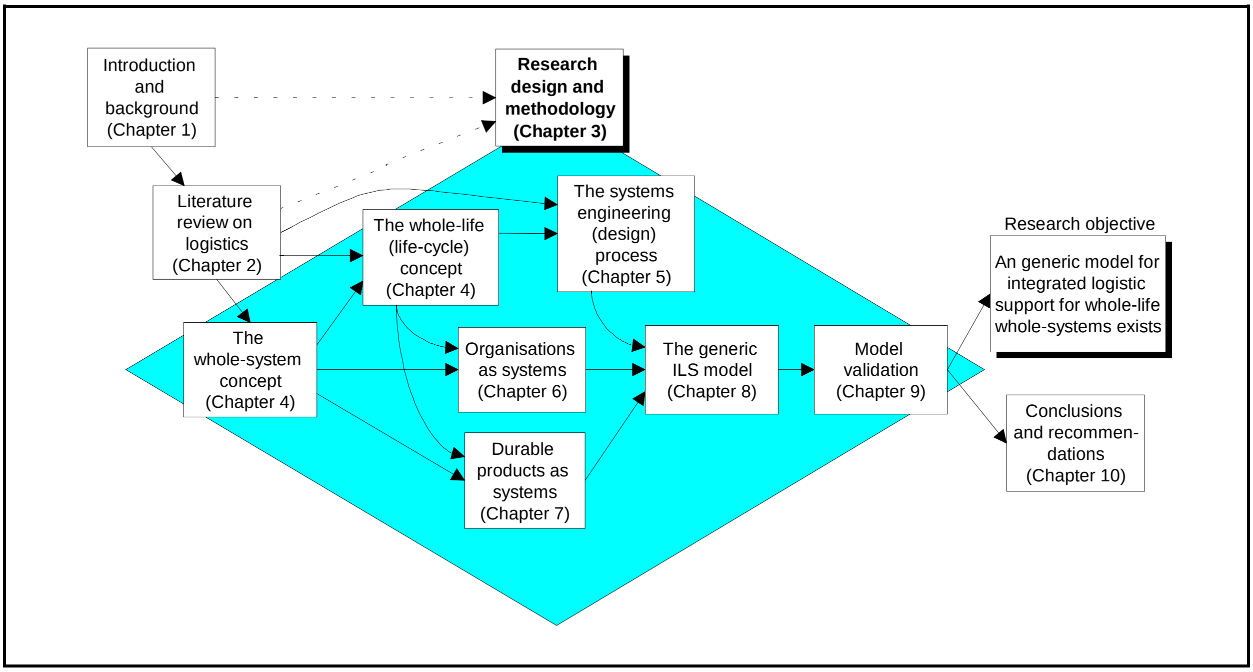
Chapter 3

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.

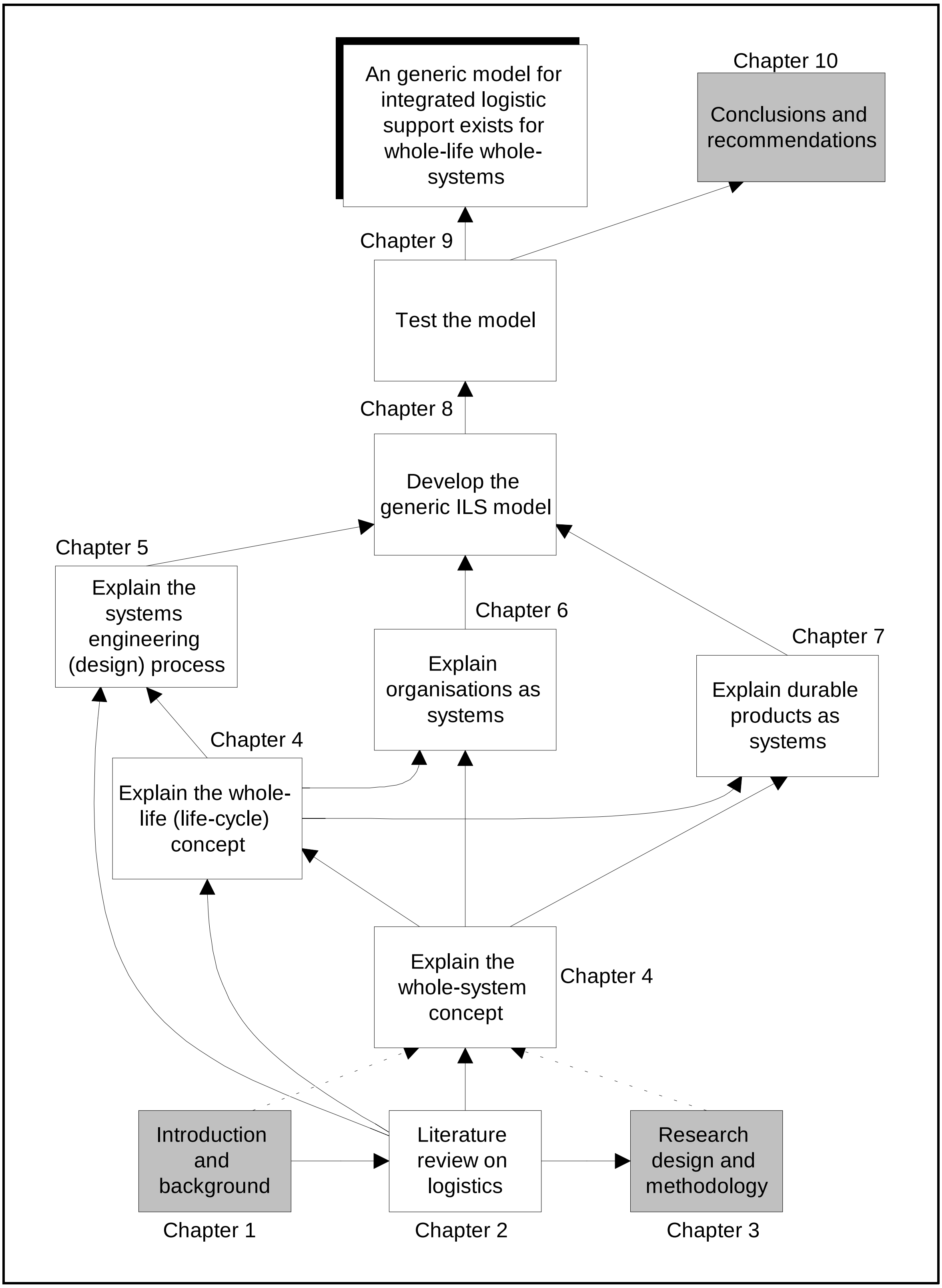


Figure 3.1: The structure of the research

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.