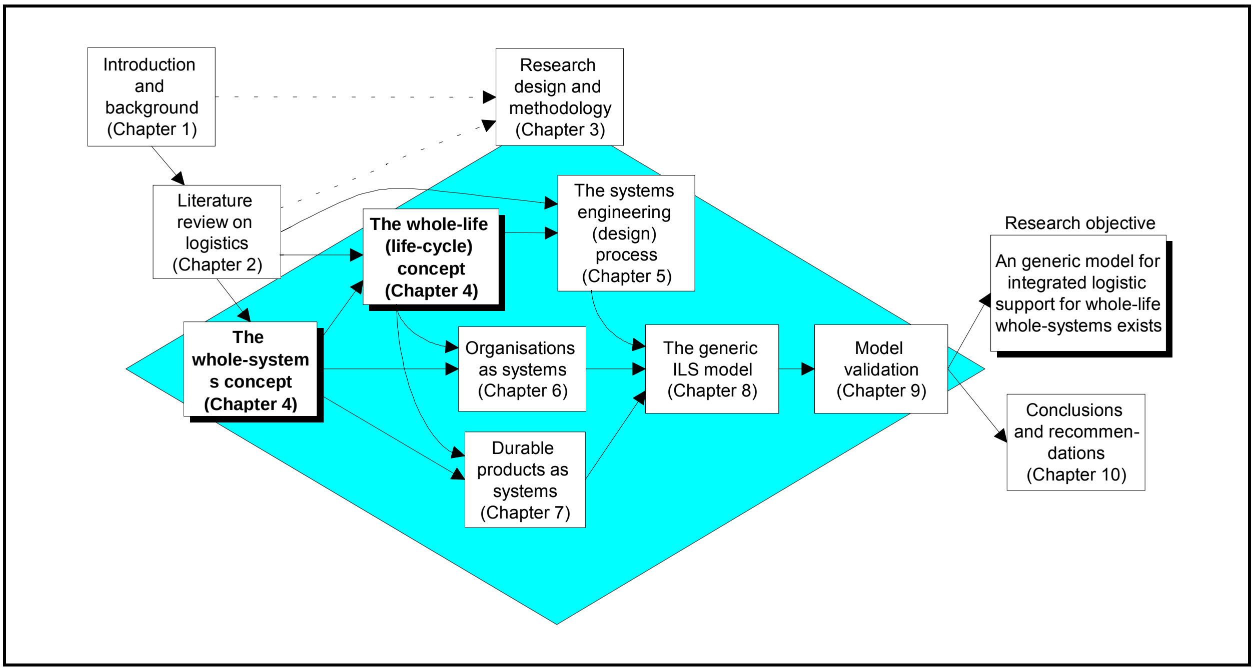
Chapter 4

The whole-life whole-system concept

"These are the generations of the heavens and of the earth when they were created, in the day that the LORD God made the earth and the heavens."

Genesis 2:5, KJV



4.1 Purpose and outline of the chapter

The purpose of this chapter is to provide the theoretical background to systems and the concept of viewing a system as a whole and over its whole-life. The theory and concepts presented in this chapter are prerequisites for the development of a generic approach to integrated logistic support as the said approach has its foundation in systems theory. The other prerequisite, the process of bringing a system into being, will be presented in the next chapter.

The outline of the chapter is as follows:

- A definition will be provided for a generic system.
- System characteristics will be discussed by looking at the history of systems thinking and how it evolved into a modern view of systems characteristics. This modern view will be provided to support the definition of a generic system.
- A distinction will be made between different categories of systems which will demonstrate that the definition of a generic system is valid irrespective of the type of system observed.
- System structures will be discussed to demonstrate the common functions within any system and how they interrelate and interact to perform a useful purpose. This discussion is necessary to highlight integrated logistic support as one of the essential functions required within a system.
- The whole-system concept will be presented to demonstrate that systems do not exist in isolation. This fact will be used to demonstrate that all functions within a system are influenced at least to some extent by its position within its hierarchy. Position in the hierarchy implies interfaces with other elements on the same, higher and lower levels of the hierarchy.
- The whole-life concept will be presented to illustrate that
  - systems exist in time,
  - system performance later in the life-cycle is affected by early life-cycle decisions, and
  - it is thus imperative to approach any system from a life-cycle perspective.
- The measurement of system success (in terms of its stated goal) will be presented to demonstrate that despite the fact that systems and system goals differ, generic system success measurements can be defined. The discussion on generic system measurements will be used to demonstrate that integrated logistic support (as one of the essential system functions) has a major impact on the generic system success measurements.

4.2 Definition of a system

A system is a set of interrelated components working together and self-sufficiently at its level towards some common objective over a period of time [Adapted from Blanchard and Fabrycky, 1998:2]. The generic function of a system is to process inputs into outputs through its components and it exists within a wider system with which it interacts. The common objective, purpose or goal of a system is determined by the owner of the system.

Having given a definition of a system it is necessary to discuss what a system consists of. Blanchard and Fabrycky [1998:2] state that a system consists of the following:

- *"Components are the operating parts of the system consisting of input, process and output. Each system component may assume a variety of values to describe a system state as set by some control action and one or more restrictions.*
- *Attributes are the properties or discernable manifestations of the components of a system. These attributes characterise the system.*
- *Relationships are the links between components and attributes."*

Blanchard and Fabrycky [1998:2-3] continue to explain that any system that alters material, energy or information, consists of different components namely:

- Structural components; the static parts that keep the system together.
- Operating components; those components that perform the alteration of material, energy or information.
- Flow components; material, energy or information being altered.

Blanchard and Fabrycky [1998:2-3] and Ackhoff [1999:15-16] describe that the set of components of a system has the following properties:

- "*The properties and behaviour of each component of the set has an effect on the properties and behaviour of the set as a whole.*
- *The properties and behaviour of each component of the set depends upon the properties and behaviour of at least one other component in the set.*
- *Each possible subset of components has the two properties listed above; the components cannot be divided into independent subsets*."

Another view of systems is that of Aslaksen and Belcher [1992:8] stating that a system consists of three related sets:

- "A *set of elements, which may be of any type (e.g. hardware, software, activities, concepts, people), but they must form a set; that is, there must exist a rule that allows a decision to be made about whether an object is a member or not of the set.*
- *A set of interactions between the elements which may also be of any type, and while they will often take the form of an interchange of energy or information, they are by no means restricted to having a physical nature. They can be purely logical (e.g. the ordering of elements).*
- *A set of boundary conditions which are the interactions between the elements and all other objects (i.e. the outside world), to the extent that they are chosen to be considered in any given case. The set of boundary conditions is often divided into subsets that are treated in basically different ways as far as the functions of the system are concerned, such as inputs / outputs and environmental conditions*.

Another definition for a system is provided by M'Pherson [1980:549] that states the following: *"A system is usually defined as a complex organisation of men, equipment, resources and operations through whose integrated functions an operational need is satisfied . This specialized concept of a system has developed over the last 30 years to deal with the problems that arise from the complex structure and behaviour of modern human activity and technological systems."* M'Pherson [1980:549] continues to say that "*this definition barely conveys the intricacy of the system concept with its hierarchical levels and lateral functions that change and evolve in time - all nesting in enclosing system shells."* Even though M'Pherson's landmark article was published twenty years ago, his arguments and definition still hold true today.

The way in which systems are observed vary widely. This will become obvious in the discussion on the classification of systems in § 4.4. Of importance is not how systems are observed but whether the object of observation is in actual fact a system or just an aggregate of related things with no common objective or purpose. Thus, if an aggregate of related objects is to be classified as a system, it must exhibit the following properties [M'Pherson, 1980:550]:

- "*The structure must consist of many elements that are connected through many interrelationships - which implies the existence of loops and complexity.*
- *The organisation's behaviour must be dynamic and of such a character that it is not easily inferred from the reaction to their inputs of the individual elements in the organisation.*
- *The behaviour should be purposeful and directed towards the achievement of some goals.*"

M'Pherson [1980:550] argues that the properties defined above are such *"commonly accepted properties of 'systems', but successful systems i.e. ones that survive, improve and achieve their objectives, require additional attributes namely:*

- *The structure is compartmented into operational, directional and supporting sub-systems interlinked by an information sub-system.*
- *The structure as a whole must be at least reliable and resilient, while - for longer term survival - the structure may also have to be adaptive or capable of reorganisation.*
- *At this level a system would have to be intelligent and normative, i.e. it is aware of deficiencies within itself, and defines better structures or goals*."

These properties as defined by M'Pherson are fundamental in the argument that logistic support should take place in an integrated manner with the whole-system over its whole-life and will be explored further in this study.

4.3 A modern view of system characteristics

The development of systems theory can be divided into two distinct phases namely the Machine Age and the Systems Age.

4.3.1 The machine age [Blanchard and Fabrycky, 1998:10-11; Ackoff, 1999:6-14]

The first phase of the development of systems theory is based on an approach consisting of two ideas by which people seek to understand systems and the world around them. This first idea is called reductionism consisting of the belief that everything can be understood if it is reduced, decomposed and/or disassembled into simple indivisible parts. A system is explained by taking apart all its components to its lowest possible level, seeking an explanation of each individual part, after which these explanations are aggregated to explain the whole, a process known as analysis.

The second idea consists of ‘mechanism’, where all phenomena are believed to be explainable using only cause and effect relationships. The cause was believed to be both necessary and sufficient to explain the effect. Nothing else is therefore required to explain the effect other than its cause and permits no exceptions. Not permitting exceptions creates a laboratory effect which implies a controlled environment where anything external to the environment cannot influence the cause-effect relationship. Consequently, causes external to the controlled environment (laboratory) are ignored leading to closed-system thinking (see § 4.4).The resultant view of the world (and systems) is thus purely deterministic and yields a conception of the world as a machine.

4.3.2 The systems age [Blanchard and Fabrycky, 1998:11-12; Ackoff, 1999:14-25]

Within the second phase (systems age) of the development of systems theory, reductionism, mechanism and the analytical mode of thinking are supplemented with expansionism, teleology (concepts such as functions, goals, purposes, choices and free will) and a synthetic (or systems) mode of thought.

Expansionism is an approach that considers the larger whole. Therefore objects, processes or events, relationships and outcomes are seen within the bigger picture. Expansionism’s focus is on the whole, instead of the individual parts, but does not deny the existence of the parts. This alternative view of systems, shows expansionism as being different but compatible with and supplementary to reductionism.

Synthetic thinking is concerned with explaining something as part of the whole and its role within that system, as opposed to analytic thinking that tries to explain the parts of the system. Synthetic thinking helps with the understanding of the system that is not possible with analytical thinking. The synthetic mode of thought is based on the observation that when a single part of the system is improved, it does not necessarily lead to an improvement of the system as a whole. Synthetic thinking therefore does not follow the additive rule as analytical thought does.

Synthetic thinking versus analytical thinking is best illustrated using a chain as an analogy. The purpose of a chain is to have strength. Strength is a chain’s prime measurement. The strength of the chain is determined by one and only one weakest link. Even if all the links are of a strength that are more or less the same, the chain will break at one link only if sufficient force is applied to the chain. This is only true because of the interdependent nature of the links, which qualifies the chain as a system. It now follows that improving the strength of the chain is only possible if the weakest link is improved. Improving any other link does not improve the strength of the chain. This demonstrates that improvement of a chain as a system, with strength as its prime measurement, does not follow the additive rule. An improvement of one strength unit on a non-weakest link does not get added to the strength of the chain as a whole.

Analytical thinking very often follow the additive rule. Another measurement for a chain is weight, but it is definitely not the prime measurement for a chain in its intended application. If the weight of the chain is to be reduced, then weight can be removed from any link, which will lead to a weight reduction of the chain as a whole. A reduction in one weight unit from an individual link will lead to a reduction of one weight unit of the chain as a whole. This approach treats the links as independent, which allows the additive rule to be followed. However, by removing weight at random from individual links to decrease the weight of the chain, will in the end lead to a decrease in the strength of the chain, as there is a relationship between the strength of a link and the amount of material required (and thus weight) to ensure that strength. The chain analogy demonstrates how synthetic thinking supplements analytical thinking in the understanding of systems which is not possible with analytical thinking on its own.

Synthetic thinking on its own will not make any sense unless the teleological component is added. Teleology is concerned with the view that systems must have some purpose, or that phenomena are explained by their ends or purpose. This means that systems must be able to display choice of either means or ends, or both. Only by using this view can synthetic thinking make sense as synthetic thinking is concerned with explaining something as part of the whole and its role within that system, as mentioned earlier.

4.3.3 The effects of the development of systems theory

The new systems mode of thought brought about the following ideas to viewing systems, providing fundamental insight in understanding them:

- Holism (or expansionism) where the focus is on the system rather than on its components:
  - Systems exist in a hierarchy (The system at one level may be the component of another system at the higher level).
  - A system exists in an environment and has inputs from and outputs to the environment (Boundaries of the system).
  - Systems exist in time (The life-cycle or whole-life concept).
- Synthetic thinking which means the system is greater than the sum of its parts:
  - The system has emergent properties i.e. properties that does not exist when the parts exist in isolation e.g. when H_2 and O_2 interact to form H_2O [Gharajedagi, 1999:45-48].
  - Optimising individual components does not necessarily lead to an optimal system meaning a system is constrained in its output by a single part. [Wang, Han & Spoere in Wang Ed., 1997:15]
  - The system is subject to entropy because of the entropy of its individual parts and relationships amongst them [Aslaksen and Belcher, 1992:70].

- Teleology is a doctrine preoccupied with systems that are goal seeking or purposeful:
    - Each system consists of functions that work towards a common goal. [Ackoff, 1999:24]
    - The owners of the system have the sole right to determine the common goal [Goldratt, 1990a:11].
    - The system have choice and free will with regards to the approach (or strategy) to follow in pursuit of the goal.
    - The system is reliable and resilient, but can also adapt readily to environmental changes [M'Pherson, 1980:550].
    - The system is aware of its deficiencies and can act normative [M'Pherson, 1980:550].

4.4 A classification of systems [Blanchard and Fabrycky, 1998:4-7]

In order to illustrate the broad range of aggregations of components and interrelationships that work towards a common goal, the following classification of system types is presented:

- *Natural versus man-made systems*

  Natural systems can almost be classified as the mother of all systems. They are deemed to be the origin of systems as they came into being by natural processes whereas man-made systems are those systems where man has intervened in establishing relationships between components and attributes for a specific purpose. All man-made systems are embedded in natural systems, sometimes with detrimental effect, e.g. the Chernobyl disaster which caused many deaths, severe suffering and environmental pollution due to a system failure. Technological advancement will see to the creation of many more man-made systems, which requires a more acute analysis of the impact these systems will have on the natural systems or environment.

- *Physical versus conceptual systems*

  Physical systems are those systems that are real in the sense that they occupy physical space and are composed of physical components. In contrast to physical systems, conceptual systems are the organisation of ideas where symbols or some other medium represent the interactions and attributes of the components. There is however, a strong relationship between conceptual systems and physical systems. This is what Covey [1992:99] refers to in his statement that *"all things are created twice. There's a mental* (idea, concept) *or first creation, and a physical or second creation to all things".* The first creation is the conceptual system (the design of the system), whereas the second creation is the realisation of the idea or concept (the physical system that has come into realisation). It is however possible that sometimes a conceptual system may be a physical system, such as a breadboard electronic circuit, a scale model of a building or a proto-type of a vehicle. The fact that the conceptual system (first creation) is also of a physical nature, does not make it the physical system (second creation).

- *Static versus dynamic systems*

Another way to observe systems is to classify them as static (passive) or dynamic (active) systems. This implies that within a static system there is structure but no activity and within a dynamic system there is structure with activity. However, within a static system, such as a bridge, (or even the scale model of a building) there are components, attributes and interrelationships according to Blanchard and Fabrycky's view, and elements, interactions and boundary conditions according to Aslaksen and Belcher's view, thus making a static system qualify as a system. There is also a purpose for the system. Furthermore, within the wider system in which it exists, activity does take place, which means that on the bridge's level it is a static system, but the higher level, the transportation system, there is activity and changes in attributes. Looking at it from another perspective a system can only be static over a short period of time. Even when viewing the bridge on its own system level, dynamic activity took place in the construction of the bridge, and deterioration takes place over time (because of the second law of thermodynamics) during its operational phase. Thus static systems exhibit that static characteristic only over a short period of time. An example of a dynamic system is a university, combining facilities, lecturers, students, information, money, energy, management skills, land, support and materials to achieve a certain outcome.

- *Closed versus open systems*

The openness or closedness of a system has to do with its interaction with its environment. In closed systems, very little or no interaction with the environment takes place. The environment only provides a context for the system. An example of a closed system is a closed vessel where chemical equilibrium is eventually reached when various reactants are mixed together. Open systems are systems where the flow components cross the boundaries of the system. Open systems interact with their environment, such as a business organisation.

4.5 The whole-system concept

A basic system consists of the system in question, or the system of interest (SOI), the system that creates the system of interest or realisation system (RS), as well as the wider system (WS) within which both these previously mentioned systems exist. Each system draws resources from the resource environment within the wider system as shown by Rottier [1999:Figure 4.1]. A fairly comprehensive, detailed and complex model for the different types of systems and their interactions is provided by M'Pherson [1980:551], but for the purpose of this study simplified models, derived from M'Pherson's model, will be used to illustrate the whole-system concept.

The realisation system is the system that creates the system of interest. For the realisation system to contemplate the creation of a new system, a need or opportunity for the new system must exist within the wider system, that has created a gap or deficiency within the host system as demonstrated in Figure 4.1. This need can be filled by the system of interest which means it has to have a purpose to be able to fill the gap and satisfy the need in the operational arena. The position of the realisation system within the wider system is explained in § 4.5.1 and § 4.5.2.

It can thus be hypothesised that for any system to come into existence, a realisation system must exist first. This hypothesis is in line with the age old question how the universe came into existence. The Creation is, as far as this author is concerned, the first example of bringing a system into being, performed by God being the realisation system [Genesis 1], making systems engineering the oldest profession contrary to the popular belief that prostitution is the oldest profession.

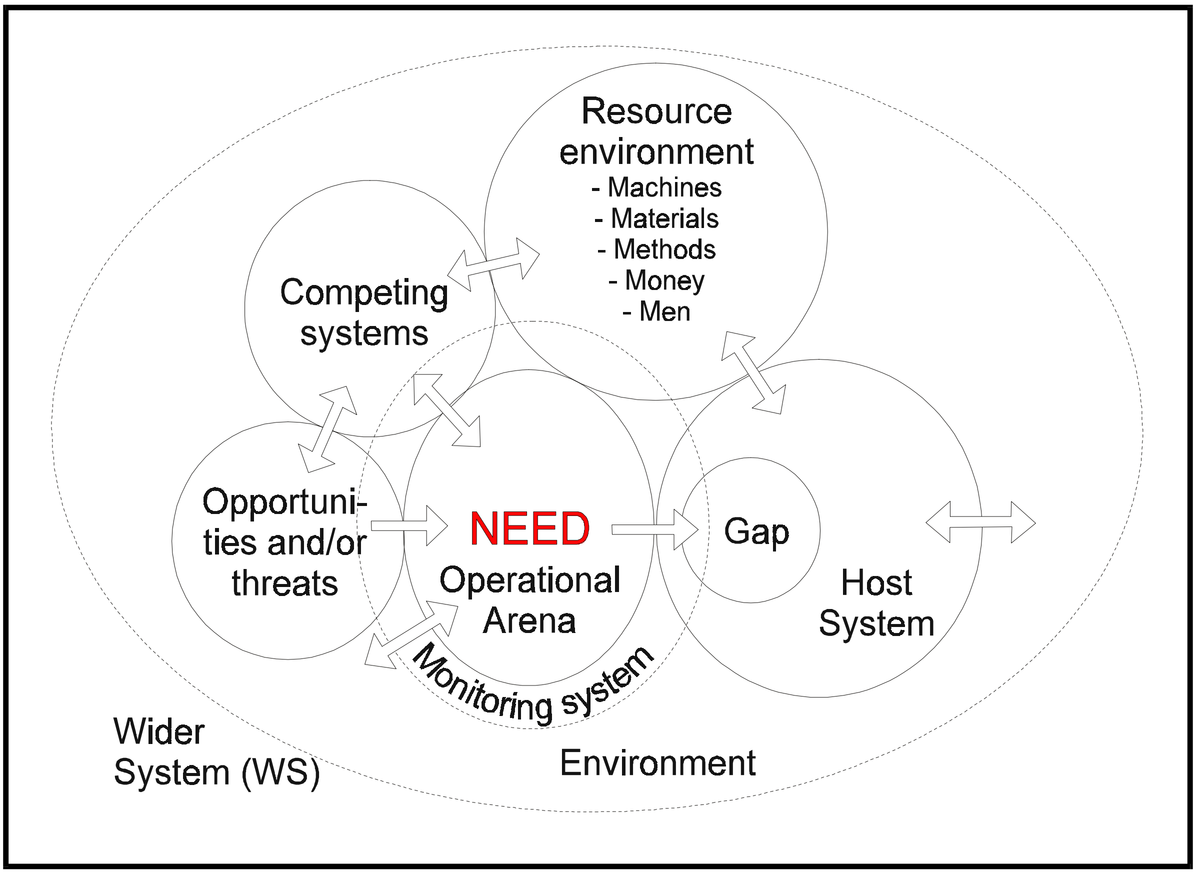


Figure 4.1: The need within the wider system
[Adapted from M'Pherson, 1980:551]

The whole-system concept can be described as a need that exist within the wider system, which is being satisfied by a system of interest, created by a realisation system and inserted into a host system (HS), which in turn, is also part of the wider system. In order to fully understand the meaning of the whole-system concept, it is necessary to explore the different elements of this concept in more detail.

4.5.1 The wider system (WS) [Adapted from M'Pherson, 1980:552]

The wider system can be broken down into the following compartments:

- *The host system* is the higher level or parent system within which the system of interest is inserted, or the parent organisation which has acquired, and will be using, the system of interest. The host system must have a need for the system of interest.

This need is conveyed to the planning system of the host system through the monitoring system. The planning system of the host system (which is part of a higher level management system) can go about in three ways to realise the system of interest [Figure 4.2]:

(a) Buy a commercial of the shelf (COTS) system (a system that is already in existence and is commercially available).

(b) Contract the development of the system of interest from an outside organisation through the outside organisations realisation system capability on a cost-plus or performance based contract (this may consist of adapting or modifying a COTS system to better satisfy the need of the host system).

(c) Develop the system of interest themselves through the host system's own realisation system capability.

- *The operational arena* is that part of the wider system that is directly affected by the insertion of the system of interest in the host system, the system of interest's resource requirements, as well as its outputs.
- *The opportunities or threats* are the influences which cause the need to exist in the operational environment in the first place.
- *The resource environment* is made up of the 5 M's - men, machines, money, materials and methods (including information). The resource environment as a whole must have a realisation system capability, otherwise the resources cannot be supplied. These components of the resource environment, can be considered as the building blocks (the five M's) of any system and are many times interactively part of the realisation system, the system of interest and the wider system. This means that for example the men that are part of the realisation system may become part of the system of interest and host system once the system of interest has been established and inserted into the wider system.
- *The competing systems* are the other systems within the wider system competing for resources, market, territory and power.
- *The economic, social, technological, legal and natural environment* are environments external to the operational arena, but is affected directly or indirectly by the system of interest because of its operations, but also influences the operational arena and the host system.

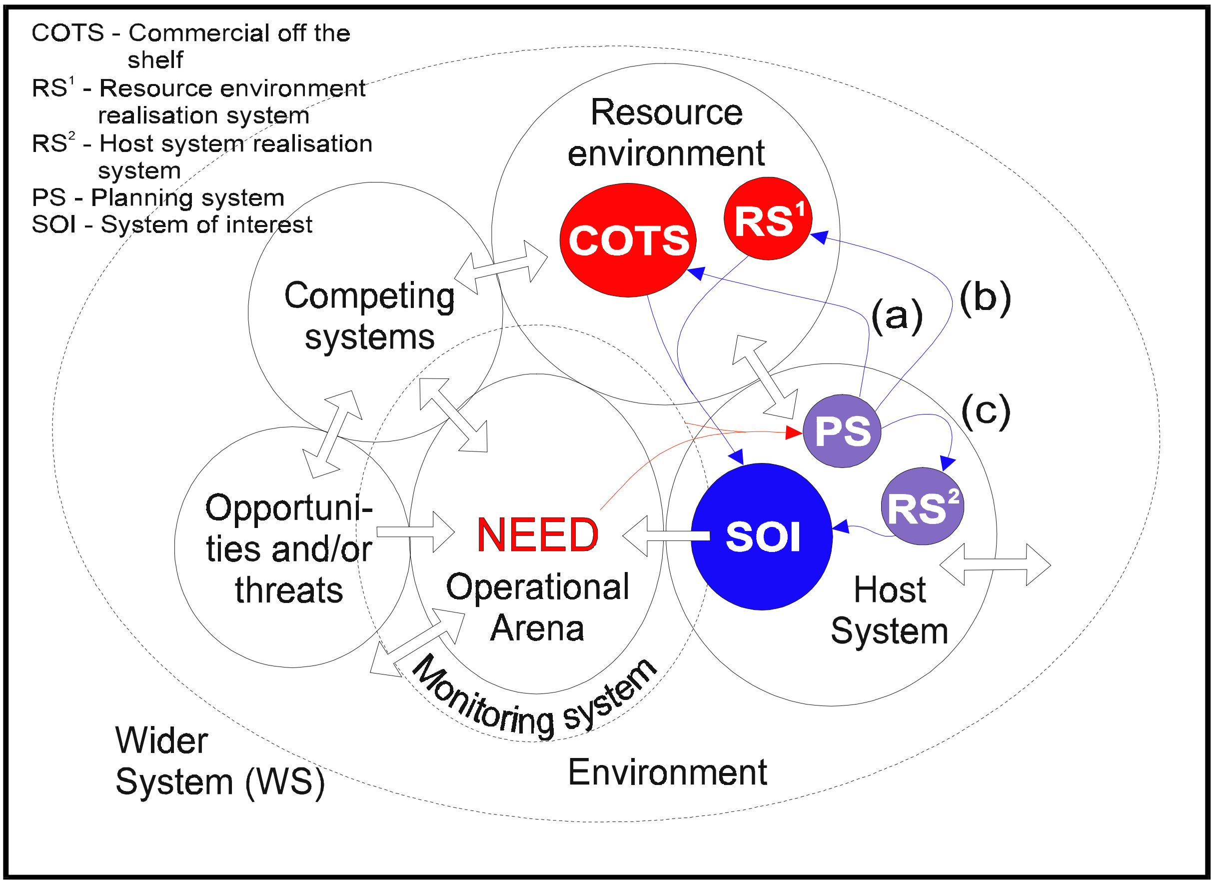


Figure 4.2: The host system's ways of realising the system of interest (SOI)
[Adapted from M'Pherson, 1980:551]

- *The monitoring system* retrieves information and provides feedback to management, designers and those controlling operations. The sources of data can be either intrinsic or extrinsic:
  - Intrinsic data is generated within the host system, by the host system. Normally this data is not available to those outside the host system.
  - Extrinsic data is generated within the operational arena and is normally available to all systems within the wider system.

4.5.2 The realisation system (RS) [M'Pherson [1980:551-552]

M'Pherson [1980:551] states that the realisation system consists of at least five parts:

- *The planning system* surveys the problem, threat or opportunity, produces possible solutions, analyses and evaluates the alternatives, and develops the project plan.
- *The development system* designs, develops and engineers the selected system of interest concept.
- *The acquisition system* manufactures, constructs, tests, commissions and launches the system of interest from a design concept into an operational system inserted into the real world.
- *The information system within the realisation system* provide timely, accurate and relevant information to the realisation system.
- *The support system of the realisation system* ensures continuity of the realisation system.

The realisation system must also possess the capability to establish policy, do marketing and financial management of the realisation system by itself or through its host system. Sometimes the system of interest remains part of the realisation system (it came into being for the benefit of the realisation system but inserted in the wider system) which means that the realisation system is also the host system (see Figure 4.2 (c)), for example an organisation designing and commissioning a production plant.

Sometimes the system of interest is designed and developed for a specific customer or the mass market (the system of interest came into being for the benefit of a customer which is also part of the wider system). This means that the realisation system is separate from the eventual host system. In this case a separate management system has to exist to do the policy making, marketing- and financial management of the system of interest when it is inserted into its host system. Normally the system of interest will either adopt the host system's management system or the management system of the system of interest will be integrated into the host system's management system. In the case where the system of interest's management system is integrated into that of the host system, it must be done in such a way that the host system will be able to handle the new management requirements for the system of interest.

4.5.3 The system of interest (SOI) [M'Pherson [1980:551]

The system of interest is the system that is created by the realisation system based on a need for a useful system within the host- and wider systems. The system of interest is the system described by M'Pherson [1980:551] as the proto-system and consists of four sub-systems:

- *The operational sub-system* is that part that provides the useful output of the system by transforming inputs into outputs.
- *The management sub-system* plans, organises, directs and controls the operational system and associated service systems.
- *The information sub-system* provides feedback from and monitor the status of the operational and other service functions, and wider system the environment.
- *The support sub-system* has as its primary function to supply and maintain all other systems.

The system of interest must have a useful purpose over a period of time for its owner. The different sub-system are discussed in more detail in § 4.6. Once the system of interest has been created by the realisation system, and before being installed within the host system, it has to be tested and accepted. After the system of interest has been accepted and installed in the host system, it has to be commissioned before it can start operations and its useful life. Sometimes installation and commissioning need to take place before final testing and acceptance take place.

4.5.4 An integrated view of the whole-system concept [M'Pherson, 1980:551-552]

The whole-system concept (Figure 4.3) is the aggregate of the system building blocks:

- *The system of interest within the host system* after it has been inserted within the host system, meaning the gap that existed within the host system has now been filled and the need within the operational arena can be satisfied.
- *The realisation system* is the system bringing the system of interest into being, using one of the approaches described in § 4.5.1.
- *The management processes of the realisation system and the system of interest* ensure the management of the development process (i.e. the realisation process),

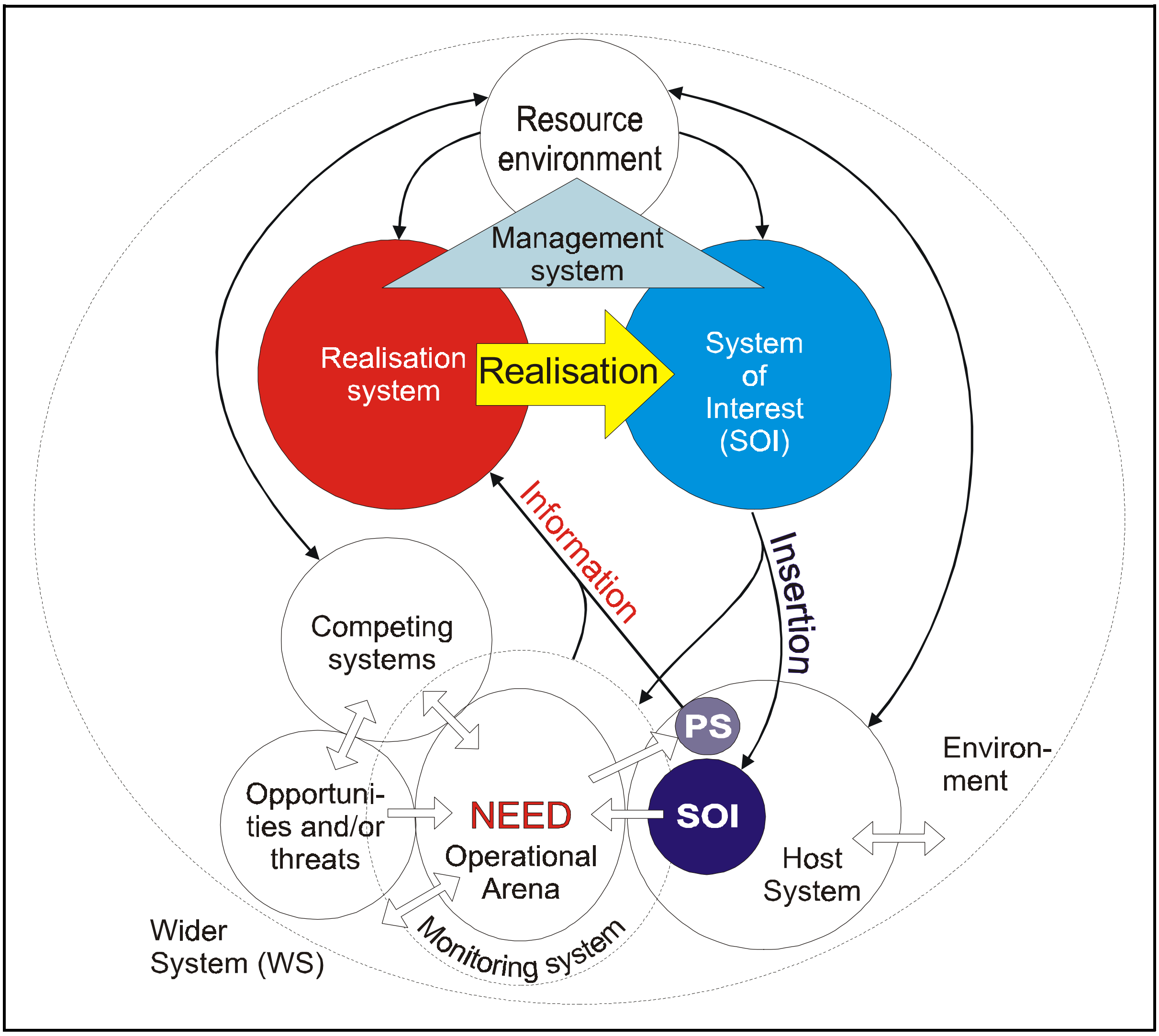


Figure 4.3: The whole-system concept
Adapted from M'Pherson [1980:551]

but must continue to manage the implementation process and eventually the operations and support of the systems of interest. Even though the management responsibilities may be transferred between different systems as the system of interest progresses through its life-cycle, the system of interest should not experience discontinuity of its management when it's management is transferred from the realisation system to the host system.

- *The interfaces with the wider system and resource environment* are the influences amongst and flow of information between the systems within the wider system.
- *The feedback and monitoring systems* are the mechanisms to capture and transfer data and information within the individual systems and the wider system.

4.6 System structures

A generic system structure is defined by M'Pherson [1980:550] and consists of interlinked system functions, sub-systems and system levels as shown in Figure 4.4. Conceptually all systems must have this structure to qualify as a purposeful system. M'Pherson [1980:550] calls it *"the Proto-System as it is a template or prototype for all arrangements of properties that are to qualify as surviving purposeful systems. The basic structure of the proto-system displays all the descriptive systemic properties (components, links, loops, levels, clusters, boundaries, hierarchy, functions, transmissions and dependencies) which have now been organised to provide a model of any operational and surviving system."* According to M'Pherson [1980:550] the essential sub-systems required within every goal-orientated (purposeful) system to survive for a useful life-time are:

- *"Operational System (*P_1*,* P_2*, ...*P_j*,...;IP; IC; OC)*
  The functional processes that produce the useful output (P_1*,* P_2*, ...*P_j*,...;). This output is often partially consumed within the system (i.e. intermediate products) before the final output is discharged in the operational arena. The Information Process IP, Information Control IC and the Operations Control OC are integral parts of the Operational System.*

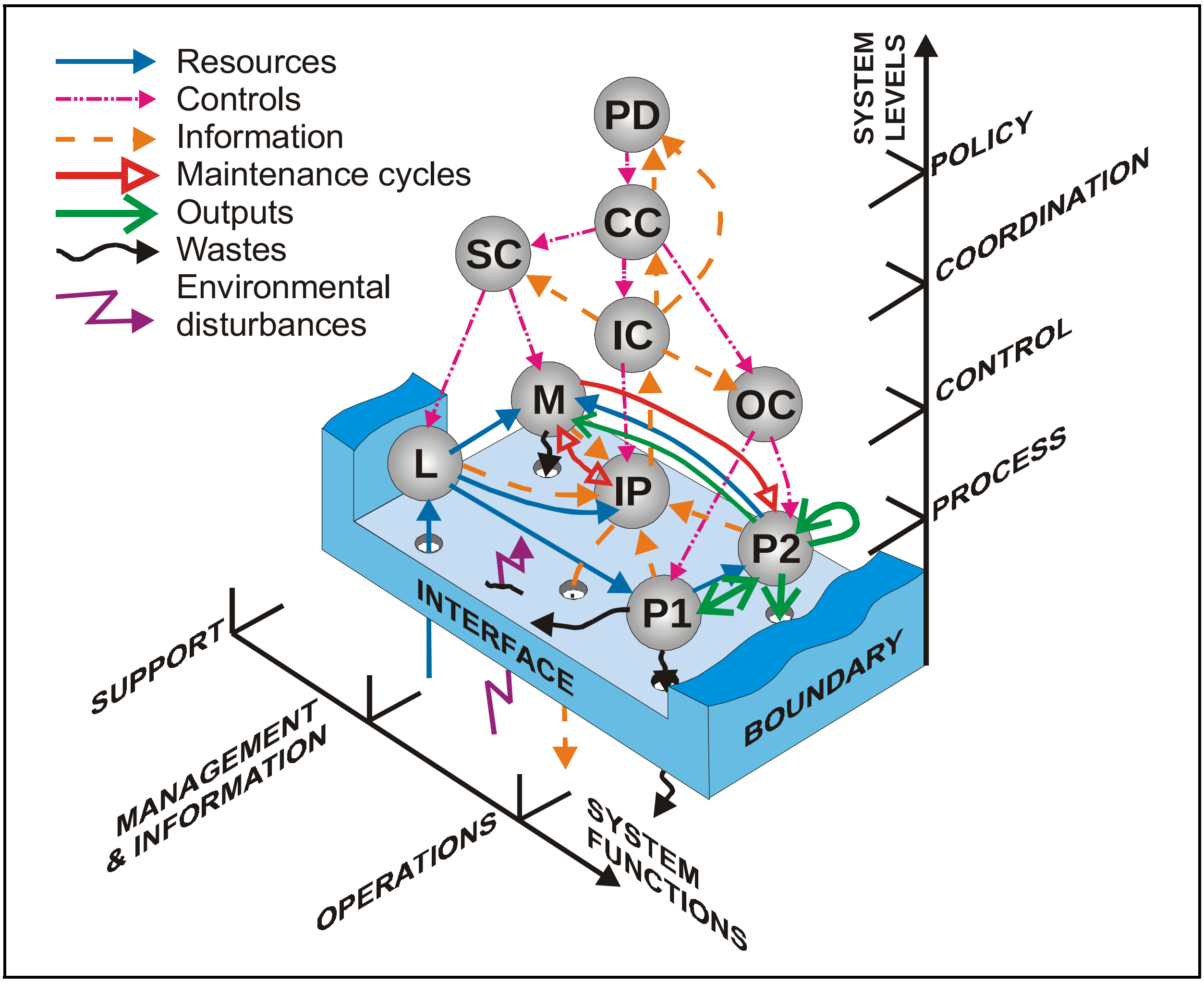


Figure 4.4: Structure of the Proto System
[M'Pherson, 1980:550]

- *Management System (PD, CC; IC)*

  To direct and co-ordinate the functional processes (CC - Co-ordination Control) according to the received policy/strategy whereby the system is to achieve its objectives (PD - Policy Development). The management system needs to be linked to the information system (IC - Information Control)

- *Information System (IP, IC)*

  The central core of information processes that collects information about the state of functional processes and of the environment for processing and transmission to the appropriate level of the management and control hierarchy."

M'Pherson [1980:550] then continues to describe the need for operational support and maintenance by stating: "*Any operational system that supplies an action, product or service (a) consumes resources and energy that will have to be replaced, and (b) will deteriorate due to wear, tear or failure. No system on earth can escape the second law of thermodynamics. Consequently, a surviving system needs another sub-system to counteract resource consumption and performance degradation:*

- *Support system (L, M; IP, IC; SC)*
  L is the logistic sub-system processing resources from the environment, and M is the maintenance process through which all operational units have to cycle periodically for repair, maintenance and restoration."

The resource flow and maintenance cycles in Figure 4.4 are shown only for the functional and information processes. All other processes including management, should also be connected to the support system but has been omitted from this figure for the sake of clarity.

The Proto-System can be used to explain many different systems, for example:

- A biological system, eg. the human heart controlled by the brain.
- A product system (durable product), eg. a motor vehicle operated by its owner.
- An organisation, managed with the purpose of achieving the organisational goal.
- An economic system of a country directed and controlled by local, regional and national government.

The Proto-System is thus a general model that provides the creator and owner of a system with a broad outline of all functions and relationships that exist within any system. This research will further expand on the support function, consisting of the logistic and maintenance sub-systems.

4.7 The whole-life or system life-cycle concept

4.7.1 Covey's view of the life-cycle

"*To begin with the end in mind means to start with a clear understanding of your destination. It means to know where you're going so that you better understand where you are now and so that the steps you take are always in the right direction* [Covey, 1992:98]. This is true for any system. Where one is now, constitutes the need or the gap which exists. Where one wants to go, is to have the gap filled by a system. "*Begin with the end in mind is based on the principle that all things are created twice. There's a mental or first creation, and a physical or second creation to all things*" [Covey, 1992:99]. The first (mental) creation equates to evaluating concepts, testing a chosen concept and developing the chosen concept further up to the point where a detailed design exists that will satisfy an identified need. The first creation is just the map or the blueprint. It is not yet the physical creation. Once the first creation has been completed, the second creation takes place. The second creation is the physical making, manufacturing, construction or putting into place of what has been designed with the first creation. This sequence of dependent activities are shown in Figure 4.5.

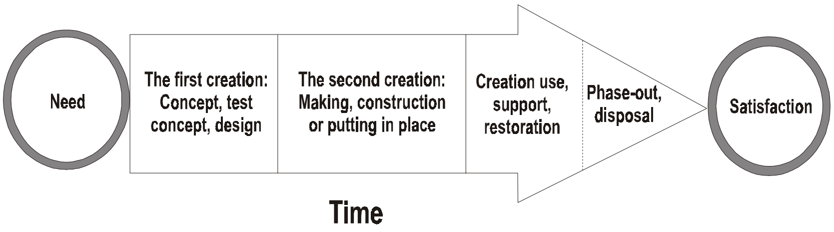


Figure 4.5: Satisfying a need through the two creations

Satisfying the need can be done in active (dynamic) or passive (static) mode. In the active mode, the creation is consumed, operated or utilised, such as an ice-cream or a motor vehicle. In passive mode, need satisfaction exists purely because the creation exist, for example a painting or work of art. Sometimes the creation requires ongoing input (support) to keep up the ability. Sometimes the creation's ability deteriorates over time or fails completely which requires actions pro-actively or reactively to either prevent deterioration or failure, or else to restore ability after deterioration or failure. At some time, the creation may not satisfy the need anymore, due to ageing, the disappearance of the need, a new creation that may satisfy the need better, or just because it cannot be restored to its original capability. Even though Covey never uses the words life-cycle or whole-life, it is clear that this is exactly what he means.

4.7.2 Hall's view of the life-cycle

In his landmark article, Hall [1969:18] is of the opinion that systems engineering - the engineering discipline which is concerned with the engineering of systems - reveals three fundamental dimensions which are as follows:

- The first dimension is based on time divided into a coarse structure of a sequence of activities called phases, each marked at its end by a major decision milestone. This sequence of activities in the life of a system runs from conception to retirement, which really translates to the time period from the statement of the original need to point in time where:
    - the system does not satisfy the need anymore,
    - the need does not exist anymore, and/or
    - a new system has come into being that better satisfies the need.
- The second dimension consists of a problem solving (logic) approach, of which all the steps must be performed irrespective of the nature of the problem. These steps may be done repetitively within a phase. This is the so-called fine structure of systems engineering where the flow of logic, not time, is the dominant characteristic.
- The third dimension consists of the body of knowledge, facts, information, models, procedures, methods, formulas and algorithms that are associated with a discipline, technology or profession. The type of system will determine what will be required as far as the third dimension is concerned.

Within these three dimensions of systems engineering, it is clear that the first dimension is primarily concerned with the life-cycle. This dimension demonstrates that systems and bringing them into being cannot be removed from the concept of the life-cycle.

4.7.3 M’Pherson’s view of the life-cycle

“Systems exist in time”. This is the view expressed by M'Pherson [1980:552] in his classic article on systems and systems engineering. The fact that systems exist in time is implied in the statement that systems are to have a purpose and useful life. One cannot talk about life and not imply any lapse of time. Life implies coming into being or birth, growing into maturity, having a useful adult life, retirement and eventually death. This is what M'Pherson [1980:552] describes as the birth - life - death - rebirth process that may be called the system life-cycle. It is a concept that is also widely used in the marketing environment, known as the S-curve, even though marketers view the life-cycle only from the perspective of distinct phases in the selling history of the product. The development phases are largely ignored [Kotler, 1984:353-374].

“*For any one system, there is a point in time prior to which its particular concept did not exist, and there is another point in time beyond which it will not exist because it will have been scrapped, destroyed or evolved into another form*” [M'Pherson,1980:552]. This whole process is characterised by generic modes and phases which are applicable to all systems. These modes and phases are summarised in Table 4.1 [Adapted from M'Pherson, 1980:553 and Hall, 1969:19].

One has to consider that the phases do not necessarily strictly follow one after the other, but they may also overlap and run simultaneously and are of an iterative nature. The progression is from top to bottom, and not serial in nature as might be implied. Although the detail may vary, the life-cycle functions are generic and applicable to all systems [Blanchard and Fabrycky, 1998:21]. Even though the modes of the system life-cycle remains basically the same irrespective of the type of system, the type of system under

Modes	Phases (Coarse Structure]
Realisation	Program planning
	Conceptual and preliminary design
	Design and development
Acquisition	Industrialisation
	Production
Operations	Insertion
Renovation	Operations and support
	Renewal
Retirement	Phase-out

Table 4.1: The generic life-cycle modes and phases

[Adapted from M'Pherson, 1980:553 and Hall, 1969:19]

observation will determine the exact phases and activities required for the particular system. The type of system will therefore cause some differences within the phases and activities of the system life-cycle. For the purpose of this research the following system life-cycles will be investigated:

- The life-cycle of an organisation, categorised as organisations which:
  - Develop and sell systems or durable goods.
  - Develop and sell services to the customer.
  - Develop and sell consumer goods.
- The life-cycle of a product system (durable item) which gets sold to a customer.

Each of these life-cycles and the differences between them will be discussed in more detail in subsequent chapters.

One of the big advantages to be gained by following the life-cycle approach, is to limit the effects of the way engineers and scientists often view the world. According to M'Pherson [1980:548], "*conventional education and training of engineers tends to make them device* *and function oriented, which is then compounded by the professional designer's zeal to produce the best performing machine (or whatever) at the prescribed cost. The designer's performance horison is often limited to the specification and the acceptance trials, whereas good systems engineering requires that all related factors within the total life-cycle be taken into account during the early appraisal and design stages*". M'Pherson [1980:553] continues to say that "*the life-cycle is an important concept in the engineering of systems as it orients the design of the system of interest towards effective operations throughout its useful life rather than just satisfying the performance specification at the start of its operational life. The extent of the useful life has to be defined at the design stage from predictions of the future operational effectiveness and costs when the system is in service - which may extend to a time horison anything from 5 to 30 years ahead*."

4.7.4 New technology and the life-cycle

The duration of the useful life naturally depends on the development and introduction of new technology. In some areas the development of new technology is much more rapid than in other areas. How technology influences the life-cycle of a system depends on the impact the technology has on the ability (performance), availability and/or the affordability characteristics of the system under observation. If a new technology can be introduced in a new system to replace an existing system, it will be considered viable only if the benefits gained (improved performance and availability, as well as reduced total cost) by the introduction of the new system are more than the overall cost to terminate the life-cycle of the current system. Replacing a current system with a new system (using new technology) is not to be confused with extending a current system’s life-cycle by introducing a new technology into the current system.

Another dimension relating to new technology is to consider the rate at which systems using new technology are introduced to the market. A good example of an increased rate of system introduction using new technology is described by Womack, Jones and Roos [1991:119-126]. They describe how in the late 1980's, the Japanese car companies renewed and expanded their vehicle range every four years as opposed to the European firms who have reduced their vehicle range and extended the time between new vehicle introductions to between six and eight years. At the same time, the Americans, even though they have expanded their vehicle range, also extended the time between new vehicle introductions to between six and eight years. Thus the life-cycle duration of the Japanese products are actually declining. Goldratt (1986:6) is also of the opinion that product life-cycles are shrinking all the time.

The question that needs to be answered is whether an increased rate of new system and technology introduction has an effect on the duration of the life-cycle of existing systems. There cannot be one single answer. One has to investigate the type of system (both new and existing), the new technology or opportunities for new technology, the system level where technology can be inserted and the market behaviour. Several cases can be presented. If there is a major performance/cost benefit to be gained by introducing a new technology within a new system, the life-cycle of existing systems will be cut short, as is the case with computers and other electronic systems. If no major performance/cost benefit can be gained, new system and technology introductions can offer new buyers bigger variety, but will not necessarily shorten the life-cycles of existing systems. A new product and technology introduction offered to provide more variety is a good strategy in an expanding market when new buyers in the different niche markets are entering all the time, as is the case with the automotive industry. If new system and technology introduction is in a limited and saturated market and no major performance/cost benefit can be gained, the market behaviour will determine the reduction on increment of existing system’s life-cycles. The market focussed on keeping at the leading edge of technology will cause existing system’s life-cycles to reduce, as is the case with the military forces of the superpowers. The market focussed on minimising cost will strive to extend the life-cycle of existing systems as is the case with the airline industry. The conclusion that can be drawn from this discussion is that the life-cycle of a system remains important irrespective of the rate of new technology introduction and the extent the life-cycle is shortened or extended because of new technology.

4.7.5 Moving away from the life-cycle?

A phenomenon found in recent literature, is the value of the life-cycle being questioned and perceived not to be valid anymore. Patterson in Sage and Rouse [1999:59] refers to system engineering process models which he directly equates to life-cycles. In a subsequent statement Patterson [Sage and Rouse, 1999:98] continues his argument with: *"The trend away from rigid standardisation of systems engineering process models* (which Patterson equates directly to life-cycles) *can be understood better when viewed in the context of system acquisition. A relatively new trend in acquisition management is the widespread used of performance-based contracting (PBC), a procurement tool based upon the systems engineering approach that emphasises the purpose of the acquisition."* As has already been demonstrated in Figure 4.2, the way in which the realisation system go about in creating the system of interest, does not distract from the whole-system concept or the whole-life (life-cycle) concept. This author comes to the conclusion that Patterson is confusing the idea of a system life-cycle with the idea of following a certain methodology (determined by the type of system and the capability of the realisation system) in order to bring a system into being. Both these dimensions are included in the view that Hall [19969:18] provides on the engineering of systems. Both these dimensions are necessary for successfully bringing systems into being, but they are not the same. Arguing that a change is necessary in the methodology (as Patterson does) does not mean that the life-cycle concept is invalid.

As was already shown in previous paragraphs, the life-cycle concept is fundamentally part of any system and cannot be ignored in any way or "*moved away from*" as argued by Patterson in Sage and Rouse [1999:98]. Disregarding or moving away from the life-cycle concept is ignoring the fundamental characteristic of a system that it exists in time. This author can associate with the idea of moving away from rigid standardisation of systems engineering process models to innovative new approaches of bringing systems into being.

4.7.6 An integrated view of the life-cycle

Three different views on the life-cycle are integrated into one view in Figure 4.6 as adapted from Blanchard [1998:19], Covey [1992:99] and M'Pherson [1980:551] to provide a broad outline of the life-cycle concept. As can be seen from this figure, the concepts remain the same and demonstrate that the life-cycle is generic in nature, even though the actual words used to describe the life-cycle modes differ. This integrated view describes the logic and sequence of the different phases of how a system comes into being, how it is operated, supported and maintained, and eventually phased out and disposed of.

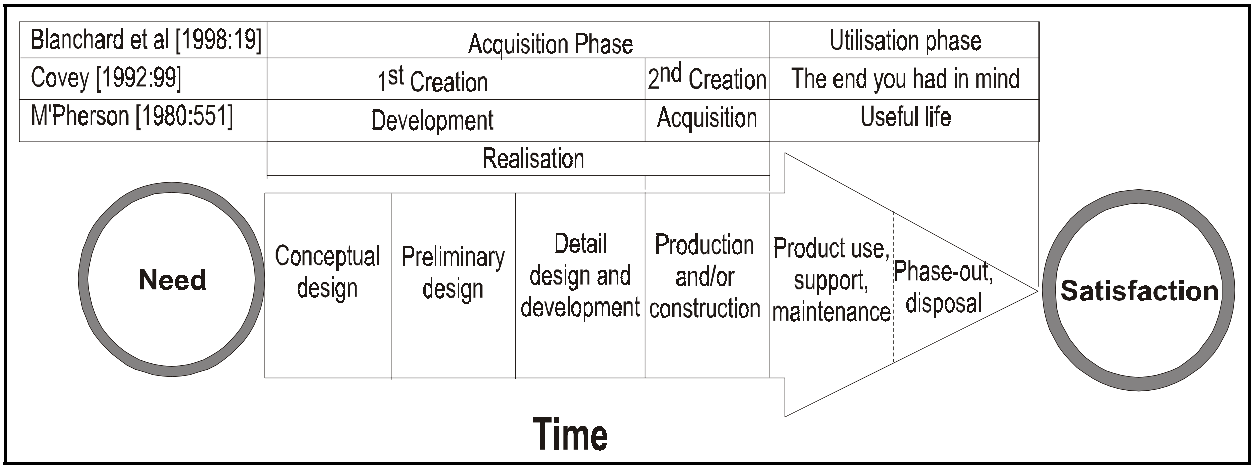


Figure 4.6: The generic life-cycle phases
Adapted from Blanchard & Fabrycky [1998:19], Covey [1992:99]
and M'Pherson [1980:551]

It can thus be concluded that the life-cycle concept is the time dimension of a system, and that the problem solving and know-how dimensions required to bring the system into being fit into the time framework provided by the life-cycle concept. The life-cycle concept is thus truly the cradle to grave view of the system.

4.8 Measurements of system success

Throughout this study mention is continuously made of the purpose or goal of a system, as well as the life-cycle of a system. Without a goal or purpose an arrangement of components is just a conglomerate and not a system, and if there is no time associated with the system it just cannot exist. The goal or purpose of a system is vitally important as it is required before any measurements of system success can be defined. The life-cycle of the system is vitally important because the system takes on different states while progressing through time. These different system states will determine which system parameters are important for that particular state and time. Without a goal to be measured over time, the measurements means nothing. *"Measurements are the direct results of a chosen goal. There is no way that we can select a set of measurements before the goal is defined"* [Goldratt, 1990a:14].

4.8.1 Overall system measurements

The nature of the system of interest will determine its goal and therefore the specific measurements for each of the system functions. As functions differ from system to system it is therefore impossible or very difficult to establish generic measurements for a system. It is however true that systems cannot exist in isolation from their environments because of the interdependencies between the system of interest and its host system. This means that irrespective of the nature of the system, generic measurements on the system level can be defined based on the facts that a system has to have a purpose, it is subject to entropy and that it exists in time. The generic measurements for any system are the so-called three A's [Adapted from M'Pherson, 1981:72,74; Blanchard and Fabrycky, 1998:35; Blanchard, 1998:33; Aslaksen and Belcher, 1992:312]:

- Ability refers to the capability or desired output of the system of interest by altering material, energy or information. Stated differently ability refers to the benefit the system is to provide to its owner or achieving the purpose for which the system was designed and built.

- Availability refers to system readiness when the system is required for use and dependability refers to the system's reliability to complete any operational task with little risk of failure. From here on this author will only refer to availability, as both availability and dependability are functions of operating time (reliability) and downtime (maintainability/supportability) [Blanchard, 1998:33].
- Affordability refers to the benefit derived from system operation being more than the cost of acquisition, operation, support and disposal.

These system level measurements will have to be translated to lower level measurements to suit the specific nature of the system, but in the end the lower level measurements should always translate back to the three generic overall system measurements. The combination of the three measurements is normally referred to as the cost-effectiveness of the system. Many authors, Blanchard and Fabrycky [1998:Chapter 17 - Design for affordability (Life-cycle cost)], Sage and Rouse [1999:Chapter 6 - Cost management], as well as Aslaksen and Belcher [1992:Chapter 14 - Cost effectiveness] devote entire chapters to measurements. The emphasis in all cases is mostly on cost as the titles to their chapters indicate. The prime measurement all these authors focus on is cost effectiveness, which is expressed as the ratio of system effectiveness (SE) to life-cycle cost (LCC) [Aslaksen and Belcher, 1992:311]:

$$Cost\ Effectiveness\ (CE) = \frac{System\ Effectiveness\ (SE)}{LifeCycleCost\ (LCC)} \tag{4.1}$$

For more clarity, system effectiveness and life-cycle cost will be discussed in more detail in order to present a new equation namely benefit effectiveness.

4.8.2 System effectiveness (SE)

System effectiveness is primarily dependent on the system ability and the system availability. Aslasken and Belcher [1992:311] express system effectiveness as *"a measure of how well a system performs the functions it was designed to perform, or how well it* *meets the requirements of the system specification. It is often defined as the probability that the system can successfully meet an operational demand within a given time period when operated under specific conditions*." This definition is also found in Blanchard and Fabrycky [1998:360]. As opposed to life-cycle cost which is concerned with economic issues, system effectiveness is concerned with the technical issues of the system. System effectiveness can be expressed in its generic form as:

$$System\ Effectiveness = f(Ability,\ Availability) \qquad (4.2)$$

According to Blanchard and Fabrycky [1998:84], ability is concerned with the characteristics of design that relate to the technical performance of the system, meeting requirements or the extent to which the original purpose of the system is achieved. This can be expressed as a percentage. Achieving more than 100% does not necessarily mean improved ability, for example, a chemical plant exceeding its production requirement may not enhance the value of the owning organisation if the market will not buy the excess production. Ability is an indication of conformance, degraded conformance or total non-conformance of the system in relation to what is required at that point in time.

Availability [Adapted from Blanchard, 1998:33] is the probability that a system, when used under stated conditions, will operate at any point in time as required. Availability is a function of the reliability and maintainability of the design [Blanchard, 1998:33; Aslaksen and Belcher, 1992:270]. This concept will be discussed in more detail later but for the time being it will suffice to express availability as [Blanchard, 1998:80]:

$$Availability = \frac{MTBF}{MTBF + MTTR} \qquad (4.3)$$

where MTBF is the mean time between failure, an indication of reliability, and MTTR is the mean time to repair, an indication of maintainability.

For system effectiveness it is clear that one wants an increase in ability up to 100%, while at the same time have an increase in availability up to a level of 100%. The improvement in availability can be achieved by increasing MTBF and decreasing MTTR. Thus a system with 100% capability and 100% availability is 100% effective, something that can only be achieved in a perfect world or over a very short period of time. Equation 4.2 can thus be modified and expressed as:

$$\textit{System Effectiveness} = \textit{Ability} * \textit{Availability} \tag{4.4}$$

4.8.3 Life-cycle cost (LCC)

Life-cycle cost is concerned with the economic issues associated with each of the modes of the life-cycle. Each mode of the life-cycle consist of distinct phases each generating certain cost, that is to be borne by the involved parties. The equation for life-cycle cost can be expressed as follows:

$$\textit{Life Cycle Cost (LCC)} = \sum_{i=1}^{n} \textit{Cost}_{(\textit{Phase } i)} \tag{4.5}$$

Using this expression alone without considering the benefits derived from the system of interest, is unfortunately a negative way of looking at the overall system performance as it stresses the negative side of the basic nett benefit equation which can be expressed in its generic form as follows:

$$\textit{Nett Benefit} = \sum_{i=1}^{n} \textit{Revenue}_{(\textit{Phase } i)} - \sum_{i=1}^{n} \textit{Cost}_{(\textit{Phase } i)} \tag{4.6}$$

By looking at it from a nett benefit perspective, it allows the creator of the system to not only look at cost profiles over the life-cycle, but also to look for opportunities to generate revenue from the system of interest during any of the phases of the life-cycle. Revenue may be generated for example by selling a newly developed technology for the system, or from the income generated by using the system during its operational phase. In order for the nett benefit to be as high as possible, it means that the revenue stream must increase and the cost stream must decrease. One must however, be very careful, as the nett benefit may also be increased by increasing the cost resulting in an increase in revenue. An example is where the cost of increasing quality (an increase in cost) may cause the sales to double, which will lead to an increase in revenue which may be more than the increase in the cost. Conversely, a reduction in cost may also lead to a decrease in revenue and thus a decrease in nett benefit. An example would be where an organisational system retrenches people in order to save cost which may lead to a reduction in revenue because of skill and capability loss.

4.8.4 A new equation - benefit effectiveness

This author prefers to use the term benefit effectiveness, which implies that the system should be effective overall (ability, availability and affordability) as the benefits overall should be more than the cost overall. This approach allows the benefit effectiveness to be expressed as a ratio similar to the cost effectiveness ratio, with the higher value being better if a trade-off between systems are to be made. Thus, the original Cost Effectiveness equation (Equation 4.1) can be modified into a Benefit Effectiveness equation for systems that have revenue generating capability as follows:

$$Benefit\ Effectiveness = \frac{Ability * Availability * \sum_{i=1}^{n} Revenue_{(Phase\ i)}}{\sum_{i-1}^{n} Cost\ _{(Phase\ i)}} \qquad (4.7)$$

For systems that do not have a revenue generating capability the equation is as follows:

$$Benefit\ Effectiveness = \frac{Ability * Availability}{\sum_{i-1}^{n} Cost\ _{(Phase\ i)}} \qquad (4.8)$$

which translates back to the original cost-effectiveness equation as presented in Equation 4.1. The advantages to be gained from using a benefit effectiveness approach as opposed to a cost effectiveness approach are:

- The emphasis of the system design and system operation is on achieving the system goal and objectives, not saving costs.
- System design and system operations are not limited by a view to limit or save cost in the short term but approach the system from an overall life-cycle nett benefit point of view.

4.8.5 The necessary conditions

The measurements that have been discussed, namely ability, availability and affordability, are the system of interest's measurements viewed from the host system's perspective. From the wider system perspective, there are also measurements, called necessary conditions which are applicable to the system of interest and the host system. These necessary conditions should also be considered when working towards the attainment of the three A's. These necessary conditions pertain to:

- The safety of people operating and maintaining the system.
- The environmental impact of the system eg. pollution.
- The social impact of the system eg. job creation and infrastructure creation.

If any property of the system compromises safety, the environment and/or the society, the design of the system has to be changed in the case of a new system, or the system must be modified in the case of an existing system to ensure that the system has social as well as environmental value alongside its technical and economic value.

4.9 Chapter summary

Systems consist of interrelated sets of components that work together and self-sufficiently towards a common goal over a period of time. This definition conveys the essence of the nature of systems. Some major system characteristics have been discussed in this chapter and will be used in this research as the basis of developing the generic life-cycle approach to integrated logistic support for whole-life whole-systems for man-made systems.

These major system characteristics are summarised as follows:

- Systems exist for a purpose, the purpose being defined by the owner of the system.
- Systems exist in a hierarchy, what may be a system on one level, may be the component on another.
- Systems interact with their environment, getting input and providing output across system boundaries.

- Systems exist in time, implying a birth - life - death cycle, which is basically the same for all systems. For man-made systems the phases consist of realisation, acquisition, operation, renovation and retirement.
- Systems have properties which are more than the sum of the individual components.
- Systems are constrained in their output which leads to the fact that optimisation of a single part does not necessarily lead to an optimal system.
- Systems are subject to entropy because no system can escape the second law of thermodynamics, which implies that continuous supply and maintenance are required for the upkeep of the system ability.
- Systems (of interest) come into being through a realisation system in reaction to a gap that exists between a need in the operational arena of the host system and the host system ability. The system of interest, the realisation system and the host system are all contained within a wider system.
- System measurements are the result of the chosen goal of the system, however, generic measurements can be defined for any system namely:
  - Ability (to measure the achievement of purpose).
  - Availability (to measure available system time for achievement of purpose).
  - Affordability (to measure revenue and cost associated with the system's achievement of purpose).
- Necessary conditions exist within the wider system that require system designers to consider safety, environmental and sociological issues.