# A GENERIC APPROACH TO INTEGRATED LOGISTIC SUPPORT FOR WHOLE-LIFE WHOLE-SYSTEMS

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## DECLARATION

I declare that the thesis, that I hereby submit for the degree Philosophiae Doctor (Engineering) at the University of Pretoria, is my own work and has not been previously submitted by me for a degree at another University.

Petrus Johannes Pretorius

# ABSTRACT

**A generic approach to integrated logistic support for whole-life whole-systems**

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Definitions for logistics are numerous. Logistics is furthermore divisionalised amongst functional lines as well as industry lines. Therefore one hears about military logistics, business logistics, marketing logistics, engineering logistics, logistics relating to e-commerce and some more. Within the various professional disciplines and societies the viewpoints differ even more than the definitions. The reason for this confusion when it comes to defining and understanding logistics is because of the way in which logistics is functionalised. With all these different functional focusses the emphasis tends to be on detailed logistics solutions often causing sub-optimisation of systems. There seems to be a lack of a unifying logistics approach that will allow consideration of the dynamic nature of systems to ensure system optimisation rather than sub-system optimisation.

This thesis proposes a different approach to prevent the sub-optimisation of logistics by viewing logistics from a system perspective rather than a functional perspective and at the same time consider the life-cycle of the system of interest. When viewing logistics from a system perspective, the question to ask is not to which function logistics belong, but within each phase of the system life-cycle, what the contribution is logistics needs to make to the overall system performance. In order to view logistics from a system and life-cycle perspective, there needs to exist an understanding of systems and system concepts. This understanding has to be supplemented by an understanding how systems are created. As logistics is concerned with man-made systems, two types of man-made systems require

understanding, namely organisational systems and product systems, also known as durable goods.

By using the system principles of holism, synthetic thinking and teleology, it is demonstrated that all systems can be described by generic sub-systems (the logistic sub-system being one of them), the success of all systems can be measured using the generic system measurements of ability, availability and affordability, and that all systems go through a life-cycle. Based on the reality that organisations and durable products/services all possess system characteristics as described above, and that non-durable products/services form part of a higher level system, a generic model has been constructed indicating the relationships and flow of the managerial and technical logistics activities which need to take place at each stage of the system's life-cycle to ensure that the system ability, availability and affordability requirements are met.

To validate the model, high level system dynamic relationships were constructed and the outcome of the application and non-application of the model argued using thought experiments. This was done using an imaginary system comparing the effects if the dynamic approach to logistics for the system is ignored to the effects if the dynamic approach to logistics for the system is followed. The thought experiment was done for all dimensions of logistics, namely operational support and maintenance support as well as for the management of each dimension throughout the life-cycle.

It is thus concluded that following a dynamic approach to the logistics of a system greatly enhances the system performance.

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# Abbreviations

| | |
|---|---|
| CLM | Council of Logistics Management |
| CM | Corrective maintenance |
| DTF | Demand time fence |
| ERP | Enterprise resource planning |
| FMECA | Failure mode, effects and criticality analysis |
| FRACAS | Failure reporting, analysis and corrective action system |
| HS | Host system |
| ILS | Integrated logistic support |
| IPC | Illustrated parts catalogue |
| LORA | Level of repair analysis |
| LSA | Logistic support analysis |
| MMIS | Maintenance management information system |
| PHS&T | Packaging, handling storage and transportation |
| PM | Preventive maintenance |
| PPPM | Preparation, preservation, packaging and marking |
| PS | Planning system |
| RCM | Reliability centred maintenance |
| RS | Realisation system |
| SA | Supportability analysis |
| SOI | System of interest |
| SOLE | Society of Logistic Engineers |
| WIP | Work in process |
| WS | Wider system |

*“It is easier to perceive error than to find truth, for the former lies on the surface and is easily seen, while the latter lies in the depth, where few are willing to search for it”*

**Johann Wolfgang von Goethe**

# Chapter 1
# Introduction

"*Small changes can produce big results - but the areas of highest leverage are often the least obvious.*"

Peter Senge [1990:63]

"*The real leverage in most management situations lies in understanding the dynamic complexity, not the detail complexity.*"

Peter Senge [1990:72]

## 1.1 Purpose and outline of the chapter

The purpose of this chapter is to provide an introduction and overview of the research undertaken. Some background and basic definitions for logistics are provided to demonstrate the different viewpoints that exist which leads to the research problem and the research hypothesis. The basic premises for the research are stated. The research design and research methodology are briefly introduced, followed by a roadmap to explain the logic and layout of this thesis. The principal results of the research are stated, followed by the principal conclusions of the research.

## 1.2 Background to logistics

Logistics is a term that has been defined many times in many different ways. Gourdin [2002:1] states that "*logistics is a term that many people have heard of but few can define*". It was (and still is) the topic of many heated debates. It is the topic of many text books. Several professional organisations exist serving the different logistics communities. Logistics has been studied from many different angles. Table 1.1 gives an indication of some of the different ways in which logistics is viewed, illustrating that the viewpoints are based primarily on a functional perspective.

| Interest group | How logistics is viewed |
|---|---|
| Design engineers | Design of system support |
| Manufacturing | Scheduling of processes and resources |
| Purchasing | On-time supply of raw material from suppliers |
| Material management | Warehousing and materials handling |
| Marketers | On-time delivery to customers and distribution |
| Financial managers | Cost of logistics activities |
| Customer relations | Customer satisfaction |
| Military | Availability of equipment, supplies & personnel |

**Table 1.1 Different viewpoints on logistics**

Because logistics has been defined in so many different ways, it provides for many different viewpoints towards logistics. A number of these definitions are provided in Chapter 2. It can however be stated that the definitions can be categorised into two major categories namely those definitions relating to the military and military operations and those definitions relating to movement of material with the aim of satisfying customer requirements within a business.

The two primary viewpoints on logistics can probably be best summarised, on the one hand by the Webster Dictionary definition (Webster,1963:497): *"The procurement, maintenance, and transportation of military material, facilities, and personnel"*. The Council of Logistics Management (CLM), on the other hand, offers the following definition: *"Logistics is the process of planning, implementing and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods and related information from point of origin to point of consumption for the purpose of conforming to customer requirements"* [Lambert and Stock, 1993:4].

M'Pherson [1980:550] provides a different viewpoint to logistics when he defines four sub-systems within any system. They are the operational, the management, the information and the support sub-systems. The function of the support sub-system is to supply and maintain the other sub-systems. M'Pherson breaks the support sub-system down into two functions, namely logistics and maintenance. However, he always treats logistics and maintenance together as the support sub-system.

## 1.3 The nature and the scope of the problem researched

As a large number of definitions for logistics as a discipline exist, which do not seem to relate to each other and which create confusion, it leads to a lack of understanding with regards to the integration of these "islands" of logistics, resulting in sub-optimal designs of organisations, products and services, even though many of these definitions claim to describe an integrated approach to logistics. From the different definitions that exist for logistics, many which have been included in Chapter 2, it is concluded that these definitions of logistics are primarily based on a functional view of logistics. Functional in this sense pertains to the functions of an organisation. This functionalisation of logistics is confirmed by the different views of logistics expressed in Table 1.1. Senge [1990:3] confirms that functionalisation and fragmentation are creating enormous problems: *"From a very early age, we are taught to break apart problems, to fragment the world. This apparently makes complex tasks and subjects more manageable, but we pay a hidden, enormous price. We can no longer see the consequences of our actions; we lose our intrinsic sense of connection to a larger whole."*

Organisations exist as complex systems. Organisations interact with other organisational systems; they also exist as part of a bigger system called the supply chain, which creates interdependencies and new complexities amongst these systems. Organisations produce systems in the form of durable products, many times complex in itself, which creates interdependencies and complexities between the suppliers and the customers of the durable products.

Complexity within systems can be handled in two ways. The first way to handle complexity is to handle many variables at the same time; this is called detail complexity. The second way to handle complexity, is dynamic complexity where cause and effect are subtle, and where the effects of interventions are not obvious [Senge, 1990:71] or stated differently: *"Cause and effect may be separated in time and space"* [Gharajedaghi, 1999:49].

Gharajedaghi [1999:xv] expresses the following views on interdependencies and complexities: *"The imperatives of interdependency, the necessity of reducing endless complexities, and the need to produce manageable simplicities require a workable systems methodology and a holistic frame of reference that will allow us to focus on the relevant issues and avoid the endless search for more details while drowning in proliferating useless information."* He [Gharajedaghi] further clarifies what the difference is between a multidisciplinary approach and a systems approach: *"Contrary to a widely held belief, the popular notion of a multidisciplinary approach is not a systems approach. The ability to synthesize separate findings into a coherent whole seems far more critical than the ability to generate information from different perspectives. ...*[systems thinking] *deals with the challenges of interdependency, chaos, and choice using an elaborate scheme called iterative design.*" It is thus clear that in order to understand the dynamic complexities of the integrated logistic support system, a systems approach needs to be taken to provide a holistic frame of reference to identify the focus areas that allows high areas of leverage.

From the above, the research problem has been defined as follows:

> **Too much focus is placed on logistics as a functional discipline (detail complexity) without an understanding of the integrated nature of logistics within a system (dynamic complexity). This focus on the detail complexity of logistics many times result in actions that are counterintuitive[1] without considering or recognising how these counterintuitive actions negatively influence system success over time.**

[1] *Counterintuitive* actions refer to actions intended to produce a desired outcome, but causing the opposite outcome [Gharajedaghi, 1999:48]. The counterintuitiveness of a system is a consequence of the dynamic complexity (delays between cause and effect) within a system [Senge, 1990:89-92].

The research hypothesis is the following:

**A whole-life whole-system approach to integrated logistic support (an approach to the dynamic complexity) will allow each definition of logistics (the different approaches to the detail complexity) to be understood and applied correctly within the system context of organisations and product systems, thus supporting system goals.**

To prove the hypothesis, a graphical model explaining the dynamic complexity of integrated logistic support will be developed and validated, demonstrating the need and validity for the whole-life whole-system approach to integrated logistics. This model will be limited to man-made systems.

The basic premises (each of which will be confirmed by the literature study) of the research are the following:

- A systems approach is required to solve systems problems.
- Systems go through a birth-life-death cycle (the system life-cycle).
- A formal process is necessary to bring systems into being and take it through its life-cycle.
- An organisation is a system which may itself deliver (or affect) new man-made system solutions e.g. durable products.
- Logistics (or support) form part of any system.
- Logistics consists of a technical dimension and a managerial dimension, both of which are to be designed using a formal process.

Thus, a system approach is required to view logistics within the system throughout the entire life-cycle of the system.

As opposed to the many functional definitions that exist, the Integrated Logistic Support Guide definition for logistics [adapted from Blanchard, 1998:3] will be used as a valid definition for logistics. The term integrated logistic support is used (rather than only the word logistics) and is defined as follows:

**Integrated logistic support is a disciplined, unified and iterative approach to the management and technical activities necessary to:**

- **Integrate support considerations into system and equipment design.**
- **Develop support requirements that are related consistently to readiness objectives, to design, and to each other.**
- **Acquire the required support.**
- **Provide the required support during the operational phase to ensure safety, ability, availability and affordability of the system of interest.**

In this definition, logistic support has the meaning of supplying and maintaining the system sub-systems, according to M'Pherson's [1980:550] system view of the support sub-system that includes both logistics (supply) and maintenance (support).

This definition has been chosen for the following reasons:

- It takes a whole-system approach.
- It takes a whole-life (life-cycle) approach.
- Objectives of the integrated logistic support have been clearly stated.
- It caters for all processes (management and technical, supply and maintenance).

## 1.4 The method and objective of the research

This research is an empirical model-building study using secondary textual data to construct a schematic (graphical) model of the dynamic relationships between the managerial and technical integrated logistic support activities of a system throughout the full system life-cycle. The objective of the research is to improve the understanding of system design and operation in order to enhance the overall system performance parameters of ability, availability and affordability. The model is validated by using implication diagrams and logical deduction (thought experiments) to compare the logical consequences of ignoring a systems approach to integrated logistic support with the logical consequences of using a systems approach to integrated logistic support.

## 1.5 Thesis roadmap

Figure 1.1 provides a roadmap of the thesis and shows the logical sequence of chapters. The roadmap will be included at the beginning of each chapter highlighting the position of the relevant chapter within the overall scheme of the thesis.

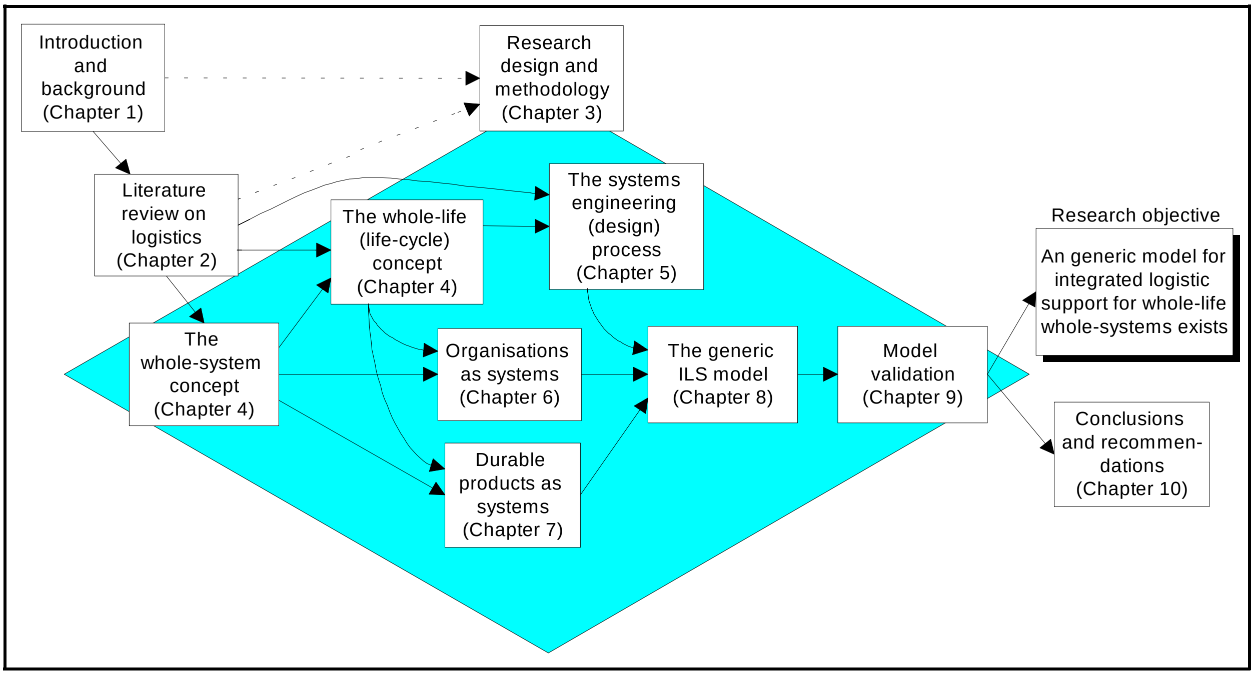



**Figure 1.1 Thesis roadmap**

The first three chapters provide the introduction and background to the research, along with the research design and research methodology. Chapters 4 - 7 provide the theoretical background that serve as the building blocks for the model for integrated logistics. The main building blocks for constructing the model are the systems and life-cycle concepts, the way in which systems are brought into being, how organisations and durable products exhibit system behaviour, and how organisations and durable products require logistic support to be able to meet the system requirements. The literature review of logistics (Chapter 2) is required for the discussion of the whole-systems concept and the whole-life (life-cycle) concept (both in Chapter 4). These two concepts, are required to explain that both an organisation (Chapter 6) and durable products (Chapter 7) exist as systems.

Chapter 5 explains how systems are engineered. Chapters 2, 4, 5, 6 and 7 are required to establish the foundation for an integrated logistic support model, which follows in Chapter 8. Chapter 8 is the main contribution of this thesis, where the generic approach to integrated logistics for whole-life whole-systems is presented as a schematic (graphical) model explaining the dynamic complexity of the technical and managerial processes over the life-cycle of the system and its influence on system success. Within Chapter 9 the model is validated using thought experiments and implication diagrams. With some further refinement, these implication diagrams can be used as the basis of a system dynamic model for simulation and prediction of system performance. The conclusions and recommendations of the research are presented in Chapter 10.

## 1.6 The principal results of the research

Generic sub-systems exist within every system regardless of the type of system investigated. The support sub-system (from here on it will be referred to as the integrated logistic support system) is one of the generic sub-systems of a system, and this sub-system is crucial for system success. When the integrated logistic support system is ignored, the whole-system concept is not valid anymore and the system as a whole not be optimised, as one of the generic sub-systems that is required for a complete system and its contribution towards total system success is not considered. Systems exist in time (they follow a natural birth-life-death cycle). For each phase of the life-cycle different managerial and technical activities are required. Taking the whole-system and whole-life characteristics of systems into consideration, generic measurements of system success can be defined, namely ability, availability and affordability. These measurements are applicable to any system irrespective of the type of system or the system hierarchy level on which the system exists and functions.

All organisations (public and private, for-profit and not-for-profit) organisations exist as systems. Many products (those categorised as durable products) exist as systems. Services and consumable goods are not systems in themselves but exist as part of organisational systems.

A system and life-cycle approach to logistics allows the creation of a model that explains integrated logistics support as part of a system that goes through a birth-life-death cycle. Different managerial and technical activities are required as the system goes through each phase of the life-cycle in order to achieve the overall goal of the system measured as system ability, system availability and system affordability. The dynamic nature of integrated logistic support is obvious as most of the effects experienced by the system during its operational phase are caused by actions taken during the design phase.

Implication diagrams provide a mechanism to conduct a thought experiment to allow the comparison of systems whose creators choose to employ a whole-life whole-systems approach to integrated logistic support and those systems whose creators choose not to employ a whole-life whole-systems approach to integrated logistic support.

## 1.7 The principal conclusions of the research

For any system to be successful over its entire life-cycle, a whole-life whole-system approach to integrated logistic support (as advocated by the model that has been developed) needs to be followed. If this is done, the system will be more successful in its goal achievement expressed as ability, availability and affordability. Integrated logistic support is required and essential for its contribution towards system success. Integrated logistic support have to be viewed form both an operational as well as a maintenance perspective, as both these perspectives contribute towards ability, availability and affordability. The major impact of integrated logistic support is caused early in the life-cycle, in the design phase of the system, but only realised during the operational phase due to the dynamic nature of integrated logistic support. If integrated logistic support is ignored, the cost and time implications to improve the system later in its life-cycle may be prohibitive to improve ability and availability. It must also be recognised that different requirements exist for the management and technical activities as the life-cycle progresses. Within the model it is also shown that some of the managerial and technical activities may overlap for periods of the life-cycle.

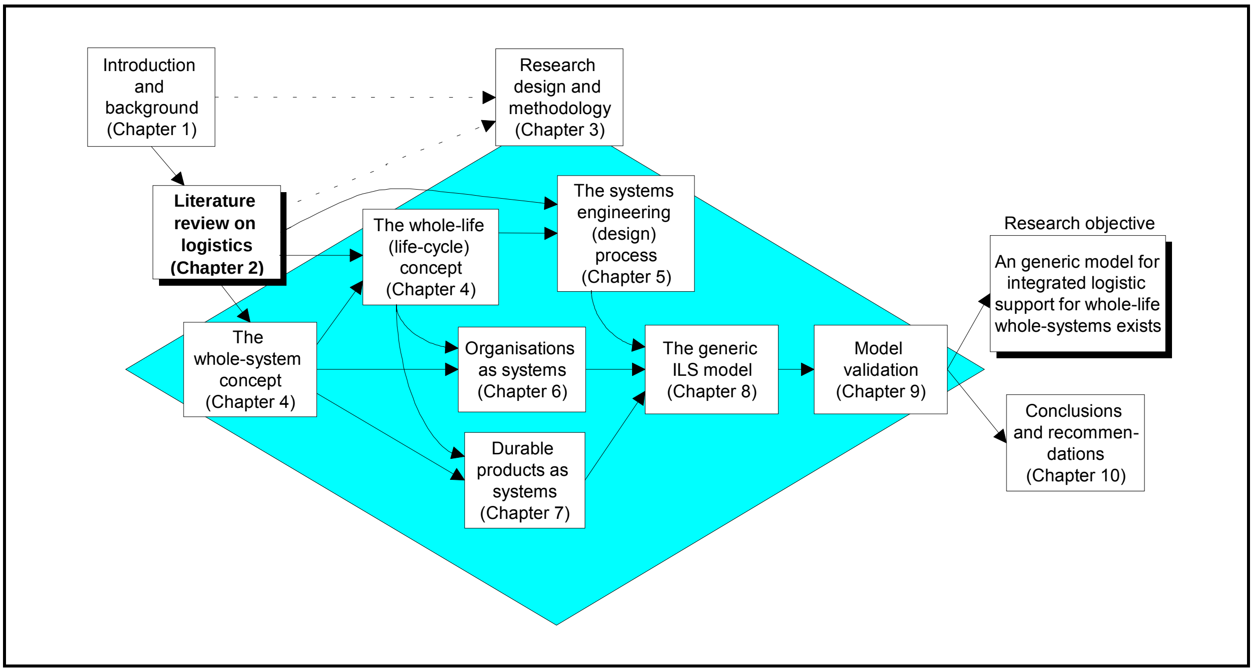
Further research is necessary to investigate the detail complexity of integrated logistic support to ensure that it ties in with the dynamic complexity of integrated logistic support i.e. how counterintuitive actions can be eliminated from the detail complexity of integrated logistic support to fully support the dynamic complexity of systems expressed as optimum ability, availability and affordability.

# Chapter 2

# Logistics - The undefined overly defined concept

*"I don't know what the hell this logistics is that general Marshall is always talking about, but I want some of it!"*

Admiral King [Gourdin, 2002]




## 2.1 Purpose and outline of the chapter

The purpose of this chapter is show that even though a large number of definitions for logistics in some form or another exist, the concept of logistics is still a very confusing one. Most definitions of logistics seem to contradict one another, and when the meaning of the definitions are analysed, the confusion becomes even more. Taking it one step further, when the goals for logistics associated with some definitions are analysed, the situation becomes ridiculous at times. Furthermore, models explaining logistics are limited to the definition they try to explain or are totally oversimplified.

The chapter starts out by taking a historical view on logistics, followed by some dictionary definitions, after which some older and more recent views of logistics are investigated. Some logistics models are investigated to demonstrate the need for an integrated logistics model. The chapter concludes by confirming the problem statement posed in Chapter 1.

## 2.2 A historical perspective on logistics

Logistics is as old as the world itself. The word logistics is derived from the Greek word *logistikos*, which means to be adept or skilful in calculation. Even though the concept of the calculation of requirements for support may be connected to the meaning of the word, it does not provide us with anything more concerning the origin of the word logistics [De Klerk,1993:5].

Since the earliest times logistics has been associated with supplying masses of people with their needs. One of the first examples of a massive logistics exercise (even though not called logistics) can be found in Exodus 16, where the Lord supplied Israel with quails and manna in the desert. This in itself was not the logistical exercise, as it was a Godly act, but it must have been a huge logistical exercise to set up camp, provide water, firewood for cooking and heating and to provide waste services. No mean feat if you consider that there were 603 550 men above the age of twenty, all that were able to go forth to war in Israel, excluding the Levites [Numbers 1:46-47]. This seems to be one of the first examples where logistics is associated with a military force.

Examples where the role of logistics has been described with regard to its importance to the ultimate success of a military campaign are Sun Tzu Wu in *The Art of War* (500 BC), Alexander the Great, the Romans, Napoleon and Hitler. Both Napoleon and Hitler failed with their attempts to invade Russia because their supply lines were too long and could easily be disrupted, in their case partially at least by the harsh reality of the winter weather [Gourdin, 2001:1-2].

Lambert, Stock and Ellram [1998:5] state that logistics as an area of study first gain attention in the early 1900's with the distribution of farm products, as part of the organisational strategy and as a way of providing time and place utility to goods sold. These authors further link the success of the Allied victory in WWII to logistics, as well as in the Persian Gulf War in 1990-1991 [op cit]. The first dedicated text books appeared in the 1960's, and this period (1956 to 1965) is regarded as the period of conceptualisation of logistics, including the application of the systems approach [Bowersox, Closs and Helferich, 1986:7]. 1966 to 1970 was a period to test logistics for relevancy, where for most of the time, the logistics concepts became reality and passed the test of time [op cit: 9-10]. The next period, 1971 to 1979, was the period where logistics became institutionalised within countless private and public enterprises, despite the changing priorities, the most significant being environmental concerns and the energy crisis [op cit: 11-12]. The period from 1980 to 1990 experienced significant political and technological change such as transportation deregulation, the introduction of microcomputer technology and the communication revolution [op cit: 12-14]. In the final part of the previous century and the beginning of the third millennium, logistics concepts that came to the fore are globalisation [Bloomberg, LeMay and Hanna, 2002:6], supply chain management and enterprise resource management (ERP).

## 2.3 Logistics definitions

The most basic definition for logistics comes from the Webster Dictionary [Webster,1963]: *"The procurement, maintenance, and transportation of military material, facilities, and personnel."* Another very basic definition can be found in the Oxford Paperback Dictionary [1979]: *"The organization of supplies and services"*, while The South African Pocket Oxford Dictionary [1987] defines logistics as: *"The art of supplying and organising (orig. military) services and equipment etc."* A more recent Webster Dictionary definition is [Webster, 1988]: "*The aspect of military science dealing with the procurement, maintenance, and transportation of military material, facilities and personnel*". From a clinical definition point of view, logistics is very much viewed as an activity related to the military and military operations, probably because of the fact that *"logistics is firmly rooted in the historical doctrine of war"* [Gourdin, 2001:2]. Closely associated with the previous definitions, the US

Air Force defines logistics as *"The science of planning and carrying out the movement and maintenance of forces. In its most comprehensive sense, logistics pertains to those aspects of military operations which deal with (a) design and development, acquisition, storage, movement, distribution, maintenance, evacuation, and disposition of material; (b) movement, evacuation, and hospitalization of personnel; (c) acquisition or construction, maintenance, operation disposition of facilities; (d) acquisition or furnishing of services"* (Compendium of Authenticated Systems and Logistics Terms, Definitions, and Acronyms, 1981:401). In this definition we find for the first time that reference is made to the life-cycle cycle. Also of note is that this definition also includes maintenance as a pertinent activity part of logistics.

The Council of Logistics Management (CLM) offers the following definition: *"Logistics is the process of planning, implementing and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods and related information from point of origin to point of consumption for the purpose of conforming to customer requirements"* [Lambert and Stock, 1993:4 and Blanchard, 1998:3]. Ballou (1987:7) adds a descriptor to logistics and provides the following definition: *"Business logistics deals with all move-store activities that facilitate product flow from one point of raw-material acquisition to the point of final consumption, as well as the information flows that set the product in motion for the purpose of providing adequate levels of customer service at a reasonable cost"*.

The Society of Logistics Engineers (SOLE) defines logistics as *"The art of science and management, engineering, and technical activities concerned with requirements, design, and supplying and maintaining resources to support objectives, plans and operations"* [Blanchard, 1992:4]. Interesting to note that in this definition, logistics is considered an *art* of science and management, engineering and technical activities, which makes it very open for different interpretations.

To make things even more complicated, another definition is provided for integrated logistic support (ILS) in the *DSMC Integrated Logistic Support Guide* [Blanchard, 1998:3]: *"Integrated logistic support is a disciplined, unified, and iterative approach to the* *management and technical activities necessary to (1) integrate support considerations into system and equipment design; (2) develop support requirements that are related consistently to readiness objectives, to design, and to each other; (3) acquire the required support; and (4) provide the required support during the operational phase at minimum cost"*.

From a marketing perspective, Christopher [1992:xi] provides a definition for marketing logistics: *"Logistics is the process of strategically managing the acquisition, movement and storage of materials, parts and finished inventory from suppliers through the organization and its marketing channels, in such a way that current and future profitability is maximized through the cost-effective fulfilment of orders".*

Viewing it form an operations management side, Chase, Aquilano and Jacobs, [2001:339] provides the following definition: *"Logistics is a term that refers to the management of functions that support the complete cycle of material flow: from the purchase and internal control of production materials; to the planning and control of work-in-process; to the purchasing, shipping and distribution of the finished product".*

Bloomberg, LeMay and Hanna [2002:6] provides the following definition: "*Integrated logistics is defined as the process of anticipating customer needs and wants; acquiring capital, materials, people, technologies, and information necessary to meet those needs and wants; optimizing the goods- and service-producing network to fulfill customer requests; and utilizing the network to fulfill customer requests in a timely way".*

To summarise, it seems as if logistics can be categorised in at least two dimensions, namely those logistics activities that relate to the military and military operations, and those logistics activities relating to movement of material from point of origin to point of consumption to ensure that proper business can be conducted.

## 2.4 Existing logistic models

### 2.4.1 Components of logistics management

Lambert, Stock and Ellram [1998:3] define logistics management as *"Logistics is the process of planning, implementing and controlling the efficient, effective flow and storage of goods, services and related information from point of origin to point of consumption for the purpose of conforming to customer requirements"*, a definition gleaned from the Council of Logistics Management. Of interest is that these authors provide this definition for logistics *management*, whilst the Council of Logistics Management uses (almost) exactly the same definition to define just *logistics* [Blanchard, 1998:3]. Lambert, Stock and Ellram [1998:4-5] subsequently provide a model for what they call components of logistics management, shown in Figure 2.1.

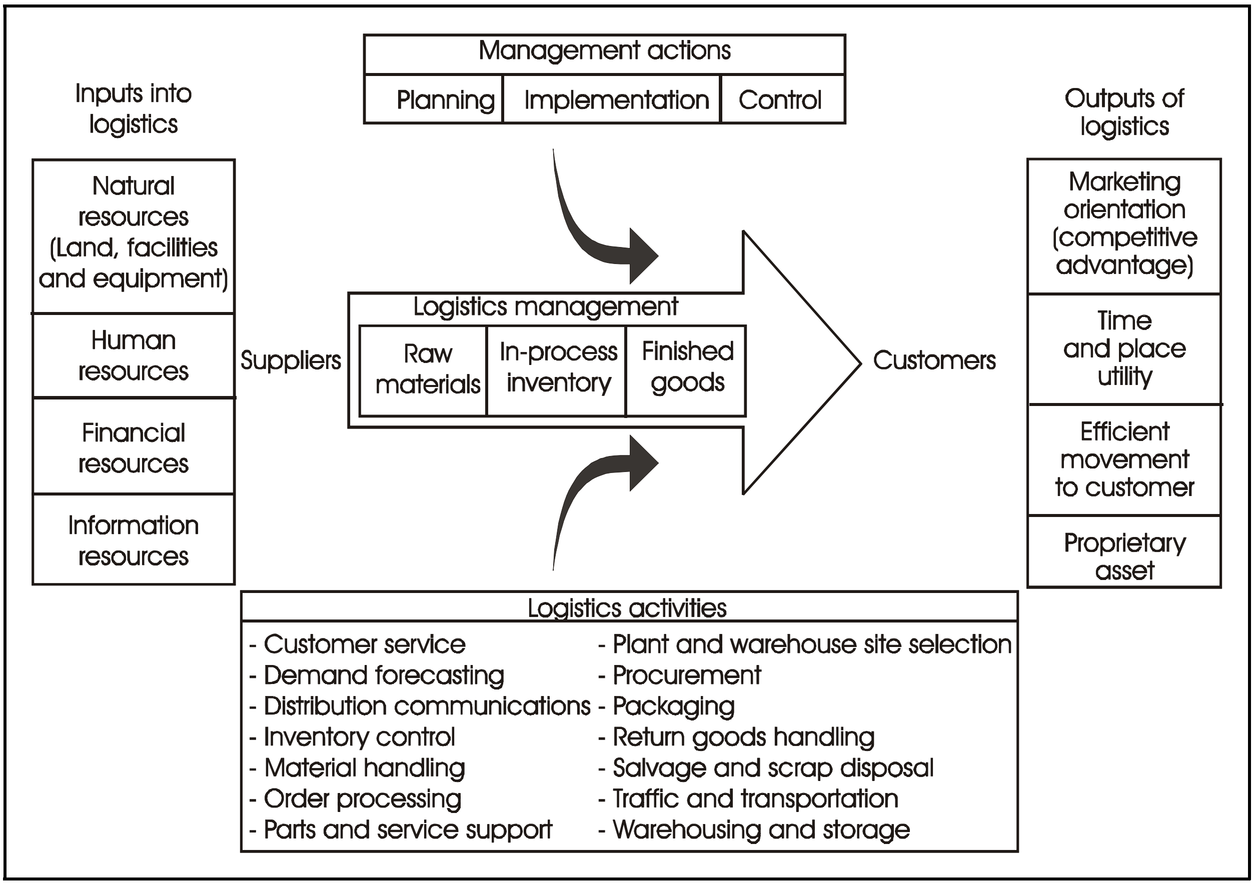



**Figure 2.1: Components of logistics management**
[Lambert, Stock and Ellram, 1998:5]

This model is primarily in support of the definition they use for logistics management and focuses on the flow of material (business logistics) from supplier through the organisation to the customers. These authors provide a breakdown of the inputs into logistics, the management actions applied to the flow process where logistics management is applied to the flow of raw material, in-process inventory and finished goods, as well as a breakdown of the output of logistics. They also provide a list of typical logistical activities that need to be managed. No indication is given of the life-cycle or system approach to the logistics management and activities.

### 2.4.2 The scope of business logistics

Ballou defines three primary activities for logistics. They are transportation, inventory maintenance and order processing. The relationships between these activities are shown in Figure 2.2. The concepts of transportation and order processing are straight forward. However, inventory maintenance needs some clarification. Inventory maintenance refers to those activities that allows one to provide time value by keeping finished goods inventory. As one cannot keep finished goods of a service, the model is not applicable to

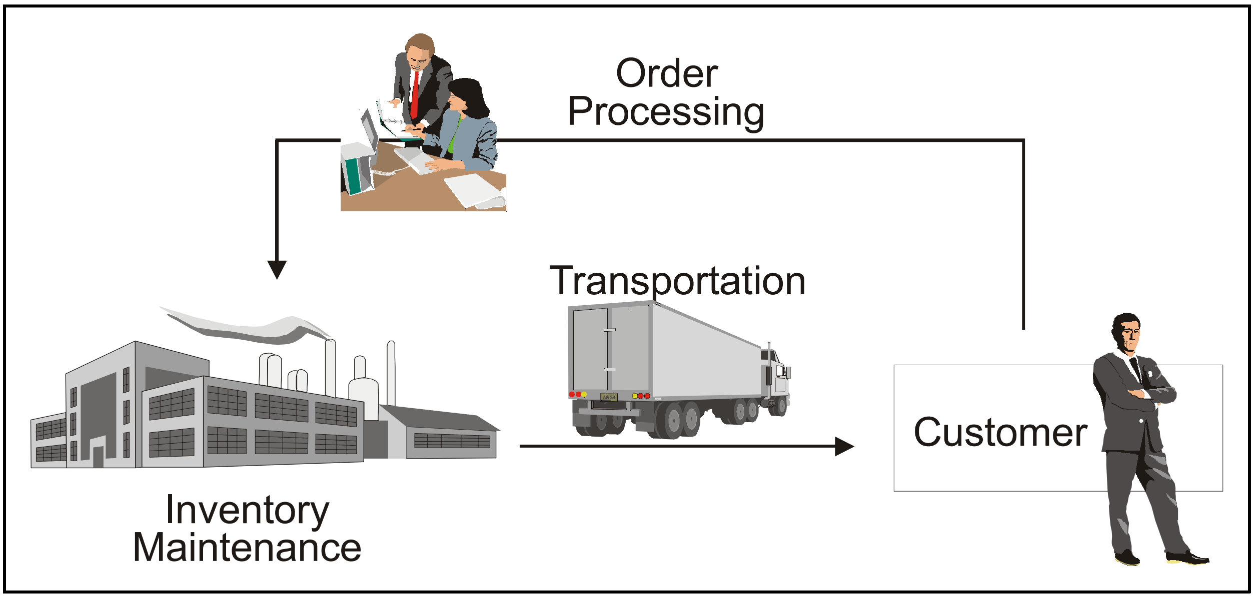



**Figure 2.2: The relationship of the three primary logistic activities to serving a customer - the “Critical Loop”** [Ballou, 1987:8]

service industries. However, if the definition of inventory maintenance is changed to those scheduling and inventory activities required to fill an order, whether it is filling the order from stock, through MRP scheduling or using the JIT philosophy, it can be made applicable to the make-to-order (and thus service) environment as well. A further refinement of Ballou's three primary activities is to link a number of organisations together in the supply chain, which is shown in Figure 2.3.

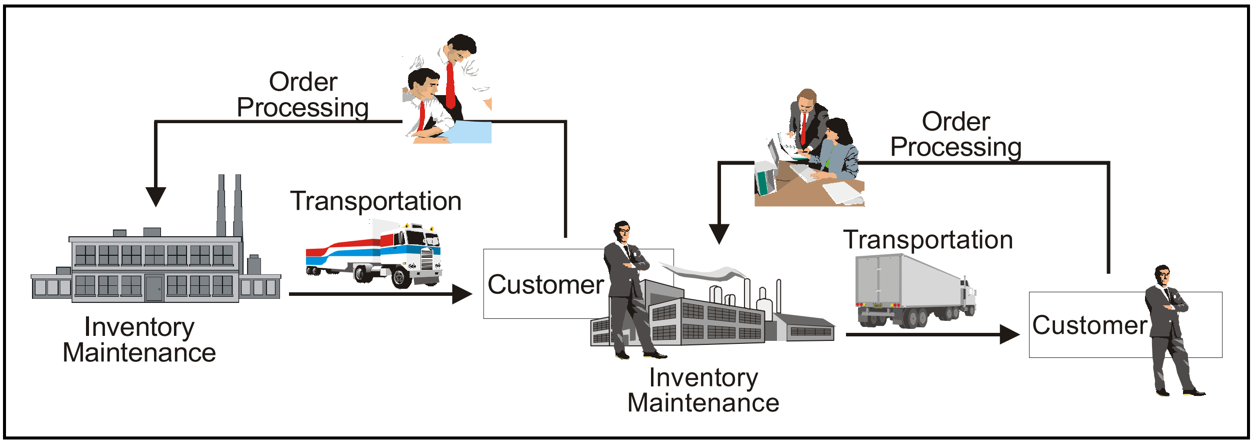



**Figure 2.3: The three primary logistic activities creating the supply chain**
Adapted from Ballou [1987:8]

It is now obvious that when one considers the organisation in the middle of Figure 2.3, everything to the left is the physical supply or materials management, whilst everything to the right is physical distribution.

Ballou [1987:17-18] proposes a model of integrated logistics as shown in Figure 2.4 and calls it the scope of business logistics. His idea of integration relates to the integration of materials management (physical supply) and physical distribution, which also brings closer ties with the operations function. This model, although emphasising different aspects than the model of Lambert, Stock and Ellram (as discussed in § 2.4.1), is also a model of material flow from point of origin to point of consumption. As is the case with the model of Lambert, Stock and Ellram [1998:4-5], a life-cycle and systems approach is not deemed important enough to include a time and system integration dimension within the model.

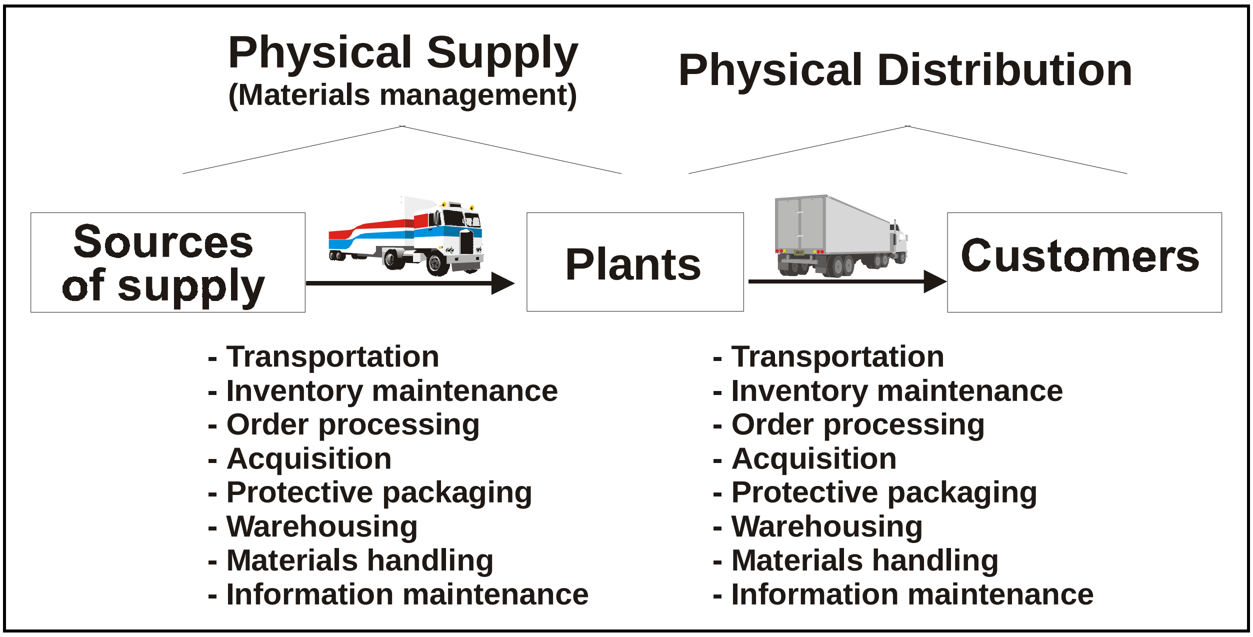



**Figure 2.4: The scope of business logistics**
Ballou [1987:18]

Of note is that all activities of the physical supply are exactly the same as the activities of physical distribution. The integration point which is not immediately visible is at order processing. Order processing of the physical supply deals with the dependent demand items, which are calculated from the order processing of the physical distribution, or independent demand. The independent demand is derived from actual customer orders and forecasts. This approach is similar to the value chain concept of Porter [1990:40-42] which will be further discussed in Chapter 6.

### 2.4.3 Logistics in the system life-cycle

Blanchard [1998:11] seems to be the only author to specifically address logistics in the life-cycle. The model he proposes (shown in Figure 2.5) is one that this author subscribes to. The problem with Blanchard's model is that it does not show sufficient detail and that it limits its focus to only parts of the overall system. His main emphasis is on the system/product and the support capability design. Furthermore, no clear distinction is made between the managerial and technical logistics activities.

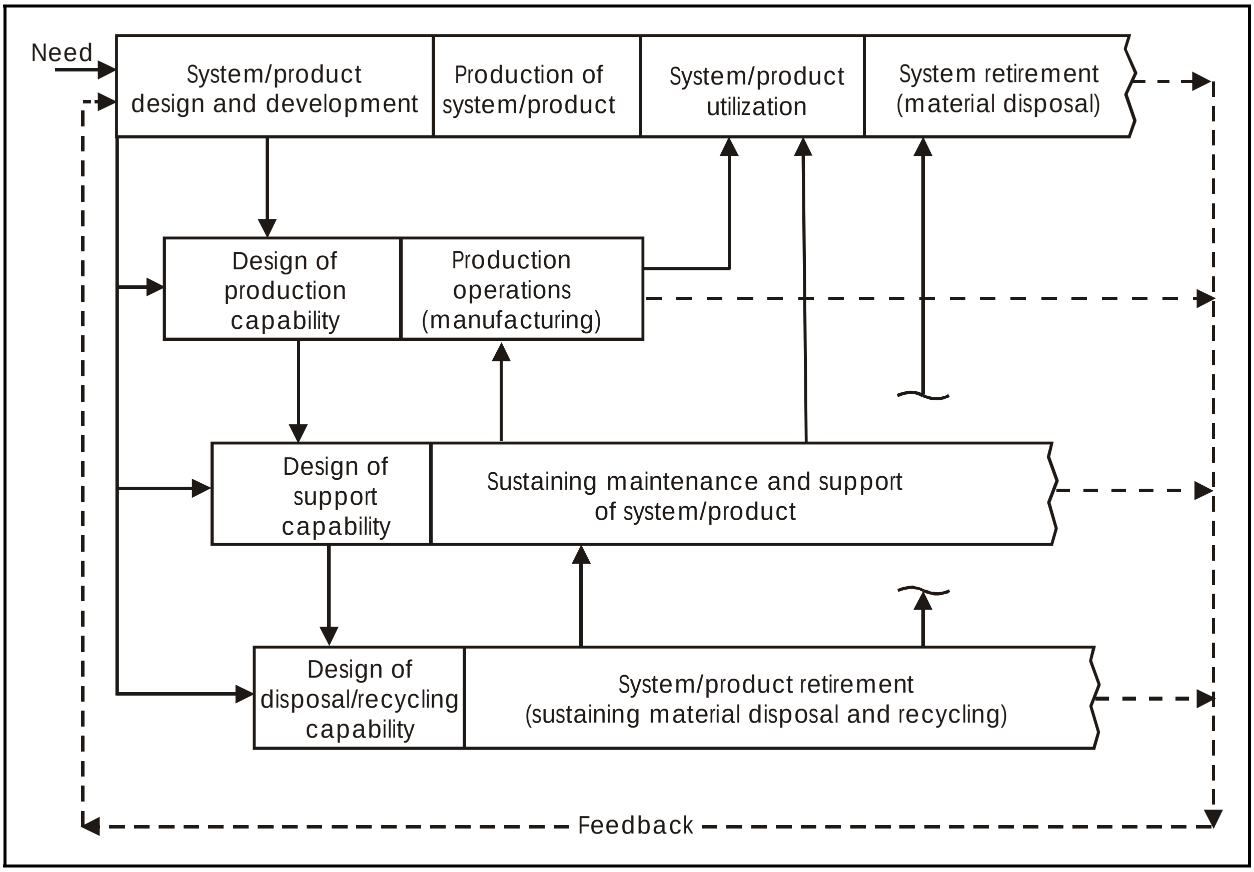



**Figure 2.5: The interrelationships of the life-cycle phases in system development** [Blanchard, 1998:11]

This model supports the idea of simultaneous or concurrent engineering, and can be enhanced by extending it to different system hierarchy levels, for example the design of the production capability will also require the design of its own production capability (in other words the ability to construct the production capability), design of the production capability support function, and the design of the disposal/recycling function of the production capability. The ideas conveyed on a high level within this model will be used as the foundation for the proposed model resulting from this research.

## 2.5 Confirmation of the problem statement

The above definitions and models of logistics confirm the magnitude of differences when logistics is viewed. This is further compounded by the fact that very few authors actually ask the question why logistics is needed within the organisation. Green [1991:3] is correct in saying that integrated logistic support is crucial to the ability of a system to serve its intended purpose, but then categorically state that *“the goal of logistics is to reduce the burdensome cost of logistics through better management, organization, and utilization of all resources to the maximum extent possible”* [op cit: 6]. If the above goal is to be true, then logistics should be eliminated as that would result in the lowest (i.e. zero) logistics cost. Furthermore, if maximum utilisation is to be strived for as part of this goal, material should be moved for the sake of utilisation even if the demand does not justify material movement. It implies using a transportation system to move material that does not need movement, only adding to overall costs. Trying to achieve maximum utilisation of resources at all times as a system measurement is to disregard the system nature of organisations and supply chains.

If such confusing and contradicting statements are made within the writings of one author, trying to make sense of many more viewpoints seems to be very difficult. The question that immediately follows, is what makes this attempt at clarifying the concept of logistics different to those that have tried before? The answer is that the major difference lies with taking a systems and life-cycle approach (dynamic complexity) as opposed to try and functionalise logistics (detail complexity). This is what this thesis attempts to do.

## 2.6 Chapter summary

Logistics has been with mankind since the beginning of time even though its formal definition only came much later. Different phases of the interest in logistics on the man-made environment have been identified, and the effects and impact of logistics can be measured and quantified within each phase. However, some very contradictory definitions exist that create confusion as to exactly what this thing called logistics is. This confusion is attributed towards functionalising logistics as opposed to taking a systems and life-cycle approach to understanding logistics.

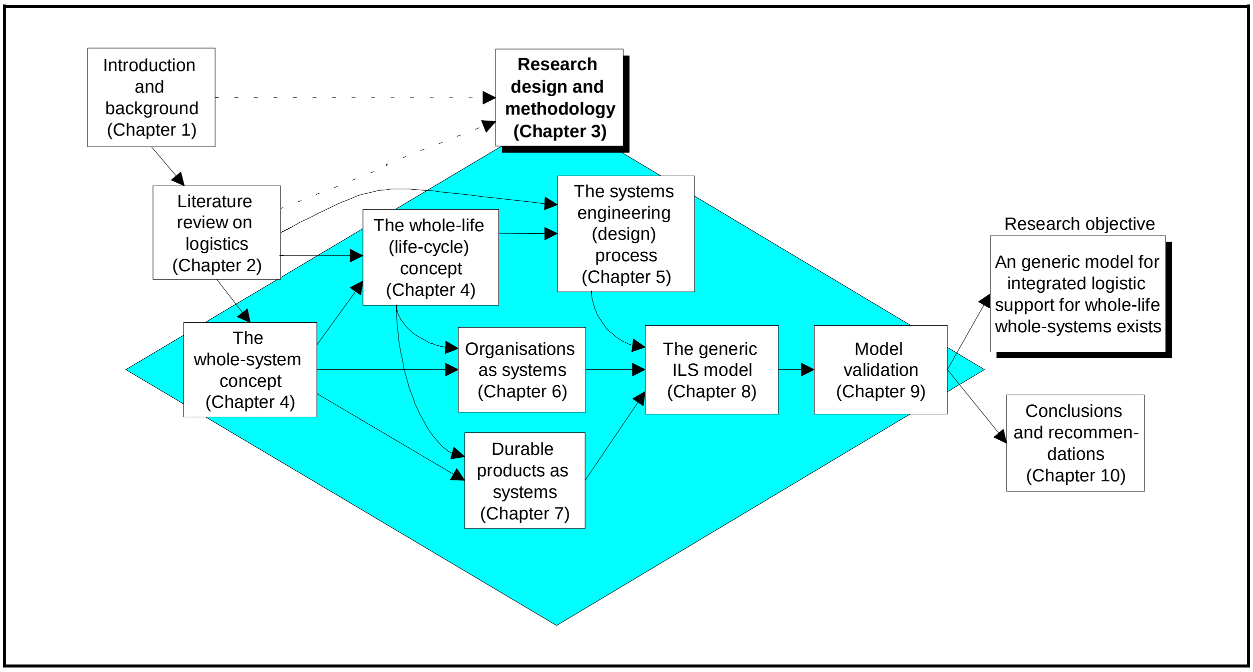
# Chapter 3

# Research design and methodology

*"For which of you, intending to build a tower, sitteth not down first, and counteth the cost, whether he have sufficient to finish it? Lest haply, after he hath laid the foundation, and is not able to finish it, all that behold it begin to mock him, saying, this man began to build, and was not able to finish."*

Luke 14: 28-30

King James Version




## 3.1 Purpose and outline of the chapter

The purpose of this chapter is to provide the detail of the research design and methodology so that the approach taken to develop a generic model for integrated logistics support of whole-life whole-systems can be understood. The nature of science and the scientific method is discussed to put in perspective the research design that follows. Within the research design discussion, the research design will be described and classified, followed by the conceptualisation and mode of reasoning employed. Next the research methodology is introduced consisting of the objective of the research, followed by the structure of the research and the process employed to conduct the research. As this research is concerned with model building, a brief explanation of modelling basics follows.

## 3.2 The nature of science and the scientific method

The difficulty to exactly define what science is, arises from the fact that science is not static, but dynamic, and its meaning evolves with the evolvement of science itself. Defining science will not stop its evolvement, thus finding a definition is not to attain an ultimate definition of science, but to at least reach a common understanding of the concept [Ackoff, 1999:293].

Without going into too much detail, science exhibits the following properties:

- Science is a process of enquiry to:
  - answer questions,
  - solve problems, and
  - develop more effective procedures for answering questions and solving problems [Ackoff, 1999:293].
- The products of scientific inquiry are a body of knowledge and information that allows improvement of the environment, and a body of processes and procedures which generates the body of knowledge and information [Ackoff, 1999:297].
- Science can be a qualitative or a quantitative inquiry. One of the best examples of a qualitative inquiry which is regarded as *the* outstanding achievement of the nineteenth century was the theory of evolution. The theory of evolution has nothing to do with measurements but is concerned with qualitative changes, and treats them qualitatively [Dingle in Ackoff, 1999:294]. *"Even if one disagrees with Dingle's characterization of the theory of evolution, the point is not removed: an eminent historian of science is willing to include in science a theory that he considers to be totally qualitative"* [Ackoff, 1999:294].
- Not all inquiry is scientific. Thus, excluded from science are the common sense inquiries. The difference between common sense and science lies within the fact that science is approached with a controlled process in the sense that it is effectively directed toward the attainment of desired objectives [Ackoff, 1999:295]. Huxley [in

Ackoff, 1999:295] argues: "*Science is, I believe nothing but trained and organized common sense, differing from the latter only as a veteran differ from a raw recruit: and its methods differ from those of common sense only so far as the guardsman's cut and thrust differ from the manner in which a savage wields his club*". Thus it seems as if the differentiation between a scientific and non-scientific enquiry is a grading scale between the two extremes. It should also be noted that much of the common knowledge and common sense that exist today are based on the products of yesterday's science [Ackoff, 1999:295].

- The scientific method is not preferable in all cases. Even if the scientific method can give a better solution than some common sense enquiry, there are situations where the application of the scientific method is not justified. Examples are in the case of an emergency, where a good answer in time is preferable to a better answer too late. Looking at daily decisions being made is another example, such as what to wear and where to eat, where the application of the scientific method is not justified when the value of the outcome is compared with the associated cost [op cit].
- Control is necessary but not sufficient to distinguish the scientific grade. Science is also concerned with self-perpetuation and self-improvement. Thus scientific endeavours must continuously provide feedback on how to improve the conducting of research itself. Thus many research reports include a discussion on how the research ought to have been done in the light of the experience gained in conducting the research, in order to test and evaluate research procedures to improve the research process itself [Ackoff, 1999:295-296].

Having a common understanding of what science is, a definition can be provided for the scientific method, or the approach to conducting scientific research. Leedy [1997:94-95] defines the scientific method as "... *a means whereby insight into the unknown is sought by (a) identifying the problem that defines the goal of the quest, (b) gathering the data with the hope of resolving the problem, (c) positing a hypothesis both as a logical means of locating the data and as an aid to resolving the problem, and (d) empirically testing the hypothesis by processing and interpreting the data to see whether the interpretation of them will resolve the question that initiated the research".*

In the light of the above discussions, empirical data does not necessarily mean quantitative numerical data, but can be qualitative textual data. Furthermore, testing the hypothesis is not limiting the researcher to the use of statistical analysis, but deductive logic can be employed as a means of conceptualisation and mode of reasoning to arrive at a conclusion.

## 3.3 The research design

### 3.3.1 Design description

The type of research undertaken is a theory-building or model-building study. Such a study is aimed at developing new models and theories to explain particular phenomena. This type of research is aimed at answering questions of meaning and explanation, questions of theoretical linkages and coherence between theoretical propositions, and questions related to the explanatory and predictive potential of the theories and conceptual models [Mouton, 2001:176]. Theories and models render causal accounts of the world for understanding, that may also allow predictions to be made of the behaviour under certain circumstances of what is being modelled. Theories and models thus allow for conceptual coherence to a domain of science and simplify our understanding of the world. The danger of new theories and models can be that they make implausible claims on reality, or they may be vague, conceptually incoherent, inconsistent and confusing [Mouton, 2001:177], something that will be guarded against during this research.

This thesis proposes a model that is fundamentally a model for understanding with primary application in post-graduate education (management, business and engineering), but can also be used for prediction on a conceptual level (see § 3.5.1 for a discussion on the purpose of models). The predictive capacity of this model depends on the high level relationships between actions (both technical and managerial) taken at various stages in the life-cycle to influence the generic system measurements of ability, availability and affordability. Predictions are possible as the relationships between the actions mentioned and the outcomes on the system measurements can be explained by implication diagrams. Further research (typical system dynamic simulations) will have to be done to investigate how sensitive the system outcomes are to the actions taken. Sensitivities may differ from system to system.

### 3.3.2 Design classification

The research is of an empirical nature. Secondary textual data is the main data source for the research. The experience of the researcher provides limited primary data. The degree of control and the structure of the research design is medium to low as opposed to a laboratory experiment where a high degree of control and structure of research design is possible. In order for the model to be tested using quantitative empirical data would be impossible, as the requirements for a valid comparison between organisations and/or product systems prohibit such a comparison both from a timing and availability of valid data point of view. As this research is concerned with systems spanning their entire life-cycles, qualitative empirical data should be obtained for organisations and product systems from conceptualisation until phase out/retirement. Also, market conditions, environmental impacts and other influencing factors have to be the same for the systems under comparison, and above all, one must find systems that employ the approach proposed by this thesis to compare to systems that do not follow the approach proposed by this thesis. Because of the above impracticalities, the next paragraph will introduce the specific approach selected for the conceptualisation, mode of reasoning and validation employed within this research.

### 3.3.3 Conceptualisation and mode of reasoning

Deductive reasoning is used for this research. The form of deductive reasoning used is conceptual explication, which is where the meaning of a concept is clarified through the deductive derivation of its constitutive meanings. Even though there is much criticism of deductive reasoning because of its qualitative nature, it is still one of the most powerful methods to construct conceptual models and build new theories, without which science cannot make progress [Mouton, 2001:117]. This is in accordance with the statement in § 3.2, namely that the evolvement of science is continuous, implying the need for new models and theories. This continuous evolvement of science requires the premises and hypotheses to be kept tentative. According to Rubenstein and Firstenberg [1995:17], hypotheses are not proven true in science, they are just subscribed to on a tentative basis until proven wrong. Deductive reasoning would be fatal when hanging on to false premises and assumptions in the face of evidence to the contrary. Thus the criticism should not be against deductive reasoning, but against false logic or false premises employed. In the absence of proof of false premises and logic, the hypothesis must be accepted, at least tentatively until new evidence can be found which will then invalidate the hypothesis. Qualitative inquiry (thus inductive reasoning) has been demonstrated to be a valid scientific research conceptualisation e.g. Stephen Hawking on cosmology, Einstein on relativity, and Bohr and Heisenberg on quantum physics [Professor Paul Kruger, personal communication, 27 February 2002].

## 3.4 The research methodology

### 3.4.1 Methodology defined

A methodology[1] is an approach or method to bring something into being or to accomplish something. A methodology first has to define what is to be accomplished and secondly how it is to be accomplished. In order for the process to take place, an understanding must exist of the function and structure of what is to be brought into being or accomplished. Thus, bringing something into being is the equivalent of design, which is dealing iteratively with function (goals and objectives), structure and process [Gharajedaghi, 1999:110]. According to Gharajedaghi [op cit] function defines outcomes and effects, structure defines components and their relationships, while process defines sequence of activity and the know-how to produce the outcome. In this document function refers to the desired outcome of the research, structure refers to the structure of the research and the structure of this document, and process refers to the model building process employed to achieve the desired outcome by linking the different components together into one structure. As the

[1] *Methodology* is sometimes defined as the study of methods. In this thesis however, methodology will have the meaning of a method or approach to bring something into being.

objective of this research has already been stated, only the structure and process will be discussed further.

### 3.4.2 The structure of the research

The outcome of the research (what has to be accomplished) has been defined in Chapter 1. Defining the structure of the research is the next logical step in the methodology. The research structure map and how the research relates to this document is shown in Figure 3.1, which indicates the logical flow and sequence of data and information required for establishing the generic model for integrated logistic support for whole-life whole-systems. The sequence of chapters within this document has significance as it is the same sequence in which the research was conducted.

The shaded blocks in Figure 3.1 are indicating background information and other requirements set for documenting research and is not part of the model or the deductive reasoning required to arrive at the model. The square block at the top of Figure 3.1 defines the final outcome of the research.

The first chapter provides the introduction, background, problem statement and hypothesis of the research. The literature study on logistics is conducted to confirm the problem statement and hypothesis and is documented in Chapter 2. In the first two chapters the need for a systems approach to be followed is demonstrated, thus providing justification for the research design and methodology, which is documented in Chapter 3.

In order for the model to be developed, a basic understanding of systems and system concepts is required. Included in the system concept is the whole-life or life-cycle concept. Of major concern are the generic system measurements of ability, availability and affordability. The system and life-cycle concepts are discussed in Chapter 4. Following the knowledge gained on the systems concept, an understanding of how systems come into being is the next prerequisite for the model. In Chapter 5 the systems engineering process is discussed, which is the generic design process applicable to systems.

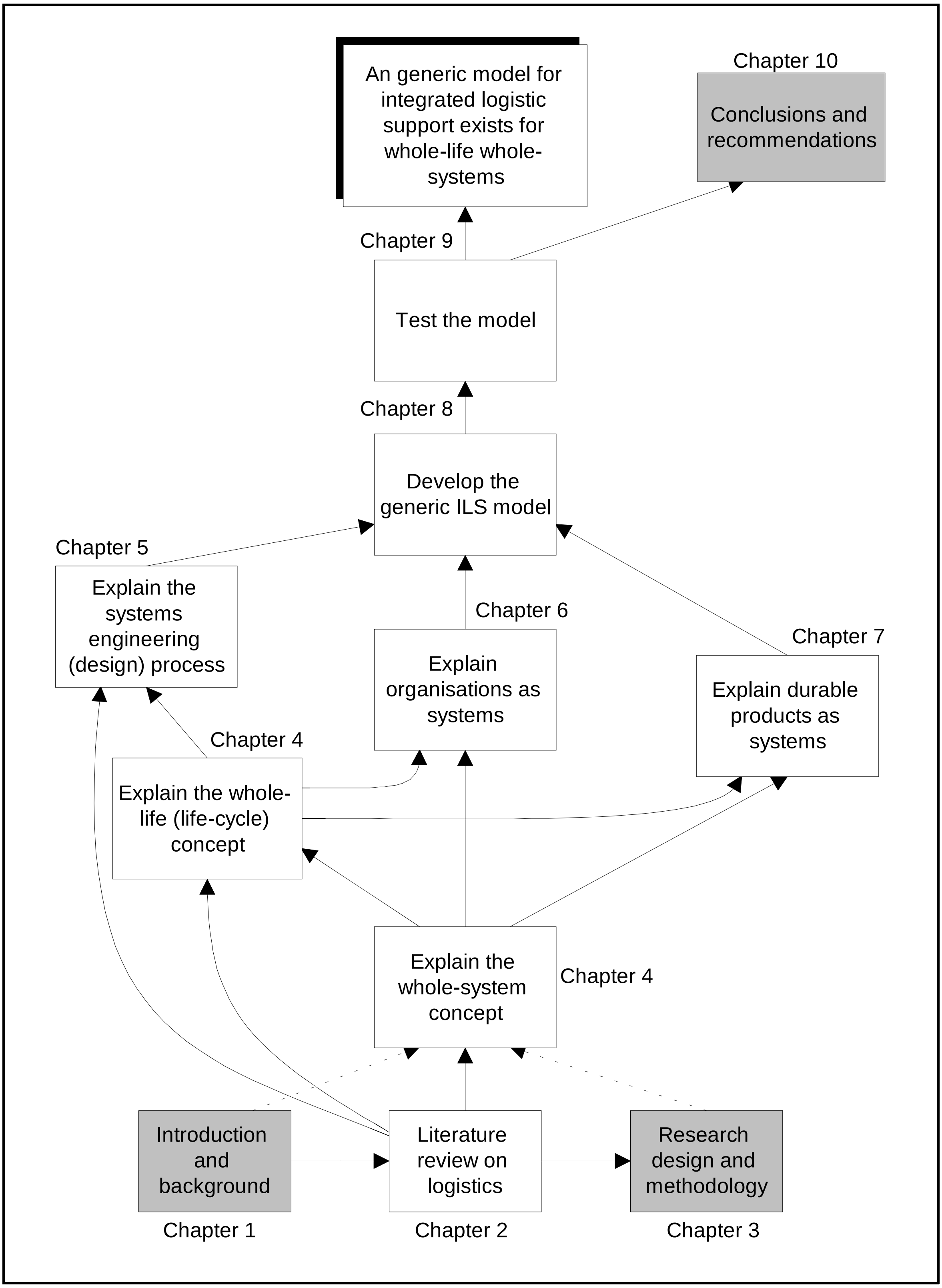



**Figure 3.1: The structure of the research**

Two main categories of systems exist in reality which are important for this research. They are organisational systems and product systems. Organisational systems are discussed in Chapter 6 while product systems (also known as durable goods) are discussed in Chapter 7. Within these two chapters the background provided by the preceding chapters on systems, the system life-cycle and how systems are brought into being, are used to demonstrate that organisations and durable products exhibit system characteristics which qualify them as systems, and that they should be brought into being using the systems engineering process in order for them to achieve system success. System success for both these types of system are measured as ability, availability and affordability.

Within Chapter 8 deductive reasoning is used to combine the systems concept, the system engineering concept, the applicability of a life-cycle approach and the support requirements set by organisational and product systems to construct an integrated logistic support model for whole-life whole-systems. The application of the model on the management level (management activities) as well as the execution level (technical activities) throughout the life-cycle of the system under consideration will allow for the improvement of the ability, availability and affordability. Chapter 8 contains the main contribution of this research, which is providing a model for understanding the dynamic complexities of the integrated logistic support within any man-made system.

Validation of the model takes place in Chapter 9. Due to the nature of the model and the absence of numeric empirical data, implication diagrams are used for validation. These implication diagrams serve the further purpose to demonstrate the relationships between the lower levels of abstraction of the system measurements of ability, availability and affordability. These relationships can be detailed for each system and practically applied for decision making throughout the life-cycle of the system.

To conclude this document, the results and conclusions are presented, and recommendations for further research are made in Chapter 10.

### 3.4.3 The model building process

Modelling consists of two major phases. The first phase is to achieve a simple high level of abstraction to serve as a starting point and the second phase is to achieve the desired level of abstraction. The fundamental steps for model building are [Rubenstein and Firstenberg, 1995:156, 161]:

- Establish the purpose of the model.
- Identify the possible elements that may relate to the purpose.
- Select those elements that are relevant to the purpose.
- Link elements that can be related by virtue of strong structural, functional or interactive connection between them.
- Reiterate the previous step until the desired level of abstraction is achieved.
- Test the model for errors of omission and commission.
- Validate the model against measurements or observations.
- Modify the model.

## 3.5 Modelling basics

### 3.5.1 The definition and purpose of models

To be able to visualise or think about something, one needs an image or picture of it. An image can be defined as that which exists in the mind as the product of careful mental activity. Whenever complex phenomena are imagined, a model is normally used [Gharajedaghi, 1999:110], especially when the image is to be conveyed from the originator of the image to others. A model is thus an abstract description of the real world, a simple representation of a more complex reality, a construct of the way things are, or a paradigm - the way the world is viewed [Rubenstein and Firstenberg, 1995:152]. Models are constructed to enhance and facilitate understanding and prediction. Models for understanding is only possible within a larger frame. If the idea (model) or event cannot be put into a frame, understanding is not possible e.g. the fall of an apple from a tree is understood only in the larger frame of gravity [op cit:153]. Models for prediction include parameters which are considered to contribute to the outcomes of interest e.g. a map can be used to predict the distance and travelling time between two cities. The amount of detail on the map (level of abstraction) depends on the purpose of the map i.e. a country map and a city map will have different levels of abstraction but also different purposes [op cit: 155].

There is also a strong relationship between models of understanding and models of prediction. Models of understanding identifies functional relationships and/or cause and effect relationships between events within a structure, which can then be used to predict the occurrence of future events and effects. In some cases, the effects are caused through the control of the relevant parameters [op cit: 153]. An example would be a model that attributes a low learning capacity to a class of students, which may become self-fulfilling when a teacher treats a class in accordance with the statement of the model [op cit: 185].

### 3.5.2 The relationships between methodologies and models

A methodology, as has been defined in § 3.4.1, is an approach to bring something into being, answering the questions of why (function), what (structure) and how (process). When the function and structure of a methodology are combined, an explanation and prediction of system behaviour can be provided. Thus within a methodology, function and structure can be represented by a model; adding process to the model will allow practical application of the model in the real world. As this thesis is concerned primarily with the development of an integrated logistic support *model*, the focus will be on function and structure. Limited discussion of process is included in this document for the sake of clarity. Where applicable, references to sources providing descriptions of process are also included. Further research may be required to move from the level of dynamic complexity to detail complexity.

### 3.5.3 Form and content of models

All models share two common features: form and content. Form describes the way in which the content of the model is represented, while content describes the boundaries of the model [Rubenstein and Firstenberg, 1995:163]. The more instances to which a model can be applied in its single form, the more widely applicable and generic it becomes. In the same way that one form can be used to describe many contents, one content can be described by many different forms. The choice of model type to best represent the function and structure of the phenomenon being modelled is thus critical.

### 3.5.4 Classification of models

**Verbal models** [Rubenstein and Firstenberg, 1995:164]

Verbal models use natural language to provide understanding and perform predictions and can appear in conjunction with block diagrams, tree diagrams and other modes of graphical representations. These models are categorised as qualitative models. The advantages a of verbal model are that it can provide fertile ground for new ideas or new directions that may enrich the field of study and provide for a broad understanding of the phenomenon being modelled. The disadvantage is that natural language introduces ambiguity, more meaning than intended, or different meaning.

When using verbal models, the basic element of the model, namely words, is a third level abstraction in terms of remoteness of what is modelled. The first level is the real thing, which cannot be the model itself, and therefore per definition not a real abstraction but called the first level of abstraction anyway. The second level of abstraction is called resemblance in the form a sign, drawing or graphic, which provides for a likeness to make it easily understandable. Thus, the more second level abstractions are included in a verbal model, the more likely that ambiguities will be eliminated. Words, the third level abstraction, are not resemblance, but symbols that depend on a code. This remoteness of the abstraction from what is modelled that give symbols their power of consolidation, but also allows for ambiguity and richness.

**Mathematical models** [Rubenstein and Firstenberg, 1995:164-166]

A mathematical model is a different form of verbal model used to quantitatively explain and predict certain outcomes. They may be simple or very complex and are presented as mathematical equations or manipulations consisting of dependant and independent variables, constants and parameters. Parameters can be changed to allow for wide application of the model provided the boundaries of the model are not exceeded.

**Analog models**

Analog models are based on similarities in relationships that exist between different phenomena e.g. the water pump being an analog model for the heart and blood circulation. Analog models can be very powerful and descriptive, but may suffer from the errors of omission and commission. The features that are included should only be those that describe the real-life phenomenon of concern and not try and make it complete. Analog models can be physical systems serving as an analog model to something else, or it can be a conceptual model that take the form of mental pictures rather than physical models [Rubenstein and Firstenberg, 1995:166].

**Schematic models**

Schematic models graphically represent a phenomenon, situation or process. The value of a schematic diagram lies in its ability to describe the essential aspects to enhance and facilitate understanding of a situation and the relationships between the components within the model. Schematic diagrams can show sequence e.g. a process flow chart, relationships e.g. an organisational chart and time-varying events e.g. a human-machine chart [Blanchard and Fabrycky, 1998:146].

**Other classifications**

Other classifications of models exist which will be mentioned but not discussed in detail. These classifications are [Rubenstein and Firstenberg, 1995:167-168]:

- Physical versus abstract.
- Descriptive versus functional.
- Causal versus correlative.
- Deterministic versus probabilistic.
- Isomorphic versus homomorphic.
- Optimisation models.
- Dynamic models.
- Simulation models.

### 3.5.5 The art of building models

From the classification of models one can derive the essential features of models. They are the form of representation, the content of the real-world problem of interest it models, the level of abstraction and whether it is a quantitative or qualitative model. Also, all models must have a purpose. The purpose will determine the choice of model. Within large models different model types may be used on different levels of abstraction. On the higher system levels one would normally find qualitative models and on the lower system levels qualitative models will receive preference. This, however, is only a rule of thumb and many exceptions may exist.

The general rules that govern model building are the rules of aggregation through analysis and synthesis. More than that, there exists no general theory (model) for building models. The process is so universal and creative in nature that providing rigid guidelines and prescriptions for the modelling process may be counterproductive and stifling to the ingenuity of those who endeavour to take this road [Rubenstein and Firstenberg, 1995:168].

The type of model to be developed for the purpose of this research (see § 3.3.1) is a schematic (graphical) model as this type of model best serves the purpose of enhancing and facilitating qualitative understanding on a conceptual level.

### 3.6 Chapter summary

Not all inquiry is scientific. For an inquiry to be scientific, a scientific method or methodology needs to be followed. The scientific method requires that a specified goal or objective needs to be defined, followed by the structure of the research and a process to perform the research.

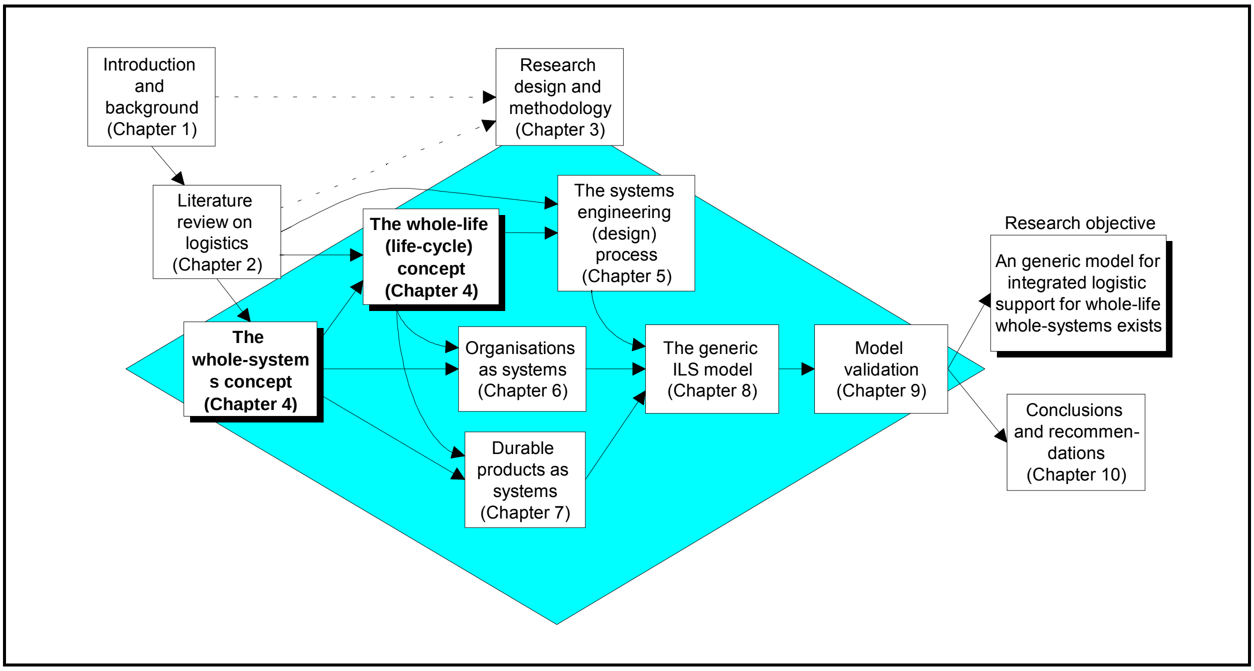
This research is an empirical model-building study using secondary textual data with the aim to construct a schematic (graphical) model of the relationships between the managerial and technical integrated logistic support activities of a system covering the complete system life-cycle. Third level (verbal) abstraction will support the understanding of the model. The aim is to improve understanding of system design and operation in order to enhance the overall system performance parameters of ability, availability and affordability.

Models are representations of reality with the purpose of promoting understanding of the real world and to predict system behaviour under certain conditions. Constructing a model requires a formal process of defining the purpose of the model, identifying all the elements that may relate to the purpose, selection of the relevant elements and relating them according to the connections amongst them. Finally the model is reiterated until an acceptable level of abstraction is achieved, after which the model is validated and adjusted accordingly. Model building is a creative process that should not be inhibited by strong prescriptions how to go about building models, as long as the model serves its purpose.

# 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.

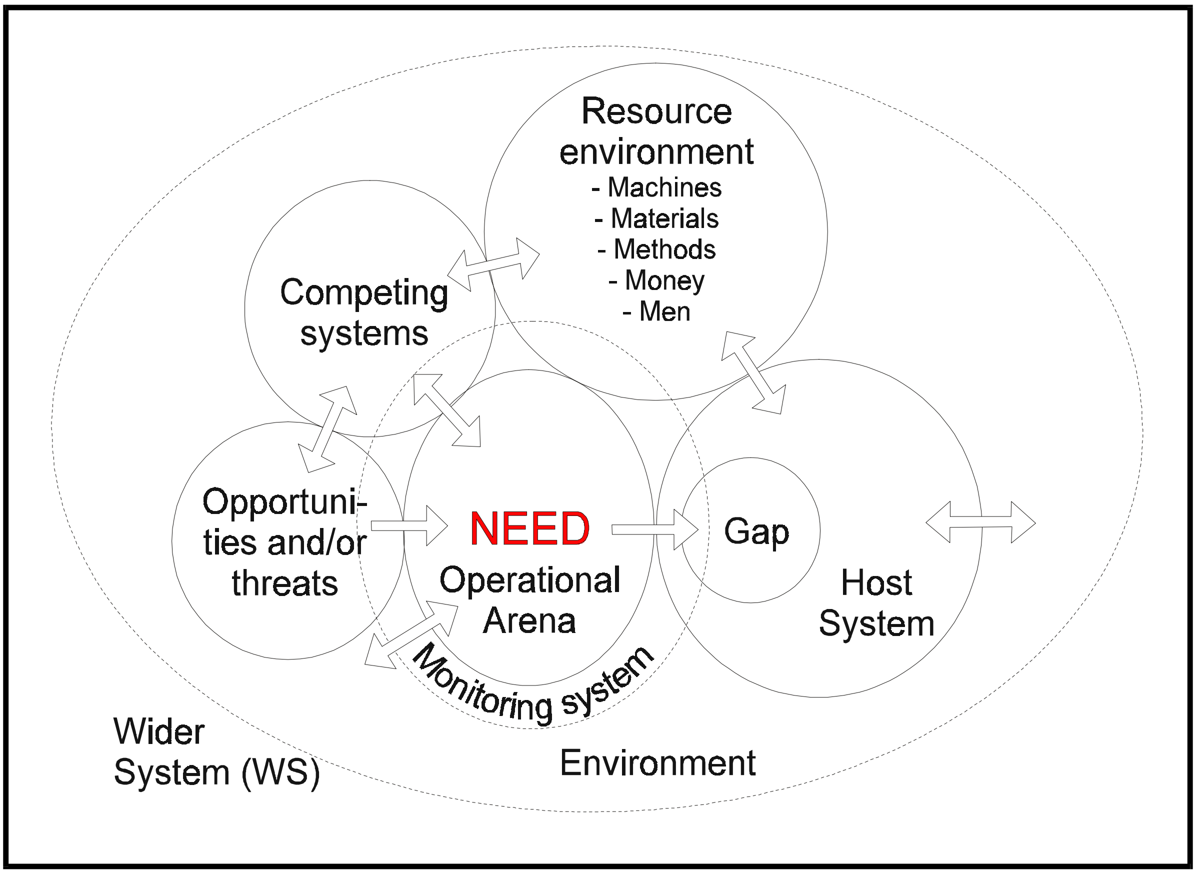



**Figure 4.1: The need within the wider system**
[Adapted from M'Pherson, 1980:551]

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.

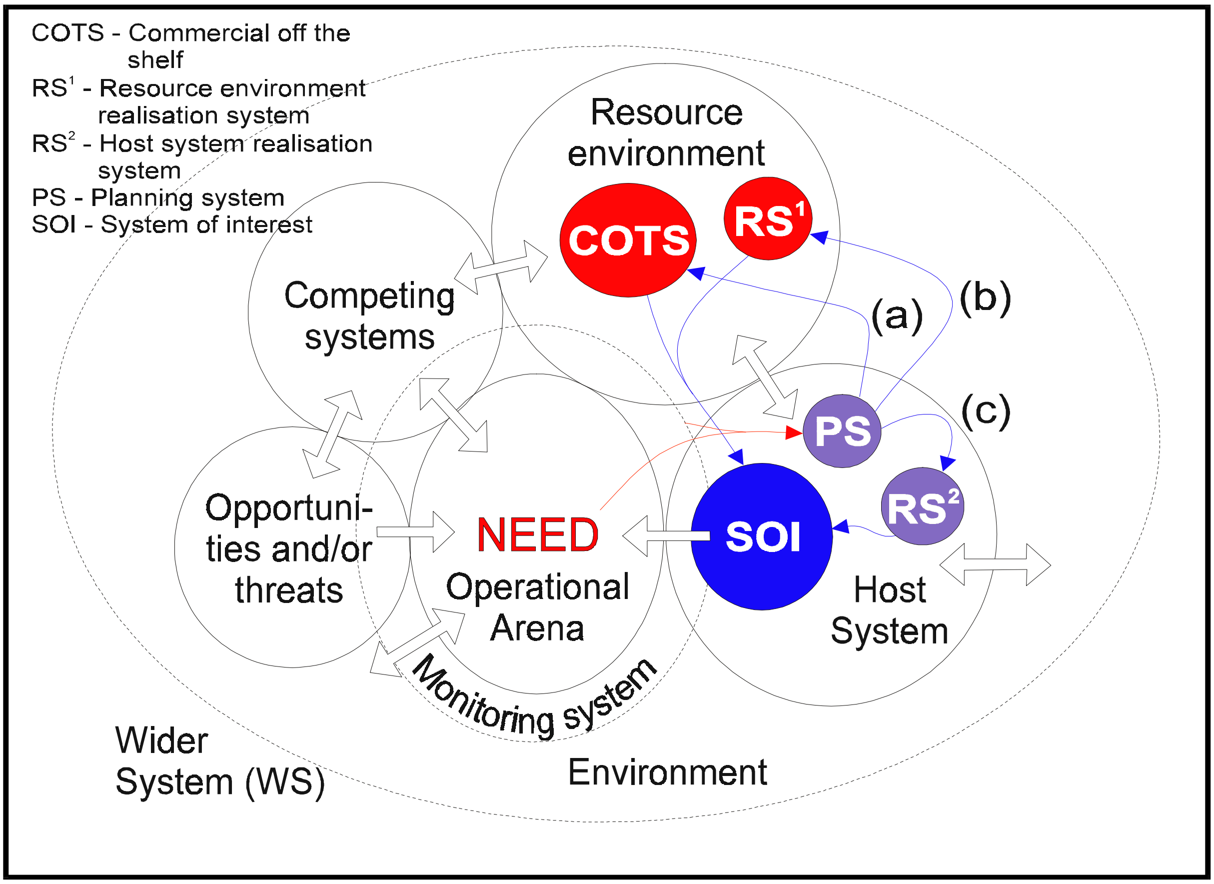



**Figure 4.2: The host system's ways of realising the system of interest (SOI)**
[Adapted from M'Pherson, 1980:551]

- *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),

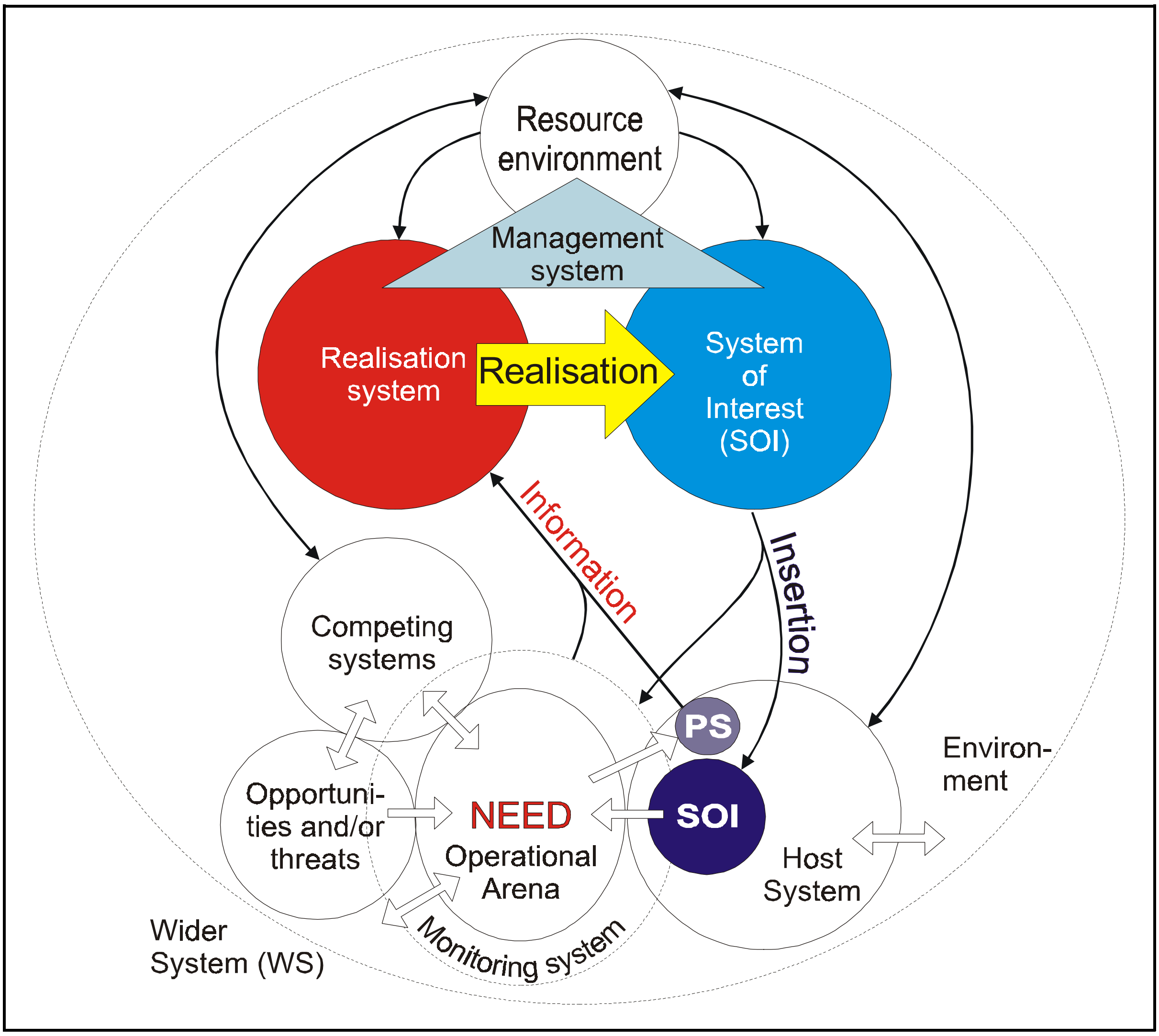



**Figure 4.3: The whole-system concept**
Adapted from M'Pherson [1980:551]

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.*

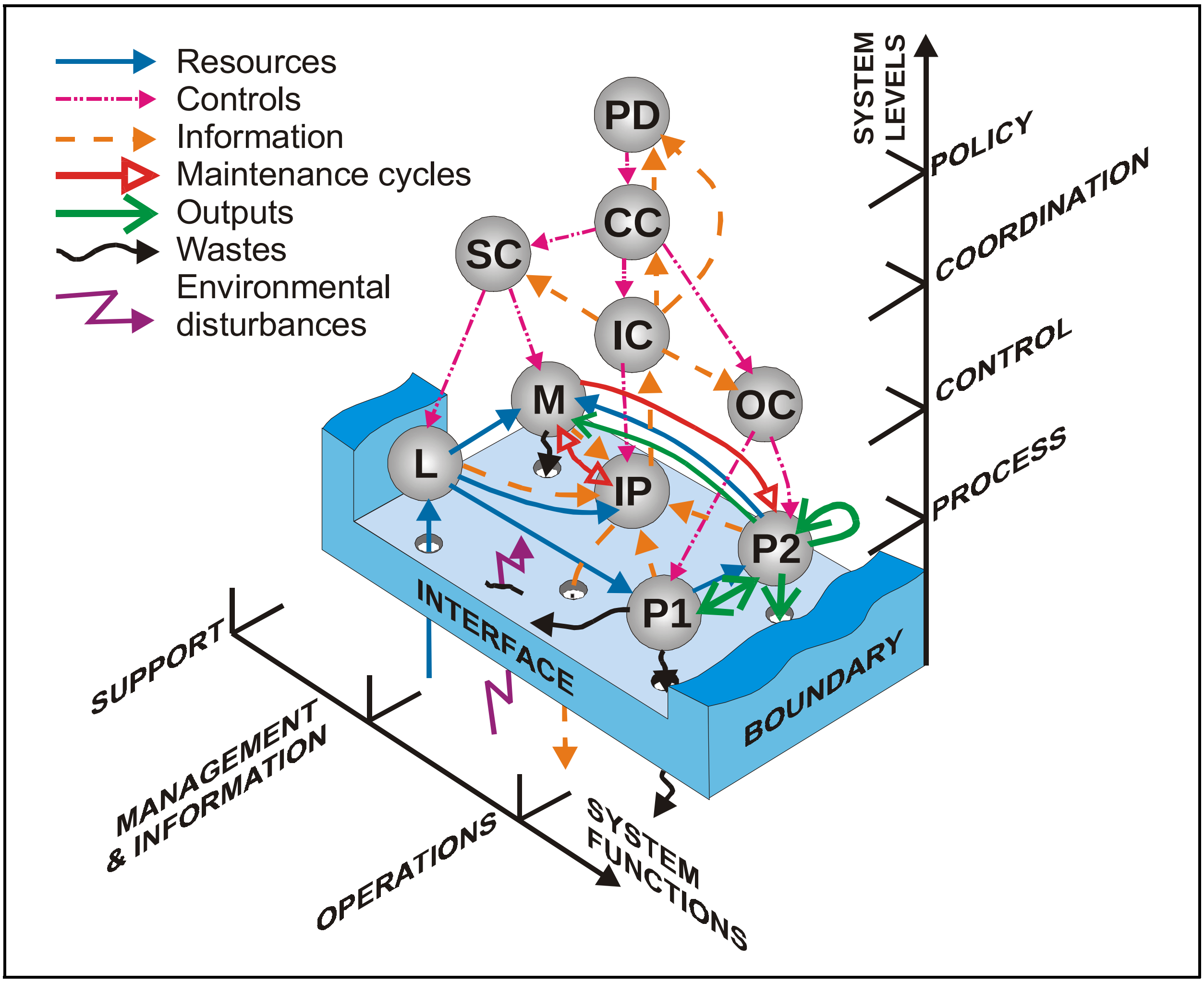



**Figure 4.4: Structure of the Proto System**
[M'Pherson, 1980:550]

- *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.

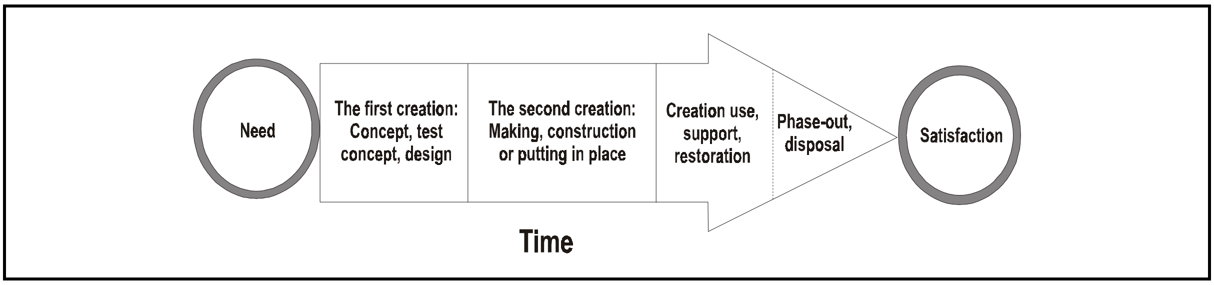



**Figure 4.5: Satisfying a need through the two creations**

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.

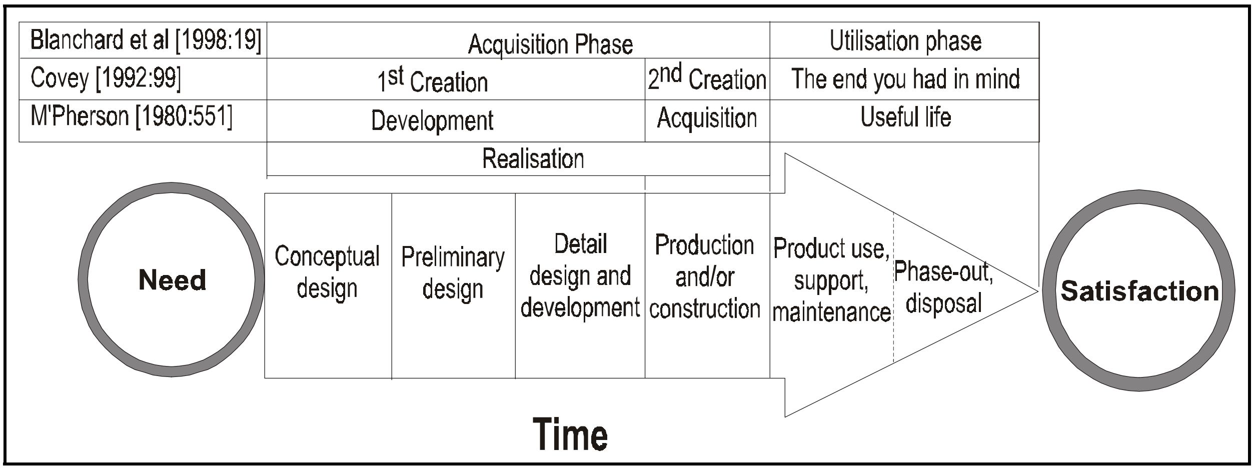



**Figure 4.6: The generic life-cycle phases**
Adapted from Blanchard & Fabrycky [1998:19], Covey [1992:99] and M'Pherson [1980:551]

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:

$$System\ Effectiveness = f(Ability,\ Availability) \tag{4.2}$$

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]:

$$Availability = \frac{MTBF}{MTBF + MTTR} \tag{4.3}$$

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:

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

### 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:

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

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:

$$Nett\ Benefit = \sum_{i=1}^{n} Revenue_{(Phase\ i)} - \sum_{i=1}^{n} Cost_{(Phase\ i)} \tag{4.6}$$

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.

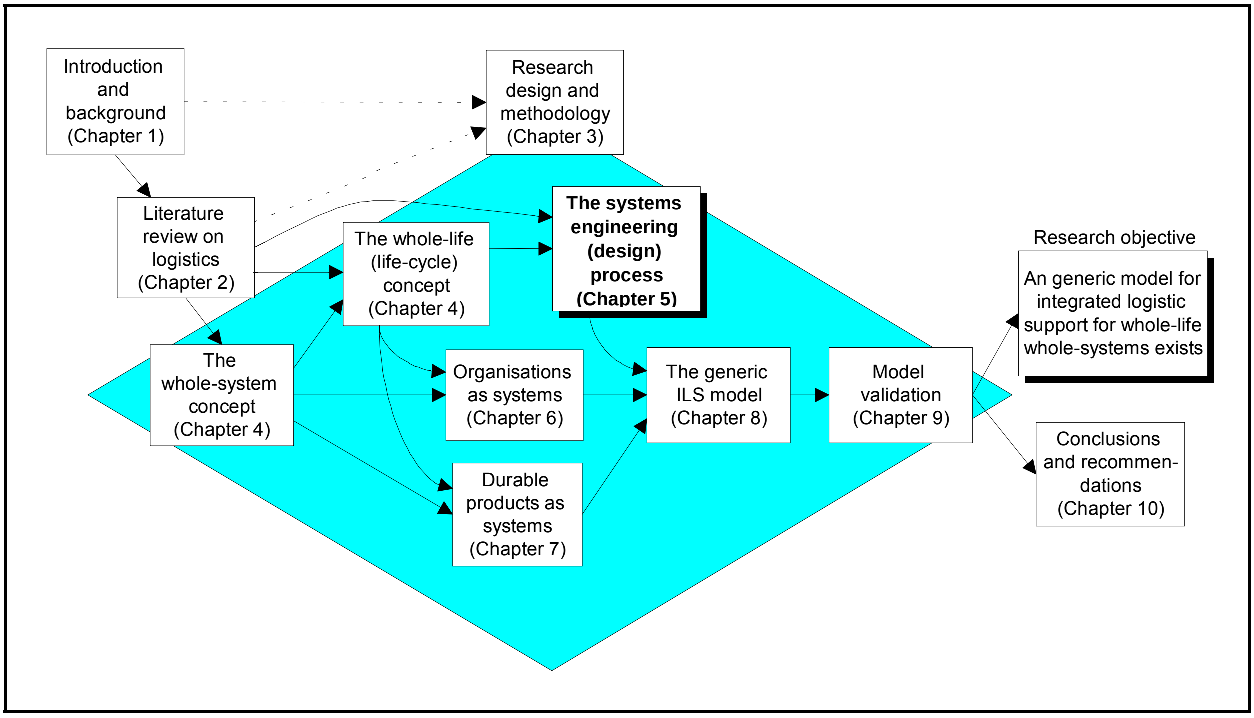
- Systems exist in time, implying a birth - life - death cycle, which is basically the same for all systems. For man-made systems the phases consist of realisation, acquisition, operation, renovation and retirement.
- Systems have properties which are more than the sum of the individual components.
- 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.

# Chapter 5

# Bringing systems into being

*"Solving problems always use the simplest solution, but no simpler."*

*Albert Einstein*




## 5.1 Purpose and outline of the chapter

The purpose of this chapter is to provide an outline of the process employed to bring systems into being. This process of bringing systems into being is generally referred to as the systems engineering process. In the previous chapter, an outline of the nature of systems was introduced, providing an insight into the ability, availability and affordability measurements of system success and these measurements' relation to the whole-life whole-system concept. This chapter serves as necessary background for the development of a generic approach to integrated logistic support for whole-life whole-systems.

The outline of the chapter is as follows:

- A brief motivation will be provided for the continuous need for new systems.
- The need for a formal process to bring systems into being is explained.
- Before systems engineering as a formal process can be introduced, the multiple dimensions of such a formal process have to be defined and explained.
- Systems engineering is presented as a formal process that will allow the realisation system to bring the system of interest into being.
- After a formal definition for systems engineering is given, an organisational perspective of systems engineering is provided to allow for deeper understanding of systems engineering.
- An extensive discussion on the role and impact that systems engineering has on ability, availability and affordability follows. Aspects covered are cost-effectiveness, life-cycle cost and design influence considerations.
- The chapter is concluded with the basic requirements for the formal process to bring systems into being.

## 5.2 The quest for new systems

Man's involvement in and fascination with systems go back far in history. The first recognition man has had of systems must surely have been the awareness of him being part of the natural systems of the earth and the universe. Irrespective of man's belief how the universe came into being, the underlying commonality of all religions is that some realisation system in some form or another must have existed (or still exists) that was responsible for creation. As this research is concerned with man-made systems, no attempt will be made to explain creation's realisation system. It is best left to the cosmologists, theologians, philosophers or the faith one has.

The human-made world is made up of everything that was brought into being by man for use, consumption or appreciation by man. No doubt, many man-made creations are to the detriment of man and his natural environment. The ecological impact of the Aswan Dam on the Nile river is a good example of the negative effects of not following a systems approach [Blanchard and Fabrycky, 1998:5]. Still, there is a continuous pursuit to improve the standard of living of the human race which drives the never-ending quest for new and better products and systems. This never-ending quest requires from realisation systems (those systems that bring other systems into being) to also improve the way they go about determining needs, defining concepts, do preliminary and detailed design, do physical creation (production and/or construction), insertion into the host system, operations and support and finally phasing out.

## 5.3 The need for a formal process

Already in the early civilisations, the human race has demonstrated the capability to undertake the creation of complex man-made systems. Good examples of this ingenuity are the Egyptian Pyramids and the Great Wall of China. Bringing about creations of this magnitude and complexity, must unquestionably have had a formal process controlling the life-cycle of those systems. In more recent times, during the 1950's and 1960's, the Americans undertook major developments with their space and military programs. These developments required the integration of many distinct disciplines and technologies into an overall complicated but optimised result. This is regarded as the birth of systems engineering in its modern form and has since found application outside of the military and space programs in a wide variety of industries. [Shenhar in Sage and Rouse, 1999:113].

The need for a formal process to bring systems into being is stated unequivocally by Blanchard and Fabrycky [1998:xiii]: *"Experience in recent decades indicates that properly coordinated and functioning human-made systems, with a minimum of undesirable side effects, require the application of an integrated, life-cycle oriented 'systems' approach. The consequences of not applying systems engineering in the design and development and/or reengineering of systems have been disruptive and costly."*

## 5.4 The multiple dimensions of systems engineering

Before a definition of systems engineering can be provided, it is necessary to clarify the multiple dimensions of systems engineering. Having gone through the agricultural and industrial revolutions, and being within the information age based on the intricacies of electronics as well as the complex interfaces between technologies and humans, it is obvious that the world is becoming more and more complex. New and emerging technologies reveals unexpected opportunities for bringing into being new and improved systems and products [Blanchard and Fabrycky, 1998:14, 17]. In a world where needs can be satisfied in various ways - which means that there can be no single solution to complex problems, or a single way to take a system through its life-cycle - it must be obvious that no single person can be responsible for the creation of a complex system. Complex systems can only be created through the combined efforts of many people and teamwork [Blanchard and Fabrycky: 1998,14-15] . It can be stated further that systems engineering is not only about solving problems ***for*** customers, but ***with*** customers [Shenhar in Sage and Rouse, 1999:114-115 and M'Pherson, 1980:549]. Another implication of the existence of multiple solutions to a problem is that the problem solving will be of an iterative nature to arrive at the 'best' solution.

It can be concluded that there are two distinct dimensions to systems engineering, i.e.:

- The technical component, the dimension that is concerned with the technical requirements and interdisciplinary integration of technologies and humans within the system.
- The managerial component, the dimension that is concerned with the planning, organising, directing, controlling and provisioning of resources to take the system through its life-cycle from need identification to phasing out.

In view of these assertions and using the simple model provided by Shenhar in Sage and Rouse [1999:115], a revised model is proposed in Figure 5.1. *"In its simplest terms, systems engineering is both a technical process and a management process. To successfully complete the development of a system, both aspects must be applied throughout the system's life- cycle."* [Defence Systems Management College, 1983]. To many it may be a contentious point whether systems engineering really covers the total life-cycle of the system of interest. Even though this contention will not be discussed further at this point, it assumed that both components of systems engineering are required throughout the total life-cycle of the system of interest. The premise for this is that systems

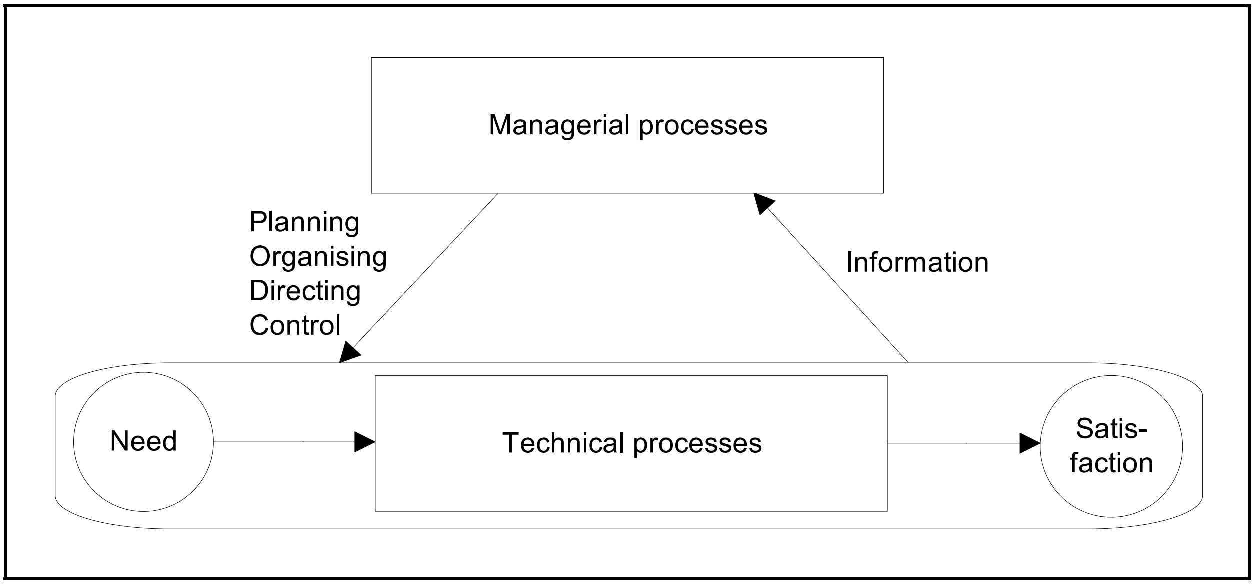



**Figure 5.1: The multiple dimensions of systems engineering**
[Adapted from Shenhar in Sage and Rouse:1999,115]

engineering is concerned with whole-life whole-systems which means the management component of the system of interest does not cease once the system goes into operation, but takes on a different meaning. This different meaning will be put into perspective later in the study .

## 5.5 Systems engineering defined

Shenhar in Sage and Rouse [1999:114-115] provides an extensive discussion of the different definitions for systems engineering. As this study is not primarily focussed on systems engineering, a simple definition for systems engineering will be stated and supported by a more comprehensive definition that is found in recent literature.

> **In its most basic form, systems engineering is the formal iterative process of management and technical activities required by the realisation system to bring the system of interest into being and to aid in ensuring a useful life as part of the host system until retirement.**

A more formal definition is provided by Shenhar in Sage and Rouse [1999:115]. This definition is revised to demonstrate the managerial component of systems engineering more specifically, which is lacking in Shenhar's original definition. The more formal definition is as follows [Adapted from Shenhar in Sage and Rouse, 1999:115]:

**Systems engineering is the application of scientific, engineering and managerial efforts to:**

- **Identify an operational need (in a commercial or military area, in the public or private sector), together with a marketing and technological opportunity that leads to the creation of a system that will address this need.**
- **Transform an operational need into a description of system performance parameters and a preferred system configuration through the iterative use of analysis, definition, synthesis, design, test and evaluation.**
- **Ensure integration of all related (physical and functional) parameters and interfaces within the system of interest, with the host system as well as with the wider system in a way that best meets the operational need.**
- **Ensure the management of system ability, availability and affordability throughout the life-cycle of the system of interest, through evaluation and improvement of both technical and managerial components of the system of interest.**

The formal definition for systems engineering implies that:

- Systems engineering covers the entire life-cycle, from need identification up to the point where the system of interest does not exist anymore.
- Systems engineering requires a whole-system design approach (design of all technical ***and*** managerial components of the system of interest) without which successful integration on the different system levels will not be possible.
- Systems engineering seeks to find the best combination of technologies, processes, interfaces and relationships within a system and its environment to satisfy the need, implying that no single 'optimal' solution for a problem exists.

## 5.6 M'Pherson's perspective on systems engineering

M'Pherson [1980:553-557] provides three different perspectives on systems engineering. The foundation for his perspectives is the assertion that one has to build a framework based on the combination of the whole-life and the whole-system concepts. This framework is then used to *"tackle the problems of planning, designing and managing the whole-system realisation problem"* [M'Pherson, 1980:553]. This statement again supports the view that there are two distinct components within systems engineering, namely the technical activities and the management activities.

M'Pherson's first perspective (the organisational perspective) deals with the realisation processes within the realisation system along with a time line (the whole-life concept), leading to insertion of the system of interest into the host system. Using this perspective, systems engineering is a *"dynamic multivariable, multiloop system which will have an interesting dynamic behaviour that is likely to require careful tuning, co-ordinating and control if it is not to display signs of instability"* [M'Pherson, 1980:554]. The organisational perspective is discussed later in this chapter using Figure 5.2.

M'Pherson's second perspective is what he calls the system design perspective, which deals with creating the right system. M'Pherson [1980:554] argues that *"no matter how well the project is planned and organised, the effort will be largely wasted if the operational system that results is the wrong system, even though it may be excellently designed in itself".* Systems can be wrong by not meeting the customer's requirement (ability, availability, affordability and safety), not being matched to the actual operational environment, being badly timed, or not being matched to the social or natural environment. Systems engineering strives to guard against such errors by integrating as many considerations and criteria as necessary into the design process resulting in whole-system design [M'Pherson, 1980,554-555].

The third perspective provided by M'Pherson [1980:556] is called the system planning perspective. This perspective shows the system of interest as the end result of an integrated design process consisting of six dimensions that all have to exist in an integrated way. These six dimensions are:

- The operational structure of the system of interest.
- The associated equipment of the system of interest.
- The logistics system to provide support to the operations and maintenance of system of interest.
- The maintenance system to restore availability of the system of interest after deterioration of ability has taken place.
- The manpower system to provide management, operational and support skills to the system of interest.
- The management system to take operational, maintenance and financial responsibility for the system of interest.

No single dimension can be designed in isolation nor can it exist on its own. This perspective of M'Pherson places the emphasis on the management of the systems engineering process throughout the realisation phase, and it also emphasises the realisation of a management system for the system of interest.

M'Pherson's organisational perspective [1980:554] is combined with his system planning perspective [1980:556] in Figure 5.2 to emphasise important characteristics of systems engineering. Figure 5.2 highlights the management of the systems engineering process and the insertion of the management system of the system of interest into the management system of the host system.

This combined perspective clearly shows the management implications for systems engineering are much more profound than commonly believed. The whole-life whole-system concept requires that the whole-system is to be designed, followed by an insertion of the operational, support and monitoring systems. It has been demonstrated earlier in this chapter that systems engineering includes a management component, thus it follows naturally that in order to follow the whole-life whole-system concept, the management system of the system of interest should be realised and acquired in an integrated way with the rest of the system. As acquisition includes insertion, it follows that, not only should the physical system be inserted into the host system, but the management system of the system of interest should also be inserted into the management system of the host system. This adaptation to M'Pherson's organisational perspective of systems engineering, along with the continuous monitoring and evaluation feedback loop, implies a management

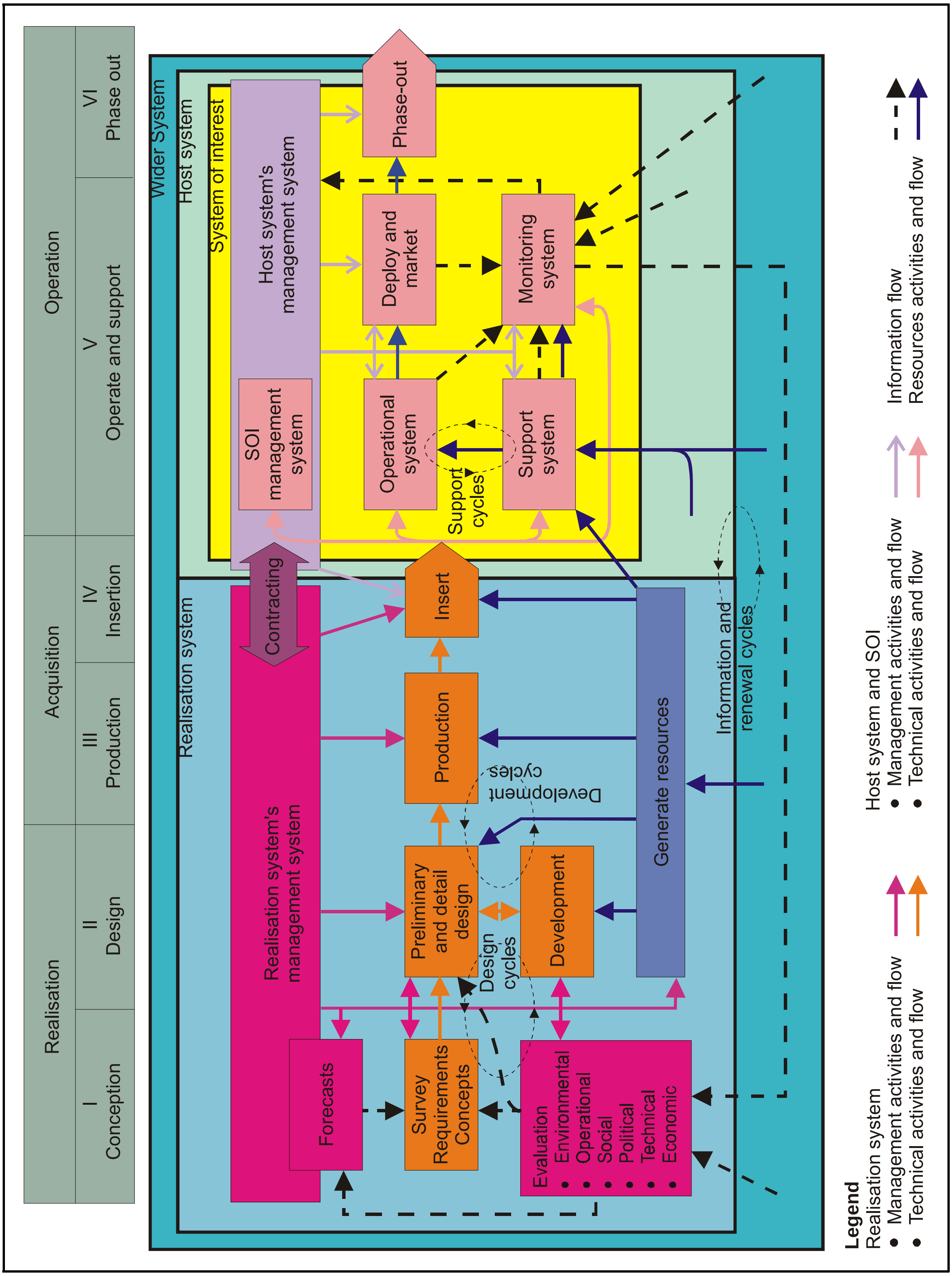



**Figure 5.2: An integrated perspective of systems engineering**
[Adapted from M'Pherson, 1980: 554, 556]

system within the realisation system to continue to exist throughout the life-cycle of the system of interest, as well as continuously interfacing with the management system of the host system, normally through contracts in some form, placed by the host system on the realisation system.

The continued existence of the management system of the realisation system throughout the life of the system of interest, is required in order to:

- Provide the interface between the host system and the realisation system for continued support of the system of interest.
- Gather data to trigger an improvement program for the system of interest. This improvement program requires the systems engineering process to be followed once more, as the systems engineering process is applicable to reengineering/ improvement programs as well [Blanchard and Fabrycky, 1998:xiii].
- Gather data and information to better satisfy the requirements of the customer when a new system of interest is to be realised within the particular environment.

## 5.7 The role and impact of systems engineering

Systems engineering is about effectiveness. Effectiveness is doing the right things. The emphasis on doing the right things is required primarily during the acquisition phase in order to make sure that when it comes to the utilisation phase, the system will continuously meet the ability, availability and affordability requirements. The utilisation phase is primarily concerned with efficiency, or doing things right, with the minimum amount of waste. This is based on the premise that the inherent design characteristics of a system is determined very early in its life-cycle, and that the effectiveness of a system is thus determined very early in the systems realisation phase.

Blanchard and Fabrycky [1998:xiii] state that *"the consequences of not applying systems engineering in the design and development and/or reengineering of systems have been disruptive and costly"*. This view is supported by other literature [Defence Management College, 1983:1-i]: *"These large, highly interactive systems that are on the forward edge of technology, have a natural process of evolution, or life-cycle, in which actions taken (or* *not taken) in the very early stages can mean the difference between success and failure. When the outcome is certain only after the expenditure of hundreds of millions of dollars, even wealthy nations cannot afford many failures. The purpose of systems engineering is to prevent these failures through a unified approach that completely defines all requirements on the system and establishes a system configuration which is proven early-on to be capable of meeting those requirements. Systems engineering is often referred to as a 'front-end' process. That is, the majority of systems engineering tasks are completed in the initial phase of the program, when about 5% of the program's funding is expended. This initial effort results in defining the configuration and size of the system and its logistical support. The resulting program commitment of funds typically represents 90% of program life-cycle costs. Accuracy and completeness of the early systems engineering effort is therefore essential in maintaining the program within budget constraints"*. What is not emphasised enough, however, by this view, is that the systems engineering effort does not only have a major impact on affordability (life-cycle cost), but also ability and availability.

Many authors [Blanchard and Fabrycky; 1998:573; Defense Management College, 1983:16-7; M'Pherson, 1981:76] provide frameworks for cost-effectiveness of a system. For the purpose of this chapter, it would suffice to use a simple framework derived form the arguments presented in § 4.8 that emphasises benefit-effectiveness rather than cost-effectiveness. This framework is depicted in Figure 5.3.

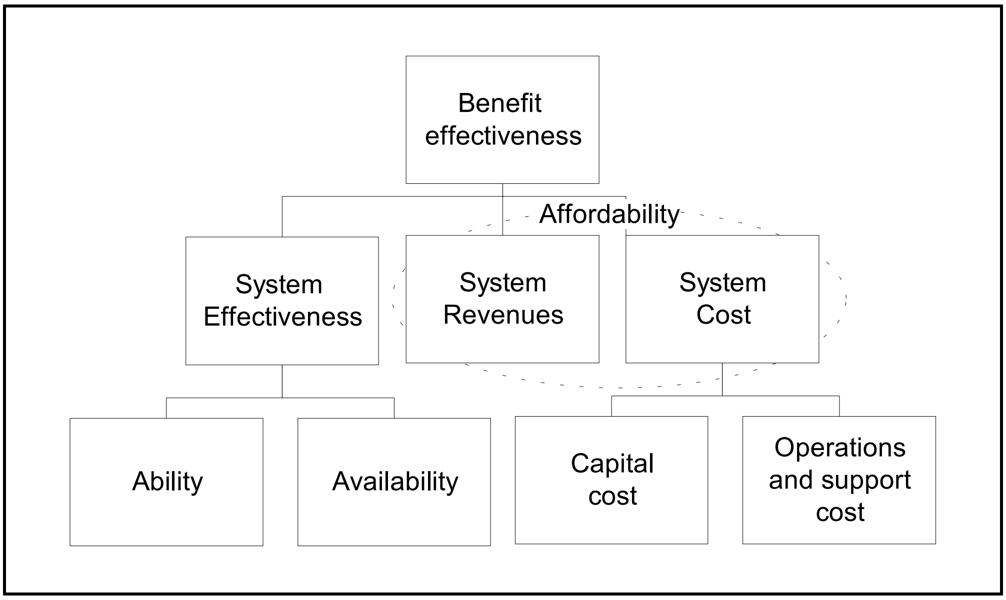



**Figure 5.3: Benefit-effectiveness breakdown**

It can thus be concluded that the systems engineering process has to emphasise the ability, availability and affordability of the system while it is still under design in order for the system to meet requirements during the operational/utilisation phase.

### 5.7.1 The ability perspective of systems engineering application

A system's ability is the reason for the existence of the system in the first place. Using the problem or need statement of the customer or market into consideration when designing the system's ability is therefore of the utmost importance. As more and more over-capacity tend to emerge in the USA, similar to what already exist in Europe and the East, there will be increasingly a customer-driven market rather than a market dictated to by the realisation systems. Thus only products (including services) meeting customer requirements will be sold [Wang, Han, Spoerre and Zhang in Wang, 1997:2]. Also, customers have become more sophisticated, knowledgeable and insistent on high quality products and services regardless of price [Watkins in Wang, 1997:21].

In the past, a sequential design process was used primarily because realisation systems were organised along functional lines. This resulted in partial designs being 'thrown over the wall' from the one functional group to the next. The end effects of this approach were long development times, poor integration, severe production problems, outputs not meeting market requirements and excessive change costs.

From the ability perspective, systems engineering has to place the engineering of systems ahead of concern for components of the system and specifically emphasise [Blanchard and Fabrycky, 1998:18]:

- Methods to improve definition of requirements and how they relate to true customer needs. Methods such as quality function deployment (QFD), value engineering and functional analysis can be used.
- Addressing the total system from a whole-life perspective to ensure that ability can be maintained throughout the total life-cycle. This addresses both the production and support functions without which ability is not possible.

- Considering the interfaces of the system of interest with its host system to the extent they are compatible and dependant to allow full system ability.
- Organising the system design and all other related design disciplines into one concurrent mainstream design effort.
- Establishing a disciplined review and evaluation process for appropriate and timely feedback to ensure requirements consistency throughout the life-cycle.

System requirements are to be related to specific design criteria and all design decisions should be traceable to original requirements. This is especially important to ensure that system designs do not include unnecessary parts which are not needed, making for a less reliable and more costly design. Systems designs having unnecessary parts or functions are becoming more common primarily because of the ease with which design features can be added through the use of electronics and software. On the other hand care must be taken that functions are not omitted, something that frequently happens with order qualifiers (see § 6.5 for a definition of order qualifiers) as these are many times not explicitly expressed as a requirement; the customer assumes that the realisation system knows the minimum requirements.

Ability of the system of interest nor only depends on how well it was designed, but also on how well it is produced. A well designed system but produced poorly will not achieve the ability levels expected of it. Design for produceability is therefore also important to consider during the design. Design guidelines for produceability have also been found to generally apply to operations (including support), thus an additional benefit is gained in the sense that it does design for producability not only improves ability, but also availability. Naturally improved availability will also lead to improved affordability. Schonberger an Knod [1997:101] provide a general list of guidelines for design for operations (including production):

- Design to target markets and target costs.
- Minimise the number of parts and number of operations (viz. production, operations and maintenance activities)
- Design to known, complete customer requirements.
- Design to process capabilities of own process and those of suppliers.
- Use standard materials, processes and procedures with known, proven quality.

- Use modular/reusable designs. This includes standardisation and rationalisation.
- Design for ease of production, operations and maintenance.
- Design for foolproof production, operation and maintenance ('*poka-yoke*' is the Japanese word for avoid mistakes).
- Design for robustness.

Design for ability is very much dependent on the nature of the system and the technology employed for its design. Further detail on the overall approach to ability design can be obtained from Blanchard and Fabrycky [1998], Wheelwright and Clark [1992] and Wang [1997].

### 5.7.2 The availability perspective of systems engineering application

Availability of the system of interest is dependent on two variables, namely reliability and maintainability, discussed in § 4.8.2. These two variables are inherent design characteristics, which means that the values these variables will take on during the system of interest's life, will depend primarily on the design of the system of interest itself. When the interrelationships between design and these inherent characteristics are analysed, understanding can be gained how the application of the system engineering process can influence the future availability of the system of interest.

As has been indicated in § 5.7.1, the first perspective of system engineering application is to specify and create those characteristics of the design that will render the functional ability to meet the requirements stated for the system of interest. In order to carry out design, individual technical design disciplines are required, for example mechanical design, electrical design, electronic design, structural design and information design. By virtue of the fact that design decisions are made, for example size, weight, material composition, tensile strength and interfaces between components, the reliability and maintainability characteristics are established. It is thus important for the functional designer to be aware of the implications of the design decisions on reliability and maintainability, as these characteristics are inherently set by the design itself.

The detail or subsystem designer is not the only one responsible for the inherent characteristics of the system. On the system level a major role is to be played by the systems engineer with regards to the inherent characteristics of the whole-system. On the system level the system engineer is responsible to oversee the operational support system and the maintenance system design. The scope, magnitude and success of these systems largely depend on integrated design on system level and the inherent design characteristics of the functional and physical design itself. As indicated in the previous chapter, availability can be expressed as [Blanchard, 1998:90]:

$$Availability = \frac{MTBF}{MTBF + MTTR} \tag{5.1}$$

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

This equation can be analysed further in terms of the MTTR figure. Firstly, the inherent availability of the system can be expressed as [Adapted from Blanchard, 1998:80]:

$$Availability_{Inherent} = \frac{MTBF}{MTBF + MTTR_{CM}} \tag{5.2}$$

where $MTTR_{CM}$ is the mean time to repair, including corrective maintenance time, but excluding preventive maintenance time and maintenance lead time.

Inherent availability is accomplished within an ideal support environment (i.e. all support resources are available when required) [Blanchard, 1998:80-81].

Secondly, availability can be viewed as achieved availability, in a similar fashion to inherent availability, but with preventive maintenance time included and can be expressed as [Adapted from Blanchard, 1998:81]:

$$Availability_{Achieved} = \frac{MTBF}{MTBF + MTTR_{CM + PM}} \tag{5.3}$$

where $MTTR_{CM + PM}$ is the mean time to repair, including corrective maintenance time and preventive maintenance time, but excluding maintenance lead time.

Achieved availability is also accomplished within an ideal support environment (i.e. all support resources are available when required) [Blanchard, 1998:80-81]. An argument can be raised which of the inherent or achieved availability should be the higher of the two. The first impression is that inherent availability should be larger than achieved availability, as the MTTR component consists only of corrective maintenance as opposed to achieved availability, where the MTTR consists of both corrective and preventive maintenance. The purpose of preventive maintenance is to maintain the system in an operable condition, i.e. to perform maintenance activities that prevent failures from occurring, it is thus clear that an increase in preventive maintenance time should lead to a reduction in corrective maintenance time. Thus, if the decrease in corrective maintenance time is more than the increase in preventive maintenance time, then it can well be that the achieved availability be higher than the inherent availability. If the achieved availability is higher than the inherent availability, it is an indication of a well designed preventive maintenance program.

Thirdly, real life availability is expressed as operational availability [Blanchard, 1998:81], where the system is used in an actual operational environment and can be expressed as [Adapted from Blanchard, 1998:81]:

$$Availability_{Operational} = \frac{MTBF}{MTBF + MTTR_{CM + PM + MLT}} \tag{5.4}$$

where $MTTR_{CM + PM + MLT}$ is the mean time to repair, including corrective maintenance time, preventive maintenance time and maintenance lead time.

In the calculation of operational availability, the mean time to repair includes all the time required from the point in time a support requirement has been identified, until the point in time where the functional ability has been restored (corrective maintenance). It also includes the total time required to retain a system in its full operational state (preventive maintenance). Maintenance lead time (as used in Equation 5.4) includes all delays such as ordering, provisioning, transportation, acquiring the required personnel and other resources, administrative delays and others. This figure ($MTTR_{CM + PM + MLT)}$) is also referred to as the maintenance downtime (MDT) [Blanchard, 1998:58].

The application of the availability figure can vary widely, as can be seen with the different definitions. In the final instance, however, the most important availability figure is the operational availability. Operational availability is where reality determines the success of the system of interest. Blanchard [1998:81] makes out an interesting case when each of the availability figures should be used and applied. In the case where the realisation system has no control or influence over the host system it is proposed that inherent and achievable availability figures be used for evaluation of the system. This author, however, is of the opinion that the realisation system can influence the operational availability to a large extent even if the realisation system has no direct control after insertion of the system of interest. This influence can be achieved through proper design of the inherent characteristics (MTBF and $MTTR_{PM + CM}$) as well as good overall logistic support system design. If the system of interest does not perform to its ability when it is not operated according to the instructions and requirements set by the realisation system, the realisation system cannot be held responsible for non-performance. However, if the host system operates the system of interest properly according to the set operating instructions, it will be able to utilise the ability of the system of interest as intended. Likewise, if the system of interest has good inherent characteristics (MTBF and $MTTR_{PM + CM}$) and a proper integrated logistic support system has been designed with associated instructions, requirements and management procedures, ensuring a low logistic delay time ($MTTR_{LDT}$) figure, and the host system adheres to that, then the realisation system does have a major influence on and control over the operational and support arena of the system of interest. Understanding of the above is crucial in establishing a generic approach to integrated logistic support for whole-life whole-systems.

### 5.7.3 The affordability (life-cycle cost) perspective of systems engineering application

If the expenditure over the life-cycle of a system is analysed, a distinctive cost profile common to most systems exists. The cost profile of a system can be broken down into the cost of development, acquisition, operations and support and retirement/disposal. The distribution of these costs over time can be plotted to provide the system life-cycle cost [Adapted from Blanchard and Fabrycky, 1998:591] in Figure 5.4.

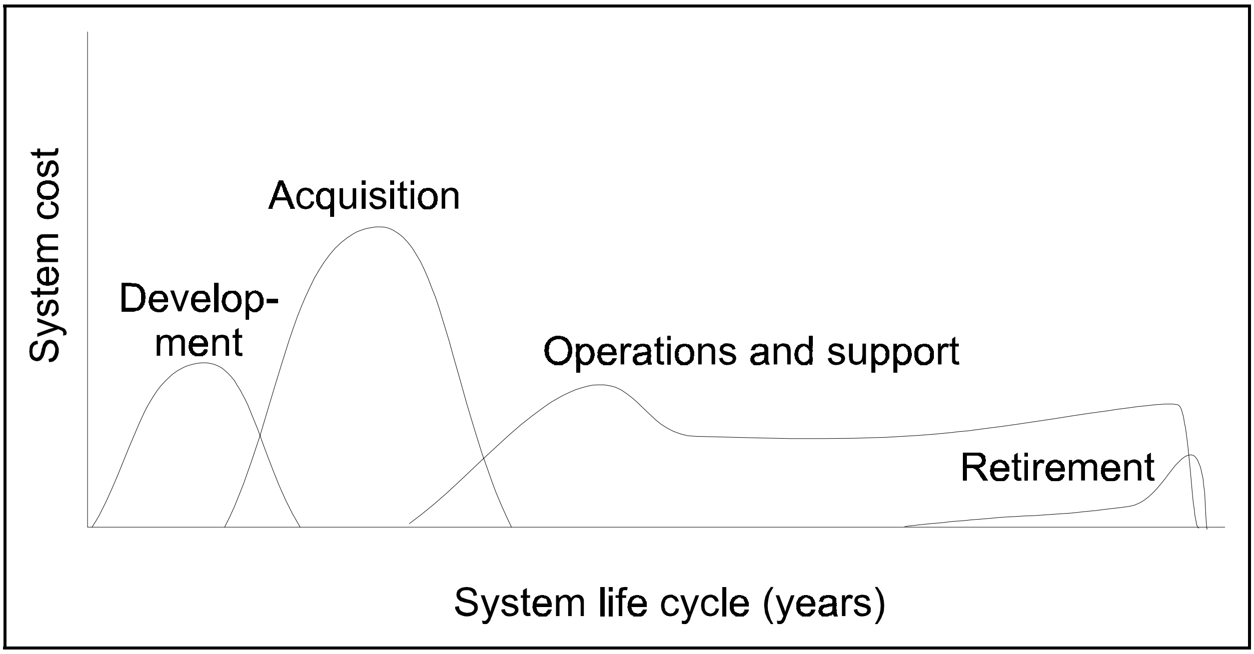



**Figure 5.4: The life-cycle cost components**
[Adapted from Blanchard and Fabrycky, 1998:591]

The money spent during the development phase is normally less than the money spent during the acquisition phase. The reason is that the physical creation (production or construction) is much more capital intensive than design. This normally does not hold true for software design. Another reason is that changes to a concept (paper or electronic format) during design is much less expensive than changes to something that already exists in its physical form, which is true once production/construction has started. The protrusion on the graph at the start of the operations and support phase (Figure 5.4) is associated with the insertion cost of the system of interest into the host system. Insertion cost is normally spent on establishing infrastructure, initial stocking, and the staffing and training of personnel associated with the new system. Insertion cost was chosen randomly to be shown as part of the operations and support cost. Choosing where to show the insertion cost is irrelevant because the graph only shows all associated costs with the life-cycle phases and does not take into account which system (realisation or host) bears the cost for each life-cycle phase. Where it is known which system is to bear the cost of a specific phase, different life-cycle cost profiles will be needed for the host and realisation systems. For the time being this distinction is not required. Thus, when the costs of all the different phases are added together the resultant life-cycle cost profile can be seen in Figure 5.5. [Blanchard and Fabrycky, 1998:591].

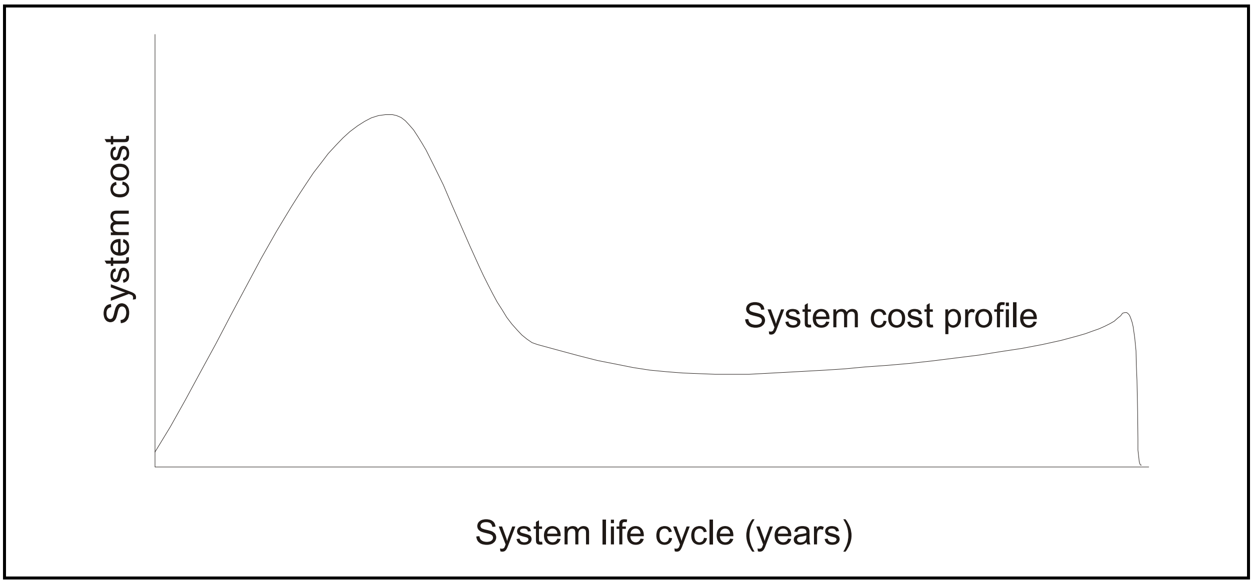



**Figure 5.5: Total life-cycle cost**
[Blanchard and Fabrycky, 1998:591]

Both the previous two graphs provide the cost per time unit, it therefore follows that the total life-cycle cost of the system is represented by the area under the curve. As systems engineering has as one of its aims to reduce total life-cycle cost - Blanchard and Fabrycky [1998:557] call it design for affordability - it is clear that decisions early on in the system design (and having a major impact on the life-cycle cost or affordability of the system), must be taken with utmost care. Conceptually the design for affordability is the conscious design effort to change the shape of the life-cycle cost profile in order to reduce the area under the curve shown in Figure 5.5, while at the same time meeting and/or exceeding the ability and availability requirements of the system. This extra design effort to reduce the total life-cycle cost is assumed by many to increase the development cost.

The question that might be raised is whether it really costs more to make an affordable design. That is, will the life-cycle cost of the more affordable system (Figure 5.6 (b)) be higher during the initial phases as opposed to the life-cycle cost of the less affordable system (Figure 5.6 (a)) during the initial phases? Without going into an extensive debate, this author is of the opinion that it should not necessarily be more expensive during the initial phases to design the more affordable system as opposed to the less affordable system. It can be motivated by the fact that within the design phase, many design changes cause higher cost. If good engineering is employed - designing well the first time round -

the many design changes will not be needed, reducing the overall design cost. Designing well the first time round is the same principle as the quality principle defined by Philip Crosby [Schonberger and Knod 1997:81], the principle that quality is to be ensured the first time. Schonberger and Knod explain Crosby's notion that all the things which prevent jobs from being done right the first time is costing money and thus constitute a waste, but to be able to get quality for free, one must work hard at it. Thus by working hard at employing good engineering, making new designs will cost less than doing it over and over until the customer is satisfied. It can thus well be that the life-cycle cost of a system, well designed the first time round, be lower for all time periods of the life-cycle, as denoted by line (c) in Figure 5.6.

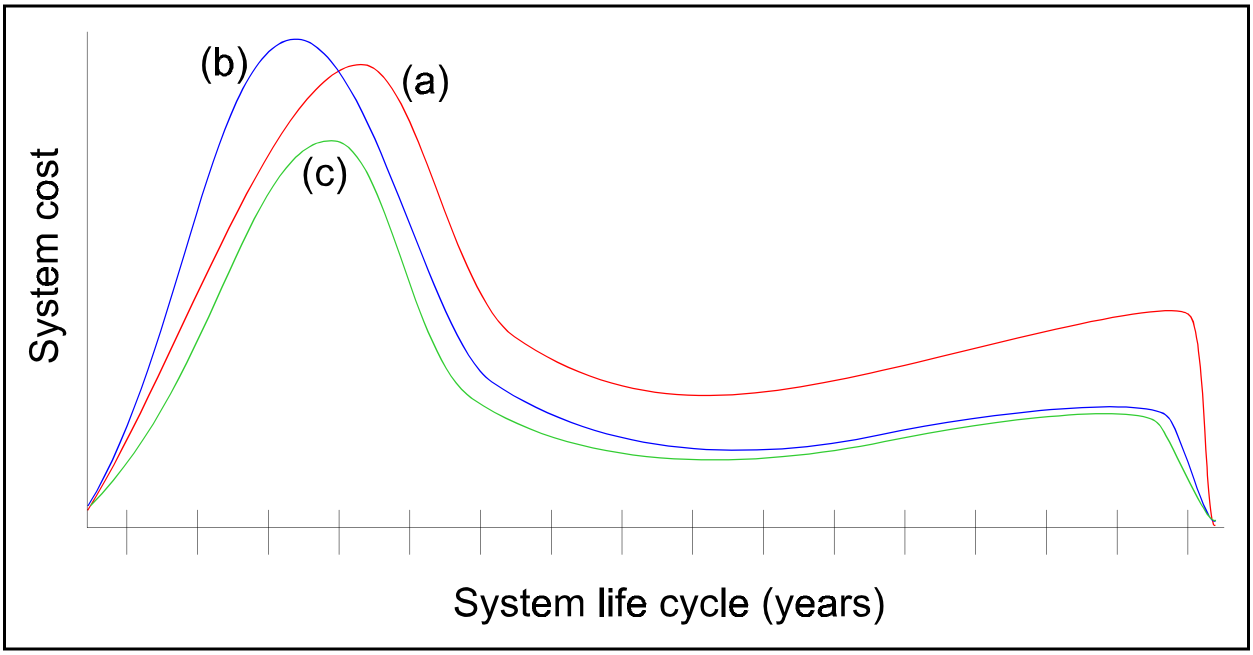



**Figure 5.6: Designing for affordability - Shifting the life-cycle cost (LCC) profile**

According to Blanchard and Fabrycky [1998:38] it is estimated that anything between 50% and 75% of the projected total life-cycle cost can be committed as a result of the decisions made during the conceptual and preliminary design phases. Another source [Defense Management College, 1983:17-1] estimates that up to 95% of the system life-cycle cost will be committed by the time the detail design has been completed, while at the same time only about 5% -10% of the actual life-cycle cost will have been spent. Whatever the figures are is not important, but it is important to realise what effect early design decisions have on life-cycle cost that will be spent later in the system's life. The relationships between the opportunity to influence the design, life-cycle cost committed, cost of change and cumulative life-cycle cost spent are shown in Figure 5.7 [Adapted from Blanchard and Fabrycky, 1998:37, 561 and Blanchard, 1998:82].

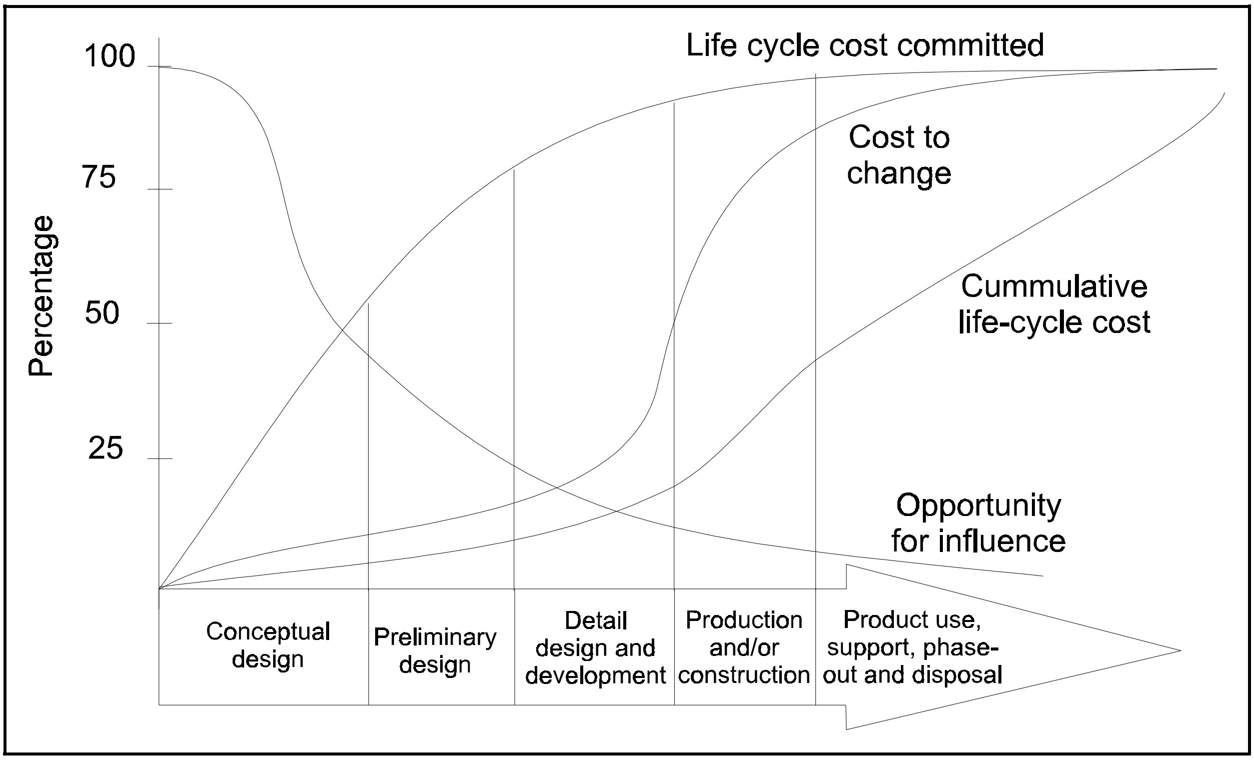



**Figure 5.7: Systems engineering influence on design and cost**
[Adapted from Blanchard and Fabrycky, 1998:37, 561 and Blanchard, 1998:82]

It must also be realised that with every decision made during the concept phase, not only is the total life-cycle cost determined, but a commitment is made towards the following:

- Technology employed for the system and sub-systems.
- Technology employed for production/construction.
- Technology employed for operations, support and maintenance.
- Operational, support and maintenance resources.

A major problem often experienced with the development of complex systems is the people responsible for taking the system concept through realisation into production, are not the same people responsible for its operation and support, even if the realisation system is within the same organisation as the host system. This functional division within organisations and having a budget allocated to the realisation system to bring the system of interest into being, many times lead to local optimisation of the overall system. As long as the realisation system meet the ability requirements of the system of interest within their allocated budget, it is many times perceived that the realisation system has performed well. After inserting the system of interest into the host system it is handed over to the host system's operational and support function. High life-cycle cost and low availability of the system of interest is now the problem of the operational and support function of the host system. Thus the non-performance of the realisation system in terms of the system's low availability and poor life-cycle cost becomes visible much later in the life-cycle when it is far too late. This non-performance is often wrongly blamed on inadequate management and technical competencies of the operations and support function of the host system, instead of blaming it on the realisation system failing to follow a whole-life, whole-system approach. It is therefore critical that the realisation system is contracted to develop and demonstrate, not only the ability requirements of the system of interest, but also the availability and life-cycle cost as part of the performance parameters of the system of interest.

## 5.8 The realisation system's approach to bringing systems into being

Having discussed the fundamentals of bringing a system into being, it leaves the discussion of an approach to doing so. As the goal of this research is not to provide extensive guidance to the overall systems engineering process, this section only provides a summary of the necessities of systems engineering.

Many factors influence the actual implementation of systems engineering and will vary from program to program. However, there is general agreement regarding the fundamental principles underlying systems engineering as well as the objectives that are to be achieved when following the systems engineering approach [Blanchard and Fabrycky, 1998:24]. These authors introduce different process models of systems engineering [Blanchard and Fabrycky, 1998:30-31)] which will not be discussed further.

The fundamental commonalities between all systems engineering processes are the following [Adapted from Blanchard and Fabrycky, 1998:23-24]:

- The realisation system should follow a holistic approach and top-down approach to system development in order to make sure that all interdependencies of the system characteristics are understood and consciously designed with the system's end goal, ability, availability, affordability and constraints in mind.
- The realisation system must ensure that the whole-life or life-cycle of the system of interest is considered to ensure proper achievement of system goals and objectives within the life-cycle constraints, and not only the development constraints. The following life-cycle phases should be considered:
  - Need exploration and requirements definition.
  - Concept design.
  - Detail design.
  - Production and/or construction.
  - Insertion.
  - Operations and support.
  - Retirement and phasing out.

  The phases do not always follow one after the other, they may overlap. The purpose of the overlapping of phases is two-fold namely:
  - To reduce the development time, especially where the risk is low to continue to the next phase whilst completing the previous one.
  - To ensure simultaneous consideration of system requirements such as safety, operability, supportability, reliability, maintainability, manufacturibility and affordability. This is sometimes referred to as concurrent engineering, which in any case is just good systems engineering.
- Underlying the systems engineering process is the basic approach to problem solving within each realisation phase namely:
- Proper identification of needs.
- Definition of the phase requirements.
- Generation of alternatives through analysis and synthesis.
- Selection of the best alternative.
- Design of the selected alternative.
- Integration of lower levels with the higher levels of the system.
- Testing on all levels and comparing test data with the requirements and objectives.
- Setting objectives for the next phase.

This process consist of many feedback loops and is the basic approach followed in each phase of acquisition. This process is shown in Figure 5.8 [Adapted from Blanchard and Fabrycky, 1998:27] and combines the top-down and bottom-up approaches to ensure system performance through analysis, design, synthesis, integration and test and evaluation.

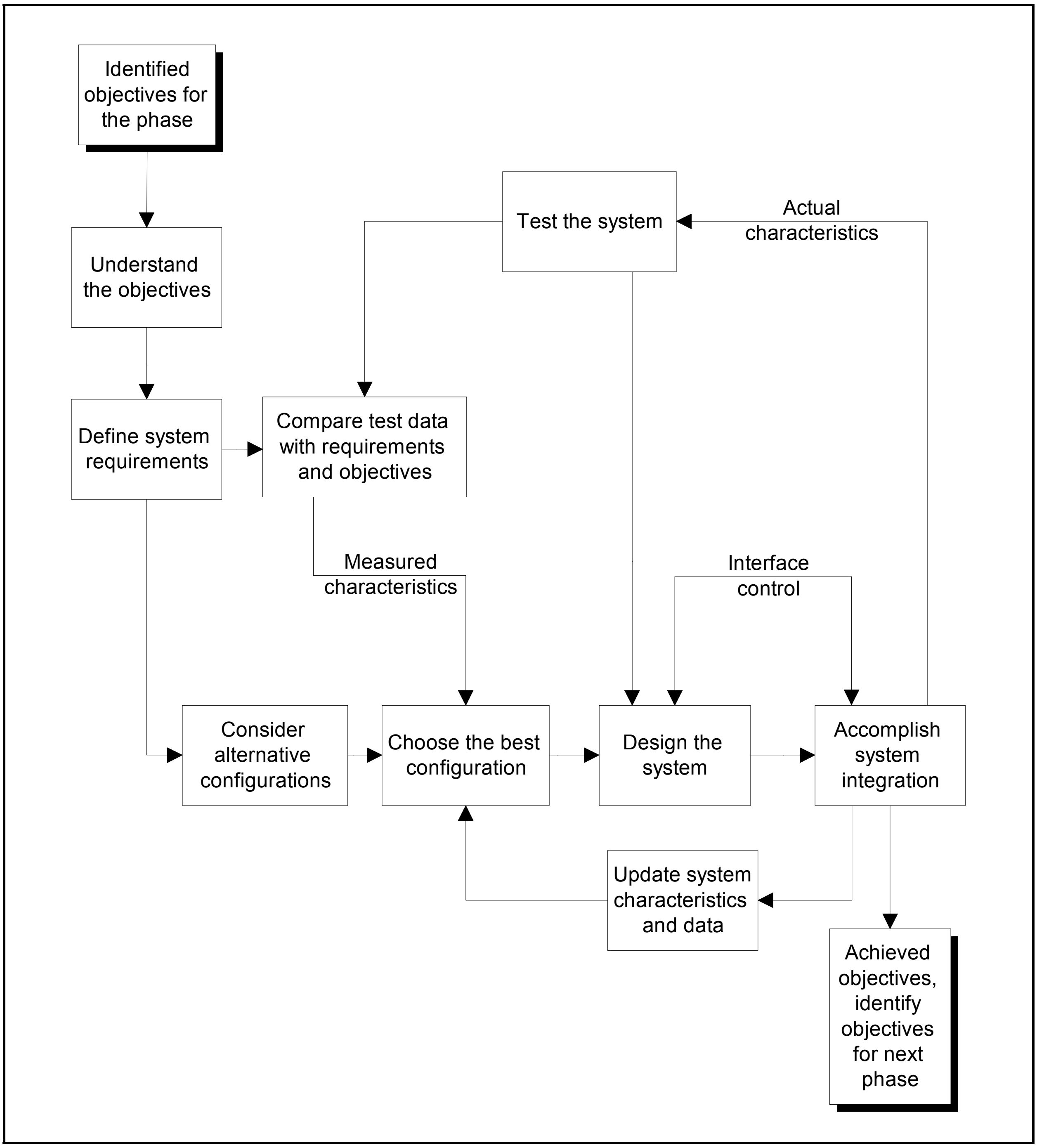



**Figure 5.8: Generic steps and feedback loops within acquisition phases**
[Adapted from Blanchard and Fabrycky, 1998:27]

- The systems engineering process draws from a wide variety of disciplines and technologies that needs to be integrated into a final system configuration. This requires an excellent understanding of the many interdisciplinary design and operational disciplines on the part of the systems engineer to ensure that the original customer requirements are met effectively and efficiently. In order to do this an extensive knowledge base is required by the systems engineer. The systems engineering process and resources required need to be managed from start to finish, i.e. the complete life-cycle of the system and is illustrated in Figure 5.9, adapted from Rottier [1999:39].

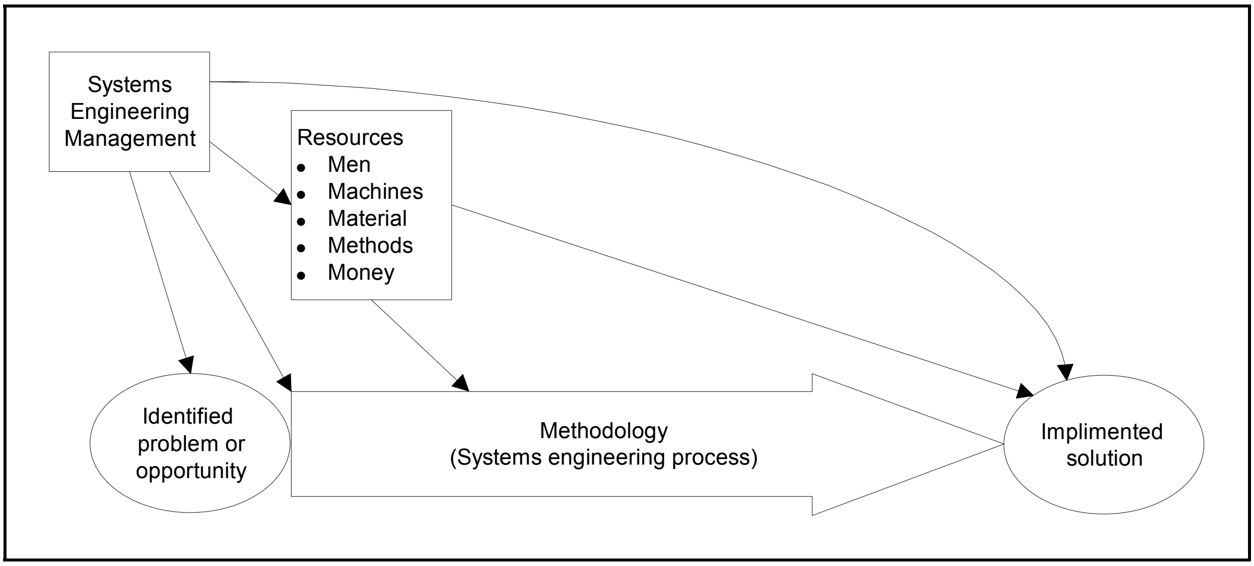



**Figure 5.9: The systems engineering process and its interfaces with systems engineering management and required resources**
[Adapted from Rottier, 1999:39]

- The resources required for executing of the systems engineering process consist of:
  - Men, those people performing the systems engineering.
  - Machines, consisting of technologies, equipment, facilities, tools, models, hardware and software required for the systems engineering activities.
  - Material and utilities to perform the systems engineering activities.
  - Methods, the know-how to perform the systems engineering activities as well as the knowledge base (data) required to do so.
  - Money, to pay for the resources used in the systems engineering process.

## 5.9 Chapter summary

New systems are required all the time due to the changing needs of man and also due to new technologies that are emerging which can improve the standard of living of man. Because of the ever increasing complexity of systems it is not possible anymore to have a single person responsible for the creation of a system and taking it through its life-cycle. Therefore team-work is of the utmost importance. Considering the aforementioned, the complexity and team-work requirements of bringing systems into being and operating them throughout their life-cycles require a multi-dimensional approach to bringing systems into being. These two dimensions are:

- The technical dimension that ensure technical compatibility of all parts of the system as well as human interfacing using:
  - analysis,
  - synthesis,
  - integration, and
  - test and evaluation.
- The management dimension that ensures the application of resources (men, machines, material, money and methods) to achieve the system objectives through:
  - planning,
  - organising,
  - directing, and
  - control.

Systems engineering is thus the formal process that ensures both the managerial and technical requirements of the system are met throughout the system's life-cycle, from conception to phasing out. Even though many feel that systems engineering has no role to play after the system of interest has been inserted, commissioned and successfully handed over to the host system, it is not true. The logistics engineering component of systems engineering, which will be discussed in much more detail later in this thesis, has an active and most important role to play during the operational and eventual phase out of the system of interest.

The implications of systems engineering for the realisation system is to view it from an organisational perspective. This means that the realisation system, whether part of the host system or not, must have the following capabilities:

- The capability to take the system of interest from conception to insertion into the host system.
- The capability to develop the management system of the system of interest alongside its technical capability and insert the management system into the host system's management system.
- The capability to provide support (technical and managerial) for the system of interest throughout its purposeful life.
- The capability to manage the realisation system's resources to accomplish the above mentioned.

Systems engineering is concerned with benefit-effectiveness consisting of ability, availability and affordability. When the interrelationships and dependencies between the design activity (whether conceptual or detail design) which provides for ability, and the other two key measurements of a system (namely availability and affordability) are considered, one can clearly see the importance of making the right design decisions early in the design process. Failing to take the availability and affordability into consideration when designing the system of interest, will make the system a total burden to operate from both an availability and cost point of view.

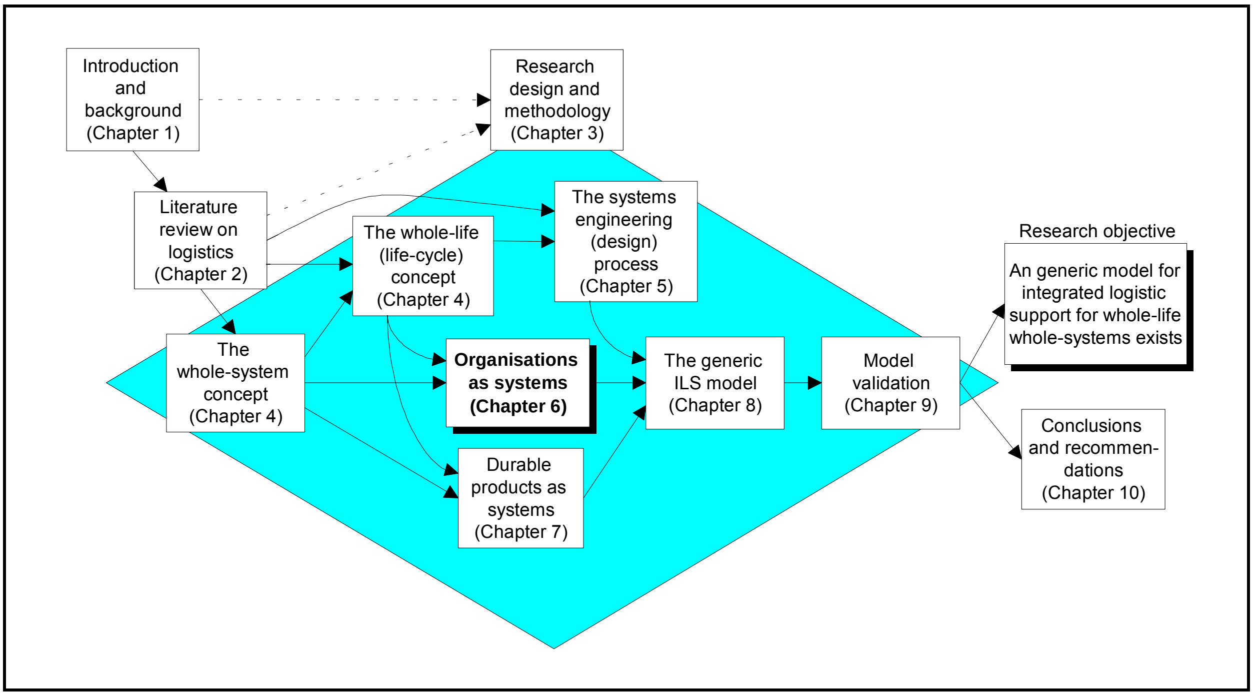
Irrespective of the type of system that is to be brought into being, a generic approach to formally go through the phases of creating the system can be followed. The approach and each phase can be tailored to suit the specific application. Understanding how to bring systems into being is essential for understanding the role and process of integrated logistic support in achieving the systems engineering objectives of ability, availability and affordability.

# Chapter 6

# The organisation as a system

*"Living systems have integrity. Their character depends on the whole. The same is true for organizations; to understand the most challenging managerial issues requires seeing the whole-system that generates the issues."*

Peter Senge [1990:66]




## 6.1 Purpose and outline of the chapter

The purpose of this chapter is to demonstrate that an organisation is a system because it exhibits all the system characteristics discussed in Chapter 4. However, this author will not attempt to demonstrate that organisations exhibit each and every system property discussed in Chapter 4. The most important system characteristics of an organisation will be highlighted in this chapter.

The outline of the chapter is as follows:

- The goal oriented nature of an organisation, irrespective of its nature or specific reason for existence, will be demonstrated.
- It will be shown how the generic system measurements, ability, availability and affordability, are applicable to an organisation, while also highlighting the generally accepted measurement of productivity and its relationship to these measurements.
- The hierarchy of systems within which the organisation exists pose necessary conditions that create the boundaries and constraints for the organisation. The necessary conditions will be discussed and it will be shown how they relate to the goals of profit and non-profit organisations.
- The role organisational strategy plays in creating a system perspective for the organisation is discussed and an approach to strategy formulation is introduced.
- Different ways of viewing the systemic nature of the organisation are discussed. The views are the functional interrelationship view (Porter's value chain [Porter, 1990:40-42]), and two life-cycle perspectives (Purdue enterprise reference architecture [Williams, 1994:142] and Rottier's enterprise life-cycle [Rottier, 1999:27-29]).
- Relationships between organisations (interactions across system boundaries), also known as the supply chain (Porter's value system [Porter, 1985:34]) are discussed.

Understanding the systemic nature of an organisation will allow the identification of requirements for a model of integrated logistic support that will improve understanding of the successful creation and operation of the organisation as a whole-life, whole-system.

### 6.2 The goal or teleology of an organisation

No organisation come into existence and continues to exist without a purpose, thus it is concluded that organisations exist for a reason. The goal of an organisation cannot be predicted beforehand or by outsiders, neither can it be imposed, unless we operate in a communist society. However, an organisation's purpose or goal is determined solely by its owners, otherwise the word ownership requires redefining. It is unimaginable that an organisation exists purely for the sake of its own existence [Goldratt, 1990a:10,12]. This holds true for a public company and a private company, a for-profit and a non-profit organisation. Ackoff [1999:59-61] defines four essential characteristics of an organisation as a system, three of which relate directly to the goal or purpose of the organisation:

- *"An organisation is a purposeful system that contains at least two purposeful elements which have a common purpose.*
- *An organisation has a functional division of labor in pursuit of the common purpose(s) of its elements that define it.*
- *The functionality distinct subsets (parts of the system) can respond to each other's behavior through observation and communication.*
- *At least one subset of the system has a control function where achieved outcomes are compared with desired outcomes (purpose), and make adjustments toward reducing the observed deficiencies."*

King and Cleland in Pearce and Robinson [1988:75] provide seven reasons why a mission statements exist. Their first and seventh reasons are of interest to this study. The first reason for the existence of a mission statement according to King and Cleland is *"to ensure unanimity of purpose within the organisation"* [op cit]. Thus, when analysing the mission statement of an organisation one should be able to see the reason for the existence of the organisation. The seventh reason King and Cleland provide states that a mission statement is necessary in order *"to specify organizational purposes and the translations of these purposes into goals in such a way that cost, time and performance parameters can be assessed and controlled"* [op cit]. A clear link should thus be made between the purpose of the organisation and its measurements. This sentiment is shared by Goldratt [1990a:14]*: "Measurements are a direct result of the chosen goal. There is no way that we can select a set of measurements before the goal is defined."* Thus the defined purpose or goal in the mission statement will determine the measurements of the organisation. Measurements cause behaviour, illustrated by Goldratt's [1990a:26] observation of reality: "*Tell me how you measure me, and I will tell you how I will react. If you measure me in an illogical way... do not complain about illogical behaviour".* Invariably, an organisation stating in its mission statement that it wants to be the lowest cost provider of service X or product Y will have prime measurements relating to cost. Similarly, an organisation stating it wants to be the biggest in a particular market segment, will place prime importance on measurements of market share. From this short discussion alone, it can be seen that it is critical to define the goal of an organisation correctly, so that the correct measurements can be derived and thus the correct behaviour be induced. Gharajedaghi [1999:143] supports this view on having the correct measures when he states "*we are much better of with an approximation of relevant variables than with precise measurements of wrong ones".*

However, many times organisations confuse the goal of the organisation with strategy, the necessary conditions, or even the means. McCormack [1984:199] states the most pressing problem established companies face is their bigness, which makes it so much easier to get off on tangents, forgetting why they are in business in the first place, which in the case of a for-profit organisation, is to make a profit. Forgetting about the goal often starts within the mission statement. Many times, the mission statement, intended to provide the definition of the goal, does not reflect the real goal. Ackoff [1999:125] starts his discussion on mission statements with: *"Most corporate mission statements are worthless."* A more elaborate discussion on this topic for profit oriented organisations can be found in Goldratt [1990a:10-13], a discussion that ends with the following: *"It is quite disturbing to see so many publicly held companies where top management confuses the necessary conditions, the means, and the goal. Such confusion often leads to misdirection and long-term destruction of the company. Customer service, product quality, good human relationships, are definitely necessary conditions, sometimes even means. But they are not the goal. The employees should serve the shareholders - that's what they are getting paid for. Serving clients is just the means to the real task, serving the company's shareholders."*

The example used previously of the organisation wanting to be the lowest cost provider, can be used to demonstrate how the wrong goal in the mission statement may lead to negative effects to the system as a whole. If this company has a profit motive, then its goal should be to make more money now as well as in the future. They may have selected to achieve their goal by reducing cost to become the lowest cost supplier, but this orientation reflects their strategy and not their goal. The most probable reaction to this mission statement would be to start reducing cost. Resulting from that a reduction in quality may follow which will invariable lead to an increase in quality costs. So much for becoming the lowest cost provider. Cutting expenses generally boils down to slow suicide, because of the systemic relationship between income and expense. For more elaborate discussions on the nature and effects of cost cutting see Carlzon in Zbar [1994:77], Noreen *et al* [1995:143], Morgan [1994:23], Goldratt [1990b:92-93] and Corbett [1998:16].

Ackoff [1999:22] argues that systems should be viewed in an output-oriented way (teleologically), rather than in an input-oriented way (deterministically). He continues to state that organisations have a purpose of their own. He defines three levels of purpose when organisations are studied as a system, namely the purposes of the system, of its parts, and of the higher level system of which the system is part (the suprasystem) [op cit:23-24]. From this it can be concluded that any organisation exhibits the generic properties of a system, namely that it was built for a purpose or to be goal-seeking, and that it exist within a higher level system. This last property implies the existence of an organisation within a system hierarchy and interaction with its environment.

## 6.3 Generic organisational measurements

Looking at the organisation from a system point of view, the generic measurements defined for any system, namely ability, availability and affordability, can also be applied.

### 6.3.1 Organisational ability

The ability of an organisation is the ultimate function that allows the organisation to achieve its defined goal. Immediately one gets the feeling that it is impossible to generically define the goal of all organisations as the differences between types of organisations will not allow such a generic definition of a goal. According to Goldratt [1990a:12] it is possible to define a generic goal for at least one group of companies. Those companies trading their shares on the open market have stated their goal unambiguously, namely to make more money now as well as in the future. To answer the question what the goal of a company trading its shares on the open market is, is the same as asking the question: “Why did the shareholders invest their money in that organisation?” The goal of organisations who do not trade their shares on the open market or who do not have shares at all, can only be determined by those who own that company (see § 6.2). Even these companies must have a goal, otherwise there is no reason for their existence. In order for any organisation to achieve their goal, the organisation must possess a certain ability. Without that capability, achievement of the goal is not possible.

The ability of an organisation can be defined as a set of interrelated activities using certain inputs to deliver an explicit output. Irrespective of the goal of the organisation, the interrelated activities or processes are the actions of people using information, material, equipment, facilities and capital to produce the desired output. The output or goal of the organisation can be regarded as an emergent property. As was highlighted in § 4.3.3, emergent properties do not exist within the individual parts of the system, but are the product of the interactions of the parts. Gharajedaghi [1999:46] argues that "*the mere notion of interaction signifies a dynamic process producing a time-dependent state*." This means that the emergent properties are being continuously reproduced online and in real time, and they are dependent on the reproduction process. If these processes are to stop, the emergent properties will also cease to exist. It requires many simultaneous interactions among many parts of the organisation to produce the desired outcome, which can be expressed as the organisation's ability. To understand the outcome as an emergent property, one needs to understand the interactions of the processes or parts as well.

For a profit oriented organisation, profit and return on investment are characteristics of the organisation. However, none of these are characteristics of any of the parts of the organisation. Thus, profit and return on investment are emergent properties of the organisation as a system, and it comes about due to the interactions of the different parts (ability) to generate these emergent properties. Gharajedaghi [1999:46] confirms it in his statement: *"If success is an emergent property, then it has to be about managing interactions rather than actions."* Success is being defined as achieving the goal. It can thus be concluded that ability measures the capacity to achieve the goal (emergent property) of the organisation as a system. Therefore it is not necessary to know the goal of each and every organisation to know that ability is a generic measurement of any organisation, irrespective the actual goal of the organisation.

### 6.3.2 Productivity as a measurement of organisational ability

One generic organisational measurement that is often used is productivity or ability to translate input into output. In its most basic format productivity is the ratio of output to input. The question is whether it tells anything about the goal of the organisation? Many times productivity improvements are measured on a local level which may look impressive but does not add anything to the well-being of the organisation in achieving its goal. For example the installation of new equipment may cause the operation time on a certain part to decrease by 50%. When measured on a local level this may seem significant. But does it mean that the organisation increases its profits by 50%? If not, it is not a 50% productivity improvement. It will be less or can even be zero. In the worst case productivity can even be impacted on negatively. Therefore it is imperative that the measurement of productivity be viewed in its true context, namely that "*productivity is the act of moving an organisation closer to its goal*." [Goldratt, 1992:32]

It is further important that the two components of productivity be considered. They are:

- Effectiveness or doing the right things (to achieve the goal).
- Efficiency or doing things right (the things to be done to achieve the goal).

The above two components will not be discussed in further detail at this point but will be expanded on later in this thesis.

### 6.3.3 Availability

The understanding of the interaction of processes leads to the next generic system measurement, namely availability. An organisation, being an open system and interacting with its environment [Gharajedaghi, 1999:29], is constrained in its output (or goal achievement) [Wang, Han & Spoere in Wang Ed., 1997:15] and is subject to entropy [Aslaksen and Belcher, 1992:70]. It now follows naturally that organisational systems cannot be available 100% of the time. The implication is that the ability of the organisation is not available (the system is down and not functioning) or may have deteriorated over a period of time. As the organisational system is purposeful it will seek to restore the availability in order to achieve the required output. Non-availability of the organisational system may be caused by a single event or a combination of events. It can also be caused by an operational deficiency (e.g. lack of raw material) or deterioration or failure of one or more of the resources (e.g. equipment breaking down). In order to restore the availability a different set of processes need to be set in motion to that effect. These different sets of activities is what M'Pherson [1980:550] (as discussed in § 4.6) calls the support activities performed by the support subsystem.

### 6.3.4 Affordability

The third generic system measurement applied to an organisation is affordability. Very simply affordability translates to deriving more benefits from achieving the goal than the costs associated with deriving those benefits. The costs are calculated by looking at the sum of all costs associated with all processes (direct and indirect) to produce a desired outcome or goal, as well as the costs associated with maintaining and restoring availability (support processes). For a profit making company the benefits translate to the income generated. For a non-profit organisation the benefits must justify the costs, as in the case of a country's military force.

## 6.4 The necessary conditions and its relationship with the goal

A necessary condition is something that if it is violated, the achievement of the goal is not possible. The necessary conditions of a company are the boundaries within which it has to operate. Goldratt [1994:271] states that the goal does not justify the means, as it is futile to define a goal without defining the boundaries within which the organisation can attempt to reach it. Necessary conditions are normally imposed by power groups. Some examples of power groups and the necessary conditions they impose are the following [Goldratt, 1990a:11] and Ackoff [1999:333]:

- Government impose necessary conditions such as taxes, minimum wages, maximum allowable pollution levels.
- Customers impose necessary conditions such as minimum level of customer service and product quality, i.e. they define the order qualifiers and order winners.
- Employees impose necessary conditions such as minimum job security and fringe benefits.
- Society within which the organisation operates impose necessary conditions such as expected production and distribution of wealth.

If the necessary conditions are violated the organisation will face a real threat of being closed down in some way or another. Still, a clear distinction must be made between necessary conditions and the goal of the company. Even though these power groups do impose necessary conditions, they do not have the right to determine or interfere with the organisation's goal. Defining the goal lies solely in the hands of the owners of the organisation. Thus the organisation should strive to meet its goal within the boundaries set by the power groups. Linking it back to systems theory, the organisation needs to be designed with a specific purpose, inserted into its host system (the economic, social, political, environmental and technological environments), and operated to achieve its goal without violating conditions set by the host system.

In the final analysis, all organisations (irrespective of their nature) can be classified as for-profit or non-profit organisations. This covers all types of organisations from a one man concern, companies whose shares are privately held, companies who trade shares on the open market, to government departments and welfare organisations. Two diagrams are proposed to show the interactions between necessary conditions and the goal of the organisation.

Figure 6.1 shows the necessary conditions for profit-oriented companies. Each of the three components are equally important. The goal of making money now as well as in the future satisfy the needs of the shareholders or owners of the business. The first necessary condition of satisfying the market looks after all concerns of the host system. This includes the concerns of the direct customer, government, environmental groups and society at

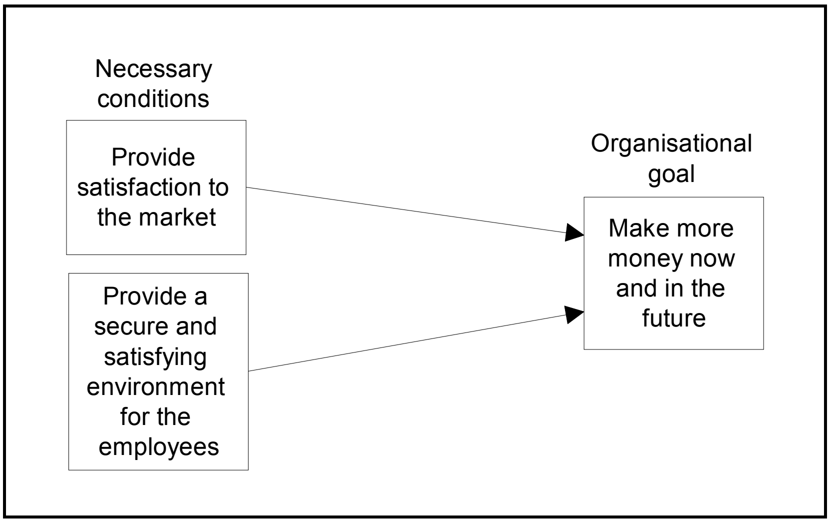



**Figure 6.1: The goal and necessary conditions for a profit oriented organisation**

large. The second necessary condition of providing a secure and satisfying environment for the employees looks after the needs of those people employed by the organisation [Goldratt, 1994:273] in terms of job security, work satisfaction, career prospects and self-fulfilment. The requirements set by this last necessary condition is extensively covered by Wickens [1995: xvi, 88], and echoed by Ackoff [1999:126] and Richard Branson of Virgin [ Wickens, 1995:100], and will not be discussed in more detail as part of this research.

Figure 6.2 shows the three necessary conditions applicable to non-profit organisations. Whatever the goal is, determined by the owners of the organisation, the three necessary conditions as stated hold true. The difference between the profit organisation and the non-profit organisation is that making money, is not a goal - as is the case with the profitorganisation - but a necessary condition for the non-profit organisation. Making money ensures the survival of the non-profit organisation. Without cash and at least being able to break even, any non-profit organisation will cease to exist, irrespective how noble its goal may be. This necessary condition does not specify the means of making money; the non-profit organisation may even be subsidised. However, the necessary condition remains.If the subsidy is to be removed and it does not make money in another way, the organisation will cease to exist.

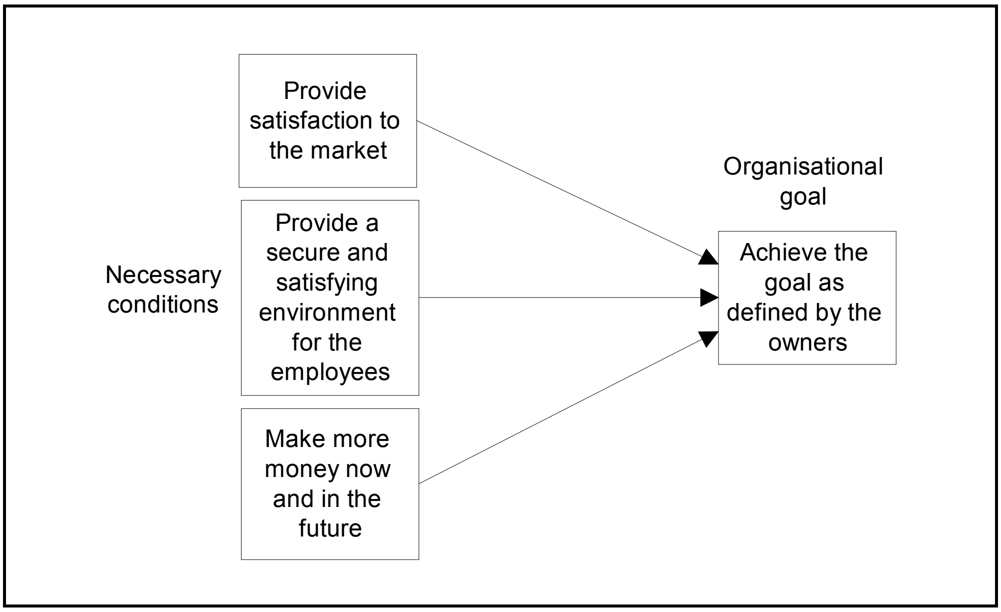



**Figure 6.2: The goal and necessary conditions for a non-profit organisation**

In recent debates [Lagace, 2002] it has been stated clearly by Harvard Business School professor James E. Austin that *"'Profit' need not be a dirty word at a nonprofit organization".* A very strong argument is made out by Alfred Wise (director of the Community Wealth Ventures for-profit consulting unit within Share Our Strength, an anti-poverty nonprofit) in Lagace [2002] whether *"we can teach [the people we serve the importance of being self-sufficient while not being self-sufficient ourselves?"*

The necessary condition of making money for non-profit organisations may lead the non-profit organisation to make a profit in pursuit of its chosen goal and to ensure its continued existence. Making a profit does not suddenly change the goal of the organisation or turn it into a for-profit organisation. The difference between these two types of organisations lie with what happens to the profit when a profit is made. In most countries throughout the world, within the profit organisation, the owners have the right to decide what to do with the profits; they may even take it all. Similarly, in non-profit organisations worldwide, any profits made have to go towards the goal; the owners are not allowed to enrich themselves.

## 6.5 Strategy formulation

The realisation of the systemic interactions between these necessary conditions and the goal is the foundation on which strategy should be planned to provide an organisation with a sustainable competitive advantage. Because strategy is the direction an organisation takes to achieve its goal [Goldratt, 1994:275], and because necessary conditions may not be violated in pursuit of the goal, a chosen strategy should be discarded if it clashes with any of the necessary conditions.

Hill [1994:18, 25] is of the opinion that corporate strategy statements are flawed in that they are many times just a compilation of functional strategies and nothing more. Furthermore, a second mistake is that functional strategies are developed independently of one another and the corporate whole, ignoring the systemic nature of the organisation. In order to arrive at a sound strategy, the whole (systems) picture should be taken into account and the interactions amongst the functions should be considered.

The arguments that follow are formulated for a profit oriented organisation, based on the preceding theories and observations. Using the same reasoning logic, a similar model can be deducted for non-profit organisations, but is not explored further in this research.

From a strategic point of view, in order to provide satisfaction to the market (the first necessary condition) the organisation is to provide a product and/or service that:

- meets the order qualifier requirements Hill [1994:33], where order qualifiers are those characteristics of the product, service and /or organisations that will make the customer consider the organisation as a possible supplier; and
- exceeds the order winner requirements [op cit], where order winners are those characteristics of the product, service and /or organisations that will make the customer choose the organisation and product/service above the competitors.

For order qualifiers, an organisation has to be as good as its competitors; for order winners, an organisation has to be better than his competitors. Order qualifiers and order winners are not static, they are time and market specific [Hill, 1994:32]. This means that in order to remain competitive, an organisation has to be flexible to adapt to changing market needs. This flexibility implies responding to changing market needs by changing order qualifiers into order winners, order winners in order qualifiers or creating new order qualifier and order winning criteria.

The second necessary condition, namely that of providing a secure and satisfying environment to the employees, is a subject that has been written about and debated for a long time. For the purpose of this thesis this author will stick to defining three prerequisites for meeting this necessary condition, namely:

- The organisation has to provide security to its employees, that means an absence of uncertainty as far as possible.
- The organisation has to provide satisfaction to its employees, resulting in employees feeling a sense of value contributing towards the overall organisational performance.
- The organisation has to provide scope for their employees, where endeavours can be undertaken by employees to further themselves within the company while at the same time contribute even more to the goal of the organisation.

Taking all the above into consideration, a systems view of developing a strategy can be developed. This view is shown in Figure 6.3 for a profit-oriented organisation. The goal and necessary conditions, once seen in a logical interaction, clearly defines the sequence of satisfying these necessary conditions and also how these strategies fit together. Thus strategy development cannot be a haphazard disconnected process of establishing functional strategies to end up in an organisational strategy, as has been observed by Hill [1994:18, 25]. Naturally, there are many outside factors influencing strategic decisions. For the sake of clarity, these are not included in the diagram as the focus is on the goal, necessary conditions and the prerequisites to that.

The organisation must clearly start with facing the market in determining the actual needs and opportunities that exist or potentially exist. Having identified the need or potential need in the market, the current (and future) abilities of the operations (or delivery) process must be considered to establish the market requirements (which include both the order qualifiers and order winners) for a product and/or service that will satisfy the market. This interaction

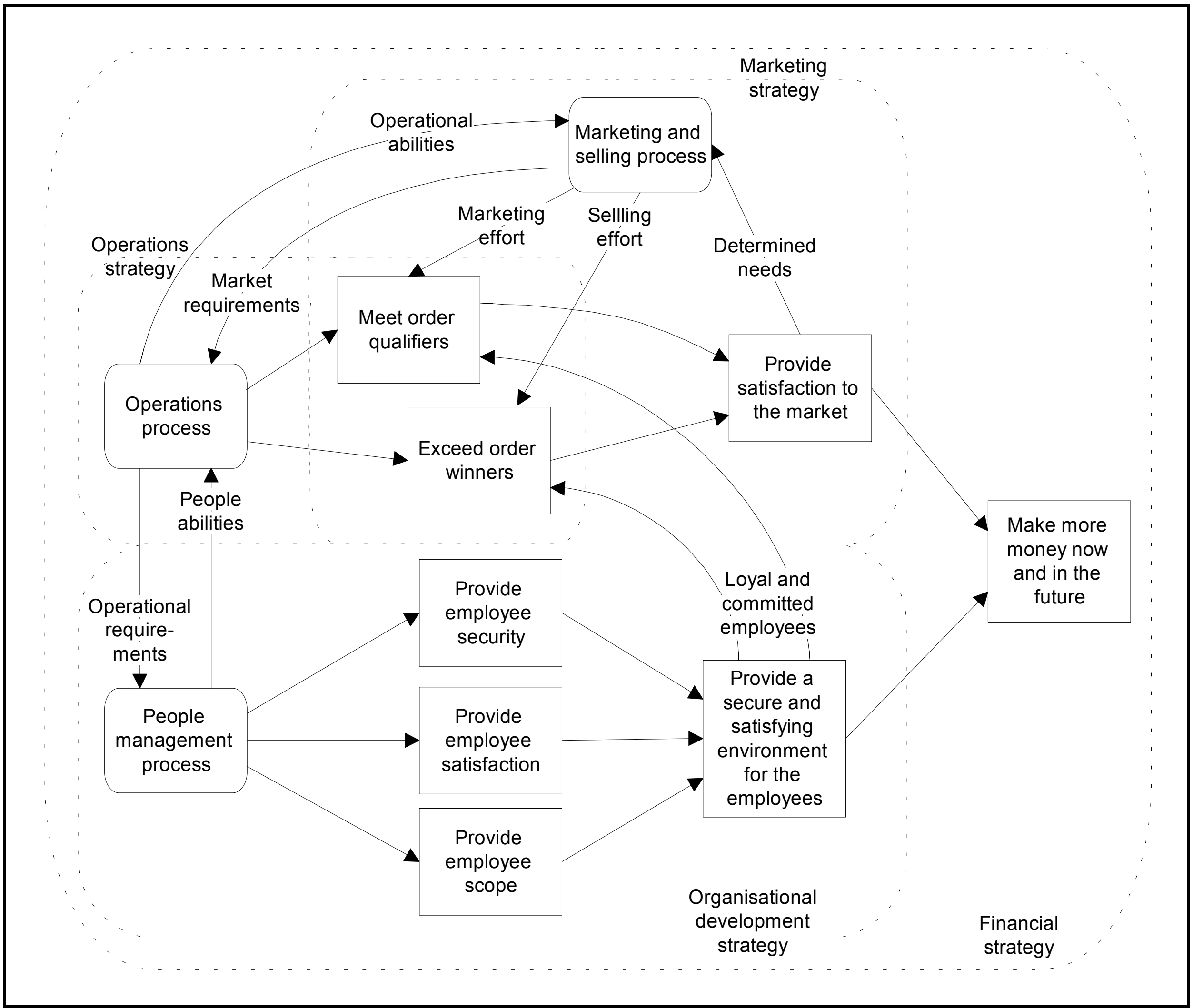



**Figure 6.3: The systemic nature of strategy development for a profit oriented organisation**

between market analysis and operational capability is to ensure that what is promised by marketing can be delivered by operations. Only now can a marketing strategy be formulated. The marketing strategy is the first strategy that should be in place. Organisations should be very cautious not to confuse a strategy of being market-led or a strategy of being marketing-led. Having a marketing-led (functional) perspective as opposed to a market-led (business) perspective can be very dangerous [Hill,1994:41]. Going for a marketing-led strategy will again lead to a local optimum, which is not congruent with the systems view. One must beware of becoming so internally focussed and ignoring the customer, as is demonstrated by the next statement about General Electric (GE). *"Many of GE's best managers devoted far more energy to internal matters* *than to their customer's needs. As GEers sometimes expressed it, theirs was a company that operated 'with its face to the CEO and its ass to the customer' "* [Tichy and Sherman,1993:6].

The second strategy is the operations strategy that should consider how to deliver the market requirements provided by the marketing function. Based on the market requirements and the ability of people that can be used within operations, a strategy for operations is developed to give direction to delivering products and/or services that will meet the order qualifiers and exceed the order winners as set by the market. In essence, the order qualifier and order winners (quality, flexibility, lead time, service, low variability, product/service profitability) [Schonberger & Knod, 1991:7], are created within the operational environment. Thus the operational strategy deals with a series of decisions concerning process selection (conversion, fabrication or assembly), flow structures (project, job shop, batch, assembly, continuous flow), quality, investment decisions (make or buy), degree of automation versus manual labour and other [Chase et al, 1998:96-98]. This strategy must provide, over time, the necessary support for the order-qualifiers and order-winners [Hill, 1994:41]. In short it is to establish the most appropriate mode to provide these sets of products or services AND to provide the infrastructure, policies and mechanisms required to support the operational processes. This operational support has three dimensions that has to be established along with the ability to deliver product and/or services:

- The flow of raw material from the organisation's suppliers to the organisation, as well as the distribution of end products to the markets of the organisation (business logistics).
- The support required to maintain the operational system in a functional state (maintenance).
- The support required by customers for the commissioning, utilisation and maintenance of the product/service they have bought from the organisation (after-sales-service).

Hill [1994:41] warns organisations of incorrectly seeing operation's role as being the provider of corporate requests. Corporate strategy debate should include discussing the implications of decisions for operations and thus the organisational system as a whole. Erroneously viewing operations as the provider of corporate requests has been based on two incorrect assumptions:

- Within a given technology, operations is able to do everything.
- Operation's contribution concerns the achievement of efficiency rather than effective support of market needs.

The operations strategy should therefore be totally integrated with the overall strategy and cannot be viewed as unimportant or disconnected. The performance of the system as a whole will suffer if this strategy is neglected. In the final instance, the operations function should become the source of competitive advantage for the organisation, as this is primarily the function where the order qualifiers and order-winners are created.

The third strategy is the organisational development strategy. This strategy takes into consideration the people requirements for the organisational system as a whole considering quantity and quality of people needed for operations and marketing. It supports the human side in terms of assessing the people's needs from a personal and organisational point of view. The organisational development strategy is further aimed at providing employee security, satisfaction and scope (meeting the second necessary condition). In this context, the phrase people management is preferred to human resource management. This view is shared by Wickens [1995:xvi] where he argues that the statement "*Our people are our biggest asset*", is a hypocritical one, as executives rarely act that way. Making such a statement implies subconsciously that 'our people' are something separate from 'us', that they belong to the company, as if the company owns them. Assets are shown on the balance sheet; no company has ever shown their people as asset on their balance sheet. He continues to say that *"the real company is just as much the people who work in it and give their time as those who are outside and invest their money"* [op cit].

Wickens [1994:88] further argues that another hypocritical statement made by organisations is *"we are all one family here"*. He argues that no children choose their family but will in most cases stick together and support each other within the family in the good times and the bad. Individuals have a choice whether to accept a position or not, or if they are in a job they have the choice to stay there or not. Organisations have a choice to appoint a person or not and to keep him in the organisation's employ or not. It is not characteristic of a family to have these choices. Breaking the relationship between an employee and an organisation is not hard to do. Thus, loyalty has to be earned, it does not come from a written piece of paper (the mission statement). This demonstrates the importance of the organisational development strategy.

Quite obvious in Figure 6.3 are the interrelationships between the marketing, operations and organisational development strategies. These interrelationships probably illustrate the systemic nature of organisations best. This interaction between marketing, operations and people is what Carlzon [1989:3] calls the "moment of truth", where the customer meets with the organisation, directly or indirectly, through its employees, processes and product and/or services. This is also where customer perceptions about the organisation are formed . These customer perceptions may be right or wrong, but nevertheless, the customer will act upon his perceptions in future dealings with the organisation and this is what ultimately translate to customer satisfaction. To a customer his perception is reality. Therefore carefully aligned strategies between marketing, operations and organisational development through the employees are of the utmost importance. This approach is echoed by Richard Branson, Chairman of Virgin Atlantic Airways, when he states [Wickens, 1995,100]: *"We give top priority to the interest of our staff; we give second priority to the interests of our customers; and third priority to the interests of our shareholders. Working backwards, the interests of our shareholders depend on high levels of customer satisfaction, which enable us to attract and retain passengers in the face of intense competition. We know that the customer's satisfaction which generates the all-important word-of-mouth recommendations and fosters repeat purchase, depends in particular upon high standards of service (and this) depends on happy staff, who are proud of the company they work for."*

The last strategy is the financial strategy that will allow the organisation to finance the other strategies, make investment decisions in line with the goal of the organisation and develop a dividend policy, which is beyond the scope of this research.

## 6.6 The organisation as a system of dependent variables

In order to get the correct perspective on the way an organisation functions, considering the goal, necessary conditions, prerequisites to the necessary conditions and how it all translate into a coherent organisational strategy, it is necessary to switch the *"view of organisations as systems of independent variables to viewing them as systems of dependent variables*. *Many functions have to carry out, in sync many tasks, until a sale is realized, until throughput is gained"* [Goldratt, 1990a:52-53]. This means that organisations should be viewed as a chain or a grid of chains. Even though the strength of a chain is determined by its weakest link, all other links are required to make up the chain. If any one link is missing, the chain loses its overall strength. The focusing efforts should always be at improving the weakest link, without forgetting the importance and dependencies of all the other links. Thus, a better way of looking at an organisation is to view it as a set of dependent functions, of which all must perform at least as well as the weakest link, to achieve the desired output. Three different views of the organisation are now presented to illustrate different perspectives of the organisation as a system.

### 6.6.1 Porter's value chain concept of the organisation

One popular approach to view organisations as a system is the value-chain concept as defined by Porter [1990:40-42] and illustrated in Figure 6.4. The basic philosophy of the value chain is that *"firms create value for their buyers through performing these (discrete)activities."* [Porter, 1990:40]. Value is defined as the amount customers are willing to pay for whatever the organisation is selling to them [Porter, 1985:38]. The value chain shows all activities that an organisation uses to create value for its customers. The margin is the difference between total value (sales or income) and the collective cost (expenses) to perform these activities. He classifies five primary activities of the value chain and shows four more support activities that support the primary activities. The dotted lines illustrate that some of the secondary activities may be associated individually with primary activities or the total chain, whereas the firm's infrastructure supports the whole value chain [op cit].

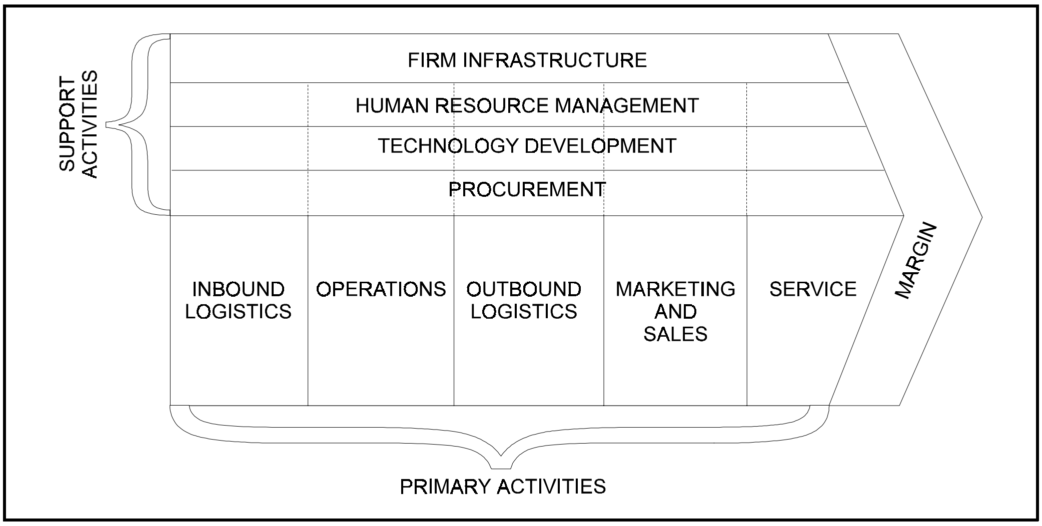



**Figure 6.4: Porter's value chain**
[Porter, 1985:37]

Porter's [1985:39] idea with the value chain is to be able to examine competitive advantage. He prefers the value chain concept to the value added concept (which he defines as selling price less the cost of purchased materials) for the following reasons:

- Value added incorrectly distinguishes raw material from the many other purchased inputs used in an organisation's activities.
- Cost behaviour of activities cannot be understood without simultaneously examining the costs of the inputs used to perform them.
- Value added fails to highlight the linkages between an organization and its suppliers that can reduce cost or enhance differentiation.

Porter's value-chain concept of "*the ultimate value a firm creates is measured by the amount buyers are willing to pay for its product or service*" [1990:40], clearly demonstrates the point that the way he defines value is not equal to product cost. Product cost is based on the amount of activity and resources spent (value added) on delivering the product or service. Value is based on the perception of the buyer of the benefit(s) which can be gained from having the product or service. Thus if Porter's value chain is to be understood correctly, one must rather look at adding value to the organisation than adding value to a product or service, which will make the reasons for preferring the value-chain concept to the value-added-concept, much more defendable However, a detailed discussion on this topic is beyond the scope of this thesis.

By looking at value as value to the company (achieving the goal) as opposed to value of the product/service, it eliminates the confusion over whether money spent is an investment or an expense [Goldratt, 1992:59-60]. *"The whole concept of adding value to a product is a distorted local optimum. So we should not be surprised if it will cause distortions in the company's behaviour. The local viewpoint of adding value to a product causes companies to slow down considerably their efforts to reduce material inventory. Local optima do not add up to the optimum of the total"* [Goldratt, 1990:24-51,51].

Porter [1990:41] thus supports the principle that an organisation must be viewed as a system when he states that "*a firm is more than the sum of its activities. A firm's value chain is an interdependent system or network of activities, connected by linkages. Linkages occur when the way in which one activity is performed affects the cost or effectiveness of other activities. Linkages often create trade-offs in performing different activities that must be optimized. For example, a more costly product design, more expensive components, and more thorough inspection, can reduce after-sale service costs. Linkages also require that activities be coordinated. On-time delivery requires that operations, outbound logistics, and service activities such as installation should function smoothly together."*

### 6.6.2 The Purdue enterprise reference architecture

As opposed to Porter's value chain which simply looks at an organisation from a running concern or operational phase point of view, the Purdue enterprise reference architecture [Williams, 1994:142] takes a life-cycle approach and view the organisation through all its phases from concept to the operational phase. An adaptation of the model is shown in Figure 6.5. In this model the phases used to describe the life-cycle are the concept phase, followed by the definition and design phases, leading into construction/installation and finally operations. The model does not cater for recycling and phase-out, even though it may be implied in some phases. Even though the architecture was primarily developed to model organisations that uses computer integrated manufacturing (CIM), the model can

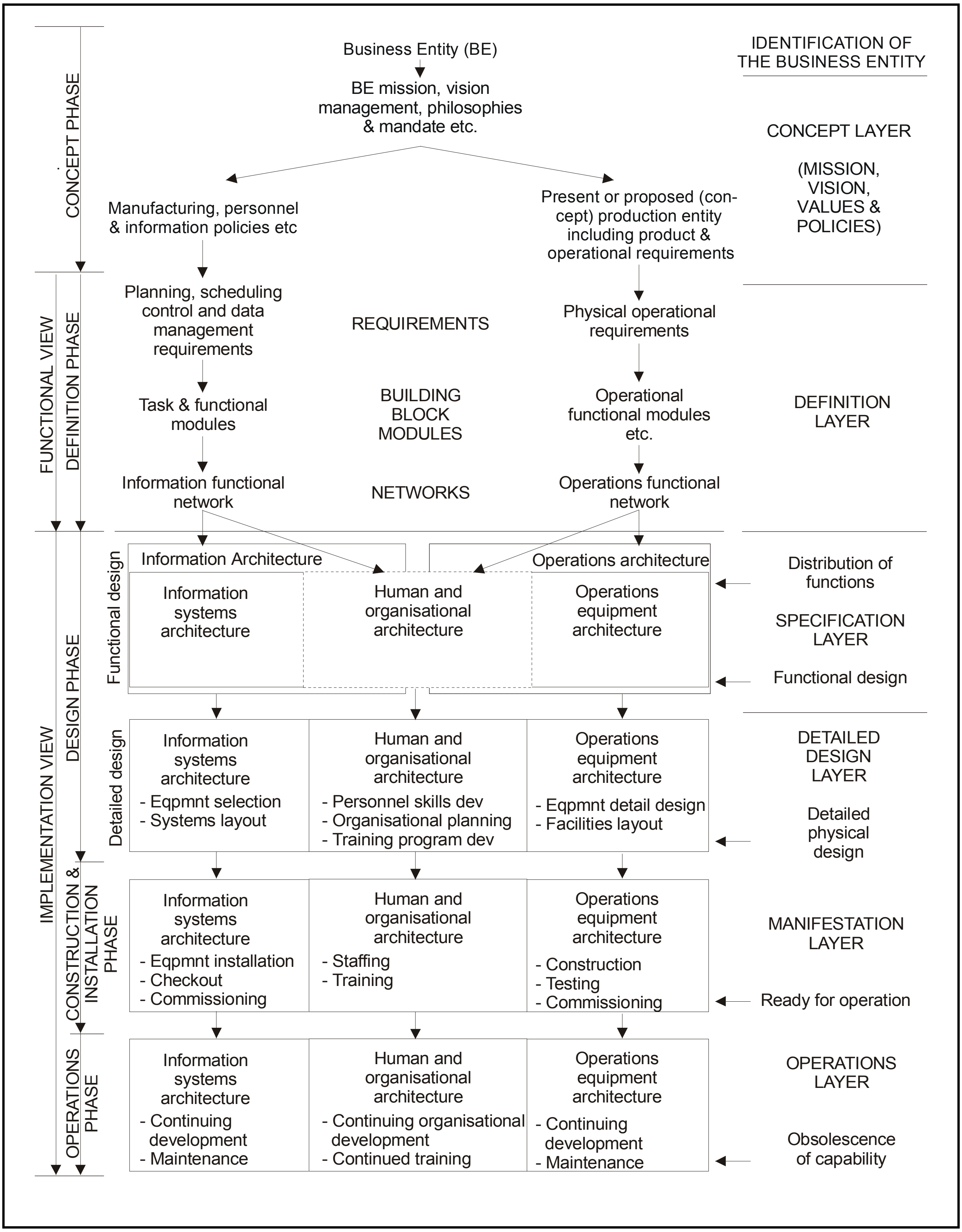



**Figure 6.5: Block diagram of the Purdue Enterprise Reference Architecture**

Adapted from Williams [1994:142-143]

be applied to the development and operation of an organisation regardless of the industry or field of endeavour [Williams, 1994:142]. The changes that were made to the model by this author were primarily removing the references to manufacturing and replacing it with operations. In making these replacements the model was made generically applicable to manufacturing and service organisations, and thus also for any profit and non-profit organisation.

When comparing this architecture to systems engineering, the technique discussed in Chapter 5 that concerns itself with bringing systems into being, the similarities are obvious. It boils down to the same approach but translated specifically to use the terminology when an enterprise is taken from concept, through functional and detail design, into construction/installation and operation. It can thus be concluded that this architecture also supports the system's view of organisations.

The whole idea of an organisation having a "life", which implies a life-cycle, is confirmed by Senge [1990:17]. He refers to a study conducted by Royal Dutch/Shell in 1983 that found one third of the firms in the Fortune 500 in 1970 had vanished. It was estimated at that time that the average lifetime of the largest industrial enterprises was less than forty years, which is roughly half the lifetime of a human being.

### 6.6.3 Rottier's enterprise life-cycle

Similar to the Purdue enterprise reference architecture, Rottier [1999:27-29] also takes a life-cycle approach to view the organisation through all its phases from concept to the operational phase. As opposed to the Purdue model which emphasises the design phase, Rottier places a major emphasis on the operating phase (Figure 6.6). The different phases of the enterprise life-cycle adapted from Rottier [op cit] are:

- *Identification of the opportunity/need for an enterprise*. This phase marks the start of an enterprise. It is the entrepreneurial phase where new opportunities or gaps in the market are identified, or possibilities exploited because of new technologies.

- *Establish an enterprise capability, including the enterprise support capability*. This phase is similar to the detailed design phase of a new product after a viable concept has been established in the previous phase. This phase is probably the one phase in the organisational life-cycle that gets neglected the most. Similar to a product design the support design is left until later which results in it not being done at all or done in a haphazard fashion. The reasoning most of the time is to get the organisation up and running (or the product to the market) as quickly as possible inorder to start generating income. The peripherals (support system) will be added later. This approach normally results in having sub-optimal design of the sub-systems that are to support the smooth flow of work through the enterprise, both from a supply/distribution and preventing disruptions to flow (corrective and preventive maintenance) point of view. Once the design of the organisation is completed, it can be ‘constructed’. However, in reality, the ‘construction’ of an enterprise many times ‘happens’ as design goes along. Similarly, the ‘construction’ often determines the design, not by conscious effort, but by default. The part of the enterprise that gets designed by default most often, is the support system.
- *Operate, support and improve the enterprise capability*. This phase is what the enterprise is all about. All normal business functions (marketing and selling operations, finances and people management) are required to effectively achieve the goal of the organisation. It is important from the viewpoint of this thesis to take note of the following support related functions within this phase:
  - Support the capability, which consists of the business logistics (those activities which ensure the effective flow of work through the enterprise), as well as the corrective and preventive maintenance which are required to eliminate as far as possible disruptions to the flow.
  - Develop products/services, which is a three layered process, namely the design of the product or service itself, the design of the product or service delivery process and the design of the support capabilities associated with the new product or service.
  - Providing support (after sales service) for products/services, an activity which can generate a substantial income to the organisation.

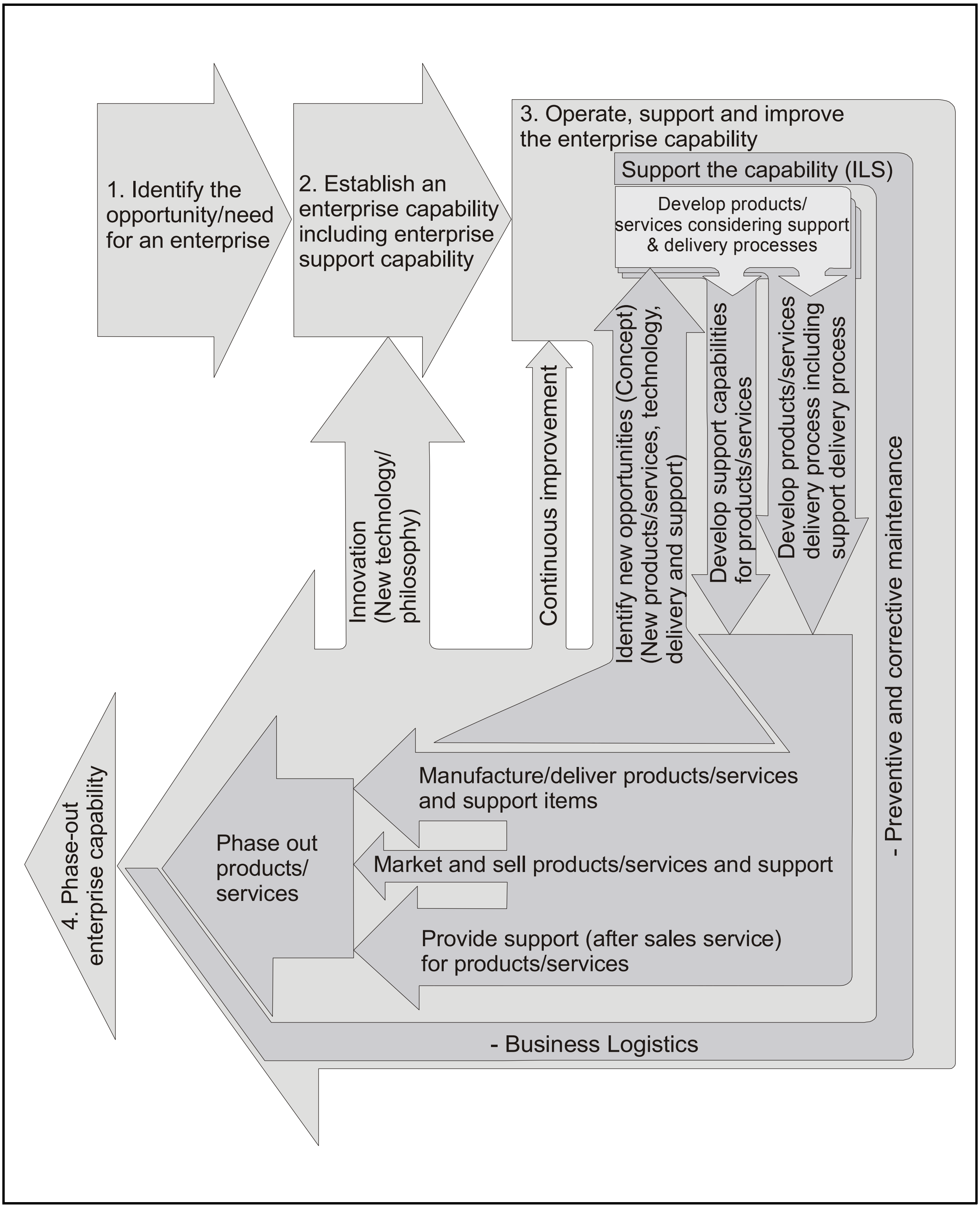



**Figure 6.6: The enterprise life-cycle**
Adapted from Rottier [1999:28]

The first function mentioned, namely support the capability, can only be successful if it was considered in an integrated way when the design of the organisation was done in the previous phase. In a similar way, the support provided for a product or service can only be done successfully if the support design is considered simultaneously with the product or service design.

It is also clear from this model that the third phase of the enterprise life-cycle, is taking products and/or services through their (similar) life-cycles of concept, design, build, operate and support, with phasing out the final life-cycle phase.

Continuous improvement efforts are required to improve the overall capability of the enterprise, while innovation (which may consist of new technologies or new philosophies) normally requires a major redesign of the enterprise capability that results in a step improvement of overall capability. This redesign may also require a relook at the support design, or support improvement may be the focus of a new innovation (e.g. lean thinking and JIT).

- *Phase out of enterprise capability.* This phase represents the end of an enterprise. As opposed to discontinuing a product or service, discontinuation of an enterprise is much more traumatic as it has an impact not only on the market and customers, but also on suppliers, employees and the socio-economic environment in which they operate. Enterprises come to the end of their life-cycles when continuous improvement efforts and/or innovation cannot improve their capability to a level where it can sustain the goal of the enterprise.

## 6.7 The larger system context - the supply chain

Even though the terms supply chain and supply chain management have become popular only recently, the concept was already defined by Porter [1985:34] at the end of the 1980's, calling it the value system (Figure 6.7). He states that " *a company's value chain for competing in a particular industry is embedded in a larger stream of activities that I term the value system. The value system includes suppliers, who provide inputs (such as raw* *materials, components, machinery, and purchased services) to the firm's value chain. On its way to the ultimate buyer, a firm's product often passes through the value chains ofdistribution channels. Ultimately, products become purchased inputs to the value chains of their buyers, who use the products in performing activities of their own"* [Porter, 1990:43].

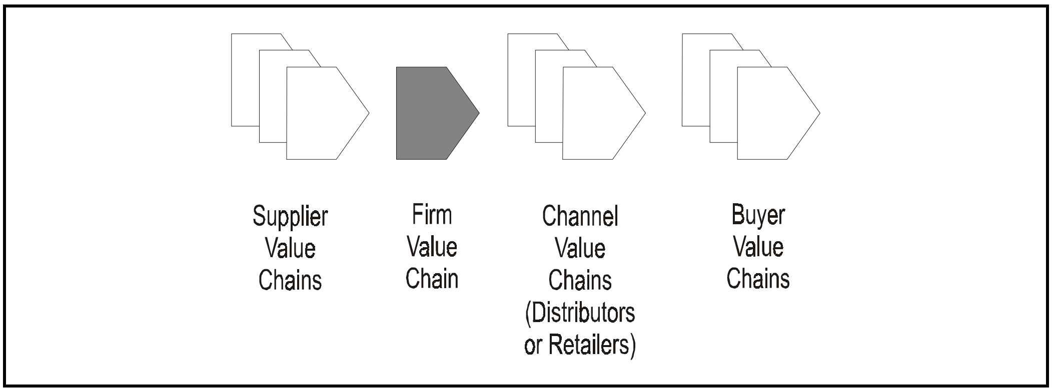



**Figure 6.7: Porter's value system**
[Porter, 1985:35]

What Porter calls the value system, is thus nothing else than the popular concept of the supply chain as it is known today. The importance of the supply chain cannot be overemphasised. Linking the value chain to the value system he states that *"gaining and sustaining competitive advantage depends on understanding not only the value chain but how the firm fits in with the overall value system"* [Porter, 1985:34]. To recognise the existence of, and the dependencies within the supply chain is important from two perspectives:

- The larger context must be considered when designing a system to ensure proper integration with the host system.
- Stuffing the supply chain will not lead to long term profitability of the organisation. Unless the final customer has bought, a sale has not been made. [Goldratt, 2000:223].

## 6.8 Chapter summary

Organisations exhibit many system characteristics. The major system characteristics proving that organisations indeed exist as systems are the following:

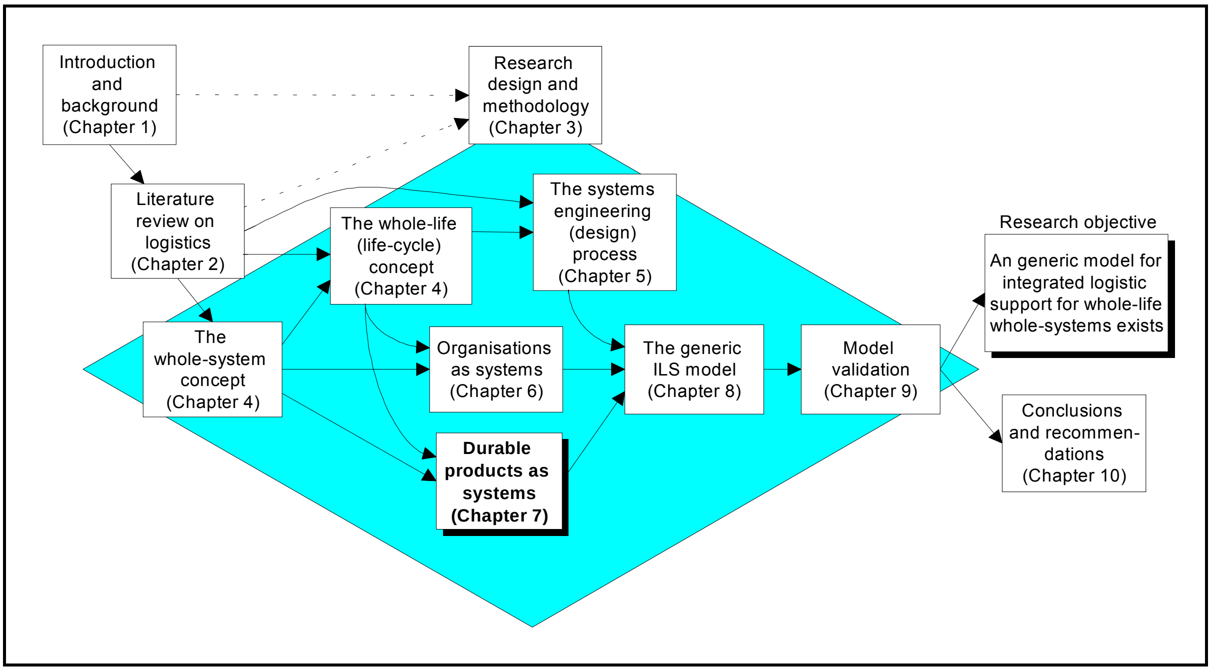
- Organisations are goal seeking which should be stated explicitly in their mission statements. The mission statements should be worded in such a way that the correct measurements can be derived in order to induce correct behaviour within the system.
- Organisations can use the generic system measurements of ability, availability and affordability to measure system performance i.e. achievement of the goal. Productivity is an ability measure that should be used on system level. If used on a local level, results may lead to an optimised sub-system but a sub-optimised system.
- Generic necessary conditions exist that defines the boundaries within which organisations exist and operate. These necessary conditions cannot be violated if the goal of the organisation is to be achieved.
- The necessary conditions dictate an approach to strategy formulation to ensure the best possible chance for the system to operate at it's full potential. The functional strategies and their sequence are:
  - The marketing strategy.
  - The operations and support strategy.
  - The organisational development strategy.
  - The financial strategy.
- Organisations act as systems of dependent variables both in interrelationships (the value chain), external relationships (supply chain) and time (life-cycle).

# Chapter 7

# Product systems

*"When customers make a purchase they buy more than just a product; they have expectations regarding the degree of after-sales support the product or service carries with it."*

Norman Blem [1995:39]




## 7.1 Purpose and outline of the chapter

The purpose of this chapter is to describe the concept of a product and how a durable product can be viewed as a system. It will also be shown how non-durable products and services interface with the higher level systems of which they are part. Knowing the system characteristics of products and services and how they interface with the higher level systems will allow understanding of how the product generates the need for support. This understanding is essential for the development of an integrated logistics support model applicable to the life-cycle of products and services.

The outline of the chapter is as follows:

- A definition for a product is provided that includes the customer's view of value.
- Different classifications of products are provided.
- Support relationships between products and the realisation systems are investigated.
- The notion that capacity is required to be able to deliver the support is introduced.
- Master planning as a tool to arrive at support capacity requirements is investigated.

## 7.2 Definition of a product

A formal definition for a product is provided by Kotler [1984:463]: *"A product is anything that can be offered to a market for attention, acquisition, use, or consumption that might satisfy a want or need. It includes physical objects, services, persons, places, organizations, and ideas."* At first it may seem strange to use one word, product, to describe both products and services, and using a definition from a not such a recent source. This approach to a product as being the offering to the market, is echoed by more recent publications as well [Schonberger & Knod, 1997:6; Chase, Aquilano & Jacobs, 2001:9].

Schonberger and Knod [1997:6] argues that goods and services form a continuum on a tangibility scale and that examples at either end of the continuum (a pure good or a pure service), are rare. Figure 7.1 shows a few examples on the tangibility scale.

A large number of commonalities between goods and services are listed by Schonberger and Knod [1997:6-7], but only two differences can be identified:

- *"Goods may be stored; services are consumed during delivery.*
- *Goods are transformed from other goods; in services, sometimes the clients themselves are transformed."*

**Highly tangible**

- Simple parts (screws, diodes, switches)
- Commodities (tobacco, iron ore, fruit)
- Simple finished goods (books, furniture, fabrics)
- Complex finished goods (motor cars, ships, missiles, organisations)
- Software (Computer programs, technical manuals)
- Designs of tangible goods (Engineering design, architecture)
- Performance (Catering, child care, training)
- Ideas (Consulting)

**Highly intangible**

**Figure 7.1: The tangibility scale**
Adapted from Schonberger & Knod [1997:330]

This fine line between goods and services, collectively labelled products, is further explained by Kotler [1984:463] in Figure 7.2 where the core, tangible and augmented product is shown. At the core of any product are the benefits that the customer seeks, as opposed to the features the goods or service may exhibit.

Schonberger and Knod [1997:13] take a more customer oriented approach to defining the wants of the customers, which must ultimately be translated into a product, in order to satisfy customer requirements. They define six generic requirements set by customers:

- High levels of quality.
- A high degree of flexibility.
- High levels of service.
- Low prices.
- Quick response or short lead times.
- Little or no variability.

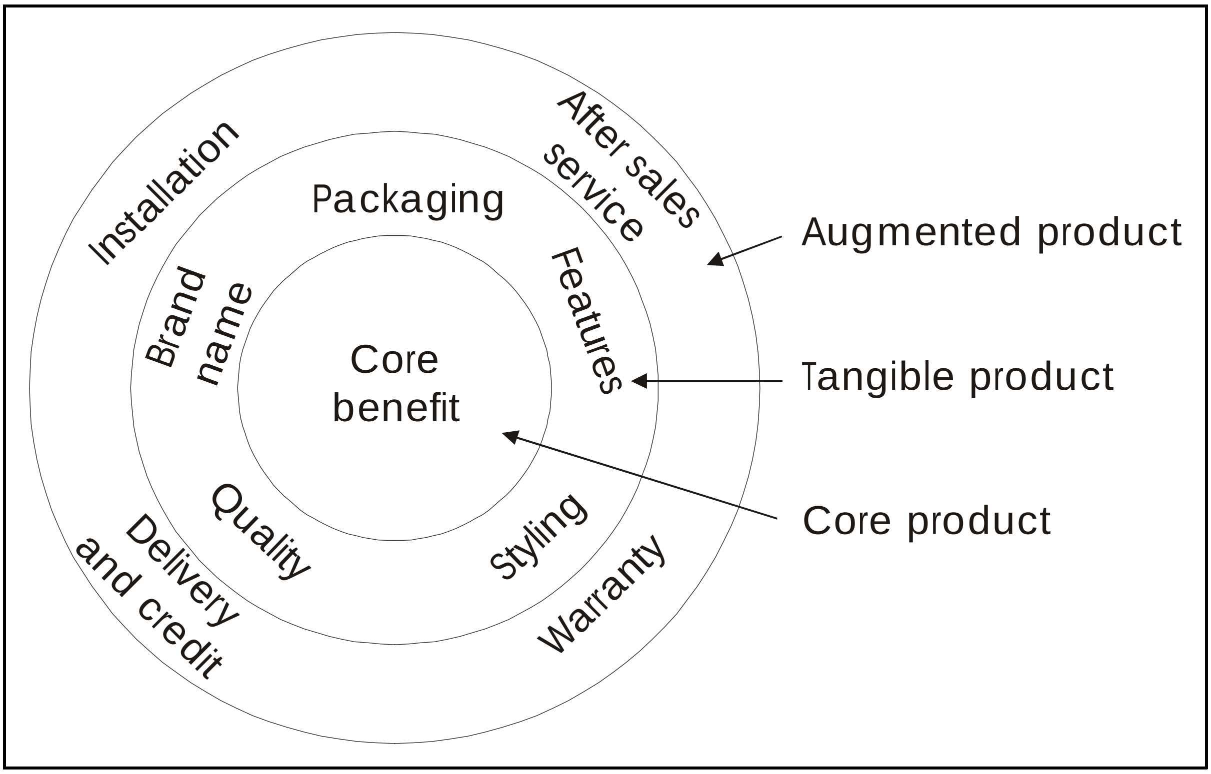



**Figure 7.2: Three levels of product**
Adapted form Kotler [1984:463]

These requirements are expressed by the customers as order qualifiers and order winners (See § 6.5). Also, the customer does not treat the requirements as a trade-off list. They expect all requirements to be met. Thus the customers view the obtaining and use of a product from a system perspective, because meeting the order qualifying requirements and exceeding the order winning requirements will create an emergent (system) property, namely customer satisfaction.

Kotler [1994:38] expands on this idea of value when he proposes a diagram which shows the determinants of customer delivered value (Figure 7.3). Customers prefer to buy from the company they perceive to deliver the highest customer value. It is thus clear that in order to be successful, the market satisfaction (one of the necessary conditions for achieving the goal - § 6.4) is dependent on creating products that meet the order qualifiers requirements and exceed the order winning requirements. It is also clear that the term product can be used to describe both goods and services.

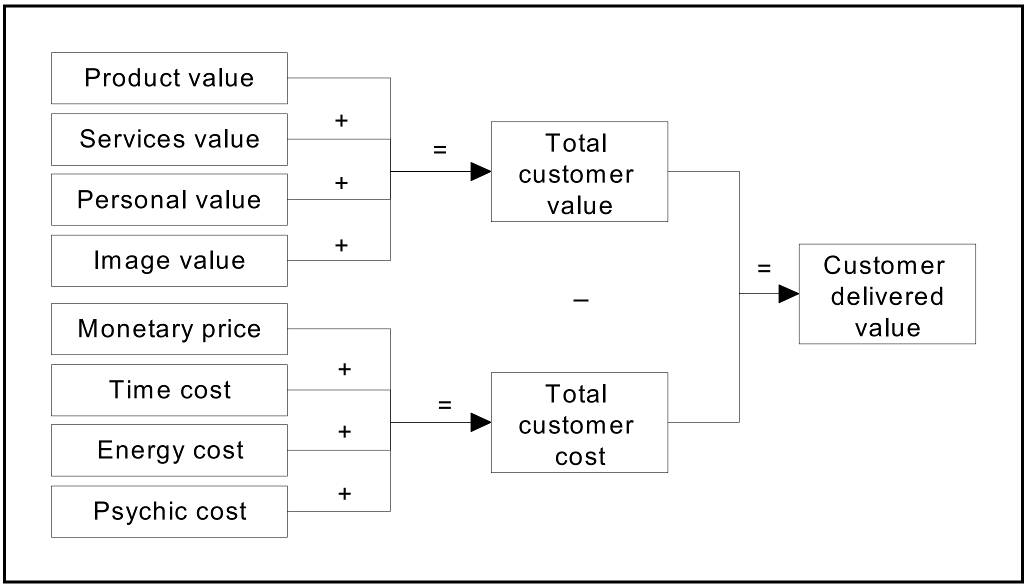



**Figure 7.3: Determinants of customer value**
Kotler [1994:38]

Comparing the views of Kotler, Schonberger and Knod to the generic system measurements of ability, availability and affordability, it is realised that they also use a system perspective to the customer view of a product. The comparison is shown in Table 7.1.

| **System measurement** | **Kotler's [1984:463] equivalent** | **Schonberger's [1997:13] equivalent** |
|---|---|---|
| Ability | Core benefit<br>Tangible product<br>• Features<br>• Quality<br>• Styling<br>• Brand name<br>• Packaging | High quality<br>High flexibility |
| Availability | Augmented product<br>• After sales service<br>• Installation<br>• Delivery and credit<br>• Warranty | High service levels<br>Short lead time<br>Little or no variability |
| Affordability | Total customer cost<br>[Kotler, 1994:38] | Low price |

**Table 7.1: Comparison of customer expectations and system measurements**

## 7.3 Classification of products

Several product-classification schemes have been defined to aid in understanding the characteristics of products in order to better satisfy customer requirements. These product characteristics (and thus the classification schemes) can be used to explain the relationships between a product and the associated support it needs to satisfy customer requirements of ability, availability and affordability.

### 7.3.1 Durability and tangibility classification of products

Kotler [1984:465] classifies products into the following three groups:

- Nondurable goods are tangible goods that are normally consumed relatively fast in one or a few uses. A characteristic of this type of good is that after sales service is normally limited to a toll free number where consumer enquiries and complaints are handled. A repeat purchase is normally based on a short term need and the fact that previous goods have been consumed.
- Durable goods are tangible goods that get used repetitively over a longer period of time. A repeat purchase of durable goods is based on the following factors:
  - Ultimate failure where it is not cost-effective to restore the capability once more i.e. cost of repair is more than the cost of replacement.
  - Unavailable support that makes restoring the capability impossible e.g. discontinued or unsupported product.
  - Introduction of a new technology that improves the ability, availability, affordability and/or the safety of the new product to such an extent that a new product is actively sought by the customer. The new technology may render the old product and its old technology obsolete. In such a case it is referred to as a disruptive technology [Christopher in Sheridan, 2000:8] e.g. computers and word processors replacing typewriters.
  - A perceived benefit that is subjective, e.g. buying a new car when it only provides the new owner with more status.

- Services are activities, benefits or satisfaction that are on offer by a company. Services are essentially intangible and does not result in the ownership of anything. It may or may not be tied to a physical product. It may also be viewed as the contact between the organisation and the customer, a service component that exists for every organisation. Field services are where the service provider goes to the customer and facility based services where the customer comes to the service provider [Chase *et al*, 2001:208].

### 7.3.2 Industry sector classification of products

Two broad industry categories are defined for the classification of products namely consumer goods and industrial goods. Each of these categories are further broken down into sub-categories.

- Consumer goods can be classified according to consumer shopping habits [Kotler, 1984:465-467]. The following categories exist:
  - Convenience goods are goods purchased on a regular basis without a lot of comparison to alternatives e.g. newspapers, toiletries and tobacco.
  - Shopping goods are goods where the customer compares alternatives based on the order qualifiers and order winners e.g. furniture, appliances.
  - Speciality goods is where the customer goes for unique characteristics and/or brand identification e.g. specific brands of fancy products.
  - Unsought goods are goods the customer does not know about e.g. new technology goods such as DVD and WAP devices. Alternatively the customer knows about it but does not normally think of buying e.g. life insurance and tax services.
- Industrial goods refer to those goods that are bought by organisations. Kotler [1984:467-469] classifies the industrial goods according to how they enter the production process and their costliness.
  - Materials and parts that are used or transformed in the transformation into the final product e.g. raw materials, manufactured materials/parts.
  - Capital items are normally used to execute transformation processes e.g. buildings and fixed equipment, as well as tools, operational and office equipment.

- Supplies are those goods that are used to operate and support the transformation process, but do not become part of the finished product e.g. operating supplies (lubricants, coal, computer supplies) and maintenance and repair items (spare parts for repair of capital equipment, cleaning material).
- Services are those products that get consumed internally e.g. business advisory services (legal, management consulting) and maintenance and repair services (overhauls, corrective maintenance and cleaning).

### 7.3.3 Hierarchy classification of products

As stated in Chapter 4, systems exist in a hierarchy. A systems hierarchy was proposed by Barnard [1987] in an internal document for Armscor, the South African Armaments Corporation. This systems hierarchy was proposed specifically for military systems. Barnard’s hierarchy was adapted by Rottier [1999:13] to show how the levels of the system’s hierarchy can be applied to goods systems, a human reference environment as well as in a service environment. The adapted hierarchy of systems is shown in Table 7.2.

From the table it is evident that the relationships between the examples of systems in the systems hierarchy are not very strong on the lower levels, maybe non-existent, but on the higher levels in the hierarchy, these systems tend to move closer together and become part of one another. It thus follows that the major system to system interaction takes place on system level 9, the level where a system can become self-sustained, perform as a realisation system and take responsibility for system outcomes. Products supplied by the realisation system can be delivered to a customer on any of the system levels. Generally speaking, anything supplied to level 4 and above can be classified as durable goods while anything supplied to level 3 and below will be classified as non-durable goods. Viewing it from the above perspective, raw materials used during production of non-durable and durable goods can be also be considered as non-durable  is consumed during the production/transformation process and does not exist in its original form after the production/transformation process has taken place.

| | System level | Military [Barnard] | Goods manufacturing sector [Rottier] | Services sector [Rottier] | Human reference [Rottier] | Durable goods |
|---|---|---|---|---|---|---|
| 12 | Multi national | Multi-national peace keeping force | Multi-national manufacturing corporation | Multi-national service corporation | Human race | International transportation system |
| 11 | National or Social system | National defence force | Manufacturing corporation part of country's economy | Service corporation part of country's economy | National population | National transportation system |
| 10 | Group of companies | Defence force arm | Manufacturing corporation in sector | Service corporation in sector | Societal grouping | Regional transport system |
| 9 | Self-sustaining system | Air transport wing | Manufacturing enterprise serving a market | Service enterprise serving a market | Human taking responsibility for self | Local transport system |
| 8 | User function operational capability | Transport aircraft with ground support | Car manufacturing capability | Operational division | Human | Family transportation capability |
| 7 | System | Transport aircraft | Body shop | Business systems | Blood circulation system | Motor car |
| 6 | Sub-system | Communica-tion sub-system | Robotic welding capability | Information system | Blood pumping capability | Propulsion capability |
| 5 | Equipment | HF radio | Robot | Computers, databases | Heart | Drive train |
| 4 | Assembly | PC board | Gearbox | Sub-routines | Heart valve | Gearbox |
| 3 | Components | IC | Gears, bearings, wheels | Code line | Tissue, bone, muscle | Gears, bearings, wheels |
| 2 | Materials | Silicone | Steel, plastic, ceramics | Data elements | Cells | Steel, plastic, ceramics |
| 1 | Natural resources | Ore | Ore, chemicals | Meta data | Water, chemicals | Ore, chemicals |

**Table 7.2: Examples of systems in the systems hierarchy**
Adapted from Rottier [1999:13] and Barnard [1987]

## 7.4 Support relationships between products and their realisation systems

Using the knowledge of the classification of products, it is easy to see the relationship between, for example the manufacturer of cars (the realisation system of the motor car) and the customer (human system) who owns and operates the motor car (the system of interest). Showing these relationships in Figure 7.4, the concept of a supply chain immediately comes to the fore.

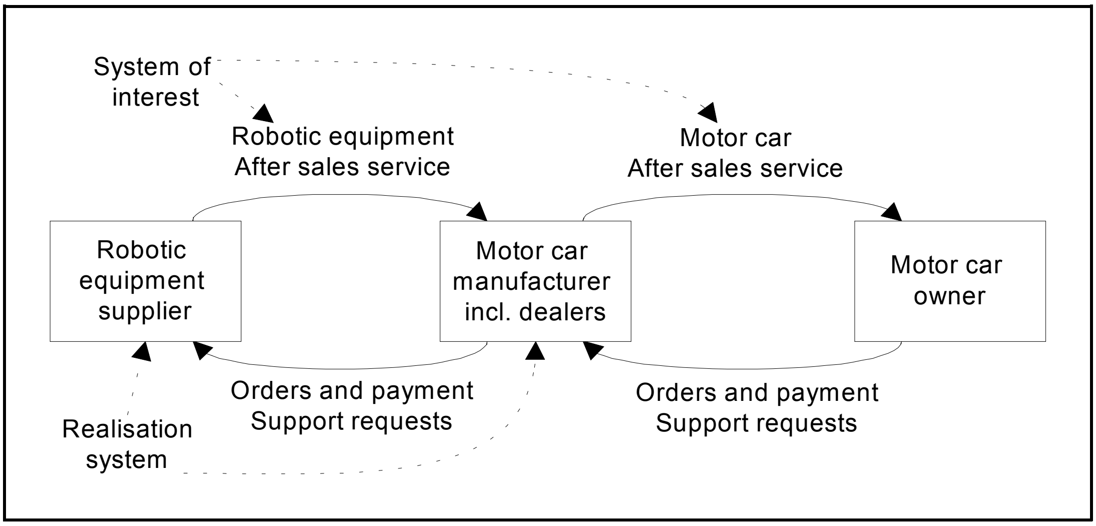



**Figure 7.4: System support relationships**

A further relationship exists between the manufacturer of the motor car and the supplier of the robotic equipment the motor car manufacturer uses. To the car manufacturer the robotic equipment is a durable product that needs to be operated and supported in the manufacturing of the car. The car manufacturer will buy support from the robotics supplier in the same way the owner of the car will buy support from the motor car manufacturer through its dealerships. Similarly, the owner of the car will buy non-durable goods (e.g. fuel) in order to be able to realise the benefits of owning the car.

From the above it is also clear that both the robotic equipment supplier and the motor car manufacturer operate in both the goods manufacturing sector in providing a durable system or product to their respective customers, as well as in the services sector in providing after sales support for the durable system each has supplied. It is also obvious that a supplier of consumables (non-durable products) to the motor car manufacturer (or the owner of the motor car) will not supply after sales service to the same extent as the robotic supplier, due to the nature of its product. After sales service will be limited to technical advice with regards to the use of the product and handling problems surrounding its use and making sure the non-durable item is available to the customer at the right place at the right time.

The more complex the product (or service) the more extensive the after sales service/support normally is. In both cases (supply of a durable product and the supply of a consumable product)  the organisation supplying the product is the realisation system, while in both cases the product delivered to the customer is the system of interest. In both cases the system of interest require after sales support from the realisation system, irrespective of whether it is a durable or a consumable product.

Table 7.3 provides some examples of support requirements for the different classifications of products. From the table it is obvious that a major part of the support of a product lies within the realisation system and/or the resource environment. If the support from the realisation system and/or the resource environment cease to exist, the product will most probably reach the end of its life-cycle.

The multiple dimensions of systems and the engineering of systems were introduced in § 5.4. The two distinct dimensions are the technical component or activities and the managerial component or activities. These components are as applicable to a product as it is to any other system and have to be considered for all products that will allow the product to meet all dimensions of the customer expectations. As indicated in Table 7.3, all the support activities (both managerial and technical), are necessary for the product to be able to meet customer requirements and expectations as expressed in Table 7.1.

| | Product example | Support required for | Typical technical support activities | Typical support management activities |
|---|---|---|---|---|
| Durable product | Motor car | Durable product | Providing spares and consumables, preventive and corrective maintenance, customer training, technical data | Spare location and quantities, after sales service location, skill levels required |
| | | Distribution system | Warehousing, preventive and corrective maintenance of transportation | Distribution system management, inventory management |
| | | Production system | Production equipment maintenance spares, preventive and corrective maintenance of production equipment | Maintenance spares inventory management, maintenance management, supply management |
| Consumable product | Fuel | Distribution system | Warehousing, preventive and corrective maintenance of transportation | Distribution system management, inventory management |
| | | Production system | Production equipment maintenance spares, preventive and corrective maintenance of production equipment | Maintenance spares inventory management, maintenance management, supply management |
| Facility based service | Car wash | Service delivery system | Service requirement consumables and spares, service equipment maintenance spares, preventive and corrective maintenance of service equipment | Service requirement, consumables and maintenance spares inventory management, maintenance management, supply management |
| Field service | Car service at customer's home | Distribution system | Warehousing, preventive and corrective maintenance of transportation | Distribution system management, inventory management |
| | | Service delivery system | Service requirement consumables and spares, service equipment maintenance spares, preventive and corrective maintenance of service equipment | Service requirement, consumables and maintenance spares inventory management, maintenance management, supply management |

**Table 7.3: Example support requirements**

## 7.5 Capacity required to support the product system

Chase, Aquilano and Jacobs [2001:217] define the line of visibility as the dividing line between those activities the customer can see and those activities that he does not see. For an organisation to provide the product or service and to support its product or service many activities are required that the customer does not see. These activities relate primarily to making sure that the right capacity is available at the right time at the right place.

Capacity refers to a provider's capability of performing transformation activities of goods and services demanded by the customer [Schonberger and Knod, 1997:228]. Transformation can take place as reshaping, conversion, fabrication, and assembly of material, but transformation can also take the form of storage or a change in the location of material. Transformation can also be changing the state of a system e.g. restoring the capability of a system through corrective maintenance after the system has failed [Chase *et al*, 2001:8-9]. Thus capacity consists of many different elements all of which must be present to be able to deliver the output (products, services and support) required through the transformation activities. Having capacity is thus an emergent property of the realisation system's elements working together.

Transformation can be presented very simply as input-process-output supported by elements within this model needs to be integrated to achieve the desired output (Figure 7.5). Starting with the output, the processing (transformation) needs are determined. Once these needs have been established, the resource needs (inputs) can be defined. The management component entails the planning, organising, directing and control of the activities necessary to get the inputs and perform the transformation to deliver the outputs. A major element of management is to establish sound policies for decision making within the transformation process to ensure the achievement of organisational goals. The technical and management dimensions are again very obvious in this model.

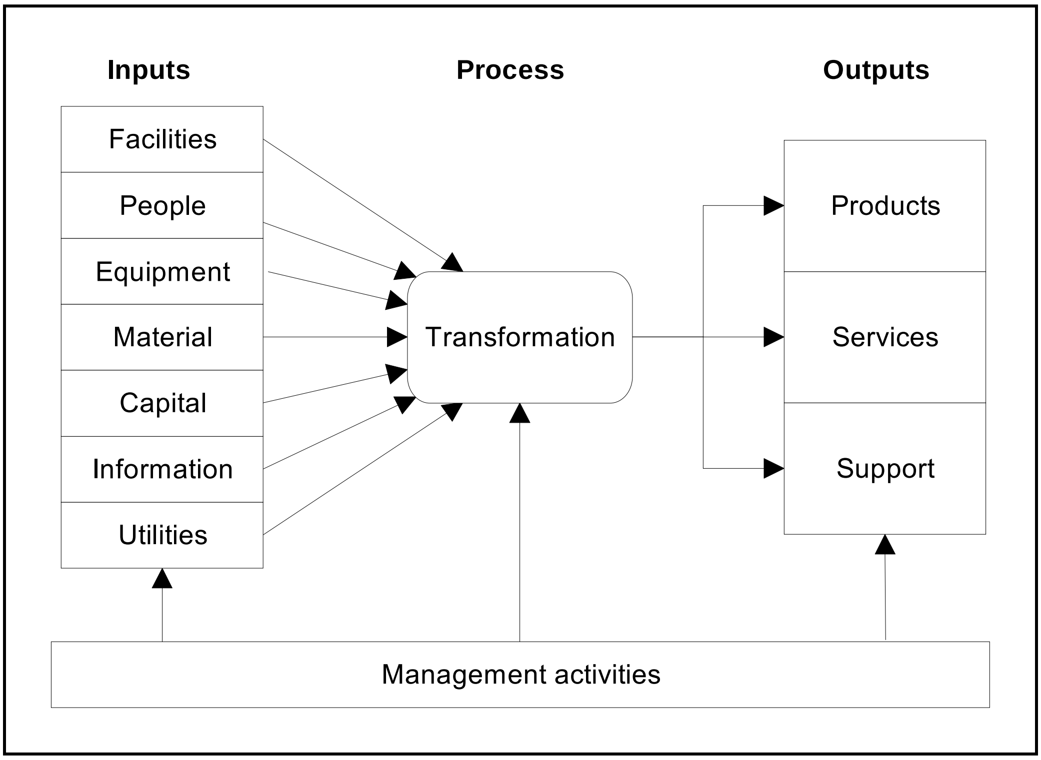



**Figure 7.5: Input-Process-Output model**
Adapted from Schonberger and Knod [1997:6]

## 7.6 Master planning as a tool to arrive at support capacity requirements

Master planning is the natural consequence of the input - process - output model applied to the realisation system providing the product, service and support. Master planning is done to ensure that demand and supply meet. Master planning consists of demand management, capacity planning and master scheduling. Master planning has as its aim to balance all demand from all sources of demand to ensure that sufficient capacity exists within the organisation to meet the product demand within the specified long, medium and short term time frames. Doing master planning within the realisation system allows the product delivered to the customer, to exist as a system meeting ability, availability and affordability requirements. Without master planning the customer will not be able to derive system benefits from the product or service provided.

### 7.6.1 Output and support demand management

Demand management has as its purpose to consider all sources of demand to establish and influence the output requirements of products, services and support over the long-, medium- and short term [Chase *et al*, 2001:434]. Different time horisons are included in demand management for different reasons [Schonberger and Knod, 1997:179-180]:

- Long term demand management is used to provide information for the business plan to ensure sustained long term profitability.
- Medium term demand management is used to provide information to obtain resources to meet the medium term aggregate demand.
- Short term demand is aimed at providing information of what output is to be supplied, when and in what quantities.

Two main input sources are used for demand management, namely forecasts and actual orders. Naturally master planning becomes much easier and the outcome more predictable and exact if one can work only on actual orders as opposed to forecasts. Performing demand management with actual orders is far more accurate than working with forecasts due to far less uncertainty present in actual orders than in forecasts.

Demand management is concerned only with independent demand. Independent demand is defined as the demand for the output of the organisation which cannot be derived directly from the demand for other products or influences e.g. the sales of motor cars. Even though external influences such as the interest rate may influence the quantity of demand, it cannot be calculated directly what the effect of a 1% interest rate increase will be on the demand for new cars. Dependent demand on the other hand is the material requirements calculated from the independent demand and is not included in demand management. An example is the demand for tyres in motor car production; for every one car to be produced and sold (independent demand), five tyres (dependent demand) will be needed. However, certain dependent demand items may also exhibit independent demand characteristics. If the organisation producing cars also sell tyres as a spare part the spare part demand will also be an independent demand and needs to be included in the demand management. The relationship between dependent and independent demand is normally documented in a bill of material (BOM) as the quantity per next higher assembly (Qty/NHA) and is commonly used in the goods manufacturing environment to calculate quantities of dependent demand items needed.

The application of demand management to the support environment entails the consideration of all orders and forecasts for support services in the case where such services are on offer to the market e.g. after sales service of the durable product in the form of preventive and corrective maintenance. The other support demands (those that are not sold to the customer *per se* but are required for the continuance of the product or service delivery to the market) must also be planned for, but can be done only after the first loading of the master schedule. (Also see § 7.6.2 and Figure 7.7). This additional support demand takes the form of operational requirements and distribution demand, as well as demand for preventive and corrective maintenance of production, service delivery and transportation systems. As with the case of output demand management, support demand management also come in the form of orders and forecasts. Operational requirements and preventive maintenance are the equivalent of an order (little uncertainty about the requirements) whereas corrective maintenance is similar to a forecast.

### 7.6.2 Output and support capacity planning

Once demand management is in place, information is available to make long, medium and short term capacity planning decisions. Mention was made in § 7.5 of the capacity elements required for transformations of input into output. These capacity elements required for transformations (and thus capacity) are:

- Facilities (e.g. buildings, warehouses and land).
- People skilled and trained to perform what is required of them.
- Equipment (e.g. machines and trucks).
- Material (e.g. raw material, spare parts and consumables).
- Capital to buy the required capacity and operate it on a continuous basis.
- Information of what to do, when to do it and how to do it.
- Utilities (e.g. electricity, water, steam and communication).

Different time scales apply to different capacity element decisions. Long term demand information is used to do strategic capacity planning as long term investments are based on long term trends. Overall strategic capacity changes (increase or decrease) are based on the long term demand information and is normally associated with facility, capital, location, new product range and process selection decisions. Medium term demand information is used to establish the capacity need for obtaining people and their training, equipment, longer term material supply contracts, inventory levels and location, as well as process design, commissioning and maintenance of the production capability. Short term demand information is used to establish the capacity needed for the volume and timing of output to be supplied, and considers capacity unavailability due to planned (preventive) maintenance. Allowance is to be made for unavailability of capacity or downtime due to unplanned (corrective) maintenance. Short term demand is planned in the master schedule and must consider available short term capacity to ensure that the master schedule is not overstated. Overstatement of the master schedule implies overloading of the existing capacity resulting in not meeting the output volume and timing requirements. Setting up the master schedule is discussed in more detail in § 7.6.3. Figure 7.6 shows the relationships between demand management and capacity planning. The financial planning interface is shown for completeness.

The dependent demand calculation discussed in the § 7.6.2 need not be limited only to the material required. The relationship between independent and dependent demand items and other capacity resources, including support resources, can also be defined, resulting in a capacity plan for all capacity elements in the short, medium and long term.

From Figure 7.6 the interfaces between the output or market demand management and capacity can be clearly seen. It is however not so clear exactly how the support demand is generated and how it interfaces with capacity planning. The driving force behind demand management is and will always be the market demand in the form of orders and forecasts. The orders and forecasts serve as an input to do the first round of setting up the master schedule considering available capacity. This loading will place a certain production load on the available capacity. The volume and timing requirements of the master schedule will serve as an input to do the production requirements planning in order to meet the master schedule.

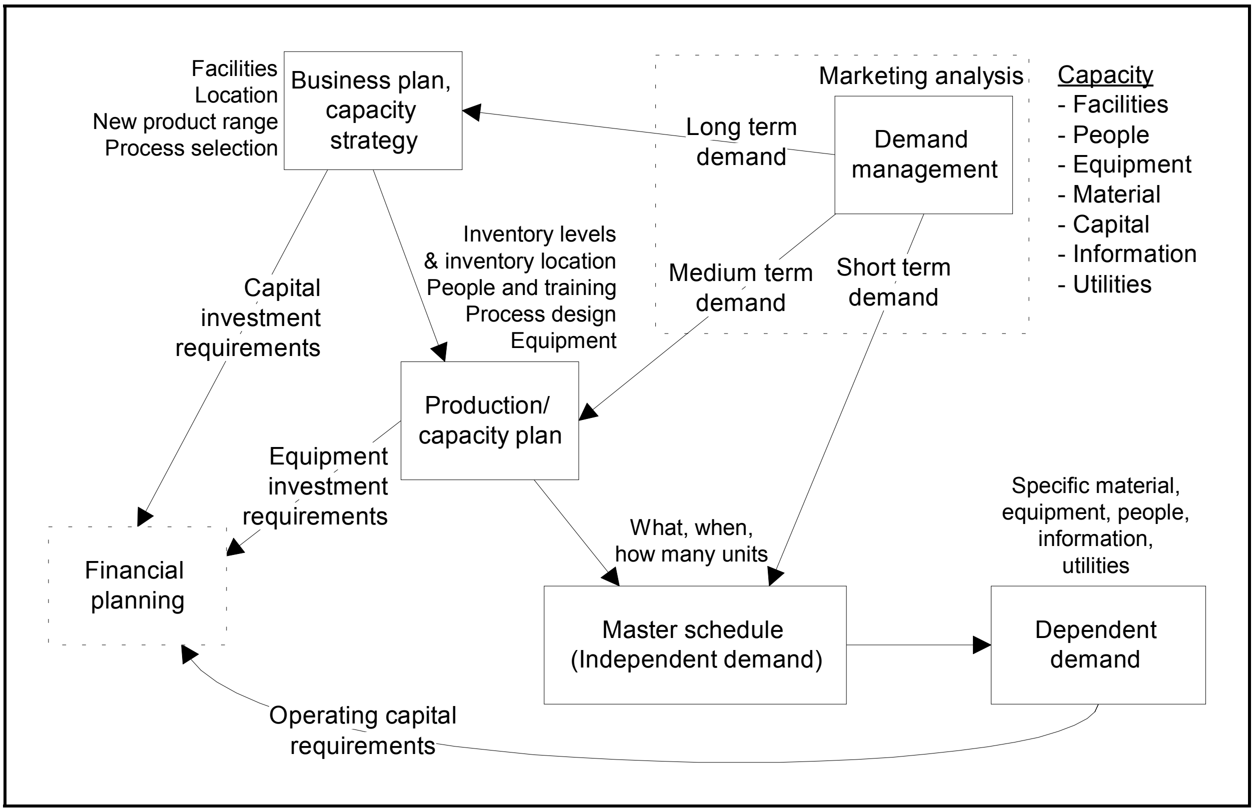



**Figure 7.6: The interface between demand management and capacity planning**

The input required may include capacity load implications such as setup times and additional quality checks. The output planned will require distribution which implies a load on the distribution capacity. The production and distribution requirements will imply the deterioration of production and distribution equipment used (failures and potential failures) that necessitates preventive and corrective maintenance (PM and CM). Preventive and corrective maintenance requirements along with the production and distribution requirements are then analysed as part of the support demand management to determine an aggregate support capacity load. This support demand management is part of traditional operations and maintenance management. The support capacity load is then fed back into the capacity planning system which may influence the master schedule. It is thus an iterative cycle between demand management and capacity planning until a viable master schedule can be achieved. The iterative process of balancing supply with demand is shown in Figure 7.7.

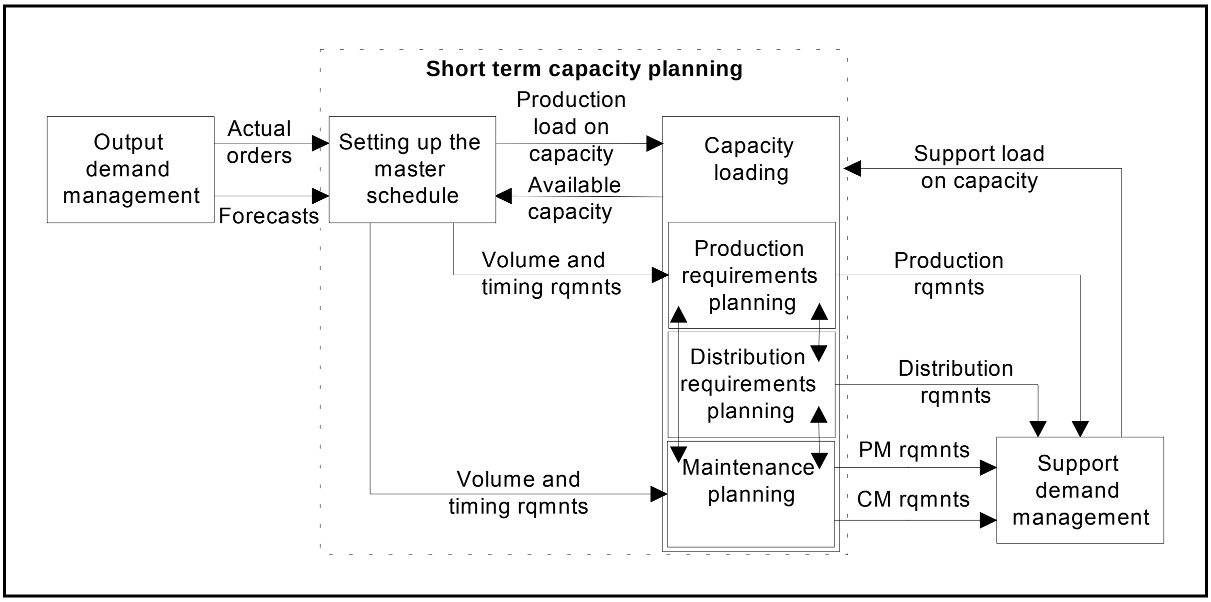



**Figure 7.7: Support demand management interfaces**

### 7.6.3 Setting up the master schedule

The master schedule is an achievable end-item plan of what should be produced, when and in what quantities, and is at least as long as the cumulative lead time. Only independent demand items are included on the master schedule. Dependent demand is calculated. The master schedule attempts to match supply with demand. The demand side consists of two components, namely actual orders and short term forecasts. The supply side consists of the actual master schedule, i.e. the specific quantities planned for a specific time slot based on forecasts and actual orders, quantity on hand (if stock can be kept) and quantity available to promise (ATP). The demand time fence is the time within which changes to the quantities of the master schedule or the design are not desirable or acceptable as any changes may cause the master schedule to become invalid as it may be impossible to adjust the capacity necessary to handle the changes and still meet the due date. An example of a master schedule is shown in Table 7.4.

| Time bucket | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| Supply | Sales forecast | | 60 | 70 | 60 | 65 | 70 | 50 | 50 |
| | Actual orders | | 40 | 30 | 20 | 10 | 7 | 5 | 3 |
| Demand | Master schedule | | 100 | | 100 | | 100 | | |
| | Available to promise | | 30 | | 70 | | 85 | | |
| | On hand | 20 | 80 | 50 | 90 | 25 | 55 | 5 | -45 |

Demand time fence (DTF)

Available to promise = Master schedule - Actual orders up to next MS entry

On hand = Opening stock + Master schedule - Actual orders (within DTF)

On hand = Previous on hand + Master schedule - Sales forecast (outside DTF)

**Table 7.4: Master schedule example**

The development of the master schedule as shown in Figure 7.8 entails considering the production/capacity plan which is a statement of the medium term demand, the short term forecasts and the capacity requirements set by the dependent demand such as setup times. The capacity support requirements (preventive and corrective maintenance allowances) are also considered. Whenever a new short term demand arises in the form of an order, the master schedule is checked to see whether the demand can be filled by selling from stock (the quantity on hand is more than zero). If the order can be filled from stock, the master schedule is updated (quantity on hand) and the product delivered to the customer. If stock is not available, the master schedule is checked for stock available to promise in a future time bucket. If delivery is possible in a future time bucket, the master schedule is updated (actual orders) and the promise is made to the customer when delivery will take place. If there is none available to promise, it implies that the actual orders (demand) now exceed what has been planned to supply. This requires an update to an existing master schedule entry or a new entry on the master schedule line. Once the new entry has been placed on the master schedule line, a check must be done to see the amount of capacity is required and whether the order can be executed with the available capacity in that time bucket. If the newly placed master schedule is not realistic, the master schedule of the new order must be placed later or priorities of existing orders be changed. The process of checking whether the master schedule is realistic is repeated until the

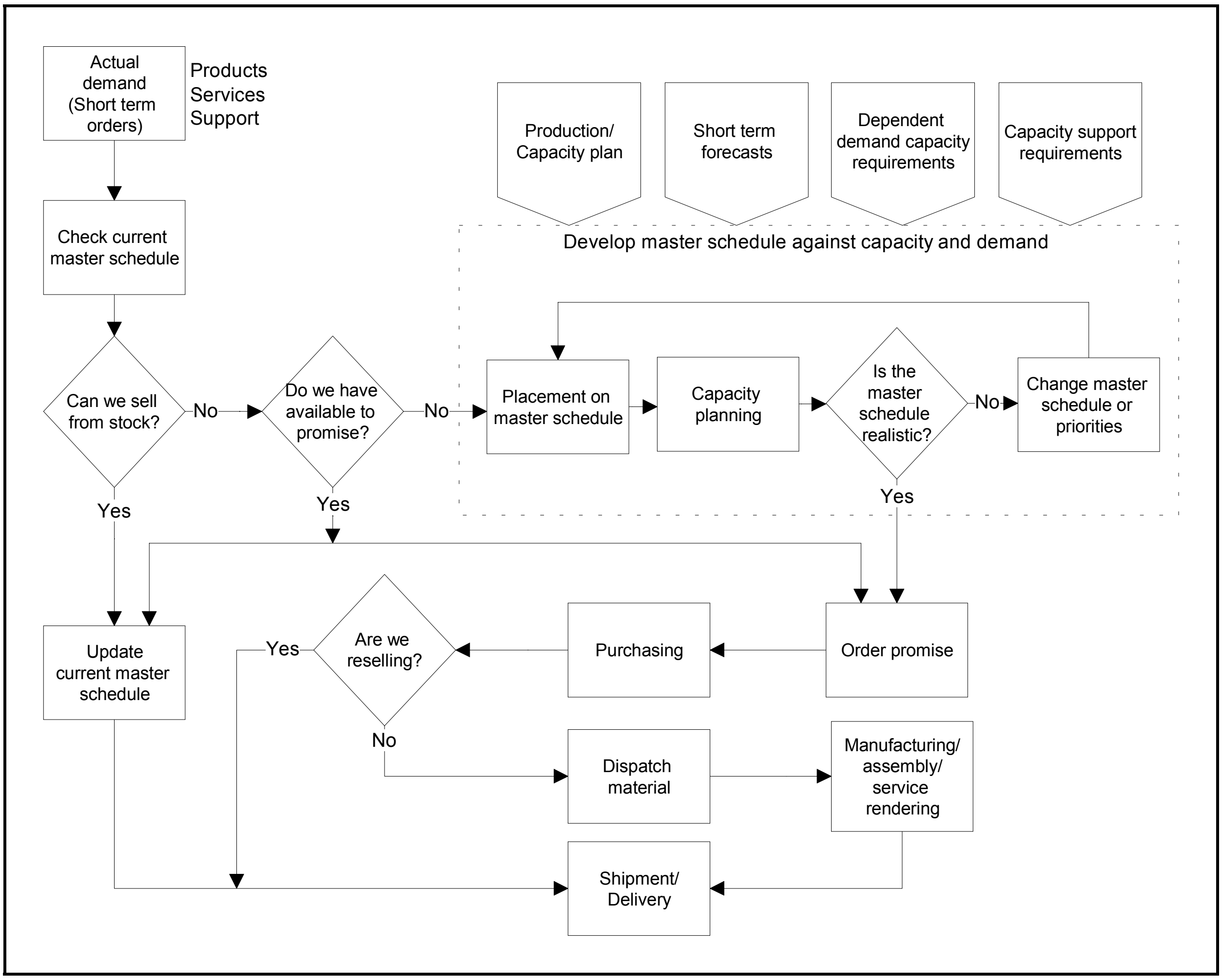



**Figure 7.8: Master schedule development and execution**

master schedule is achievable. Only then can the order promise be made. The master schedule continuously drive the purchasing of materials and consumables, the scheduling of processes and other resources to transform the input into outputs in order to finally deliver the output to the customer. It is obvious that if the support load on the capacity (dependent demand capacity requirements and capacity support requirements) are ignored, it will not be possible to set up an achievable master schedule.

## 7.7 Chapter summary

Products (a collective term to describe goods and services) are the output of an organisation in exchange for a reward which allows the organisation to achieve its objectives. Customers expect to experience value in buying the product in order for their needs to be fulfilled. Irrespective of the nature of the product (durable, consumable or service), or where the product fits in the hierarchy of systems, customers have multi-dimensional expectations which can be translated to the ability, availability and affordability of the product in meeting their requirements.

In order for the organisation to meet the multi-dimensional nature of customer expectations, capacity is required to transform inputs into outputs. The capacity requirements for support derived from the actual market requirement can be categorised as follows:

- The direct after sales service and support that is part of the market demand where the customer is willing to pay for it (normally after sales service and support for durable products).
- Production system support required to have the right inputs at the right time.
- Distribution system support required to have the output at the right place at the right time.
- Distribution system support due to ageing and deterioration of equipment used for distribution of outputs (preventive and corrective maintenance).
- Production system support due to ageing and deterioration of equipment used to transform inputs into outputs (preventive and corrective maintenance).

These dimensions of support can be categorised as support for the product itself and support for the systems that produce and deliver the product. Thus the nature of the product (durable, consumable or service) does not determine whether support is required, but which activities are associated with the product to keep the customer satisfied. These activities are, as for any system, divided into management and technical activities.

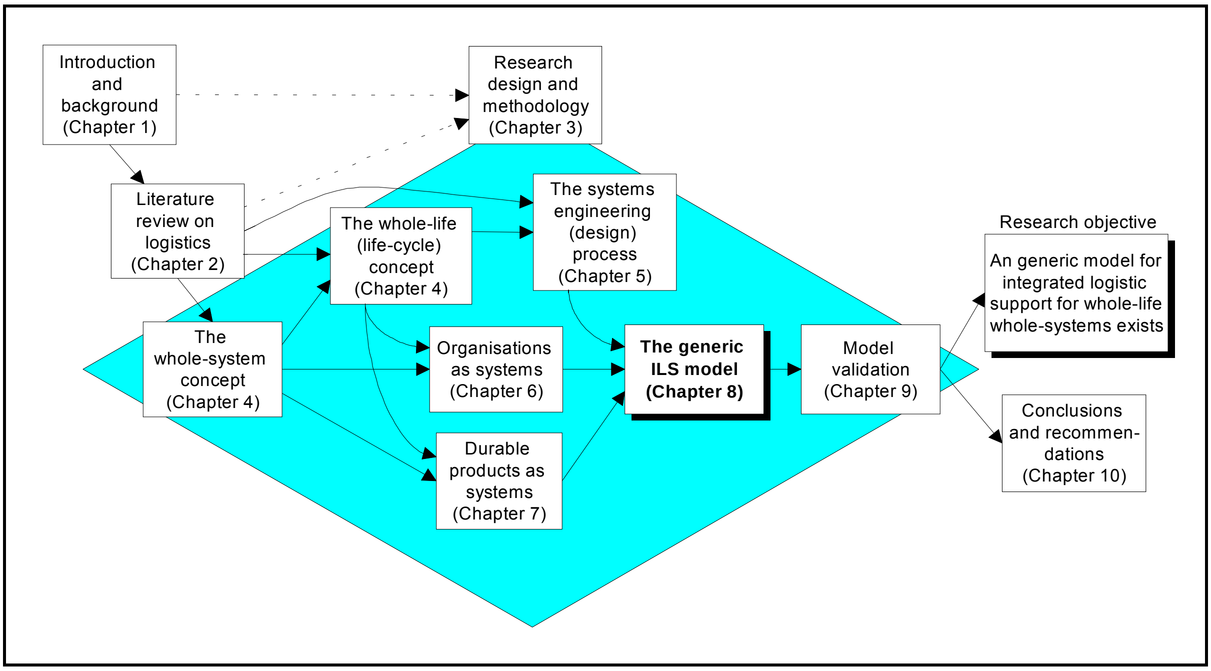
# Chapter 8

# A generic integrated logistic support model for whole-life whole-systems

*"... a perfect method should not only be an efficient one, as respects to the accomplishment of the objects for which it was designed, but should in all its parts and process manifest a certain unity and harmony."*

George Boole in Pretorius [1991:i]

Nineteenth century scientist




## 8.1 Purpose and outline of the chapter

The purpose of this chapter is to present the model that explains the generic approach to integrated logistic support for whole-life whole-systems. The chapter starts by stating the requirements for a generic approach to integrated logistic support for whole-life whole-systems, based on the knowledge gained in the preceding chapters. The two life-cycle dimensions, namely logistics engineering and operational logistics are introduced as the two major life-cycle activities relating to the integrated logistic support of a system. Each dimension is discussed with regards to definition, as well as their respective technical and management activities in relation to the life-cycle phases. Logistics engineering and operational logistics are then integrated into one life-cycle model for a whole-system. The integrated model with all its interfaces will be discussed. The model is then verified to ensure that all the requirements stated in § 8.2 have been met.

## 8.2 The requirements for a generic model for integrated logistic support

In the preceding chapters the reader was introduced to system concepts, the life-cycle concept, the systems engineering process and how organisations and products exhibit system characteristics. From these concepts one can derive the requirements for successful integrated logistic support for an organisation and/or products. These requirements were the main findings of the preceding chapters and will be used to measure the validity of the model. The requirements can be summarised as follows:

- It must view the whole-system and the interfaces with its environment.
- It must view the system over its entire life-cycle.
- It must allow for the iteration of ideas to achieve an optimum system design.
- It must consider the operational environment when the conceptual design is started.
- The systems engineering process must be continued throughout the life of the system until phase-out.
- It must view both the technical and managerial logistic processes related to the system.
- It must be valid for any type of man-made system.

## 8.3 Broad outline of the model

Before the model is presented in detail, a broad outline is provided in the form of a roadmap to allow the reader to put each part of the model in the context of the bigger picture. The roadmap to the components of the model is presented in Figure 8.1. Each component has a reference to the paragraph in which it is presented.

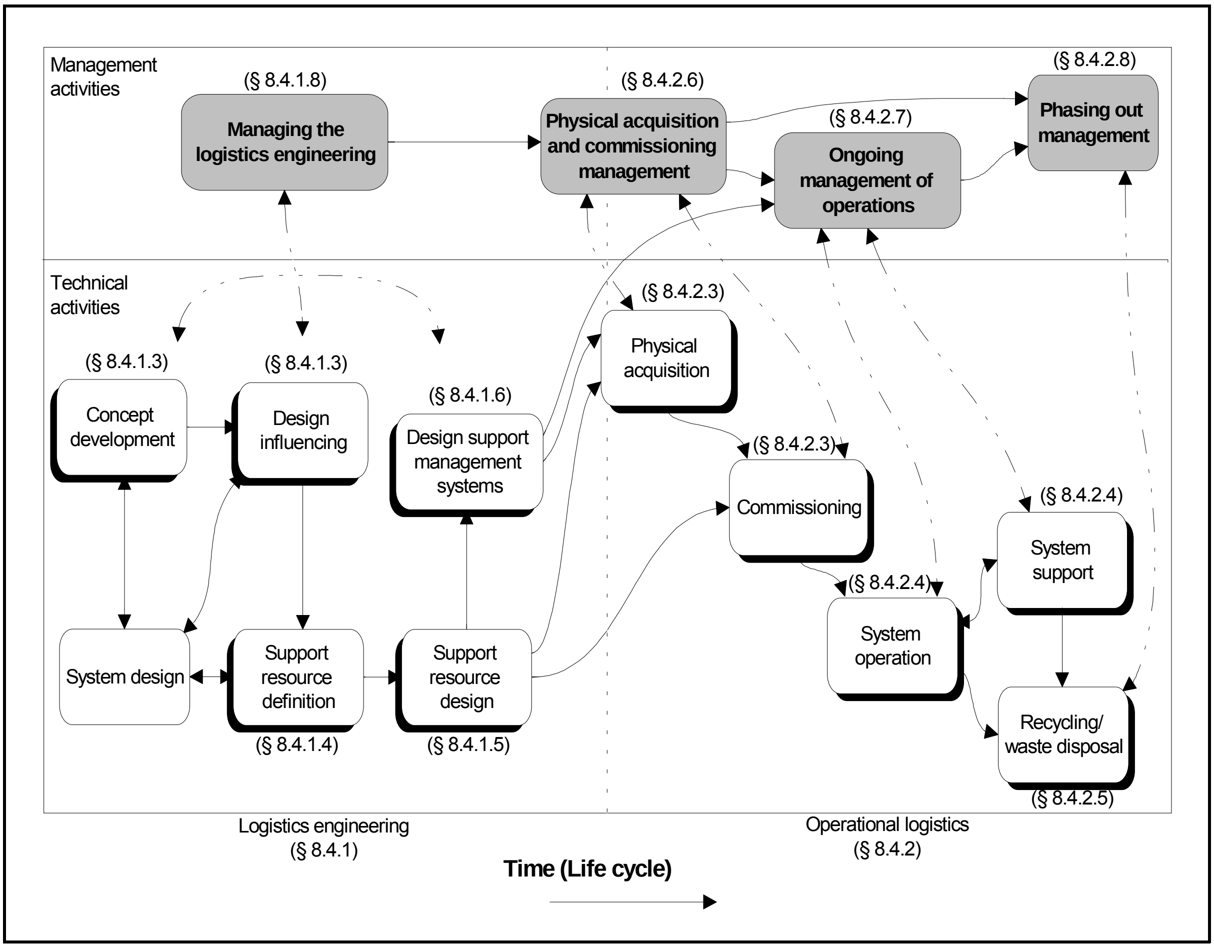



**Figure 8.1: Outline of the proposed model for integrated logistic support for whole-life whole-systems**

On the horisontal axis the life-cycle is presented. The life-cycle is divided into two distinct parts (the split is shown as a vertical dotted line) namely the acquisition phase where the logistics engineering activities take place) and the operational phase (where the operational logistic activities take place). Each phase is split into two types of activities on the vertical axis (the split is shown as a horisontal solid line) namely the management activities (shaded activities) and the technical activities (white activities) associated with each phase. Within each quadrant the main activities and process dependencies which are required for the approach to integrated logistic support for whole-life whole-systems are shown. Arrows on solid lines indicate process sequence and interaction while arrows on dotted lines indicate management activity interfaces with the technical activities.

## 8.4 The dimensions of the integrated logistic support model

The foundation for the integrated logistic support model is a definition that was gleaned from the US defence sector and subsequently modified. This definition was selected for the following reasons:

- It has a systems approach as it specifically addresses systems.
- It allows for iteration of ideas in line with the systems engineering process.
- It specifically cover both technical and management activities.
- It has a life-cycle approach in that each of its objectives are associated with a major system life-cycle phase.

The definition [adapted from Integrated Logistic Support Guide in Blanchard, 1998:3] for integrated logistic support is the following:

A disciplined, unified and iterative approach to the management and technical activities necessary to:

- Integrate support considerations into system and equipment design.
- Develop support requirements that are related consistently to readiness objectives, to design, and to each other.
- Acquire the required support.
- Provide the required support during the operational phase to ensure ability, availability and affordability of the system of interest.

The original definition has been changed very little. The change relates to the last bullet of the definition, which originally read: ”provide the required support during the operational phase at minimum cost.” The reason for the change is that it will be difficult to optimise (minimise) the system cost during the operational phase because the operational and support costs of the system has already been determined during the design phase of the system. Also, the purpose of the support is not only affordability (which relates to cost), but to provide the best possible combination of the system performance characteristics, which are ability, availability and affordability. Naturally the highest levels of safety are to be maintained at all times. In any case, minimum cost can only be achieved where the system is not operated thus defeating the original purpose of the system.

Some words in the definition needs to be clarified. *Disciplined* refers to an approach that requires skill, commitment and control. *Unified* refers to the integrative nature of the approach where integration needs to take place between the support and the system of interest of which it is part, between the different support elements as well as between the support system and the host system. *Iterative* refers to the multi-dimensional interactions that are considered repetitively until a satisfactory solution is found, as well as the repetition of the process into more detail on the lower levels of the system hierarchy.

In § 4.7 a comparison was made of the life-cycle ideas from Blanchard, Covey and M'Pherson (See Figure 4.5). Two major phases of the life-cycle have been defined, namely the acquisition and utilisation phases of the system. Thus the integrated logistic support definition is also split in two to cater for logistics engineering, primarily taking place in the acquisition phase and operational logistics, primarily taking place in the utilisation phase.

### 8.4.1 Logistics engineering

#### 8.4.1.1 Terminology

Before a definition is supplied, a choice must be made whether to use the term logistics engineering or engineering logistics. This can only be done when the intended meaning of the term is understood. The word logistics is the term that describes the overall support required for successful life-cycle operation of system and its associated parts (a noun). The word engineering can be interpreted in two different ways. Firstly it can denote a professional discipline (a noun) and secondly it can denote the ability to contrive or bring about change (verb). If these two words are combined as engineering logistics, it leaves room for misinterpretation if both are viewed as nouns. This will denote a part of logistics that belongs to the engineering fraternity, which is an obvious fallacy. However, using engineering as a verb and logistics as a noun will convey the essence of the phrase, namely 'bringing about or bring into being the support system'. Using the term logistics engineering as opposed to engineering logistics conveys the intended meaning without so much room for misinterpretation and is thus the preferred term.

### 8.4.1.2 Logistics engineering defined

Blanchard [1998:23] defines logistics engineering as the *"...basic design-related functions, implemented as necessary to meet the objectives of ILS. This may include:*

- *The initial definition of system support requirements (as part of the requirements analysis task in systems engineering).*
- *The development of criteria as an input to the design of not only those mission related elements of the system but for the support infrastructure as well (input into design and procurement specifications).*
- *The ongoing evaluation of alternative design configurations through the accomplishment of trade-off studies, design optimisation, and formal design review (i.e., the day to day design integration tasks pertaining to system supportability).*
- *The determination of the resource requirements for the support based on a given design configuration (i.e., personnel quantities and skill levels, spare and repair parts, test and support equipment, facilities, transportation, data, and computer resources).*
- *The ongoing assessment of the overall support infrastructure with the objective of continuous improvement through the iterative process of measurement, evaluation, and recommendations for enhancement (i.e., the data collection, evaluation, and process improvement capability)."*

What lacks in this definition is focus on the management of the logistics engineering process, as well as the design activity of the management system to ensure the effective management of the resource requirements once the operational phase is entered. Considering the shortcomings mentioned as well as the adapted definition for integrated logistic support, logistics engineering can thus be defined as the management and technical activities necessary to:

- Integrate support considerations into system and equipment design.
- Identify and detail the support requirements of the system.
- Design the support system and support resources.
- Design the management system of the support system.

The above are required to ensure the ability, availability and affordability of the system during the operational phase, without compromising the safety of the system.

This definition for logistics engineering forms the first building block of the model for integrated logistic support. From the above definition it is clear that the technical dimension of logistics engineering consists of four categories. They are design influencing (including the establishment of the operations and support concepts), identification and detailing of the support resources, the design of the support resources and the design of the support management system. The management dimension of logistics engineering consists of managing of the four technical activity categories.

#### 8.4.1.3 Design influencing

Design influence is the first technical objective of logistics engineering. Design influencing aims to improve the design very early in the design phase (refer to Figure 5.7) when the cost of change and improvement is at its least. The philosophy of design influencing is to improve the design characteristics in such a way that less of the support elements are required. When less support elements are required, it automatically reduces the extent and complexity of the logistic support management system. Less support elements will also reduce the life-cycle cost of the system. To be able to influence the design, the characteristics of the logistic environment and the logistic characteristics of the design have to be understood. This allows for the improvement of the design with respect to ability, availability and affordability. Safety, concern for the environment and manufacturability are also included in influencing the design.

It is thus clear that before design influencing can be done, an understanding of the host system and the host system environment in which the new system will be inserted is necessary. This understanding is the result of an analysis conducted as part of the systems and logistics engineering processes to bring a system into being and is documented as the operations and support concept. The operations and support concept is a first, rough, draft design of the overall system and consists of various concepts which will be used throughout the design process. It also forms the basis for life-cycle costing [Blanchard, 1998:175-183]. The different concepts are the:

- Operations concept.
- Maintenance concept.
- Supply support concept.

**The operations concept**

The operations concept provides the concept system functionality (ability) as a set of performance measurements, the typical applications the system may be subjected to, the typical environmental conditions it will be exposed to, operational requirements for support and the operational distribution. In the military environment the operations concept is known as the mission profile. It is a statement of the intended system's functions with associated performance measurements based on the requirements set by the host system. It serves as the foundation for all design (hardware, software and support). It is vitally important to know the frequency of operations and durations, availability requirements and environmental conditions to be able to influence the design and eventually design the support system. It is easy to conceive that a motor vehicle used for suburban travel on tarred roads and a 4X4 vehicle used for serious off-road work in harsh environmental conditions will have different operational concepts with different demands for operational and maintenance support. The fact that both have four wheels and are self-propelled is more or less where the commonalities end. For a more extensive discussion on the operations concept see Blanchard and Fabrycky [1998:50-52] and Blanchard [1998:101-114] where it is explained under the heading of operational requirements.

**The maintenance concept**

The second concept that should be established is the maintenance concept. Many times in the past design attention has been directed to only part of the system when addressing system concepts and requirements. The attention was normally limited to only those parts of the system that deal directly with the operations, namely the prime hardware and software, operational personnel, operational data and flow of operational material. [Blanchard, 1998:114]. This misdirected focus naturally leads to systems not meeting there overall requirements of ability, availability and affordability.

As has been demonstrated in Chapters 4 and 5, logistic support needs to be considered from the beginning, which requires the development of the maintenance concept along with the operations concept. According to Blanchard[1998:114], the maintenance concept is "...*a before-the-fact series of illustrations and statements on how the system is to be supported for supportability*". The maintenance concept can be viewed as the blueprint of the maintenance system of the host system into which the new system will be inserted. The way in which the maintenance support of the host system is currently organised has to be taken into consideration when the maintenance concept for the system of interest is developed. The existence of a maintenance support structure within the host system does not invalidate the development of a maintenance concept. Designers of the system need to understand and be able to quantify the support factors and influences of the maintenance support system on the new design in the same way they need to understand and quantify the demands of the operational support system on the new design.

The maintenance concept, which evolves from the definition of the system operational concept, describes [adapted from Blanchard, 1998:116-121] the:

- Organisational responsibilities for support which refers to a number of levels where support activities take place. Mostly three ***levels of support*** are defined namely:
  - Organisational level.
  - Intermediate level.
  - Specialised level.
- Anticipated levels of repair within the support levels. ***Levels of repair*** has to do with specific skill or competencies that are available within a support level. There can be more than one level of repair within a support level. For each level of repair the following is described:
  - The maintenance approach (e.g. modular replacement vs. component repair).
  - The general overall repair and maintenance policies and/or constraints applicable.
  - The major logistic elements and resources available.
  - The effectiveness criteria for maintenance on that level.
  - The maintenance environment and conditions under which maintenance will be performed.
- Anticipated approach to the management of the maintenance function.

The difference between the support levels and the levels of repair for a motor car is demonstrated in Table 8.1.

| Support level | Level of repair | Typical approach | Typical tasks |
|---|---|---|---|
| **Organisational** | Owner/driver | Operational effectiveness | Fuel, oil, water, functional checks |
| | Home workshop, place of operation | Operational availability | Replace globes, fuses, change flat tyre |
| **Intermediate** | Dealer workshop | Operational availability/ cost effectiveness | Scheduled and unscheduled maintenance |
| **Specialised** | Manufacturer | Cost effectiveness | Warranty claims, specialist repairs |
| | Specialist supplier | Cost effectiveness | Technology specific specialist repairs, e.g. auto-electrician |

**Table 8.1: The difference between support levels and level of repair**

Blanchard [1998:114-121] can be consulted for a more complete discussion of the maintenance concept. The sources listed in § 8.4.1.6 can be consulted on maintenance management, which forms the foundation of the maintenance concept.

**The supply support concept**

The third concept that needs to be developed is the supply support concept. The supply support concept is concerned with the flow of material, both from the operational and maintenance point of view. It describes the concepts of procurement and re-supply, incoming transportation, outgoing transportation, materials handling and inventory management. Some authors [Christopher, 1997:vii] also use the term marketing logistics when describing the supply chain as a "*fusion of marketing and logistics*". The supply support concept describes the interfaces between the various organisations, organisational levels and levels of repair in terms of how procurement, transportation, flow and storage of material of all forms will take place. The supply support concept is the first blueprint of the business logistics or movement logistics design. Numerous books are available on business logistics, some of which are Ballou [1987], Lambert, Stock and Ellram [1998], Robeson and Copacino [1994], Gourdin [2001], Christopher [1992], Bloomberg, Le May and Hanna [2002], The Harvard Business Review on Managing The Value Chain [2000] and Bowersox, Closs and Helferich [1986].

The supply support concept is currently receiving much attention due to the e-revolution and Enterprise Resource Planning (ERP) systems. A number of books on the e-value chain and Enterprise Resource Planning systems are available, some of which are the writings of Poirier and Bauer [2000] and Davenport [2000]. Of note is that there is a rising number of authors criticising the hype about e-commerce and ERP systems. A notable critic of e-commerce is Van Hoek [2001:21-28]. He contends that the supply chain dimension of e-commerce is neglected badly and poorly managed, as e-commerce is currently biassed to sales and marketing. He further states that other e-commerce applications will not take off if basic operational performance cannot be assured. Goldratt, Schragenheim and Ptak [2000] have devoted an entire book to the reasons why ERP systems do not deliver what has been promised. They also propose how to correct it. Their main finding is that ERP tries to optimise elements of the system (mostly the value chain), without considering the system as a whole. Ptak and Schragenheim [2000] propose how to approach ERP from a systems perspective.

**Design influencing and system measurement relationships**

Certain relationships exist between the system measurements and the logistic support system measurements. To be able to influence design, these relationships should be known. The major relationships are shown in Figure 8.2.

The logistic measurements related to the system measurements that are targeted for design influencing may include (but are not limited to) the following:

- Improving reliability e.g. better materials, redundancy, standby sub-systems.
- Improving maintainability e.g. reduced maintenance and maintenance delay time.
- Design for supportability e.g. accessibility, fault indication and isolation, safety, testability and self protection.

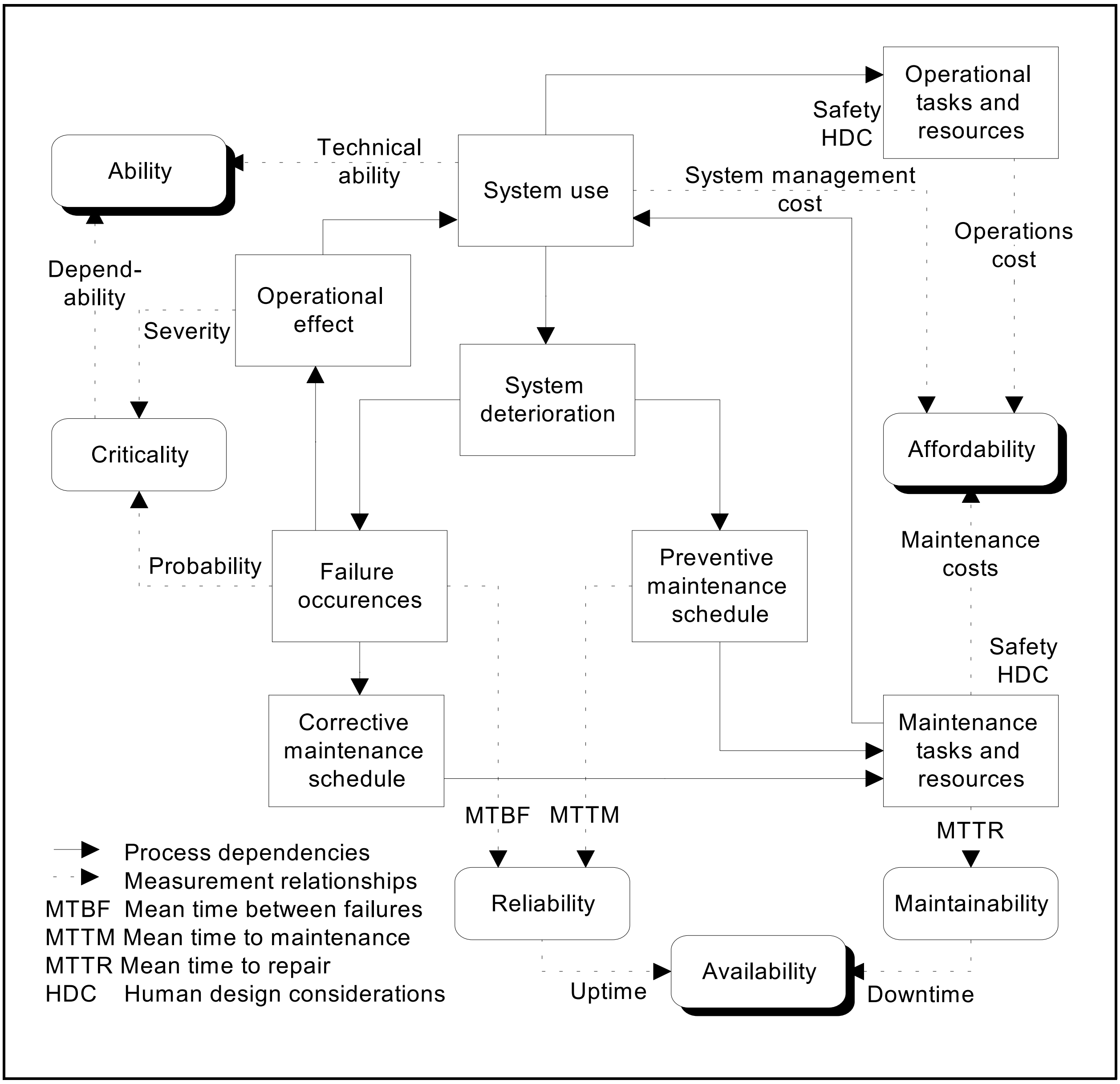



**Figure 8.2: The relationships between the integrated logistic support measurements and the system measurements**

- Design for human factors e.g. considering human capabilities for operation and support, ergonomics.
- Design for manufacturability e.g. reduction of the number of components, standard processes, easy assembly/disassembly
- Design for quality i.e. to make sure requirements are met, for economic feasibility and total cost of ownership
- Design for safety of the system, personnel and the environment

Without discussing each in detail, other formal design influence activities may include (but are not limited to):

- Standardisation which can take place on a modular level or on an item level. Rationalisation is to select a small number out of the large standard components to limit support requirements.
- Exploiting new technological opportunities by establishing design and support technology approaches and utilising technological advancements to achieve supportability improvements in the new system/equipment. This activity promotes the ongoing interfaces with research and development projects.
- Exploiting new management techniques such as lean manufacturing and drum-buffer-rope to manage operations and distribution systems in order to reduce lead times and improve quality.
- Comparative analysis of similar systems to select or develop a baseline comparison system representing the characteristics of the new system/ equipment to:
  - Project supportability related parameters.
  - Judge feasibility of the new system supportability.
  - Identify targets for improvement.
  - Identify supportability, cost and readiness drivers for the new system.
- Analysing the impact of the system of interest on the host system is to assure effective fielding of the system of interest under design along with all required resources. It provides the quantitative basis for operational budgeting and includes:
  - Quantifying the effect on existing systems.
  - Aids in the acquisition decisions to improve overall capability.
  - Manpower and personnel impact of the deployment.
  - Plans to alleviate any potential fielding problems
- Post-production support analysis is to ensure potential post production support problems are identified and addressed. Post-production support establishes plans to ensure effective life-cycle support over the total life of the system. This analysis attempts to alleviate problems with:
  - Reprocurement.
  - Closing of production lines and/or expected discontinuance of manufacturers.
  - Obsolescence of design.

The approach taken to perform the design influencing is called supportability analysis (SA) or logistic support analysis (LSA) and is an iterative and continuous analysis process [Blanchard, 1998:160], while at the same time considering the operations concept, the maintenance concept and the supply support concept. As extensive literature exists on how to perform this analysis [See Blanchard, 1998: Chapter 4; Green, 1991: Chapter 5; Mil-Std 1388-1A], it will not be discussed in detail in this thesis. A rather rudimentary representation of the process is included in the model for completeness sake. The first technical activity of logistics engineering, namely the design influencing which includes the establishment of the operations, maintenance and support concepts, is shown in Figure 8.3.

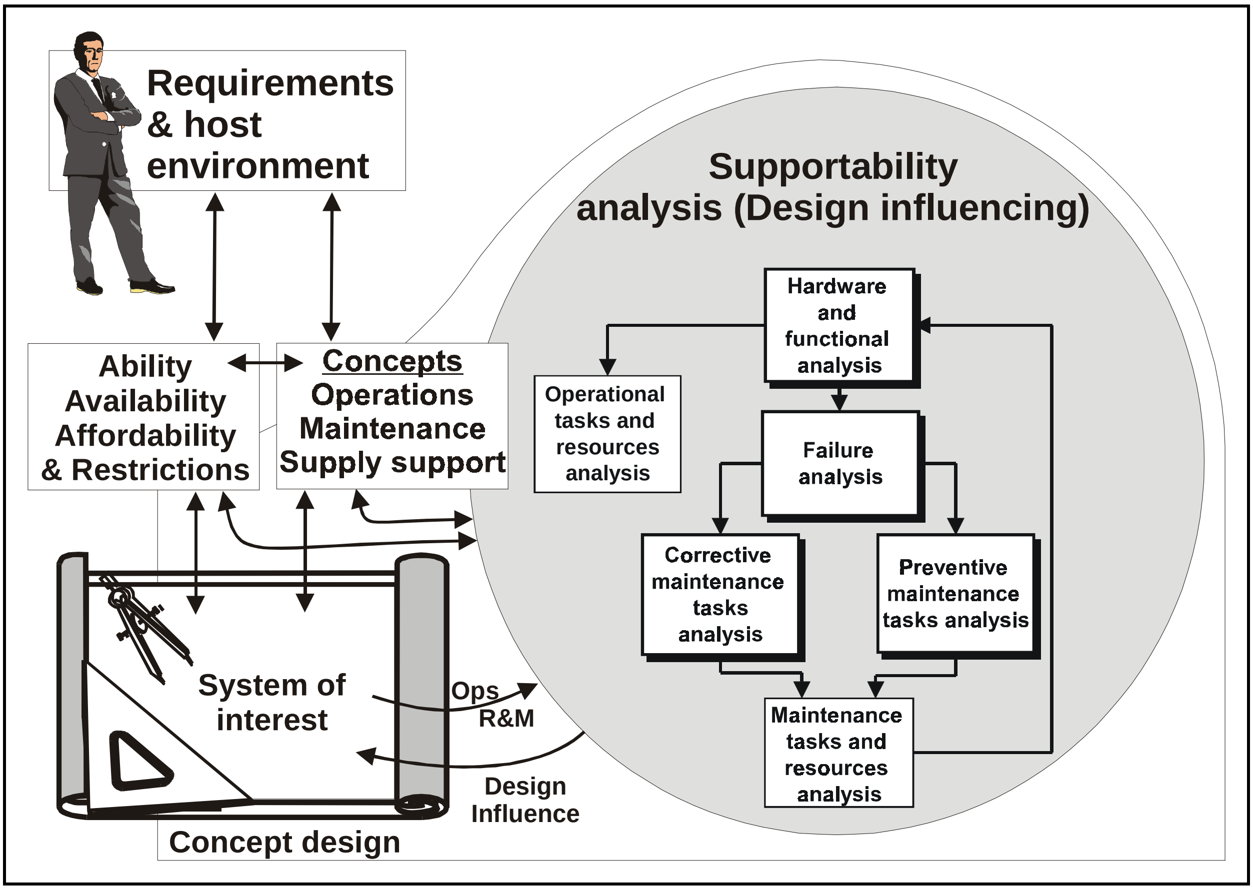



**Figure 8.3: Logistics engineering**
**Establishing the concepts and design influencing**

### The design influencing process

Design influencing is done very early in the life-cycle of the system during the concept and preliminary design phases (see Figure 4.5). The first input to the design influencing activity is the system measurements and restrictions imposed by the host system. These system measurements and restrictions are derived through an interactive process with the host environment using the systems engineering process of system requirements analysis (see Blanchard and Fabrycky [1998:48-72]). The development of the different system concepts is part of the system requirements analysis but is shown separately to highlight their importance for logistics engineering. These system concepts are the second input to the design influencing activity. The concepts set the framework within which the supportability analysis for design influencing is done. The same supportability analysis process is used for resource identification. Emphasis and focus of design influencing activities within the supportability analysis processes are indicated with a shadow behind the process block.

The supportability analysis uses the system characteristics (operational parameters, as well as the reliability and maintainability characteristics) of the concept system as defined through the systems engineering process as the basis for analysis. Once the operational parameters are understood within the context of the operations concept using the hardware and functional analysis, operational tasks and resources can be derived and analysed. These tasks and resources are analysed for possible improvement and any improvements are fed back to the mainstream design activity. The major objective of this analysis is to improve the ergonomics, safety and the man-machine interface between the operator of the system and the system itself [See Blanchard, 1998:259-264].

The hardware and functional analysis provides data for the failure analysis where possible failure modes of the system functions and hardware are identified. These failures are then analysed where a criticality (based on the severity and the probability of the failure) is assigned to each failure. Failures with a high level of criticality immediately qualifies the function/hardware for redesign. A medium criticality identifies function/hardware candidates for preventive maintenance provided preventive maintenance is applicable and effective, otherwise redesign may be mandatory, especially if it is a safety critical failure being analysed. A technique called reliability centred maintenance or RCM can be used to determine whether preventive maintenance is applicable and effective [See Blanchard, 1998:199-204]. A low criticality indicates a low demand for support, which means during the operational phase it will be left until failure, then corrected using corrective maintenance. This part of the supportability is generally known as a failure mode, effects and criticality analysis or FMECA [See Blanchard, 1998:183-187,245].

Following the failure analysis is the maintenance task analysis for both preventive and corrective maintenance tasks required to correct or prevent the failures. Maintenance tasks are defined on a high level and an analysis is done to establish mean times to repair (an indication of maintainability), resources required and costs associated with the task (an indication of affordability). Tasks are analysed for possible unsafe maintenance conditions and may lead to proposed design changes [See Blanchard, 1998:194-199].

The maintenance task and resource analysis will be done in great detail later when the resource identification is done which means it gets very little attention when design influencing is done. For the purpose of design influencing the maintenance task and resource analysis is done (using the data from the preventive and corrective maintenance tasks analysis) to identify safety, long maintenance time and high cost drivers amongst the tasks and the resources to be able to influence the design. It is also used to identify any possible resource (repairable spare parts, equipment, facilities etc) which may have a major impact on the support system and require a further analysis. Such identified support resources (e.g. a hydraulic test bench which may be a system in its own right) are taken through the same supportability analysis process.

The design feedback provided by the supportability analysis (it can come from any of the supportability analysis processes) are considered along with the system requirements and the different concepts. A decision is made which proposed design changes to implement and which not, considering the impact on the system measurements. The objective is to find the best trade-off between the system ability, availability and affordability without compromising the safety of the system and the people involved in operation and maintenance, or the impact on the environment.

At the end of the concept and preliminary design phases the major design decisions have been made and it becomes more difficult and costly to change the design after the start of the next phase of the life-cycle. Therefore the opportunity for influencing the design during the concept phase has to be utilised in an effective and timely matter to have the maximum benefits from this activity within logistics engineering.

#### 8.4.1.4 Identification and detailing of the support resources

The identification and detailing of the support resources is done using the same supportability analysis process used for the design influencing and is shown in Figure 8.4. The emphasis of the supportability analysis is to identify and detail the support resources, thus the last process of the supportability analysis as indicated by the shadowed process.

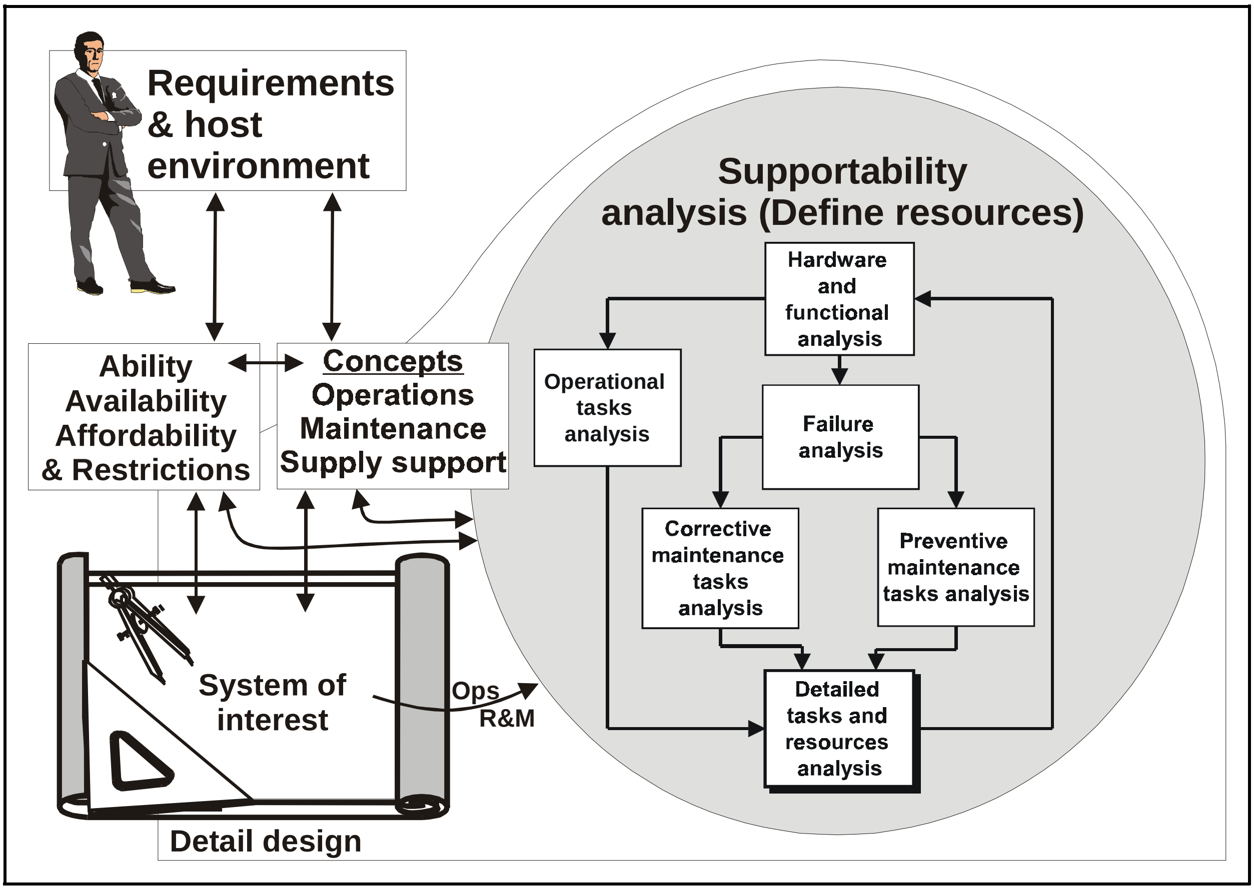



**Figure 8.4: Logistics engineering**
**Identification and detailing of the support resources**

The process is executed in order to generate the data necessary to provide detailed requirements for the support resource elements to be designed.

As can be seen by the different emphasis of the supportability analysis, the identification and detailing of the support resources is called the back-end analysis, as opposed to the design influencing front-end analysis. The input to the supportability analysis for resource identification and detailing is the same as for design influencing, namely the operational parameters and the reliability and maintainability characteristics. Design influencing of the system design is not present (or at best, very limited).

All the activities of the supportability analysis are repeated for the identification and detailing of the support resources. The hardware/functional analysis is done again to make sure that the complete system has been analysed. As lower levels of detail is designed, more system components are added requiring support. The operational task and resource analysis is reviewed to cater for any new system components that have been added. The operational tasks and resources are identified and detailed in order to provide a complete engineering data package of operator functions and tasks, sequence of activities and error, safety and hazard data. [Blanchard, 1998:259-263].

The failure analysis is revisited to make sure that all possible failures have been identified, as the failure analysis is important from the technical data point of view, so that fault finding procedures can be developed and included in the technical data element. The failure analysis is also the trigger for maintenance tasks to be identified which now have to be detailed and support resource requirements established.

The maintenance analysis provides an engineering data package covering all scheduled and unscheduled maintenance functions, tasks and associated support requirements for the system and equipment being analysed [Blanchard, 1998:440]. Part of the maintenance analysis is the level of repair analysis or LORA [See Blanchard, 1998:204-210]. For an extensive discussion on the maintenance task and support resource analysis consult Blanchard [1998: Appendix C].

The outcome of the supportability analysis to define and detail the support resources are the following:

- Identified en detailed operational, preventive and corrective maintenance tasks.
- Identified procurable support requirements for each task.
  - Operational materials.
  - Spare and repair parts.
  - Consumables.
  - Tools and equipment.
- Identified higher level system support resources.
  - Materials handling equipment.
  - Facilities.
- Identified people and training requirements for:
  - Operational tasks
  - Maintenance tasks.

The logic of Figure 8.5 shows the flow from the operational task analysis (front-end) into the detailed task and support resource analyses (indicated with shadowed blocks). The

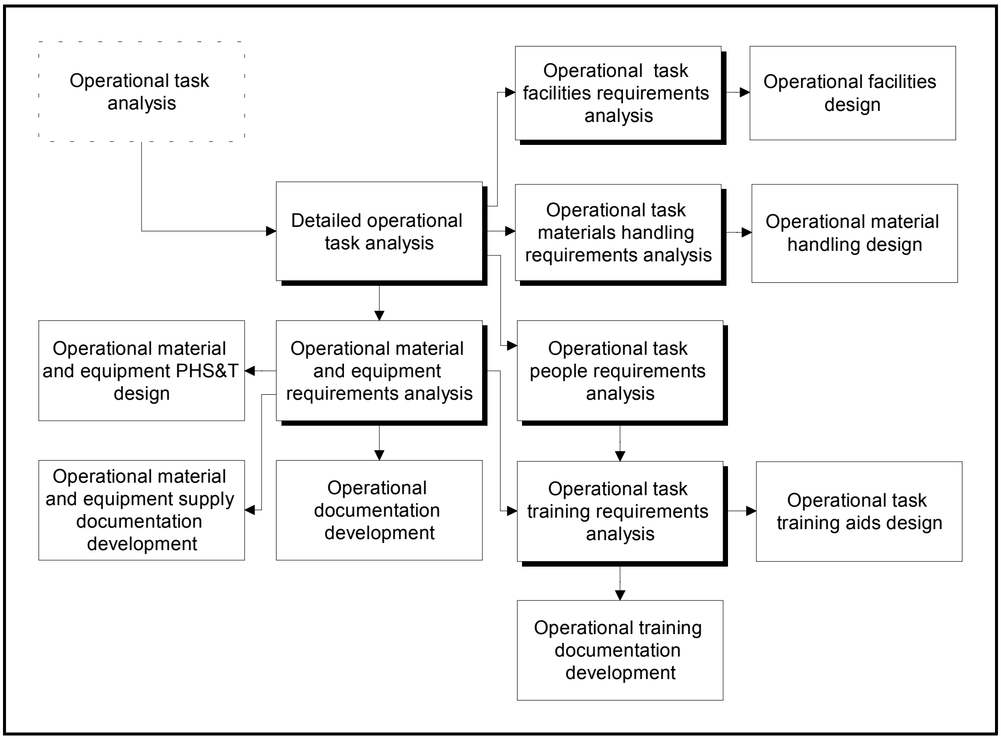



**Figure 8.5: Detailed operational task and resource analysis**

interfaces with the next logistics engineering activity (the normal blocks), namely design of the support resources, are also shown.

The same logic applies to the maintenance task analysis. The difference, however, is that the detailed task analysis for both preventive and corrective maintenance tasks is derived from the failure analysis. The reason why maintenance is done is to either restore system ability after a failure has occurred, or to sustain system ability in anticipation of failures. No maintenance would be required if there were no failures. The logic of the flow from the failure analysis into the detailed maintenance task and maintenance support resources is shown in Figure 8.6. Without the outcomes of each of the task and resource analyses, detailed design of each of the support resources will not be possible. Failure to perform these analyses will result in a support system that is poorly put together with an adverse effect on ability, availability and affordability.

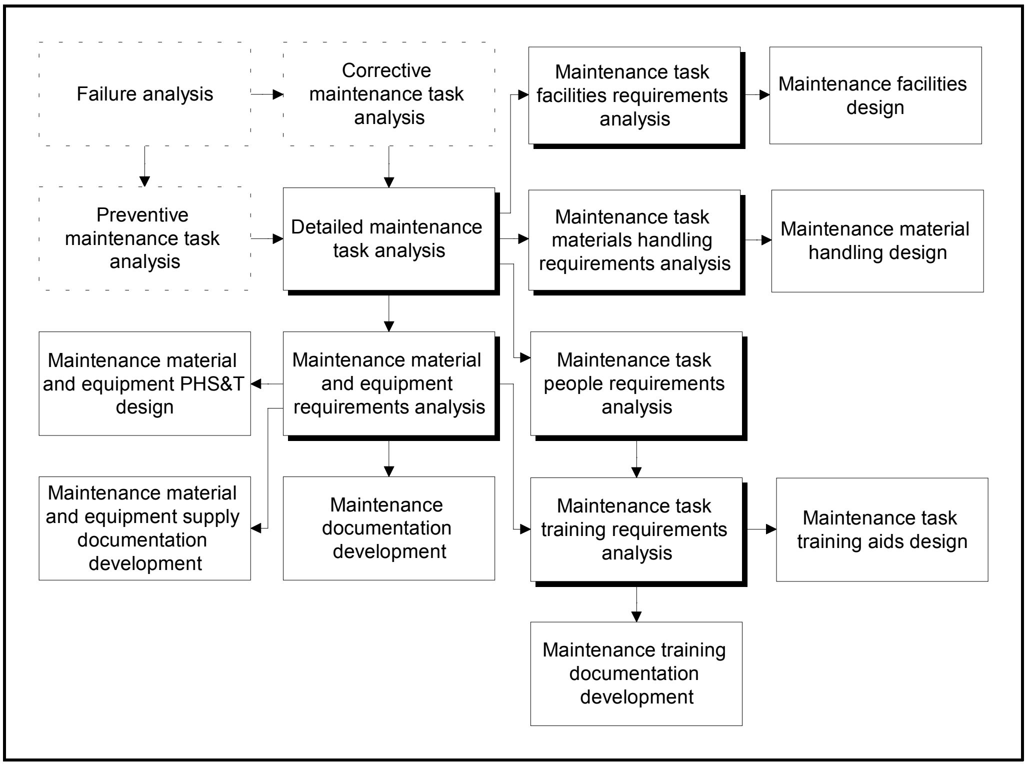



**Figure 8.6: Detailed maintenance task and resource analysis**

#### 8.4.1.5 Design of the support system and support resources

Once the support resource elements have been identified and detailed, the definition has to be integrated into the system of interest's support system and after which each element is designed to the level of detail required to be able to procure and commission the element. The support system is defined as collectively, those tangible support resources required to operate and support a system to achieve its ability, availability and affordability requirements (definition adapted from Green, 1991:385).

As the supportability analysis details the requirements for support by only considering the operations and support concept, it is now necessary to integrate all elements of the required support by considering locations and quantities of deployment of the system, as well as existing support infrastructure. This integration is called support planning and defines the requirements for overall system support based on a known design. Where the operations and support concept is the input to system design, the support plan is one of the results of the engineering process to bring a system into being [Blanchard, 1998:114] and can be viewed as the operations and support concept map that is now populated with the technical design of the support system. The support planning as part of the support system and support resources design process is shown as the first process in Figure 8.7.

The support system and support resource design consists of three mainstream efforts. The first is the support planning and design of all the procurable resources. A procurable resource is defined as any raw material, operational item, spare or repair part (repairable or non-repairable), consumables, special supplies, tools and special equipment, computers and software, workshop equipment or any item which will, in the course of the system's operational and retirement phases, be taken into the system as a controlled inventory item. Within the support planning effort initial and replenishment quantities, supply sources and distribution per level of repair and location of each procurable item is calculated considering demand, lead times, distance from supply and distribution channels available.

Within the framework of the support plan, the tool and equipment design takes place, the preparation, preservation, packing and marking (PPPM) of all procurable resources is

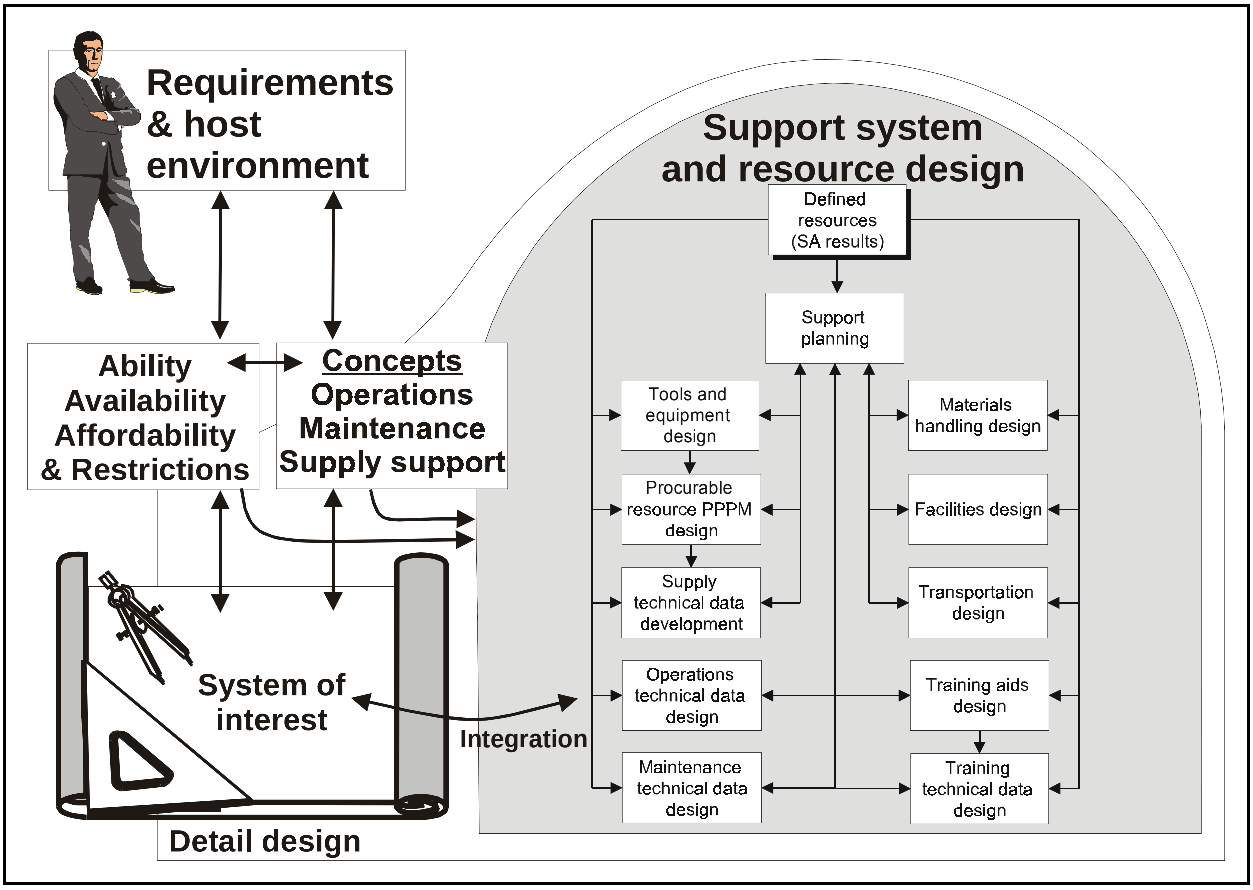



**Figure 8.7: Logistics engineering**
**Design of the support system and support resources**

designed and the supply documentation such as illustrated parts catalogues (IPC's) are developed. The design of the support elements themselves can influence the support planning, which means that good communication from the support resource design back to the support planning has to exist.

The second part of support system and support resource design is the support planning and support resource design of the materials handling, the operational and support facilities as well as the transportation design. The support planning of these three elements entails the establishment of overall materials handling and facility requirements (including warehousing and stockkeeping facilities) at each location and at each level of repair based on a flow model of input, processing and output through the system. Once this has been established, the transportation requirements can be determined. The requirements for these three elements then serve as the input to the detail design of the materials handling equipment, all required facilities and the transportation equipment. As in the case with the procurable resource design, good communication must exist between the detail design of these support resource elements and the support planning.

The third dimension of the support system and support resource design is the support planning and the development of the technical data of the system. Technical data include all procedures for operations (such as system installation, system preparation, system checkout, system start-up and shut-down procedures, operation procedures, emergency procedures, training procedures for operators) and preventive and corrective maintenance procedures (such as fault finding, preparation for maintenance, repair, check-out after maintenance action, assembly and disassembly procedures, preservation and de-preservation, overhaul and modification procedures, training procedures for maintenance personnel). The support planning ensures that a proper structure exists within which the technical data is formatted and presented e.g. published documentation or interactive multimedia. Interaction exists amongst the different support resource elements being developed as they are all addressing the same system. Inputs form the other two dimensions (procurable resource planning and design as well as the materials handling, facilities and distribution planning and design) of support planning are also considered as this information becomes part of the technical data of the overall system.

Of major importance during the support system and the support resources design is integration between the designed support system and the system it intends to support. Design integration is important on three levels. The first level is the integration between the designed support resources and the system design itself e.g. the spare part identified and designed is fully exchangeable with the corresponding part on the system itself. The second level is the integration amongst the support resources e.g. the spare part identified is correctly imaged and referenced in the supply documentation. The third level is the integration between the support system and the host environment e.g. the supply documentation's format is the same as that of the host environment. Even though these three levels of integration seems to be easy to accomplish, it is exactly these three integration levels that are neglected resulting in severe support problems.

Another concern of vital importance is the consideration of the support required for support resources. Many of the support resources identified and designed may require support in itself e.g. a complex hydraulic test bench may be regarded as a system on its own to which the complete systems engineering process including the supportability analysis have to be applied. It is thus possible to get support for support. This fact reiterates the reality of the hierarchy of systems. Disregarding the support requirements for the support system more often than not render a system totally incapable of performing its intended mission.

Scrutinising each of the support resources, it can be appreciated that the design of each of the resources requires a certain skill and training. Industrial engineers are probably most suitably trained to do facility layout while the facility structure may be best left to architects and civil engineers. Similarly, preservation and packaging design is a speciality area in its own right, whilst development of the training system will require its own unique approach and techniques. This part of logistics engineering truly requires a team effort from many different specialists. Due to the diverse nature of skills and techniques required to perform the overall support system and resource design, it will not be discussed in any more detail in this thesis.

#### 8.4.1.6 Designing the support management system

The final technical dimension of logistics engineering is to design the support management system. The support management system consists of policies, procedures and directives that will allow the system manager to manage the support of the system of interest during the operations and retirement phases. The host system may take responsibility for this design or it may be done in cooperation with the realisation system. Naturally when the host system is matured in its life-cycle, a major design effort for the support management system of the system of interest will not be necessary. The design effort will be limited to those parts of the support management system that is unique to the system of interest and the parts necessary to integrate the support management system of the system of interest with the support management system of the host system. Designing a new organisation from scratch will be an example where a major effort is needed to design the support management system. Designing a standard modular component (e.g. an alternator) for the motor car manufacturing and after-market sectors, may be an example where very little effort will be expended on the design of the support management system. It will most probably be limited to integrating the interfaces between the supplier and its markets.

The primary input into the design of the support management system is the operations and support concept, which can be viewed as the framework within which the support management system has to fit. The support management system consists of three dimensions that need to be designed and integrated with the management system of the host system. The interrelationships between these dimensions are shown in Figure 8.8. They are:

- The design of the operations management system.
- The design of the maintenance management system.
- The design of the people management system.

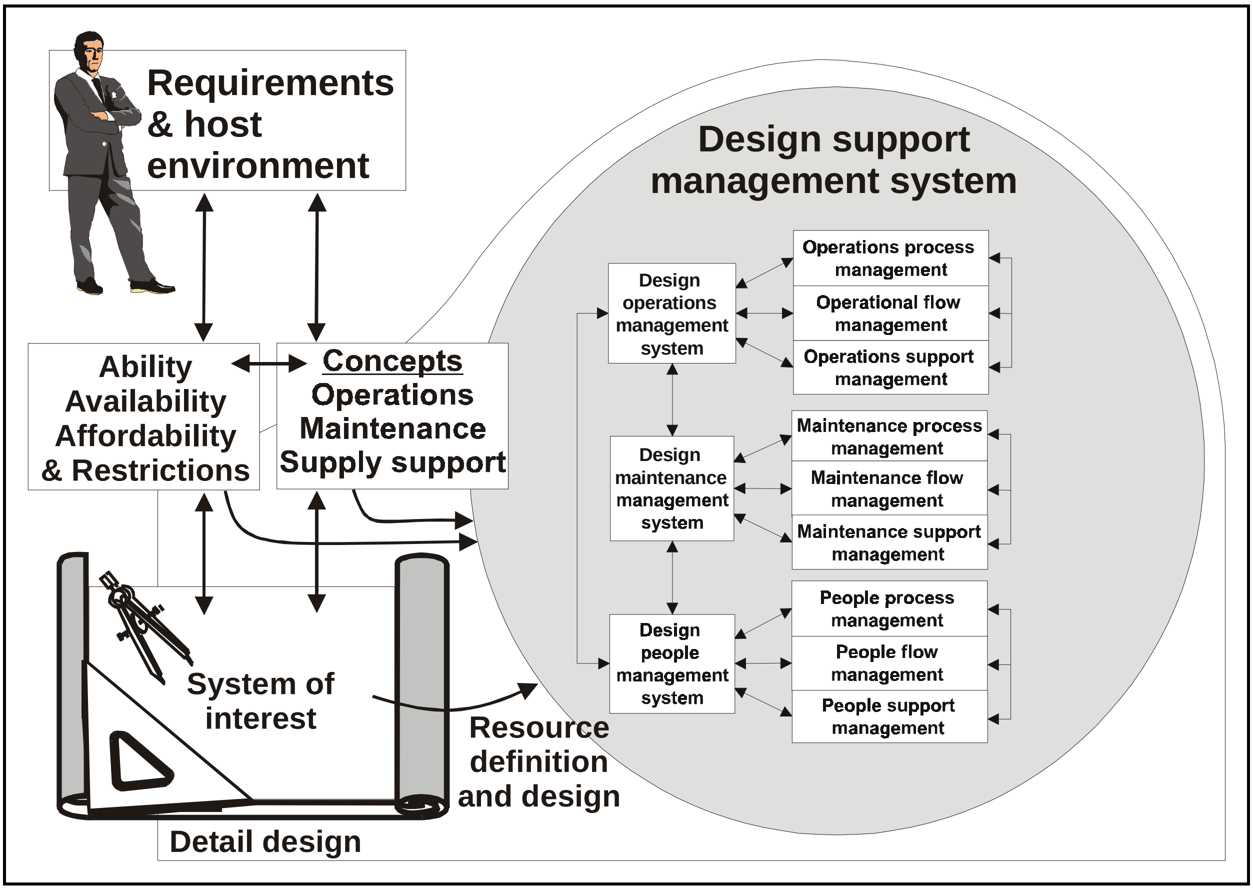



**Figure 8.8: Logistics engineering**
**Designing the support management processes**

The operations process management design must consider the approach to operations management (continuous, mechanised batch, assembly batch, job-shop, project), measurements of operations success, management of available capacity i.e. managing bottleneck capacity, strategy development, work authorisation system, change management, configuration management, the reporting system, the quality management system and the information system. The operations flow design needs to consider demand management and scheduling, work release, buffer inventories and lot sizes of work-in-process (WIP) and management of the work in process materials handling system. The operations support management design needs to consider the management of the distribution system, input and output stock levels, contracting and interfaces with suppliers and distributors and outsourcing. Naturally the interaction between the process, flow and support management of operations should be considered simultaneously as they all work towards the same goal of ability. Similar to the detailed design of the support resources, each management element mentioned above requires a specialist in its own right and will not be discussed in further detail as part of this thesis. Although an attempt was made to make the management elements as complete as possible, it is not suggested that it is a complete list. Many good sources exist on the management of operations and the supply chain which can be consulted [Chase et al, 2001; Goldratt, 1992; Ptak and Schragenheim, 2000; Schonberger and Knod, 1997; Stevenson, 1993; Starr, 1996; Russell and Taylor, 1998].

The maintenance management design must consider the approach to maintenance management (centralised/decentralised and in-house/outsourced), measurements of maintenance success, management of maintenance capacity, the maintenance organisation, maintenance strategy, the maintenance management information system (MMIS) including the maintenance job card and reporting system, the failure reporting, analysis and corrective action system (FRACAS) and the maintenance quality system. The maintenance flow management design needs to consider maintenance demand, scheduling of preventive and corrective maintenance, prioritising of maintenance actions, management of maintenance in progress and management of the maintenance materials handling system. The maintenance support system needs to consider the management of the maintenance supply system, maintenance stock levels, contracting and interfacing with suppliers and outsourcing. Similar to the operations management, the three subdivisions of maintenance management design are done simultaneously and integrated with one another. Maintenance management and its design is also a specialist area in its own right and will not be discussed further in this thesis. Sources to consult on the management of maintenance and its design are Campbell [1995], Kelly [1997], Pintelton, Gelders and Puyvelde [1995], Herbaty [1990] and Mann [1983].

The people process management design must consider the organisational structure (functional, matrix, divisional), measurements of people management success, people management strategy, managing of people capacity, authority and responsibility, job design and performance appraisal. The people flow management design considers scheduling of operations and maintenance personnel, the leave system and decision making. The people support management design needs to consider personnel recruitment, placement, the remuneration system, training and career development. Again, it is not suggested that the above is a complete list of the people management elements. For more information, experts in the field such as Wickens [1995], Cascio [1998], Harvey and Brown [1996] and Robbins [1990] can be consulted.

An interesting observation is that within the design of the operations management, the maintenance management and people management systems there are certain recurring themes. These recurring themes will be the integrating factors between the different management systems e.g. demand for operations will lead to a demand for maintenance. Both the demand for operations and maintenance will lead to a demand for people. Within each of the management systems, capacity is to be managed (See § 7.5 and 7.6). Capacity required for operations will determine the demand for maintenance and thus also people capacity for both operations and maintenance. Another recurring theme is scheduling. Scheduling operations should consider the preventive maintenance schedule (operations capacity not available for delivering output) and the availability of people to perform both operations and maintenance. Provision should also be made for corrective maintenance within the schedule. Once the schedule has been set up for both operations and maintenance, detailed people scheduling can take place. The above example again illustrates the integrated nature of systems and that integration should be considered throughout design.

#### 8.4.1.7 Integrating the logistics engineering technical elements

Four technical dimensions of logistics engineering have been introduced, namely:

- Design influencing including the establishment of the operations, maintenance and supply support concepts.
- Identification and detailing of the support resources.
- Design of the support system and support resources.
- Design of the support management system.

Figure 8.9 proposes a simple model to integrate these different technical dimensions of logistics engineering. The sequence of events are indicated by the numbers, starting with the development of the operations, maintenance and supply support concepts. Although the establishment of the different concepts was discussed as part of design influencing, these concepts are shown separate as they form the foundation of the four succeeding

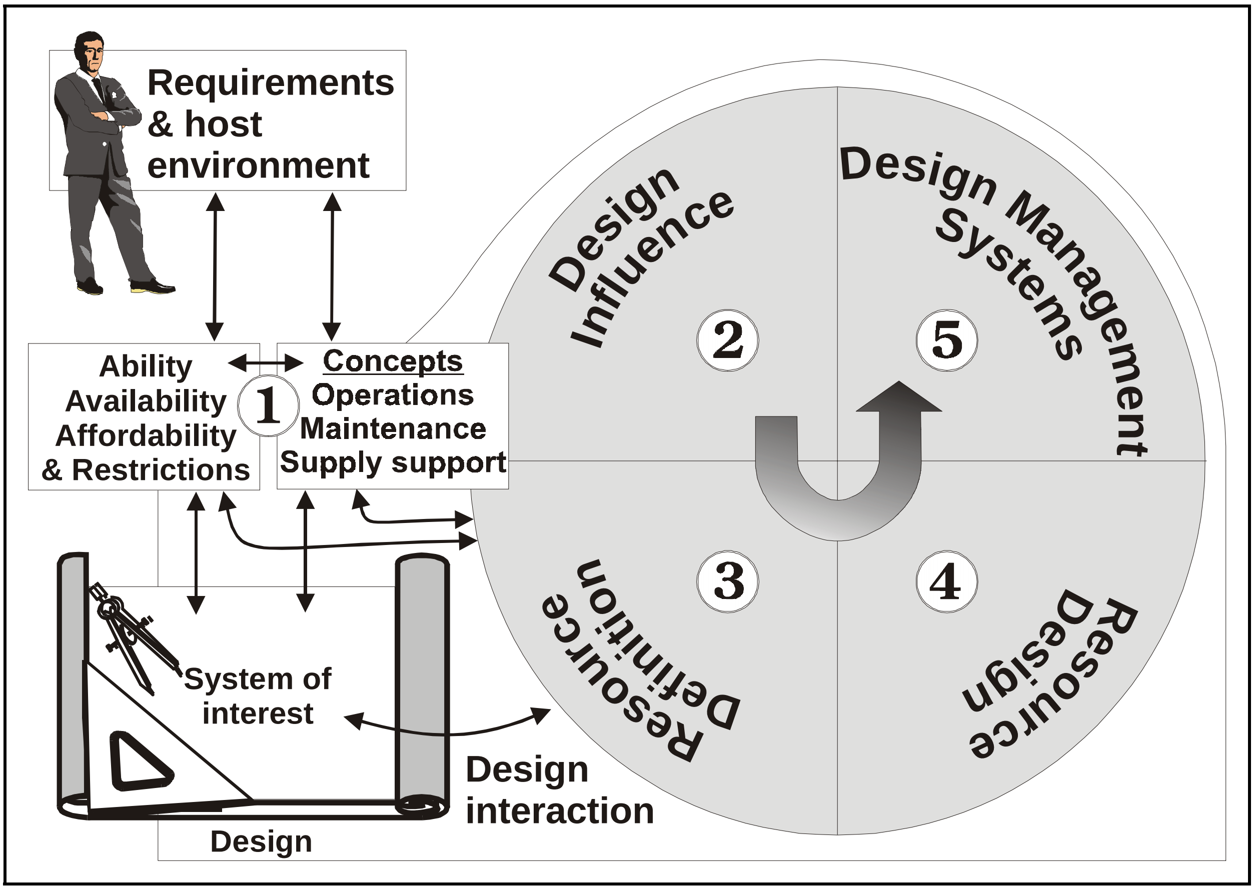



**Figure 8.9: The logistics engineering technical activities**

activities. The four dimensions of design influence, support resource definition, design of the support system and support resources, and the design of the support management system are shown as discrete quadrants. However, there are overlaps and recursive interaction when it comes to the timing of these technical activities. These overlaps will be shown on the overall integrated model using the ILS focus elements. Establishing the concepts and design influence are represented by the first ILS focus element, and the support resource definition and design, and support management system design are represented by the second integrated logistic support (ILS) focus element (Figure 8.11).

#### 8.4.1.8 Managing the logistics engineering process

The management of the logistics engineering process encompasses normal project management activities. A project is defined [Kerzner, 1995:2] as *"any series of activities and tasks that:*

- *Have a specific objective to be completed within certain specifications.*
- *Have defined start and end dates.*
- *Have funding limits (if applicable).*
- *Consume resources (i.e., money, people, equipment)."*

Logistics engineering has a definite objective, i.e. to bring an integrated logistic support system into being that will allow the system of interest to perform according to the ability, availability and affordability requirements while maintaining high levels of safety. Developing and designing the integrated logistic support system has a definite start and a definite finish date, also, funding is limited in most cases. Logistics engineering definitely consumes resources. Thus project management is the obvious approach to managing logistics engineering. As the management of the logistics engineering is conducted from within the realisation system while the logistics engineering is applied to the system of interest, the management activities within the model will only become visible once the different building blocks are integrated. (The integrated model is shown in Figure 8.11). The detail of the project management approach will not be discussed as there are a large number of sources available on the topic of project management [Goldratt, 1997; Nicholas, 2000; Duncan, 2000; Kerzner, 1995 and Newbold, 1999].

### 8.4.2 Operational logistics

#### 8.4.2.1 Terminology

The term operational logistics is not commonly found in literature. Sparrius [1991] is the only other author found that uses this terminology. This author is of the opinion that the lack of the use this terminology is because the concept of logistics has been assigned to so many functional groupings i.e. military, marketing, business etc, that another functional grouping of logistics is just not considered. However, when the term operational logistics is used in the context of this thesis, it is done, not with a functional grouping in mind, but with a life-cycle phase in mind. Similar to logistics engineering, which is linked to the creation life-cycle phase of the system of interest, operational logistics is linked to the operational phase of the system of interest. As opposed to having a functional grouping of logistics, the life-cycle grouping of logistics allows understanding of logistics from a whole-life, whole-system perspective. It thus allows the breaking down of barriers between the functional groupings of logistics.

#### 8.4.2.2 Operational logistics defined

Using the same definition for integrated logistic support (§ 8.4) and the same logic to derive the definition for logistics engineering, operational logistics is concerned with the second half of the life-cycle of the system of interest and thus the remaining part of the ILS definition. Very specific issues are important during the operational phase which requires different approaches to its management and execution. Thus operational logistics can be defined as those management and technical activities necessary to:

- Physically acquire and commission the required support.
- Provide the required support during the operational phase to allow safe operation of the system when required, while at the same time minimise the cost to the extent allowed by the system design.
- Recycle and dispose of waste of by-products, expendable spares and non-repairable spares during the operational phase and disposal or phasing out of the system of interest at the end of its life-cycle.

This definition of operational logistics provides the second building block for the integrated logistic support model for whole-life whole-systems.

While the management of the design phase was one dimensional (it consisted only of the management of the four logistics engineering technical activities), the management of the operational logistics during the operational phase is multi-dimensional. The management focus of the operational logistics is phased despite the fact that there may be certain overlaps in terms of timing (See the integrated model in Figure 8.11). The first dimension is the management of the physical acquisition and commissioning, the second dimension is the management of the ongoing operations of the system, while the final dimension relates to the management of the recycling and/or waste disposal i.e phasing out parts or the complete system of interest.

The technical dimension of the operational logistics consists of the physical acquisition and commissioning of the system, followed by the operation, maintenance and the phasing out of the system of interest.

#### 8.4.2.3 Physical acquisition and commissioning of the system of interest

This phase in the life-cycle is the transition of the system from the realisation system to the host system. The nature and complexity of the system of interest will determine the extent of this transition process, what will be involved and what the cost of the transition would be. If the example of a motor car is used, it is quite obvious that the extent of the transition also depends on where you are in the supply chain. To the buyer of a newly released model, the transition from the dealer to the user is a fairly simple process, probably limited to the dealer explaining to the new owner what makes this particular model unique, how it is operated and at what intervals maintenance services are to be performed. From the dealer's perspective, however, a major effort is required to make the transition from the manufacturer (who is also the designer) to the dealer. The dealer needs to obtain the new model's unique spare parts and illustrated parts catalogues, update his facilities with new equipment and special tools, have the salesmen and technicians trained and update the dealership's management system to also include the requirements for the new model.

Of major concern is the extent of support that needs to be provided by realisation system throughout the transition phase. The more complex a system is, the longer and more extensive the support provided by the realisation system would be. Problems with commissioning and infant mortality, as well as extensive training may cause the realisation system to operate and maintain the system until such time the host system is in a position to take over all these responsibilities.

The technical activities of the physical acquisition and commissioning include (but is not limited to):

- The acquisition and preparation of suitable land.
- The construction and commissioning of facilities.
- The procurement and commissioning of equipment and tools required for the system.
- The recruitment and training of operating, support and other personnel.
- The procurement, distribution and initial stocking of warehouses.
- Establishment of the support system and the support system startup.
- Performing the system startup and system operation until transfer to the operations function.
- Negotiating contracts for all activities listed above, while making sure that all legalities are adhered to such as international law and customs requirements.
- Handling of warranties and warranty claims.

#### 8.4.2.4 Operating and maintaining the system of interest

If the logistics engineering has been done properly during the design phase and the transition from realisation system to host system has been smooth, the operating and maintaining of the system of interest should be a fairly straightforward effort. The cycle of operating and maintaining the system is shown in Figure 8.10.

The operating support for the system of interest consists of having the right material, people, information and any other operational support resource available at the right place at the right time to ensure proper system operation. Thus operating support has as its aim to support system operation. As the system is operated continuously or intermittently, the

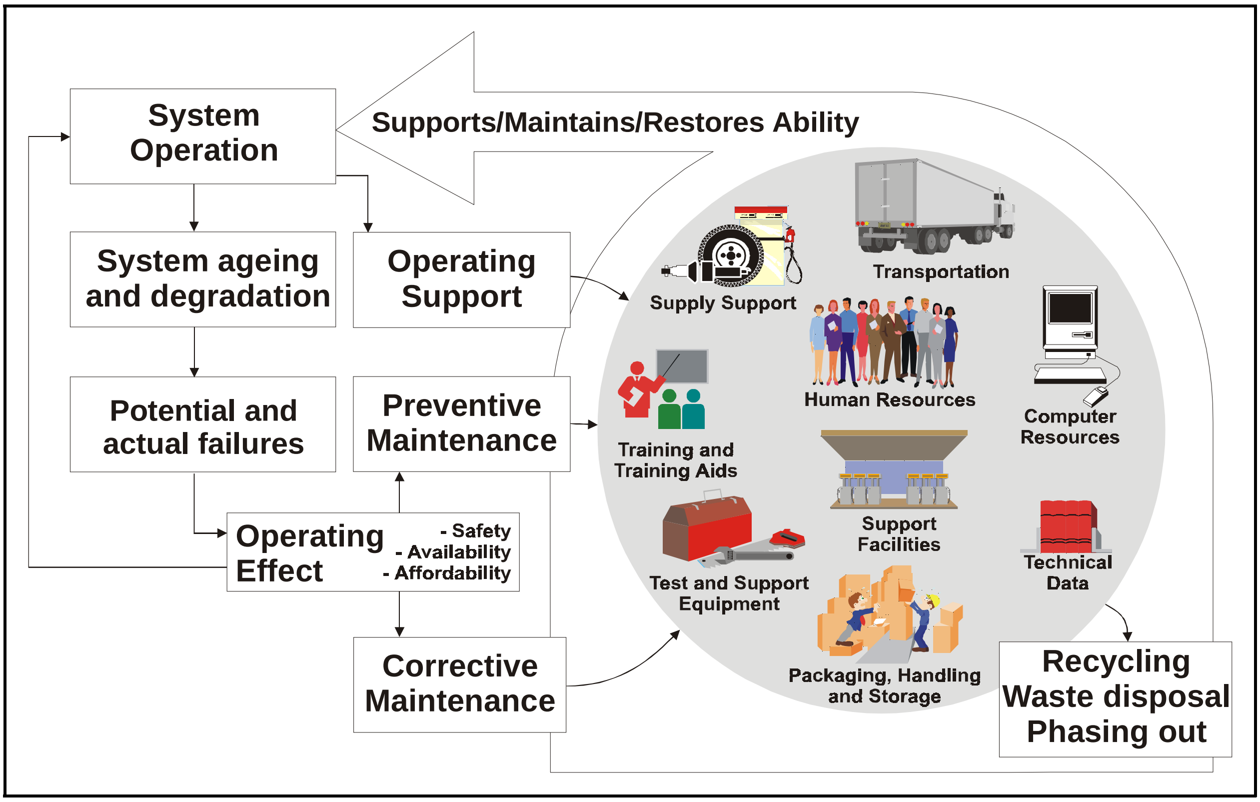



**Figure 8.10: Operational logistics**
**Operating and maintaining the system of interest**

system ages due to operational stresses and due to the lapse of time, giving rise to possible and actual failures. Potential failures resulting in severe effects on safety, availability and affordability are eliminated as far as possible by doing preventive maintenance. Preventive maintenance requires the support elements to maintain system ability to enable system operation. Corrective maintenance is done in the case where a failure has actually occurred, and the support elements are needed to restore the system ability to allow future system operation. Naturally, recycling and waste disposal continues throughout the operation cycles of operation and maintenance but is discussed separately in § 8.4.2.5 due to its importance.

The operational logistics is thus providing all the support to ensure system ability and availability, while at the same time making sure that overall system support does not contribute to the waste of resources (i.e. its impact on affordability). The execution (technical dimension) of operational logistics consists of (but is not limited to):

- Procurement of raw material, spare parts and consumables.
- Incoming transportation, warehousing, materials handling and stock keeping.
- Material release for operations.
- Material release for preventive and corrective maintenance.
- Data collection of system performance.
- Implementation of corrective action to improve system performance.
- Packaging and marking where applicable.
- Outgoing warehousing, stock keeping, materials handling and transportation.

#### 8.4.2.5 Recycling, waste disposal and phasing out the system of interest

Phasing out of the system is not only limited to when the system of interest gets to the end of its life-cycle, but should also include retirement of parts of the system on an ongoing basis throughout its operational phase. This is due to consumables and non-repairable items, along with repairable items beyond economic repair, or repairable items that cannot be safely restored, that need to be recycled or disposed of. Recycling and waste disposal is covered extensively in ISO14000 series of standards on the environment. However, phasing out of the system of interest is not covered widely in literature. Blanchard [1998] devotes an entire chapter to it (albeit a very short one), while Green [1991:36] only mentions it in a paragraph.

The technical aspect of recycling, waste disposal and phasing out is concerned with the safe handling of material from a people, system and environment point of view. Although recycling, waste disposal and phasing out is inherently an operational logistics responsibility within ongoing operations and maintenance, the environmental issues are currently getting such high priority that it is treated as a separate but interdependent issue. It entails all procedures, equipment and other support resources required to perform these activities. Naturally recycling and waste disposal should have been considered during the design process. During the operational phase the recycling and proper waste disposal should be done. More and more laws come into effect worldwide concerning design for the environment. The result is that more and more products are designed to be manufactured from recycled material, using materials and components that are recyclable, products that are easy to repair so that its life-cycle can be extended and designing less packaging that is also more environment friendly.

An example of recycling would be the Xerox program to recycle copier parts from which they build “new” copiers. McDonalds and Chrysler have waste audit programs that concentrate on reducing the amount of waste generated by those companies. In Germany a law was passed in 1994 that mandates the collection, recycling and safe disposal of PCs and household appliances, thus holding companies responsible for products even after their product’s life-cycle has ended. [Russell and Taylor, 1998:201].

#### 8.4.2.6 Managing the physical acquisition and commissioning

As has been stated in § 8.4.2.3 this phase is concerned with the transition of the system from the realisation system to the host system. Even if the transition takes place within one organisation (e.g. the R&D division designing and constructing a system solution for the operations division) the transition needs to be managed. If not, there is a very real possibility that the intended system benefits will be reduced or not realised at all. Management of the physical acquisition and commissioning of the system of interest starts very early in the life-cycle. In fact, the ideal time to start planning for this phase in the life-cycle is right at the beginning of the life-cycle. Information provided by the logistics engineering process (especially the early fielding analysis and support planning) is used to plan for implementation and forms the budgeting basis for the operational phase. Thus the management of the physical acquisition and commissioning is to make sure that all activities listed in § 8.4.2.3 are properly planned and overseen.

Similar to the management of the logistics engineering process, management of the physical acquisition and commissioning is an effort with a specific start date and a specific end date, while a definite goal is to be met within that time frame. Thus project management is also the appropriate management approach. Depending on the size of the system, physical acquisition and commissioning may be viewed as a program with a number of separate but interdependent projects making up one program e.g. constructing facilities will be one project while training of all relevant personnel may be another. In §

8.4.1.8 a number of good sources are listed that provide information how to properly manage projects.

#### 8.4.2.7 Managing the ongoing operations

Once the system has reached a state where the host system is fully capable of operating and supporting[1] the system, it becomes the responsibility of the operations function to manage the operations and support on an ongoing basis. Where the previous phase managed the events leading up to startup and the initial operations, the system is now operated to achieve its intended purpose for an undefined period of time. This period will end when the need for the system does not exist anymore, when the cost of operating and maintaining the system is more than the benefits derived, when it becomes unsafe to operate or maintain the system, or when a new technology comes along that will render the system obsolete and it being replaced by a new technology system.

The ongoing management of operations has three objectives, namely to:

- Manage the activities to support the operations in order for the ability requirements to be met.
- Manage preventive maintenance to sustain system ability in anticipation of possible failures (ensure availability).
- Manage corrective maintenance to restore ability after failure (ensure availability).

All this is done considering the best possible trade-off between benefits and cost associated with the system while maintaining all applicable safety standards.

The approach taken to manage operations will be dependent on the type of operational capability. The type of operational capability must have been taken into consideration when the support management system was designed as part of the logistics engineering process.

[1]For some systems the host system will not provide all the support for the system of interest. The host system may contract to the resource environment (which may be the realisation system) to support the system of interest. However, responsibility for support remains with the host system.

Within organisational systems (and it is conceivable that all durable and non-durable products as well as services are in some way integrated into an organisational system) the management of operations are classified as continuous and interrupted operational systems. The lower level classification of the continuous and interrupted categories along with typical characteristics and examples are shown in Table 8.2 [Adapted from Russel and Taylor, 1998:234].

Operations of organisational systems may fall into any of the stated categories from continuous process to project. Product systems and services will typically fall within the job shop category, where the demand for application of the product system or the demand for the service is very much dependent on customer's needs on a day-to-day basis. Military operations can typically be classified as a project, where the variety of application can differ from scenario to scenario, dependent on the offensive or defensive strategy. Further detail on the management of different types of operational systems may be obtained from the sources listed in § 8.4.1.6.

From a support system point of view, it is imperative to have a good measurement system to establish if system ability, availability and affordability objectives are met. Such a measurement system will be one of the prime inputs used by those in charge of managing operations. The three levels of integration of the support system are evaluated, namely whether the support elements integrate with the system, the support elements integrate with one another and the support elements integrate with the host system support system. Adjustments are to be made where there are shortcomings with the designed system, on both the technical as well as the management dimensions, or where the design has overcompensated e.g. where there are too many spares of a certain type. Data on operational performance and operational resources consumed, actual failures and failure rates, preventive and corrective maintenance and maintenance resources consumed are analysed not only for corrective action on the system of interest, but also used for improving future designs of similar systems.

| | Continuous | | | Interrupted | |
|---|---|---|---|---|---|
| | Process | Batch | | Job shop | Project |
| | | Mechanised | Assembly | | |
| **Type of product** | Commodity<br>Collective service | Make to stock | Make to stock<br>Assemble to order | Assemble to order<br>Make to order | Design to order<br>Make to order |
| **Type of customer** | Mass market | Mass market | Mass market<br>Individual customers | Niche markets<br>Individual customers | Single, individual customer |
| **Product Demand** | Relatively stable<br>Very high | Relatively stable<br>High | Fluctuates<br>High to low | Fluctuates<br>Medium to low | Infrequent<br>Low |
| **Product Variety** | Very few | Few | Few to many | Many, varied | Infinite |
| **Production System** | Highly automated<br>Process industry | Special purpose<br>Automated | Special purpose<br>Manual labour | General purpose<br>Flexible | Vary according to Industry |
| **Primary type of worker skill** | Equipment monitors | Limited range<br>Low level specialised | Limited range<br>High level specialised | Wide range<br>High level | Experts<br>Craftsmen |
| **Advantages** | Very efficient<br>Easy to control<br>Consistency | Efficiency<br>Speed<br>Consistency | Efficiency<br>Speed<br>Limited flexibility | Flexibility and variety<br>Quality<br>Personal attention | Customised<br>Latest technology |
| **Disadvantages** | Very capital intensive<br>Far-reaching errors<br>Difficult to change | Capital intensive<br>Lack of responsive-ness | Capital intensive<br>Limited flexibility<br>More complex | Low efficiency & slow<br>Complex scheduling<br>Difficult to control | High risks<br>Small customer base<br>Expensive |
| **Examples** | Mining<br>Telecommunications<br>Chemicals<br>Municipal services | Brewery<br>Soft drinks<br>Foodstuffs<br>Lightless plants | Motor manufacturing<br>Banking<br>Fast foods<br>Appliances | Machine shop<br>Printing shop<br>Restaurant<br>Aviation industry | Construction<br>Ship building<br>Consulting<br>R&D, design |

**Table 8.2: Different types of operational systems**
[Adapted from Russel and Taylor, 1998:234]

#### 8.4.2.8 Managing the recycling, waste disposal and phasing out of the system

Management of the recycling, waste disposal during the operational phase and phasing out of the system of interest at the end of its life-cycle should consider:

- Operational waste management i.e. recycling and/or disposal of consumables and unneeded by-products of system operations.
- Maintenance waste management i.e. recycling and/or disposal of maintenance consumables, by-products, non-repairable parts and repairable parts that cannot be restored safely or economically.
- System retirement management i.e. recycling and/or disposal of the system itself along with all associated support that will not be required any further due to the retirement of the system of interest.

Naturally the requirements for recycling and disposal must have been considered during the logistics engineering phase to be able to manage it during the operational and retirement phases. It is too late to start considering it once recycling and disposal is needed due to environmental pressures and legislation, or simply being stuck with a lot of waste generated by the operations and support of the system of interest.

## 8.5 Integrating the logistics engineering and the operational logistics over the life-cycle

The two major life-cycle phases for a system have now been described along with what happens with respect to the management and technical dimensions within each of acquisition and operations. All these dimensions can now be integrated within one model to allow full understanding of a generic model for integrated logistic support for whole-life whole-systems. The integrated model is shown in Figure 8.11. The model depicts the life-cycle phases of a system on the horisontal axis. Three dimensions are shown on the vertical axis. The first dimension on the vertical axis shows how the integrated logistic support focus changes as the system goes through its life-cycle. The second dimension shows how the focus of the technical activities change from logistics engineering to operational logistics as the life-cycle progresses. The third dimension shows how the

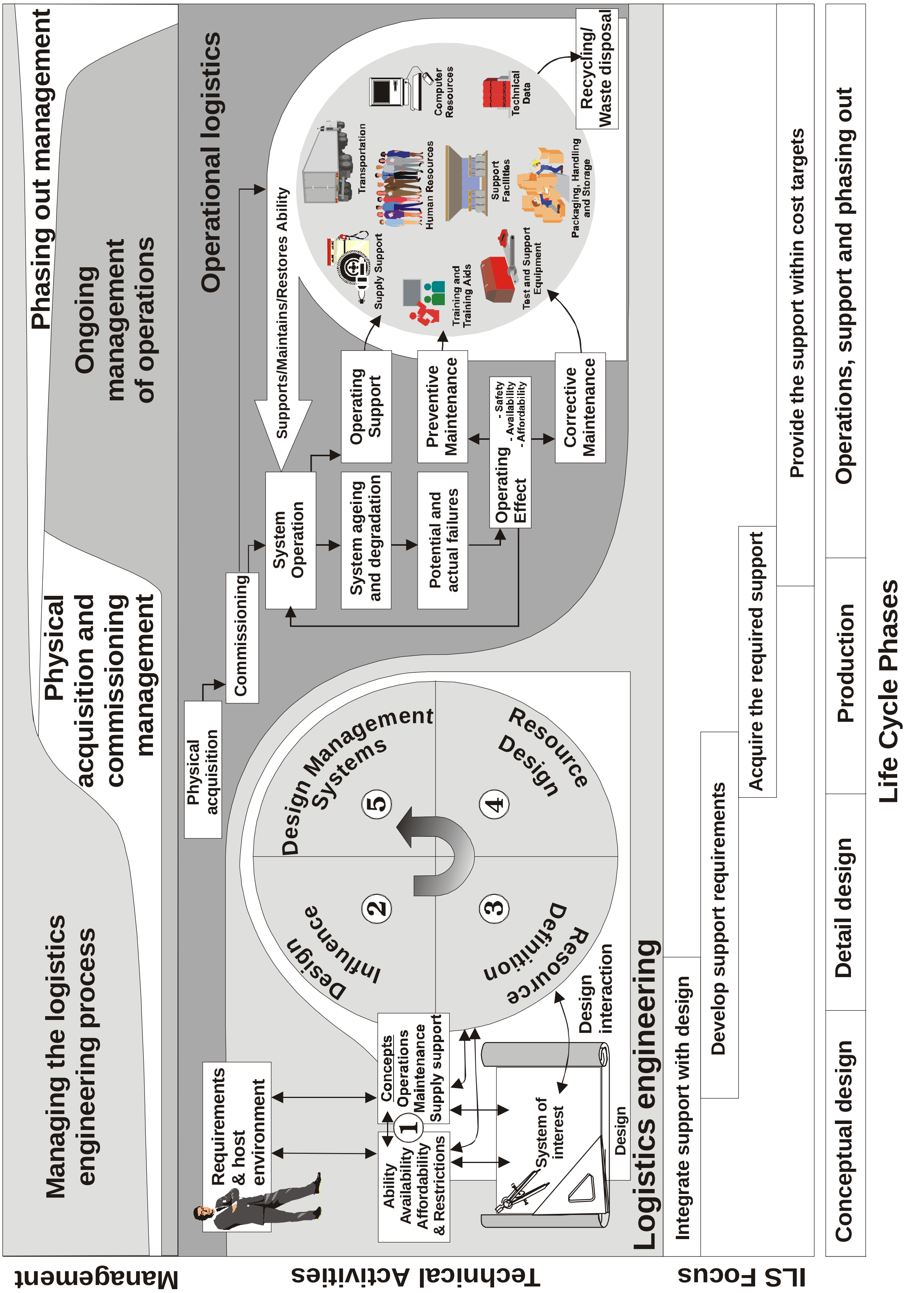



Figure 8.11: The generic integrated logistic support model for whole-life whole-systems

management emphasis changes from managing the logistics engineering process to managing the physical acquisition and commissioning, to managing the ongoing operations and the phasing out of the system.

The technical activities initially has its focus on the logistics engineering. It starts out with the development of the concepts (① in Figure 8.11). An active involvement from the intended host environment of the system of interest is required to provide the necessary input to ensure that the operations, maintenance and supply support concepts are in line with the requirements of the host system. The technical activities of logistics engineering continues by influencing the design (② in Figure 8.11), after which the support resources are defined and designed (③ and ④ in Figure 8.11). The final technical activity of logistics engineering is to design the management systems of the system of interest (⑤ in Figure 8.11). At this point in the life-cycle the logistics engineering technical activities tapers off within the realisation system while the technical activities within the host system starts to pick up to ensure that the operational logistics activities start taking place.

Towards the end of the logistics engineering process the management thereof reduces and the focus of the management activity now moves to managing the physical acquisition and commissioning of the system of interest (insertion into the host system) which will be followed by the management of ongoing operations once the transition from the realisation system and the host system has taken place successfully. Both the management of the insertion and the operations start very early in the life-cycle of the system of interest as establishing a complete operations and support infrastructure (or just modifying existing infrastructure) requires long lead times and needs to be properly managed. Very soon after insertion management has started, another management activity namely phase out management (which is normally part of operations management but shown separately for clarity and highlighting its importance) is started. As the system deteriorates over time towards the end of its life-cycle more emphasis is placed on phasing out which eventually become the prime focus when the system reaches the end of its life-cycle and the total system is phased out. Note that the logistics engineering technical activities never stops to ensure support over the entire life-cycle of the system. Because the logistics engineering activities continue until the end of the system's life-cycle, the management thereof also has to continue to the end of the system's life. These ongoing logistics engineering technical activities gather data on the overall performance of the system of interest to allow its improvement, and also to learn valuable lessons to make sure that future systems can benefit from what has worked well and what has gone wrong in the current system.

The output of the technical activity resource design (④ in Figure 8.10) combined with the management activity managing the physical acquisition and commissioning, provides for the physical support infrastructure consisting of all those elements shown in the circle of operational logistics in Figure 8.10. The outcome of the technical activity design management systems (⑤ in Figure 8.10) combined with the management activity of managing the commissioning provide for the management infrastructure required to perform the ongoing management of operations.

The two major life-cycle phases (acquisition and operations) can also be viewed as the effectiveness and the efficiency phases. Effectiveness referring to doing the right things, efficiency referring to doing things right. For a system to be successful, the logistics engineering activities and its management should focus on doing the right things to ensure a successful system during the operational phase from a ability, availability and affordability point of view. Once insertion takes place, the inherent design characteristics will determine how effective the system will perform when the system is operated and maintained efficiently. It is very difficult and expensive to change a design once it is inserted in the host system. It can thus be stated that the effectiveness of the system during the utilisation phase is established early during the acquisition, due to the design influencing. The effectiveness is further determined by how well the system operations and support design has been done during the latter part of the acquisition phase, and how well it is managed and executed during the operational phase.

## 8.6 Verification of requirements

Although the next chapter will have a more in depth look at the validity and applicability of the model, this paragraph briefly illustrates that the model meets the requirements set for the development of the model set in § 8.2.

### 8.6.1 Viewing the whole-system and the interfaces with its environment

This requirement is met by having the operational environment involved from the start of the life-cycle of the system of interest. This is done either through direct involvement of the host system who expressed the need for the system of interest or in the absence of a specific customer, by doing market research. Development of the concepts further ensures that all interfaces are taken into account. When combined with the proto system model by M'Pherson (see § 4.6) a powerful vehicle is available to define the whole-system and all its interfaces.

### 8.6.2 Viewing the system over its entire life-cycle

Irrespective of how the life-cycle phases are defined, all these phase are covered within the model. The discussion on the different views of the life-cycle in § 4.7.5 clearly demonstrates that this requirement has been met.

### 8.6.3 Allowing for an iteration of ideas to ensure optimum system design

The iteration of ideas need to take place early in the life-cycle of the system, primarily during the conceptual design. The arrows in both directions between the different activities within the development of the concepts and the design influencing is indicative of the iterative nature of the model.

### 8.6.4 Consideration of the operational environment when the conceptual design is started

This requirement provides a specific view on the previous three requirements as the time lapse between the beginning of the life-cycle (conceptual design) and the start of operations may be considerable. If the operational requirements are not taken into consideration as early as the conceptual design it may take a long time (and be very costly) to find out that the operational requirements were not considered from the beginning. That is why the operational logistics technical activities are started when the life-cycle starts to ensure that the operations, maintenance and supply support concepts are integrated into design from day one.

### 8.6.5 Continuation of the systems engineering process until phase out.

The continuance of the systems engineering is indicated in the model with the logistics engineering and its management continuing until phase out to ensure that any operational, maintenance and supply support problems within the system of interest and the host system can be solved and possibly be improved on. This allows for continued improvement of ability, availability and safety and this continued support is many times required to extend the life-cycle of a system.

### 8.6.6 Inclusion of both technical and managerial processes

The logistics engineering consists of four different categories of technical activities with one managerial process. During the transition phase from the realisation system to the host system the logistics engineering technical processes output is used to manage and perform the physical acquisition and commissioning of the system of interest. This flows into the management of ongoing operations and the phasing out of the system. During the operational phase the technical activities consists of operating the system, as well as performing preventive and corrective maintenance while at the same time the recycling and waste disposal takes place until final disposal of the system of interest.

### 8.6.7 Validity for any man-made system

This model can be applied to organisations of any type - manufacturing or service, static systems like a bridge, any repairable equipment of any nature, even the battle design of a defence force. Consumable products do not qualify as systems, but have logistics implications for the organisations and the supply chains (both which are systems) within which they are consumed. Their logistics requirements are to be planned for along with the system of which they are part.

### 8.7 Chapter summary

A generic model was constructed that explains the integrated logistic support for a whole-system over its entire life-cycle. The model explains structure and function, without providing a lot of detail on the process. The individual processes are covered extensively in literature. As a wide range of functions are included in the model, and the process of each function is comprehensive in its own right, the processes were not included. Some processes were included only for the sake of clarity. The main emphasis of the model is thus to explain this author's view of the relationships between the different technical and managerial functions of the integrated logistic support of a complete system over its entire life-cycle.

The requirements for such a model derived from the preceding chapters were primarily concerned with making the model complete from a total life-cycle and total system perspective, and to make sure that both the technical and managerial functions are included. The two distinctive major life-cycle phases, namely the acquisition phase and the utilisation phase, are used to define the functions of logistics engineering and operational logistics respectively.

The logistics engineering technical functions are the responsibility of the realisation system of the system of interest and consist of:

- Influencing of the design (including the establishment of the operations, maintenance and support concepts).
- The identification and detailing of the support resources.
- Design of the support system and support resources.
- Design of the support management system.

The management of the logistics engineering is also the responsibility of the realisation system and consist of conventional project management principles applied to the four technical functions mentioned above.

The operational logistics technical functions are the responsibility of the host system of the system of interest (but can be contracted to the resource environment) and consist of:

- Physical acquisition and commissioning of the system of interest.
- Operating and maintaining the system of interest.
- Recycling, waste disposal and phasing out of the system of interest.

The responsibility for the management of the operational logistics may differ from system to system. Normally the management of the physical acquisition and commissioning is shared between the realisation system and the host system which requires clear lines of responsibilities and deadlines. Mostly there is a gradual transfer from the realisation system to the host system. When this phase ends, the management of ongoing operations normally starts. The management approach taken depends on the type of system and the organisation (host system). Different management approaches exist for:

- Continuous processes.
- Mechanised batch processes.
- Assembly batch processes.
- Job shops.
- Projects.

Management of the recycling, waste disposal and phasing out is normally the same as for the physical acquisition and commissioning and the ongoing operations.

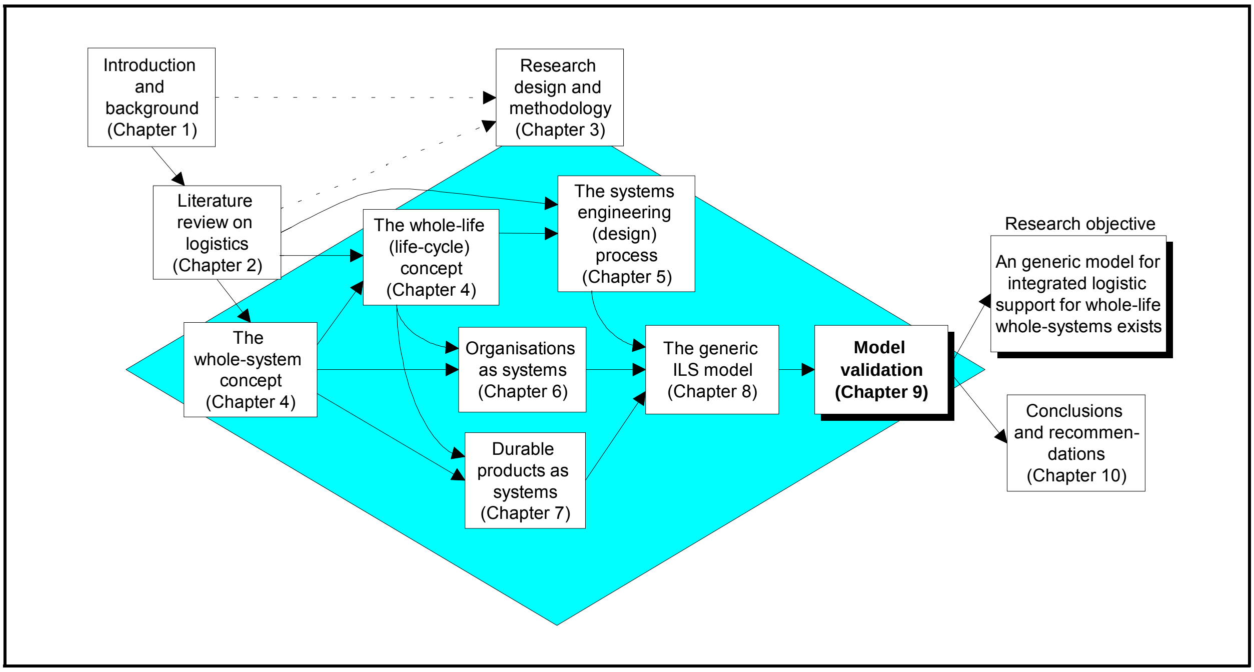
Viewing integrated logistic support from a whole-life whole-system perspective allows achievement of the generic system measurements, namely ability, availability and affordability.

# Chapter 9

# Validating the integrated logistic support model for whole-life whole-systems

*"We can consider models for creation of the solar system without waiting for another creation in order to have observations that will cause a validation or modification of the model."*

Rubenstein and Firstenberg [1995:162]




## 9.1 Purpose and outline of the chapter

The purpose of this chapter is to provide a more formal validation of the model describing the generic approach to integrated logistic support, to the extent that it is possible to provide such a formal validation. As this thesis is concerned with the construction of a model, it is necessary to provide some background to the approach how a model should be validated. The concept of a thought experiment is introduced as an approach to validating the model. A basic thought experiment that has been applied to an organisation as a system, is introduced to show the validity of using thought experiments. The structure of the thought experiment to be conducted for validating the model is then introduced.

The thought experiment is conducted comparing the effects of an approach that does not consider an integrated approach to logistic support, with the effects of using the approach proposed in this thesis, by investigating the impact of the two approaches on overall system measurements. The comparison is done for both the operational support and the maintenance support perspectives of integrated logistic support, while considering both the technical and managerial activities.

## 9.2 Model validation and thought experiments

A models never reflects reality in its totality. If a model is to fully reflect reality, it is not a model anymore, but reality itself. Models are normally homomorphic, which means that a number of real world components are represented in the model by only one modelling component. At best a model comes close to reality and the ‘truth’. Models normally have much less content than the real world problem (or solution). Due to aggregation some elements of the real world are ignored causing the model to be homomorphic.

Ignoring some components from the real world may cause the model to be oversimplified or even invalid for understanding and prediction. Whether an element is ignored willfully or by mistake, this inadequacy of models is called error of omission. Sometimes elements are ignored wilfully to simplify the model or to eradicate something from the model that does not fit a preconceived idea. Whitehead in Rubenstein and Firstenberg [1995:161] notes: “*If you only ignored everything which refuses to come in line, your powers of explanation were unlimited*.” The second error that is associated with modelling is when more content is included in the model than what exists in the real world. This type of error is call an error of commission.

The process of model validation is shown in Figure 9.1. According to Rubenstein and Firstenberg [1995:161], it is in a sense true that the validation process is never ending, as the figure suggests. They conclude that a model that is supported continuously by evidence and requires no modifications, become valid theory, and the postulates of the model that represents an observed regularity become laws. Not all models can be validated by measurements and observations. For example the models for the creation of the universe or the solar system depict elements and their relationships that will cause creation. Such models are considered without having to wait for another creation in order to have validations or modifications to the models [Rubenstein and Firstenberg,1995:162].

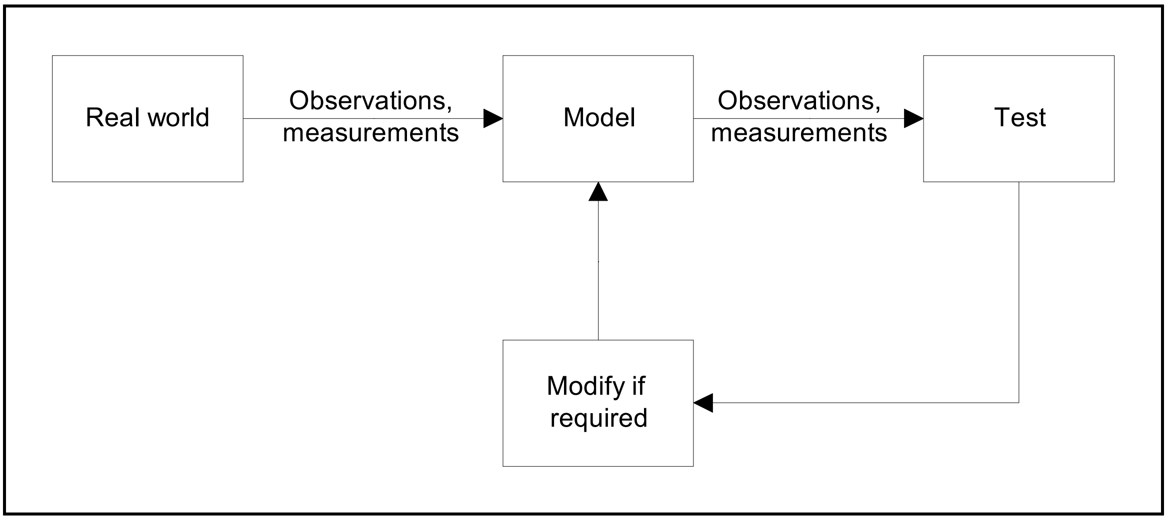



**Figure 9.1: The model validation process**
Rubenstein and Firstenberg [1995:161]

The question that arises is how the model presented in this thesis can be validated. It definitely is not a model in the same category as a model of creation, nor is it a mathematical model which can be validated using primary numerical data. Conceptually the best way to validate the model is to get real world data of systems over their entire life-cycles comparing those systems which follow the approach proposed by the model and those systems which do not follow the proposed model, measuring and observing the effect of management and technical activities performed or not performed on the ability, availability and affordability of the system in question. In order for the comparison to be valid, a comparison has to be made between the life-cycles of organisations of similar size, industry and product/service range within similar economic conditions, such as labour supply and level of training, accessibility to other resources and economic climate. This is to ensure that the measurements are not skewed by external factors. The same has to be done for product systems. The above requirements set for validation of the model seems to be an impossible task. The first reason for the impossibility of such a validation is that the life-cycle durations may be of such a substantial length, that the validation will take many decades to complete, as the life-cycle duration of the average organisation is in the order of 40-50 years [De Geus, 1997:7]. The second reason for the impossibility of the validation of the model is the difficulty to find two systems (read organisations) within the same environment and external interfaces, one willing to take the approach proposed by this research and the other ignoring it. Having done such a validation, one would also be limited to a conclusion that the model is valid (or invalid) only for the organisations that have been used in the validation.

There is however, an approach of validation that can be applied without suffering from the stringent requirements set for a real life experiment. This approach is called a thought experiment, which are experiments performed in the laboratory of the mind [Brown, 1991:1]. According to Brown [op cit], thought experiments are hard to explain beyond the metaphor just cited. Thought experiments which can be visualised, involve mental manipulations and are often (but not always) impossible to implement as real life experiments. Kuhn [1977:252] expands on the idea of thought experiments when he states that for a thought experiment to be effective, it must present a normal situation. A normal situation is when the person conducting the experiment feels well equipped by prior experience to handle the experiment. Nothing within the thought experiment must be entire unfamiliar or strange. To a large extent this implies that one has to have a good background or experience, as well as intuition about the subject of the thought experiment to be able to conduct the thought experiment.

Norton [in Brown, 1991:46] states that thought experiments are merely arguments; derivations from given premises. The information required for the thought experiment does not come from the reporting of new empirical data. The information should be non-controversial, elicited from information we already have by identifiable argument. Well known scientists who used thought experiments to great effect were Galileo, Einstein, Stevin, Heisenberg and Newton [Brown, 1991].

Given the above arguments, it seems appropriate to use a thought experiment for the validation of the generic integrated logistic support model. The thought experiment is based on the premises that all systems go through a life-cycle, that design should be a conscious effort and that organisations and products can be viewed as systems requiring both managerial and technical activities throughout its life-cycle.

## 9.3 Goldratt's thought experiment applied to an organisation as a system

Goldratt [1990:14-18] uses a thought experiment to derive generic operational measurements for an organisation. Based on the goal of a for-profit organisation, namely to make more money now as well as in the future, the thought experiment is conducted for a money-making machine. Thus the organisation's complexities are reduced to such a level where the essence of the organisation can be understood by analysing the money-making machine as a metaphor for an organisation. As durable products exist for a particular purpose, they can also be treated as money-making machines e.g. a manufacturer of motor vehicles buy an assembly robot (a product system) first and foremost to perform production activities but ultimately to help the organisation to make more money. Even in the event where a durable product is not bought to assist in making money, there still has to be a benefit which in the end can be equated to making more money. Three measurements are deductively defined for a money-making machine (i.e. the organisation or the durable product). These measurements are throughput or the money-making machine's ability to generate money (or benefits in the case of a not-for-profit system), inventory which indicates the amount of investment required to buy, own and operate the money-making machine, and operational expense which is associated with the cost of operations of the money-making machine. The formal definitions for the three measurements are the following [Goldratt, 1990:19, 23, 29]:

- Throughput is the rate at which the system generates money through sales and can be expressed as :

$$Throughput = Volume(Selling\ price - Variable\ cost) \tag{9.1}$$

where variable cost refers to true variable cost.

- Inventory is all the money the system invests in purchasing things the system intends to sell. Inventory consists of all, raw material, work in process, finished goods, fixed assets and moveable assets. The goal is to make money, not to own assets. If assets do not make money, they should be sold.
- Operating expense is all the money the system spends in turning inventory into throughput and consist of all fixed costs, whether direct or indirect, that does not change with an increase or decrease in volume.

## 9.4 Using Goldratt's machine as the subject of the thought experiment to validate the generic model for integrated logistic support

The measurements of throughput, inventory and operational expense as defined by Goldratt in his thought experiment are in line with the measurements of systems (ability, availability and affordability) as defined in this thesis. Throughput relates to ability, while inventory and operational expense relate to affordability. The system measurement that is not directly addressed in the measurements of the money-making machine, is availability. However, if Goldratt's thought experiment is scrutinised, one would find the availability dimension when the throughput is considered in line with its definition as a function of time, i.e. a rate and thus availability. The rate also implies a lapse of time and thus the life-cycle approach. A further point on the life-cycle approach is that inventory relates to the investment required to obtain and operate the system, again indicating a lapse of time and therefore the life-cycle. Furthermore, operational expense relates to the cost of obtaining, starting up and operating the money making machine. Again, a lapse of time is suggested and thus the life-cycle is implied. Within cost of operation the cost of maintenance is also included. The same money-making machine in Goldratt's thought experiment can thus be used as a thought experiment to validate the model proposed by this research, applicable to both organisational and product systems, as all three the system measurements can be demonstrated to improve through this experiment.

However, not all systems have profit motives and to simplify the thought experiment, the thought experiment will be reduced to just a machine. The generic operational measurements are also applicable to non-profit organisations. In order to cater for non-profit organisations, the definition of throughput is changed from 'generating money through sales' to 'generating goal units'. The limiting of the thought experiment to a machine is valid, as all systems (now represented by the machine) are built for a purpose defined as goal units, and the measurements of ability, availability and affordability are still applicable. The thought experiment is thus used to demonstrate how the application of the principles and interactions of the integrated logistic support model to a machine over its life-cycle will improve the ability, availability and affordability and thus overall machine performance.

Using a machine as the subject of the thought experiment, does not reduce the thinking to the machine age of systems thinking (see § 4.3.1). System age thinking (see § 4.3.2) is still used as the machine is still viewed within its larger context (expansionism), it is goal seeking (teleology), and optimising a single part (e.g. ability) does not necessarily improve the system as a whole (synthetic thinking).

## 9.5 The structure of the thought experiment

As has been shown in the Chapter 5, all things are created twice. Covey [1992:99] states that "*you really have to make sure that the blueprint, the first creation, is really what you want, that you have thought everything through. Then you put it in bricks and mortar*." Covey [1992:100] further argues the principle that all things are created twice by stating that the first creation can be either of conscious design or it can be left to chance. What is implied in Covey's statement is that design should be a conscious effort followed by the physical construction. What he fails to address, but what follows naturally, is after the construction one needs to consciously manage and use (operate) what has been created, otherwise it will not fulfil its purpose.

As has been demonstrated in § 4.8.1, system (and thus machine) success is measured using the three measurements of ability, availability and affordability. If any one of these dimensions of success is not met, the machine cannot be successful in pursuing its goal. These measurements are to be considered during the design as a conscious effort to achieve all three measurements. The first measurement is concerned with the machine's functional ability i.e. what the machine can do. Machines are designed and operated to achieve a specific purpose. If that purpose or goal cannot be achieved, the machine is useless. The second measurement is concerned with the machine's availability to perform its intended function. A machine with excellent ability but no availability is also useless. The third measurement ensures that the machine is affordable i.e. the benefits derived from the machine are more than the associated cost.

In order to perform the thought experiment, the two integrated logistic support dimensions (introduced in § 4.6) of the machine are to be considered. They are the logistic subsystem, from here on referred to as the operational support, and the maintenance subsystem, from here on referred to as the maintenance support. The operational support and maintenance support of the machine are necessary for the ability, availability and affordability that will lead to overall system success. These relationships are shown in Figure 9.2. These two dimensions provide clarity on how good design decisions during the acquisition phase and the execution thereof during the operational phase, along with the management of the design and operational activities throughout the life-cycle will ensure improved ability, availability and influence affordability of the machine.

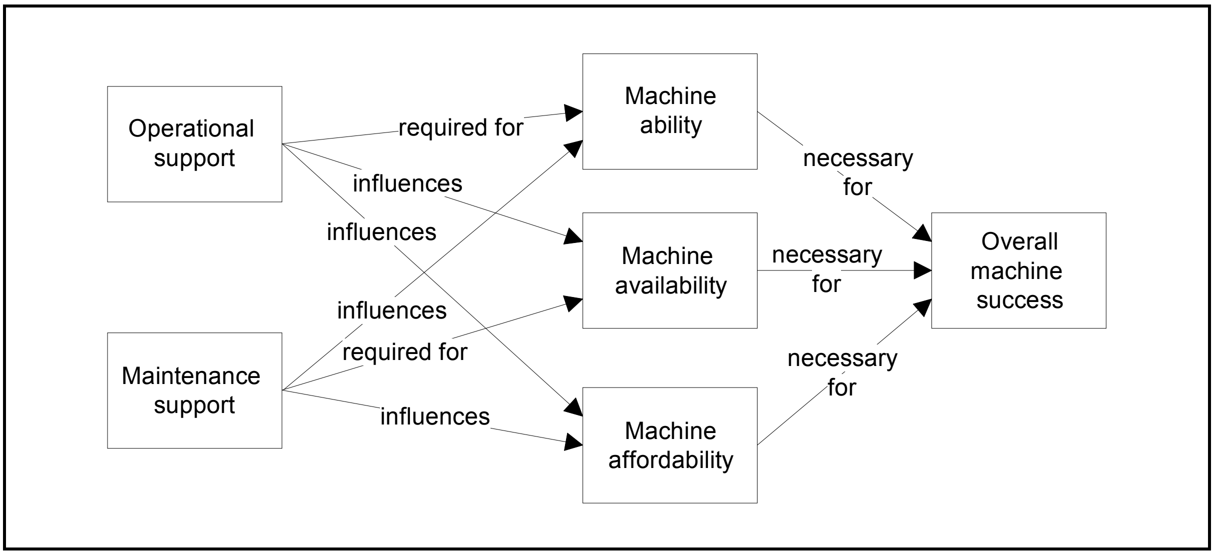



**Figure 9.2: The relationship between the two dimensions of integrated logistic support and the system measurements**

The operational support dimension deals with the operational requirements of the machine to perform its intended function. The first part of the thought experiment is conducted by viewing the design of a machine without considering the operational support required. This is then compared to when the design is a conscious effort where the principles of the integrated logistic support approach as proposed by the model for integrated logistic support are considered. This first part of the thought experiment is dealt with in § 9.6.

The maintenance support dimension deals with the maintenance requirements, derived from the interrelationships between the inherent design characteristics and its influence on the requirements for restoring and/or retaining the machine in an operable state. Thus the second part of the thought experiment will be conducted by viewing the design of a machine without considering the maintenance support required during its operational phase. This will then be compared to the design being a much more conscious effort where the principles of the integrated logistic support approach are considered. This second part of the thought experiment is dealt with in § 9.7.

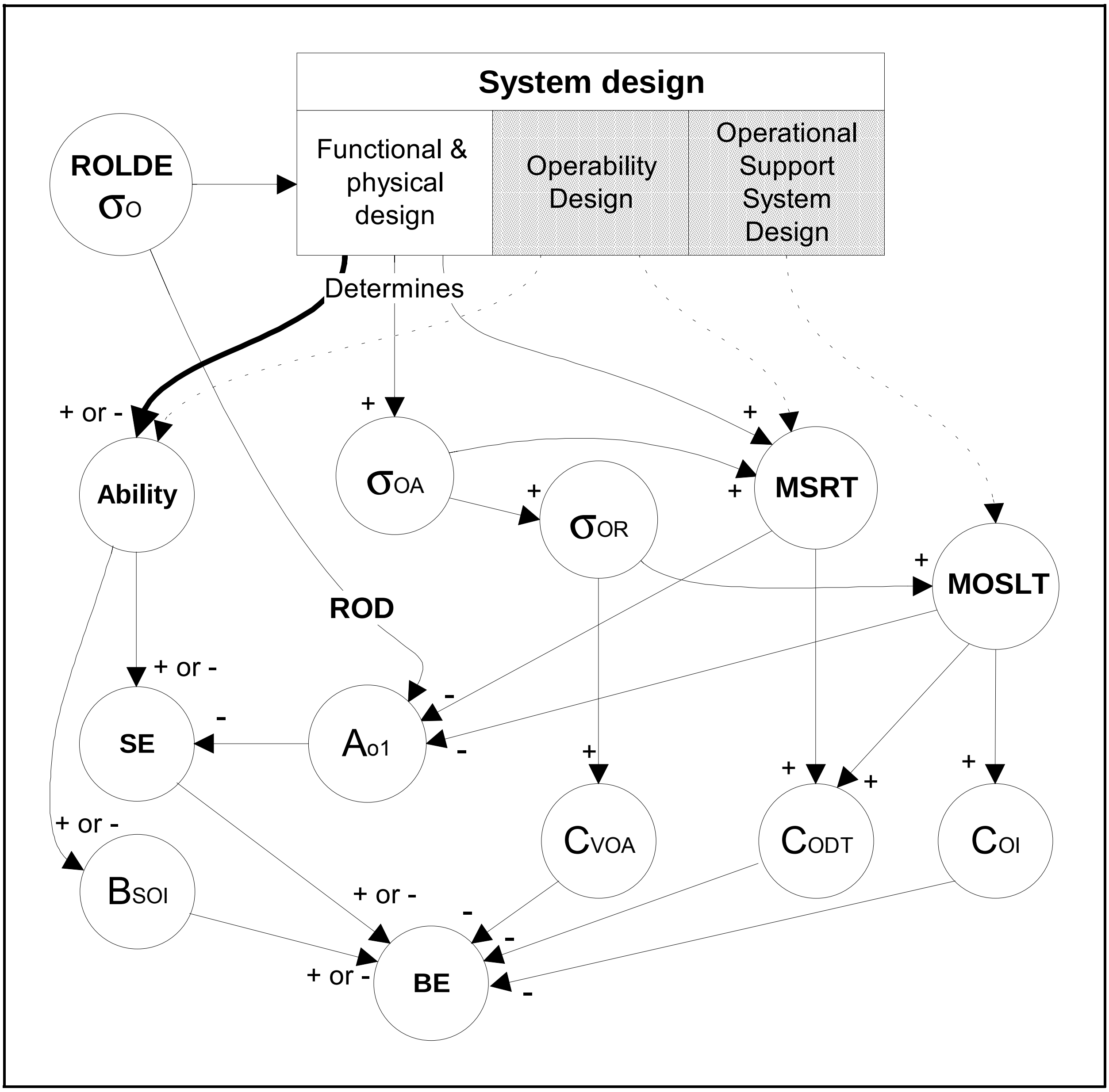
The thought experiment will be concluded by validating the management requirements as proposed by the model for integrated logistic support to ensure ability, availability and affordability of the machine during each of the life-cycle phases. This final part of the thought experiment is dealt with in § 9.8.

## 9.6 The operations support perspective of achieving machine success

When considering the design activities of a machine from an operational support perspective, it can be divided into different sets of activities, namely the functional and physical design, the operability design (the ease with which the machine can be operated) and the operational support system design (the business logistics). These design activities can be linked to the overall system measurements discussed in § 4.8.1, namely ability, availability and affordability of the machine, and the relationships between the design activities (operational perspective) and the overall system measurements can be identified and explained using implication diagrams.

### 9.6.1 Implication diagram tracing machine success when ignoring the approach to integrated logistic support

Figure 9.3 shows the complex interactions between the design activities (operational support perspective) and the overall measurements. It is an implication diagram tracing the effects of emphasising functional and physical (ability) design without consciously considering the operability design and the operational support system design. Ignoring these last two design activities more often than not increases the mean system replenishment time (MSRT) and the mean operational support lead time (MOSLT).




| | | | |
|---|---|---|---|
| ROLDE | Required operations load, duration and environment. | $\sigma_O$ | Operations demand rate. |
| ROD | Required operations duration. | $\sigma_{OA}$ | Operations activity demand rate. |
| MSRT | Mean system replenishment time. | $\sigma_{OR}$ | Operations resources demand rate. |
| MOSLT | Mean operational support lead time. | $B_{SOI}$ | Benefits derived from the ability of the system of interest. |
| $A_{O1}$ | Operational availability (Operational support perspective). | $C_{OI}$ | Cost of operations infrastructure. |
| BE | Benefit effectiveness. | $C_{VOA}$ | Variable cost of operations activities. |
| | | $C_{ODT}$ | Opportunity cost of operational down time. |

**Figure 9.3: Implication diagram focussing on ability only, ignoring operational operability design and operational support system design**

The dark line between functional/physical design and ability in Figure 9.3 indicates that the emphasis of design is on improving the machine's ability whereas the shaded areas indicate that the other design activities and their interfaces (dotted lines) with the measurements, are not getting any emphasis and are being ignored. This emphasis on functional and physical design causes the ability of the machine to improve. However, if consideration is not given to operability design, the ability of the machine may even decrease because of more complex man-machine interfaces, the inability of the human to operate and control the machine or poor ergonomic design. Emphasising ability design may cause an increase in ability, but at the same time cause a much bigger demand for operational activities ($\sigma_{OA}$) (e.g. increased power output for a Formula 1 Grand Prix car but higher fuel consumption, therefore more support activities to replenish the fuel). An increase in the demand for operations support activities immediately increases the demand for operational resources ($\sigma_{OR}$). Take note that the type of operation undertaken by the machine will determine which operational activities and resources will be required e.g. high flying reconnaissance versus take-off and landing training with the same aircraft.

Conceptually a machine's availability is expressed as the ratio of machine's available operational time divided by the total machine time. In order to explain this dimension of operational availability it is necessary to take the required operation duration (ROD) for the machine as the total machine time. From a machine user's perspective the machine is required to be available for the total duration of machine operation which implies 100% availability. The available time can however be interrupted by operational activities which are required to ensure operations, e.g. refueling and operator relief/changeover. This figure is expressed as the mean system replenishment time (MSRT) and reduces the available time for operation. Having the necessary operations support resources (fuel, fresh operator) available when needed depends on the support system and is expressed as the mean operational support lead time (MOSLT). This figure also reduces the available time for operation if the machine has to wait for operations support resources e.g. raw material required is not available. The operations support perspective allows the availability equation to be expressed as:

$$A_{o1} = \frac{ROD - MSRT - MOSLT}{ROD} \quad (9.2)$$

Regarding the affordability, there is a variable component which will cause a variable cost ($C_{VOA}$) associated with operations e.g. fuel or raw material required, which will increase with an increase in the demand rate for operational support resources ($\sigma_{OR}$).

The mean system replenishment time (MSRT) is influenced by two factors. The first factor is the frequency of operational activities required. The higher the frequency the more time is spent on doing operational activities (e.g. one pit stop vs two pit stops for a Formula 1 Grand Prix car). The second factor is the ease or difficulty of performing these operational activities. How short these times are depends heavily on integrating the physical design with the operation support system design e.g. the success of a Formula 1 Grand Prix car pit stop is determined by closely integrating the physical design of the car (design of wheel attachments and fuel tank/receptacle) and the design of the support resources (mechanics, jacks, tools, fuel replenishing equipment, spares).

An increase in the demand for operational resources will cause a bigger demand on the operation and support system that are to supply these resources. This bigger demand on the operations support system will lead to an increase in the mean operational support lead time (MOSLT). The bigger the load on the operational support system, the higher the cost of operational infrastructure ($C_{OI}$).

The combined effects of the increase in mean system replenishment time (MSRT) and the mean operational support lead time (MOSLT) will cause the operational availability ($A_{O1}$) to go down (refer to equation 9.2). Even though ability has gone up, it would only be luck if the decrease in availability balances out with the increase in ability when the system effectiveness is calculated (see equation 4.4). Considering the increase in all costs identified and an increase in overall ability, combined with a most probable drop in system effectiveness, the nett benefit calculation (see equation 4.7) will determine in the final instance the nett effect of the attempt to improve ability. Again, it will only be luck if the conflicts balance out. Thus it is concluded that integrated functional/physical, operability and operational support system design is imperative from an operational perspective in order to achieve overall system success.

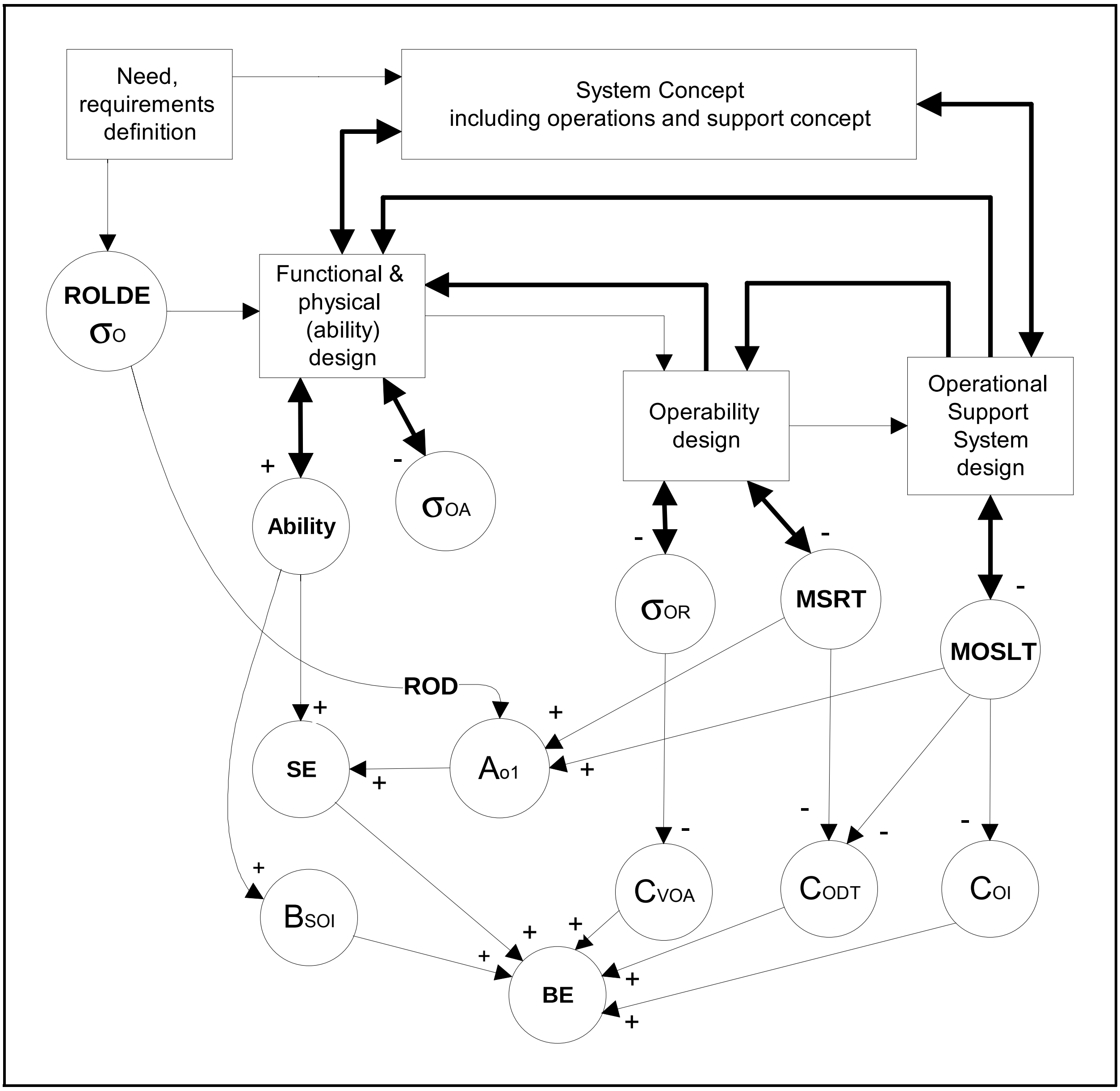
The operational support perspective leading to the achievement of overall system success is thus based on two premises. The first is that no system can truly be a closed system which implies that any system needs to be supported to perform its intended function otherwise it will (eventually) cease to function. Thus the support system must be of conscious design. The second premise is the design can be influenced to improve the man-machine interface and the operability characteristics of the system.

### 9.6.2 Implication diagram tracing system success when machine operability design and operational support system design is a conscious effort

Figure 9.4 provides a view of the integrated logistic support design activity as proposed by the model in Chapter 8. Thin lines indicate flow from one activity to another or cause-effect relationships. Dark lines indicate design influencing loops from one design activity to another or between a design activity and parameters that need to be improved.

Tracing the logic in Figure 9.4, the outcome of the functional and physical design activity is the ability of the design with its associated man-machine interface. The demand for operational activities ($\sigma_{OA}$) consists of two dimensions. The first dimension of operational demand relates to the people and resources directly interfacing with the machine in order to operate the machine. Factors to be considered when doing the functional and physical design with regards to the operating personnel and resources are the following:

- Operator skills and operator task complexity.
- Ease of machine operation and machine control.
- Consideration of operating environmental conditions.
- Ergonomics of the machine operator interface.
- Safety of operating personnel.
- Standardised operating procedures.
- Additional training requirements for operating personnel.




| | |
|---|---|
| ROLDE | Required operations load, duration and environment. |
| ROD | Required operations duration. |
| MSRT | Mean system replenishment time. |
| MOSLT | Mean operational support lead time. |
| $A_{O1}$ | Operational availability (Operational support perspective). |
| BE | Benefit effectiveness |
| $\sigma_O$ | Operations demand rate. |
| $\sigma_{OA}$ | Operations activity demand rate. |
| $\sigma_{OR}$ | Operations resources demand rate. |
| $B_{SOI}$ | Benefits derived from the ability of the system of interest. |
| $C_{OI}$ | Cost of operations infrastructure. |
| $C_{VOA}$ | Variable cost of operations activities. |
| $C_{ODT}$ | Opportunity cost of operational down time. |

**Figure 9.4: Implication diagram of the generic approach to integrated logistic support (Operational support perspective)**

The second dimension of the demand for operations ($\sigma_{OA}$) consists of the personnel and resources required to provide operational support and keep the machine running. These activities are not to be confused with maintenance activities. In some cases there is no distinction between the personnel and resources required for operation and those personnel and resources required for operational support (e.g. the operator of a tractor on a farm will, apart from ploughing, also replenish the fuel) while in other cases there is a clear distinction between the personnel and resources required for operation and operational support (e.g. a racing driver responsible for operation and his pit crew responsible for operational support). The aim of functional/ physical design is thus to increase the ability by taking into consideration the man-machine interface by reducing the amount of operator activity while at the same time reduce the demand for operational support activities. This approach is not an attempt to eliminate people from systems. The rule of thumb as far as this author is concerned is to have operators do those tasks which are within human capability and judgement, and where the performance of the human in executing the task is superior to that of equipment or technology. Factors to be considered when doing the functional and physical design with regard to the operating support personnel and resources are the following:

- Operational support skills and operational support task complexity.
- Ease of machine operational support and operational support system control.
- Consideration of operational support environmental conditions.
- Ergonomics of the machine operational support interface.
- Safety of operational support personnel.
- Standardised operational support procedures.
- Additional training requirements for operational support personnel.

The demand for operational activities ($\sigma_{OA}$) is heavily influenced by the required operational load, operational duration and operational environment. The frequency of demand for operations ($\sigma_{O}$) will also have a major influence on the demand for operational activities ($\sigma_{OA}$), especially if the machine has major start-up and shut down operational support requirements e.g. a steel mill.

The operability design uses input provided by the ability design to analyse the physical characteristics of the design along with the man-machine interfaces to ensure that the operational resources (operating and support) can be minimised as much as possible without affecting performance. Operability design consist of two dimensions. Firstly it is concerned with the design of the operational activities, both the operations tasks and the support tasks. Secondly it is concerned with the identification of operational resources required to perform those tasks. Feedback is provided to improve the design in order to have fewer (but more effective and efficient) operational tasks and less operational resources. Feedback is also provided to ensure that the interfaces between the design and the support system resources are compatible to ensure the lowest possible mean system replenishment time (MSRT). The less the demand for operational resources ($\sigma_{OR}$), the less the variable cost of operations activities ($C_{VOA}$).

The operational support system design uses input obtained from the operability design to ensure availability of all operational resources. The operational support system design must be done considering the operability (task) design and the demand rate and quantities for operational resources. The operational support system design has as its aim to provide the machine with the required resources for operations, both the operations dimension and the support dimension. This operational support system is what is commonly referred to as the business logistics or supply chain of the system. The unit of measure is the mean operational support lead time (MOSLT) and is calculated from the point in time where the machine is down due to a requirement for operational support, to the point in time where the resources are available to do the support. The actual support task, termed replenishment, will not be included in the mean operational support lead time (MOSLT); it is accounted for by the mean system replenishment time (MSRT). The operational support system design consists of all the managerial and technical designs to ensure that the operations support can take place, including activities like warehouse design, support inventory management systems, and selection, appointment, training and development of operating personnel. The operational support system can be a totally new system, or it can be a modification to the host system's existing operational support system. Failure to consciously design the operational support system of the machine will cause major disruptions during the operational and support phase.

The reduction of both the mean operational support lead time (MOSLT) and the mean system replenishment time (MSRT) will increase the operational availability ($A_{O1}$) of the machine (refer to Equation 9.2). The overall operational support system design should thus ensure that the mean operational support lead time (MOSLT) be zero from an operations point of view. This should be done without an excessive increase in the cost of infrastructure ($C_{OI}$), which during the operational phase will be considered a fixed cost. This implies that the operational support system must function in such a way that operations are not stopped during a required period of operation due to shortage of operational resources. The only way to achieve this, is to have a properly designed operational support infrastructure that considers the operational requirements. For more information on the principles of a distribution system design see Goldratt [1999]. It can be argued that the cost of infrastructure ($C_{OI}$) will rise dramatically in order to decrease the mean operational support lead time (MOSLT), as redundancy in the support system is required to achieve a low mean operational support lead time. However, it has been proven that the mean lead time of any operation can be reduced by not investing in huge amounts of redundancy, but to have high availability of resources and by processing/ordering in small lots more often [Goldratt, 1986 and 1999], which allows the total investment or cost of infrastructure ($C_{OI}$) to decrease. The approach is similar to the JIT philosophy of inventory reduction [Cheng and Podolsky, 1993:44-45].

The combined reduction of mean operational support lead time (MOSLT) and the mean system replenishment time (MSRT) will lead to a reduction in the cost of machine operational downtime ($C_{ODT}$). From the above it follows that the operational support system must be designed to use some form of buffer to make operational support lead time appear to be zero from an operational point of view. The bigger the buffer is, the higher the cost of operational infrastructure ($C_{OI}$), but at the same time the lower the cost of operational down time ($C_{ODT}$) due to higher availability of operational resources. As has been demonstrated in the previous paragraph, the cost of operational infrastructure ($C_{OI}$) need not increase, provided that the buffer within the operational support system is designed and managed properly. The design of this buffer should be based on the principle of smaller lots more often which will result in shorter overall lead times and reduced inventory.

Even though ability design and operability design are shown as separate blocks, the approach to be followed is to integrate these two design actions into one. These two design activities are interlinked through the design and overall design characteristics. The designer should thus know what the impact of any design decision is on the operability of the system and be able to trace the effects of the design decision down to the benefit effectiveness (BE) of the system of interest.

Figure 9.4 can thus be used to trace the effect of conscious integrated logistic support design decisions on the operability of the machine and the operational support system. It is not claimed that it represents a complete set of interdependent system characteristics, but it is used to convey the idea of the integrated nature of systems and how an integrated logistic support approach can improve the system performance.

## 9.7 The maintenance support perspective of achieving system success

When considering the design activities of a system from a maintenance perspective, it can be divided into different sets of activities, namely the functional and physical design, the reliability design, the maintainability design and the maintenance system design. These system design activities can be linked to the overall system measurements discussed in § 4.8.1, namely ability, availability and affordability, and the relationships between the system design activities (maintenance support perspective) and the overall system measurements can be identified and explained.

### 9.7.1 Implication diagram tracing system success when ignoring the approach to integrated logistic support

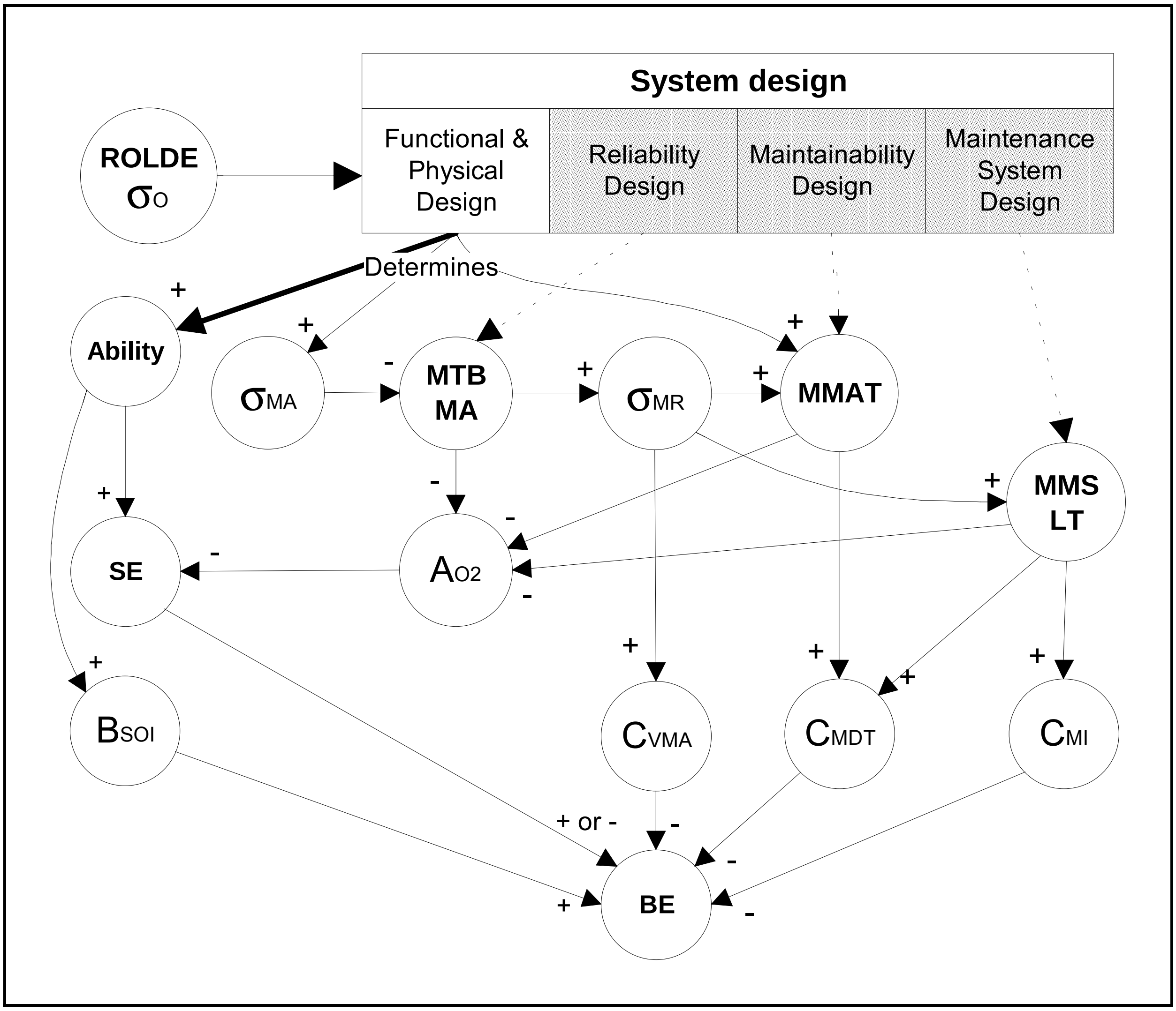
Figure 9.5 shows the complex interactions between the system design activities (maintenance support perspective) and the overall system measurements. Figure 9.5 is an implication diagram tracing the effects of focussing on functional and physical (ability) design without consciously considering the reliability design, the maintainability design and the maintenance system design. Ignoring these design activities more often than not decreases the reliability figure (mean time between maintenance actions - MTBMA) and increases the maintainability figures (mean maintenance activity time - MMAT and mean maintenance support lead time - MMSLT), resulting in a lower availability.

The dark line between functional/physical design and ability in Figure 9.5 indicates the emphasis in design is on improving the ability whereas the shaded blocks indicate that the other design activities and their interfaces (dotted lines) with the system measurements are not getting any emphasis and are being ignored. When the emphasis is placed on the functional and physical design it will cause the ability to improve. If consideration is not given to reliability design, the demand for maintenance activities ($\sigma_{MA}$) will increase (due to more possible failure modes, more parts, more complex interfaces), which will result in the mean time between maintenance activities (MTBMA) to decrease. This implies more maintenance activities, thus an increase in the demand for maintenance resources ($\sigma_{MR}$).

It has been shown previously in this thesis that availability is a function of both reliability and maintainability (see Equation 4.3). The reliability figure is expressed as the mean time between maintenance activities (MTBMA), implying the inclusion of both preventive and corrective maintenance activities in the availability figure. Maintainability is expressed as the sum of the mean maintenance activity time (MMAT) and the mean maintenance support lead time (MMSLT). The second dimension (the maintenance perspective) of operational availability ($A_{O2}$) can thus be expressed in the following equation:

$$A_{O2} = \frac{MTBMA}{MTBMA + MMAT + MMSLT} \qquad (9.2)$$

Emphasising the functional and physical design more often than not increases the mean maintenance activity time (MMAT). This is because factors like accessibility, ease of fault finding, use of standard components and other maintainability issues are ignored or forgotten in favour of improving the ability of the design. The increase in the demand rate for maintenance resources ($\sigma_{MR}$) and the increase in the mean maintenance activity time (MMAT) both cause a bigger demand on the maintenance system (whose design is also ignored) with a resultant increase in the mean maintenance support lead time (MMSLT).




| | | | |
|---|---|---|---|
| ROLDE | Required operations load, duration and environment. | $A_{O1}$ | Operational availability (Maintenance perspective). |
| MTBMA | Mean time between maintenance activities. | $\sigma_O$ | Operations demand rate. |
| MMAT | Mean maintenance activity time for both preventive and corrective maintenance. | $\sigma_{MA}$ | Maintenance activity demand rate. |
| MMSLT | Mean maintenance support lead time. | $\sigma_{MR}$ | Maintenance resources demand rate. |
| SE | System effectiveness. | $B_{SOI}$ | Benefits derived from the ability of the system of interest. |
| BE | Benefit effectiveness. | $C_{VMA}$ | Variable cost of maintenance activities. |
| | | $C_{MDT}$ | Opportunity cost of maintenance down time. |
| | | $C_{MI}$ | Cost of maintenance infrastructure. |

**Figure 9.5: Implication diagram focussing on ability only, ignoring reliability, maintainability and maintenance system design**

The combined effects of the decrease in the mean time between maintenance activities (MTBMA), and the increase in both the mean maintenance activity time (MMAT) and the mean maintenance support lead time (MMSLT), will cause the operational availability to go down (refer to Equation 9.2). Even though the ability has gone up, it would be luck if the decrease in availability balances out with the increase in ability when the system effectiveness is calculated (see Equation 4.4). It is also clear that the increased demand rate for maintenance resources ($\sigma_{MR}$) will have the variable cost of maintenance activities ($C_{VMA}$) increase (more spares, consumables), and the increase in mean maintenance lead time (MMLT) will cause the cost of maintenance infrastructure ($C_{MI}$) to increase (more facilities, personnel, warehouses, maintenance management systems). The cost of maintenance downtime ($C_{MDT}$) will increase due to the increase in mean maintenance activity time (MMAT) and the increase in mean maintenance support lead time (MMSLT).

The nett effect on the system will be seen in the benefit effectiveness calculation (see equation 4.7). Even if system effectiveness does go up, which is not very likely because of decreased availability, and a positive effect is seen on the benefits delivered by the system because of the increase in ability, the benefit effectiveness will probably go down because of the effect of the increase in cost. Again, an increase in net benefit effectiveness will be luck if the increase in ability is pursued at the expense of reliability, maintainability and the maintenance system design.

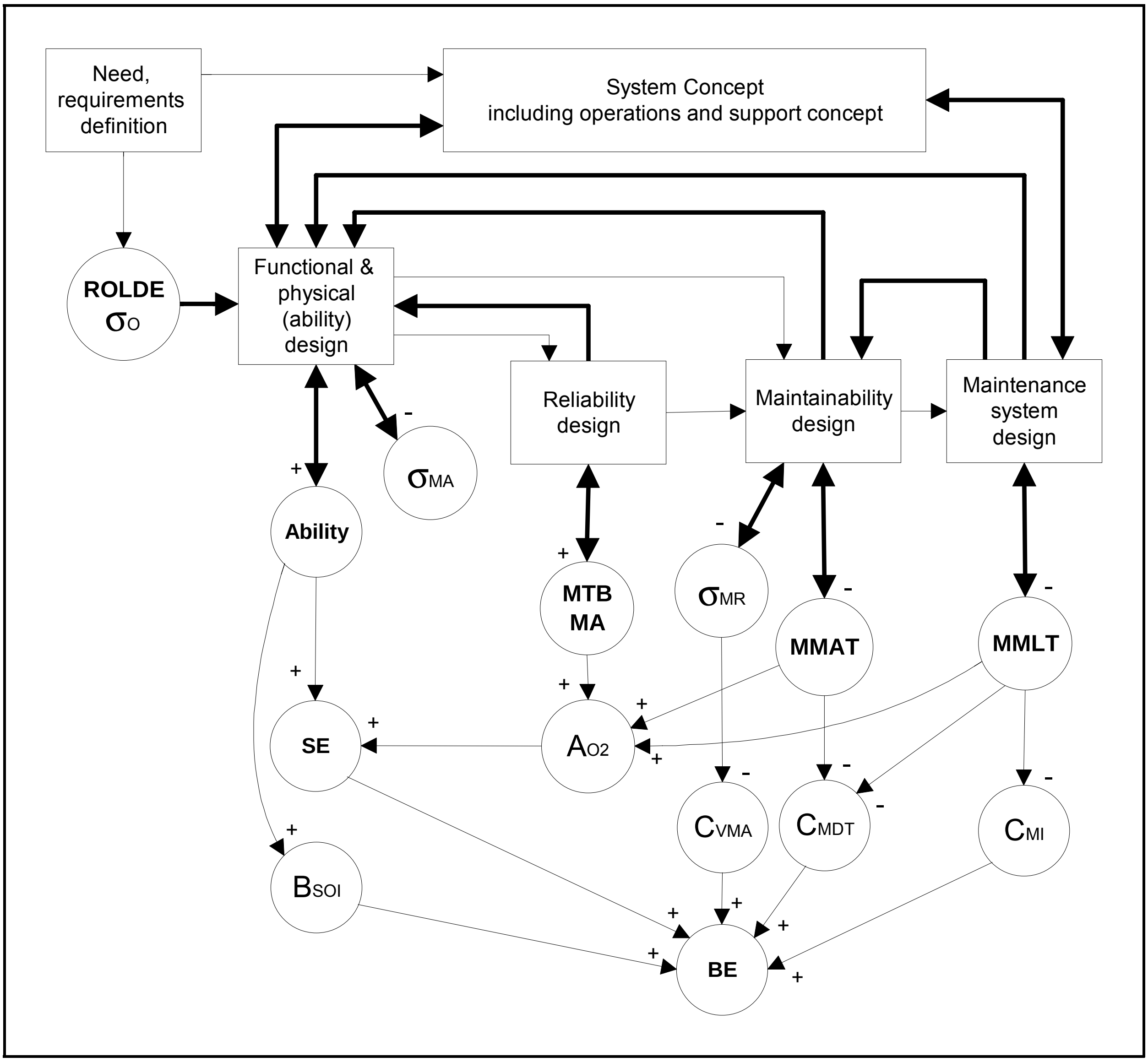
It can thus be concluded that designs cannot be optimised independently, which means that design trade-offs are to be made between the different design activities to get a better overall design [M'Pherson, 1981:574]. From the maintenance perspective, the design activities required to achieve overall system success are the reliability design, maintainability design and the maintenance system design. On the higher system level these design activities are interlinked by the operations and support concept (which was discussed in § 8.3.1.3), which allows the different design activities to make use of each other's output within a common framework, but also allows feedback or design influencing. This integrated approach to logistic support design takes into consideration not only the performance characteristics of the design (ability), but the overall system performance and improving the overall system outcome expressed as the nett benefit of the system.

The maintenance perspective leading to the achievement of overall system performance is based on three premises. The first premise is that systems are not perfect and the mean time between failure is not infinitely large, thus maintenance activities - both preventive and corrective - are required. The second premise of the maintenance perspective is that a design can be influenced or changed to improve the inherent reliability and maintainability characteristics of the design. The third premise is that the maintenance support system has to be properly designed in order to provide the maintenance support to achieve the ability, availability and affordability requirements of the system.

### 9.7.2 Implication diagram tracing the system success when system reliability, maintainability and maintenance system design is a conscious effort

Figure 9.6 provides a view of the integrated design activities proposed by the model in Chapter 8. Dark lines indicate design influencing feedback from one design activity to another or between a design activity and a parameter that needs improvement.

Tracing the logic in Figure 9.6, the outcome of functional and physical design is the ability of the design as well as the demand rate for maintenance activities ($\sigma_{MA}$). The aim is improving the ability but at the same time decreasing the demand for maintenance activities ($\sigma_{MA}$). When designing, designers should consider the different modes of operation of the concept under consideration, expressed as the required operation load and duration, the environment in which the operation will take place (ROLDE), as well as the demand rate for operations ($\sigma_O$). These two (ROLDE and $\sigma_O$) in combination will have a major influence on the demand rate for maintenance activities ($\sigma_{MA}$). A high operational demand rate implies many stop-start situations, which may cause more wear and tear on the system, whereas a low demand rate may have less wear and tear due to fewer stop-starts. Long durations of operations may require high reliability with few start-ups and shut-downs, such as a satellite system, but at the same time require good maintainability to minimise down-time as much as possible. Using a system in a controlled environment, such as an electronic system in a clean room with well trained operators, as opposed to a military system in harsh environmental and battle conditions, will have a major influence




| | | | |
|---|---|---|---|
| ROLDE | Required operations load, duration and environment. | $A_{O1}$ | Operational availability (Maintenance perspective). |
| MTBMA | Mean time between maintenance activities. | $\sigma_O$ | Operations demand rate. |
| MMAT | Mean maintenance activity time for both preventive and corrective maintenance. | $\sigma_{MA}$ | Maintenance activity demand rate. |
| MMLT | Mean maintenance lead time. | $\sigma_{MR}$ | Maintenance resources demand rate. |
| SE | System effectiveness. | $B_{SOI}$ | Benefits derived from the ability of the system of interest. |
| BE | Benefit effectiveness. | $C_{VMA}$ | Variable cost of maintenance activities. |
| | | $C_{MDT}$ | Opportunity cost of maintenance down time. |
| | | $C_{MI}$ | Cost of maintenance infrastructure. |

**Figure 9.6: Implication diagram of the generic approach to integrated logistic support (Maintenance support perspective)**

on the probability of experiencing breakdowns. The intensity of the load (running at full capability or at half load) also influences the demand for maintenance activities ($\sigma_{MA}$).

Thus the demand for maintenance activities ($\sigma_{MA}$) is a direct result of the inherent failure modes of the design. This means that the inherent reliability of the design is a direct consequence of ability design, influenced by the required operation load, duration and environment (ROLDE) and demand for operations ($\sigma_O$), and expressed as mean time between maintenance activities (MTBMA). It is therefore imperative that reliability design takes place as a conscious interactive design action order to get satisfactory performance ***and*** reliability of the design. Reliability design receives its input from the ability design and takes into consideration how the design can fail, the frequency of failures (the demand rate for maintenance activities), and the effects and seriousness of the failures.

If the ability is satisfactory, but the reliability and/or safety is not, feedback should be given to the ability design to improve the design from a reliability and/or safety point of view. Design feedback from a safety point of view, aims to change the design to eliminate a certain failure mode to make the design more safe, or to add safety measures to reduce the probability of that safety failure from occurring. Design feedback from a reliability point of view aims to change the design in order to increase the reliability by reducing the demand rate for maintenance activities ($\sigma_{MA}$), thus increasing the mean time between maintenance activities (MTMBA). Improved reliability also implies less maintenance requirements resulting indirectly in a lower life-cycle cost. The design changes implemented to improve safety and reliability may cause the performance to either suffer or improve. In the final instance, the design has to strike a balance between performance, safety, and reliability to get the best overall system outcome within the available time and cost constraints of the development phase. The final outcome of reliability design is the mean time between maintenance activities (MTBMA), which implies both preventive and corrective maintenance that will be required by the system during the operational phase.

The data generated by the ability design and the reliability design serves as input to maintainability design. The maintainability design analyses the physical characteristics of the design, taking into consideration the nature and frequency of maintenance required to restore system availability (corrective maintenance), as well as the nature and frequency of the need to maintain system availability (preventive maintenance).

Maintainability design consists of three dimensions. The first dimension is concerned with the potential hazards and unsafe conditions of maintenance caused by the ability design. If, for instance, a high pressure vessel can be opened for maintenance without forcing the maintainer to bleed the pressure first, the design is inherently unsafe from a maintenance perspective. Thus, design feedback is given to improve the design from a maintenance safety point of view. Inherent design characteristics that cause unsafe maintenance conditions are identified to change the design to eliminate those unsafe maintenance conditions.

The second dimension of maintainability design is concerned with the inherent maintainability of the design which determines the amount of time required to restore the system to its original ability after a failure has taken place, or the time taken to retain it in its original state, provided all maintenance resources are available. This dimension is expressed as the mean maintenance activity time (MMAT). The maintainability design action is therefore concerned with the inherent maintainability design characteristics of the design and feedback is given to ability design in order to improve the design from a maintainability point of view. Similar to reliability influence, such design influence may cause the performance either to improve or suffer. Typical inherent maintainability characteristics that can be influenced to reduce the mean maintenance activity time (MMAT) are:

- Accessibility to components and sub-systems..
- Ease of performing maintenance activities, including ergonomics.
- Use of standard connectors.
- Ease of failure detection and failure isolation.
- Standardisation and rationalisation.

A reduction in the mean maintenance activity time (MMAT - the time required to perform the physical maintenance activity) will have a positive influence on the operational availability of the system. The mean maintenance activity time (MMAT) will partially determine the cost of maintenance downtime ($C_{MDT}$). The other component that determines the cost of maintenance downtime is the mean maintenance support lead time (MMSLT) which will be discussed in more detail as part of the support infrastructure of the maintenance system.

The third dimension of maintainability design is concerned with the identification of maintenance resources required to perform the maintenance activity and expressed as the demand for maintenance resources ($\sigma_{MR}$). The maintenance resources fall into two categories, namely a variable part and a fixed part.

The first maintenance resource category consists of the variable part e.g. consumables and spares, whose quantities are determined by the inherent maintainability of the design (e.g. using quick release fasteners for an attachment versus using four screws for the same attachment) and the nature of the maintenance activity design (e.g. modular replacement vs component replacement). Many times these quantities of spares or consumables will be required every time the maintenance activity is performed. Sometimes these quantities are based on a probability distribution or averages e.g. in 50% of the cases where a wheel repair is to be done a new tire is required. The demand rate for maintenance activities and the demand rate for the variable component of the maintenance resources will therefore result in a certain variable cost for maintenance activities ($C_{VMA}$).

The second category of the maintenance requirements consists of the support infrastructure or the fixed component of the maintenance system. The quantities of these maintenance resources are normally not discrete for the maintenance activity and is expressed as a percentage of a required resource's time that is needed to effect the maintenance activity. Examples of this fixed component are the percentage of one man-month required to perform a wheel repair, and the percentage of facility capacity that is required for the same maintenance activity. These resource capacities are normally fixed in the short to medium term, and many times also in the long term. It is much more difficult to adjust these resource levels once the system is in operation as opposed to adjusting the variable component of the maintenance resources. This fixed component also comprises the overall management system of the support system, which as a result determines the mean maintenance support lead time (MMSLT). This lead time includes all delays, technical and managerial, from the point in time where the system is down due to a failure or requiring preventive maintenance, to the point in time where the system is functional once more, the actual maintenance time excluded. The actual maintenance time is accounted for by the mean maintenance activity time (MMAT). Therefore, the resources considered to be the fixed component determine the cost of the maintenance infrastructure ($C_{MI}$) of the system, indirectly influenced by the demand rate for maintenance activities ($\sigma_{MA}$) and the demand rate for maintenance resources ($\sigma_{MR}$). It should be obvious that the mean maintenance support lead time (MMSLT) and the mean maintenance activity time (MMAT) combined are the major factors determining the cost of maintenance downtime ($C_{MDT}$).

In comparing the impact of the mean maintenance activity time (MMAT) and the maintenance lead time (MLT) on operational availability ($A_{O2}$ - see Equation 9.2), it is clear that the overall downtime should be mostly dependent on the mean maintenance activity time (MMAT). Therefore the design of the overall maintenance system plays a major role in the operational availability of the system of interest to ensure that no maintenance activity is delayed because maintenance resources are not available.

Even though ability design, reliability design and maintainability design are shown as separate blocks in Figure 9.6, it ultimately consists of one action namely design, which are interlinked through different design parameters and characteristics. The arrows from ability design leading to reliability design and maintainability design highlights this point. By doing ability design, the reliability and maintainability characteristics are implicated, thus what is required from the designer is to know the impact of any design decision on safety, reliability, maintainability and eventually maintenance cost. Therefore the design action should allow all dimensions, performance, reliability, maintainability and resultant cost to be considered at the same time to get the best design possible from an ability, availability and affordability point of view. It also has to be brought in line with the end goal of the system, a figure which is indicated by the benefits of the system of interest ($B_{SOI}$) that are to be delivered. In the final instance, the benefit effectiveness (BE) integrates ability, availability and affordability into one figure.

Figure 9.6 can thus be used to trace the impact design decisions will have on the different maintenance parameters of the system when the integrated approach to logistic support is used. It is not intended to provide a complete set of interdependent system characteristics (for example the cost of the design actions are not included), but can be used to illustrate how interdependent system and design characteristics are and how the generic approach to integrated logistic support influence can be used to influence the ability, availability and affordability of the system.

## 9.8. The management perspective of achieving machine success

To understand the importance of managing the structured, integrated approach that considers all relevant characteristics of the design in order to achieve an able, available and affordable system, a further thought experiment can be conducted to see what the expected effects are if proper management focus is directed towards each phase of the life-cycle. Without going into the same amount of detail as in the previous thought experiment, it is still possible to conduct the experiment without too much effort.

Not all phases of the life-cycle are managed in the same way as each life-cycle phase has a different objective and requires different methodologies and techniques. The main premise, however, is that people normally do what they like best. When people have to choose between filling out their tax returns as opposed to taking a trip to the beach, most people will choose the latter. When an operations manager of our machine have to choose between production and doing maintenance, he will most probably choose production, as production time is a much more favourable measurement than time spent on maintenance. Similarly designers would much rather spend time designing new features and improved ability than analysing possible failure modes to design remedies or maintenance procedures for that. Thus if one wants anybody who designs, operates or maintains the system to do what is good for the system as a whole, and not only do the things they like, the only remedy is for management to plan, organise, direct and control all the activities required for successful machine operation, even those activities people normally despise. Thus, all measurements must be considered by management at the same time.

Within the acquisition phase, management has to look after those design activities ensuring full integration between ability, operability and operational support system design, as well as integration between ability, reliability, maintainability and maintenance support system design. Consideration for safety is naturally part of both the operational support and maintenance support perspectives and should also be managed as such.

Within the construction phase, management has to ensure that not only the machine is built, but also that the support system is put into place from both the operational and maintenance point of view to ensure that operations can take place at the time of commissioning the machine, but at the same time handling any breakdown of the machine by either preventing the failure before occurrence or correcting the failure after its occurrence. The overall operational support system and the maintenance support system have to be managed as well.

The same logic can be followed for the management of the recycling, waste disposal and phasing out of the machine. It can thus be concluded that without the management activities that change focus as demanded by the changing requirements of the technical activities of each phase, and integrating all the different aspects that will make for a good system, the technical activities can never achieve the machine's desired ability, availability and affordability requirements. If one chooses to ignore these management activities, very little will be done on the logistic support system with a resultant negative effect on the overall measurements of the machine, especially availability and affordability.

## 9.9 Chapter summary

When a model is constructed, it should also be validated to the extent possible. Not all models can be validated using empirical data. Conceptual models such as the one proposed in Chapter 8, can be validated using a thought experiment. A thought experiment is an experiment of the mind, where the implications and consequences of applying or not applying the model are thought through in a structured manner. The techniques used in validating the model proposed by this research is implication diagrams.

Implication diagrams have been used to predict the outcome on system measurements when the technical dimension of the model describing the approach to integrated logistic support is applied or ignored. For both the operational support and the maintenance support, one can expect to have much better system performance if the model is applied to the development and operational phases of the system life-cycle. In the case where the model is ignored and functional design is done at the expense of operational and maintenance support design, one can expect the ability to improve but have severe problems with availability and affordability of the system.

The management dimension described in the model for integrated logistic support is also required to ensure that the technical dimension is executed in a proper way, resulting in an overall improvement of the system measurements. Not properly managing the technical activities will cause a regression of the system measurements.

# Chapter 10

# Conclusions and recommendations

*"I am not sure I should have dared to start; but I am sure that I should not have dared to stop."*

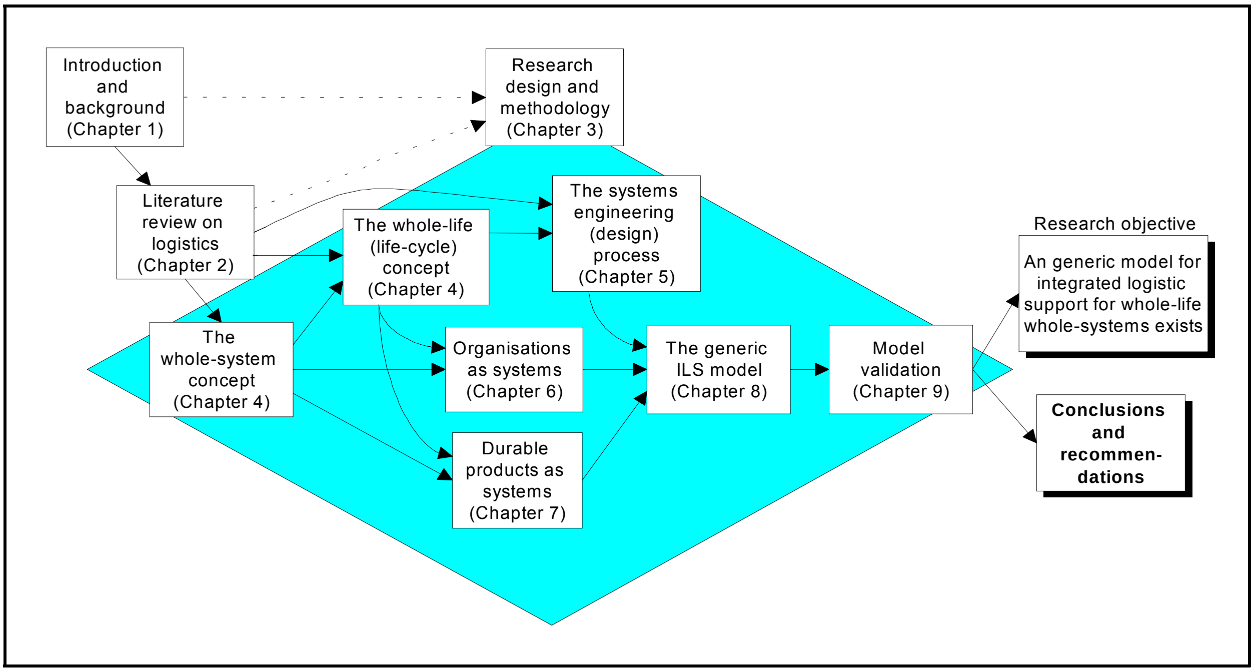
Winston Churchill

*"Real knowledge is to know the extent of one's ignorance."*

Confucius

*"It is better to ask some of the questions than to know all the answers."*

James Thurber




## 10.1 Purpose and outline of the chapter

The purpose of this chapter is to summarise the findings of this research and to draw conclusions. The theoretical contribution and practical application of the research is discussed, and recommendations for further research are made.

## 10.2 Summary of research results

### 10.2.1 Dynamic and detail complexity of systems

There is a major difference between the dynamic complexity and detail complexity of systems. Detail complexity is primarily concerned with the workings of the components of systems whereas the dynamic complexity deals with the interactions of system components that causes the emergent properties of systems. Because of the differences that exist between detail and dynamic complexity of systems it is necessary to have a sound understanding of systems in order to recognise and understand these differences. Only then can the system be managed on both the dynamic and detail complexity levels.

### 10.2.2 Generic sub-systems

It is possible to define sub-systems that are generic for all man-made systems, irrespective of the actual system under investigation. These sub-systems are the operating sub-system, the management sub-system, the support sub-system and the information sub-system. The interactions between these generic sub-systems can be explained using the dynamic complexity of systems. Having defined generic sub-systems for any man made system, it is thus also possible to define a generic approach to each of the generic sub-systems. This research focussed on the generic approach of the support sub-system (or integrated logistic support system), this sub-system being crucial for success of the overall system. If the integrated logistic support sub-system is ignored, the whole-system concept is not valid anymore. In order to be able to present a generic approach to the integrated logistic support system, the approach must be presented on the dynamic complexity level of systems, as the generic character of the approach is embodied in the dynamic complexity of systems. The detail complexity level of systems may require different approaches to integrated logistic support for different man made systems.

### 10.2.3 The dimensions of the system view

The holistic view of systems allows the understanding of systems existing in a hierarchy, the system having boundaries and interacting with its environment through inputs and outputs, and systems having a life-cycle. Understanding the holistic view of systems allows the importance of the life-cycle to be highlighted and the need for different managerial and technical activities for each sub-system within each phase of the life-cycle.

The synthetic view of systems allows understanding of the system being greater than the sum of its parts because emergent properties exist for the system that do not exist as part of any of the sub-systems, systems are constrained in its output by very few (mostly one) components (making sub-optimisation a very real possibility), and systems are subject to entropy on both the component and interaction levels of the system. Understanding the synthetic view of systems the need for the support sub-system is verified, and also the need to view the dynamic complexity to ensure system optimisation instead of only optimising the support sub-system.

The teleology view of systems allows understanding of the system being goal seeking and that the system exist for a purpose. Being goal seeking, measurements are required to measure the level of achieving the goal. Taking the teleology view and understanding whole-system and whole-life characteristics of systems, generic measurements of system success can be defined, namely ability, availability and affordability. These measurements are applicable to any system irrespective of the type of system or the system hierarchy level on which the system exists and functions.

### 10.2.4 The systems view and its relation to the support sub-system model

The above systems views can be applied to any man-made system. For the purpose of this research, these system views can be applied to all organisations (public and private, for-profit and not-for-profit) organisations as they all exist as systems. The systems view can also be applied to all durable products, as they also exist as systems. Services and consumable goods are not systems in themselves but exist as part of organisational systems.

Using a systems and life-cycle view, it can be demonstrated that a generic approach to the managerial and technical activities of the support sub-system for all man made systems can be taken. This generic approach to the support sub-system is presented as a graphical model and is called the generic approach to integrated logistic support for whole-life whole-systems. The fundamental system characteristics that were considered for the development of the model are the following:

- Systems go through a birth-life-death cycle (the life-cycle concept). Phases in the life-cycle follow a certain sequence which cannot be changed around.
- Apart from the technical activities that take place within a system, a system also requires managerial activities to plan, organise, direct and control the technical activities, and both the technical and managerial activities differ from life-cycle phase to life-cycle phase.
- A system exists for a particular purpose, which implies the need for measurements to measure goal achievement, requiring the integrated logistic support system to fit in with the system measurements.
- Due to the dynamic nature of systems, integrated logistic support actions taken during a particular phase may be aimed at providing positive system outcomes much later in the system's life-cycle.
- Systems need both operating and maintenance support for continuous goal achievement.

### 10.2.5 Implications of the model for integrated logistic support

System success can be expressed by the generic system measurements. Using the integrated model for whole-life whole-systems, strong relationships between actions taken during the early phases of the life-cycle and system success (generic system measurements) later in the life-cycle can be defined. The implication of applying the model to the system life-cycle can be demonstrated using the relationships between the actions and the system success measurements. Having a thorough understanding of these relationships can aid any designer to improve decision making from a system perspective. Implication diagrams provide a mechanism to conduct a thought experiment to allow the comparison of systems who choose to employ a whole-life whole-systems approach to integrated logistic support and those systems who choose not to employ a whole-life whole-systems approach to integrated logistic support.

These thought experiments can be considered a high level system dynamic simulation arguing the logic of the relationships between the actions proposed by the model and system success, rather than assuming the validity of relationships and using real life data to make comparisons. For the researcher interested in the detail complexity of systems, the relationships between the actions proposed by the model and system success measurements presented in this research can be used as the basis for detail complexity simulations and research.

### 10.2.6 Contributions of the research

The contributions of this research are the following:

- It provides a life-cycle approach to integrated logistic support as opposed to the functional view of logistics.
- It emphasises the dynamic nature of integrated logistic support sub-system within the system context as opposed to the detail complexity of logistics which often leads to sub-optimisation of the system of which the support sub-system is part.
- It shows the relationship between the managerial and technical activities within each major phase of the life-cycle.
- It highlights the importance of the logistic sub-system and the sequence of technical and managerial activities in its contribution towards system success.
- It provides a high level mathematical relationship between the managerial and technical activities associated with integrated logistic support and the generic system measurements of ability, availability and affordability.

## 10.3 The principal conclusions of the research

In order for any system to be successful, the correct system measurements need to be defined that will fully support the stated goal. All sub-systems that are part of the system should be measured according to their contribution to the overall systems success, and not according to some sub-optimising measurement for the sub-system itself.

Taking a functional view of logistics often leads to sub-optimisation of the overall system, as certain support activities (such as maintenance) are measured separately from the overall system and not according to its overall contribution to system success. Furthermore, much of the bad support system performance during the operational phase of the system life is the result of poor initial system design, i.e. focussing on functional design and ignoring or neglecting the support design.

Integrated logistic support should be based on a life-cycle approach for both the operational and maintenance support, from both a technical and managerial point of view. Failing to do so, will lead to sub-optimised system performance. The major contribution that can be made by the support sub-system, is during the early life-cycle phases. Placing the emphasis on support design during the early life-cycle phase does not mean providing the support can be neglected later on in the life-cycle.

A structured, integrated approach to designing and providing the system support, based on sound system measurement, is needed throughout the life-cycle. Both the sequence of managerial and technical activities are important. The generic integrated logistic support model for whole-life whole-systems provide such an approach.

## 10.4 Further research

Further research is necessary to investigate the detail complexity of integrated logistic support to ensure that it ties in with the dynamic complexity of integrated logistic support i.e. how counterintuitive actions can be eliminated from the detail complexity of integrated logistic support to fully support the dynamic complexity of systems expressed as optimum ability, availability and affordability.

As has been stated in § 10.2.5 the relationships between the actions relating to the support sub-system and the system measurements can be used as the foundation for models that describe the detail complexity of integrated logistic support. Further research can use the model and relationships between the support actions and the system measurements to identify areas of system improvement. Typical questions that may be investigated may include the following:

- How large (or small) should lot sizes be?
- What impact will the improvement of reliability and maintainability have on the system measurements?
- Should a design be changed to have less support requirements?
- How many support levels are needed for the system?
- How should the supply chain be designed?
- Will a major redesign during the operational phase provide sufficient benefits?
- How much protective capacity is needed within the maintenance department?

The key to success would be to establish the detail relationships between the operational and maintenance support action, and the ability, availability and affordability of the system.

*"It is not the critic who counts, not the man who points out how the strong man stumbled, or where the doer of deeds could have done better. The credit belongs to the man who is actually in the arena, whose face is marred by dust and sweat and blood, who strives valiantly, who errs and comes short again and again, who knows the great enthusiasms, the great devotions, and spends himself in a worthy cause, who at best knows achievement and who at the worst, if he fails, at least fails while daring greatly. His place shall never be with those cold and timid souls who know neither victory nor defeat."*

Theodore Roosevelt

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