CHAPTER 5

SYNOPSIS

INTRODUCTION

The term "synopsis" means a summary of the main points of an argument or theory. This chapter aims to provide a concise summary of the most important aspects of the generic simulation modelling methodology.

The most important factors that motivated this research are identified and discussed in the first section. The three main factors are the following: the shortcomings of the original simulation modelling method, the nonexistence in the literature that was surveyed of any strategy or methodology to address the simulation modelling problems that are posed by stochastic continuous systems and the fact that neither Arena nor Simul8 make provision to accommodate the simulation modelling problems that are posed by stochastic continuous systems.

The second section provides a summary of the process that was followed during the completion of the research. The main problem was dealt with by applying the complex problem solving process. This process comprises the following: identify the main problem, segregate the main problem into subproblems, conceptualise and develop methods and techniques to solve the subproblems and integrate the methods and techniques into a methodology.

All the elements of the generic simulation modelling methodology are summarised in the third section. The "toolbox" of the generic methodology contains the following eight methods and techniques: the variables technique, the ITI evaluation method, the ED evaluation method, the ERM method, the FC method, the iterative-loop technique, the time "bottleneck" identification technique and the production lost "bottleneck" identification technique. The generic methodology comprises two parts, namely: an iterative-loop technique part and a simulation model part. The simulation model consists of a "virtual" part that is represented by the logic engine high-level building block and a "real" part that is represented by the four different high-level building blocks of the ERM method.

In the fourth section the methods, techniques and other attributes of the original simulation modelling method and the generic simulation modelling methodology are identified and compared. The “toolbox” of the generic methodology contains eight methods and techniques of which only four are used by the original method. The comparison of the attributes indicates that the generic methodology provides effective solutions for the three most important shortcomings of the original method. The most important attributes of the original simulation model and the Arena and Simul8 simulation models are also compared.

The strengths and weaknesses of the generic simulation modelling methodology are summarised in the fifth section. The six most important strengths are the following: the use of a “toolbox” of eight methods and techniques and the identification of the secondary “bottlenecks” (flares), the use of five high-level building blocks and two hierarchical levels, the fact that no warm-up period is necessary, the use of input and output files, spreadsheet variables and preformatted output spreadsheets, the availability of both the ITI and ED evaluation methods in the same simulation model and the characteristics of simulation models that are developed with the generic methodology. The three most important weaknesses are the following: the fact that the logic engine high-level building block is not 100% generic, the need to develop the five high-level building blocks into a template format and the need to develop a concise, simplistic and user-friendly manual.

The contribution to knowledge of the research is discussed in the sixth section. The contribution to knowledge is a generic simulation modelling methodology that can be used to model stochastic continuous systems effectively. The generic methodology makes “knowledge work” more productive. The efficiency of the generic methodology can be attributed to a structured approach and the characteristics that are exhibited by simulation models that are developed with the generic methodology, namely: short development and maintenance times, user-friendliness, short simulation runtimes, compact size, robustness, accuracy and a single software application.

Some ideas on future developments, the possible range of application and different usage perspectives of the generic simulation modelling methodology are provided in the seventh section. The most important weaknesses of the generic methodology are an obvious starting point for any future developments. The possible range of application of the generic methodology is primarily in the petrochemical industry but any stochastic continuous system can readily be accommodated by the generic methodology. The three different usage perspectives within the possible range of application of the generic methodology are the following: the classic Industrial Engineering usage perspective, the training usage perspective and the Sustainable Development usage perspective.

The last section reflects on the research that is presented in this document with a few philosophical musings. Eight seemingly disjointed ideas are discussed, namely: lateral thinking can lead to innovative solutions, simplistic concepts can provide elegant solutions for complex problems, paying attention to detail does render better solutions, complex problems should be approached with the complex problem solving process, unfortunately there is no *Chemical Plant Simulation for Dummies*, the triple bottom-line approach is the future, simulation modelling is as much an art as a science and the search for the truth is the quest of the enquiring mind.

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5.1 MOTIVATION FOR THE RESEARCH

The origins of the research that is presented in this document are detailed in Section 1.1. The background information that is provided there, however, is not the only motivation for this research. The aim of this section is to provide a concise summary of the most important factors that initiated the research.

The motivation for the research (*i.e.* the development of a generic simulation modelling methodology) can be ascribed to the following three main factors:

a) The shortcomings of the original simulation modelling method.
b) The absence in the literature that was surveyed of any complete or coherent strategy or methodology to address the simulation modelling problems that are posed by the class or type of system that is considered in this document (*i.e.* systems that exhibit the same characteristics as the Synthetic Fuel plant).
c) The lack of any provision in the simulation software packages that were scrutinised to accommodate the simulation modelling problems that are posed by the class or type of system that is considered in this document.

The following paragraphs detail the points stated above. During 1999 the feasibility of updating the final 1996 simulation model was investigated. Comprehensive changes were needed and the shortcomings of the original simulation modelling method effectively scuppered the project (see Sections 1.1 and 1.4). Even though the project was cancelled, the investigation revealed that a need existed in the industry for a generic simulation modelling methodology that could be used to develop simulation models of the class or type of system that is considered in this document. The investigation presented a unique opportunity to use the original method as a point of departure for the development of a generic methodology.

Systems of the class or type of system that is considered in this document are described as stochastic continuous systems, thereby referring to their two most distinctive characteristics and indicating that they are subject to random (stochastic) phenomena such as failures and that they are characterised by continuous processes (flow) (see Section 1.5). A survey of the available literature revealed that no complete or coherent strategy or methodology existed to address the simulation modelling problems that are posed by stochastic continuous systems. Certain aspects of the simulation modelling problems are addressed by different sources, but no single integrated or comprehensive solution or methodology is proposed, conceptualised, developed, verified and validated, used, *etc.* in the existing sources.

Section 1.6 indicates that traditionally the development of simulation software packages has focused primarily on the ability to model discrete-event systems, because most manufacturing and service systems are discrete-event systems. Continuous systems have been, and still are, neglected by both the simulation software packages and the literature. For example, Pegden *et al.* (1998) dedicate approximately 6%, Harrell and Tumay (1999) approximately 3% and Kelton *et al.* (1998) less than ½% of their respective books to the modelling of continuous systems. The *Simul8®: Manual and Simulation Guide* (1999) does not even address continuous systems.

Neither Arena nor Simul8 make provision to readily accommodate the simulation modelling problems that are posed by the class or type of system that is considered in this document. Section 1.6 indicates that the limited continuous modelling ability of Arena cannot adequately accommodate the simulation modelling problems that are posed by stochastic continuous systems. There are no ready-to-use templates with high-level building blocks (in the simulation software packages) or step-by-step guides (in the manuals) to lead prospective modellers through the process of developing simulation models of stochastic continuous systems, in either Arena or Simul8. Prospective modellers are mostly left to their own devices in both simulation software packages when simulation models of this class or type of system are encountered.

Summary

In this section the most important factors that motivated this research are identified and discussed. The three main factors are the following: the shortcomings of the original simulation modelling method, the nonexistence in the literature that was surveyed of any strategy or methodology to address the simulation modelling problems that are posed by stochastic continuous systems and the fact that neither Arena nor Simul8 make provision to accommodate the simulation modelling problems that are posed by stochastic continuous systems.

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5.2 SUMMARY OF THE RESEARCH PROCESS

The purpose of this section is to provide a summary of the research process that was followed to complete the research that is presented in this document. It is both a concise history of the research process followed and, at the same time, a generic research process for the development of a methodology in the simulation modelling environment. In this specific instance the complex simulation modelling problem that is resolved is the development of a generic simulation modelling methodology that can be used to model stochastic continuous systems effectively.

The research process comprises the following:

a) Identify a clearly demarcated shortcoming in the current state of knowledge to solve the problem. Use the following process:
   i) Assimilate all the background information (see Sections 1.1 and 1.4).
   ii) Do a preliminary literature survey (see Sections 1.2, 1.3, 1.5 and 1.6).
   iii) Investigate all additional sources of information, for example, knowledgeable persons, simulation software packages, the Internet, *etc.* (see Sections 1.6 and 3.1).

b) Use the output of Point a) to determine if the problem is worthy of a structured research effort. If the answer is yes, continue.

c) Identify "best practice" research tools, techniques, methods, procedures, processes, *etc.* (see Botha and du Toit (1999:1-14), Davis and Parker (1979:1-148), Leedy (1993:1-348) and *Manual for Research and Postgraduate Studies (Master's Degree and PhD)* (2000:1-30)).

d) Prepare a research proposal. The research proposal should address at least the following topics: an introduction, an objective statement (*i.e.* a problem statement), the importance of the research, a preliminary literature survey, a proposed research method, the limitations, the risks and the contribution to knowledge (see Davis and Parker (1979:57-76), Leedy (1993:149-182) and *Manual for Research and Postgraduate Studies (Master's Degree and PhD)* (2000:3,27)). This point is sometimes regarded as the first step of the formal research process.

e) Submit the research proposal to the appropriate Departmental Research Committee. If the research proposal is accepted, continue.

f) Complete the required administrative procedures and continue with the formal research process under the leadership of the assigned supervisor.

g) Develop or implement management processes for the management of the formal research process. The management processes should include at least the following concepts: a schedule spreadsheet with the activities (*i.e.* the tasks and the task elements) and the timescale of each activity, a timekeeping spreadsheet with the activities and the man-hours spent on each activity, a literature survey spreadsheet with the relevant information about the appropriate references and a register with a list of the research related meetings and the minutes of the meetings.

h) Prepare and submit progress reports at regular time intervals, for example, annual, biannual or quarterly progress reports. The purpose of the progress reports is to establish a credible "paper trail" that provides traceability to the formal research process. The documentation of any deviation from the research proposal is of special importance. As the research progresses, a new insight into the problem may be gained. This could lead to a deviation from the original goal of the research that is documented in the research proposal.

i) Do a thorough literature survey (see the references that are dispersed throughout this document). This is an activity that continues unabated until the research process is completed.

j) Compile a detailed system description of the system that is under scrutiny (see Section 1.2).

k) Identify the system characteristics (see Section 2.1).

l) Conceptualise and develop a solution (*i.e.* a generic simulation modelling methodology) with the complex problem solving process that is advocated by Leedy (1993:71) and *Rule Thirteen* (see Section 5.8) of Descartes (2003:164-169). Use to the following process:
   - i) Identify the main problem. In this instance the main problem is the fact that the system characteristics that are identified in Section 2.1 have to be accommodated in a simulation model that conforms to the design criteria that are stated in Section 1.5 (see Section 2.1).
   - ii) Segregate the main problem into subproblems (see Section 2.2).
   - iii) Conceptualise and develop methods and techniques to solve the subproblems (see Sections 2.2 to 2.6).
   - iv) Integrate the methods and techniques into a methodology (see Section 2.7).

m) Develop simulation models with the methodology. Use the following process:
   - i) Investigate the simulation software packages (see Section 3.1).
   - ii) Develop a simulation model breakdown from the system description (see Section 3.2).
   - iii) Construct the simulation models and determine an appropriate iteration time interval and the minimum sufficient sample sizes (see Sections 3.3, 3.4 and 3.5).
   - iv) Verify and validate the simulation models (see Section 3.6).

v) Enhance the simulation models, if possible (see Section 3.7).

n) Apply the simulation models (*i.e.* conduct scenario analysis). Use the following process:

i) Identify and detail alternative scenarios (see Section 4.1).

ii) Use the simulation models to generate results for each alternative scenario (see Sections 4.2 and 4.3).

iii) Compare the results of the alternative scenarios and reach conclusions (see Section 4.4).

o) Present a paper about the research at a recognised symposium or conference (see Albertyn and Kruger (16th European Simulation Multiconference, 2002:29-36)).

p) Publish an article about the research in a recognised technical or scientific journal (see Albertyn and Kruger (2003:57-60)).

q) Compare the research results with the research goal that is documented in the research proposal. If the research goal is met or exceeded, proceed.

r) Document the research (see this document).

s) Submit the document for examination purposes and complete the examination.

The *Manual for Research and Postgraduate Studies (Master's Degree and PhD)* (2000:2) provides the following guidelines for the examination of a doctoral thesis:

> "*Candidates must provide proof that they can plan, initiate and execute* [as well as document] *independent and original research.*"

Summary

This section provides a summary of the process that was followed during the completion of this research. The complex problem solving process was used to address the main problem. The complex problem solving process comprises the following: identify the main problem, segregate the main problem into subproblems, conceptualise and develop methods and techniques to solve the subproblems and integrate the methods and techniques into a methodology.

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5.3 SUMMARY OF THE GENERIC METHODOLOGY

The purpose of this section is to provide a concise summary of all the elements of the generic simulation modelling methodology.

In Section 2.1 the characteristics of the class or type of system that is considered in this document are identified. Stochastic continuous systems are characterised by the following: continuous processes, two types of discrete events (*i.e.* the chronological services and stochastic failures) and complex interrelationships. The main problem of this research is the fact that these system characteristics have to be accommodated in a simulation model that conforms to the design criteria that are stated in Section 1.5. Seven methods and techniques to effectively accommodate these system characteristics in a simulation model are conceptualised and developed in Sections 2.2 to 2.6. The seven methods and techniques are integrated into the generic simulation modelling methodology in Section 2.7 and in Section 3.7 an additional method is added when the Arena and Simul8 simulation models are enhanced. That gives a total of eight methods and techniques that are integrated into the generic methodology.

The "toolbox" of the generic simulation modelling methodology contains the following eight methods and techniques:

a) The variables technique uses variables to represent process flow as real numbers (see Section 2.2).
b) The ITI evaluation method (*i.e.* the fixed time interval technique detailed in Chapter 2) uses a fixed time interval to advance a simulation model in time (see Section 2.2).
c) The ED evaluation method advances a simulation model in time by evaluating the simulation model only when an event takes place (see Section 3.7).
d) The ERM method determines the state of the modules in the system that is under scrutiny at any given moment in time (see Section 2.3).
e) The FC method identifies the momentary "bottleneck" in a complex system at any given moment in time (see Section 2.4).
f) The iterative-loop technique determines the governing parameters for every specific system description of the system that is under scrutiny, for example, the gas-feedback-loop-fraction, the steam-division-ratio, the oxygen-division-ratio and the FC method parameter set in the instance of the Synthetic Fuel plant (see Section 2.5).
g) The time "bottleneck" identification technique identifies the primary "bottlenecks" based on the time that each primary point of evaluation is the "bottleneck" (see Section 2.6).
h) The production lost "bottleneck" identification technique identifies the primary

"bottlenecks" based on the production that is lost due to each primary point of evaluation (see Section 2.6).

The key objective of this research is to provide a generic simulation modelling methodology that can be used to construct simulation models of stochastic continuous systems effectively. Section 2.2 indicates that the throughput of a plant is considered to be the definitive measurement of plant performance and the first rule of operation in Appendix B states that the Synthetic Fuel plant always strives to maintain the maximum possible rate of production or throughput. It is therefore clear that the determination of the maximum possible throughput, as a function of time, is of vital importance in a simulation model of a stochastic continuous system. Equation 2.4 (repeated here in a generic format for the sake of the continuity of the argument) indicates that the maximum possible throughput of a stochastic continuous system (*i.e.* the Synthetic Fuel plant) is a function of the maximum possible throughput of each of the elements of the stochastic continuous system (*i.e.* the smaller plants).

$$Throughput_{SCStmMaxPos}(t) = f(Throughput_{EmtMaxPos}(t) \; for \; No.1 \; ... \; n_{Emt}) \quad (ton, m^3, nm^3/h)(Eq.:2.4rep)$$

Where:

$Throughput_{SCStmMaxPos}(t)$	:	The maximum possible throughput of the stochastic continuous system, as a function of time, in ton/h, m^3/h or nm^3/h.
$Throughput_{EmtMaxPos}(t)$	:	The maximum possible throughput of the element, as a function of time, in ton/h, m^3/h or nm^3/h.
n_{Emt}	:	The number of elements, as a constant.

The generic format of the terms "Synthetic Fuel plant" and "smaller plant" are used throughout this section. The term "stochastic continuous system" is used instead of "Synthetic Fuel plant" and the term "element" is used instead of "smaller plant". The term "module" remains unchanged.

It is not easy to determine the maximum possible throughput of a stochastic continuous system, as a function of time, because of the continuous process, the fact that the number of available modules in each of the elements is a function of time (*i.e.* the modules are subject to services and failures) and the complex interrelationship characteristic of such a system (*i.e.* the presence of feedback-loops, the division of the output of some of the elements, *etc.*).

A scrutiny of the aforementioned "toolbox" of eight methods and techniques indicates that it provides solutions to all the problems that are posed in the previous paragraph. The variables technique uses variables to represent the process flow of the continuous process. The ERM method determines the number of available modules in each of the elements at any given moment in time and then the FC method identifies the momentary "bottleneck" and determines the maximum possible throughput of the stochastic continuous system at that specific moment in time. The FC method uses a parameter set that is determined with the iterative-loop technique. The FC method parameter set is unique for every specific system description and incorporates the influence of the complex interrelationship characteristic (*i.e.* the presence of feedback-loops, the division of the output of some of the elements, *etc.*). The ITI and ED evaluation methods are used to advance simulation models of stochastic continuous systems in time and the time and production lost "bottleneck" identification techniques are used to identify the primary "bottlenecks".

It is obvious that the eight methods and techniques are applicable at different stages during the completion of a simulation run. Most of the methods and techniques are used continuously by the simulation model during the simulation run. The only exception to this rule is the iterative-loop technique that determines the governing parameters of the system that is under scrutiny before the start of the simulation run. Therefore the generic simulation modelling methodology comprises two separate parts, namely: an iterative-loop technique part and a simulation model part. The iterative-loop technique part accommodates the specific system description of the system that is under scrutiny and the simulation model part contains the seven methods and techniques that accommodate the time dependent behaviour of the system that is under scrutiny.

This concept is graphically depicted in Figure 5.1: *Generic Simulation Modelling Methodology Parts, Methods and Techniques (Updated)*. (Figure 5.1 is an updated version of Figure 2.3 that replaces the fixed time interval technique with the ITI evaluation method and includes the ED evaluation method.)

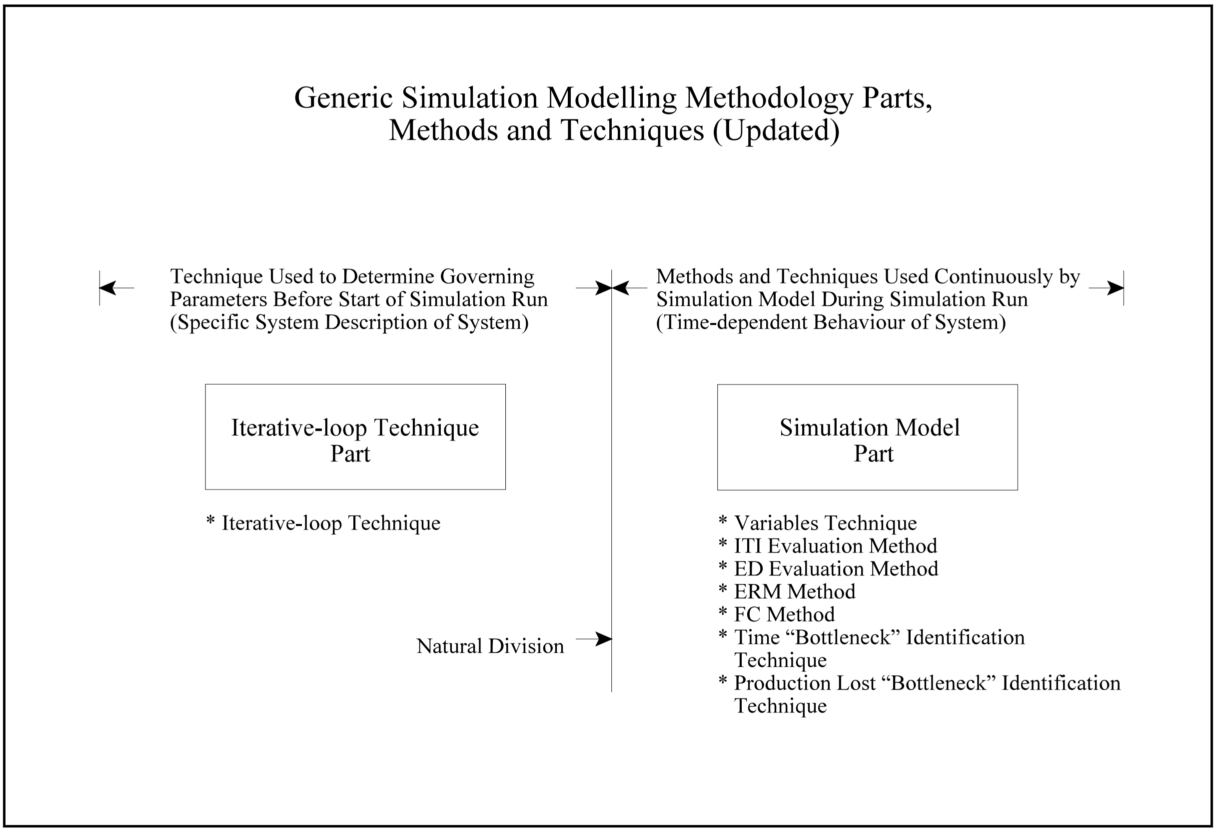

Figure 5.1: Generic Simulation Modelling Methodology Parts, Methods and Techniques (Updated)

The simulation model itself consists of a "virtual" part that deals with the continuous processes and all the other concepts that are necessary for the simulation model to function and a "real" part that deals with the behaviour of the modules. The "virtual" part of the simulation model is represented by the logic engine high-level building block. The "real" part is represented by the four different high-level building blocks of the ERM method, namely: an element with a multiple service cycle and failures of the modules, an element with a service cycle and failures of the modules, an element with a service cycle of the modules and an element with failures of the modules. The basic structure of the simulation model is graphically depicted in Figure 5.2: *Simulation Model Parts and Building Blocks (Updated)*. (Figure 5.2 is an updated version of Figure 2.4 that replaces the fixed time interval technique with the ITI evaluation method and includes the ED evaluation method.)

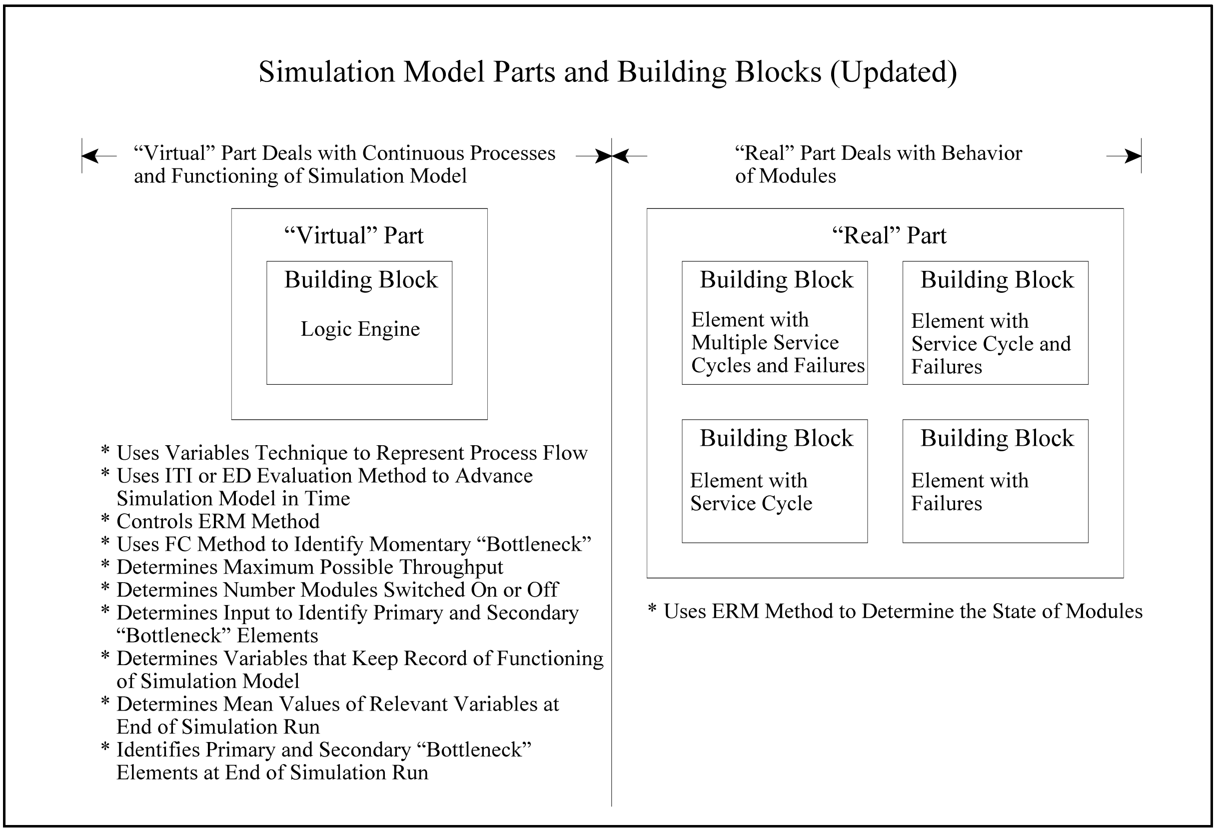

Figure 5.2: Simulation Model Parts and Building Blocks (Updated)

Summary

In this section the generic simulation modelling methodology is summarised. The "toolbox" of the generic methodology contains the following eight methods and techniques: the variables technique, the ITI evaluation method, the ED evaluation method, the ERM method, the FC method, the iterative-loop technique, the time "bottleneck" identification technique and the production lost "bottleneck" identification technique. The generic methodology comprises two parts, namely: an iterative-loop technique part that determines the governing parameters of the system that is under scrutiny before the start of a simulation run and a simulation model part that uses the other seven methods and techniques continuously during the simulation run. The simulation model consists of a "virtual" part and a "real" part. The "virtual" part is represented by the logic engine high-level building block and deals with the continuous processes and all the other concepts that are necessary for the simulation model to function. The "real" part deals with the behaviour of the modules and is represented by the four different high-level building blocks of the ERM method, namely: an element with a multiple service cycle and failures of the modules, an element with a service cycle and failures of the modules, an element with a service cycle of the modules and an element with failures of the modules.

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5.4 COMPARISON OF THE ORIGINAL METHOD AND THE GENERIC METHODOLOGY

The detail discussions about the differences between the original simulation modelling method and the generic simulation modelling methodology are dispersed throughout this document. This section presents the essence of these differences in tabular format and concise discussions. The methods, techniques and other attributes of the original method and generic methodology are identified and compared. Some of the attributes of the original simulation model and the Arena and Simul8 simulation models are also compared.

A comparison of the methods and techniques that are used by the original simulation modelling method and the generic simulation modelling methodology is presented in Table 5.1: *Methods and Techniques Used by the Original Method and the Generic Methodology*.

Table 5.1: Methods and Techniques Used by the Original Method and the Generic Methodology

Method or Technique	Original Simulation Modelling Method	Generic Simulation Modelling Methodology
Variables Technique	Yes	Yes
ITI Evaluation Method	Yes	Yes
ED Evaluation Method	No	Yes
ERM Method	Yes (Original version)	Yes (Enhanced version)
FC Method	No	Yes
Iterative-loop Technique	Yes (Original version)	Yes (Enhanced version)
Time "Bottleneck" Identification Technique	No	Yes
Production Lost "Bottleneck" Identification Technique	No	Yes

Table 5.1 reveals that only four of the "toolbox" of eight methods and techniques that comprise the generic simulation modelling methodology are used by the original simulation modelling method. The variables technique and the ITI evaluation method are used by both the original

method and the generic methodology. The ED evaluation method, however, is an option that is only available in the generic methodology. The ERM method of the original method (*i.e.* the original version) is less compact and accurate than the ERM method of the generic methodology (*i.e.* the advanced version) because the latter reduces the number of queues that is used and it introduces techniques that address the "disturbed service sequence" phenomena (see Section 2.3). The FC method is unique to the generic methodology and it is the "jewel in the crown" of the generic methodology because it makes an invaluable contribution to eliminate the shortcomings of the original method. Both the original method and the generic methodology use the iterative-loop technique to determine the governing parameters of the system that is under scrutiny before the start of a simulation run. The iterative-loop technique of the original method (*i.e.* the original version) only determines the gas-feedback-loop-fraction, steam-division-ratio and oxygen-division-ratio (in the instance of the Synthetic Fuel plant), while the iterative-loop-technique of the generic methodology (*i.e.* the enhanced version) also determines the FC method parameter set. The original method uses the throughput utilisation values to identify the primary "bottlenecks", while the generic methodology uses the time and production lost "bottleneck" identification techniques to identify the primary "bottlenecks".

Table 5.2: *Comparison of the Original Method and the Generic Methodology* provides a concise comparison of some of the most important attributes of the original simulation modelling method and the generic simulation modelling methodology.

The first three rows in Table 5.2 represent the attributes that are identified in Section 1.4 as the three most important shortcomings of the original simulation modelling method, while the next three rows represent the attributes of the generic simulation modelling methodology that counter these shortcomings. The generic methodology reduces the number of queues that is used and addresses the "disturbed service sequence" phenomena in the ERM method. The generic methodology immediately starts the simulation run while the original method uses the first time interval to set up the simulation model and only then starts the simulation run. The generic methodology also uses high-level building blocks, hierarchical levels, enhanced animation, preformatted spreadsheets, identifies the secondary "bottlenecks" (flares) and makes provision for the ITI and ED evaluation methods.

Table 5.2: Comparison of the Original Method and the Generic Methodology

Attribute	Original Simulation Modelling Method	Generic Simulation Modelling Methodology
FORTRAN subroutine with complex structures that are, to a large extent, not generic	Yes	No
Complicated structure that uses two different software packages to construct a simulation model with a complex structure and difficult interfacing, compiling and linking	Yes	No
Complex structure that complicates "debugging"	Yes	No
FC method that is, to a large extent, generic	No	Yes
Simplistic structure that accommodates a simulation model in one simulation software package	No	Yes
Simplistic "debugging" because of simplistic structure	No	Yes
Reduced number of queues used in the ERM method	No	Yes
Address the "disturbed service sequence" phenomena in the ERM method	No	Yes
Immediate start of the simulation run	No (First time interval used to set up simulation model)	Yes
High-level building blocks	No	Yes
Hierarchical levels in simulation model	No	Yes
Animation	Yes (Basic)	Yes (Enhanced)
Preformatted spreadsheets	No	Yes
Identification of the secondary "bottlenecks" (flares)	No	Yes
ITI and ED evaluation methods	No	Yes

A comparison of the original simulation modelling method and the generic simulation modelling methodology would not be complete without a comparison of the original simulation model and the Arena and Simul8 simulation models. Table 5.3: *Comparison of the Original Simulation Model and the Arena and Simul8 Simulation Models* provides a comparison of some of the attributes of the original simulation model and the Arena and Simul8 simulation models. Where applicable, values are provided for both the ITI and ED evaluation method option Arena and Simul8 simulation models.

Table 5.3: Comparison of the Original Simulation Model and the Arena and Simul8 Simulation Models

Attribute	Original Simulation Model	Arena Simulation Model	Simul8 Simulation model
ITI (hour)	1	(ITI) 1	(ITI) 1
n_{Rep}	10	20	20
Runtime (min)	171	(ITI) 24,0 (ED) 8,6	(ITI) 17,0 (ED) 6,8
GasPro (nm^3/h)	1349900	(ITI) 1326773,7 (ED) 1332471,8	(ITI) 1331462,8 (ED) 1332253,3
StdDev (nm^3/h)	6030	(ITI) 8066,6 (ED) 6620,5	(ITI) 7154,9 (ED) 7462,5
n_{Sam}	5 (1% deviation from real-world and 99% confidence interval)	(ITI) 14 (ED) 11 (0,5 deviation from real-world and 99% confidence interval)	(ITI) 12 (ED) 13 (0,5 deviation from real-world and 99% confidence interval)
Deviation (%)	0,59	(ITI) -0,410 (ED) 0,018	(ITI) -0,058 (ED) 0,001
Size (KB) (Iterative-loop technique)	(FORTRAN file) 6	(FORTRAN file) 13	(FORTRAN file) 13
Size (KB) (Simulation model)	(SIMAN files) 46 (FORTRAN file) 50	(Arena file) 2438	(Simu8 file) 937

Where:

ITI : The iteration time interval (hour).

n_{Rep} : The number of replications completed.

Runtime : The simulation runtime for n_{Rep} replications (minute).

GasPro : The mean output throughput value of the Gas Production plant, calculated from n_{Rep} replications (nm^3/h).

StdDev : The standard deviation from the mean output throughput value (nm^3/h).

n_{Sam} : The minimum sufficient sample size.

Deviation : The deviation of the specific mean output throughput value from the mean output throughput value of the Gas Production plant during the 1993 production year (%).

Size : The simulation model size (kilobyte).

All the values in Table 5.3 pertain to a simulated time period of one year (see Appendix L) and all the values about the original simulation model follow from the *Magister* dissertation (Albertyn, 1995). The simulation runtime of the original simulation model for 10 replications of a simulated period of one year and with an iteration time interval of one hour is 171 minutes and therefore it can be concluded that the simulation runtime for 20 replications of a simulated time period of one year and with an iteration time interval of one hour would be 342 minutes or 5,7 hours (see Section 3.4). This implies that the ITI evaluation method option Arena and Simul8 simulation models represent an approximate twentyfold improvement in simulation runtime over the original simulation model, while the ED evaluation method option Arena and Simul8 simulation models represent an approximate fortyfold improvement in simulation runtime over the original simulation model. The minimum sufficient sample size of the original simulation model is calculated with an allowance for a 1% deviation from the real-world output throughput value of the Gas Production plant, while the minimum sufficient sample sizes of the Arena and Simul8 simulation models are calculated with an allowance for a 0,5% deviation from the real-world output throughput value of the Gas Production plant.

It is of special significance to note that none of the original simulation model or the ITI and ED evaluation method option Arena and Simul8 simulation models deviate more than 1% from the mean output throughput value of the Gas Production plant during the 1993 production year.

Summary

This section identifies and compares the methods, techniques and other attributes of the original simulation modelling method and the generic simulation modelling methodology. The "toolbox" of the generic methodology contains eight methods and techniques of which only four are used by the original method. The generic methodology also uses more refined and enhanced versions of two of the four methods and techniques that are used by the original method. The comparison of the attributes of the original method and the generic methodology indicates that the generic methodology provides effective solutions for the three most important shortcomings of the original method. The most important attributes of the original simulation model and the Arena and Simul8 simulation models are also compared.

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5.5 STRENGTHS AND WEAKNESSES OF THE GENERIC METHODOLOGY

The detail discussions concerning the advantages (*i.e.* the strengths) and the disadvantages (*i.e.* the weaknesses) of the concepts of the generic simulation modelling methodology are dispersed throughout this document. This section distils the strengths and weaknesses of the generic methodology into concise lists.

The strengths of the generic simulation modelling methodology are the following:

a) The exclusion of transient behaviour reduces complexity even though, paradoxically, it can also be perceived as a possible limitation (see Section 1.7).

b) The use of the variables technique leads to short simulation runtimes and therefore also short development and maintenance times. The variables technique also ensures high accuracy. (See Section 2.2.)

c) The use of the ERM method leads to a compact simulation model size, total control over all the relevant aspects of the services and accuracy (see Section 2.3).

d) The use of the FC method impacts positively on all the design criteria of the generic simulation modelling methodology, namely: short development and maintenance times, user-friendliness, short simulation runtimes, compact size, robustness, accuracy and a single software application (see Section 1.5). The FC method is, to a large extent, generic and is also principally responsible for the simplistic structure of the generic methodology that accommodates the simulation model in one simulation software package and simplifies "debugging" (see Section 2.4).

e) The use of the iterative-loop technique provides a structured and accurate technique to determine the governing parameters of the simulation model (see Section 2.5).

f) The time and production lost "bottleneck" identification techniques accurately identify the primary "bottlenecks" (see Section 2.6).

g) The secondary "bottlenecks" (flares) are identified (see Section 2.6).

h) The division of the generic simulation modelling methodology into two separate parts (*i.e.* an iterative-loop technique part and a simulation model part) leads to a compact simulation model size and support the short simulation runtime design criterion (see Section 2.7).

i) The division of the simulation model into two separate parts (*i.e.* a "virtual" part that is represented by the logic engine high-level building block and a "real" part that is represented by the four different high-level building blocks of the ERM method) leads to a structured simulation model and therefore supports user-friendliness (see Section 2.7).

j) The use of high-level building blocks leads to short development and maintenance times, user-friendliness and a compact simulation model size. The compact simulation model size design criterion is supported by the fact that the four different high-level building blocks of the ERM method do not include any options that are unnecessary or unwanted. (See Sections 2.3 and 2.7.)

k) The use of the variables technique leads to a major benefit because no warm-up period is necessary to wait for the simulation model to "fill up" with entities before the simulation run can start. No warm-up period leads to short simulation runtimes and high accuracy. (See Section 2.7.)

l) The fact that the generic simulation modelling methodology immediately starts the simulation run (versus the original simulation modelling method where the first time interval is used to set up the simulation model) leads to a small improvement in accuracy (see Section 2.7).

m) The fact that logic engine high-level building block is generic, to a large extent, supports the short development and maintenance times and user-friendliness design criteria (see Section 3.3).

n) The fact that four different high-level building blocks of the ERM method are truly generic, supports the short development and maintenance times and user-friendliness design criteria (see Section 3.3).

o) The use of input and output files and spreadsheet variables greatly simplify the manipulation of input and output variables. These input and output mechanisms enhance user-friendliness. (See Section 3.3.)

p) The use of two hierarchical levels to represent the simulation model leads to a structured simulation model and therefore it supports user-friendliness (see Section 3.3).

q) The animation of the output throughput graph, the momentary "bottleneck" status of the primary "bottlenecks" and the flares (secondary "bottlenecks") support user-friendliness, because the realistic representation of a simulation model in a format that is immediately recognisable is fundamental to the successful familiarisation with, orientation to, and acceptance of, the simulation model by clients and users (see Section 3.3).

r) The use of the ITI evaluation method leads to accuracy (if an appropriate iteration time interval is used) and short simulation runtimes can be achieved by increasing the iteration time interval up to the acceptable limit (see Section 3.7).

s) The use of the ED evaluation method leads to accuracy and there is no need to determine a bandwidth of iteration time intervals that render valid results (see Section 3.7).

t) The availability of both the ITI and ED evaluation methods in the same simulation model and the ability to switch between the two evaluation methods at will, affords the modeller tremendous flexibility in terms of required accuracy and simulation runtimes (see

Section 3.7).

u) The use of preformatted spreadsheets to manipulate and present the results of simulation runs supports the user-friendliness design criterion (see Section 4.1).

v) The design criteria of the generic simulation modelling methodology lead to simulation models with the following characteristics: short development and maintenance times, user-friendliness, short simulation runtimes, compact size, robustness, accuracy and a single software application (see Section 1.5).

w) The generic simulation modelling methodology emphatically resolves all the shortcomings of the original simulation modelling method and presents a structured approach that accommodates all the simulation modelling problems that are posed by the class or type of system (*i.e.* stochastic continuous systems) that is considered in this document (see Sections 5.3 and 5.4).

The weaknesses of the generic simulation modelling methodology are the following:

a) The exclusion of transient behaviour is perceived as a possible limitation even though, paradoxically, it can also be perceived as a possible advantage (see Section 1.7).

b) The logic engine high-level building block is not truly 100% generic, because the unique concepts of a specific simulation model that are usually described by the process logic or rules of operation of that specific simulation model cannot be accommodated generically and therefore a part of the logic engine high-level building block of that specific simulation model will contain certain concepts that are unique to that specific simulation model (see Section 3.3).

c) The weakness of the ITI evaluation method is that a bandwidth of iteration time intervals that render valid results has to be determined before the simulation model can be used (see Sections 3.4 and 3.7).

d) The weakness of the ED evaluation method is that the simulation runtime for a specific simulation model in a specific simulation software package is a given that depends on the computer hardware configuration (see Section 3.7).

e) The five high-level building blocks of the generic simulation modelling methodology have to be developed into a template format. In a template format high-level building blocks are displayed as icons and are manipulated with the "drag and drop" functionality (to add high-level building blocks to the simulation model) and with high-level building block menus (to manipulate the parameters of the high-level building blocks). Currently the high-level building blocks are manipulated with the "copy and paste" functionality (to add high-level building blocks to the simulation model) and with the menus of the basic building blocks (to manipulate the parameters of the high-level building blocks).

f) A concise, simplistic and user-friendly manual has to be developed to provide a summary of the basic principles of the generic simulation modelling methodology and explain how the high-level building blocks should be used to construct a simulation model.

Section 1.4 indicates that the stochastic nature of simulation models of stochastic continuous systems complicates “debugging”. This was perceived as a weakness of the original simulation modelling method but, as a matter of fact, it is one of the inherent problems of all stochastic simulation models. It is therefore debatable whether it should be considered as a weakness of the generic simulation modelling methodology, or merely as an inherent characteristic.

Summary

This section summarises the strengths and weaknesses of the generic simulation modelling methodology. Twenty-three strengths and six weaknesses are identified and discussed. The six most important strengths are the following: the use of a “toolbox” of eight methods and techniques and the identification of the secondary “bottlenecks” (flares), the use of five high-level building blocks and two hierarchical levels, the fact that no warm-up period is necessary, the use of input and output files, spreadsheet variables and preformatted output spreadsheets, the availability of both the ITI and ED evaluation methods in the same simulation model and the characteristics of simulation models that are developed with the generic methodology. The three most important weaknesses are the following: the fact that the logic engine high-level building block is not 100% generic, the need to develop the five high-level building blocks into a template format and the need to develop a concise, simplistic and user-friendly manual.

* * * * *

5.6 CONTRIBUTION TO KNOWLEDGE

In *The Age of Discontinuity: Guidelines to Our Changing Society* Drucker (1978:290) makes the following statement concerning knowledge and productivity:

> "*To make knowledge work productive will be the great management task of this century, just as to make manual work productive was the great management task of the last century.*"

Drucker is, of course, referring to the twentieth (*i.e.* "*... this century, ...*") and the nineteenth centuries (*i.e.* "*... the last century.*") respectively. Even though the twentieth century is something of the past now, this viewpoint can surely be projected into the first part of the twenty-first century. His viewpoint is supported by the statement in Section 1.3 that the path to understanding the behaviour of a system can be characterised as progressing through four different levels, namely: data, information, knowledge and insight. The contribution of simulation modelling, as a decision support tool, is primarily in the areas of knowledge and insight. A simulation model is ideally suited to provide knowledge about past and present system behaviour as well as insight into probable future system behaviour. The generic simulation modelling methodology can therefore be regarded as a decision support tool that, in the words of Drucker, "*make*[s] *knowledge work productive*" and hence it supports the quest for greater efficiency.

The principal contribution to knowledge is a generic simulation modelling methodology that can be used to model stochastic continuous systems effectively.

The efficiency of the generic simulation modelling methodology can be attributed to a structured approach and the characteristics that are exhibited by simulation models that are developed with the generic methodology. The characteristics of the simulation models follow directly from the design criteria of the generic methodology and therefore the characteristics and the design criteria are identical.

The characteristics (or alternatively the design criteria) of simulation models that are developed with the generic simulation modelling methodology, are the following:

a) Short development time.

b) Short maintenance times.

c) User-friendliness as perceived from the development, maintenance and usage perspectives.

d) Short simulation runtimes.
e) Compact simulation model size.
f) Robust modelling ability.
g) Accurate modelling ability.
h) Single software application.

The following points, on a one-to-one basis, provide more detail about exactly how the generic simulation modelling methodology supports the aforementioned characteristics of simulation models that are developed with the generic methodology:

a) It is difficult to substantiate the short development time characteristic because the generic simulation modelling methodology was not used to develop a simulation model of a stochastic continuous system, other than the simulation models of the Synthetic Fuel plant, from scratch. From the timekeeping spreadsheet of the research effort (see Section 5.2) it follows that approximately 450 man-hours were spent on the development of the Arena simulation model and approximately 650 man-hours on the development of the Simul8 simulation model. These figures are misleading, however, because they include the development times of the high-level building blocks in the simulation software packages and, in the case of Simul8, the time needed to "acclimatise" to the specific concepts of the software package. If these extenuating circumstances are taken into account, the development times of the simulation models are exemplary for the development of a simulation model of a stochastic continuous system of the size and complexity of the Synthetic Fuel plant. It is therefore quite reasonable to predict that a development time of approximately 300 man-hours could be achieved for a simulation model of a stochastic continuous system that is comparable in size and complexity to the Synthetic Fuel plant.

b) It is difficult to substantiate the short maintenance times characteristic of the generic simulation modelling methodology because no maintenance actions were carried out on the Arena and Simul8 simulation models. However, it is reasonable to predict that the maintenance times should be equally acceptable, if the short development times of the simulation models are taken as a point of reference.

c) The user- friendliness characteristic of the generic simulation modelling methodology is supported by the following concepts:
    i) The use of high-level building blocks (see Sections 2.3 and 2.7).
    ii) The use of input and output files by the software programme (*i.e.* PSCALC.FOR) that determines the governing parameters (see Section 2.5).
    iii) The use of input and output files and spreadsheet variables by the Arena and

Simul8 simulation models respectively to manipulate the input and output variables (see Section 3.3).

iv) The use of two hierarchical levels to represent the system that is modelled (see Section 3.3).

v) The use of a layout on the higher hierarchical level that conforms closely to the configuration of the system that is modelled is fundamental to the familiarisation with, orientation to, and acceptance of, the simulation model (see Section 3.3).

vi) The use of preformatted spreadsheets for the manipulation of the input and output variables and spreadsheet variables of the Arena and Simul8 simulation models respectively (see Section 4.1).

d) The short simulation runtimes characteristic of the generic simulation modelling methodology is supported by the following concepts:

i) The use of the variables technique ensures that the simulation models that are developed with the generic simulation modelling methodology do not need a warm-up period (see Section 2.7).

ii) If the ITI evaluation method is used, short simulation runtimes can be achieved by increasing the iteration time interval up to the acceptable limit (see Section 3.7).

iii) The use of the most basic of the standard simulation software package building blocks in the respective simulation software packages (see Section 3.8).

e) The compact simulation model size characteristic of the generic simulation modelling methodology is supported by the following concepts:

i) The use of the advanced version of the ERM method that uses a reduced number of queues, basic building blocks to construct the high-level building blocks and excludes any unused and unnecessary options in the high-level building blocks (see Section 2.3).

ii) The natural division of the generic simulation modelling methodology into an iterative-loop technique part and a simulation model part (see Section 2.7).

f) It is difficult to substantiate the robustness characteristic of the generic simulation modelling methodology because it was not used to develop a simulation model of a stochastic continuous system, other than the simulation models of the Synthetic Fuel plant, from scratch. However, the ease of the simulation model construction of both the Arena and Simul8 simulation models suggests that the generic methodology is robust (see the discussions concerning the short development and maintenance times in this section).

g) The accurate modelling ability characteristic of the generic simulation modelling methodology is supported by the following concepts:

i) The use of the variables technique (see Sections 1.6, 2.2 and 2.7).

ii) The use of the advanced version of the ERM method that allows total control over all the relevant aspects of the services of the modules, including the "disturbed service sequence" phenomena (see Section 2.3).

iii) The use of double precision accuracy (*i.e.* 15 decimal digits) by the FORTRAN software programme that determines the governing parameters (see Section 2.5).

iv) The use of the time and production lost "bottleneck" identification techniques to identify the primary "bottlenecks" (see Section 2.6).

v) The use of the variables technique ensures that the simulation models that are developed with the generic simulation modelling methodology do not need a warm-up period and therefore the risk of including data from the "unstable" warm-up period into the results is negated (see Section 2.7).

vi) If the ITI evaluation method is used, high accuracy can be achieved by using an appropriate iteration time interval (see Section 3.4).

vii) The use of variables in the Arena and Simul8 simulation software packages that are accurate to 15 and 10 decimal digits respectively (see Section 3.8).

h) The single software application characteristic of the generic simulation modelling methodology is evident in the fact that both the Arena and Simul8 simulation models of the Synthetic Fuel plant were developed in a single simulation software package. The use of a FORTRAN software programme to determine the governing parameters is not perceived as a breach of the single software application characteristic or design criterion, because the FORTRAN software programme is essentially a preprocessor that only determines the governing parameters that are used in the simulation models.

It is essential to note that the use of the FC method impacts positively on all the characteristics of simulation models that are developed with the generic simulation modelling methodology. Therefore the FC method is perceived as the single method, from the "toolbox" of eight methods and techniques that comprises the generic methodology, that makes the most significant contribution to the efficiency of the generic methodology.

Summary

An exposition on the contribution to knowledge of this research is provided in this section. The contribution to knowledge is a generic simulation modelling methodology that can be used to model stochastic continuous systems effectively. The research supports the view of Drucker (1978:290) that one of the major current management challenges is to make "knowledge work" more productive. The efficiency of the generic methodology can be attributed to a structured approach and the characteristics that are exhibited by simulation models that are developed with the generic methodology, namely: short development and maintenance times, user-friendliness, short simulation runtimes, compact size, robustness, accuracy and a single software application.

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5.7 THE FUTURE VISION

In this section some thoughts on future developments that could enrich the generic simulation modelling methodology are presented. The possible range of application and different usage perspectives of the generic methodology are also identified and discussed.

The obvious point to start any future developments is by addressing the following shortcomings (*i.e.* the three most important weaknesses) of the generic simulation modelling methodology that are identified in Section 5.5:

a) The logic engine high-level building block is not 100% generic.
b) The five high-level building blocks have to be developed into a template format.
c) A concise, simplistic and user-friendly manual has to be developed.

Section 3.3 indicates that the logic engine high-level building block is to a large extent generic because most of the concepts that are necessary for the simulation model to function are basically the same for every simulation model that is developed with the generic simulation modelling methodology. However, the unique concepts of a specific simulation model that are usually described by the process logic or rules of operation of that specific simulation model are difficult to accommodate generically and therefore a part of the logic engine high-level building block of that specific simulation model will contain certain concepts that are unique to that specific simulation model. Even though it is virtually impossible to make provision to accommodate all possible combinations and permutations of such rules of operation generically in the logic engine high-level building block, some concepts, like the inclusion of a tank to buffer flow, are more universal and therefore lend themselves more readily to generic use. In the future a "library" of universal generic concepts could be developed. The "library" would greatly enhance the generic characteristic of the logic engine high-level building block, because appropriate universal generic concepts could simply be picked from the "library" and implemented in the logic engine high-level building block when a new simulation model is developed with the generic methodology.

The development of the five high-level building blocks into a template format and the development of a manual go hand in hand. A template format for the five high-level building blocks will increase the user-friendliness of the generic simulation modelling methodology immensely through the use of icons, the "drag and drop" functionality and high-level building block menus. The development of a concise, simplistic and user-friendly manual is essential because it is unrealistic to expect prospective modellers to work through this research document to familiarise themselves with the concepts of the generic methodology. In its current format the generic methodology is still very much a developer's or researcher's tool (*i.e.* a technology demonstrator) and not an industrial engineer's tool.

The possible range of application of the generic simulation modelling methodology is already touched upon in Section 1.6. The most obvious possible range of application is found within the petrochemical industry, where the oil-from-coal process, the classic crude oil refinement process and the GTL process can all be accommodated by the generic methodology without any difficulty. In South Africa alone, examples of chemical plants that use these processes abound, for instance, the Sasol Synfuels complex at Secunda (*i.e.* the oil-from-coal process), the South African Petroleum Refinery (Sapref) south of Durban (*i.e.* the classic crude oil refinement process) and the PetroSA plant at Mossel Bay (*i.e.* the GTL process). Furthermore, there are many chemical plants all over the world that use the classic crude oil refinement and GTL processes. Each of these chemical plants is a potential client for an application of the generic methodology.

The generic simulation modelling methodology is by no means restricted to only the petrochemical industry. Any plant that exhibits the same characteristics as the Synthetic Fuel plant can readily be accommodated by the generic methodology. For example, a plant that manufactures paint or liquid detergents obviously falls within this class or type of system. In fact, a simulation model of any stochastic continuous system can be developed with the generic methodology.

The following three different usage perspectives can be identified within the possible range of application of the generic simulation modelling methodology:

a) The classic Industrial Engineering usage perspective.
b) The training usage perspective.
c) The Sustainable Development usage perspective.

The classical Industrial Engineering usage perspective is personified by the first rule of operation in Appendix B that states that the Synthetic Fuel plant always strives to maintain the maximum possible rate of production or throughput. Goldratt and Cox (1992:294) also indicate that they regard the throughput as the definitive measurement of plant performance (see Section 2.2). The classical Industrial Engineering usage perspective will use a simulation model that is developed with the generic simulation modelling methodology to evaluate different options that are aimed at increasing the throughput and hence the profitability of the system that is under scrutiny. Chapter 4 of this document, where two alternative scenarios are evaluated with the Arena and Simul8 simulation models, is a prime example of the classic Industrial Engineering usage perspective of the generic methodology.

The training usage perspective is primarily aimed at the junior engineers of chemical plants and the engineering students of tertiary institutions. A simulation model of a chemical plant that is developed with the generic simulation modelling methodology can be used by junior chemical -, industrial - and mechanical engineers as a training tool to familiarise themselves with the cause and effect behaviour of that specific plant. In the same vein, a simulation model of an imaginary continuous process system that is developed with the generic methodology can be used by chemical -, industrial - and mechanical engineering students as an introduction to the concepts of simulation and modelling and to familiarise themselves with the cause and effect behaviour of a complex system.

The following basic introduction to the concept of Sustainable Development provides a context for the discussion of the Sustainable Development usage perspective. The concept of Sustainable Development became prominent in recent years as an area of interest and concern for the entire global community. The finite resources of the earth are coming under increasing strain from the ever increasing human world population and worldwide industrialisation. It is imperative that the resources have to be managed intelligently to ensure a prosperous future for all the inhabitants of the earth. This requires the use of best practice technologies to guarantee that the resources are optimally utilised. Simulation modelling has been identified as one of the key technology areas of future research by the European Union (Geril, 2002). It therefore stands to reason that simulation modelling qualifies as a best practice technology that can be used by the Sustainable Development fraternity.

The term "sustainable" is defined as "*of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged*" (*Merriam-Webster's Collegiate Dictionary*). The most commonly accepted definition of the term "Sustainable Development" is the one put forward by the United Nations World Commission on Environment and Development in 1987. This commission is also known as the Brundtland Commission.

According to this Commission the term "Sustainable Development" means: "*... development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.*" (Sustainable Development, 2002).

The United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil in 1992 drafted a blueprint for Sustainable Development, called Agenda 21. This conference is more commonly known as the Earth, or Rio Summit (Year in Review, 1998). The central theme of Agenda 21 is the emphasis on the improvement of the quality of life, especially for the poor (Sustainable Development, 2002). In 1997 representatives from signatory nations to the United Nations Framework Convention on Climate Change attended a meeting in Kyoto, Japan. They reached an agreement, called the Kyoto Protocol, to reduce global emissions by about 5,2% by the year 2012 (Year in Review, 1999).

In 2002 the World Summit on Sustainable Development (WSSD) was held in Johannesburg, South Africa. Two official outcomes were produced, namely the *Johannesburg Political Declaration* and the *Plan of Implementation*. The three main Sustainable Development issues identified by the *Johannesburg Political Declaration* are poverty eradication, changing consumption and production patterns and protecting and managing the natural resource base. The *Plan of Implementation* endorses water and energy as Sustainable Development concerns and reaffirms commitment to Agenda 21 of the Rio Summit (The World Summit on Sustainable Development, 2002).

A ten-point action plan to protect the environment was also signed at the WSSD by leading companies and labour organisations. The plan is called *The South African Green Paper* and it contributes towards the objectives of Sustainable Development. South African signatories include prominent companies like Sasol, Iscor, Columbus Stainless, Eskom and Telkom (WSSD, 2002).

Sustainable Development has three dimensions, namely: Economic Prosperity, Environmental Quality and Social Value (Sustainable Development, 2002). The first dimension of Economic Prosperity is comparable with the classic Industrial Engineering usage perspective that strives to increase shareholder fiscal value through the maximisation of profit. This perspective is also sometimes referred to as the "accounting" perspective and finds expression in the manufacturing environment by the pursuit of engineering to optimise the processes involved. This could lead to an increase in income or a decrease in cost (see Section 1.3). The second dimension of Environmental Quality can be compared to the so-called "green" perspective. This perspective is concerned with the health of the environment and focuses primarily on resource efficiency, cleaner production and pollution prevention. The third dimension of Social Value is not a dimension where engineering can intrinsically make a huge contribution, except in the area of safety and health through the implementation of nonhazardous processes. This dimension represents the "human" perspective which primarily falls within the spheres of the health environment and that of the humanities (sociology).

The commitment of leading companies to *The South African Green Paper* indicates that the concept of Sustainable Development is supported and actively pursued by the business community. This commitment is also reflected in the marketing campaigns of some companies, where all three the dimensions of Sustainable Development are conspicuously engaged in advertising material (Sasol's Natural gas Project Surging Ahead in Mozambique, 2002). When a company base its management decisions on all three the dimensions of Sustainable Development, it is referred to as a triple bottom-line approach (Sustainable Development Case Studies, 2002). The shift towards more accountable corporate behaviour also finds expression in the fact that many business schools are adding courses on ethics to their Master of Business Administration (MBA) programmes (Scandals Put Ethics in the Syllabus, 2003).

The Sustainable Development usage perspective of a simulation model that is developed with the generic simulation modelling methodology is primarily concerned with the Economic Prosperity and Environmental Quality dimensions of Sustainable Development. The Economic prosperity dimension is supported by the classic Industrial Engineering usage perspective, while the Environmental Quality dimension is supported by the ability of the generic methodology to identify the secondary "bottlenecks" (*i.e.* the flares). Stricter government legislation, non-governmental organisations and other pressure groups are forcing companies to manage the Environmental Quality dimension more diligently (Hofstätter and Russouw, 2004). The third dimension of Social Value benefits indirectly, because a cleaner environment is a healthier environment.

Summary

This section provides some ideas on future developments, the possible range of application and different usage perspectives of the generic simulation modelling methodology. The most important weaknesses of the generic methodology are an obvious starting point for future developments. The important weaknesses are the fact that the logic engine high-level building block is not 100% generic, the need to develop the five high-level building blocks into a template format and the need to develop a manual. The possible range of application of the generic methodology is primarily in the petrochemical industry, but any plant that exhibits the same characteristics as the Synthetic Fuel plant (*i.e.* any stochastic continuous system) can readily be accommodated by the generic methodology. The three different usage perspectives within the possible range of application of the generic methodology are the classic Industrial Engineering usage perspective, the training usage perspective and the Sustainable Development usage perspective.

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5.8 LESSONS LEARNT AND REINFORCED

This section contains a few philosophical musings that are related to the research that is presented in this document.

Thinking outside the confines that are dictated by the norm (*i.e.* lateral thinking) can lead to an innovative solution. For instance, the concept of the ERM method, that is used to determine the number of available modules in each of the smaller plants at any given moment in time, is counter-intuitive because it uses entities to represent the modules rather than the cumbersome *Servers* or *Work Centers* that are usually used in simulation software packages. It leads to a compact simulation model size, total control over all the aspects of the services and accuracy.

A concept that may seem simplistic can provide an elegant solution for a complex problem. For example, the simplicity of the FC method, that is used to identify the momentary "bottleneck" in a complex system at any given moment in time, contradicts the complexity of the problem that it solves. The FC method successfully addresses one of the major problem areas of the generic simulation modelling methodology and it also impacts positively on all the design criteria (or simulation model characteristics) of the generic methodology.

In *Gallows Gecko* of Leipoldt (2001:15) the character Martin Rekker makes the following remark to Brother Doremus:

> "*If I may remark, little things make perfection but perfection, Brother, is by no means a little thing.*"

Paying attention to minute detail, whenever possible, does accumulate to render a better solution in the long run. For example, the use of the advanced version of the ERM method that allows total control over all the relevant aspects of the services of the modules (including the "disturbed service sequence" phenomena), the use of double precision accuracy by the FORTRAN software programme that determines the governing parameters, *etc.* all contribute to the high accuracy of the generic simulation modelling methodology.

Complex problems should be approached with the complex problem solving process that is suggested by Leedy (1993:71) and *Rule Thirteen* of Descartes (2003:164-169). *Rule Thirteen* addresses the first part of the complex problem solving process.

> "*If we understand a question perfectly, it must be abstracted from every superfluous concept, reduced to its most simple form and divided by enumeration into the smallest parts possible.*"

The complex problem solving process comprises the following:

a) Identify the main problem.
b) Segregate the main problem into subproblems.
c) Conceptualise and develop methods and techniques to solve the subproblems.
d) Integrate the methods and techniques into a methodology.

Unfortunately there is no *Chemical Plant Simulation for Dummies*. In *The Goal* (Goldratt and Cox, 1992:43) the character Alex Rogo remarks:

> "*The complexity in this plant - in **any** manufacturing plant - is mind-boggling if you contemplate it.*"

Chemical plants are, by the very nature of the processes involved, extremely complex systems. There is no quick and easy way to develop a high quality simulation model of a chemical plant. It takes time, commitment and diligence. The generic simulation modelling methodology can be used to model stochastic continuous systems effectively. The efficiency of the generic methodology follows from a structured approach and the characteristics of simulation models that are developed with the generic methodology, namely: short development and maintenance times, user-friendliness, short simulation runtimes, compact size, robustness, accuracy and a single software application. The generic methodology, however, is not a magic wand that can effortlessly render high quality simulation models of complex systems.

Goldratt and Cox (1992:58) advocate the commonly held belief that monetary considerations are the sole motivation for the existence of a company.

> "*The goal of a manufacturing organization is to make money.*"

This one-dimensional perspective belongs to the realm of the dinosaurs now and has to make way for a new paradigm. The new paradigm advocates that companies that want to survive and prosper have to adapt a triple bottom-line approach. Progressive companies should temper management decisions with consideration for the three dimensions of Sustainable Development, namely: Economic Prosperity, Environmental Quality and Social Value.

Simulation modelling is as much an art as a science (Kruger, 2003:39-49). Kruger uses the comparative neutral concept of simulation modelling syndromes to discuss the art of simulation modelling. For example, under the heading "*Bigger is Better*", Kruger postulates:

> "*... many more* [simulation] *models suffer from too much detail than suffering from not enough detail. An attempt should be made to keep the* [simulation] *model as simple as possible ...*"

The concept to keep it as simple as possible is one of the cornerstones of the generic simulation modelling methodology. The simplicity concept may seem to contradict the paying attention to minute detail concept, but that is exactly where the art of simulation modelling comes into the picture. One aspect of the art of simulation modelling is to identify which detail should be included and which should be excluded.

In *Walden* Thoreau (1996:289) makes the following statement:

> "*Rather than love, than money, than fame, give me truth.*"

This statement personifies the quest of the enquiring mind and may be interpreted differently if viewed from different perspectives. For example, the philosophical, political, religious, legal, scientific, *etc.* perspectives of the term "truth", may differ significantly. From the perspective of the scientist or engineer the term "truth" may be interpreted as the "better" solution or increased efficiency. The efficiency of the generic simulation modelling methodology follows from a structured approach and the characteristics of simulation models that are developed with the generic methodology. The generic methodology represents a "better" way to develop powerful decision support tools. If these decision support tools are used correctly, it will lead to the more efficient utilisation of the limited resources of the earth.

This research represents but a small step in the long journey towards a better world.

Summary

This section concludes the research that is presented in this document with a few philosophical musings. The eight ideas that are considered may seem disconnected, but they are all relevant in the context of the research. The following philosophical ideas are discussed: lateral thinking can lead to innovative solutions, simplistic concepts can provide elegant solutions for complex problems, paying attention to detail does render better solutions, complex problems should be approached with the complex problem solving process, there is unfortunately no *Chemical Plant Simulation for Dummies,* the triple bottom-line approach is the future, simulation modelling is as much an art as a science and the search for the truth is the quest of the enquiring mind.

In the summer of 1773 Samuel Johnson and James Boswell undertook a journey to the Hebrides. During a meeting between Voltaire and Boswell, before the journey, the following conversation took place (Boswell, 2000:25):

> "*When I was at Ferney* [in France, near the Swiss border]*, in 1764, I mentioned our design to Voltaire. He looked at me, as if I had talked of going to the North Pole, and said, "You do not insist on my accompanying you?" - "No, sir." - "Then I am very willing you should go." I was not afraid that our curious expedition would be prevented by such apprehensions; ...*"

And such is the journey of the researcher, many may think the journey interesting and relevant, but few are willing to go.

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