2. MODELLING METHODOLOGY

2.1 INTRODUCTION

At this stage it has become obvious that energy conversion model development, verification and integration form the heart of this study. It is important to have a structured approach to actually developing such models and for this reason a complete methodology has been developed for this purpose.

The theory and practice of energy modelling have made great advances recently [23, pp. 111 – 112], especially with the development of modern computer technology making complex calculations and model processing possible. Modelling contributes to the design and analysis process either directly, by enabling complex systems to be understood, so enabling the more complex and efficient systems to be designed, or indirectly by giving a greater degree of confidence to a design or process decision that would otherwise have to be made with a much higher degree of risk.

Modelling should not be purely mathematical and academic. In fact the art of modelling is to keep the subject as superficial but as broad as possible enabling proper results to be obtained. A process model can involve physical kinetics, engineering design, costing, accounting, mathematics, and programming [12, pp. 1 – 3]. Modelling therefore requires acquaintance with a wide range of subjects, some of which obviously need to be treated in more depth than others depending on the context of the situation.

2.1.1 Types of Models

Steven and MacLeod [24, p. 24] state that models can broadly be divided into two types, namely formal and conceptual models. Formal models are equation-based, mathematical models, whereas conceptual models are mental models or understanding about formal models.

Conceptual models are not expressible in formal terms and involve concepts such as quality or accuracy of the formal models and their applicability. Conceptual models thus really represent a basic non-mathematical understanding of a process, which is very important in the development of formal models.

Heuristic models are combinations of many different kinds of knowledge; cause-effect, spatial, temporal and taxonomic knowledge. Heuristic models are thus the most useful as they include a variety of different background and mathematical inputs.

2.1.2 Specific Criteria

The purpose of energy models are to represent low-level end-user groups reasonably accurately without being too complicated or creating unacceptable errors. In striving for a simple yet effective model, a number of development iterations will need to be done. A mathematical model is an abstraction of the real world system and will naturally require refinement after its initial development to ensure reliable accuracy [25, pp. 1 – 2].

Models must be relevant to the context in which the are found. This includes their inputs, outputs and all variables that have influence on them or are influenced by them. The theory used to develop models must be consistent and the models must be compatible to the surrounding system in which they are found.

The objective of the energy conversion models, which are to be developed, is to provide only the instantaneous, theoretical power consumption of each energy consuming or delivering component in the water reticulation system of a deep-level gold mine. These power values are to be summed to provide a combined figure for the entire system. The results can then be integrated to generate energy usage figures.

According to Roos [3, pp. 108 – 110], quantitative industrial plant models should be based on basic physical and economical properties of the plants operation. Used in a computer simulation, he continues that such models should represent the operation and functioning of the plant with fair accuracy without actually having to run the plant. Roos proposes comprehensive modelling strategies including inputs from material flow, maintenance, management set points, MD set points and variable plant costs. Manichaikul and Schweppe [26, pp. 1439 – 1441], also mention that plant modelling should include physically based load models as well as economic analysis. For the purpose of this study however, only energy conversion modelling needs to be done to provide power usage values of the different components of a deep-level mine's water reticulation system. The only attention that is to be paid to economic properties, is the electrical cost calculation from the values obtained from the energy conversion models, using different available tariffs.

2.1.3 Methodological Advances

A number of studies have been in the development of energy modelling methods, as described by Griffin [23, pp. 115 – 123]. Griffin has proposed methods to quantify the actual methodological advances in energy modelling. In his research, he has come to the conclusion that more accurate models were not as a direct result of having more data available. The biggest advances have come from improved techniques of utilising the available data. This supports the requirement for an extensive modelling methodology in which all aspects relevant to the proposed models are taken into account.

2.2 CONTEXT OF ENERGY MODELS

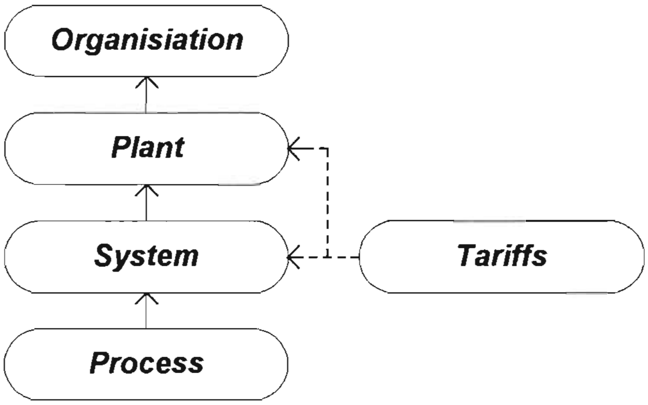

Figure 2.1: Context of models

In the hierarchy shown in Figure 1, *system* would represent the water reticulation system and *process* would represent all the functional components of the system. In the global picture, the *process* models will collectively have an output into the *system*. Energy usage values are outputs of the *system* and inputs to the *plant*, which in this case would collectively represent the entire mine's electricity consuming systems. Up to this point the flow of data from one level to another would be energy values. The data flowing to the organisation however, would be monetary values, the reduction of which would be the fundamental purpose of any such study. The *tariff* input shown may be an input to the *system* or *plant* level of the hierarchy, depending on the configuration and level at which most control can be done.

2.3 MODULAR APPROACH

In order to create versatile energy models, it is important to follow a modular, or 'building block' strategy as developed by Delport [35, pp. 46 – 51]. This allows one to use the developed modules in different configurations, and so make it practical for different mines to be able to use the models by fitting relevant components together. Referring to figure 2.1, building blocks can be generated for the *process* and *system* levels of the hierarchy.

The basic blocks for the *processes* would be of a more mathematical nature and the *system* blocks would consist of collections of process blocks and be used to couple different parts of the system, which would not be possible on the process level alone.

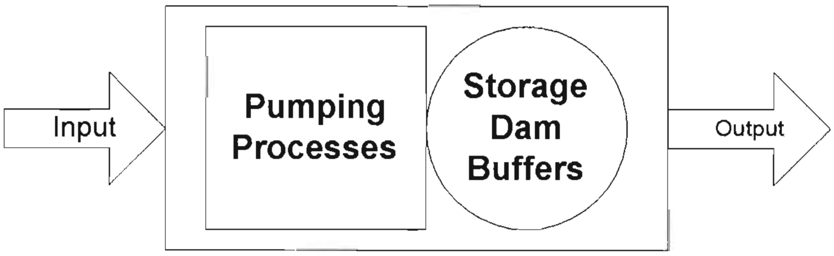

Figure 2.2: Example of a system building block for the pumping processes on a certain level of a gold mine, according to Delport's Building Block approach [9, p.46]

The underlying concept for this study is that a modular energy conversion model gets developed for each identifiable process, which will then form part of a system building block. Following this philosophy, many of the devices will consist of a number of sub-modules. Other components of the water reticulation system may have a module representing a physical device.

A crucial factor governing the development of any such modules (models), is that they are completely compatible to each other in any configuration. The inputs and outputs of each individual module must thus conform to a standard established for the entire system.

The models will be generated with the intention of automating them on computer to facilitate speedy simulation of different operating condition to find optimal solutions. For this reason it is even more important that the different 'building blocks' are completely compatible. If the models were to be used for manual calculations, one would still be able to alter values to provide compatible values. On computer however, it is naturally impossible to implement models that need to be individually checked during each calculation.

Godfrey [27, pp. 23 – 25] emphasises the importance of the integration of the electrical distribution systems, management information systems and energy management systems in a typical mining environment. This is done to be able to keep a global control on the entire operation. In the same way, it is important that models generated for different components of any of the electrical system within a mine are completely compatible to be able to be able to give overall results of any simulated conditions.

2.4 DEVELOPING MODELS

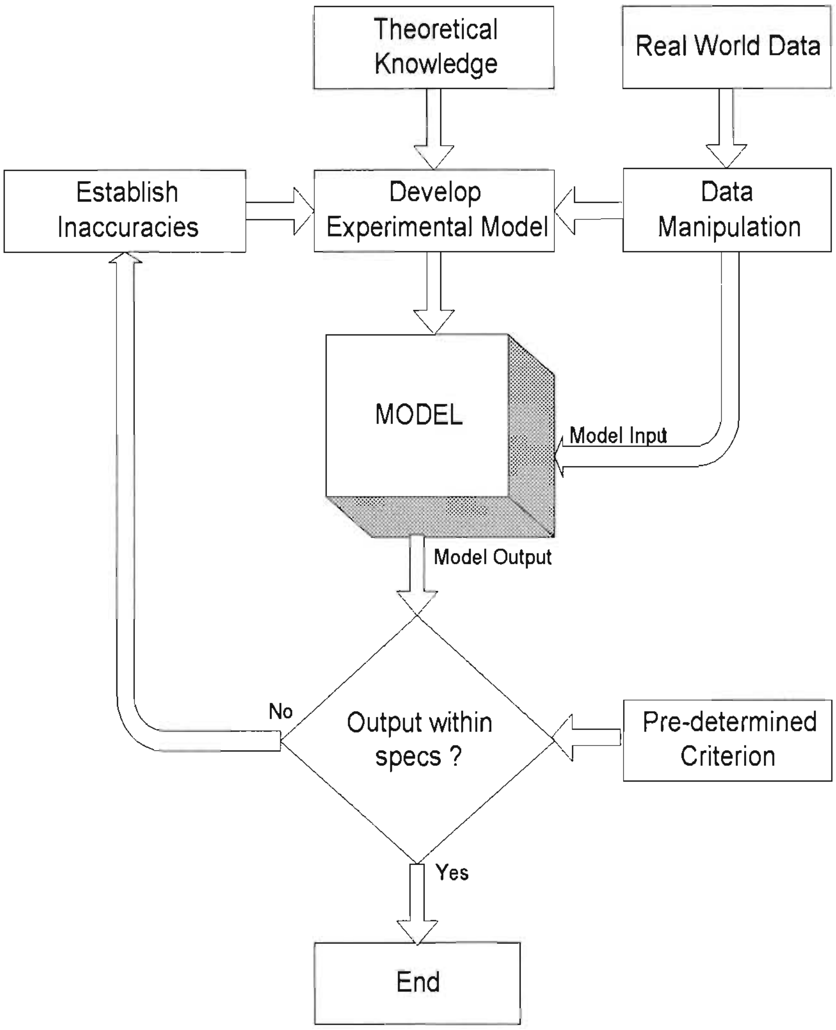

Figure 2.3: Model Development Flow Chart

Figure 2.3 is a graphical representation of the process of developing models in this methodology. The heart of the process is naturally the actual development of the model. As shown, the development stage has a number of inputs, namely theoretical knowledge, manipulated real-world data and a refining input from previous model trials. The development output is of course the actual model, which can then be tested.

The "theoretical knowledge" input represents all scientific theory of the system for which the module is being developed as well as all factors which may influence the system that have been experienced or witnessed in the practical environment. This includes basic physics and applied theory for whichever device the model is being developed. Roos [3, pp. 108 – 110] mentions that the functioning of processes in the plant should be modelled according to basic principles. Part of this input to the model development process is the set of engineering assumptions that should be made intelligently to keep the model simple but effective.

Any real-world data that is used will essentially not conform to a standard format, which is to be implemented to allow total compatibility between any modules developed. It is therefore necessary to manipulate data that may enter the development stage of such a model, to ensure that it is presented in a format, which will be used for the input of the working model. It is imperative that all data conforms to the standard laid down. For this reason, the particular assumptions, aggregations and simplifications that will be employed need to be stipulated clearly as well as the format and units of all data in the system.

In essence the model will be developed predominantly from the "theoretical knowledge" input, but the manipulated "real-world data" input is important to establish the ranges of values such as efficiencies and conversion constants that may be used. Meredith [28, pp. 16 – 18] mentions that in any particular circumstances, idiosyncrasies of the system being worked with must be taken into account. The "real-world data" input is instrumental in identifying any such idiosyncrasies in the development stage of any model. By tailoring the model at development, it reduces the process of refining the model later rather significantly.

Once the experimental model has been developed, it needs to be tested. The model represents a process and therefore has certain inputs and outputs. The inputs will naturally be the same as the manipulated data, described earlier. These are the real-world measurements that need to be processed in the artificial mathematical world, which has been generated. The outputs of the model need to be compared to the real values of the system that has been modelled. This will involve actually measuring the physical values such as power, which the model may have as outputs. These outputs then need to be within a predetermined tolerance of the actual values. This is represented by the "pre-determined criterion" and "output within specification?" stages.

If the outputs are not within the pre-determined criterion, the process needs to be repeated with the inaccuracies established now also forming an input to the development stage. The process may have to be repeated a number of times before a model is established successfully which conforms to the laid down criteria.

According to Snow [29, pp. 1.2/8 – 1.2/9], the monitoring of results is of crucial importance to the success of any energy efficiency operation. This has been proven all over the world in many areas, not only models used for energy management. In addition to this, it must be realised that the monitoring of results is not purely for the verification of models after they have been developed, but should be an on-going process to continually verify that models remain valid under operating conditions that may not stay constant.

Snow continues that once models have been developed and employed successfully, they should not simply be forgotten about and accepted that they are the optimum solution. New technologies are constantly being developed and one should keep abreast of developments, in terms of physical technologies that can be installed to improve profitability as well as technologies that can be used to develop more accurate models.

2.5 MODEL INPUTS AND OUTPUTS

2.5.1 Process Inputs and Outputs

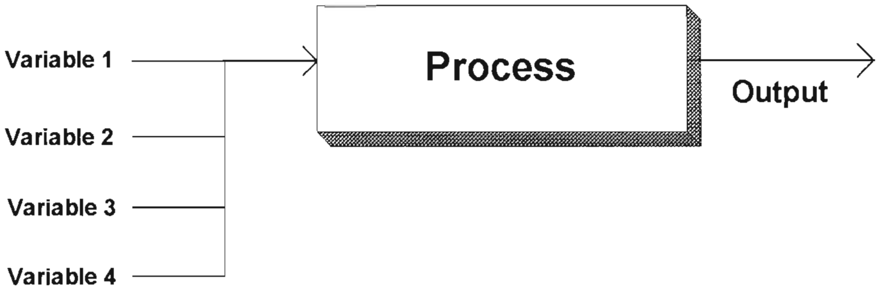

Figure 2.4: Any process that is modelled has a number of inputs and one output

Figure 2.4 represents the methodology regarding process identification. Each process that is to be modelled needs to be identified in such a way that it has a number of variable inputs, but only one output. This simplifies the modular approach and avoids situations of complicated interdependencies of different modules. One would expect the output of a process to be an energy value to facilitate the energy modelling of the system, but seeing that the processes are being broken down to a level of single output modules, only the output of a number of stages would be an energy value. Certain processes may have inputs consisting only of outputs of lower-order processes.

All variables that may influence a certain process need to be considered. Any assumptions or simplifications must be made consistently throughout the modelling process. This implies that the entire modelling process uses a consistent level of detail.

Typical inputs to a process may include physical values such as water flow rate as well as outputs from other processes such as friction head.

2.5.2 System Inputs and Output

The process models mentioned up to now really provide mathematical relationships between physical variables, which may be the outputs of other models and an output value. In the system level however, in addition to manipulating physical values, most of which are outputs of other process models, the model needs to make provision for a number of other kinds of variables.

The system-level models need to include other inputs such as electricity tariffs, production schedules, system and process limitations and constraints, management rules and buffer systems [25, pp. 10 – 12]. Seeing that not all of these values are technical, it is natural to expect that the outputs of these models are not purely technical either. The main outputs of this level of models are electricity usage values, which may be profiles or simply total figures, depending on the required level of detail, as well as buffer checks and final levels.

2.6 PROCESSES, DELAYS AND THE SYSTEM BOUNDARIES

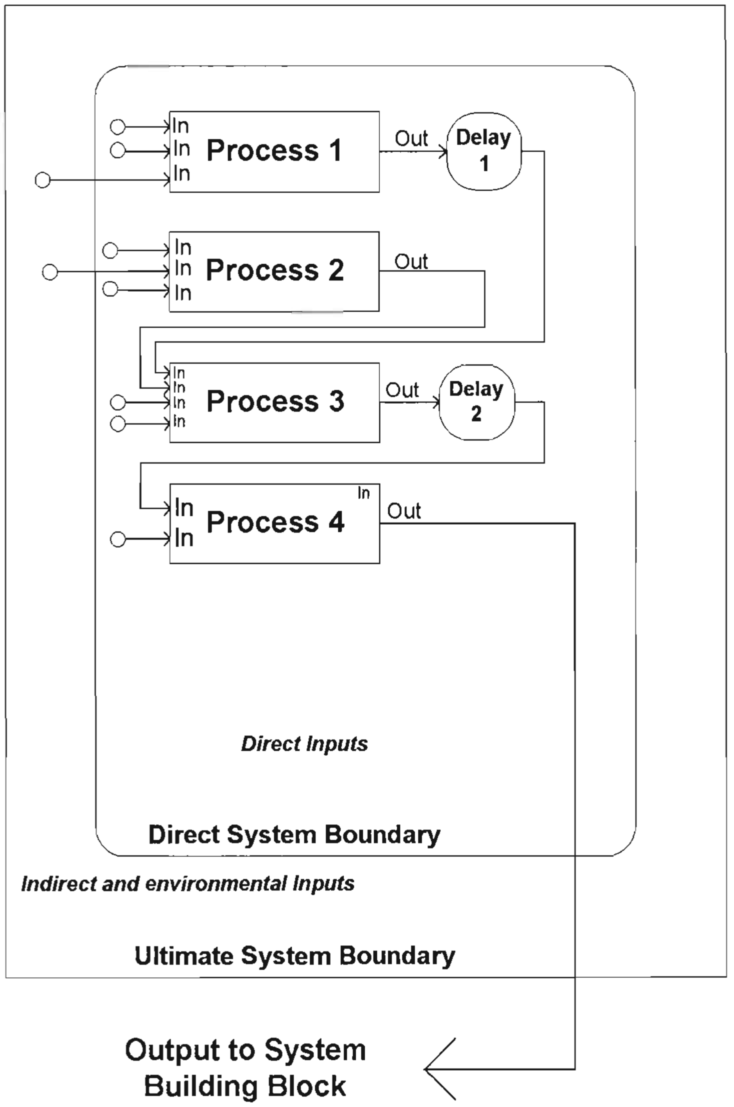

Figure 2.5: Models in context of the system boundaries

In order to keep a clear perspective of the system being modelled, finite system boundaries must be identified. Any system, which is being modelled, has certain inputs, which are obviously part of or relevant to the system. These inputs are represented in Figure 5 as falling within the direct system boundary. Complementing these inputs, are inputs from the ultimate system boundary, which would mainly consist of environmental factors and indirect influences such as management limitations on the specific system.

The general philosophy which is followed is that any delays in the system such as energy storage devices, typically dams, get represented by a process with a single input and output. According to Schweppe and Manichaikul [30, pp. 1439 – 1441], storage structures connected to individual processes are very important processes in their own right. These processes do not perform any function besides buffering. They do however form an integral part of the modelling of the system and so fall within the direct system boundary. An alternative to this is to include a buffer stage with each process for uniformity. If no buffering is relevant to a particular process, the process would then contain a “zero” buffer.

In order to once again maintain a consistent standard, once the ultimate system boundary has been established, it must not be crossed. All inputs and influences on the system that may come from outside the ultimate boundary must be neglected. It is therefore important that careful planning is done when these boundaries are established.

The output indicated is the input to the system level of the hierarchy as shown in Figure 2.1.

2.7 CONSTRAINTS

The models, which are to be developed, are intended to provide instantaneous power values that can be used in whatever mathematical way necessary. Up to now, no mention has been made of the fact that these models can only be valid under certain circumstances. If a dam is empty for example, it is impossible for a pump, which pumps from that dam to operate.

In the mining environment, all models that are developed need to comply with two major sets of constraints, namely physical constraints and management constraints. For the purpose of this study, management constraints do not play a technical role. However, for the models to be valid, they must conform to system and process limitations and constraints.

When a model is implemented it is very important that its operating conditions are verified to be valid for the entire duration of its operation. This ties in very closely with the concept of buffers mentioned earlier. Buffers tend to form one of the main constraints on models. Often buffers have safety limits built in, in case of problems. When the models are executed, it is necessary to ensure that the buffer values will always be within these set tolerances before the models are executed. A practical example of this is the checking of dam levels for the entire time that the models are to operate on the levels of the dams, before providing energy usage outputs.