.

4. **Algorithms**, which set out the logical sequence of deductions for problem solving. An algorithm is a set of rules/step-by-step procedure that precisely defines a sequence of operations. It is used for calculations, data processing and automated reasoning. The concept of algorithm is used to define the notion of decidability, which is central to explaining how formal systems come into being, starting from a small set of axioms and rules. Algorithms can be expressed in many kinds of notation including flow charts and programming languages. Natural language expression of algorithms tends to be verbose and ambiguous and is rarely used for complex or technical algorithms.

5. **Subjective probability techniques**, which aim to systemize the process of making intuitive, decisions or decisions based largely on personal experience.

Many problems faced by managers are fraught with uncertainties, Success cannot be guaranteed and may depend on matters outside our control such as the weather, the state of the economy and the decisions made by competitors. In these conditions, we have to speak of probabilities rather than certainties. **Probability theory** is used to assess the chances of success and failure and the consequent financial implications of delays in construction projects.

Mathematicians denote probability by ρ and measure it on a scale of 0 to 1, with higher values representing greater probabilities. Thus $\rho = 1$ represents absolute certainty and $\rho = 0$ corresponds to impossibility. When two or more outcomes are possible, the probability of each may be regarded as the proportion of occasions on which each occurs in the long run. Thus the probability of a tossed coin coming down heads is $\rho = 0.5$. We often need to combine the probability values of two or more outcomes and we can do this by using two rules:

i. The addition rule: if A and B are alternative outcomes in a given case, the probability of one or the other occurring is the sum of their separate probabilities.

$$\rho\ (A\ or\ B) = \rho\ (A) + \rho\ (B)$$

It follows from this rule that the sum of the probabilities of all possible outcomes in a given case is 1. An example is the chances of success and failure. If a given project has a 0.7 probability of success then its probability of failure is ρ = 0.3.

ii. The multiplication rule: This rule concerns different cases or events. The probability of outcome A, in one case, and outcome B in another, both occurring is the product of their separate probabilities.

$$\rho\ (A\ and\ B) = \rho\ (A)\ x\ \rho\ (B)$$

Example: the probability of drawing *either* the ace of diamonds or the queen of hearts is obtained by the addition rule since each excludes the other. The result is:

$$\rho = 1/52 + 1/52 = 1/26 = 0.0385$$

Suppose we have two packs of cards. The probability of drawing the ace of diamonds from the first *and* the queen of hearts from the second is given by the multiplication rule since the two events are independent. The result is:

$$\rho = 1/52 + 1/52 = 0.000370$$

6. **Bayesian analysis**, which aims to translate subjective probabilities into mathematical probability curves, thus providing a clearer analytical framework for the decision. Bayesian probability provides a rational method for updating beliefs.

   Bayesian inference derives the posterior probability as a consequence of two antecedents, a prior probability and a likelihood function derived from a probability model for the data to be observed. Bayesian inference computes the posterior probability according Bayes' rule.

2 Modelling

Modelling is a representation of a real situation. It is a fundamental technique of operational research because by representing a situation in mathematical terms, it increases management's understanding of the circumstances in which decisions have to be made and the possible outcomes of those decisions. The process of developing a mathematical model is termed mathematical modelling. A model may help explain a system, to study the effects of different components, and to make predictions about behavior. Mathematical models can take many forms including dynamical systems, statistical models, or differential equations, which usually describe a system by a set of variables and a set of equations that establish relationships between the variables. The variables represent some properties of the system, for example measured system outputs often in the form of timing data, counters, and event occurrence (yes/no).

There are six basic groups of variables namely: decision variables, input variables, state variables, exogenous variables, random variables, and output variables. Since there can be many variables of each type, the variables are generally represented by vectors. Decision variables are sometimes known as independent variables.

Exogenous variables are sometimes known as parameters or constants. The variables are not independent of each other as the state variables are dependent on the decision, input, random, and exogenous variables. Furthermore, the output variables are dependent on the state of the system (represented by the state variables). Objectives and constraints of the system and its users can be represented as functions of the output variables or state variables. The objective functions will depend on the perspective of the model's user. Depending on the context, an objective function is also known as an index of performance, as it is some measure of interest to the user. Although there is no limit to the number of objective functions and constraints a model can have, using or optimizing the model becomes more involved (computationally) as the number increases.

Many mathematical models can be classified as follows:

a) **Linear vs. nonlinear**: if all the operators in a mathematical model exhibit linearity, the mathematical model is defined as linear. A model is considered to be nonlinear otherwise.
b) **Deterministic vs. probabilistic (stochastic):** a deterministic model is one in which every set of variable states is uniquely determined by parameters in the model and by sets of previous states of these variables. Therefore, deterministic models perform the same way for a given set of initial conditions. Conversely, in a stochastic model, randomness is present, and variable states are not described by unique values, but rather by probability distributions.
c) **Static vs. dynamic:** A static model does not account for the element of time, while a dynamic model does. Dynamic models typically are represented with differential equations.
d) **Discrete vs. Continuous:** A discrete model does not take into account the function of time and usually uses time-advance methods, while a continuous model does.
e) **Deductive, inductive, or floating:** A deductive model is a logical structure based on a theory. An inductive model arises from empirical findings and generalization from them. The floating model rests on neither theory nor observation, but is merely the invocation of expected structure.

Techniques in which mathematical models find application include:

1. **Simulation:** this is the construction of mathematical models to represent real life processes or situations as they develop over a period of time. Simulation enables the model to be manipulated so that the dynamics of the system can be reproduced or simulated. One of the most commonly used simulation techniques is the Monte Carlo method, which builds into the system the chance elements that will affect outcomes. Simulation enables the likely effects of many decisions on complex situations to be estimated in conditions of uncertainty when chance elements play an important part.
2. **Linear Programming/Transportation Problems:** Linear programming uses a mathematical approach to solving problems where there are many intersecting variables and only limited resources are available. Its aim is the combination of variables that satisfies the constraints in the system and achieves the objectives sought.

Production is not complete until the product gets to the final consumer. Transportation problems thus arise each time there is need to shift product from manufacturing plants (source) to construction sites (destination). This shift may be from distribution warehouse (source) to local distribution outlet or retail stores (destination). If the cost of transporting products from original (plant) to destination is high, the profit of the firm may be affected. Therefore, management is always concerned with the distribution route, which will optimize objective. The objective may be the minimization of total cost, minimization of time or maximization of profit.

At any given point in time, each plant has a specific capacity. This capacity is called supply so; each destination has a given requirement called demand. The cost of shifting a unit of supply to the demand area is of interest in transportation analysis. Effective distribution of the available supplies to different demand points is the responsibility of the decision maker.

3. **Queuing Theory:** Queuing theory uses mathematical techniques to describe the features of queues of people, materials, work-in-progress, etc. in order to find the best way to plan the sequence of events so that bottlenecks can be avoided.

Queuing theory is applied to all areas of human endeavour where there could be delay in service delivery. It is defined as the development of mathematical models to describe various types of queuing systems so that it may be possible to predict how the system will perform in a given demand situation. Queuing Theory tries to answer questions like the mean waiting time in the queue, the mean system response time (waiting time in the queue plus service times), mean utilization of the service facility, distribution of the number of customers in the queue, distribution of the number of customers in the system and so forth. These questions are mainly investigated in a stochastic scenario, where e.g. the inter-arrival times of the customers or the service times are assumed to be random.

Components of Queuing Systems

The component of a queuing system include

- Arrival
- Queue
- Service
- Outlet or departure

Arrivals: this component is concerned with how many people or items arrive at the service point from different sources. The time between successive arrivals is of importance in this component.

Queue: it is assigned that the item or individual on arriving at the service facility does not receive prompt service. Rather, on arriving he meets some other individuals waiting to be attended to and joins in the waiting. The queue component is therefore the period between arrival at the service facility and when the service is obtained. The technique of selecting individuals for service is termed queue discipline and determines how long a person will wait before being served.

Service: This is the time between the start of service and end of service. In other words, it is the time taken to attend to an individual and this may vary from individuals or servers.

Departure: this is departure from leaving the system after obtaining service. The ease of exit from the system is very important in queuing analysis as congestion in exit may affect the queuing process. This is where the construction managers are required in the design and construction process.

Arrival Pattern

The arrival pattern depends on the nature of the population demanding service. It can be defined as the rate with which individuals requiring service arrive at the service facility, which may be in batches, individually or both. Arrival patterns can be scheduled and systematic for example, arrival at scheduled conferences or meetings, scheduled clinic days, scheduled interviews. Arrival can also be random and these include all arrival without prior notification such as tollgates, police checkpoints, telephone exchange, traffic lights, banks etc.

Measures of arrival Pattern

a) Arrival rate: this is the average number of arrivals per unit time and this is denoted by (λ). For instance, 1200 people arrived at banking hall along Rondebosch main road within the period of eight hours. This means that on the average, (960/8 =120) meaning that 120 individuals arrive at the banking hall per hour or (120/60 = 2), 2 individuals arrive at the banking every 2minutes.
b) Inter-arrival time: This is the time period between successive arrivals. It is computed as the reciprocal of the mean arrival rate.
Mathematically; inter-arrival = $1/\lambda$
Thus, IAR = ½ = 0.5 minutes (or 30 seconds)

The waiting room

There can be limitations with respect to the number of customers in the system. For example, in a bank, people prompted by the need to satisfy their desire leave the population and arrive at the service system. The departure of individuals from the population and arrival of the same to the service system results in the formation of queue and the chance to provide goods and services.

Causes of Queue

Queues could be formed due to the following factors:

1. Service facilities have limited capacity to meet customers demand immediately on arrival
2. The arrival time being faster than the service time
3. At peak periods, customer outnumber the service system
4. Inefficient use of resources
5. Breakdown of service facility

Some queuing behaviour

a) **Reneging**: This is when an individual who is already in the queue becomes tired of waiting and leaves the system or goes home before getting served

b) **Balking**: An individual on approaching the queue feels that the queue is too long and refuses to join the waiting line.
c) **Jockery**: This is a situation where an individual switch from one waiting line to another just to minimise waiting time
d) **Cycle**: This is when an individual returns back to the queue immediately after receiving service.

The service discipline

Customers can be served one by one or in batches. We have many possibilities for the order in which they enter service. We mention:

- first come first served, i.e. in order of arrival;
- random order; the selection of an individual is random or haphazard
- last come first served (e.g. in a store where bags of cement or animal feeds are packed);
- priorities (e.g. rush orders first, shortest processing time first); where an individual is given priority or preferential treatment
- Processor sharing (in computers that equally divide their processing power overall jobs in the system).

Performance measures

Relevant performance measures in the analysis of queuing models are:

- The distribution of the waiting time and the sojourn time of a customer. The sojourn time is the waiting time plus the service time.
- The distribution of the number of customers in the system (including or excluding the one or those in service).
- The distribution of the amount of work in the system. That is the sum of service times of the waiting customers and the residual service time of the customer in service.
- The distribution of the busy period of the server. This is a period of time during which the server is working continuously.

Types of Queues

a) Single queue with single service point
b) Single queue with multiple service points
c) Multiple queue with multiple service points
d) Multiple queue with single service point

Definition of terms

- **Queuing system**: This is the number of individuals in the queue plus those receiving service
- **State of the system:** this is the number of individuals in the queuing system
- **Steady State**: This is the state of the system in long run. The queue system is in a steady state when there is stability in its component parts- the arrival rate, the service facilities and the service rate.
- **Length Queue**: This is the number of customers waiting to be served. It excludes those already receiving service.
- **Service Time**: This is time taken to serve individual. It is the time between the commencement and completion of a service. Service time may be constant or it may vary from individual customers or server to another. In order to model the service time mathematically, it is assumed that the service time follow the negative exponential distribution. This probability distribution gives higher probability values for short service time and smaller probability values for longer service time
- **Service Rate**: This is the average number of service completed per unit time. This is denoted by **mu** (μ). For example 120 vehicles were served per hour on average in Mega filling station in Cape Town, if the unit of time is in hours, then μ=120 but if the unit of time is minutes, then μ= 120/60 =2 vehicles per minute.
- **Inter-service time**: This is the length of time interval between two consecutive service completions. It is measured as the reciprocal of the service. That is;

  Inter-service time = $1/\mu$, using the above example inter-service time =1/120 = 0.008333 hours or ½ = 0.5 minutes

2.4.2 Single Channel Queue

This is also called simple or basic. It is defined as a single queue with a single service point. That is, there is only one queue and one sever in the system.

Characteristics of a simple queue

The following characteristics describe a single channel queue

a) Single queue and single service point
b) Arrivals are random and follow the poisson distribution
c) The queue has a infinite capacity
d) No simultaneous arrivals
e) The queue discipline is first come first served or first-in-first served (FIFS) basis
f) Members of the queue are discrete individuals and come from an infinite population
g) Single stage service discipline
h) Service times are random and follow a negative exponential distribution
i) The system must have operated for a long time as to a steady state conditions.
j) Traffic intensity must be less than one.

Traffic intensity

The traffic intensity of a simple queue is the most important index that measures the extent of a queue. It is also called utilization factor and is a measure of the efficiency of a queue and it is denoted by ꝑ (rho).

$$ꝑ = \frac{\text{mean arrival rate}}{\text{mean service rate}}$$

$$= \lambda/\mu$$

$$\text{Or} \quad ꝑ = \frac{\text{inter-service rate}}{\text{inter-arrival rate}} = \frac{(1/\mu)}{(1/\lambda)}$$

4. **ABC Analysis:** ABC analysis classifies items such as stock levels or sales outlets into three groups:
   - A (very important);
   - B (fairly important); and
   - C (unimportant)

   depending upon their impact on events. Decisions can then be made on how to concentrate on the A items where the best results will be obtained in relation to the effort expended. ABC analysis is based on Pareto's law, or the 80/20 rule, which describes the tendency for only a small number of items (20%) to be really significant in that they produce 80% of the results as shown in Figure 16.

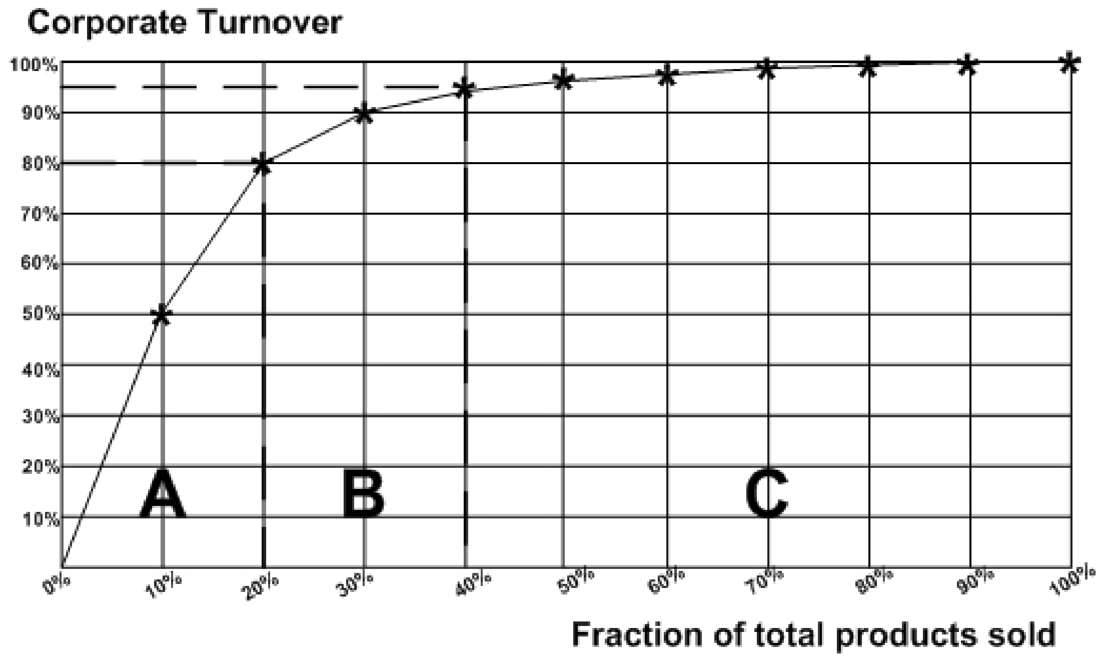


Figure 16: ABC Analysis

5. **Sensitivity Analysis:** Sensitivity is a technique, also used frequently in management accounting to predict the impact on results (e.g. profits or contribution) of varying the levels of the parameters, which affect those results. **Sensitivity analysis** is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be apportioned to different sources of uncertainty in its inputs
6. **Network Analysis:** Network analysis is a critical-path technique for planning and controlling complex projects by recording their component parts and representing them diagrammatically as a network of interrelated activities as shown in Figure 17.

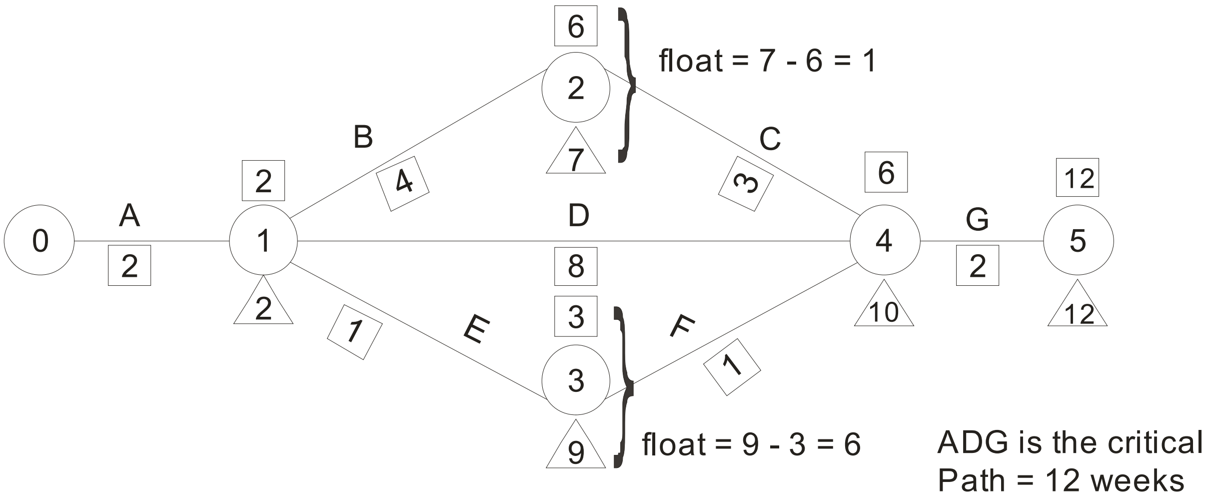


Figure 17: Critical Path/Network

7. **Statistical Techniques:** Operational research in its use of mathematics to assist in describing the circumstances, in which decisions are made, deploys statistical techniques extensively. Because chance and uncertainty play a major part in the sort of decisions OR deals with, **probability estimates** are important. So are the analysis of distributions of data and the study of the interrelationships or correlations between interacting variables.

2.4.3 Operational Research Methods

The steps used in accomplishing Operational Research is based on a sequence of three key tasks:

1. Gain understanding of the system and the relevant factors affecting it, including uncertainty and risk, so that the problem can be defined in useful terms for analysis by means of a mathematical model that represents the system.
2. Collect and analyze relevant data using appropriate decision theory, mathematical modelling, statistical and other quantitative techniques and, often with the aid of a computer analytical program, formulate and test a practical solution.
3. Present proposals for action that could assist in implementing decisions. A listing of some of the general areas of applications of the output/results of Operational Research is provided under the heading Applications.

2.4.4 Applications of the Outputs/Results of Operational Research

Operational research is largely concerned with the allocation of resources and therefore has many applications in construction management. The following are examples of the main applications of operational research:

- **Decision-making**: providing general help in making decisions, especially in complex situations with many interacting variables and in conditions of uncertainty or risk.
- **Distribution planning**: using statistical analysis, linear programming, simulations or algorithms to solve, with the aid of computes, standard transportation problems of how to achieve the best and cheapest distribution pattern. Managing freight transportation and delivery systems (Examples: LTL Shipping, intermodal freight transport) and Scheduling. Linear programming of the transport kind are concerned with the allocation of resources when these are available from several sources and are required at various destinations.
- **Facility and operation control systems planning**: using simulation to enable alternative design concepts to be evaluated and to understand the sensitivity of output to changes in shop configurations and process track speeds. Designing the layout of a site to reduce production time (therefore reducing cost).
- **Forecasting**: where models are developed to predict likely changes in demand or the impact of alternative marketing approaches, including new product development and changes in the marketing mix.
- **Inventory control**: where models and simulations are used to deal with problems of minimum safety or minimum reorder level, and ABC analysis is used to concentrate thinking on the key decision areas.
- **Long range financial planning**: where models are used to predict profit, contribution and sales turnover figures.
- **Product mix decisions**: where linear programming is used to determine the combination of products, which will maximize contribution to profits and fixed costs. In mixture problems, resources have to be divided between different products or services subject to overall constraints.
- **Production planning**: where linear programming is used to decide on what manufacturing facilities are needed and the best way to load these facilities, bearing in mind fluctuations in requirements and uncertainty in demand.
- **Profit planning**: where sensitivity analysis is used to predict the outcome of alternative assumptions about demand, prices and costs.

- **Project planning**: where network analysis is used for planning and scheduling and to assist in resource allocation. Identifying those processes in a complex project, which affect the overall duration of the project. Critical path (or network) analysis is used to plan and control the progress of complex projects by considering the sequence in which the contributions of different people take place. It identifies those activities, which must be finished on time if the completion of the project is not to be delayed, and pinpoints those activities which have time to spare.
- **Queuing problems**: where queuing theory is used to plan sequences of events in order to optimize service levels to customers and to minimize bottlenecks. In the construction industry there are many examples of queuing associated with the delivery of materials and the availability of plant. Estimates of queue length and waiting time are based upon probability concepts and the results can be used to predict the most economical way of providing the particular service required.
- **Resource allocation**: where linear programming is used to work out the workforce, materials, machine time and other resources needed to complete construction or development projects or to maintain budgeted production schedules.

Operational research does not reduce the manager's responsibility but it aims to present information, upon which decisions can be based, particularly the returns that can be expected from alternative strategies. Operational research models are however always approximations and the results they give cannot be more accurate or reliable than the data on which they are based.

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2.5 Problems in Operational Research

2.5.1 Probability

Example 1:

Observation over 100 days on the use of dumper trucks on a construction site gave the following pattern of demands:

Number of dumper trucks required	*0*	*1*	*2*	*3*
Number of days	*23*	*36*	*27*	*14*

It is expected that this pattern of demand will continue. What is the average daily cost if the trucks are hired by the day when required at an all-in cost of R2500 per day?

The trucks are also available on long-term leasing at basic charges of R5 per day with an additional cost of R1000 for each day they are used. Will it pay to use long-term leasing to meet part of the demand and, if so, how many trucks should be leased?

Solution

From the figures given in the question the probability of requiring none, one, two, or three trucks on a particular day are þ= 0.23,0.36, 0.27 and 0.14 respectively, and these four values add up to 1. If the required trucks are all hired by the day the corresponding daily bills are R0, R25, R50 and R75. Combining the probabilities with these values gives the result:

Average daily cost *= 0.23 × R0 + 0.36 × R2500 + 0.27 × R5000 +0.14 × R7500 = R3300.00*

If one truck is leased long-term, the daily costs when none, one, two and three trucks are required are, respectively, R500, R1500, R4000 and R6500. The calculation becomes:

Average daily cost= 0.23 × R500 + 0.36 × R1500 +0.27 × R4000 +0.14 × R6500 = R2645.00

It will be found that with two trucks leased the result is R2530 and with three it becomes R2820. Leasing therefore pays and two trucks should be leased.

Example 2:

A major company is planning its business strategy for the next five years. It estimates that there is a 0.3 probability of high growth in the construction market during period, a 0.5 probability of low growth, and a 0.2 probability of zero growth. Three courses of action are considered:

a) **Expansion now**. By recruiting staff immediately and developing regional offices the company would be in a strong position if growth were high but this policy would reduce profitability in the event of zero growth.
b) **No expansion**. This would put the company at a disadvantage should the market grow but would enable it to operate economically if the size of the market were static.
c) **Reappraisal after two years**. Under conditions of high growth the policy would lead to lower profits than (a) but it would enable the company to keep its options open and to choose an appropriate level of expansion for the remaining years.

The estimated outcomes, in terms of percentage profitability, are shown in Table 1 below. Analyse the problem and recommend a course of action.

	High growth	Low growth	Zero growth
Expansion now	20	13	0
No expansion	10	9	8
Reappraisal after two years	16	14	8

Table 1: Courses of Action

Solution

A convenient model for this problem is the 'decision tree'. Figure 1 below gives the details, with decision points indicated by A, B, C, and D, and chance point shown by circles. At each of the decision points B, C and D there is a choice of no expansion or an expansion appropriate to the state of the market.

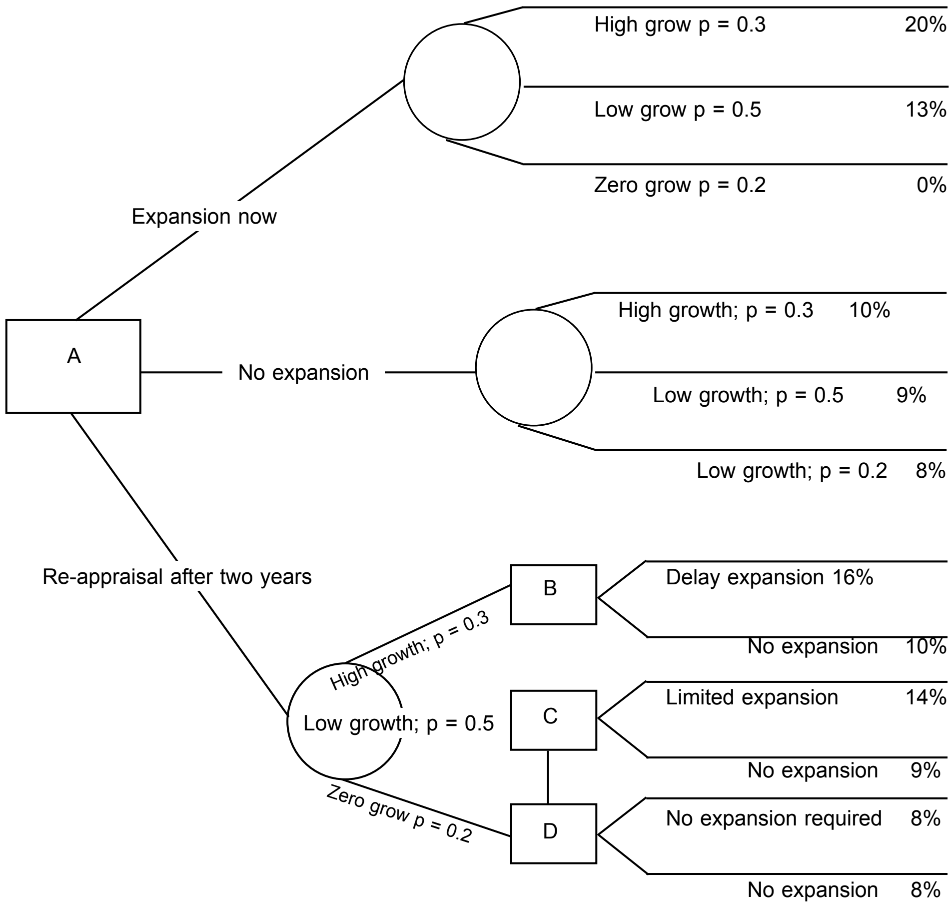
In the case of zero growth D, reappraisal merely confirms the policy of zero expansion, but at B and C the expansion choices are preferred. With these choices the decision tree is reduced to form of figure 2, the three choices at A being labelled (a), (b) and (c).

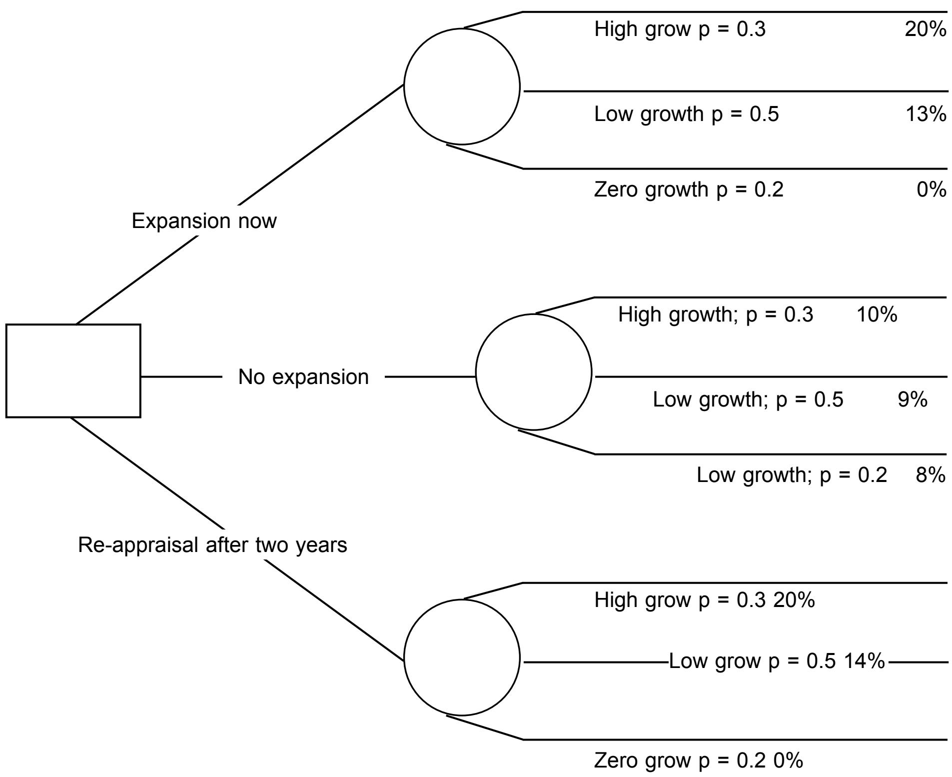
The 'average' profitability corresponding to initial decision (a) is:

$0.3 \times 20 + 0.5 \times 13 + 0.2 \times 0 = 12.5\%$

This result, found by combining the separate profitability figures in the proportion of their probabilities is often called the 'expected' value but in one sense, it is a misnomer. With the assumptions and data given in the question, the outcome will be 20%, 13% or 0%. The argument is that we will face many such problems over a period of time and we can expect the average outcome to be 12.5%.

The corresponding results for initial choices (b) and (c) are 9.12 and 13.4, respectively. The highest of the three values is given by (c) and the initial decision should be to reappraise the policy after two years.


High grow p = 0.3 20%
Low grow p = 0.5 13%
Zero grow p = 0.2 0%
Expansion now
High growth; p = 0.3 10%
A
No expansion
Low growth; p = 0.5 9%
Low growth; p = 0.2 8%
Re-appraisal after two years
B
Delay expansion 16%
High growth; p = 0.3
No expansion 10%
Low growth; p = 0.5
C
Limited expansion 14%
No expansion 9%
Zero grow p = 0.2
D
No expansion required 8%
No expansion 8%


High grow p = 0.3 20%
Low growth p = 0.5 13%
Zero growth p = 0.2 0%
Expansion now
High growth; p = 0.3 10%
No expansion
Low growth; p = 0.5 9%
Low growth; p = 0.2 8%
Re-appraisal after two years
High grow p = 0.3 20%
Low grow p = 0.5 14%
Zero grow p = 0.2 0%

2.5.2 Assignment problem

A contractor has been successful in obtaining five new projects. The projects, however, are different in value, type of work and complexity. As a result the experience and qualities required of the construction manager for each will be different. After careful consideration, five managers are selected and their skills assessed against each project. Each manager is scored on a point scale, with a maximum of 100marks indicating that the manager is highly suitable, zero mark unsuitable for work. The individual assessments are shown in table below.

Which managers should be allocated to which projects, if the company wishes to distribute them in the most effective way?

Projects

Managers		1	2	3	4	5
	A	75	28	61	48	59
	B	78	71	51	35	19
	C	73	61	40	49	68
	D	55	50	52	48	63
	E	71	60	61	74	70

Solution

In this example it is first necessary to subtract all figures from 100, since it is required to maximise the point scores for managers (i.e. minimise 100 minus point score).

Initial stage subtract point scores from 100

Table I: subtract point scores from 100

Projects

Managers						
	A	25	72	39	52	41
	B	22	29	49	65	81
	C	27	39	60	51	32
	D	45	50	48	52	37
	E	29	40	39	26	30

Step 1

Subtract the lowest number in each row from every number in its row

Projects

Managers	**A**	0	47	14	27	16
	B	0	7	27	43	59
	C	0	12	33	24	5
	D	8	13	11	15	0
	E	3	14	13	0	4

Step 2

Subtract the lowest number in each column from every number in its column

Projects

Managers						
	A	0	40	3	27	16
	B	0	0	16	43	59
	C	0	5	22	24	5
	D	8	6	0	15	0
	E	3	7	2	0	4

Step 3

Test for an assignment.

An assignment is possible if the minimum number of horizontal and vertical lines drawn through the rows and columns needed to cover all the zeros equals the number of rows or columns in the table as shown below. In this case a minimum four lines covers all zeros, thus an assignment is not possible.

Projects

Managers						
	A	0	40	3	27	16
	B	0	0	16	43	59
	C	0	5	22	24	5
	D	8	6	0	15	0
	E	3	7	2	0	4

Step 4

Find the smallest uncovered number remaining after step 3 is undertaken, then (1) subtract this number from every number in the table in step 3 above as shown below (fig i); (2) add the same number back to each number covered by step 3 lines (i.e. a number a covered by both horizontal and vertical lines will be added twice (see figure ii below); (3) try the assignment test again.

1) Smallest number is 3

Projects

Managers						
	A	-3	37	0	24	13
	B	-3	-3	13	40	56
	C	-3	2	19	21	2
	D	5	3	-3	12	-3
	E	0	4	-1	-3	1

2)

Projects

Managers						
	A	0	40	0	24	13
	B	0	0	13	40	56
	C	0	5	19	21	2
	D	11	9	0	15	0
	E	6	10	2	0	4

3) the zeros cannot be covered by less than five lines now, therefore a zero assignment is possible. If not, repeat procedure from step 4.

Step 5

In order to reach the optimal solution, it is only possible to use one route for each row and column.

Projects

Managers		1	2	3	4	5
	A	▪		0		
	B	▪	0			
	C	0				
	D			▪		0
	E				0	

Column 2, 4 and 5 each has a single zero, so those routes must be used. The extra zeros in Rows (B) and (D) can therefore the discarded. Hence the zero in column (3) must be used and zeros in Column (1) now discarded, leaving the only possible route in column (1) as the zero in Row (C).

Final solution

The final solution converted back to points is shown below. Therefore, the best combination of manager to project is:

Manager	project	points
1	C	73
2	B	71
3	A	61
4	D	63
5	E	74
		342

Projects

Managers	**A**			0		
	B		0			
	C	0				
	D					0
	E				0	

Projects

		(1)	**2**	**3**	**4**	**5**
Managers	**A**	75	28	**61**	48	59
	B	78	**71**	51	35	19
	C	**73**	61	40	49	68
	D	55	50	52	48	**63**
	E	71	60	61	**74**	70

Example 2: UCT has decided as a matter of urgency to construct a lecture theatre to be jointly used by all the departments under faculty of engineering and the built environment. Because of the need to complete the project as quickly as possible, the work has been divided into five lots, which are to be built concurrently. There are five companies large enough to undertake the construction of any of the five stages and each company has been invited to submit a tender for each of the project. The tenders (in millions of Rand) are as follow:

Company	LOT 1	LOT2	LOT3	LOT4	LOT5
A	49	84	63	82	68
B	53	92	62	83	69
C	54	86	67	78	68
D	46	86	62	76	70
E	50	82	65	80	72

i. Assuming that none of the contractors is large enough to undertake the work of more than one lot, advice the university on how the five contracts should be allocated.
ii. Determine the minimum total cost of the project based on (i) above.

Table I:

Company	LOT 1	LOT2	LOT3	LOT4	LOT5
A	49	84	63	82	68
B	53	92	62	83	69
C	54	86	67	78	68
D	46	86	62	76	70
E	50	82	65	80	72

STEP 1: Reduce each column, subtract the smallest figure from all figure in each column

Company	Lot1	Lot2	Lot3	Lot4	Lot5
A	3	2	1	6	0
B	7	10	0	7	1
C	8	4	5	2	0
D	0	4	0	0	2
E	4	0	3	4	4

STEP 2: Reduce each row; subtract the smallest figure from figures in each row.

Company	Lot1	Lot2	Lot3	Lot4	Lot5
A	3	2	1	6	0
B	7	10	0	7	1
C	8	4	5	2	0
D	0	4	0	0	2
E	4	0	3	4	4

Note assignment is not possible, there are five assignments and only four lines are used to cancel the zero.

STEP 3: Subtract the lowest uncovered figure from the entire figure in the table.

Company	Lot1	Lot2	Lot3	Lot4	Lot5
A	1	0	-1	4	-2
B	5	8	-2	5	-1
C	6	2	3	0	-2
D	-2	2	-2	-2	0
E	2	-2	1	2	2

STEP 4: Add the subtracted figure to the figure covered by the lines, twice where the lines crosses each other, then cross again to test for optimality.

Company	Lot1	Lot2	Lot3	Lot4	Lot5
A	1	2	1	4	0
B	5	10	0	5	1
C	6	4	5	0	0
D	0	6	2	0	4
E	2	0	3	2	4

STEP 5: Allocate the companies to the lots

A ⟶ LT5
B ⟶ LT3
C ⟶ LT4
D ⟶ LT1
E ⟶ LT2

Total minimum cost of the project is given as

A ⟶ LT5 = 68
B ⟶ LT3 = 62
C ⟶ LT4 = 78
D ⟶ LT1 = 46
E ⟶ LT2 = 82
R336 million

2.5.3 Linear Programming/Transportation Problems

Example 1.

A contractor is organising the supply of ready-mixed concrete to four sites. He estimates that the total daily requirement amounts to twenty-four lorry loads and he finds three suppliers who are able to meet this demand between them. The separate amounts available from the supplier (in lorry loads)

A: 4, B; 8, C; 12

And the quantities needed at four sites are;

K; 5, L; 2, M; 10, N; 7

Show on a suitable matrix, an allocation schedule that matches these amounts. In price negotiation it is agreed that transport costs will be charged to the contractor in proportion to the distance incurred. The distances involved are:

	K	L	M	N
A	6	12	2	5
B	18	21	13	12
C	11	16	5	6

Calculate the total one-way daily distance from the allocations made and obtain the schedule that gives the minimum total distance.

Solution

It is convenient to show the allocations on a matrix such as figure (a) below in which the sources are listed on the left and the destinations at the top. Each element or cell then represents one of the routes, there being twelve in the present problem. The number of lorry loads available at each source is shown to the right of the corresponding row and the number required at each destination is given at the foot of the appropriate column.

A feasible solution is one in which the numbers in the rows and columns add up to these values. Also, by bthe nature of this problem, fractional and negative numbers are excluded. Some routes are unused and corresponding cells in the matrix are left empty. It is easy to find a feasible solution by trial and error and two of the many possibilities are shown by Figure (a) and (b)

	K	L	M	N	
A		1	2	1	4
B	3			5	8
C	2	1	8	1	12
	5	2	10	7	

Figure (a)

	K	L	M	N	
A	1			3	4
B		2	6		8
C	4		4	4	12
	5	2	10	7	

Figure (b)

Indeed, with the data of present problem, there are nearly a thousand feasible solutions.

If the numbers in the matrix of figure (a) are combined with the appropriate distances, the total distance is:

$1 \times 12 + 2 \times 2 + 1 \times 5 + 3 \times 18 + 5 \times 12 + 2 \times 11 + 1 \times 16 + 8 \times 5 + 1 \times 6 = 219$ kilometers

And the corresponding total for (b) is 229 kilometers. Although these solutions are both feasible, (a) is to be preferred in that it involves the lower total distance

It might be possible to obtain a more economical solution with a 'common sense' approach of avoiding long routes and making as much use as possible of short ones. However, with such a large number of feasible solutions, this process could take a long time and there would be no way of knowing when the optimum was reached.

A more systematic way of tackling the problem is to modify the initial solution step by step in order to reduce the total distances while retaining feasibility – a process known as *iteration.* When it is found that no further improvement is possible, the optimum arrangement has been achieved. To facilitate this orocess the matrix is displayed with the route distances in the corners of the cells, shown as in Figure (c).

In seeking an initial solution we first note that if there are *m* rows and *n* columns as a feasible solution can be found with not more than *m*+*n*-1 routes in use. These are called occupied elements, the other being free elements. The value m+n-1 is called the critical number and in the present case, with m =3 and n =4, feasible solution can be found with more than six occupied elements.

A solution satisfying this rule, and known as the 'north-west corner' solution, is found as follows:

The largest possible number is entered in the top left-hand cell (Figure c). It must be 4, the row total, and the remaining cells in this row remain empty (free elements). In the first cell of the second row the largest possible number is 1 since this completes the requirements of the first column. In the second cell of this row the maximum number is 2 (the column total) and in the third it is 5, thus completing the row total. In the bottom row, 5 lorryloads are needed in the third cell to complete the requirements at destination M and remaining cell or element has the value 7. This procedure satisfies the critical number rule and is an efficient way of finding an initial solution. At this stage the total distance is

4 × 6 + 1 × 18 +2 × 21 + 5 × 13 +5 × 5 + 7 × 6 = 216 Kilometers

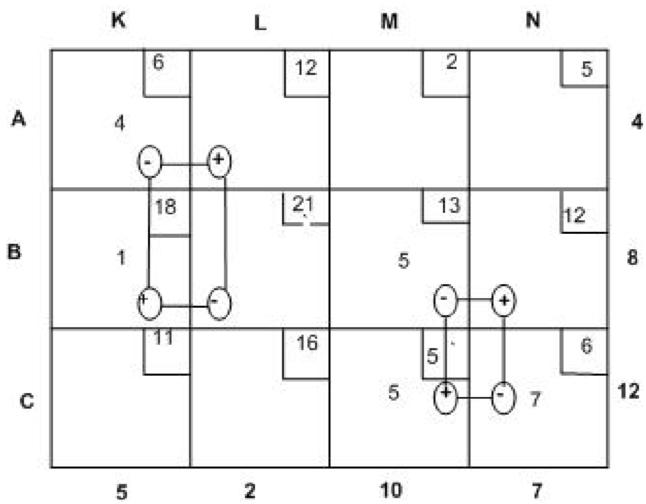


Figure (c)

The unused routes in this solution are now investigated one by one to see if improvements can be obtained by incorporating them. Consider, for instance, the effect of allocating one lorry load to route AL: this is indicated by placing a (+) sign in AL cell as shown in Figure (c). This move would upset the totals of the first row and second column, and to preservew the feasibility of the solution corresponding reductions of one lorryload each are made in the cells AK and BL, indicated by (-) signs. Finally a lorryload would have to be added to the BK route, as shown by the (+) sign in its cell. Together these four changes would lead to a different, but still feasible, solution. The effect on distance would be:

+12 – 6 + 18 – 21 = +3

The use of route AL at this stage would therefore increase the distance. On the other hand, the allocation of one lorryload to route BN with corresponding adjustments to other routes, as shown in the bottom right-hand orner of Figure (c), cause a change in total distance of

+12 – 13 + 5 – 6 = -2

And this represents an improvement. The change in the allocation to each of the routes involved need not to be limited to a single lorryload, but for each one added to BN there is a reduction of one on each of the routes BM and CN. At present BM has 5 and CN has 7, so that the proposed rearrangement can be made for a maximum of 5 lorryloads. The reduction in miles is therefore 10, the new total being 206 and modified allocations are shown in Figure (d). The process, usually called the 'steppingstone' method, is now repeated. An empty cell is selected and linked with three occupied cells by horizontal and vertical steps – 'rook' moves, in chess parlance. If allocation of one lorrylod to empty cell, and he corresponding adjustment to the others, lead to reduction in total mileage the change is made for as great a quantity as possible, the limit being reached when one of the occupied cells becomes empty.

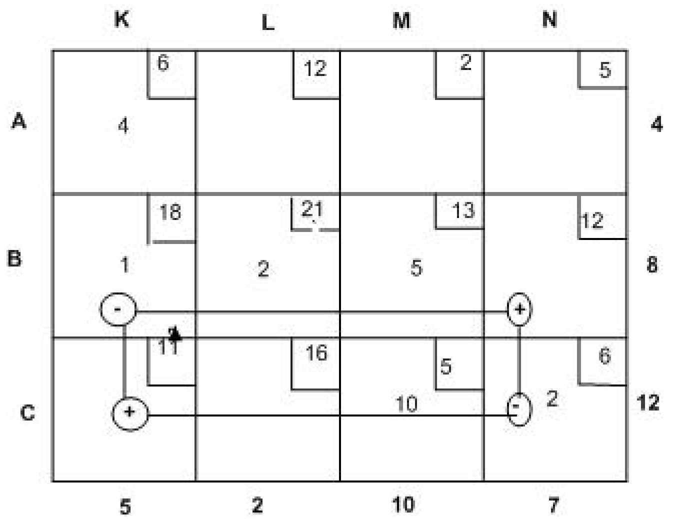


Figure (d)

The four cells involved do not necessarily form a square. The addition of one lorryload to CK for example, cannot be offset in the bottom row by subtracting one from CL because this route is empty already. Instead, CK is linked with CN, BN and BK as shown in figure (d). The change in distance is: +11 – 6 + 12 – 18 = -1

But the improvement can only be made for one lorryload because BK is then empty. The total distance is reduced to 205Km and the new allocations are shown in figure (e).

If all empty routes are tested at this stage it will be found that no further improvement is possible. AL presents a special problem because it cannot be linked with three occupied routes in a square or rectangle. The links form a more complicated path, as shown in figure (d), but the solution remains feasible because each row and column involved contains one (+) and one (-) sign. The change in distance is:

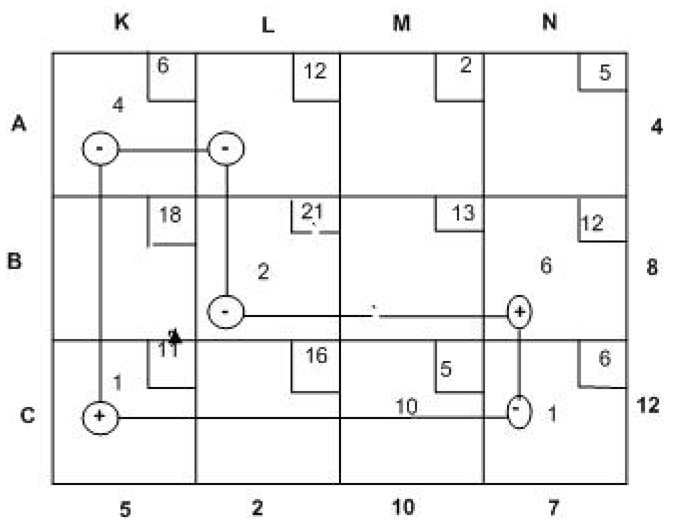


Figure (e)

+12 – 6 +11 -6 +12 -21 = +2

The minimum total distance is 205 and the allocations are:

A to K, 4; B to L, 2; B to N, 6; C to K, 1; C to M, 10; and C to N, 1

Of all the feasible solutions this is the optimum: the one with the minimum total distance. It is noteworthy in that it does not involve the shortest route, AM, at all and it makes the greatest possible use of the longest route, BL. Site L requires only two lorryloads and they are both coming from supplier B. Furthermore, site N receives all but one of its loads on the longest of the three routes approaching it, BN. These allocations may seem surprising and it might have taken a considerable time to find this optimum solution using a 'commonsense' approach.

2.5.4 Queuing Theory

Example A: The mean rates of arrival of tippers at GY& Sons Construction Company burrow pit is 7 tippers per hour and on average, 9 tippers were attended to per hour. Determine the traffic intensity.

Solution:

$$\rho = \lambda/\mu = 7/9 = 0.778$$

$$= 0.78$$

Interpretation

- ✓ The loader will be busy 78% of the time
- ✓ There is 78% probability that a tipper arriving the burrow pit will wait for service

- ✓ It indicates that the loader can be idle only in 1-78= 0.22 =22% of the time.
- ✓ Since 0.78 is the probability of meeting a queue, then 1-0.78 =0.22 is the probability of meeting no queue.

Determination of Probabilities

From the above interpretation, the following deduction can be made:

a) Probability of queuing on arrival is the same as traffic intensity
P (queuing on arrival) = ꝑ = traffic intensity

= 0.78

b) Probability that there will be a queue on arrival is; ꝑ =1=0.78= 0.22
This is the same as the probability of not meeting any tipper in the queue

c) Probability of there being **n** individuals in the system is given as

$$P_{n} = (1-ꝑ)\,ꝑ^{1}$$

Using the earlier example A; the probability of there being 1 individual in the system

$$P_1 = (1-ꝑ)\,ꝑ^1$$
$$= (1-0.78)(0.78) = (0.22)(0.78) = 0.1716$$

Probability of there being 2 individual in the system is

$$P_1 = (1-ꝑ)\,ꝑ^1$$
$$= (1-0.78)\,(0.78)^2 = (0.22)(0.78)^2 = 0.1338$$

Determination of the number of individuals in the Queue System

1. The expected number of individuals in the system (n_E)

$$\mathbf{n_E} = \lambda/\ \mu-\lambda \text{ or } ꝑ/1-ꝑ$$

$$\mathbf{n_E} = 7/9-7 = 7/2 = 3.5 = 4 \text{ persons}$$

2. The Average Length of the queue (Lq)

$$\frac{ꝑ^2}{1-ꝑ} \quad \text{or} \quad \lambda^2/\ \mu\,(\mu-\lambda) = 7^2/9(9-7) = 2.72 = 3 \text{ persons}$$

3. The average length of the queue when the queue is not empty is

$$L = \lambda / \mu - \lambda = 9/9-7 = 4.5$$

Distribution of Waiting Time

a) The mean waiting time on the (Wq)

$$Wq = \lambda / \mu (\mu - \lambda)$$

b) The average time in the system (Ws)

$$Ws = 1/ (\mu - \lambda)$$

3 The Construction Enterprise & Its Environment

3.1 The Construction Environment

In the fields of architecture and civil engineering, **construction** is a process that consists of the building or assembling of infrastructure. Far from being a single activity, large-scale construction is a feat of human multi-tasking. Normally, the job is managed by a project manager from cradle to grave, and supervised by a construction manager, design engineer, construction engineer and project architect.

The first basic concept required in the understanding of construction management is the built environment. The built environment comprises all currently existing constructed facilities. It is not a single achievement but an accumulation of the efforts and enterprise of many generations, skilled professionals and contractors engaged to undertake the construction of these facilities. The construction industry produces buildings and infrastructure, which form the built environment.

The construction industry is widely acknowledged as a major factor in the drive towards economic and technological progress (Brech, 1971). According to Ofori (1990), the construction industry may be defined as that sector of the economy which plans, designs, constructs, alters, maintains, repairs and eventually demolishes buildings of all kinds, architectural, structural and civil engineering works, mechanical and electrical engineering structures and other similar works. Thus the industry includes:

a) Persons, enterprises and agencies, both public and private, involved in physical construction; both those whose main activity is construction and the relevant part of entities engaged in other fields of activity who retain some construction activity (such as the maintenance unit of a bank or manufacturing enterprise).
b) Those providing all kinds of planning, design, supervisory and managerial services related to construction.

Kelly (1984) and UNIDO (2009) observed that the construction industry is more than a single industry but a complex cluster of industries including banking, materials and equipment manufacturers, contracting organizations and so forth. The construction industry's delivery chain consists of many complex composite parts, often operating and/or resulting in difficult and complicated circumstances involving multiple participants operating from inside and outside the industry, and results in a system or systems that may be assembled with completely new and never ending combinations and variations. The construction industry is therefore usually portrayed in terms of the following different sectors and as shown in Figure 18: –

- Professional services sector
- Contracting sector
- Public sector
- Finance and Investment sector
- Material manufacturers and supply sector
- Equipment manufacturers, supply and hire sector

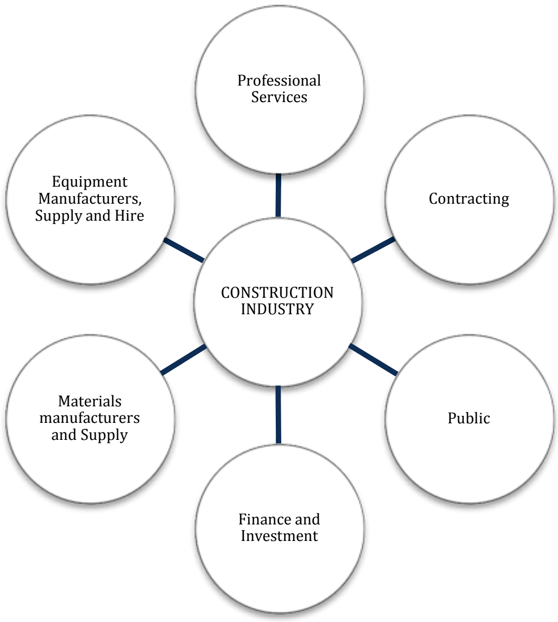


Figure 18: Sectors within the Construction Industry

3.1.1 Customer Profile

Customers provide the primary interface between construction and other human activities. These are organizations or individuals with the power or wealth to initiate construction projects or procure new facilities after it has been constructed. To varying degrees, all customers help shape what, where and how construction is undertaken. Customers able to command substantial resources invest in the built environment to meet specific needs such as the need for shelter and basic infrastructure – water, roads, and electricity.

Many construction professionals refer to their customers as clients and so the words customers and clients will be used interchangeably. A customer according to Radosavljevic and Bennett (2012) is the owner of the new facility produced by the construction actions they initiate. An **owner** is an individual or organization, which is the legal possessor of a constructed facility. The customer may however be an organization, which has a relationship with the owner. Irrespective of their interest in a facility, a customer is an individual or organization, external to the construction industry that initiates construction actions and very often benefits from the final product. The product may be a new facility or alterations to an existing facility.

Most construction customers have less influence than government who are public clients. Types of clients vary from a house owner requiring nominal changes, e.g. garage conversion, a multi-organization redeveloping industrial premises or constructing new prestigious offices, to government administrative departments. As a result, construction customers can be categorized into two as shown in Figure 19:

- Public sector clients and
- Private sector clients

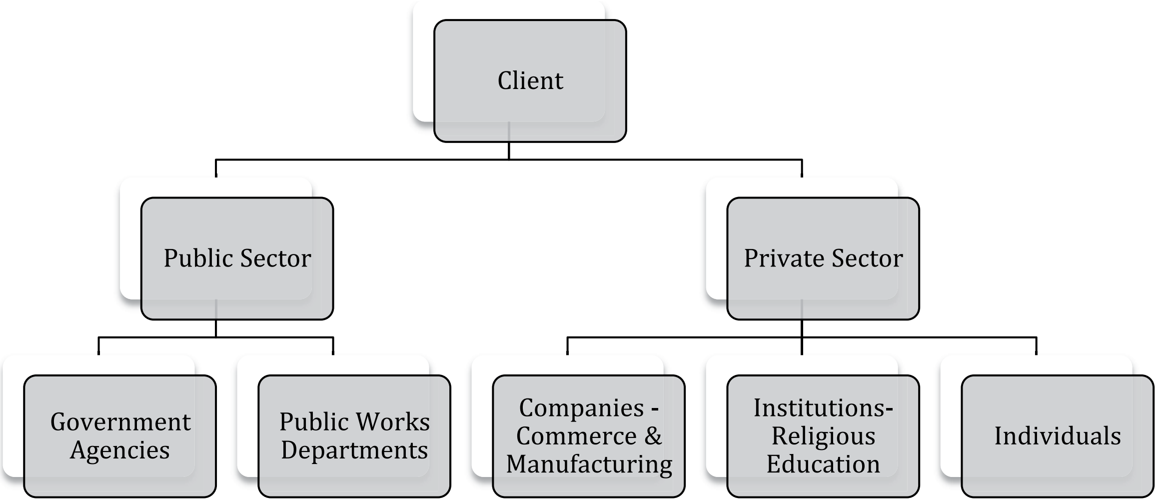


Figure 19: Categories of customers in the construction industry

Government Clients:

A major characteristic of the construction industry is that government has consistently been its largest client the world over (Hillebrandt, 1975). Government can therefore be said to be the stimulator of demand, in many regions and countries including South Africa, government bodies are the largest and most influential customers for the construction industry's products. They need buildings for most tasks they undertake – offices, schools, public housing, hospitals, and often directly provide at least part of the national infrastructure – roads, bridges, railway lines, sewer and water supply lines, electricity etc. This gives government the power to influence every aspect of construction.

The nature of government's demands, their definition of requirements/needs, the way they select construction companies and procure projects, the kind of contracts they are prepared to agree to, and the way they treat the construction companies they employ, affect the built environment and the performance of the construction industry. Governments because of their status can behave in ways in which other clients cannot.

Private Clients:

- **Individuals:**
  People need to live somewhere. In more developed societies, an overwhelming majority live in housing which is reasonably adequate. Many of these people buy a house or apartment or build one. This is for most people by far the largest single financial decision and their house or apartment is their most valuable possession. Sophisticated financial arrangements have developed to make the purchase possible for people who otherwise would never have sufficient money. Outside the formal built environment in most developing countries are slums in informal collections of rudimentary shelters. These slums represent inadequacy of housing, and a failure of the built environment to provide sufficient housing. Meeting the obvious need for more good housing should be a matter of concern for construction managers.

- **Churches and Mosques**:
  The provision of religious buildings by congregations all over the world for purposes of worship is another important avenue by which construction companies obtain substantial patronage. They are often important landmarks and provide a focus for many important activities.

- **Education:**
  Educational Institutions often require various kinds of buildings and infrastructure. Many educational buildings provide straightforward teaching spaces. Others, especially in universities, have distinct and often very specific requirements to accommodate the specialized nature of the teaching or the research they will house. The nature of educational buildings is greatly influenced by the money available to construct them. Some educational establishments have considerable financial resources and expect new buildings to showcase their wealth and represent the high quality education they provide. Other schools and universities, who have less money, try to ensure that they get the maximum amount of teaching space for their limited budgets. The source of the funds also influences what is constructed. Government who normally impose stringent rules, which govern the form and style of educational buildings, funds much education. However, there is greater design freedom for privately funded educational buildings.

- **Commerce:**
  Commercial activities directly influence what is constructed and where it is likely to be located. Commerce is defined as the buying and selling of goods and services. The great financial centres of Johannesburg, London, New York and Tokyo, include commercial districts/CBD, which were able to grow at a startling rate by exploiting the power of market forces. These Commercial Business Districts (CBD) are marked out by huge skyscrapers clad in glass and stone. These massive buildings, which were designed to be reassuring symbols of financial strength, house the global systems – banks, insurance companies, stock exchange etc., which determine the wealth/down fall of nations.

- **Manufacturers:**
  Manufacturing companies have been significant customers of the construction industry for more than 200 years. Their demands have changed both in the terms of the nature of the buildings they need and its location. The industrial revolution began in Britain with the mechanization of textile industries, the development of wrought iron and steel, and a great increase in the use of refined coal. Canals and railways allowed large factories to be located near basic resources and their products to be widely distributed. Steam power then increased production dramatically and machine tools facilitated the production of an ever-increasing range of machines for different industries.

3.2 Types of Services/Products Provided by the Construction Industry

The preceding sections portray the customers who provide the work undertaken by the construction industry. The portrayal identified some differences between buildings and infrastructure. The distinctions between buildings and infrastructure have important consequences for construction management and need further consideration. Considering the participants in the construction process, the various definitions appear to portray the industry as a series of related but discrete activities, products/services persons or organizations shown in Figure 20.

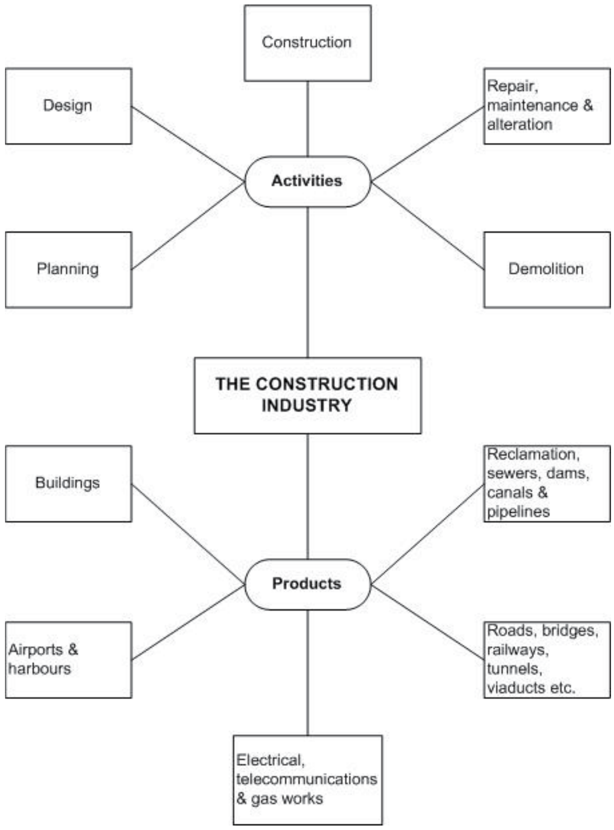


Figure 20: Activities and products/services found in the construction industry

The distinctions between buildings and infrastructure are detailed below:

- Architects design buildings while engineers design infrastructure. This divide is not entirely precise because engineers are often involved in designing parts of building (as structural, mechanical and electrical engineers), and architects are often brought into the design teams responsible for additions to the infrastructure.
- People tend to have a more direct and longer interaction with buildings than with infrastructure – people live, work, school etc. in buildings. We spend considerably greater time in buildings than infrastructure.
- Buildings involve many distinct and sometimes complex technologies. Each individual technology is supported by design, manufacturing and production methods, which to a greater or lesser extent are tried and tested. Compared to buildings, infrastructure involves relatively few distinct technologies.

- The particular problems posed by buildings are the relative large number of junctions between technologies. Some junctions between distinct technologies are well developed in established local practice. For example, traditional junctions between brick walls and wooden window frames were a matter of established craft practice. As more new and very different technologies were introduced into modern buildings, craft practice was unable to cope. Buildings therefore have to be designed in detail.
- There is a differentiation to the approach to building design in different countries. Architects may concentrate on overall appearance in America, in Britain, they may insist on designing every detail to ensure the integrity of their buildings, while in Japan, they may be part of an integrated team responsible for all the activities involved in the construction of buildings.
- New infrastructure tends to be large, often fragmented construction sites, technically difficult and have to be constructed in difficult conditions. It may cut through densely inhabited areas; involve excavating or tunneling into difficult geological conditions, or face threat of floods. The large scale of a significant number of new infrastructures, combined with the high degree of technical and environmental difficulty defines the main challenges faced by civil and other engineers.
- Civil engineers have to solve difficult engineering problems and then ensure that their designs are safely realized on site. This requires responsible civil engineering involvement at all stages of their projects. This is achieved by having designs produced by civil engineering consultants and direct construction work undertaken by civil engineering contractors. Unlike buildings, in which there is no common professional background between the project designer and constructor, infrastructure projects require that the designer and constructor have common professional backgrounds.
- The building process requires more management inputs due to the various resources, technologies, sub-contractors and suppliers that are required for its production, and also due to the complex interdependencies between the various project participants.

3.2.1 Patterns of Demand

Figure 21 shows the investment levels in construction works in South Africa between 1961 and 2009. It can be seen from Figure 4 that investment levels in the South African building sector reached and all time high in the period 2006–2008 which were the years preceding the World cup. It also shows that the demand for construction works have been rather erratic in recent years.

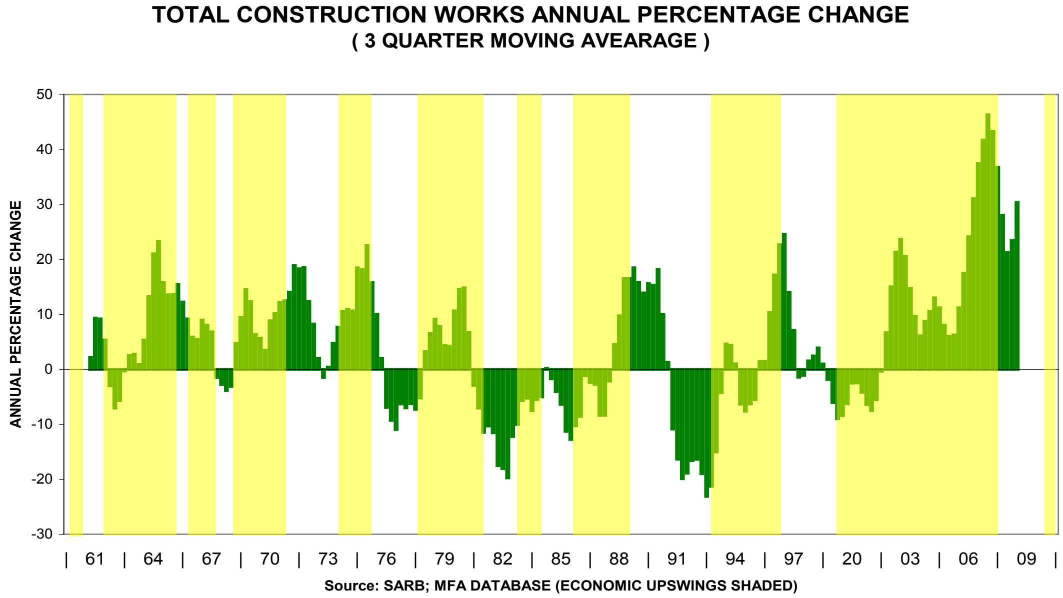


Figure 21: Total Construction Work Annual Percentage Change

Data released by the SA Reserve Bank indicate that investment levels in the South African building sector were still dropping during the third quarter of 2011. These trends can be observed in the accompanying graphs of investment in housing and non-residential buildings shown in Figure 22.

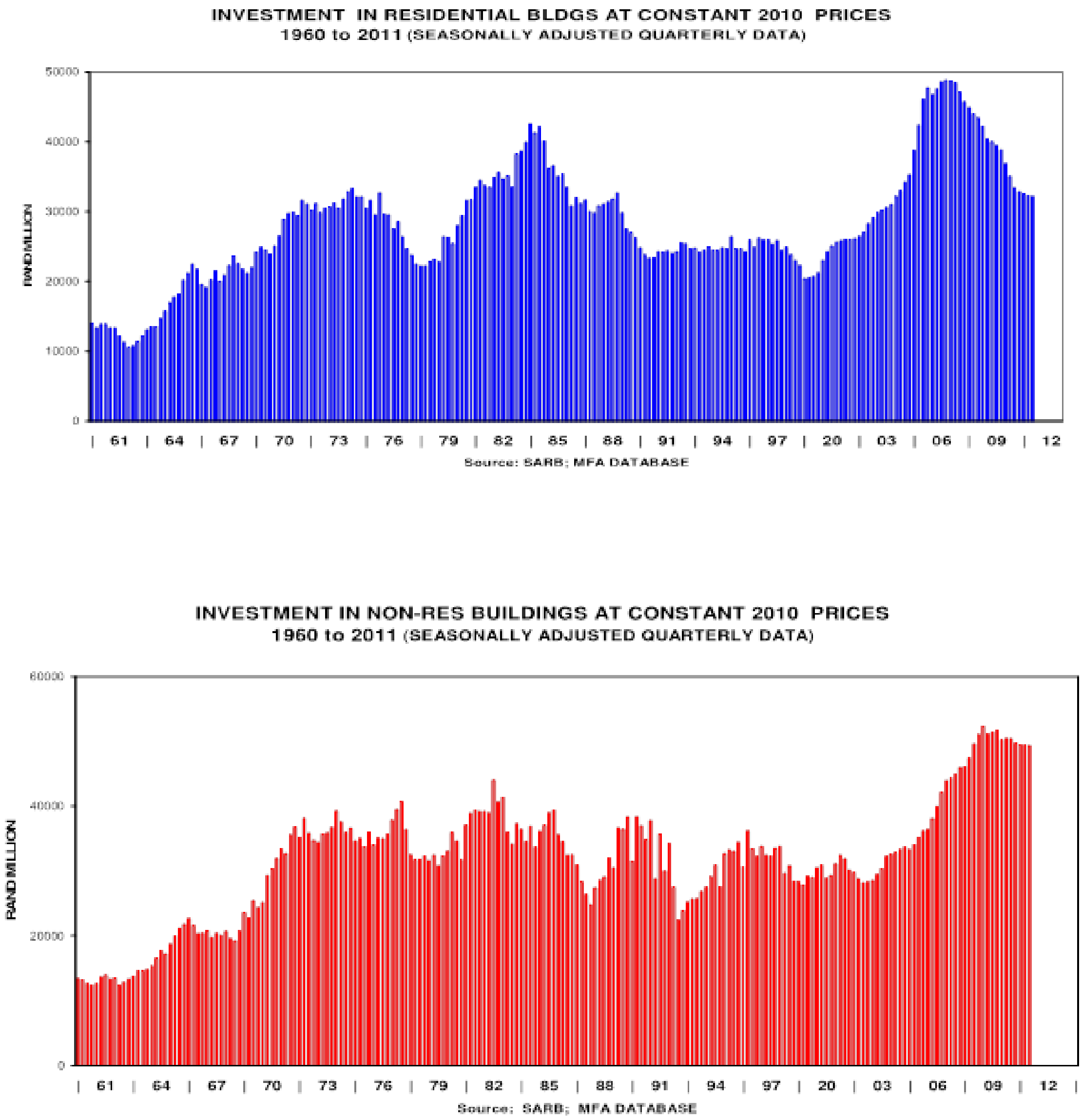


Figure 22: Total Investment in Residential & Non-Residential Buildings

It can be inferred from Figure 22 that about 100 billion Rands were invested in residential and non-residential buildings in South Africa when investment levels reached its highest levels in 2008.

3.2.2 Public Vs. Private Sector Demand

Details of contracts awarded in the public and private sector were obtained from the cidb Quarterly Monitor (2008, 2009 and 2010). The cidb Quarterly Monitor only presents information on public sector contracts for General Building (GB) and Civil Engineering (CE) cidb Class of Works. The monitor acknowledged that most contractors would however target both public and private sector opportunities. Currently, public sector spend accounts for about 25% of total General Building activity and about 80% of Civil Engineering activity, although lower grade contractors, would be more dependent on public sector contracts (cidb, Quarterly Monitor, 2009) as shown in Figure 23.

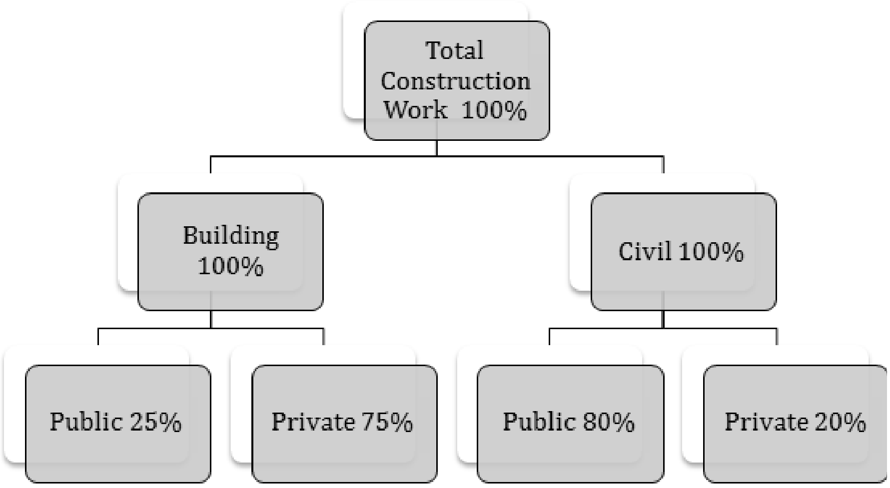


Figure 23: Public vs. Private Sector Demand in Total Construction Work

2.2.3 Composition of the Supply and Demand for Construction Activities

The construction enterprises considered encompasses two major groupings – building and civil engineering contractors and to some extent, specialist subcontractors. These contracting enterprises ranging from large, medium and small sized, interact not only with each other but also with other enterprises outside the industry.

This section draws on the Construction Industry Development Board (cidb) literature in explaining the composition and demand for construction in the South African construction industry. The cidb has refined a system that documents the workload and number of contractors registered in the industry over time and publishes this in its Quarterly Monitor. For example, the October 2010 Quarterly Monitor presents the distribution of public sector contracts awarded for South Africa as a whole between the 4th quarter 2009 and the 3rd quarter 2010 for Grades 2 to 9 contractors on the cidb Contractor Register. Information on the distribution of tenders to the Grade 1 contractors is noted to be very limited and unreliable (cidb, 2010b). The percentage distribution of the public sector awards by value and the number of recipients of these awards is presented in Table 2 and Figure 24.

Project Grade	**No of Contractors on Register**				**Public Sector Awards by Value**	
	General Building	Civil Engineering	Total No of Contractors	Percentage	General Building	Civil Engineering
9	40	50	90	1%	32%	52%
7 & 8	279	310	589	6.4%	52%	36%
5 & 6	1033	1173	2206	23.8%	12%	9%
2 to 4	3501	2853	6354	68.8%	5%	4%
Total	**4853**	**4386**	**9239**	**100%**	**100%**	**100%**

Table 2: Distribution of Number of Contractors by Grade and public sector awards and by value
Source: cidb (2010a)

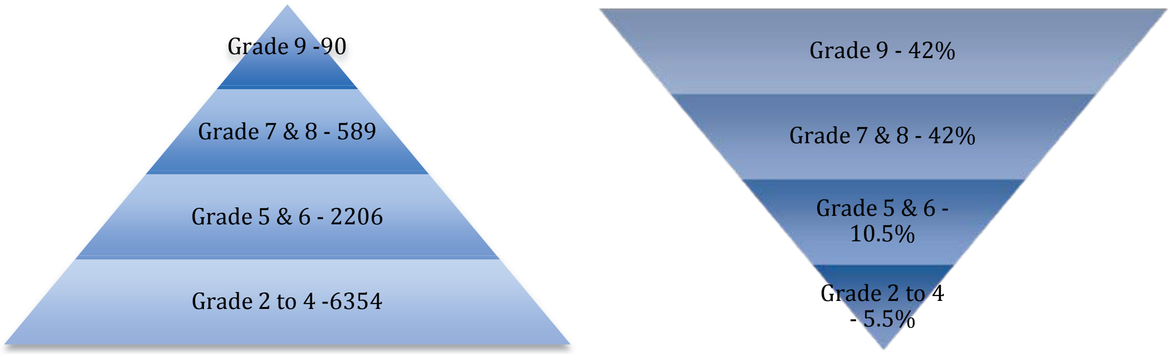


Figure 24: Distribution of Number of Contractors by Grade and public sector awards and by value
Source: cidb (2010a)

The composition of the supply and demand for public sector construction activities in South Africa, presented in Table 2 and Figure 24, is consistent with the nature of the construction industry in other countries. Despite the fact that some basic principles of sound business management are common to all enterprises, a lower level of capital is typically required to start and operate a contracting firm compared with, for example, a manufacturing firm. An entry-level contractor needs little more than a car, mobile phone and contacts in the right places. The industry tends to attract entrepreneurs, many of whom do not have adequate technical training, nor business culture, capacity or maturity.

Another characteristic of the construction industry is that most of its high value contracts are large-scale projects which cannot be sub-divided or awarded piecemeal and typically require a high level of management, financial solvency and technical capability. These are qualities and skills more frequently found amongst the Grade 7 to 9 contractors in South Africa. Further, only these grades of contractors can undertake large projects, because lower grade contractors typically find it more difficult to meet the requirements of the financial institutions necessary for the award of tenders.

The data presented in Table 2 and Figure 24 show that 84% of the value of public sector contracts in the General Building sector were awarded to Grade 7, 8 or 9 contractors, who make up 6.6% of the contractors registered in that sector. According to Rush *et al.* (2007), it is unlikely that there will be more than a few firms in this category at any given time. It also shows that 15% of the value of public sector contracts was awarded to 92.6% of registered contractors in Grades 2 to 6 across both the General Building and Civil Engineering sectors (cidb 2010a).

The data in Table 2 and Figure 24 is of concern to Government, who wishes to see a stronger presence of emerging black owned construction companies in Grades 7 to 9, in order to reverse historical economic imbalances in income distribution and employment. The absence of such a presence is a concern for the cidb, in that the effectiveness of its contractor development programmes and other policies could be questioned. Lastly, a significant number of these contractors may genuinely aspire to advance to higher grades where the competition is lower and project values are higher (cidb, 2009a).

In order for a contractor to upgrade on the cidb Contractor Register, certain capabilities need to be developed and demonstrated. Capability is not a natural endowment – it requires the ability to do something. According to Rush et al. (2007), it results from an extended learning process gradually accumulating processes, procedures, routines and structures, which when embedded, is often referred to in practice as "the way we do things around here" or culture.

3.2.4 Classification of Construction Enterprises

The construction industry is typically characterized by a pyramid like structure presented in Figure 24, with the large firms being at the apex and the smaller firms found at the base (Hillebrandt, 1984). The value of the work obtained by the construction companies exhibits a similar pyramid structure, but with a different orientation, with the large firms at the apex undertaking projects of higher financial value, whilst a significant number of small firms that undertake several projects with lower financial value are located at the base. The contractors can also be classified according to the sector of the economy in which they operate, their maximum tender value, perceived management skills and classification by area of operation. The classification of South African contractors, based on the cidb's Contractor Register is shown in Table 3.

cidb Grade	Category	Economic Sector	Maximum Contract Value awarded (R)	Managemt Skills level	Min. No. of Reg. Prof. Required	Area of Operation
1	Micro	Informal	200,000	Very Poor	0	Local
2-4	Small	Formal/informal	4,000,000	Fair	0	Local
5 & 6	Medium	Formal/informal	13,000,000	Good	5=1; 6=2	Local/regional
7 & 8	Large	Formal	130,000,000	Good & Very Good.	7=4; 8=6	Provincial / regional
9	Large	Formal	No Limit	Very Good	9=8	National/int.

Table 3: Distribution of Contractors by Grade and other classification
Source: Construction Industry Development Board (cidb, 2011)
Key: Min. No. of Reg. Prof. Reqd = Minimum number of registered professionals required

In South Africa, it is mandatory that all contracting enterprises desirous of obtaining government patronage/tender be registered with the Construction Industry Development Board (cidb). Table 3 shows the classification of the contractors into formal/informal sectors, wherein the contractors that operate in the formal sector are the ones that strictly observe government regulations with regards to construction (Mlinga and Wells (2001).

According to cidb (2008), much of the work of contractors in Grade 2-6 is obtained through sub-contracting and not as main contractors (see Figure 25). Typically according to the cidb, around 50% of work is subcontracted to lower Grade or to specialty contractors by the large contractors registered in Grades 7-9.

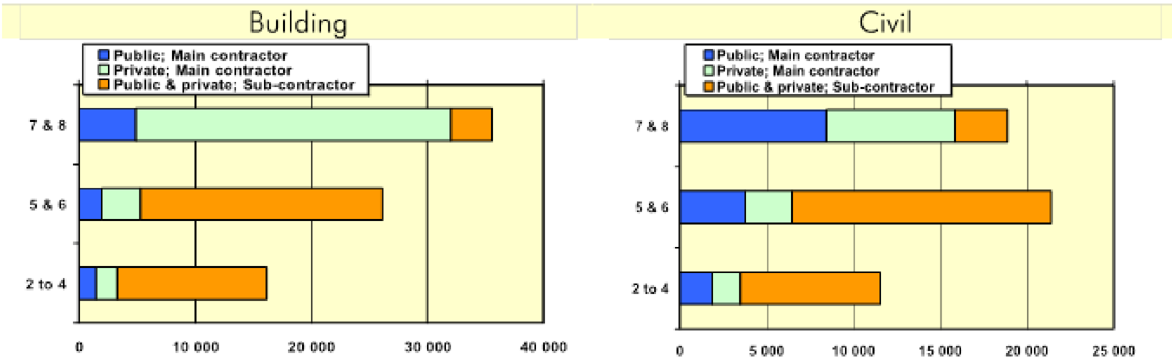


Figure 25: Source of Contracting Work

Source: cidb (2008)

3.2.5 Formation and Growth of the Construction Enterprise

Before starting business operations in South Africa or any other country, it is mandatory under the law that an individual or group of individuals should register their business name with the government agency responsible for registration. The types of business structure under the South African law are:

- Close Corporation – CC; and
- Proprietary Limited Company – PTY.

Basically, there are two steps that must be followed in the registration process:

1. An application has to be made for the registration of a CC or PTY name; and
2. A company founding statement, which provides important information about the proposed company, details of the founding members, nature of business, address of the proposed company, shareholding structure etc., must be submitted by the promoters.

3.2.6 Founding Top Management Team Profile at Company Formation

Table 4 presents details on the founding members' background profiles and sizes of the founding teams at the inception of South African construction enterprises surveyed by the author in 2011.

Profile	Frequency	Percentage
Size of the Founding Team at Inception (N = 12)		
Sole owner	4	33.3
Two owners	3	25.0
Three owners	5	41.7
Members Experience before setting up company (N = 23)		
None	1	4.4
Less than 5 years	2	8.7
Between 6 and 10 years	6	26.1
Between 11 and 15 years	4	17.4
Between 16 and 20 years	5	21.7
More than 20 years	5	21.7
Members Past Experience Together (N = 12)		
None	7	58.3
Less than ten years (8 & 6 years of experience)	2	16.7
Between 10 and 20 years (14 years)	1	8.3
More than 20 years (20 & 25 years)	2	16.7
Members Diversity of construction industry experience (N= 8)		
Same experience	2	25
Varied experience (human resources, construction, finance etc)	6	75
Member Educational Qualification (N = 22)		
None	1	4.5
Standard six	2	9.1
Matric	8	36.4
National Diploma	3	13.6
Higher National Diploma	2	9.1
Bachelors Degree	6	27.3
Member Professional Qualification (N = 23)		
SACPCMP, Pr. Eng, PRISA, MCIOB/FCIOB	6	26.1
None	17	73.9

Table 4: Background Profiles of Founding Members & Size of the Founding Team
Source: Field Survey (2011)

3.2.7 Size and Experience of Team Members:

Table 4 shows that at founding: –

i. 67% of the firms were owned by either two and three owners who had more than six years of work experience in the construction industry;
ii. 42% of the firms had team members who had past experience of working together in a construction company; and
iii. importantly, the experience acquired by the team members was varied but relevant. Some acquired experience in human resources, while others were adept at tendering, financial management, construction operations and plant management.

3.2.8 Education:

Table 4 indicates a range of the highest educational qualifications possessed by the founders. When cross-tabulated in company terms, there are only four companies out of the 12 companies surveyed in which there are owners with no tertiary education at all. These are prevalent in firms with sole owners, three of which were founded before 1994.

According to Snell and Dean (1992), cited in Wiklund and Shepherd (2003), the human capital of a small manager consists of skills and knowledge – obtained through education and experience – that assist in running the business successfully. A consistent finding for general human capital is that educated individuals are more likely to run faster-growing small businesses than those who are less educated (Wiklund and Shepherd, 2003). Applied to this study, it implies that competencies are required to grow a company, but having an educated founder will/could enable the company to grow at a faster rate.

3.2.9 Professional qualification

Table 4 also reveals that a significant number of the founding owners do not possess professional qualifications, suggesting that this is not important in establishing a successful construction company.

The results of the study imply that the size of the founding team, founding owners' past experience and past experience together, and diversity of members' in the construction industry are requirements common to individuals desirous of establishing construction company enterprises.

3.2.10 Types of Firms

According to Rush et al. (2007), as firms move into more complex environments, they need a richer set of capabilities to deal effectively with the threats and opportunities that confront them. Rush et al. (2007) located firms within four archetypes based upon their level of maturity and on nine key dimensions of the management of technology, as follows:

1. **Type 1 firms**
   These are labelled as "unaware" or "passive" and are characterized as being unconscious or unaware of the need for technological change in what may be a hostile environment, where technological know-how and ability may be vital to survival. Grade 1 contractors on the cidb register are typically Type 1 firms.

2. **Type 2 firms**
   These are defined as "reactive", in that they recognize the challenge of change and the need for continuous improvements in their technological capabilities, but are uncertain about how to respond effectively. Grades 2 to 6 contractors on the cidb register are typically Type 2 firms

3. **Type 3 firms**
   These firms have a well-developed sense of the need for technological change. Rush et al. (2007) referred to these firms as “strategic”, in that they are capable of implementing new projects and of adopting a strategic approach to continuous innovation. They have a clear idea of what has to be done, when and by whom, and have the internal capabilities in both the technical and managerial areas to implement changes with skill and speed. Grade7 and 8 contractors on the cidb register are typically Type 3 firms.

4. **Type 4 firms**
   These are said to have well-developed sets of technological capabilities and are able to help define the international frontier. Rush et al. (2007) refer to these firms as “creative”, in that they are able to adopt a proactive approach to exploiting technology for their competitive advantage. They are said to be at ease with modern strategic frameworks for innovation and understand how to use technology, markets and organization to improve competitiveness. Grade 9 contractors on the cidb register are typically Type 4 firms.

3.2.11 Growth of the Construction Enterprise

In the above section, the four types of firms identified by Rush et al. (2007) were classified based on the firm’s maturity. Others have identified different stages of small business growth (Kazanjian and Drazin, 1989; Steinmetz, 1969). According to Steinmetz (1969), a successful small business is inescapably committed to living through three critical phases of growth and four stages of growth, which he called “direct supervision”, “supervised supervision”, “indirect control” and “divisional organization” – based largely on the development of the manager and founder through these different stages. This implies that for a manager to be successful he must have trained other managers. Kazanjian (1988), cited in Kazanjian and Drazin (1989), also suggests that companies go through four stages of growth, which he called “conception and development”, “commercialization”, “growth” and “stability”.

A better understanding for the need of effective management of construction enterprises will be gathered from the answers to the following questions:

- What is the path most frequently chosen/taken by the contractors in order to develop?
- How long will it take contractors to develop from the grade when first registered with the cidb in South Africa to their current grade?
- What factors aid the growth and success of the construction companies– key success factors?

To answer these questions and to develop a theory to support the growth path of construction contractors in South Africa and the factors that aided their growth, all 62 successful contractors that have been upgraded at least three times within the last five years on the cidb Register of Contractors were sent an invitation for an interview. The population covered a wide range of work and location groupings. 14 respondents accepted the interview invite but only 12 could be interviewed due to logistic factors. The respondents were located in five of the nine provinces of South Africa namely – Western Cape, Gauteng, North West, Kwa-Zulu Natal and the Free State. Personal interviews were conducted with the principal (founding members, CEO, or director) using an interview protocol.

The purpose of the interviews was to document and develop an understanding of the factors responsible for the growth and success of the responding companies. In addition to these 12 interviewees, a small sample of four CEOs/Directors of established Grade 9 contracting organizations were interviewed. These firms were intended as a control group for the study.

Initial Grade of Registration with cidb

Table 5 presents the grade at which the interviewees were initially registered on the cidb Register of Contractors.

Company*	Initial Registration Grade					
	General Building (GB)			Civil Engineering (CE)		
	GB4	GB5	GB6	CE4	CE5	CE6
0131	1			1		
0211	1					
0111		1				
0112			1			
0311		1				
0113	1					
0221				1		
0421				1		
0114	1					
0231	1			1		
0212		1				
0121				1		
Total	**5**	**3**	**1**	**5**		

Table 5: Distribution of the Contractors that have been upgraded on the cidb register by initial Grade of Registration
Source: Field Survey (2011)

Table 5 suggests that the contractors were past the "conception and survival" stage and were probably in the "stability/maturity" stage when they registered with the cidb.

Figures 26 and 27 presents the changes in the growth path of the General Building contractors and the Civil Engineering contractors surveyed, since their registration on the cidb Register of Contractors in 2004.

	Grade 4–5 (Months)	Grade 5–6 (Months)	Grade 6–7 (Months)	Grade 7–8 (Months)	Grade 8–9 (Months)	Total (Months)
0131	21			30		51
0211	9					9
0112			12		9	21
0311		3		24		27
0113	3	18	3			24
0114	6		18	3		27
Total No. of Companies	**4**	**5**	**6**	**4**	**1**	

Figure 26: Growth Pattern of General Building Contractors on the cidb Register of Contractors
Source: Field Survey (2011)

<table>
<tr><th></th><th>Grade 4–5 (Months)</th><th>Grade 5–6 (Months)</th><th>Grade 6 -7 (Months)</th><th>Grade 7–8 (Months)</th><th>Grade 8–9 (Months)</th><th>Total (Months)</th></tr>
<tr><td>0131</td><td colspan="3">21</td><td>30</td><td></td><td>51</td></tr>
<tr><td>0221</td><td colspan="2">6</td><td>33</td><td></td><td></td><td>39</td></tr>
<tr><td>0121</td><td colspan="2">6</td><td>39</td><td></td><td></td><td>45</td></tr>
<tr><td>Total No. of Companies</td><td>3</td><td>3</td><td>3</td><td>1</td><td>0</td><td></td></tr>
</table>

Figure 27: Growth Pattern of Civil Engineering Contractors on the cidb Register of Contractors
Source: Field Survey (2011)

Figure 26 reveals that the highest growth for the General Building Contractors occurred majorly between the 4th quarters of 2006 (0604) to the 2nd quarter of 2008 (0802) – an eighteen-month period. Contractor downgrade was also observed in the period 0903 to 1001 (a 12 month period). Fig. 10 shows that significant growth was recorded for the Civil Engineering Contractors, between the 3rd quarter of 2006 (0603) and the 3rd quarter of 2008 (0803) – a twenty-four month period and one downgrade also occurred during the period 0903 to 1001.

Generally, the growth pattern seen in Figures 26 and 27 suggests that most of the companies had moved past the first stage of growth (the conception/survival stage) by the time they registered with the cidb. It can be inferred that a significant number of the contractors interviewed were in the 2nd stage of growth (the development stage) when they registered with the cidb.

Once registered on the cidb Register of Contractors, it took the General Building Contractor an average of 10 months to move up one grade and 27 months to move up three grades. Civil Engineering Contractors took an average of 12 months to move up one grade and 35 months to move up three grades. This could indicate that General Building contractors grew faster on average than Civil Engineering contractors.

The contracting companies' growth patterns are consistent with previous findings by Kazanjian and Drazin (1989) who studied the growth pattern of technology based new ventures (TBNVs) in the USA, where they found that it took companies at least 18 months to move between the different stages of growth.

The results also indicated that all the companies were still in the 3rd Stage of growth (the Stability/ Maturity stage). This is so because most of the companies expressed contentment in their present level of growth and status, having no wish to grow further, while others were making plans for expansion and commercialization, such as selling shares privately to willing takers and diversifying and expanding into new territories locally and internationally and into new products/market strategies.

A significant number of the respondents described their company's growth pattern as organic, steady, consistent and gradual, while only two acknowledged that it had been rapid. It also emerged that a significant number of the respondents acknowledged that the growth of their companies had surpassed their expectations at inception.

Moving up the cidb Register of Contractors implies that the firm had been able to procure sufficient and profitable jobs, because turnover and largest contract value completed in the last five years is a criterion used by the cidb in its grading system. Further, in its path to growth, the firm must have capitalized on its strengths, overcome its weaknesses, coped with threats to its survival and taken advantage of opportunities.

We now consider the question of how the contractors were able to grow and what factors were responsible for their growth. From the interviews, it emerged that the factors responsible for the growth and development of sub-contractors are as follows:

- **Environmental factors**: such as the opportunities available at the company inception, the level of demand and favourable government policies;

- **Organizational factors:** including the size of the founding team at inception; members' experience prior to inception; founding owners' past experience; past experience working together; and variety of members' experience in the construction industry. Strong teams with the requisite experience and education were found to have developed relatively faster.
- **Managerial factors**: such as the ability of founders to use their management capabilities; harness the company's strengths embodied in knowledgeable and qualified employees; overcome the problem of access to finance and the difficulty of securing payment from government agencies/private developers; increase turnover; re-invest profits back into the business; and making **strategic decisions**, including developing a strong financial base for the business, maintaining an excellent track record, adopting a sound procurement strategy; and developing and maintaining a strong workforce.
- **Personal and leadership qualities of founders**: such as leading effectively; possessing a strategic, balanced and authentic leadership style; training other managers/successors.

3.2.12 Diversification of Companies by Products and Services

The ability of a company to grow, improve turnover and gain greater market share is linked to its ability to diversify its services and products. Specialization of the company in different construction trades also make it easy for the company to have better control of the quality of team relationships in the project organization. In another related study, the level of diversification by services and products of the companies listed on the cidb Construction Register was surveyed. The results of this investigation are presented in Table 6.

Company Type	Contractor cidb Registration Grade				Total	Percentage of Respondents (%)
	1	2–4	5 & 6	7–9		
Civil Engineering (CE)	1	89	83	14	187	26.6%
General Building (GB)	0	126	49	5	180	25.6%
CE & GB	39	110	50	9	208	29.6%
CE & GB + other work specialization – (Mech, Elect + Special work)	20	71	31	6	128	18.2%
Total Respondents	60	396	213	34	703	100%
Total on cidb Contractor Register	n/a	6354	2206	679	9239	

Table 6: Level of Diversification of Construction Companies by Products and Services
Source: Field Survey (2010–2011)

Table 6 reveals that more companies were diversified by products into Civil and General Building contractors and other specialist works (47.8%), with a view towards increasing their market share and possibly making the construction process as straight forward as possible.

3.3 Typical Business Objectives

Business objectives may be defined as that particular state of things that the business wishes to achieve. The objective a business pursues constitutes its purpose – the reason for its very existence. Therefore, for a business to function effectively, it must formulate some objectives to give it direction.

There are different kinds of objectives encountered at different levels of the organization. To the management of an organization, objectives are the starting point of the management process and the guidelines for developing plans, the organizing required to implement plans and the guidance that needs to be offered to employees. Top management is more concerned with the mission and vision of the organization. While middle management may be more inclined to pursuing functional and departmental objectives, lower management may be more interested in operational objectives.

The typical business objectives are economic in nature and for a construction enterprise it is primarily to have sufficient work and therefore maintain their own employment through efficient service to their customers; and make profits.

Making profit, but to what degree?

For example:

	a	b	c
Invest	10,000	100,000	1,000,000
Profit	5,000	5,000	5,000

Which is more profitable?

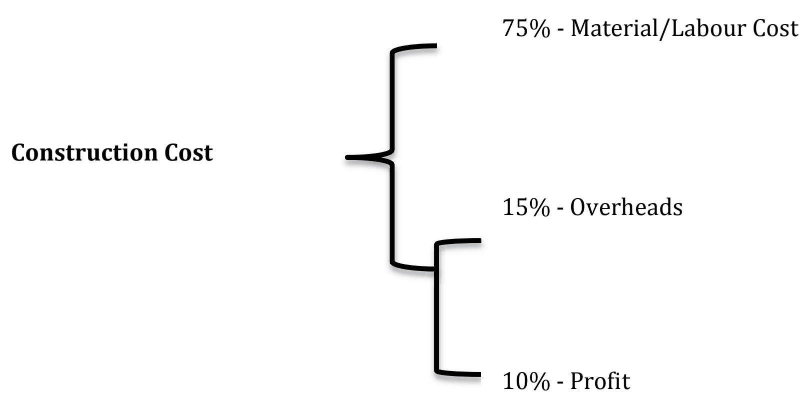


Figure 28: Break-down of construction cost

Ideally, the degree of profit, which a construction company should aim for, should be at least above the prime lending rates if it is making use of borrowed funds in contract execution. Based on this notion, a construction company has to aim for at least 10% profit in its operations in South Africa as shown in Figure 28, if it has to generate profits higher than the bank rates (Chemaly, 2011), which are presently at 8.5%.

3.4 Typical Corporate Objectives of Construction Companies determined from Field Survey

It is a founder's job to lead a team, to combine human resources and obtain the best from them. The founders who are managers of the team should therefore be people of experience, understanding and vision, and should have enough confidence to delegate responsibility and stand by decisions (Harris and McCaffer, 2001). Thus, founders can influence the survival and growth of their companies. Wiklund and Shepherd (2003), in their study of small business managers' growth aspirations and the level of growth achieved, discovered that small business managers' aspirations to expand their business is positively related to actual growth.

To measure their aspirations, the respondents in the study described in Table 5, were asked to give an indication of their mission statement and vision for the company at inception. Table 7 presents these results.

	Frequency	Percentage
Mission Statements (N = 12)		
To build a business	6	50
To make money/profit/income and empowerment	6	50
Vision Statements (N = 12)		
Survival	4	33.3
Leave a legacy	3	25
Grow a large/medium sized company	3	25
Leaders in construction in a specific geographical location	1	8.3
To be able to competitive	1	8.3

Table 7: Company Mission and Vision Statements

Table 7 indicates that, at inception, all of the contractors either set out to build profitable businesses, which would empower them, help them in their quest for a share of the construction industry business and to make money. The aspirations of some of the founding owners embodied in their vision for their companies show that contractors want: the company to grow (25%); to be leaders in the industry (8%); to be competitive (8%); and perhaps more importantly, to leave a legacy (25%). Four (33%) of the founding owners intended only to survive on a monthly basis and later on, on a yearly basis.

Other secondary objectives of construction companies/organizations would include to:

- survive in the market including succession plans
- break even (cover all expenses)
- improve its image
- have a good track record
- have highly motivated and committed employees
- maximize profits
- increase market share
- grow in size (e.g. sales, number of customers, number of employees)
- expand its geographical spread – operate abroad and across regions
- diversify by product into different types of buildings and sectors
- make reasonable returns to shareholders if a limited company (dividends) and on investment (ROI)

It can be said therefore that the objectives of management is to produce goods and services in sufficient quantity in order to satisfy the material desires of the community in which it exists, and at the same time provide a sufficient return on the capital invested.

It may therefore be argued that the primary responsibility of management is to ensure that the resources available to the business are used in the best possible ways to produce economic wealth, while placing no rights or restrictions on the general public.

Corporate/Business Objectives need to be SMART. That is:

- **S**pecific: a nominated person is responsible for delivering the objective.
- **M**easurable: set in terms of a number value e.g. sales, market share, etc.
- **A**chievable: the target can be met.
- **R**ealistic: the target must be achievable in terms of financial and human resources available.
- **T**ime-bound: within a given period of time for example, 12 months.

Strategies and Operating Policies of an organization used in the pursuit of its business objectives can be broken into two elements:

1. The ethical foundation of the enterprise:
   a) **Standards of fair trading**
      i. Tender ethically for contracts/projects that are available to the company;
      ii. Executing jobs within specifications, time and cost frame;
      iii. Satisfying the client in terms of time, cost frame and quality of workmanship;
      iv. Making the public satisfied with the company's activities – no collusion (anti-competitive reports), corruption, abandoned projects, sub-standard buildings, saving money by dubious means (use of sub-standard materials);
      v. Performing civil obligations – paying taxes, utility rates, and meeting all legal/regulatory requirements;
      vi. Precautions on site – health and safety, environmental management;
      vii. Making shareholders satisfied/content.

   b) Fair standards of employment
      Making staff happy and have a sense of belonging

2. The organizational or operational foundation concerned with the structure and conduct of the operations of the company.
   Developing certain clearly definable arrangements in order to weld the various parts of the company together so that they can act in unison.

Factors affecting the objectives pursued by a construction enterprise are as follows:

a) **Macro economic and Infrastructural constraints**
- Construction projects often require a lot of raw materials and
- a lot of infrastructural inputs – water, electricity, access etc.
- inflation – increase in costs of materials and other inputs

b) **Technical constraints**
- Access to technical tools and equipment
- Knowledge, capacity and ability of operational staff (capable/incapable)
- Level of technological development (restricts access to new/modern technology)

c) **Regulatory constraints**

Strict regulations including:
- Government laws and its implementation
- Design management
- Town planning development/bye laws
- Building regulations
- High specifications and standards

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3.6 Principles of Company Organization and Common Construction Company Organization Structures

It is necessary to divide up the work of an organization in order for the building company to handle the environmental, operational, and technological and stakeholder needs. Size and environmental complexity for example require the creation of functional departments or market based divisions to reduce the total task of the business to comprehensible activities. In addition, it has been ascertained that environmental uncertainty cause organizations to divide up its work between its members with the concomitant need to co-ordinate the divided activities.

Construction is teamwork. The first distinct type of construction organization is the **construction team**. The construction team can be described as a group of individuals who work together on a permanent basis to undertake specialist construction actions. Teams undertake construction work because construction actions require the coordinated efforts of several individuals contributing to distinct but closely related and sometimes dependent knowledge and skills. Construction teams form part of construction companies.

Radosavljevic and Bennett (2012) define a **construction company** as a permanent organization, which undertakes construction actions and so supports one or more construction teams by providing employment, financial security, legal advice, technical support and advice, training etc. Construction companies are as diverse as the construction teams they support. Therefore, it is necessary for a company to organize the teams they support in such a way that will enable the aims of the business to be achieved. Organization is the process used by managers to relate tasks to individuals, the construction teams, other firms, and other interested groups in order to achieve an economical and timely performance. In developing an efficient organization, the manager must deal with the design of the structure; delegation of responsibility; working relationships between individual and groups; and creation of a communications program designed to keep everyone fully informed.

In general, the number of managerial levels should be kept to a minimum, thus reducing management interfaces. On the other hand, too "flat" an organization may exceed the manager's effective span of control. The optimum number of persons reporting to a single manager will vary considerably, depending on the manager's effectiveness; employee skill and temperament and on the project site, nature of work/size; and project delivery dates/needs of the client. It is usually recommended that the manager should not be responsible for more than five people at any time.

3.6.1 Common Organizational Structures

Clear thought must be given not only to the **duties** and **grouping** of the various sections and departments in the company, but also to the **interrelationship** between them. Construction companies apart from the very smallest are usually organized into divisions. The basis for individual divisions varies. A **construction company** division is a distinct organizational part of a construction company. The different divisions, which constitute a construction company, are commonly arranged into what is acknowledged as an **organization structure**. An organization structure contains any or all of the following pattern/features:

a) **Concentrated Functions**
   Peculiar to sole proprietary businesses wherein all the activities of management may be concentrated in just one person

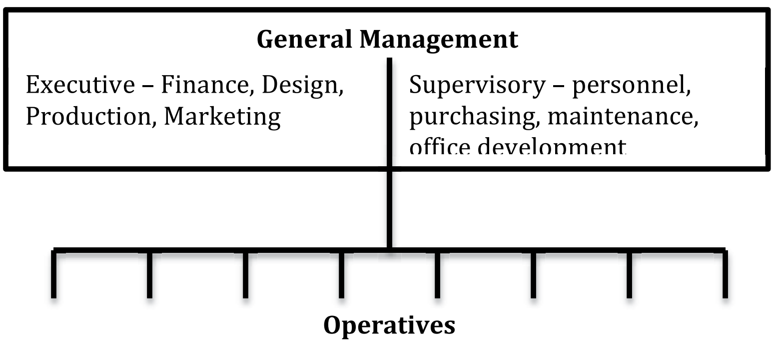

Figure 29: Company Organization Structure – Concentrated Functions

The form of division shown in Figure 29 is limited by the effective span of control permitted by circumstances.

b) **Divided Functions**
Since certain field of activities are usually more important than others e.g. production, a new chart of activities depicting the much larger and more complex structure required to meet the different situation can be drawn from a sole proprietary business.

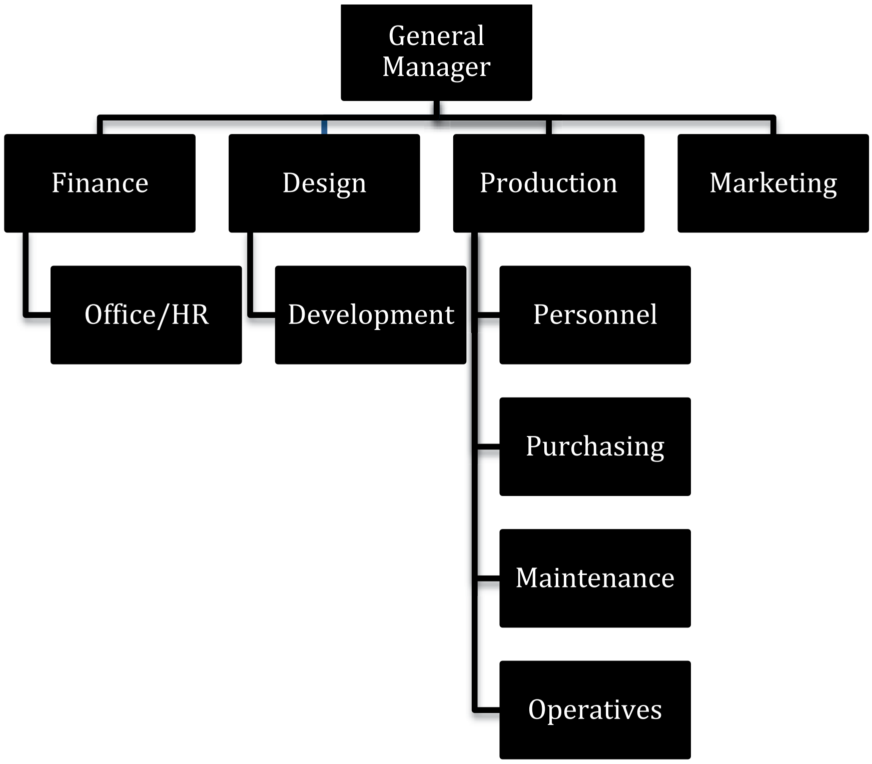

Figure 30: Company Organization structure – Divided functions

c) **Sub-division by elements**
With further expansion and additional staff each of these main functions may be sub-divided into individual elements, thus becoming much more complex with each distinct function growing additional branches e.g. marketing into estimating, public relations and quantity surveying.

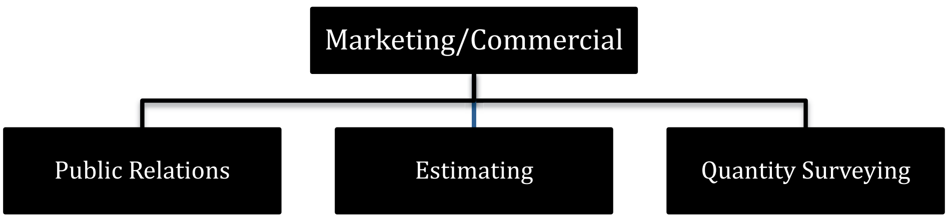

Figure 31: Company Organization structure – Sub-division by elements

d) **Sub-division by Products**

In a larger organization it might become desirable to delegate responsibility for one or several major activities, by individual products, so that further sub-division is done e.g. Production into Civil Engineering, Building and Housing.

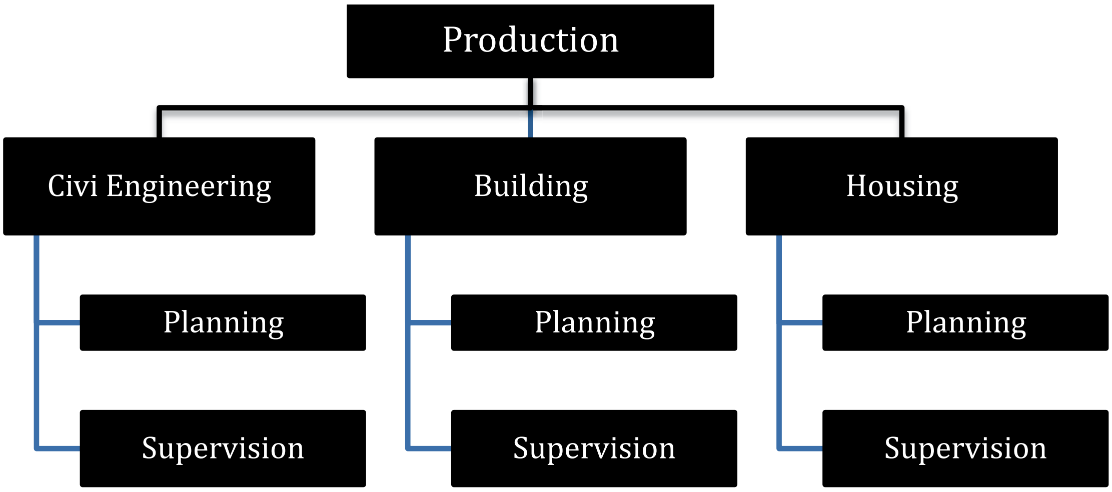

Figure 32: Company Organization structure – Sub-division by products

e) **Sub-division by Areas**

When an enterprise has grown to national status it may be necessary to open branch offices and so delegate responsibility by geographical areas. Overall responsibility for certain functions may be retained at head office with other functions may be retained at head office with other functions reproduced at each area office.

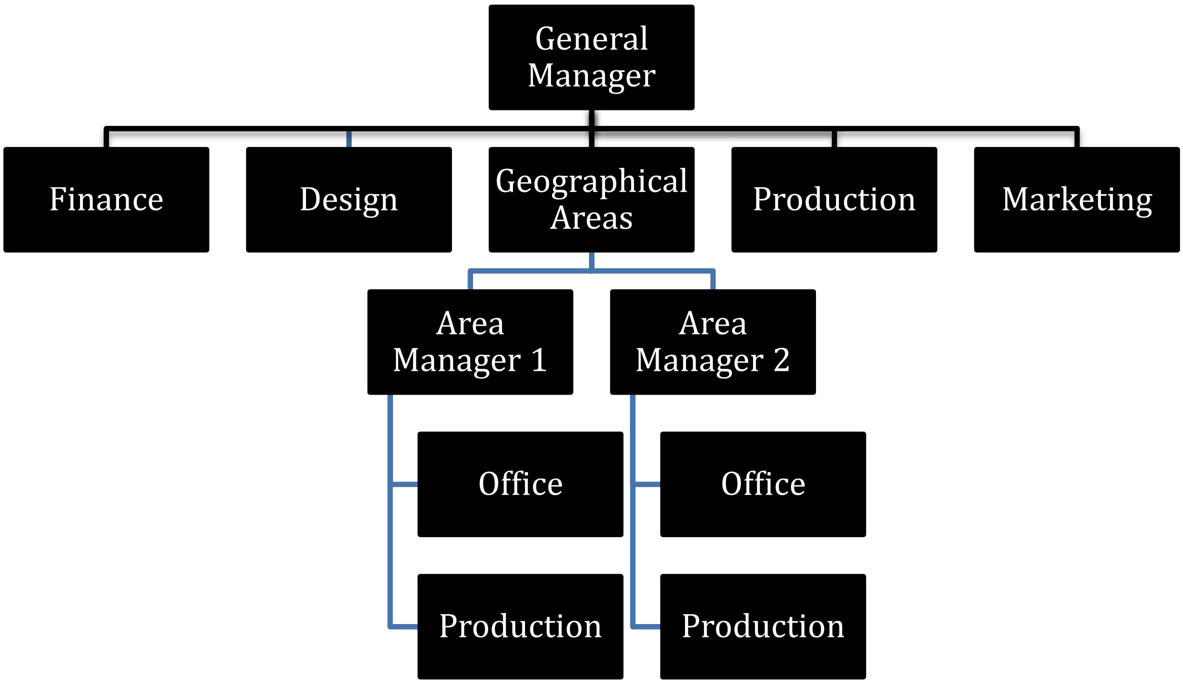

Figure 33: Company Organization structure – Sub-division by products

Just as the extent of an undertaking's divisions may vary, so may the form of its organizational structure differ. In a large organization, it is possible to find all the five methods outlined above. Each firm develops a structure to meet its particular needs. Tables 8, 9 and 10 present the results of a cidb-sponsored survey of selected construction companies. These tables show the pattern of company sub-division by area, by products and services and typical organization.

3.6.2 Construction Company Sub-Division By Area

As a company grows and become successful, certain business arrangements start to evolve. Amongst these business arrangements comes as a result of the ability of the company to transform from a small local company to a large successful company with branches/sub-divisions in different locations within a country or across its borders. Table 8 presents the geographical spread of the successful construction companies investigated, in South Africa.

Table 8 shows that the typical company sub-division by area emerging amongst the successful large contractors is that a significant number (11) of these firms are spread across at least two different locations and that seven and six of the companies have established their presence in Guateng and the Western Cape, respectively. The results suggest that success and growth of the companies into large business concerns is linked to diversification and expansion into new and more profitable markets such as Guateng and the Western Cape Provinces of South Africa.

Company	**Area**										
	Gauteng	Western Cape	Kwa Zulu Natal	North West	Mpumalanga	Limpopo	Eastern Cape	Northern Cape	Free State	International	**Total**
0131	√								√	√	3
0211	√										1
0111	√			√	√				√		4
0112	√		√								2
0221	√		√	√					√		4
0311	√		√	√	√			√	√		6
0121		√									1
0421				√				√	√		3
0212		√									1
0231			√				√				2
0222		√					√				2
0223		√					√				2
0224	√	√					√				3
0225		√						√		√	3
Total	**7**	**6**	**4**	**4**	**2**	**-**	**4**	**3**	**5**	**2**	**37**

Table 8: Sub-Division of Construction Companies by Area

3.6.3 Sub-Division of Construction Companies by Products and Services

The ability of a company to grow, improve turnover and gain greater market share is linked to its ability to diversify its services and products. The study investigated the level of diversification by services and products of the companies surveyed. The results of this investigation are presented in Table 9.

Company	**Services and Products**										
	General Building	Civil Engineering	Plant Hire Companies	Property Developers	Fire Protection	Equipment Manufacture	Housing Development	Subcontracting	Paving & Pipeline Infra	Building Materials	**Total**
0131	√	√					√				3
0211	√										1
0111	√							√			2
0112	√	√		√							3
0221		√	√						√		3
0311	√	√		√	√						4
0121		√									1
0421		√	√			√					3
0212	√										1
0231	√	√									2
0222		√					√				2
0223	√	√		√						√	4
0224	√	√		√			√		√		5
0225	√	√					√		√		4
Total	**10**	**11**	**2**	**4**	**1**	**1**	**4**	**1**	**3**	**1**	**38**

Table 9: Construction Company Subdivision by products and services

Table 9 shows that eight of the construction companies are active in at least three types of product/service markets – most commonly in civil engineering contracting, general building contracting, property development and housing development in order of commonality. Table 9 indicates that successful companies are likely to be diversified into more than one service and or product area as it grows. It can be inferred from these results that diversification has facilitated market penetration by the companies, purposely increasing their market share and turnover and making it possible for them to grow.

3.6.4 Construction Company Organization

As a business enterprise grows and becomes successful, the function of co-ordinating the various activities and personnel gradually expands beyond the capacity of one individual. The organizational structure of a company reflects its maturity – the result of its growth and development. The study investigated the span of responsibility and divisions within the construction companies surveyed. These results are presented in Table 10.

Company	Chain of Command Span/Steps of responsibility	Divided Functions within Company									
		Finance	Human Res/Admin	Qty Surveying/Est & Pricing	Project / Contract Mgmt	Commercial / Marketg/Proc	Workshop / Plant	Office	Health & Safety	Contracts Financial	**Total**
0131	3	√	√	√	√						4
0211	3	√	√		√						3
0112	3	√			√	√					3
0221	2				√		√	√			3
0311	3	√	√	√			√		√		5
0121	2	√	√x2		√					√	5
0421	3		√			√	√				3
0212	3	√		√	√x2	√					5
0223	3				√	√x2					3
0114	3			√	√	√					3
Total	**10**	**6**	**5**	**4**	**8**	**5**	**3**	**1**	**1**	**1**	

Table 10: Construction company organization by divided function

Table 10 shows, to the extent that information was available, that the leadership/management function in the companies surveyed spanned across two steps in the chain of command/hierarchy. A significant number of companies had three steps of management responsibility. This finding suggests that the growth of the companies is consistent with Steinmetz's (1969) critical phases and four stages of growth model. The organizational structures developed by a significant number of these successful construction companies indicate that they have attained the "indirect control" and "divisional organizational" stages in which the founders/leaders are "managing the managers" (Rush et al., 2007).

Further, Table 10 illustrates that the construction companies studied have at least three main division/sections, the four most common being "Project/Contract Management", "Finance", "Human Resources / Admin" and "Commercial / Marketing / Procurement", in order of commonality. This suggests that the companies investigated have management employees that fulfil other requirements such as project/contract management, finance, human resources, administration, etc.

3.7 Exercise 1

1. Draw different simplified configurations for a cidb Registered Grade 9 Construction Company's organization structure for instances where the following distinct construction services are provided:
   a) Residential buildings
   b) Non-Residential Buildings (specify – commercial, schools, hospitals)
   c) Transport Infrastructure (specify – roads, bridges etc.)

4. Also draw the organization structure for the same class of company that operates both nationally and internationally, and provides all the three construction services outlined in question 1 above.

Note: Document all assumptions made in producing the different construction company organization structures.

3.8 References/Further Reading:

Radosavljevic, M. and Bennett, J. (2012) *Construction Management Strategies: A Theory of Construction Management*, Wiley-Blackwell: London.

Rush, H., Bessant, J., and Hobday, M. (2007) Assessing the technological capabilities of firms: developing a policy tool, *R&D Management*, **37**, 3, 221–236.

Steinmetz, L.L. (1969) Critical Stages of Small Business Growth, when they occur and How to Survive Them, *Business Horizons*, **12**, 1, February, 29–36.

3.9 The Construction Company as a Complex System

Construction companies, their divisions and construction teams as suggested by Figure 34, form complex systems as they combine to undertake construction projects. A system can be defined as a complex whole with different parts working together. The parts of a system can also be classified as sub-systems or components.

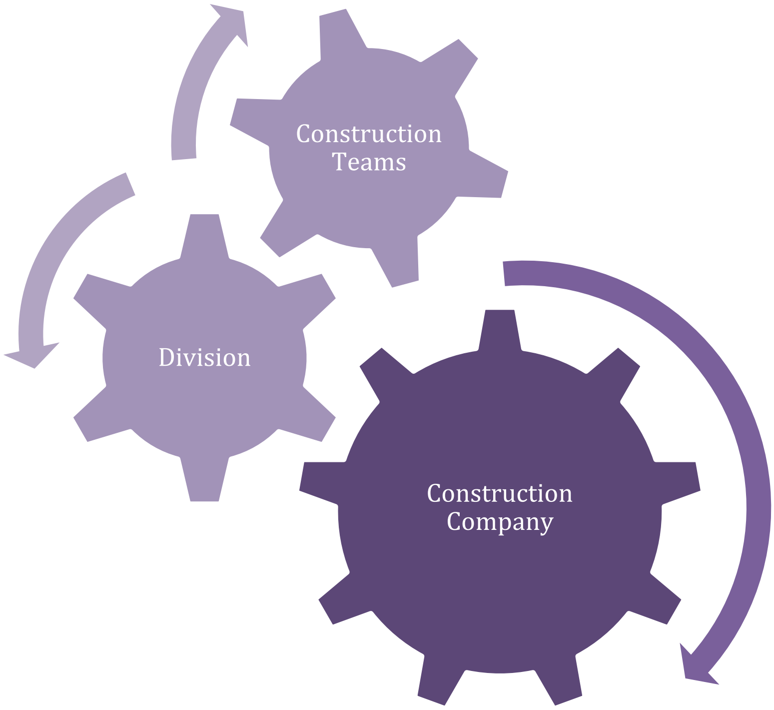

Figure 34: The Construction Company as a Complex System

A construction company can be said to be a group having an external envelope that influences and covers a loosely defined space. A company is a complex system because it is made up of different divisions or sections/sub-systems, which are inter-related, and interdependent, the different parts, which can be easily differentiated, are viewed as part of the whole structure. The company is a complex system because its divisions are usually structured according to the complex product it manages and produces.

The construction company, its divisions and construction teams, help to define, organize and reinforce the perceptual and conceptual elements of a company. Even the divisions in the case of large and medium sized construction companies are also made up of sub-divisions. These major divisions of a company, which include Finance, Human Resources, Contracts, Commercial/Marketing are responsible to the Managing Director/General Manager. The Managing Director may also seek advise from the Company Secretary on legal points and from external Consultancy Firms on general matters.

4 The Construction Project And Its Environment

4.1 Project

Project – this can be defined as an activity which has a beginning and an end, which achieves specific **objectives** through a set of defining tasks and effective use of **resources**.

4.2 What are the objectives of and the resources used by projects?

Specific **project objectives/outcomes** include:

- To scope;
- Within time;
- Within cost;
- Good accident record;
- Client/end user satisfaction;
- Quality;
- Utility; and
- Dependability.

Project Scope is the work that needs to be accomplished to deliver a product, service or result with the specified features and functions.

Tangible resources used include –

- Men;
- Money;
- Machines;
- Materials; and
- Management expertise.

Intangible resources;

- Information

4.3 The Project Life Cycle and the Cycle as a Management Tool

Project Life Cycle – this refers to a logical sequence of activities to accomplish the project goals or **objectives**. Regardless of scope or objectives, any project goes through a series of phases/stages during its life.

Management – the process of planning, supervising monitoring and controlling project **resources** in such a way that positive outcomes (**project objectives**) are achieved

Projects can be managed by using a life cycle approach. The construction manager is required in the Phases 2–4, shown in Figure 35 and Table 11 as prescribed by the South African Council for the Project and Construction Management Professions (SACPCMP – see pgs. 102–113).

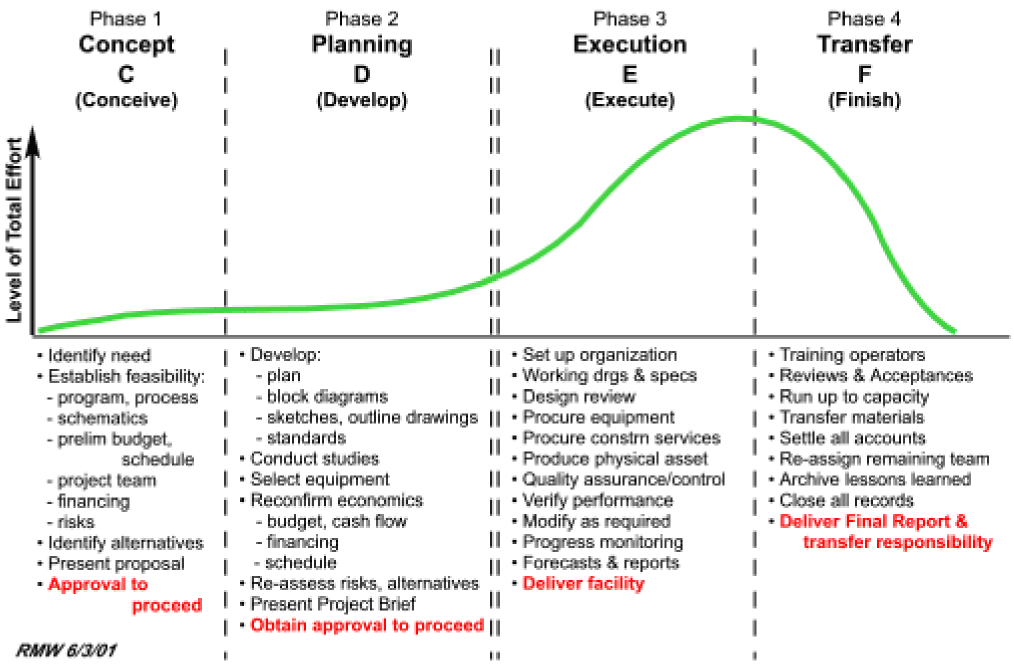

Figure 35: The Construction Project Life Cycle and Activities Performed

1. Concept n → 2. Pre-constructio n → 3. Construction → 4. Post Construction

SACPCMP CLASSIFICATN	• Project Initiation & Briefing; • Concept & Feasibility	• Design Development; • Tender Documentation & Procurement	• Construction Documentation & Management	• Project Close Out.
Activities / Services Performed	• Identify a need • Scope (Draft); • Terms of Reference. • Budget Estimate	• Develop a proposed solution; • Design Appraisal; • Plan Deliverables • Schedule Plan; • Budget; • Risk Identification; • Quality Plan	• Perform the Project; • Production of Key Deliverables; • Quality Management; • Time Management; • Budgeting & Cost Control; • Risk Management; • Issue Resolution; • Health & Safety; • Reporting;	• Contract Closeout; • Team Feedback; • Recommendations for further action; • Post Implementation Review.
Deliverables	Not Applicable	**Design Development:** • Preliminary Scope of Construction Works; • Preliminary Construction Programme; • Schedule of agreed lead times required to prepare a detailed design & documentation programme; • Proposed Construction Method Statement; • Buildability & Constructability Statements **Tender Documentation & Procurement:** • Construction Strategy & Method Statement; • Construction Management Organogram; • Procurement Strategy/Program for sub-contractors & suppliers • List of proposed sub-contractors; • Schedule of Health and Safety Requirements; • Construction Programme including resource planning;	• Health & Safety Plan • Site Establishment Plan (Site Layout); • Signed sub-contract agreements; • Quality assurance plan. • Construction communication organogram; • Record of construction meetings; • Construction programme including resources **Others not specified:** • Information requirement schedule & (RFI's); • Monthly progress payment claims; • Construction Status reports • Financial budget/cash requirements & supply of working capital	• Health and Safety File • Contract close out report – including lessons learned

Management Techniques (From the seven major processes of management) – Fayol, Urwick etc	Not Applicable	**Planning Function:** • Forecasting or Predicting • Planning • Organizing or preparing Also • Communicating	**Executive Function:** • Monitoring & Controlling • Co-ordinating • Motivating or commanding **More In-depth Planning Function:** • Planning & • Organizing and preparing Also • Communicating	
Planning Tools & Techniques Used	Not Applicable	• Work Breakdown Structure (WBS) • Bar or Gantt Chart • Network Analysis • Operational Research	• Bar or Gantt Chart • Network Analysis	
Monitoring & Control		N/A	• Updates • Management & Financial Reports • Progress reports	
Software Used		• Microsoft Project Software • OPERA (Risk prediction) • Building Information Modelling (BIM)	• Microsoft Project Software • Oracle Primavera / Sure Trak	

Table 11: Key Services Provided by the Construction Manager in the Project Life Cycle

4.4 The Project Environment

Duncan (1971) defined environment as the interaction between the system's internal and external components. This consists of those relevant physical and social factors inherent within or outside the boundaries of the construction project (external interference) that have direct influence on the decision-making behaviour of individuals and decision units. In order to make predictions about the kinds of environments in which different levels of perceived uncertainty are expected to exist, Duncan (1971) identified two dimensions of environment, which are represented along two continuums of simple-complex and static/stable-dynamic shown in Figure 36.

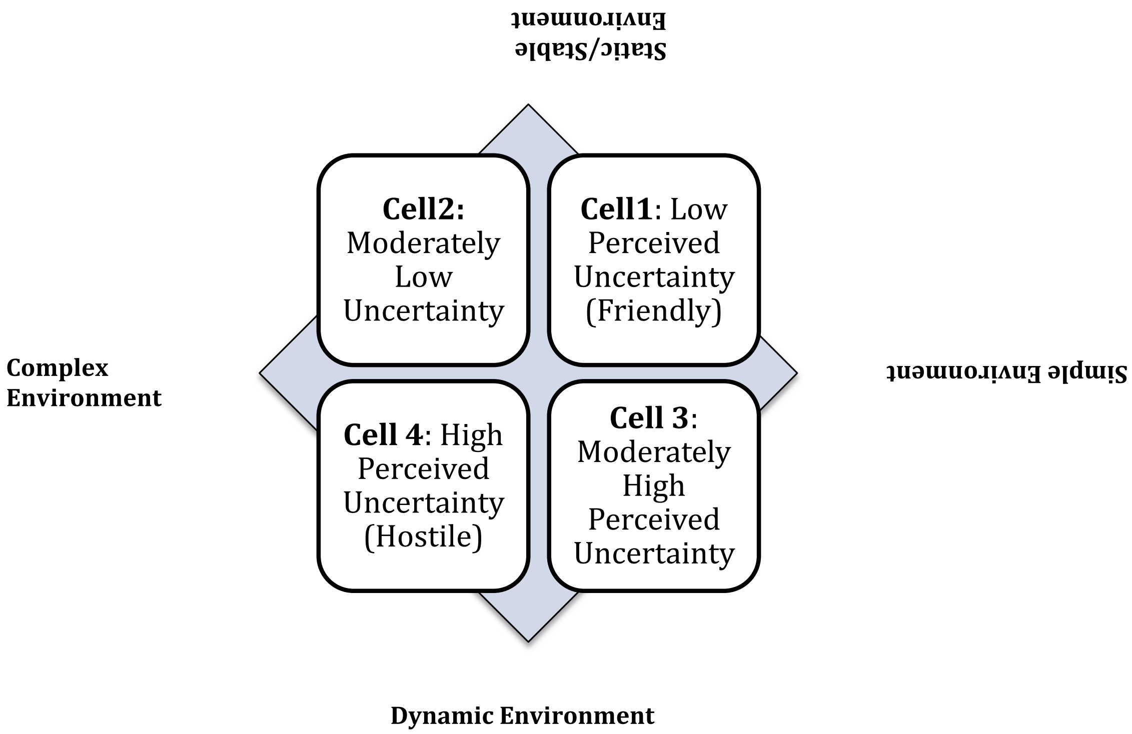

Figure 36: Two-Dimensional view of a Project Environment and Perceived Uncertainty Experienced by Individuals in Decision Units

The **simple-complex** continuum deals with the degree to which the components of environment influencing the decision situations are either few in number and similar in nature, or are many in number and different. The dimension of complexity can be measured by the:

- number of subcontractors (whose work has to be coordinated), number of construction teams determined by type of activity;
- performance variability of the construction team;
- quality of relationship between construction team members – either boundary or internal relationships;
- scale of involvement of the client and its representatives; and
- the input required in planning and programming the work.

The **static/stable-dynamic** continuum indicates the degree to which the components remain basically the same over time or are in a continual process of change. An organizaion's environment can range from static/stable to dynamic. A variety of factors can make an environment change along this dimension and real problems are caused by changes that occur unexpectedly, for which no patterns could have been discerned in advance. The factors that have been identified to influence the stability of the environment include:

- Unpredictable shifts in the economy;
- Variations and changes in client's requirements;
- Changes in project goals; and
- Labour shortages.

According to Shirazi et al. (1995), the **complex-dynamic** (hostile – Cell 4) environments are probably the most characteristic type of environment in the construction industry, involving rapid change and unanticipated decision situations. Hostility is influenced by:

- Competition;
- adverse relations between involved parties including industrial relations;
- project location; and
- extreme weather conditions

Duncan (1971) stated that 'the **static-dynamic** dimension of environment is a more important contributor to uncertainty than the **simple-complex** dimension. According to Duncan (1971), decision units with dynamic environments always experience significantly more uncertainty in decision making regardless of whether their environment is simple or complex.

In a **static/stable** environment, an organization can **predict** its future conditions and thus standardize its procedures from top to bottom, establish rules, formalize work and plan actions. In a **dynamic** environment, the organization cannot easily predict its future activities and cannot rely on standardization or formalization as a coordinating mechanism but must seek mutual adjustment and encourage informal communication.

In a **simple** environment, **information** can easily be consolidated and understood, which enables the organization to centralize control and coordinate at the top of the hierarchy with little reliance on liaison devices and mutual adjustment for coordination. When the organization is faced with a **complex** environment, it encounters problems of comprehensibility and consequently, decisions are decentralized to prevent the effects of overloading.

The **hostility** dimension has a special effect on structure through the intermediate variables of predictability of the work and speed of response for fast reactions by the organization. Hostility demands an immediate but temporary centralization of the organization structure, and direct supervision for the tightest means of coordination and control. Moreover, according to Shirazi et al. (1995), hostility is viewed as imposing a special condition on the two-dimensional matrix. Extreme hostility drives an organization to centralize its structure temporarily, irrelevant of the initial conditions.

4.5 Overview of project procurement methods

According to Love et al. (1998), the terms 'procurement systems' and 'contractual arrangements' are usually used synonymously. Love et al. (1998) defined a procurement system as an organizational system that assigns specific responsibilities and authorities to people and organizations and defines relationships of the various elements in the construction of a project. Harris and McCaffer (2001) noted that the client or adviser/project leader according to need or preference would select the type of contract. Established methods of project procurement identified by Masterman (1992) and cited by Harris and McCaffer (2001), which determines the contractual relationship between the client and other parties at the design and construction stage can be categorized as:

- Traditional (separated and cooperative) method
- Design and Build (integrated and holistic) method
- Management (management-oriented) method
- Discretionary

These methods are further sub-classified into the methods shown in Figure 37.

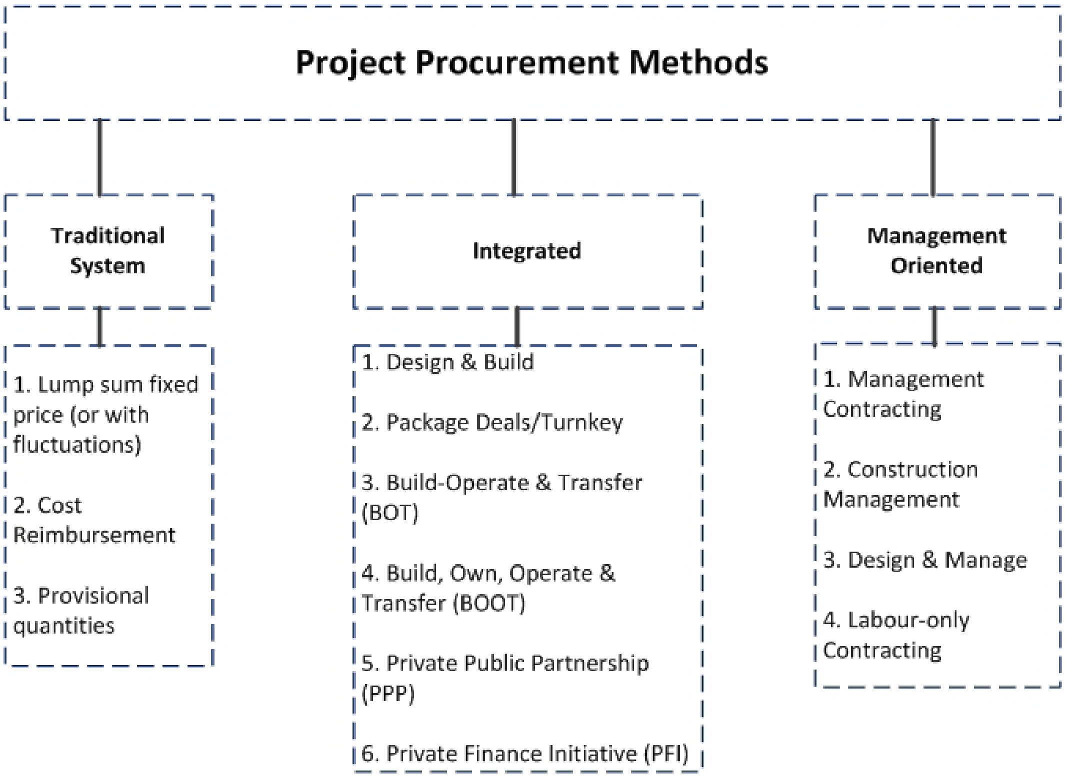

Figure 37: Classification of Project Procurement Methods

Sources: Adapted from Love et al. (1998); Osanmi (1999) and Alhazmi and McCaffer (2000)

4.5.1 Traditional Project Procurement Method

Osanmi (1999) characterizes the traditional procurement method by a clear separation of design and construction process. Harris and McCaffer (2001) notes that traditionally, clients have often preferred to engage someone able to interpret their needs into a clear design before proceeding with the construction phase. An architectural firm, engineering firm or consortium acting as consultants is responsible for design, while a general contractor handles the construction phase after entering into a construction contract with the client through competitive bidding or negotiation. Radosavljevic and Bennett (2012) noted that the developed form of traditional construction begins with a construction customer employing a design consultant. According to Love (2002), an architect is typically the first point of contact for clients and, because their advice is heavily relied upon, it is often in the interest of the architect to persuade the client to use a traditional method, as they can take a lead role in the project as well as maximize his/her fees.

The first essential activity in traditional procurement is to prepare a brief, which describes what the customer wants in the new facility and it works most effectively when the customer is clear and certain about their new facility, its implications for their organization and ensures this is all described in the brief. The second activity is the design. The design involves a variety of design specialists such as services and structural engineers and others providing specialised design knowledge and skills. The third stage is to select and employ a general contractor. The customer negotiates a contract with one construction company to take responsibility for ensuring the new facility was completed by an agreed completion date for an agreed sum of money. The selection of a general contractor often involves a competitive bidding process in which a number of general contractors offer to complete the new facility by the required date for a stated sum of money.

Initially, many of the firms selected to play the role of general contractor were those responsible for the technology which provided the main structure of the new facility, usually concrete, masonry or timber work. Over time, some of the companies given this leading role abandoned their individual specialist activities and concentrated on acting as general contractors. Others continued to use directly employed workers to undertake significant production activities. The exact pattern of subcontracting and direct employment varies widely between countries, as it is influenced by national conventions and legislation, and local labour market conditions.

Once appointed, the general contractor analyses the design information and plans the building production and commissioning activities. These plans are then effected by the general contractor selecting and employing companies to undertake any specialized manufacturing, supply general materials and undertake the production and commissioning activities. The building production and commissioning activities are supervised on behalf of the customer by the design consultants. The aim of this supervision is to ensure the quality of the new facility.

Internal and Boundary Relationships in Traditional Procurement

The approach to traditional procurement is put into practice by a project organization, which emerges in two distinct stages shown in Figure 38.

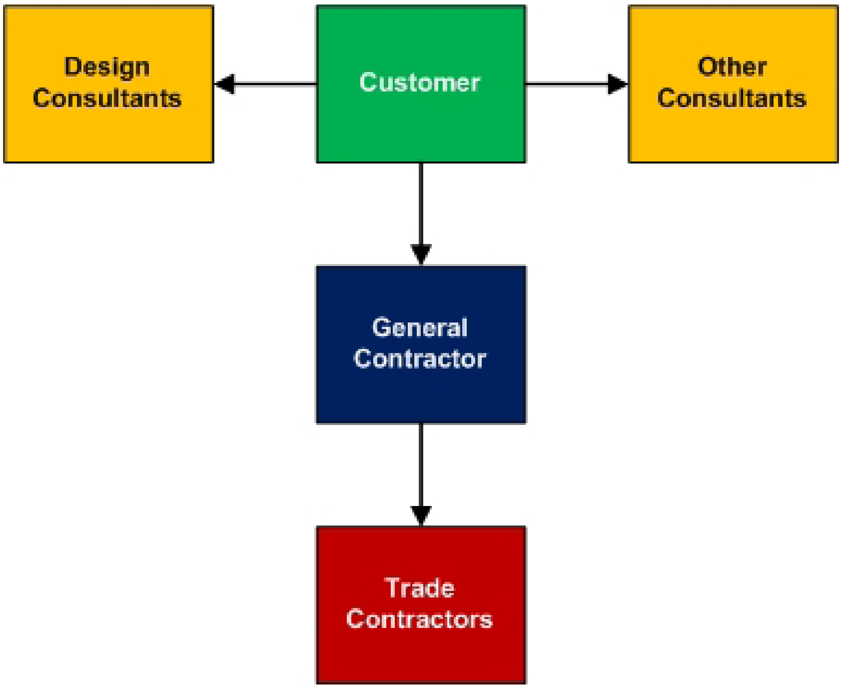

Figure 38: Traditional Procurement Method Project Organization

The project organization begins with the formal **boundary relationship** between the customer and the design consultant. The initial stage develops as specialist designers and consultants are engaged to advise and assist the primary design consultant. Some of the consultants may have **established relationships** with the primary design consultant. However, others including some selected by the customer, result in more **boundary relationships**.

Parts of the initial design-consultant-led organization persist throughout the project. However, once the general contractor is employed, the effective project organization changes. Production activities require the general contractor to employ specialist companies leading to the formation of a separate project organization organized by the general contractor. The general-contractor-led project organization works through a mixture of **boundary**, **established** and **internal relationships**. The actual pattern is dependent on the general contractor's experience of the specific type of new facility being produced and the extent to which they use directly employed construction teams.

The design-consultant-led part of the overall project organization adopts a supervisory role over the work produced by the general-contractor-led part. Invariably, the interactions between the two parts of the project organizations take place through formal boundary relationships, almost entirely shaped by the terms of the individual contracts, which brought them into the project organization.

Advantages of the Traditional Procurement Method

It works well for all the parties involved in the procurement process when the:

- client has a clear view and provides a clear brief of the new building they want;
- designer relies on technologies within the competence of local general contractors;
- competent teams ate engaged to undertake manufacturing, production and commissioning of the facility through straightforward competitive bids; and
- teams complete their work and don’t create problems for those whose work follows on.

Disadvantages of the Traditional Procurement Method

The outcomes for traditional procurement are very different when any of the conditions for success break down. The results tend to be unsatisfactory for some of those involved – work is delayed, costs escalate and quality is compromised. There are many possible causes of unsatisfactory results including:

- customers may have unrealistic aims for their new facility, they may change their mind as the building is being produced or learn about the time and costs involved in its production;
- Designers may produce complex designs which are beyond the competence of local manufacturing and construction companies;
- designs may be incomplete at the time the general contractor is appointed;

- designers may change the designs during the execution stage resulting in abortive work and increased costs;
- contractor engaged may bid unrealistically low due to inadequate production know-how and experience;
- contractor making use of inappropriate production methods; and
- a vicious circle of boundary relationships developing between the construction and design teams engaged leading to design and production failures illustrated in Figure 39.

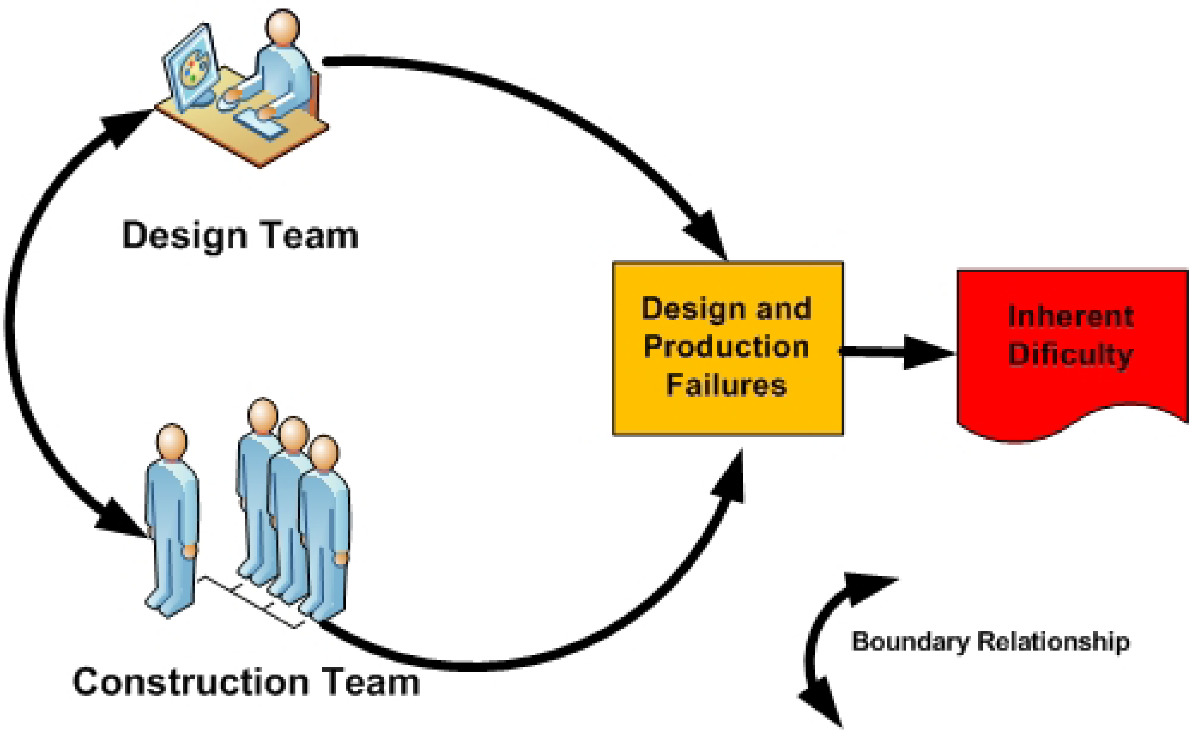

Figure 39: Vicious Circle of Boundary Relationships in Traditional Procurement Method Project Organization (Adopted from Radosavljevic and Bennett, 2012)

Traditional procurement method only works well if customers and designers request for and use well established local or conventional technologies respectively, and contractors have knowledge of appropriate production methods and effective coordination systems. Since this is difficult to achieve, it is advocated by general contractors that this procurement method be replaced by other approaches.

4.5.2 Design and Build Integrated Project Procurement Method

Design and build provides an attractive approach for construction customers frustrated by the failures of the traditional method of project procurement and to customers needing a straightforward building or simple infrastructure (Radosavljevic and Bennett, 2012). Many of these customers want to describe their requirements to a construction company and leave them to produce the new facility at a sensible cost and time. The resulting relationship between customers and design and build companies is commonly characterised as providing a single-point of responsibility.

Osanmi (1999) explains design and build or design and construct as a procurement method where the contractor provides the design and construction under one contract as different from the traditional system where design is separate from construction. Molenaar and Songer (1998) noted that design and build has steadily become a procurement method of choice for many public sector agencies in the United States. Osanmi (1999) cites that all design and build contracts have two principal characteristics: -

a) The contractor is responsible for both the design and construction and employs the services of other relevant professionals (architects, engineers etc.) that may be required, with the client having a professional agent who advises him. Contrary to this assertion, Bowen et al. (1999) found that clients are generally offered advice on only a limited selection of procurement systems.
b) The contract between the client and contractor has a final and inclusive price that does not vary unless the client requires changes to be made.

Advantages of the Design and Build Project Procurement Method

- Providing a single point of responsibility;
- Provides a straight-forward way of ensuring practical knowledge of procurement, manufacturing, production and commissioning is taken into account in the brief, design and plan; and
- Avoids the fragmented set of relationships which traditional method of project procurement requires customers to accept.

Design and Build is well established in civil engineering projects where the common professional background of customers' advisors, designers and contractors supports this arrangement. The use of design and build in building projects is well established in some countries and it has become the dominant approach to project procurement. Basic approaches to design and build which support construction management propositions include:

a) straightforward approach
b) straightforward scheme design approach
c) consultant novation approach
d) develop and construct approach

Straightforward Approach to Design and Build

In this approach, the customers with advise from architects and quantity surveyors appoint a building company at the inception of a project as shown in Figure 40. This is usually achieved by negotiating with one, or at the most, three design and build companies.

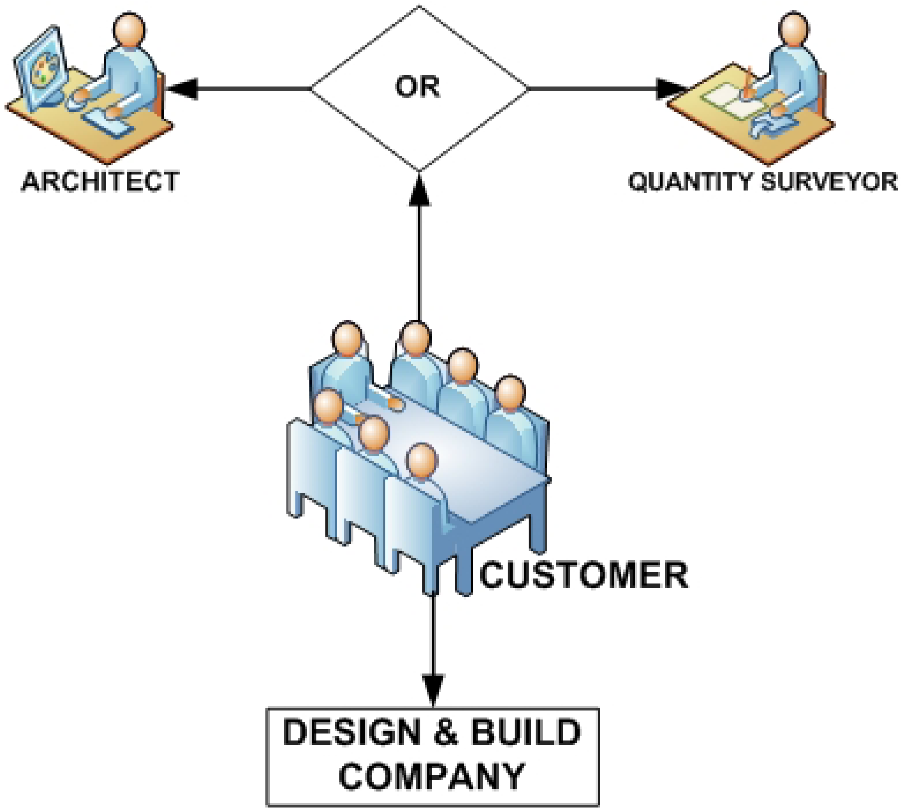

Figure 40: Straightforward Approach to Design and Build

Straightforward Scheme Design Approach to Design and Build

A variant of the straightforward approach is for the customer to employ design consultants to produce the brief and design. This is developed to a stage, which enables the customer to understand their new building and be given realistic estimates of the cost and completion date. Then a general contractor is selected usually on the basis of competitive bids as illustrated in Figure 41.

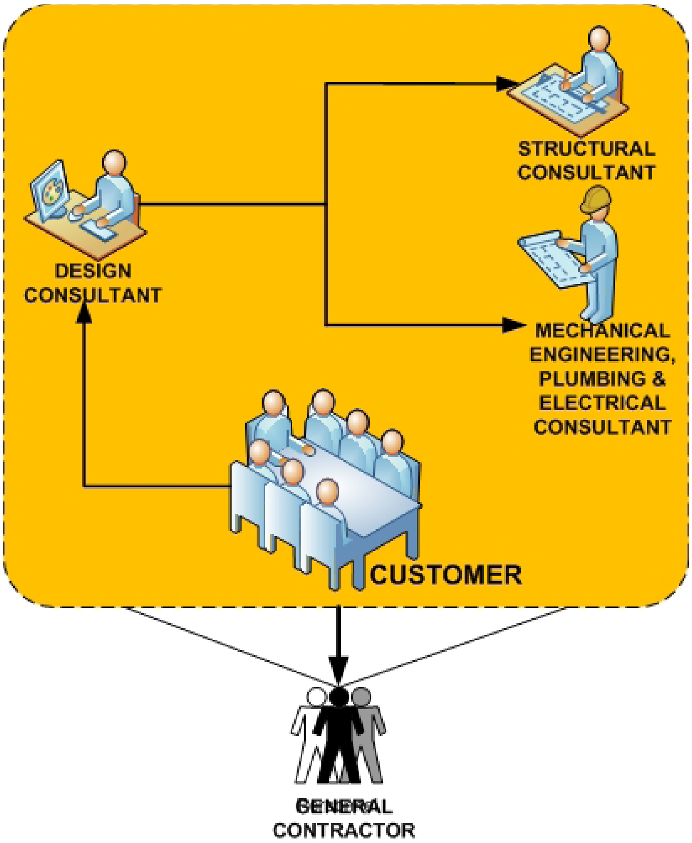

Figure 41: Straightforward Scheme Design Approach to Design and Build

4.5.3 Consultant Novation Approach to Design and Build

The selected general contractor is required to take over the employment of the customer's consultants. This is called consultant novation because the employment contracts of the consultants are novated to the general contractor. In this way, parts of the general contractor's organisation act as a design and build company for the duration of the project. This temporary design and build company takes responsibility for the design whatever stage it has reached when they are appointed. This then provides the customer with a single point of responsibility for the completion of the project. The consultants work with the design and build company to complete the design details as shown in Figure 42. According to Radosavljevic and Bennett (2012), the outcomes tend too be dogged by muddled responsibilities and generally provide poor outcomes for everyone involved.

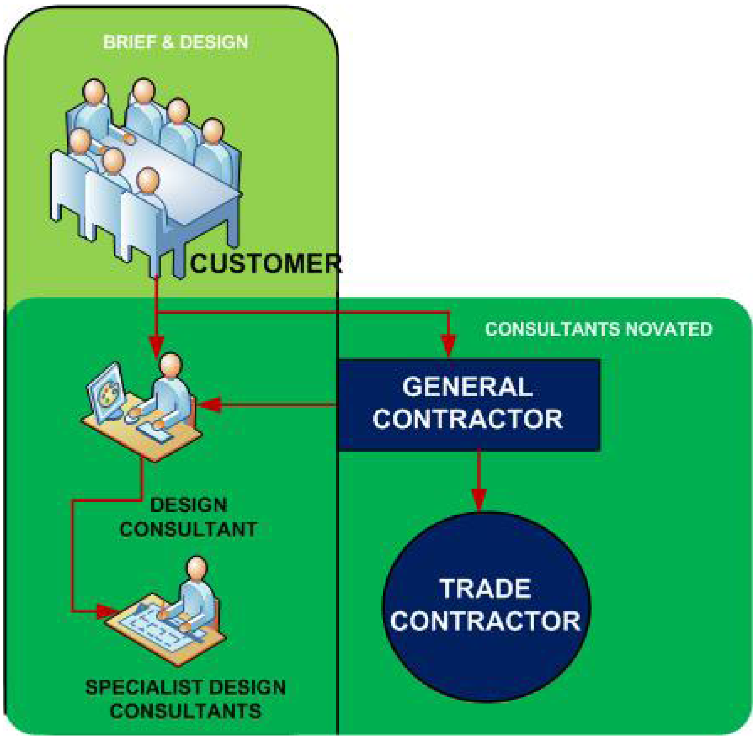

Figure 42: Consultant Novation Approach to Design and Build

4.5.4 The Development and Construct Approach

This is a more effective approach shown in Figure 43, which enables customers to use consultants to produce a brief and help them decide exactly what kind of building they need. Then a design and build company is engaged on the basis of negotiation or competitive bids and is given direct responsibility for completing the brief and design and undertaking all subsequent stages of the project. The design and build company does not take over the employment of the customer's consultants as it is done in the Consultant novation approach. The design and build company use either directly employed staff or their own choice of design consultants and subcontractors in undertaking the project in accordance with the information provided by the customer for an agreed cost and by an agreed completion date.

According to Radosavljevic and Bennett (2012), the earlier the design and build contractor is employed in the production of the brief and design, the more likely it is that the project will be successful. The customer usually retains some of their own consultants to ensure that the design and build company meets their contractual commitments. Apart from this supervision, which is usually minimal, the design and build company is able to use their knowledge of procurement, manufacturing, production and commissioning to ensure the design and plan provide the basis for efficient work.

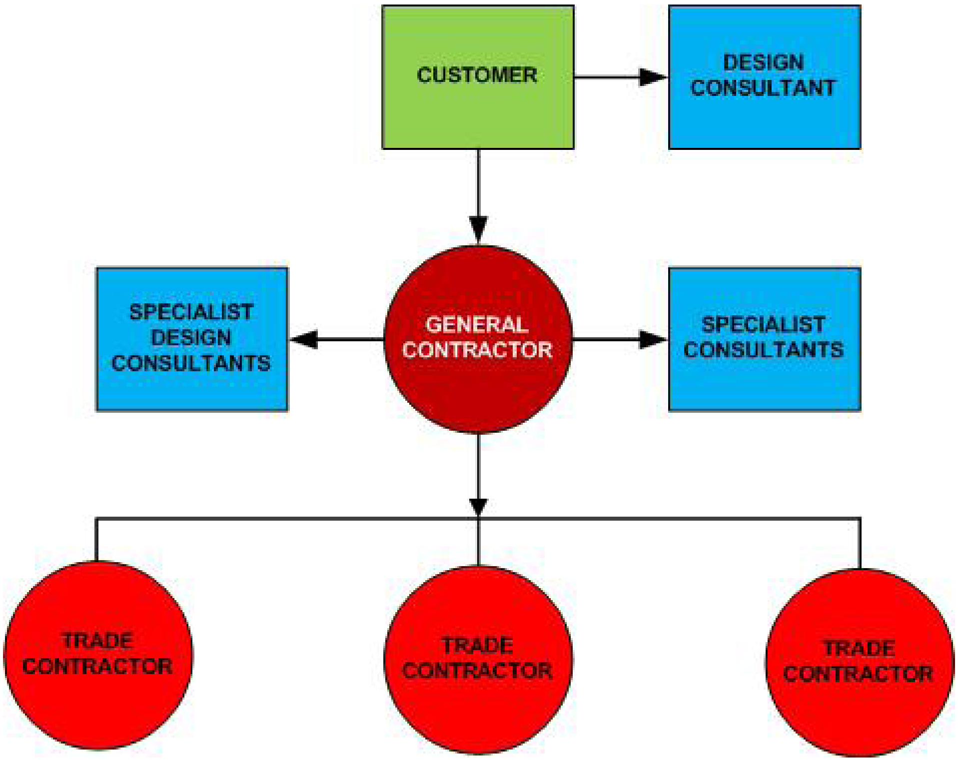

Figure 43: Develop and Construct Approach to Design and Build

4.5.5 The Design and Build Project Organization and Relationships

The design and build project organization that puts design and build into practice is influenced by the approach adopted by the customer and design and build company. A typical pattern of boundary and internal relationships is illustrated in Figure 44. Which shows a straightforward form of design and build organization.

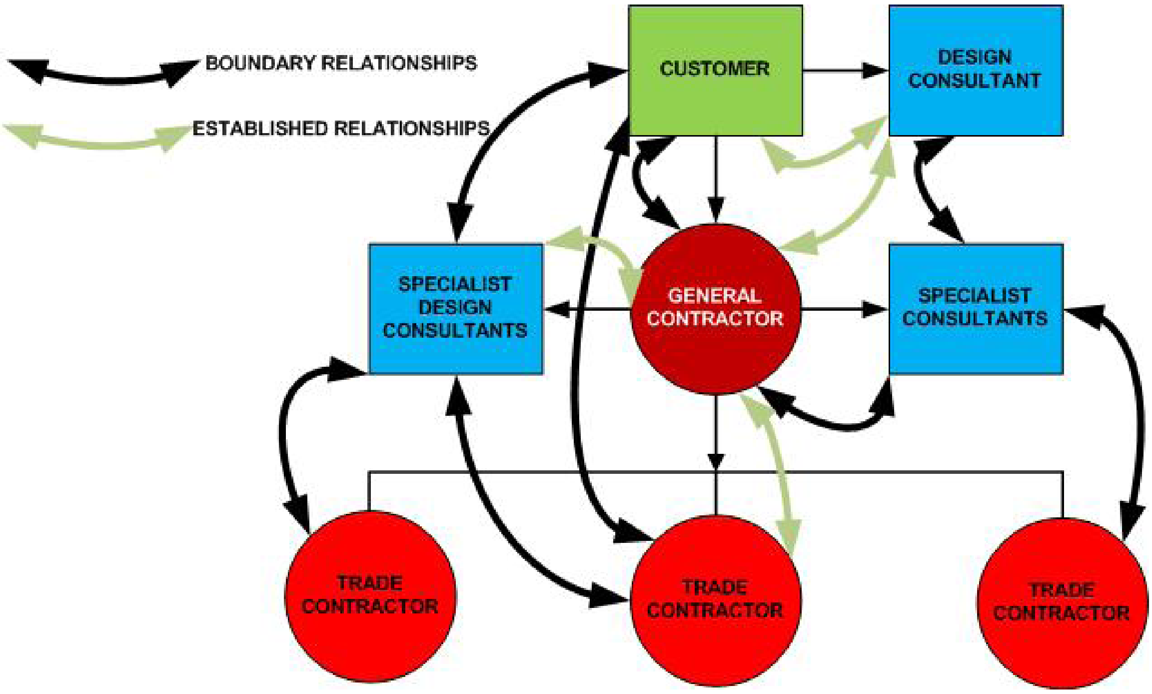

Figure 44: Design and Build Project Organization and Relationships
(Adopted from Radosavljevic and Bennett, 2012)

In the design and build approach illustrated in Figure 44, it is relatively straightforward to internalize many of the boundary relationships which exist between contractually employed construction teams in developed traditional construction. Many design and build contractors therefore develop internal specialist teams that are brought into individual project organizations, thus avoiding the potential costs and risks associated with contractual relationships. It is probable that the internal teams know each other well because they have worked together on other projects. However, the disadvantage of such an approach is it requires a relatively large organization, which in itself is likely to pose difficult organizational challenges, particularly in a rapidly changing and increasingly globalized market.

Many large general contractors seek to internalize relationships by resorting to mergers with or acquisitions of specialist contractors. While this eliminates the potential costs and risks associated with contractual relationships, it does not necessarily build effective internal relationships. Therefore, most successful design and build contractors emerge as a result of organic growth, which may be supported by the occasional acquisition of comparatively small specialist contractors.

4.5.6 The Design and Build Project Procurement Process

- Customer advised by consultants to help prepare a description of their requirements before a design and build company is involved;
- Select a design and build company on the basis of previous experience of working together, recommendations from colleagues/friends/track record, or competition. These direct approaches allow the design and build company to be involved in the project from the very first stage;
- The design and build company sets up a design team to organize the completion of the brief and design; and a management team to produce a plan for procurement, manufacturing, production and commissioning, and actively manage the costs and time; ideally, the two teams work together, usually led by a project manager who ensures the team cooperate in meeting the customer's requirements as efficiently and profitably as possible;
- The design and build construction team led by a project manager, provides the main point of contact with the customer;
- The first action undertaken by the design and build company's internal team is to ensure there is a complete brief which the customer understands and agrees. Then, designs and plans are produced, which meets all the customer's requirements, which the customer accepts, and which takes account of subsequent production and commissioning implications of the design decisions;
- Once the design and plans have been acceded to, the design and build company concentrates on undertaking the subsequent stages of the work – manufacture, production and commissioning, efficiently and effectively; and

- The customer may continue to employ consultant architects and quantity surveyors to ensure that the design and build company's proposals fully meet their requirements, check the quality and agree costs. However, Radosavljevic and Bennett (2012), some experienced customers provide minimal supervision of this kind and rely on the design and build company to meet its contractual obligations.

Features of Design and Build Project Procurement Method

The most significant feature of design and build arrangements is the lack of an independent certification role in the contract. There is no architect or contract administrator to settle differences between the parties, and there is no independent quantity surveyor responsible for preparing the basis upon which contractors tender. Other features are that the employer first approaches the contractor with his requirements and the contractor responds with proposals, which include fabrication as well as design work. A feature that is sometimes present in Design and Build deals is a Guaranteed Maximum Price (GMP). A Contract Sum Analysis (CSA) governs the price. There are no Bills of Quantities needed. The CSA is needed for the calculation of stage payment (in some circumstances), valuation of employer's change instruction and exercising the fluctuation clauses (where applicable).

Advantages of the Design and Build Project Procurement Method

The contractual relationships in Design and Build offer some advantages over other methods of procurement in that the contractor is responsible for everything. That means that the contractor is not relying on external firms for the execution of design or supply of information. By removing these blocks to effective communication and boundary relationships, studies have shown that:

- Contract programmes and budgets are more likely to be adhered to;
- Construction is likely to be faster;
- More economic buildings; and
- More efficient and effective fabrication process.

Disadvantages of the Design and Build Project Procurement Method

- Quality; particularly architectural quality suffers because where there is a conflict between aesthetic quality and ease of fabrication, the requirements for fabrication dominates. Moreover, a design and build contractor is known to put in the minimum design effort required to win a contract.
- Limited scope for variation and changes as the work proceeds.

Characteristics of Projects for which Design and Build can be considered

- The client's familiarity with construction. Novice clients who know nothing of construction and particularly clients requiring small works, will often stumble into design and build before realizing it;
- The relative importance of the client priorities in terms of time, cost, function, quality, value for money, etc.;
- Technical complexity of the project. When dealing with technically complex projects, the solution adopted by the construction industry is to specialize. The range of specialists in construction is extensive and comprehensive as a result, if technical complexity is to be confronted by the use of specified (nominated) specialists, Design and Build is unsuitable;
- A client who wishes to reserve the right to alter requirements during the construction process should not use Design and Build;
- Used where the project is one for which it makes sense to combine responsibility for design with responsibility for fabrication;
- When there is a need for an early start on site. Since the contractor is undertaking the design work, there are opportunities to overlap the design and construction processes and thus make an early start on site possible.

4.5.7 Management Oriented Project Procurement Method

Love et al. (2000) stated that Project management is not considered as a procurement method because it could be applied to any procurement method, and that the term merely means that the client has employed an agent to assist in undertaking a supervisory and coordination role within the project. The construction management procurement method differs from Project Management in that there are several trade contractors involved in this procurement process. The characteristics of the construction management procurement method are as follows: –

- There is no single main contractor;
- The client enters into several trade contracts for work package comprising portions of the project;
- A construction manager runs the project.

The labour-only form of procurement, involves the client in the purchase of materials while leaving construction to a labour-only contractor who gets paid for the cost of engaging labour, and allowance for overheads and profits. An agreement is normally reached upon who hires plants for the works, be it the client or the contractor.

4.5.8 Discussion topic

Design and build vs. management and traditional approaches. What are the main differences?

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4.6 The Project Delivery & Production Process

4.6 (Who can manage construction?)

Consider the project to construct a traditional brick house for two families in Groote Constantia, shown in Figure 45 and described below.

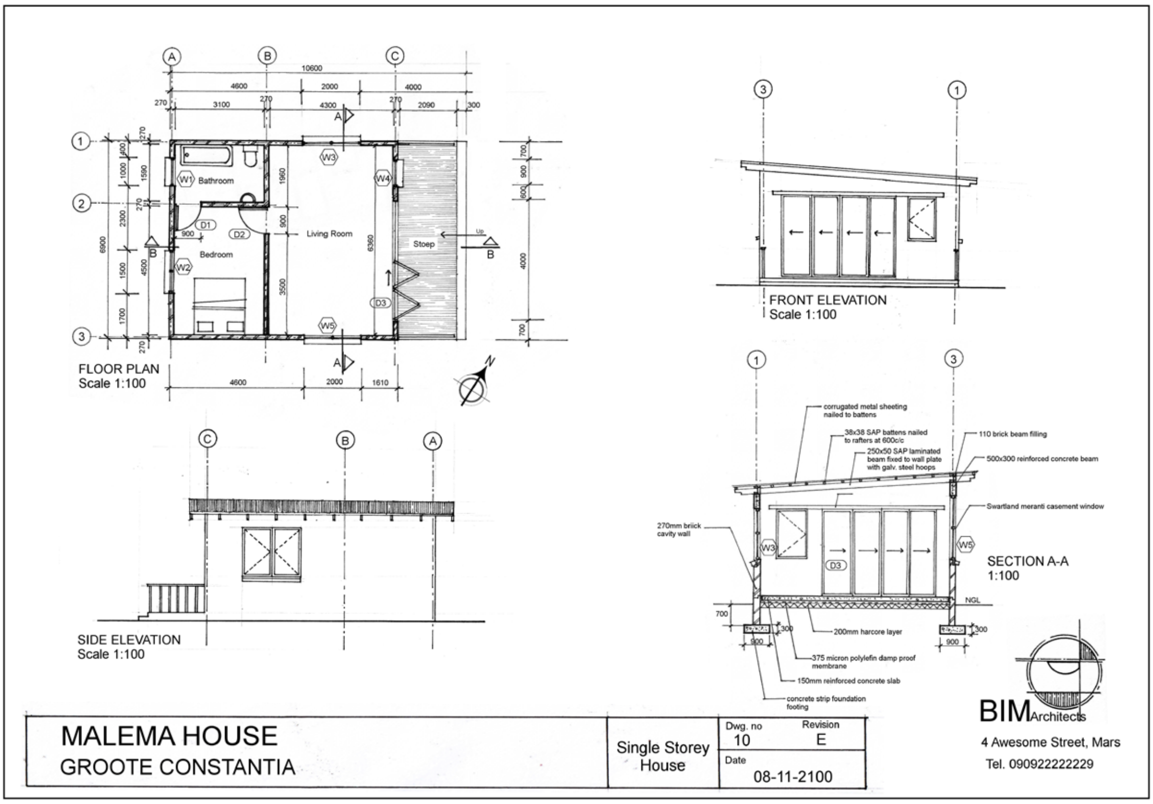


Figure 45: Traditional brick house for two families

Building the house involves a number of specialist craftsmen experienced in undertaking construction actions on individual house projects. Most activities on the house building projects will be undertaken sequentially with just a few being performed in parallel so in general, there will only be limited interactions between the trades for relatively short periods. The activities are interconnected in a logical construction sequence and the following features of established local construction will therefore have to be considered:

1. Architectural drawings, the type shown in Figure 28 will have to be produced. This will include a complete design, which gives the production teams sufficient information to undertake their aspect of the work. The architect is often engaged in the project execution stage to make sure that the design is being followed.
2. Management (the individual housing sector is dominated by customers directly managing the project. However, some employ an external project manager to over see the production activities on site).
3. Construction site preparation (this include clearing the vegetation and topsoil, grading and securing the site perimeter) as shown in Figure 46.

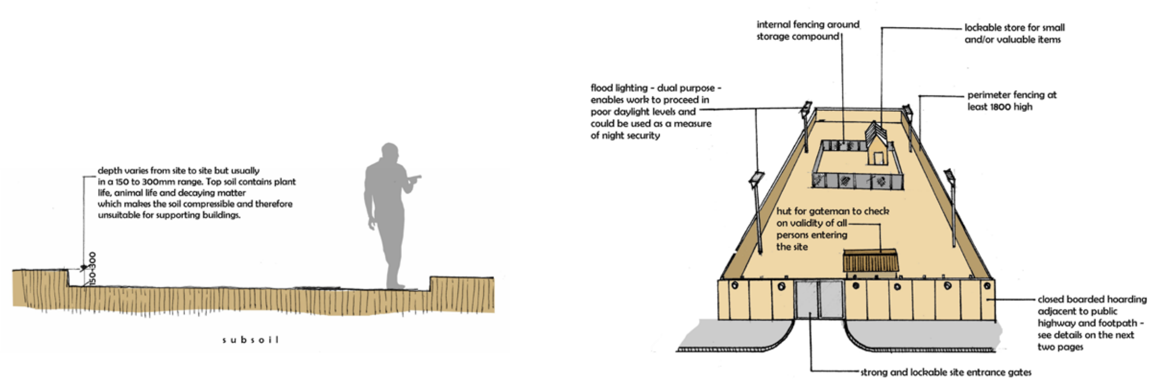


Figure 46: Clearing/removal of topsoil and site security provision

4. Setting out the building to determine the baseline and outline of the building as shown in Figure 47.

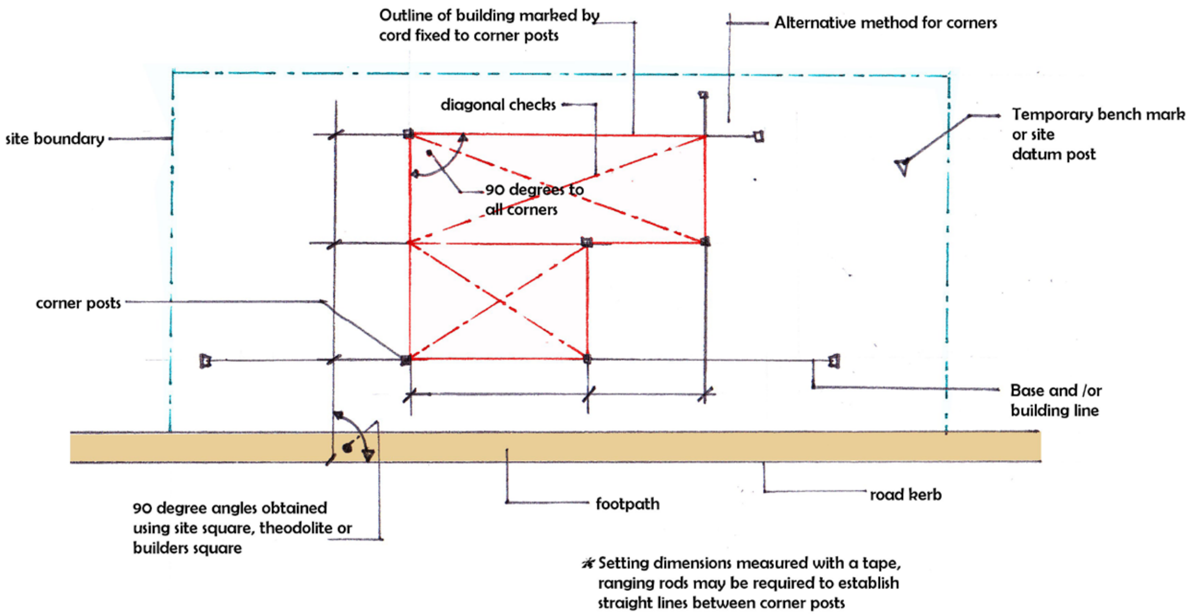


Figure 47: Setting out the Building

5. Construct the foundations (this may include several trades including those responsible for excavation, formwork, steel reinforcement, and concrete/brick work) as depicted in Figure 48.

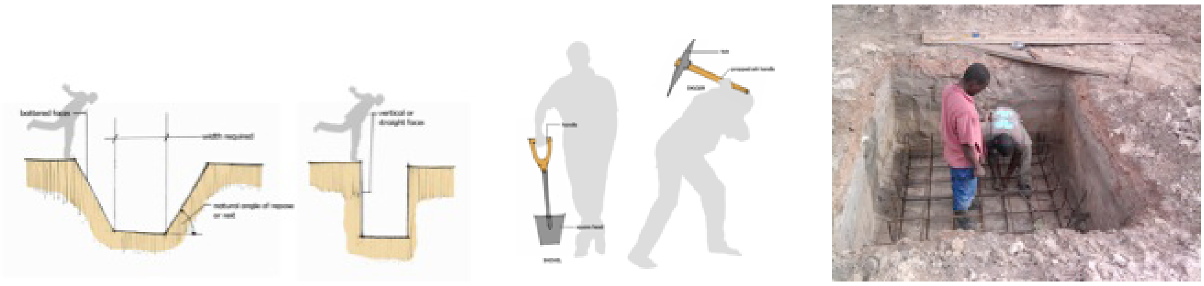


Figure 48: Foundation Construction

6. Production of oversite concrete/surface bed (this include several trades such as steel, formwork, concrete work, backfilling, etc.) illustrated in Figure 32.

Figure 49: Production of the oversite concrete/surface bed

7. Brick wall construction (external and any internal brick or block walls are constructed by a team of skillful bricklayers and their work normally includes installing external or cavity-wall insulation) as illustrated in Figure 50.

Figure 50: Brickwall and Lintel Construction

8. Roof (teams of carpenters, roofers and tilers are employed to erect, insulate and tile the roof) as shown in Figure 51.

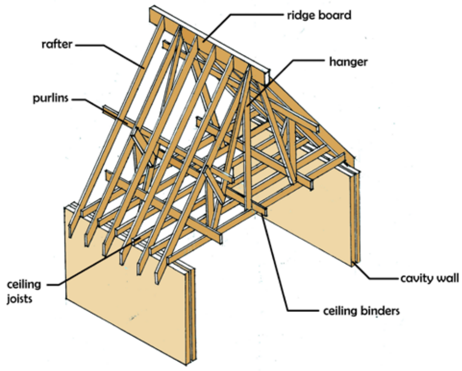



Figure 51: Roof Construction

9. Electrical works (a bungalow does not require an extensive electrical installation so a single team of skillful electricians can undertake the complete job); see Figure 52.

Figure 52: Electrical and Plumbing Installation

10. Plumbing (this would require plumbing installations in a kitchen and bathrooms but depending on the type of heating installation, a certain amount of plumbing work may be required for the heating installation); see Figure 52.
11. Applied finish such as plastering/tiling or drywall installation (internal walls may be of drywall timber frame or brick/block construction lined with drywall boards, undertaken by a team of specialist installers and finishers); see Figure 53.

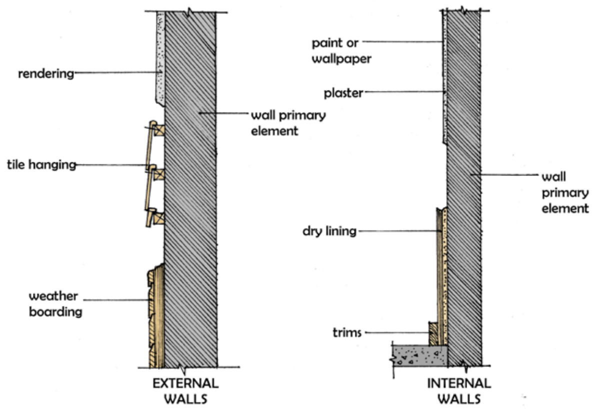


Figure 53: Types of wall finishes

Floor and wall finishes follow the laying and roughing in of the mechanical/electrical pipes and fittings. This is done in accordance with the contract specifications. The carpenter builds scaffolding or scaffolding is rented and used around external and internal walls by the bricklayers for plastering work. Plastering is applied if indicated to walls and concrete slab soffit and applied to specifications. Finishes include tiling and ceiling tiles etc. The floor depending on type can be prepared to receive a cement and sand screed only.

12. HVAC installation (a modern family home may have a relatively complicated HVAC system with integrated heating, ventilation and air conditioning but a single team of specialist HVAC installers would be able to complete the job in conjunction with plumbers); see Figure 54.

Figure 54: HVAC Installation

13. Painting and decorating (once all the services are installed and walls completed, a single team of skillful painters and decorators could paint the internal space and install decorative elements). The internal joinery doors, wardrobes, cupboards, windows, stair rails are supplied and installed usually by a nominated supplier.
14. Landscaping by landscape and garden designers and external works. The external works include the construction of the driveway, inspection chambers, gulley, manhole and fence and connection of the drainpipe to the sewer. It can also include landscaping, the construction of swimming pools, soak away pits and septic tanks. However, some of the external works can also be done in tandem with the building construction.

The relative limited number of teams and interactions involved in building a family house suggests a traditional procurement approach would be adequate. There are hardly ever more than two or three teams working on the construction site simultaneously, so any misunderstandings and errors can easily be resolved on the spot. The client would also be able to explain requirements in detail so the architect could produce a complete design prior to the start of construction.

4.6.2. Exercise 2

Consider the project delivery and the construction process of the bungalow detailed in Figure 45 and think about the following questions:

a) Determine how many different construction teams would be required to build the bungalow;
b) Outline the requirements an architect would need to consider to produce a detailed design of the bungalow;

c) It is likely that there will be rarely more than three construction teams working on site at the same time. How would you manage such a project in order to ensure a smooth sequence of activities?

d) What would you need to do if several different manufacturing and production teams report design errors?

5 Construction Management Processes And Practices Applicable To Small Projects

Construction management aims to remove the inherent difficulty in construction projects in order to make the project straightforward and easier to cope with. The processes and practices used by a construction manager are in line with the project stage. At the Design stage, during the project procurement process, the construction manager has to plan the project. After winning the bid and signing an agreement with the client, during the project Execution stage, the construction manager is involved in detailed planning and control of the construction work. The construction management processes and practices applicable to small projects and undertaken during the Project Design and Execution stages, are detailed below:

5.1 Production of a Work Breakdown Structure (WBS):

It is useful to begin the planning process by identifying all the tasks and elements of the project. WBS in project management and systems engineering is a deliverable oriented decomposition of a project into smaller components. It defines and groups a project's discrete work elements in a way that helps organize and define the total work scope of the project. A work breakdown structure element may be a work item, tasks/activities, resources, or any combination. A WBS also provides the necessary framework for detailed cost estimating and control along with providing guidance for schedule development and control.

A WBS can show the following at a glance:

- what the various elements of the project are;
- how the necessary work is distributed between the elements of the project;
- how the cost or budget is distributed between the elements of the project;
- how the larger elements of the project are subdivided into smaller ones.

Overview

WBS is a systematic approach to scoping the project work in which a logical hierarchical pattern is devised which may resemble **a family tree**. Note that tasks may have already been grouped into Work Packages in the Bill of Quantities. In a project, the WBS is developed by starting with the end objective, and successively subdividing it into manageable components in terms of size, duration and responsibility (e.g. systems, subsystems, components, tasks, subtasks, and work packages), which include all steps necessary to achieve the objectives.

Level of Detail

Not all branches of the WBS have to be broken down to the same level. The level to which tasks are identified will depend on:

- The size and nature of the project;
- The level at which a single individual or team can be assigned responsibility; and
- The level at which costs are allocated.

A work package at the activity level is a task that:

- can be realistically and confidently estimated;
- makes no sense practically to break down any further;
- produces a deliverable which is measurable; and
- forms a unique package of work which can be outsourced or contracted out.

Once tasks/activities have been identified, they need to be scheduled within the project time frame.

Categorization of Construction Works and Breakdown of Items

A building can be categorized into:

a) The substructure
b) The superstructure

The **substructure** can be defined as all structure below the superstructure, which in general terms is considered to include all structure below ground level but including the ground floor bed.

The **superstructure** can be defined as all structure above the substructure both internally and externally. It is divided into:

a) Primary elements – basically components of the building carcass above the substructure excluding secondary elements. It includes components such as internal walls, stairs and ramps, beams and columns, external walls, upper floors and roofs.
b) Secondary elements include: finishes, services (electrical and mechanical) and fixtures and fittings (subcontractor items).

Therefore, for purposes of planning, construction works can be broken into:

1. **Substructure** –
   excavation, backfill, hardcore/sand filling, blinding, concrete columns, beams/oversite bed, bases, reinforcement works, formwork, block/brick work etc.

Superstructure

2. Concrete work – concrete columns, beams, lintel, stairs (straight, dog-leg, spiral etc.), formwork, reinforcement work
3. Walls
    - Masonry – 90/100/140/150/225mm thick block/brick work
    - Wood stud/post
    - Metal stud
    - Reinforced concrete
4. Roof and roof covering
    - Single, double, trussed or framed roof
    - Slates, interlocking tiles, aluminium, metal, thatch etc
5. Carpentry – Noggins, purlins, struts, tie beams, rafters, wall plate etc.
6. Structural steelwork – I-beams, Z-purlins
7. Joinery – Doors, Frames, Ironmongery, Kitchen cabinets, Built-in-wardrobes, store shelves
8. Metal work – Steel/aluminium sliding/casement/projected windows or doors, roller shutters, mild steel railings, burglar bars
9. Plumbing installation – Single stack, One-pipe, Two-pipe or Sovent sanitary plumbing system; direct and indirect cold water supply systems; central and local hot water distribution systems; and sanitary wares.

10. Electrical installation – Electrical conduit, power and lighting circuits, wiring and equipment, light fittings, fixtures and accessories.
11. Mechanical installation – Lifts, Heating systems (hot water and warm air), Air-conditioning systems, Ventilation systems (Mechanical Ventilation Systems, Spot Ventilation etc.) and components, fittings and appliances.
12. Finishes
    - Floor – screed, tiles, etc.
    - Walls – rendering, screeded backing, tiling etc.
    - Ceiling – ceiling boards, rendering etc
13. Painting and Decorating – Emulsion, gloss and Texcote

External Works

14. External works – Drainage (manhole, inspection chamber, pipe runs, soak-away pit etc.), landscaping, pavement and parking.

Example

Figure 55 shows a Work Break Down structure that demonstrates the **progressive elaboration technique** – divides the project into systems, sub-systems and components.

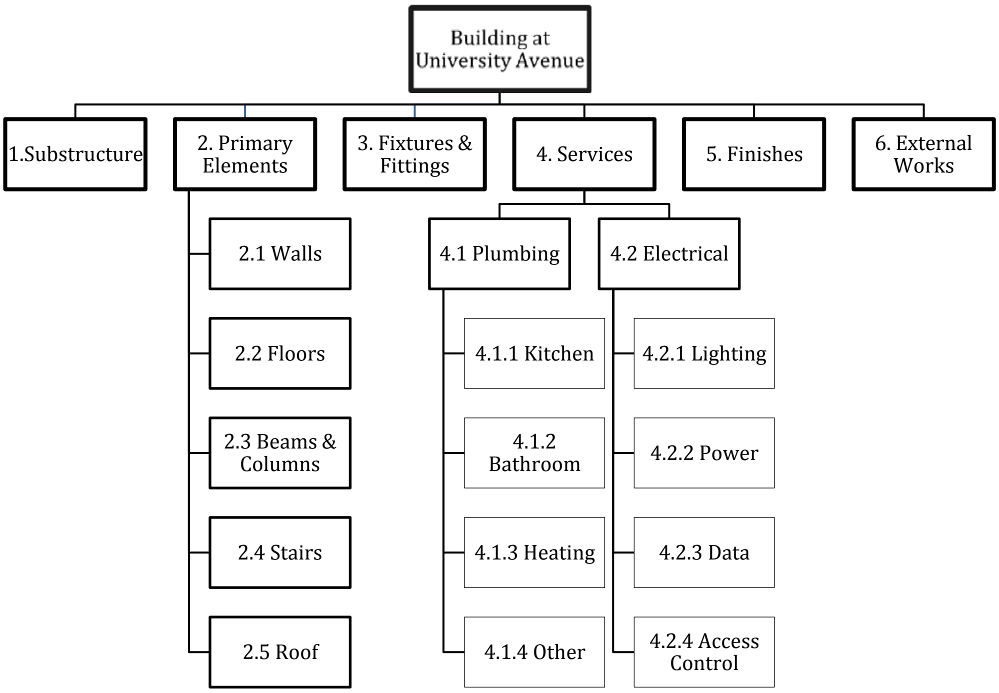


Figure 55: Work Break Down Structure for a building project

At WBS Level 1 it shows the total scope of the project, which is the construction of a building at University Avenue. At WBS Level 2, the project is divided into six systems. The two largest systems are further sub-divided at Level 3 into five sub-systems for primary elements and two sub-systems for services. At Level 4, the Plumbing and Electrical sub-systems are further divided into four components. These components could be further subdivided progressively into work packages, tasks/activities.

Misconceptions

A WBS is:

- not an exhaustive list of work. It is instead a comprehensive classification of the project scope;
- neither a project plan, schedule, nor a chronological listing. It specifies “what” will be done, not “how” it will be done;
- not an organizational hierarchy, although it may be used when assigning responsibilities.

5.2 Preparation of a Construction Method Statement

While drafting the **construction programme**, consideration will have been given to: –

- The **construction methods** to be adopted, it is possible to explore alternatives and compare them on the basis of cost
- Types of plant to be used and
- The manpower requirements for each key operation.

By the time construction programme is completed, a **method statement** should have also been drawn up, recording in detail all the decisions taken. This document later serves as a useful reminder and guide for the site management, as well as providing a basis for requisitioning plant and forecasting the labour force needed.

5.2.1 What is Construction Method?

This can be said to be the description of procedures/ways by which a project or work is to be carried out.

5.2.2 What is a Construction Method Statement?

This can be said to be a definite expression in writing of the procedure that will be adopted for accomplishing each activity identified in a construction project. It is a document prepared by the contractor and submitted along with other tender documents while tendering for a project. If the contractor wins the contract, it becomes part of the contract documents that serves as a basis for agreement between the client and the contractor.

5.2.3 The Purpose of the Construction Method Statement

The method statement is used to:

a) Record agreed intentions with the client
b) Predict the anticipated project quality, risk and health, safety and environmental requirements
c) Assess the adequacy of the project time stipulated by the contractor and the contractor's knowledge of planning
d) It gives the client a tool to assess the contractor's knowledge/know-how of the project
e) Determine how realistic the contractor's bid is

5.2.4 The Format used in presenting the Construction Method Statement

Traditionally, method statements were presented in tabular form with seven columns as shown in Table 12:

1. **First column**: construction operation/activity's serial number
2. **Second column**: description of construction operation/activity
3. **Third column**: quantity of work, usually as written in the Bill of Quantity, which can be linear, square meter or cubic or an item.

4. **Fourth column**: brief description of how the construction operation/activity would be carried out. The description given should be precise, succinct and short.
5. **Fifth column**: Labour and plant requirement for each construction operation/activity.
6. **Sixth column**: Projected duration of each construction operation/activity.
7. **Seventh column**: is for remarks, such as specifying alternative methods of construction, which may also be considered by the client.

However, nowadays it is customary to see method statements with more columns detailing items such as Health and Safety requirements, Risks identified and Quality requirements depending on the purpose and use of the method statement.

METHOD AND RESOURCE STATEMENT **CONTRACT:** Residential House Construction							**SHEET 1 OF 6** **PREPARED BY BW. DATE**: 04 Mar 12					
OPERATION NO.	**OPERATION DESCRIPTION**	**METHOD**	**QUANT.**	**OUTPUT**	**RESOURCE REQUIREMENTS**							
					LABOUR				**PLANT**			
					No.	**Trade**	**Hours**	**Own/ Sub con**	**No.**	**Type**	**Hours**	**Own/Hired**
3.	Excavation to reduced level	J.C.B. 3 Excavator (front bucket) heavy going. Excavation deposited on site not exceedg 100m haul. (J.C.B 3 Excavator used in order to utilize plant engaged on drainage operation) Banksman (Lab) to be in attendance throughout operation.	160 m^3	$8m^3$/hour	1	Lab.	20 hrs (2½ days)	Own	1	JCB 3 (Complete with driver)	20hrs (2½ days)	Hired

Table 12: Typical construction method and resource statement format

The **critical aspects** of method statement preparation are:

- The methodology i.e. the brief description of how the construction operation/activity would be carried out.
- Duration estimation
- Labour/plant requirement

5.2.5 Management Techniques Used in preparing the Construction Method Statement

The management techniques used are the basic planning function of: –

- Planning
- Forecasting and
- Organizing

Planning is the thinking process that determines what course of action shall be taken to achieve a specific purpose. Without reference to a prepared plan, attempts to steer the course of a construction project or contract can be extremely difficult; full control can only be achieved when deviations from a standard can be recognized.

Process Used

The method of construction for each construction operation/activity differs. It is determined by how well the contractor understands the scope of work and how experienced the contractor is. The method statement aims at meeting the project performance requirements of –

- Quality (up to specified standards)
- Time (within scheduled time),
- Cost (within cost)
- Health, safety and environment record ("don't do it if it is not safe", "safety first"),
- Risk mitigation

(Projects with zero lost time and injury at completion are usually considered a huge success)

5.2.5 Example I: Preparing a method statement for "Excavation"

Description of Work in the Bill of Quantity: Excavate trench to receive foundation wall footings

Methodology:

- Excavate manually using hand held tools such as diggers, shovels etc (depending on the soil type) **or** mechanical excavation using a back-actor (depending on the volume of work and scope)
- Disposal: Load excavated materials mechanically or manually into mechanical transport (dumpers, lorries) or manual transport (wheel barrows)

5.2.6 Example II: Preparing a method statement for "Concrete Foundation Footing"

Description of Work in the Bill of Quantity: Vibrated reinforced concrete 1:2:4 in foundation footing

Methodology: Concrete operations include:

- batching,
- mixing,
- transporting,
- placing and
- curing

The methodology can therefore be stated as follows: **batch** cement and other aggregates manually with the use of head pans; **mix** constituents using a concrete mixer; **transport** the concrete mixture manually using wheelbarrows or head pans, mechanically with the use of concrete pumps and hoppers attached to the tower crane; **place** manually using tamping rods or mechanically with the aid of a poker vibrator; and **cure** manually using a water hose.

The methodology follows this format for all the construction operations/activities on the project.

Plant Required

Under this column, only the type, capacity and number of plant required is specified. For example: 1No 1.2m^3 Face Shovel

Labour Required

The amount of labour required is based on the type and volume of work and the available personnel. There are constant output rates for every trade. The output rates can also be determined from previous performance or manufacturer specification for plant. Output rates are also based on work-study and it is usually specified in unit/day or unit/hr e.g. m^3/hr, m^2/day, m/day or no/day, obtainable from time sheets based on the identified tasks and work packages of the project.

Knowledge of the output rates can help in the computation of the number of personnel required for each construction operation/activity as shown in the Table 13:

S/No	Operation	Skilled Labour	Unskilled Labour	Output per hour
1.	Basement Excavation (manual)	1	8	$27m^3$
2.	Trench Excavation (manual)	1	8	$27m^3$
3.	Preparation & Fixing of Reinforcement	1	1	½ ton
4.	Concreting – column/wall footing	2	10	$20m^3$
5.	Construction Single leaf maxi brick wall	2	1	$20m^2$

Table 13: Labour Output Rates Per Hour for Construction Operations

Duration

This is based on the plant and labour output rate.

$$\text{Duration/Time required} = \frac{\text{Operation quantity}}{\text{Output rate}}$$

5.2.7 Documents that can be derived from the Construction Method Statement: -

While drafting the construction method statement, consideration will have been given to the following documents: –

- Buildability and Constructability Statements,
- Health, Safety and Environment Plan
- Quality Assurance Plan
- Organization Chart
- Risk Identification statements

5.2.8 The Software Tools Used in the preparation of the Construction Method Statement

Autodesk Navisworks 2011 © is used in:

- Finding and fixing conflicts and interferences before construction;
- Interpret design intent in the field; and
- Compare visual as-built schedules against forecasts to improve schedule oversight.

5.3 Construction Programme

The construction programme is defined by SACPCMP (2009 pg 82) as the programme for the works indicating the logic sequence and duration of all activities to be completed by the contractors, subcontractors and suppliers, in appropriate detail, for the monitoring of the progress of work. Chappell, Cowlin and Dunn (2009) defined a programme as a schedule or chart showing stages in a scheme of work. The main or master programme is usually produced by the contractor, which may produce many subsidiary programmes during the course of a contract to assist in the effective planning of sub-contract work.

5.3.1 The Purpose of Construction Programmes

a) To record agreed intentions with the client
b) To supply a time-table for co-ordinating the issue of drawings and information, the placing of orders and delivery of materials and the operations of plant and sub-contractors,
c) To prepare a basis for the introduction of payments by results or other incentives
d) To show the sequence of operations and the total output rates required of labour and plant,
e) Provide a yardstick for progressing,
f) To furnish the client with the likely financial requirements,
g) To discourage changes in design by indicating the natural consequences, whilst at the same time facilitating amendments and minimizing their harmful effects should contingencies arise.

5.3.2 The Popular Forms of Construction Programmes

The precise form in which the programme is set down on paper may depend to some extent on the type of work being undertaken and the people for whom it is intended. The popular forms of construction programmes are: –

- The network analysis – Programme Evaluation & Review Technique (PERT) and Critical path Analysis
- Gantt Chart or Bar Chart

Each method has its own particular advantages.

The Gantt or Bar Chart

The easiest to understand and most satisfactory method is the **Gantt or bar chart**. Charts of this nature are very versatile. Even when a more sophisticated technique like network analysis is used, the eventual schedule of work is usually presented in bar-chart form. The Gantt or bar chart is a valuable aid used in:

- **Scheduling the tasks** identified within the project time frame, giving a **visual representation** of the process.
- It indicates the **interdependencies** of the tasks identified using cascading arrows (i.e. instances where one activity cannot begin until another is completed).
- **Project milestones** (time points that indicate completion of key phases) and **deliverables** (defined and tangible outcomes of the project) can also be marked.

It is usual to list the items of work/activities to be carried out one below the other on the left-hand side, and show time horizontally as seen in Figures 56 and 57.

	Time (months) Items of work	9–28 Feb12 1	01-31Mar 2	3	4	5	6
1	Excavation						
2	Foundation						
3	Over site concrete						
4	Block work						
5	Concrete works						
6	Roofing						
7	Doors & Windows						
8	Electrical work						
9	Mechanical Work						
10	Finishes						
11	Painting & Decorating						

Figure 56: Explanatory Construction Programme

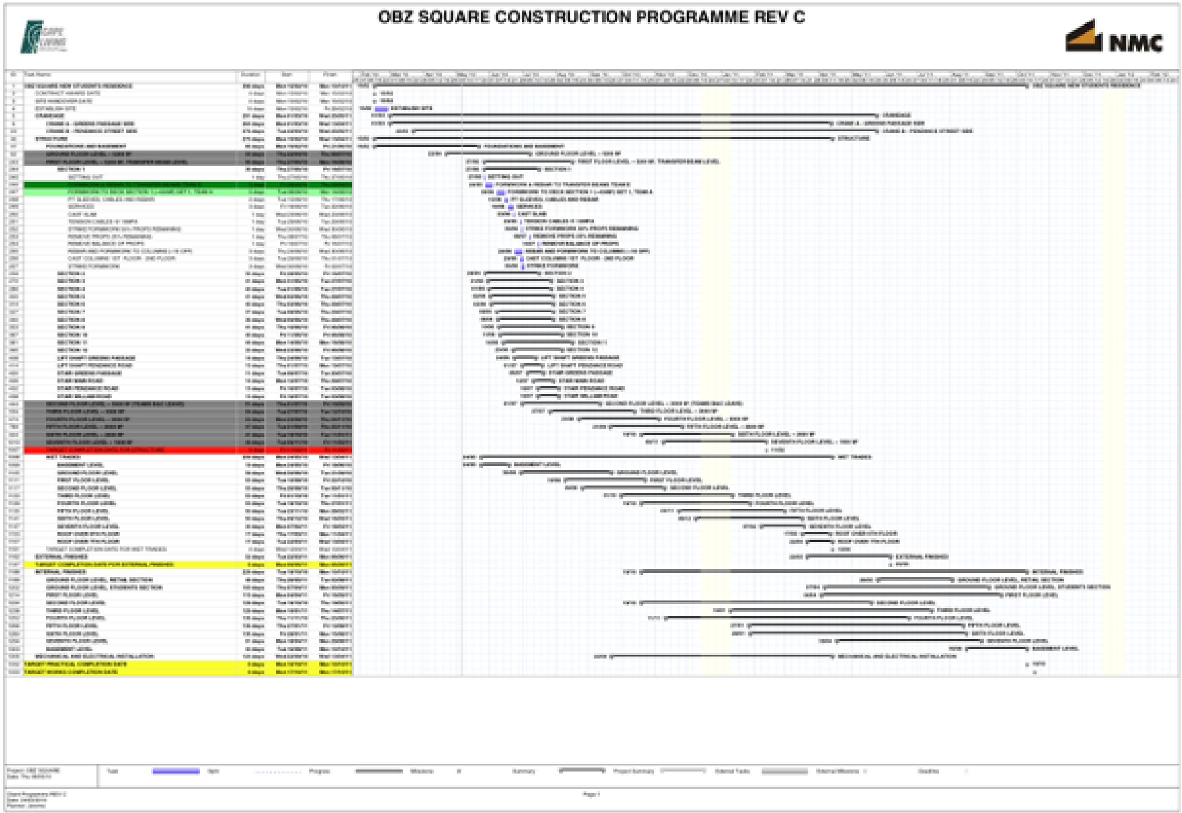


Figure 57: Detailed Example of a Construction Programme

Bars may be suitably hatched or coloured to distinguish trades, or left blank for the future recording of progress.

Advantages of the Bar Chart

1. It is very easy and simple to construct
2. It is easy to understand
3. Simplicity of updating
4. It is very easy to show the progress of work and programme of work
5. Easy to incorporate resource plan in terms of the plant schedule, material schedule and labour schedule required for the project.

Advantages of the Network Analysis:

1. It shows the relationship between the project activities
2. The programme shows critical and non-critical activities
3. It reveals the float in each project activity
4. It guides the construction manager in effective and efficient allocation of resources
5. It can be used to programme large and complex activities unlike the bar chart
6. The use of computer software makes the network analysis readily available.

Disadvantages:

1. It is very complex and difficult to prepare
2. Updating and entire control of the project is difficult
3. The level of familiarity with the technique and terminology by members of the project team is very low
4. The preparation of a resource plan or schedule with the programme as obtained in bar charts is very difficult.

5.3.3 Management Techniques Used in Preparing the Construction Programme

- Planning
- Forecasting and
- Organizing

Process Used

On being awarded a contract, the successful contractor must act quickly, thereby consolidating on the benefits of his pre-tender work. Detailed work at the earlier stage will pay dividends and will enable the contractor to be in position to analyze all additional information prior to taking possession of the site. This stage is also known as **contract preliminary planning** to distinguish it from the **short-term site planning** which follows later.

Overall planning of a project is carried out prior to the commencement of work on site, so that: –

- Management may have a thorough appreciation of the work involved
- Allow those responsible for production to sort out its main contents/constituents and decide how, in what order and at what time to do them, and
- Ensure adequate co-ordination of the labour, plant material requirements

The amount of detail depicted on programme charts varies considerably, and it depends on the intended use of the programme. For example, the construction manager may be content with an activity as broad as "Construct Foundation" while the section engineer/foreman/supervisor will break this into a finer level of detail, say "excavate, blind, fix reinforcement, place formwork, place concrete, cure concrete, strike formwork and backfill". Therefore, three definite scales are distinguishable at project planning level. These are:

a) A broad master programme,
b) Intermediate, section programmes,
c) Detailed operation programmes.

The Master or Overall Construction Programme covers the full contract period and includes the complete works in broad, overall terms. Information required for preparing the construction programme includes:

1. List of project activities
2. Activity precedence
3. Scope of project activity
4. Activity start and finish date
5. Activity duration

Time is usually plotted in months and weeks, with dates and contract week numbers entered. Holiday periods are also shown, since allowances must be made for these reduced or lost production spells. The **contract completion dates** stipulated in the contract can be drawn either as vertical lines or indicated by appropriate symbols. Any other specified or otherwise obvious stage dates are also marked.

Every major **item** or **distinct phase** of the works is listed down the left hand side, with the more important total quantities where appropriate. The number of titles should not be too numerous, but under inclusive headings the whole contract should be accounted for including preliminaries. In most instances the "**description of works**" given in the bills of quantities, with a little elaboration, is all that is required and following in the **construction sequence** so far as is possible.

The programme outline can then be sketched in following: –

- Accepted trade practice for building work,
- Experience and
- Innumerable practical considerations.

Economic periods for each operation may be calculated from: –

- The gang or machine sizes chosen and
- The anticipated output rates; or
- The time available for a particular task may be decided by other factors

Specialists and sub-contractors such as plumbers, electricians, tilers, carpenters, steel or R.C frame erectors, lift engineers, etc. must be consulted as far as possible, to ensure that they are allowed sufficient time and to enlist their full co-operation.

When the framework has been outlined, the works enumerated, and the economic periods are calculated, the construction programme can then be drafted, although it may be subject to minor revisions after the stage programmes have been prepared. Ideals aimed for in a construction programme include:

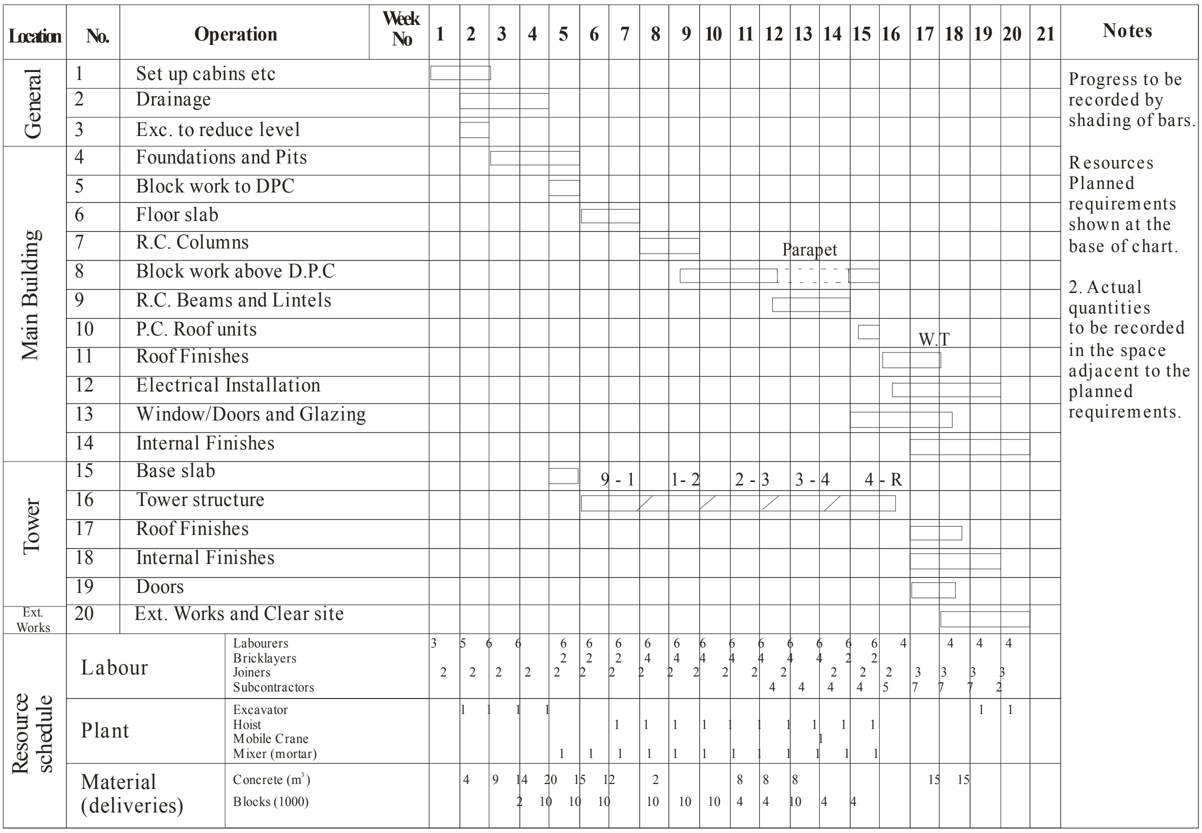
- A steady build-up from the start
- A constant level of activity thereafter with as few peaks as possible and,
- A quick run-down at the finish.

Thereafter, with the salient dates already mentioned, the strategy scheme falls into place like a jigsaw puzzle as illustrated in Table 11 and Figure 39. Once drawn-up and approved the construction programme becomes in effect a contract document, and should not be altered unless exceptional contingencies arise or a major change is made in the design.

5.3.4 Documents that can be derived from the Construction programme

The construction programme can be used in preparing: –

- **Budgets and cash flow statements/financial graphs**, which can be used as a check on the financial 'shape' of the contract. This financial graph will also provide information to the client as to his anticipated liabilities for monthly payments, and can similarly be used by the Quantity Surveyor as a target or comparison for his interim certificates;
- Materials requirement schedules;
- Labour requirement schedules. The labour required could be aggregated by categories, to show the anticipated total number of men that would be required throughout the life of the contract, if the overall labour strength is summarized and charted as a **labour graph**, it is usual to present this below the construction programme as shown in Figure 58. This graph should indicate a steady buildup and an even demand until the fall-off at completion.
- Plant requirement schedules
- Information requirement schedules



* **Figure 58:** Sample bar/Gantt chart programmes and Resource Schedule

While drafting the construction programme, consideration will have been given to: –

- The construction methods to be adopted, it is possible to explore alternatives and compare them on the basis of cost
- Types of plant to be used and
- The manpower requirements for each key operation.

By the time construction programme is completed, a **methods statement** should have also been drawn up, recording in detail all the decisions taken. This document later serves as a useful reminder and guide for the site management, as well as providing a basis for requisitioning plant and forecasting the labour force needed.

5.3.5 The Software Tools Used in the preparation of the Construction programme

The software tool commonly used in the preparation of construction programmes is **Microsoft© Office Project**. Microsoft Office Project is a powerful tool used in project management that helps construction managers to:

- Standardize and document the project plan
- Outline project phases, activities, tasks and milestones
- Analyze a project with work break down structures
- Scheduling a project based on the start or finish dates

Microsoft Office Project has hundreds of commands and its use requires lots of practice.

5.4 Materials Scheduling

The major resource requirements in order to fulfill the contract programme should be extracted from the method and resource statement and presented in the form of a histogram or schedule on the actual construction programme (see Figure 58). Many firms produce separate schedules giving greater and more comprehensive requirements; however, this decision must be taken in relation to the size and nature of the work in hand.

5.5 Risk Analysis and Identification (Forecasting Tool)

All projects have elements of risk associated with them, largely because they involve new activities and innovative work (an uncharted area so to speak or a journey into the unknown). A general analysis of risks associated with the project should be performed at an early stage to **identify the risks** and **scope their potential impact**.

On construction projects, an analysis of risks would include consideration of factors such as: –

a) **Staff**:
Would you find the right mix of people and skills for the project?

b) **Equipment:**
Is appropriate equipment available locally? Should you hire or buy construction equipment?

c) **Contract Document:**
Are there risks assigned to parties by the contract that do not have the ability to control these risks if it occurs?

d) **Dependencies on External Factors?**
What is the extent to which the successful delivery of the project relies on external parties, such as suppliers, the government, sub-contractors, consultants, etc?

e) **Extent of innovation or novelty of the project?**
To what extent does the project involve new and innovative work?

f) **Identified Health & Safety hazards** in the project work packages

After the risks have been identified, the risks can then be graded with a hazard rating of low, medium and high and the likelihood of their occurrence estimated. Contingency and containment plans for **activities** with a degree of risk associated with them, should be created which include any relevant adjustments to timescales and costs.

For a more detailed analysis of the likelihood of identified risks occurring, software is available for calculating statistical probabilities, such as OPERA, which is part of the Open Plan Professional System.

5.6 Budget and Cash Flow Requirements

For any construction project there will be a need for money. The money is used to pay for material, labour, plant, equipment, professionals and so forth. Project activity is estimated at the bidding stage. Information required include:

a) **Cost of Employing Staff:**
Recruitment costs, salary, insurance, health care, pension contributions, etc.

b) **Productivity:**
Obtainable from time sheets, based on the identified tasks and work packages of the project

c) **Material requirements**

For a successful project specific amounts of money will be allocated to each specific need. These specific amounts will all be added together and will then form the total cost of a construction project. The amount budgeted for should be the same or greater that the projected cost of the project if the project is to be executed.

a) **Budget estimate**: is the initial estimate of the money available for the proposed structure.
b) **Budget**, this is a combination of the finalized estimated cost and the money available for the proposed structure.
c) **Budgeting and cost control**, this is the process of matching actual expenses and completed work with the estimated cost (the budget).

The budget is worked out and introduced before the building work starts on site. The budget will include the cost of materials, labour and plant that is the direct cost of actually constructing the building, but there are a lot more costs also called the "overhead costs" involved such as:

- Escalation Costs
- Professional fees
- Management Cost

- Legal Cost
- Service Connection Fees
- Interest Expense on Loans
- NHBRC Development Levy

All these expenses are worked out before hand during the planning stage. When a production programme is prepared using Gantt charts or network analysis, the logic of the operation is defined and outlined, and also, the time and resources can be allocated to each activity. Every operation on the site has a normal time which is associated with its optimum cost performance. For purposes of cost control, cost centers are selected. A cost centre is a location, person, and item of equipment, activity or a group of activities for which costs may be obtained and used for the purpose of cost control. It is recommended that cost centres should be related to **operations** (or tasks).

Assuming that operations have been selected as the basis of cost control, it will then be necessary to build up a cost programme by allocating to each operation a budgeted cost in terms of materials, labour and plant. This cost will not necessarily be a reflection of the rate included in the B.O.Q. The detailed programme (done after the award of a contact) will inevitably vary in method, time and cost from the pre-tender programme and many of the bill rate will be found to be unrealistic Calvert et al., 1995). Accumulative cost or a budget can in this way be built up to match the construction programme.

Budget Format

Material and labour costs are worked out for the project. The descriptions on the left hand side of the document will show the operations to which money has been allocated money. The totals on the right hand side will show the total amount of money allocated to each operation/activity for the entire project. All the prices that are listed for the materials are the price of that item in the area where the project is taking place. It is the job of the estimator to find out the prices of the materials in the area where the project is done. Once the building cost including the other entire cost on site is worked out, a data sheet illustrated in Table 14 is drawn up. This data sheet helps the construction manager to make sure that all other costs are taken into account. It forms a template for the construction manager.

S/No	**Items of Work**	**Months**						**Total Budgeted Expenses (R)**
		9–9 Feb 12	Mar 2012	April 2012	May 2012	June 2012	1–10 J uly 12	
1	Excavation	61790						61790
2	Foundation	123585						123585
3	Oversite Concrete		61796					61796
4	Blockwork		85944	50000				135944
5	Concretewk		38836	38836	8837			86509
6	Roofing			73380	50205			123585
7	Doors & Windows				50205	73380		123585
8	Electrcl Wk			30895	30895			61790
9	Plumbg Wk			30895	30901			61796
10	Finishes					158895	88275	247170
11	Painting & Decorating						148300	148300
	Total (R)	185375	186576	224006	171043	232275	236575	**1235850**

Table14: Explanatory Budget Format

Figure 59 presents a graphical view of the monthly budgeted expenses shown in Table 14. It enables the construction manager to know the periods in which he has to source alternate funds or in which he has to review the proposed construction programme in order to level out the funds required monthly.

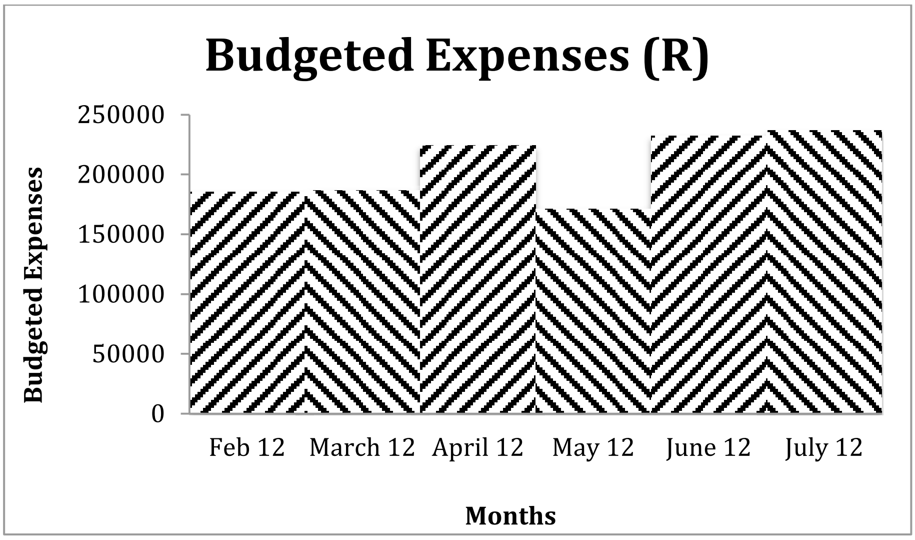


Figure 59: Graphical view of budgeted expenses shown in Table 12

While preparing budgets it should be ensured that every single aspect of the project is taken into account. And when there are foreseen expenses that are not measurable at that time, contingency sums should be allocated to these expenses. Budgets will help to keep the project on track so that overspending will not become a problem and can be used as a safety against wastage. If any problems occur one can always refer back to the budget to see what is really happening.

Budgets form the core of the financial planning for a project. If budgets are not worked out correctly and parts of the project are over looked or left out, it will certainly affect the profitability of the project and can cause failure. Budgets should be done, as accurately as possible and a buffer e.g. contingency amount should always be provided for any unforeseen events. Moreover, it should be remembered that budgets are what make clients choose contractors and the key is to budget as accurately as possible.

5.6.1 Description of Cash Flow requirements

Cash flow is used in any business not only construction. It is the process of planning when and how much money will flow in and out of the business. Cash flow is an indication of where money will come from to fund different project stages e.g. loans, profits or capital and where money is going. For building companies planning of the cash flow plays an important role. During a project there is a period of time where money will be flowing out of the business to pay for all the materials and equipment to start the construction. Only a few months after some work is done, does the business start to earn money in return for completed work. If the cash flow is not planned correctly there could be times where there is no money available in the business to continue with the project.

The cash flow is planned during early stages of the project before construction has actually started. This is known as the pre-construction phase. The cash flow goes hand in hand with the budget, where the budget tells how much money is allocated to specific elements of the project, the cash flow will tell when the money is paid to these elements. Lack of cash flow planning can cause failure of the entire project or late delivery. Throughout the duration of the entire project cash flow is used to manage what work should be finished at what stage. So cash flow is used throughout the entire project. Refer to Table 15 and Figure 60 for an example of a projected Cash flow based on projected expenses on construction project illustrated in Table 14. Managers use the cash flow statement to ensure that the construction stays on schedule with the planning and to procure loans/project funding.

Description	**Months**								**Total (R)**
	Feb 12	Mar 12	Apr 12	May 12	Jun 12	Jul 12	Aug 12	Sep 12	
Brought Fwd	0.00	(185375)	(371951)	(392004)	(357853)	(343721)	(392149)	(136646)	
Money Received (+ 10% Profit)	0.00	0.00	185375 +18538	186576 +18658	224006 + 22401	171043 + 17104	232275 + 23228	236575 + 23658	1235850 +123587
Expenses/Total Payments Made	185375	186576	224006	171043	232275	236575	0.00	0.00	1235850
Cash Flow Surplus/(Deficit)	(185375)	(371951)	(392004)	(357853)	(343721)	(392149)	(136646)	123587	

Table15: Projected Cash Flow Statement

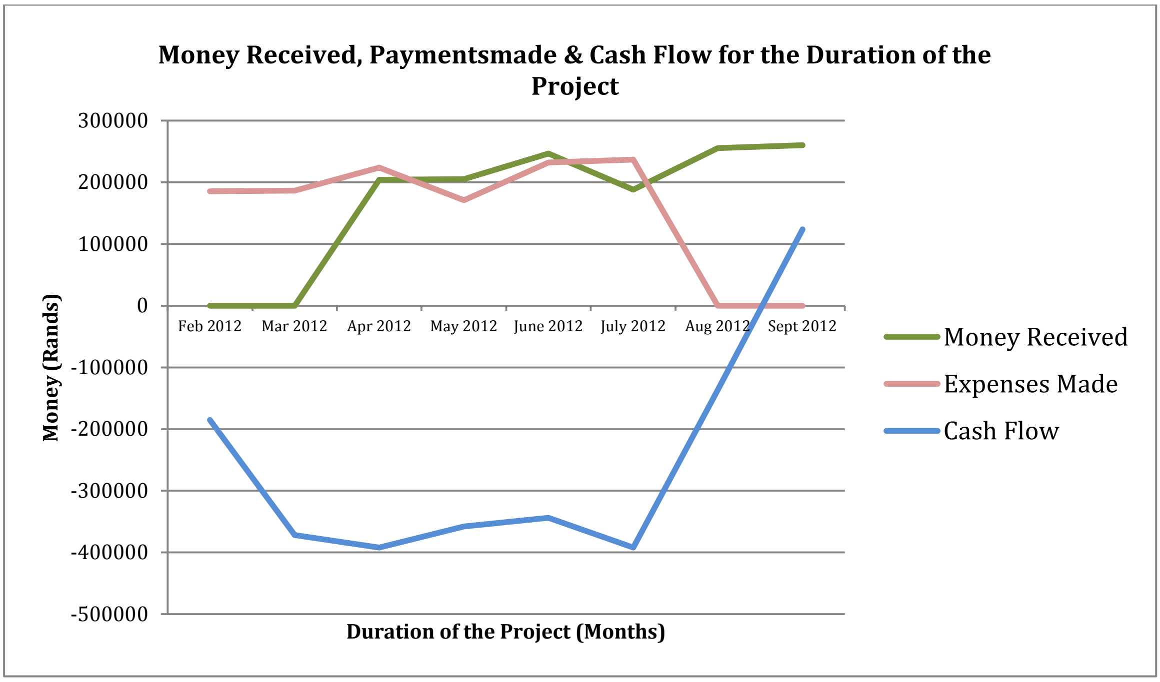


Figure 60: Construction Project Projected Cash Flow

Figure 60 shows the relationship between total money received (receipts), total payments made and cash flow surplus/deficit. The green line is the total receipt for the project. Figure 60 indicates that in September, the graph spikes up rapidly as this is the month in which the final payment was made and there were no expenses incurred. The pink line is the total expense made during construction. The line is fairly level throughout the duration of the project and only tapers down when there were no further expenses made on the project in August and September. Finally, the blue line is the cash flow surplus/deficit. The cash flow is calculated by working out the difference between the total receipts and total payments; and then, carrying forward this figure to the opening balance for the forthcoming month. The x-axis represents the amount of money, in millions of Rands and on the y-axis is the duration of the construction project, in months.

5.6.2 Software and tools used when preparing Cash Flows

Microsoft Project or Access can be used in Cash Flow preparation

Cash flow is probably the most important document produced by a Construction Manager for a project. Unless a company ties up an exorbitant amount of capital (too much to be profitable), the company must work out a specific cash flow for the project. It is the hardest thing to get right and many large companies go 'bust' if a mistake is made.

5.7 Project Control Techniques

After a construction contract has been awarded and project commenced on site, it becomes necessary to know and monitor the course of the construction project. Important aspects are therefore:

- Labour Utilization control
- Machine Utilization Control
- Materials Utilization Control and
- Cost control

Project monitoring and controlling starts once construction activities begin on site. The requirement of a control system is to detect and indicate deviation from norms. Control should consist of comparing work in hand with the planned performance, in order to direct activities to meet the objectives of the project.

The **planning techniques** are the initial instrument by which the manager will measure performance, cost and profit; correspondingly, control techniques are the instruments by which the results achieved by the manager are reflected and portrayed. As a monitoring service or instrument, 'control' obtains and supplies information for the use of the manager in assessing his performance and accomplishment.

Project control represents a service to management by providing information and proposals for control, but it does not exercise that control itself. Intercommunication and feedback of information are its vital concern, and the following steps are involved:

1. Set standard of operation
2. Prepare programmes and schedules
3. Evaluate performance and progress
4. Indicate adjustments required
5. Apply corrective measures.

The middle three of these steps recur together to form the universally applicable control sequences or feedback loop. It is for management initially to approve the overall plans of operation (as in tender planning and estimating) and later to ensure that required corrective actions are taken (as at project and site levels). An organized system of this kind ensures a ready detection of deviation from the standard and thus enables early control action to be taken.

Various routine staff management and supervisory approaches can be adopted or more formal methods introduced where **updates** on tasks are gathered regularly. Reports may be produced as part of this process. One type of monitoring is to use exception reports which only cover areas or activities, which are at **variance,** or diverging from the plan.

Regular management and financial reports, quarterly progress reports require reporting on: –

- The progress of **individual work packages**,
- Income received and expenditure by the project during the reporting period and any variations to cash flow forecast in the business plan, and
- A checklist of compliance with the project's technical standards/requirements.

5.7.1 Control Information and feedback

Essentially, control systems provide: a means of measuring the process to be controlled; comparison of this measurement against a target or standard for the process; 'feedback' of the amount of divergence so obtained (positive or negative). This information 'signal' is then used as a guide to the change (s) to be made in the process in order to revert to the required standard level of operation. Figure 61 illustrates the process of planning and controlling within construction with a feedback loop.

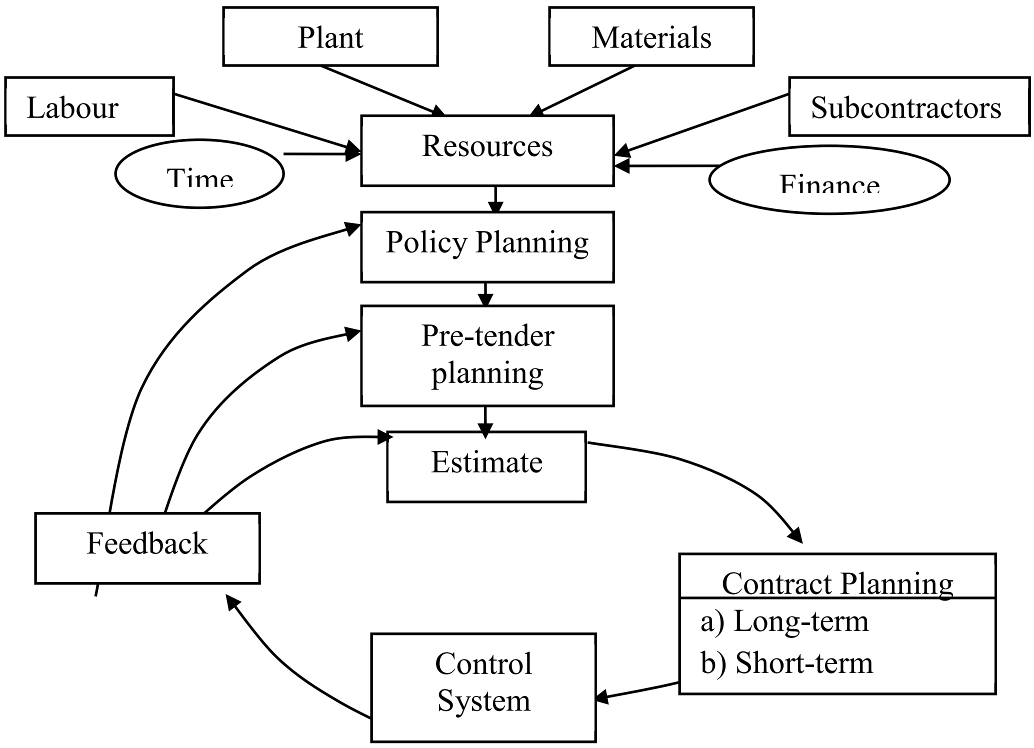


Figure 61: The process of planning and controlling within construction

5.7.2 Exercise 3

Consider the project delivery and the construction process of the building detailed in Figure 45 and attempt the following:

- Prepare a scope statement for the project;
- Draw a WBS for the project;
- Prepare a method statement for the oversite concrete bed if concreting output is $20m^3$ for a gang of 2 artisans and 10 general workers + a concrete mixer.

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