

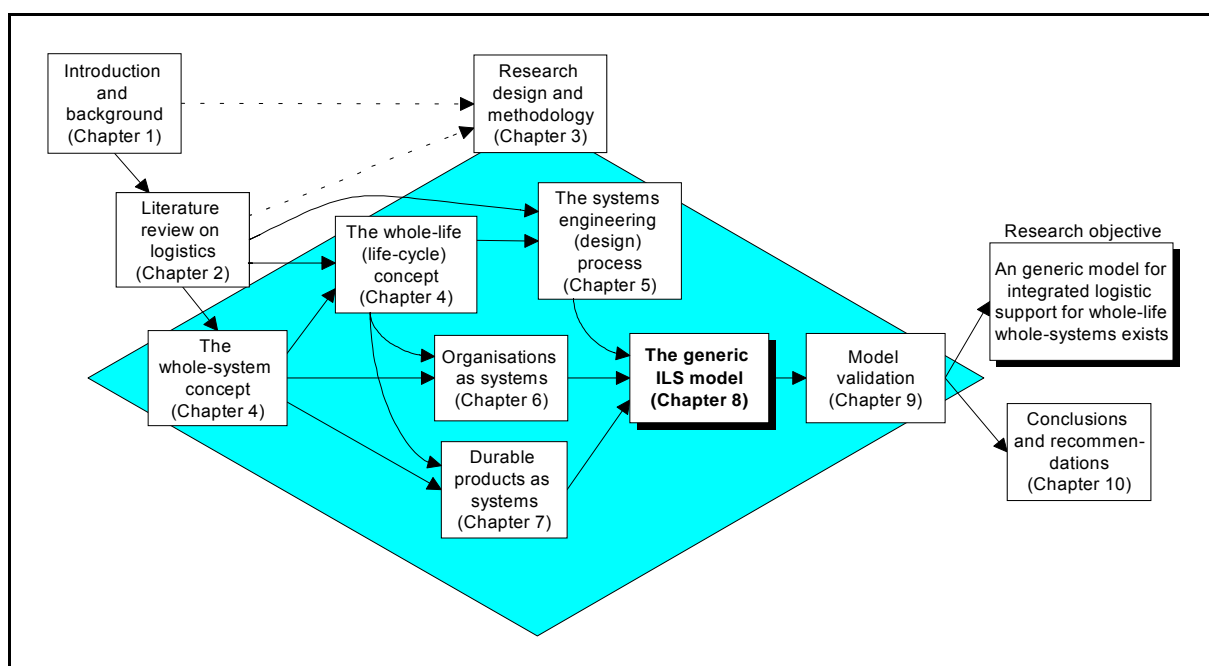
Chapter 8

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.

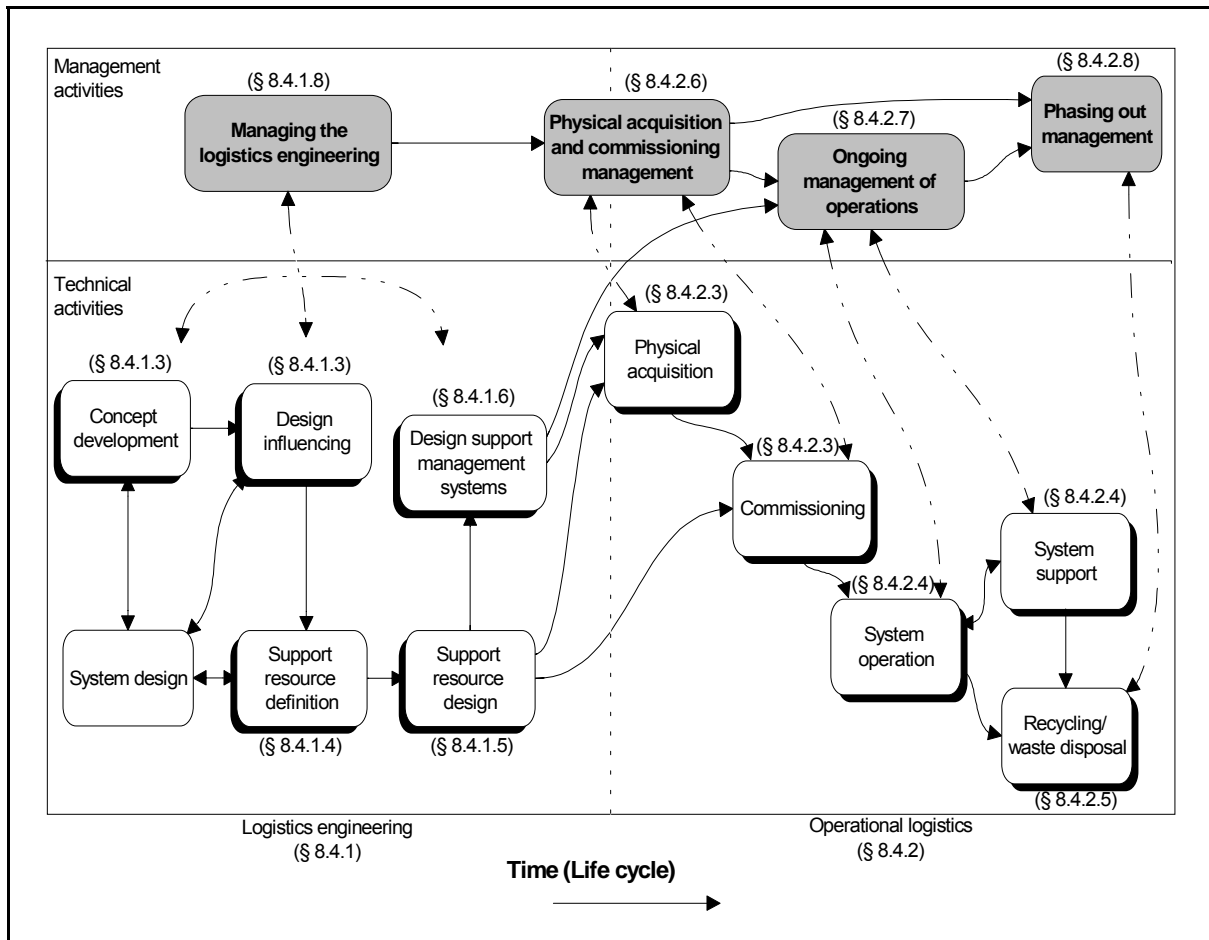


Figure 8.1: Outline of the proposed model for integrated logistic support for whole-life whole-systems

On the horizontal 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 horizontal 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 their 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 biased 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.

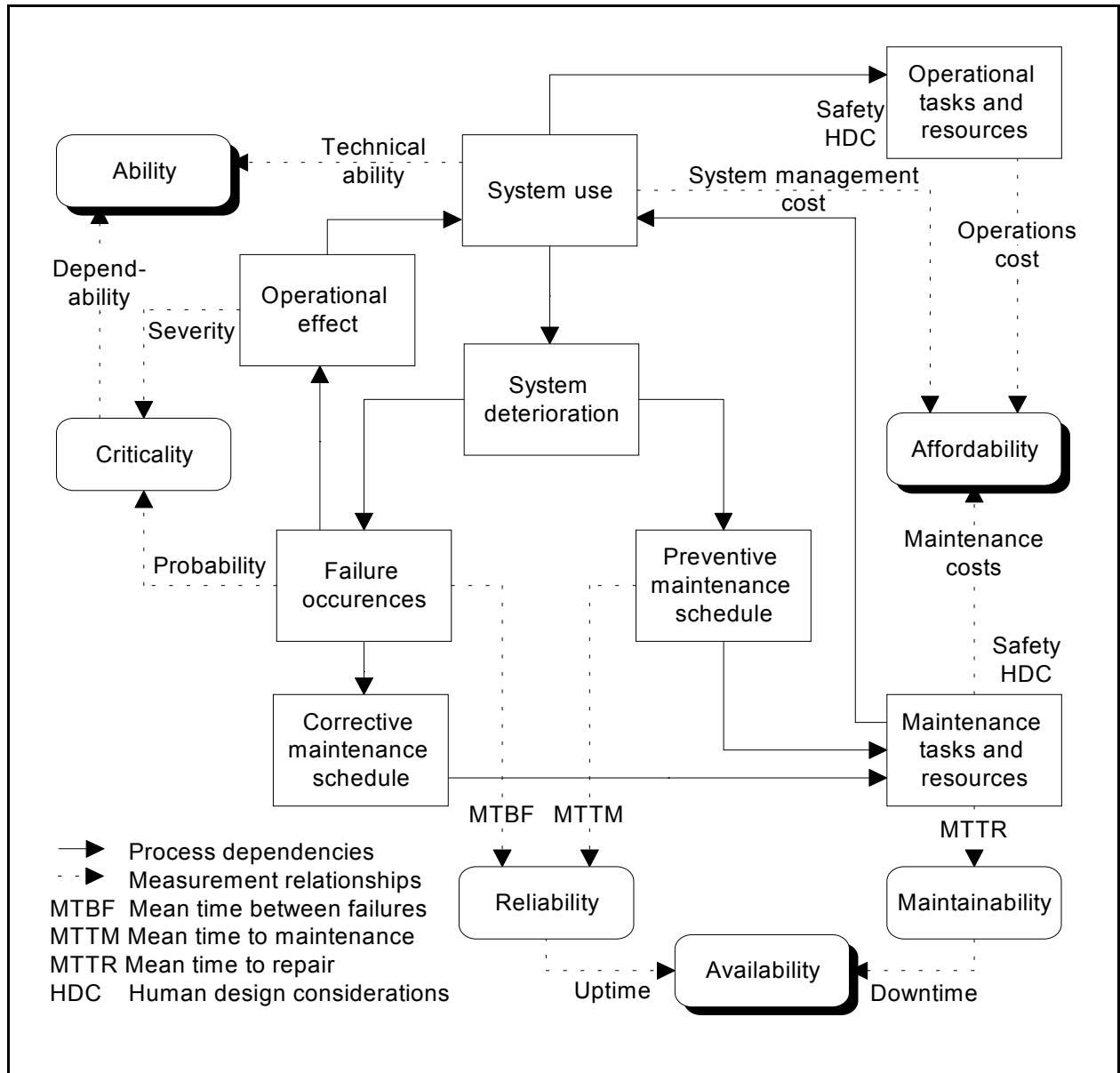


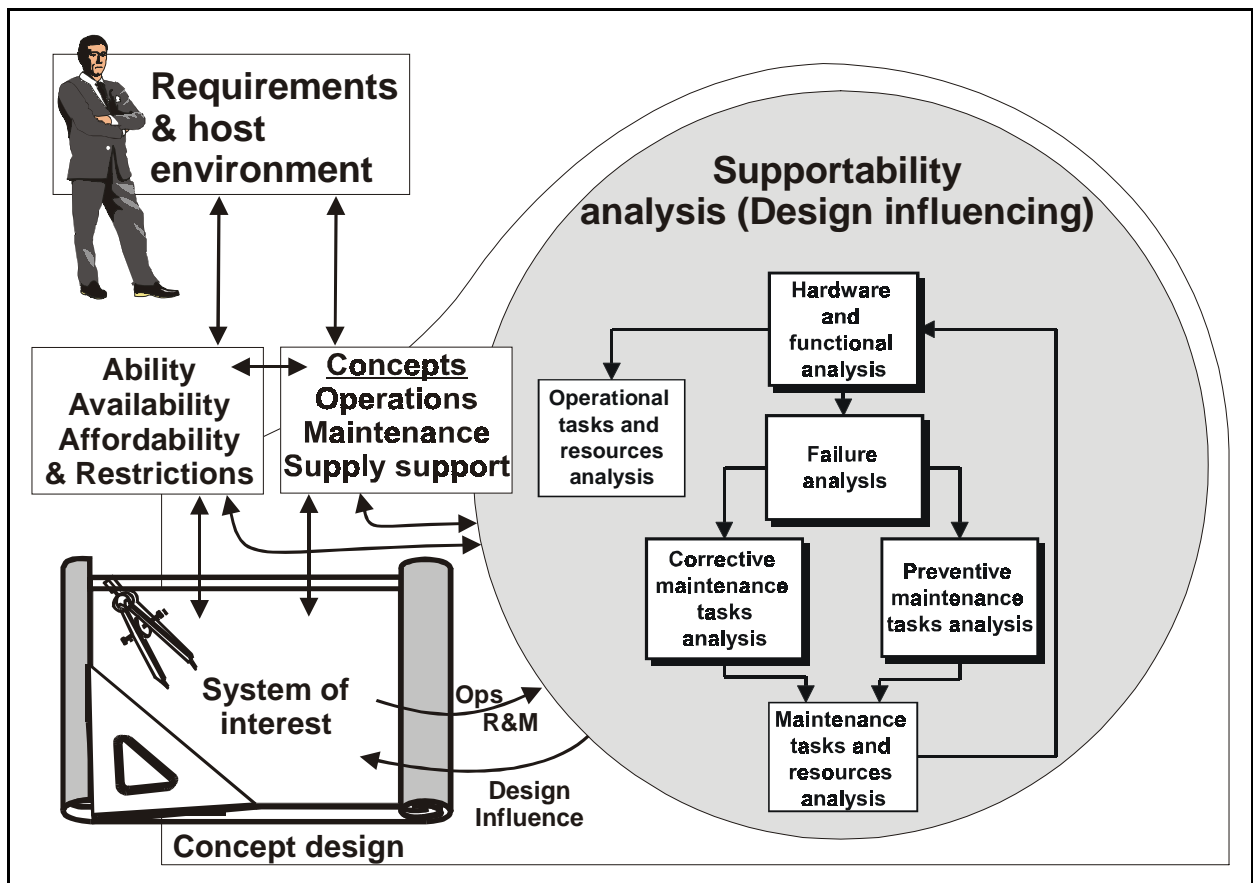
Figure 8.2: The relationships between the integrated logistic support measurements and the system measurements

- 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:
 - Reprourement.
 - 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].

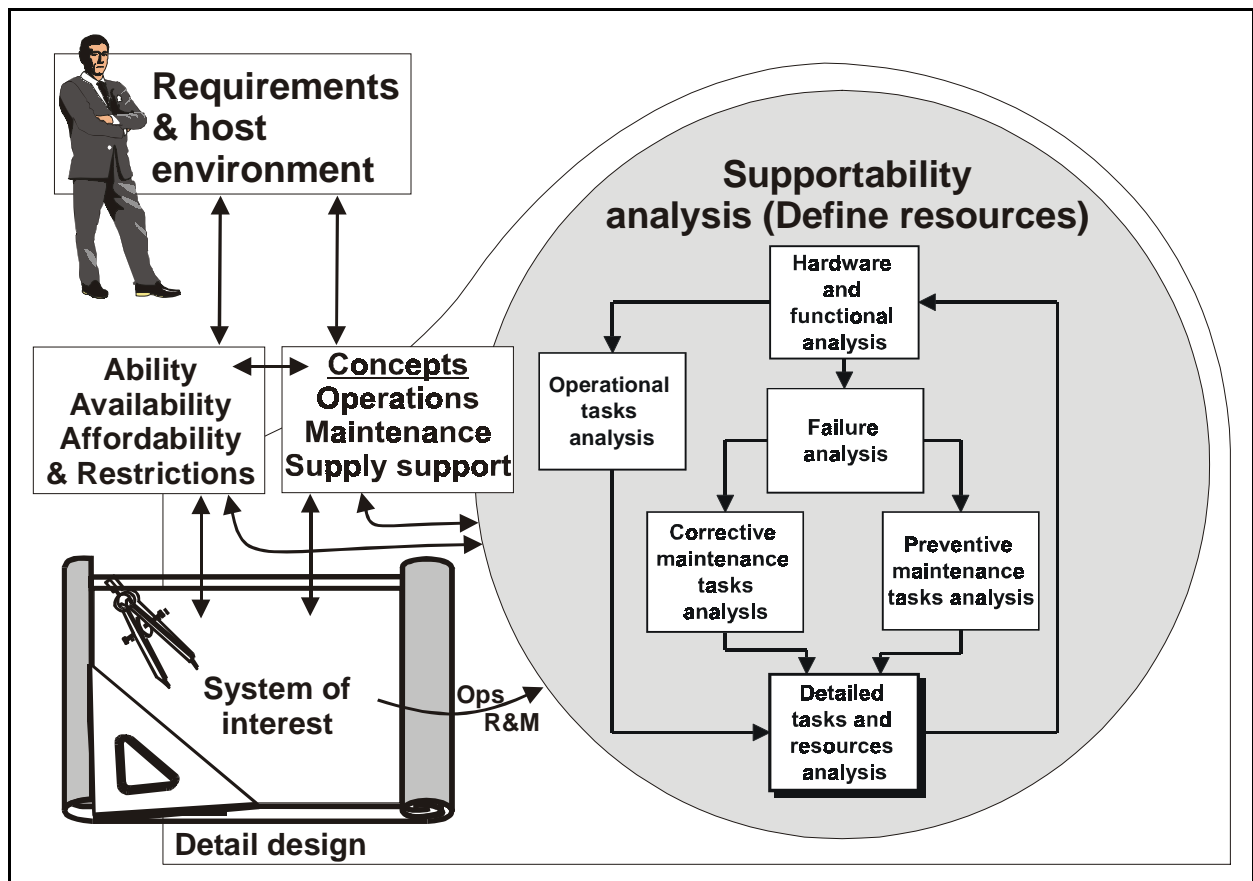
The maintenance task and resource analysis will be done in great detail later when the resource identification is done which means it gets very little attention when design influencing is done. For the purpose of design influencing the maintenance task and resource analysis is done (using the data from 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

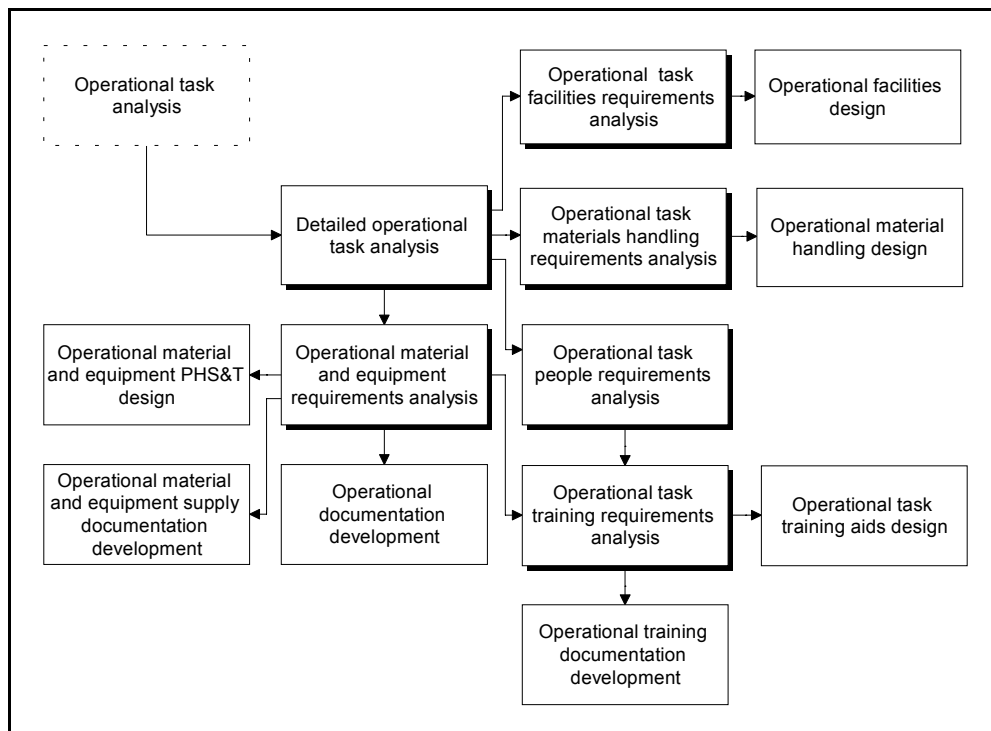


Figure 8.5: Detailed operational task and resource analysis

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.

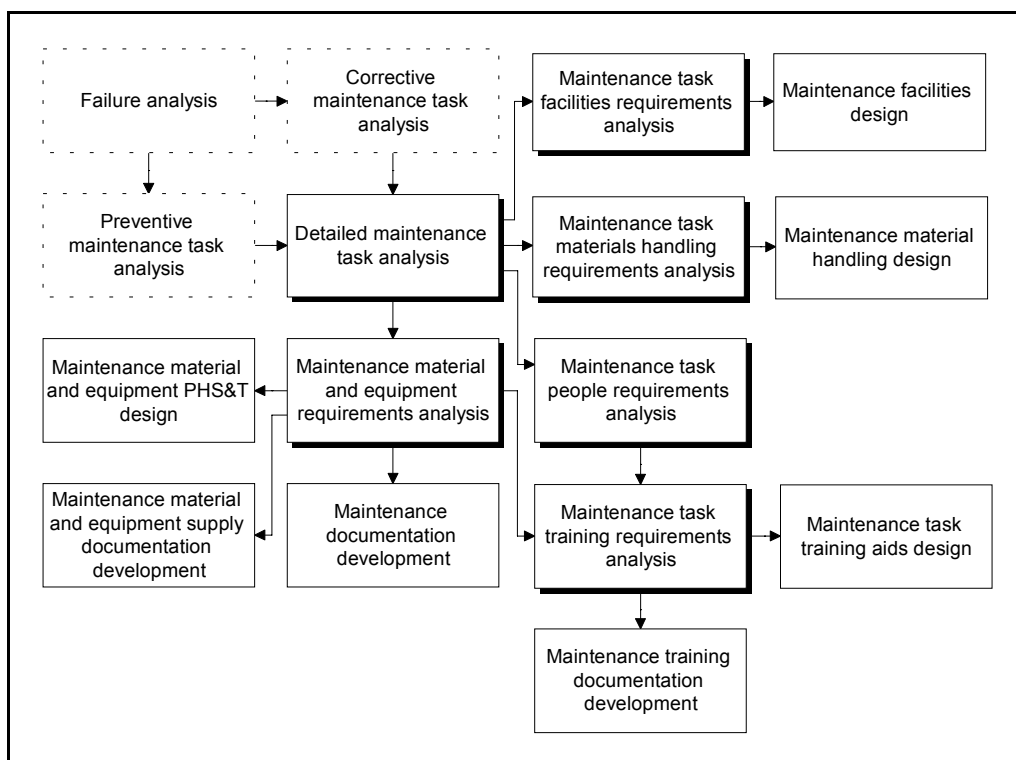


Figure 8.6: Detailed maintenance task and resource analysis

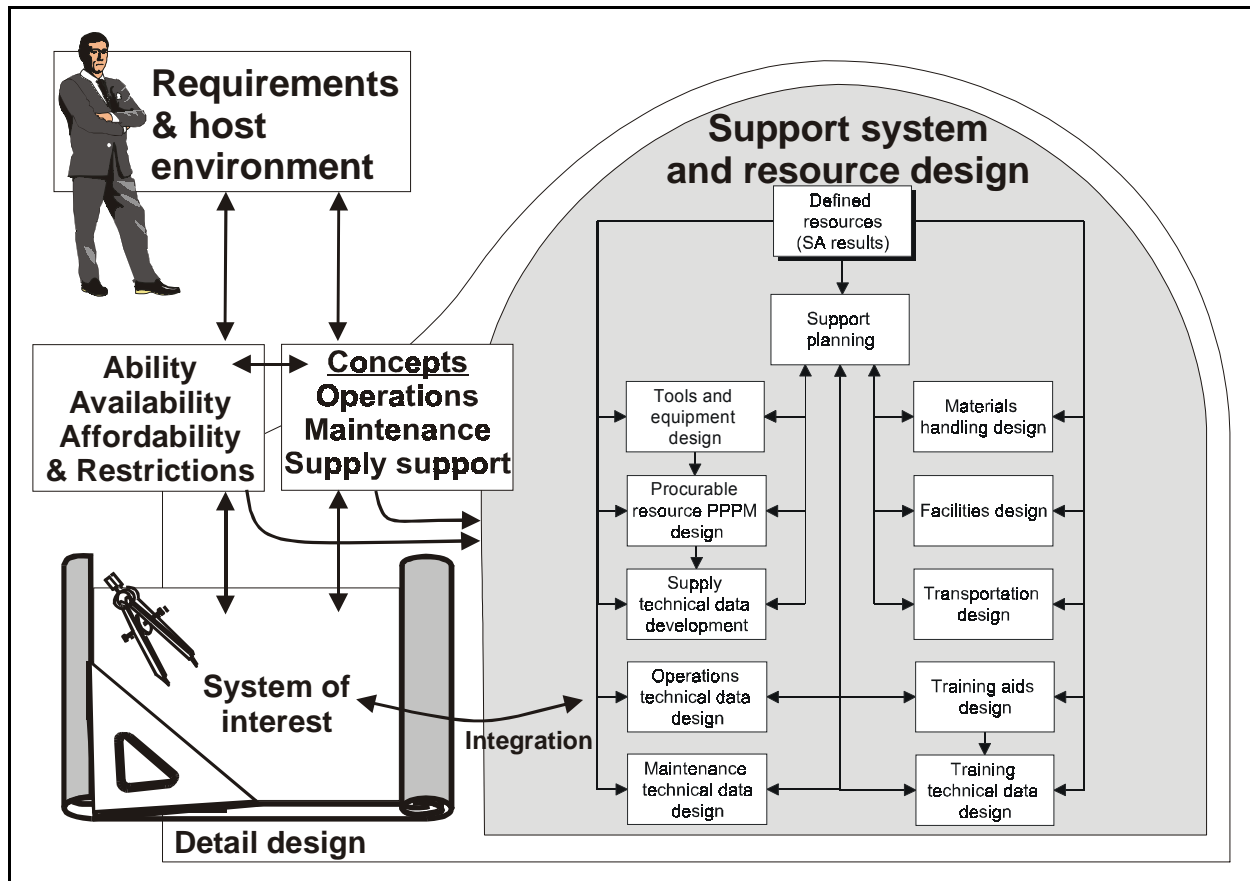
8.4.1.5 Design of the support system and support resources

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 from 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

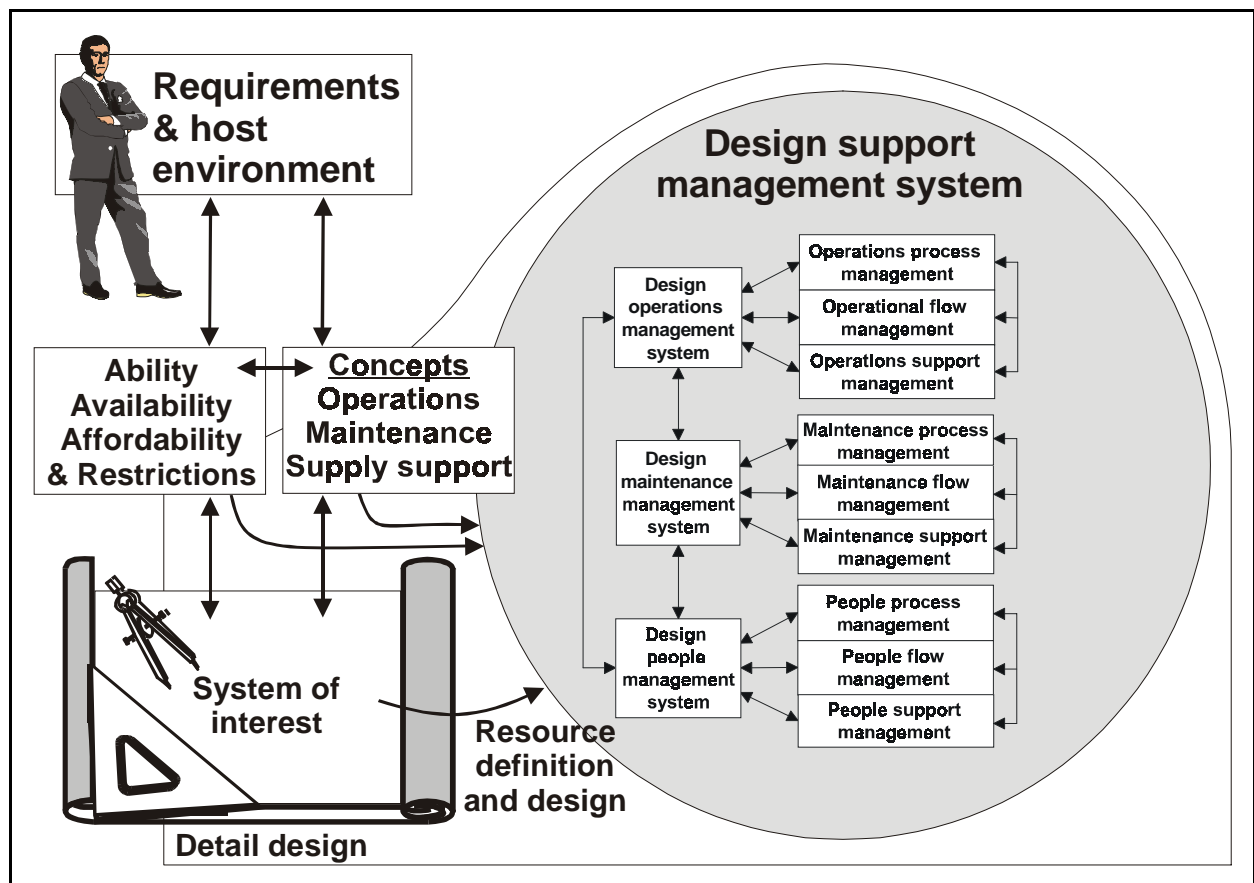
The final technical dimension of logistics engineering is to design the support management system. The support management system consists of policies, procedures and directives that will allow the system manager to manage the support of the system of interest during the operations and retirement phases. 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 sub-

divisions 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

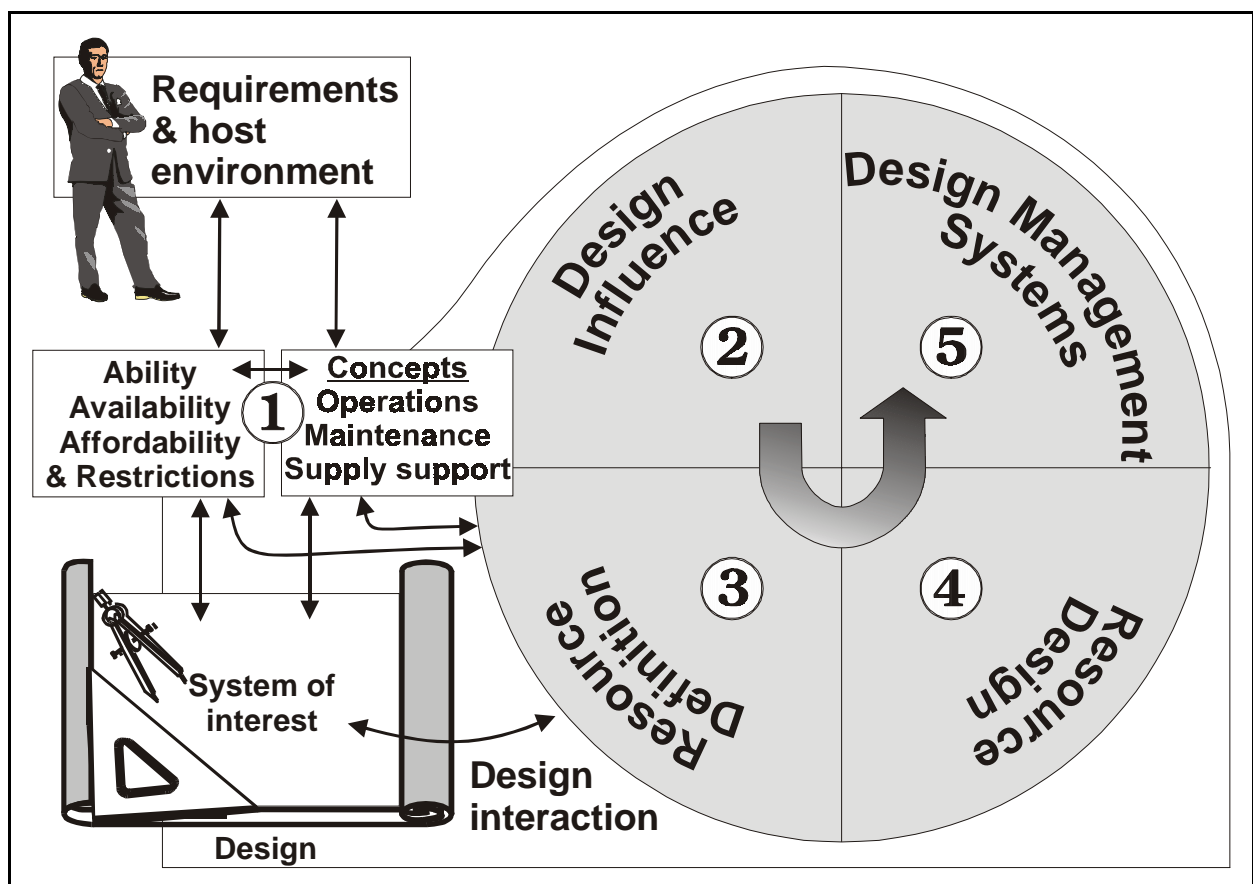


Figure 8.9: The logistics engineering technical activities

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.

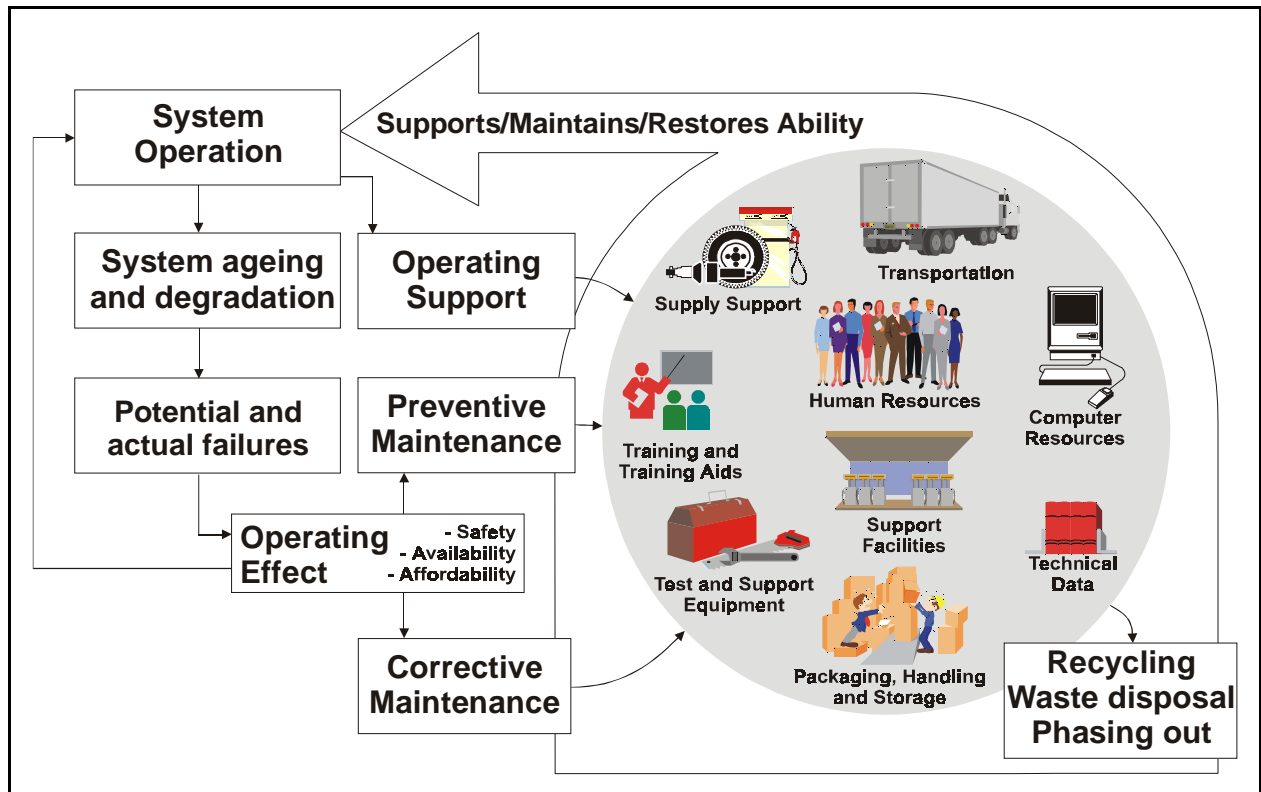
The technical activities of the physical acquisition and commissioning include (but is not limited to):

- 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 supporting¹ 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.

¹For 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 Collective service	Make to stock	Make to stock Assemble to order	Assemble to order Make to order	Design to order Make to order
Type of customer	Mass market	Mass market	Mass market Individual customers	Niche markets Individual customers	Single, individual customer
Product Demand	Relatively stable Very high	Relatively stable High	Fluctuates High to low	Fluctuates Medium to low	Infrequent Low
Product Variety	Very few	Few	Few to many	Many, varied	Infinite
Production System	Highly automated Process industry	Special purpose Automated	Special purpose Manual labour	General purpose Flexible	Vary according to Industry
Primary type of worker skill	Equipment monitors	Limited range Low level specialised	Limited range High level specialised	Wide range High level	Experts Craftsmen
Advantages	Very efficient Easy to control Consistency	Efficiency Speed Consistency	Efficiency Speed Limited flexibility	Flexibility and variety Quality Personal attention	Customised Latest technology
Disadvantages	Very capital intensive Far-reaching errors Difficult to change	Capital intensive Lack of responsiveness	Capital intensive Limited flexibility More complex	Low efficiency & slow Complex scheduling Difficult to control	High risks Small customer base Expensive
Examples	Mining Telecommunications Chemicals Municipal services	Brewery Soft drinks Foodstuffs Lightless plants	Motor manufacturing Banking Fast foods Appliances	Machine shop Printing shop Restaurant Aviation industry	Construction Ship building Consulting 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 horizontal 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

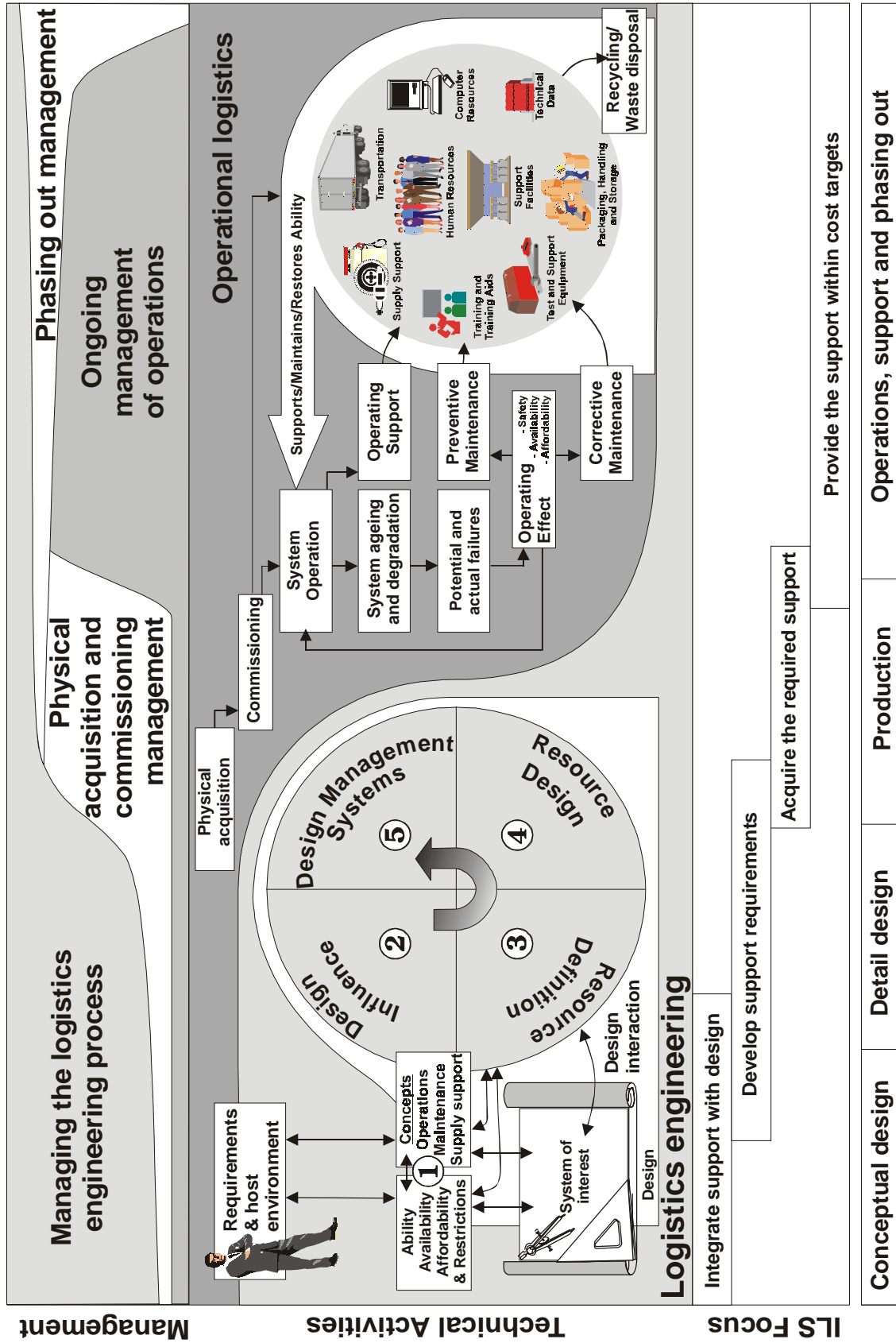


Figure 8.11: The generic integrated logistic support model for whole-life whole-systems

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.