CHAPTER 4

MODEL APPLICATION

INTRODUCTION

In this chapter the ED evaluation method option Arena and Simul8 simulation models are used to evaluate two alternative scenarios.

The first section defines the two alternative scenarios. Scenario I is representative of the Synthetic Fuel plant without the inclusion of the Oxygen Extra plant (*i.e.* the inclusion of an extra oxygen "train") and is used to identify the problem areas or "bottlenecks" in the plant. Scenario II is representative of the Synthetic Fuel plant with the Oxygen Extra plant incorporated and is used to determine how this addition impacts on the throughput of the plant. Preformatted spreadsheets are used to manipulate and present the results of the simulation runs.

In the second section the Scenario I results of the ED evaluation method option Arena and Simul8 simulation models are used to identify the primary and secondary "bottlenecks" in the Synthetic Fuel plant. In order of importance, the three most important primary "bottlenecks" are the following: Plant(II)-A, Plant(I) and Oxygen-A. The Scenario I results indicate that Oxygen-A is responsible for a large proportion of the production that is lost and that Plant(IV) and Plant(V) are the only two secondary "bottlenecks".

The Scenario I and II results of the ED evaluation method option Arena and Simul8 simulation models are used in the third section to verify the Scenario II simulation models, to compare the Scenario I and II simulation models and to establish the 99% confidence intervals for the mean output throughput values of the Scenario I and II simulation models. The two scenarios can be assumed to represent two different outcomes because the confidence intervals do not overlap. The Scenario II results are used to identify the primary and secondary "bottlenecks". The two most important primary "bottlenecks" are Plant(II)-A and Plant(I), while Oxygen-A is only responsible for a small portion of the production that is lost in Scenario II. Once again, Plant(IV) and Plant(V) are the only two secondary "bottlenecks" in Scenario II.

In the fourth section the Scenario I results of the three most important primary "bottlenecks" (*i.e.* Plant(II)-A, Plant(I) and Oxygen-A) are compared with those of Scenario II. The comparison clearly shows that Oxygen-A does not qualify as an important primary “bottleneck” in Scenario II anymore. The Scenario I and II results also indicate that the total volume and mean rate of flare values at the two secondary “bottlenecks” (*i.e.* Plant(IV) and Plant(V)) are larger in Scenario II than in Scenario I. This is caused by the larger mean output throughput value of the Gas Production plant in Scenario II. The gain in the output throughput value in Scenario II, expressed in terms of production days of the Gas Production plant, is approximately five production days. The impact, when an additional oxygen “train” (the Oxygen Extra plant) is incorporated into the Synthetic Fuel plant, is that the “bottleneck” effect of Oxygen-A is removed and that the output throughput of the Synthetic Fuel plant is increased.

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4.1 BACKGROUND INFORMATION

Section 1.1 indicates that the original simulation model of the Sasol East plant was used to investigate two alternative scenarios in the *Magister* dissertation (Albertyn, 1995:81-96). The two scenarios were used to identify the problem areas in the plant and to study the effect of a proposed change on the plant. The first scenario identified the "bottlenecks" in the plant and the second scenario determined the effect of an extra oxygen "train" on the plant. The addition of an extra oxygen "train" was chosen as a scenario, because it was one of the real-world decision options that confronted the management of the plant when the original simulation model was developed. The first scenario will be referred to as Scenario I and the second scenario as Scenario II in the rest of this document.

In this chapter the ED evaluation method option Arena and Simul8 simulation models are used to replicate the two scenarios that were investigated with the original simulation model in the *Magister* dissertation. The purpose of this replication is to further validate the generic simulation modelling methodology and to provide a basis for a comparison of the original simulation modelling method and the generic methodology.

The three most obvious differences (apart from all the other differences) between the original simulation model and the ED evaluation method option Arena and Simul8 simulation models are the following:

a) The original simulation model uses the ITI evaluation method, while the ED evaluation method option Arena and Simul8 simulation models use the ED evaluation method (see Section 3.7).
b) The original simulation model uses the throughput utilisation values to identify the primary "bottlenecks", while the ED evaluation method option Arena and Simul8 simulation models use the time and production lost "bottleneck" identification techniques to identify the primary "bottlenecks" (see Section 2.6).
c) The original simulation model does not make provision for the identification of the secondary "bottlenecks" (flares), while the ED evaluation method option Arena and Simul8 simulation models do identify the secondary "bottlenecks" (see Section 2.6).

Section 3.3 indicates that the Arena and Simul8 simulation models use input and output files and spreadsheet variables as input and output mechanisms. The input and output variables (data) in the input and output files and spreadsheet variables, however, still need further manipulation to provide coherent and comprehensible results (see the process of moving from data to information that is described in Section1.3). To this end preformatted spreadsheets were developed for the manipulation of the output files and spreadsheet variables (the input files are manipulated with a text editor). The most obvious benefits that follow from this development are standardisation in the presentation of results and ease of use. These concepts obviously also support the user-friendliness design criterion (see Section 1.5) of the generic simulation modelling methodology.

A detail discussion of all the results that are presented in the preformatted spreadsheets does not fall within the scope of this document. The following summary, however, provides an insight into the most important aspects of the results that are presented in the preformatted spreadsheets.

The most important aspects of the results that are presented in the preformatted spreadsheets are the following:

a) The mean output throughput values of the 16 primary points of evaluation (see Table 3.1). (Some of the points of evaluation have more than one mean output throughput value and in such an instance only the most important mean output throughput value is considered.) Only 13 values are presented because the three mean output throughput values of the Oxygen Plant incorporate the three mean output throughput values of the Oxygen Extra plant, when the Oxygen Extra plant is incorporated into the simulation model in Scenario II.

b) The mean output throughput values of the five secondary and seven tertiary points of evaluation (see Table 3.1). The three mean output throughput values of the Oxygen Extra plant are also incorporated into this group because they are used to verify that the simulation models operate correctly, when the Oxygen Extra plant is incorporated into the simulation model in Scenario II.

c) The mean time that each of the 16 primary points of evaluation is the primary "bottleneck", as a percentage (see the time "bottleneck" identification technique in Section 2.6). Only 13 values are presented because the three mean time values of the Oxygen plant incorporate the three mean time values of the Oxygen Extra plant, when the Oxygen Extra plant is incorporated into the simulation model in Scenario II. The three mean time values of the Oxygen Extra plant are also incorporated into this group because they are used to verify that the simulation models operate correctly, when the Oxygen Extra plant is incorporated into the simulation model in Scenario II.

d) The mean production that is lost when each of the 16 primary points of evaluation is the primary "bottleneck", as a percentage (see the production lost "bottleneck" identification technique in Section 2.6). Only 13 values are presented because the three mean production lost values of the Oxygen plant incorporate the three mean production lost values of the Oxygen Extra plant, when the Oxygen Extra plant is incorporated into the simulation model in Scenario II.

e) The mean volume in the tank and the total volumes and mean rates of flare at the secondary "bottlenecks".

f) The mean number of available modules in each of the smaller plants and the mean number of modules that is switched on or off in each of the smaller plants.

g) The mean number of services completed and missed in each of the smaller plants and the mean number of failures repaired in each of the smaller plants.

h) The mean values of various variables that monitor the functioning of the simulation models. It includes a histogram that indicates how many modules were removed for service or repair every simulation model evaluation.

i) The mean number of times that each of the 16 primary points of evaluation is the primary "bottleneck". Only 13 values are presented because the three values of the Oxygen plant incorporate the three values of the Oxygen Extra plant, when the Oxygen Extra plant is incorporated into the simulation model in Scenario II. This histogram values are used to verify the time primary "bottleneck" identification technique values if the ITI evaluation method is used.

j) The "throughput vector" that consists of the mean input throughput values of the Synthetic Fuel plant and the mean output throughput values of each of the smaller plants (see the convention that is detailed in Section 2.2).

k) The mean utilisation values of the Service and Repair Teams of all the smaller plants that are subject to services and failures, as percentages.

l) A comparison test that compares the mean utilisation values of the Service and Repair Teams of all the smaller plants that are subject to services and failures with the theoretical utilisation values to validate the mean utilisation values. Other variables that monitor the functioning of the simulation models are also subjected to logical tests.

The previous discussion on the aspects that are addressed in the preformatted spreadsheets is based on the preformatted spreadsheet of the Arena simulation model. The preformatted spreadsheet of the Simul8 simulation model contains exactly the same data and information, but not necessarily in exactly the same order.

In Section 3.7 the means of the output throughput values of the Gas Production plant are calculated from the results of the 20 replications of the simulation runs that were completed with the ED evaluation method option Arena and Simul8 simulation models. The mean output throughput values of the Gas Production plant are used to validate the simulation models and it is indicated that it can be accepted with a high level of confidence that the simulation models are valid representations of the Synthetic Fuel plant. The full results of the simulation run that was completed with the ED evaluation method option Arena simulation model represent the Scenario I results of the Arena simulation model and is shown in Appendix Q: *ED Evaluation Method Option Arena Simulation Model Results (Scenario I)*. The full results of the simulation run that was completed with the ED evaluation method option Simul8 simulation model represent the Scenario I results of the Simul8 simulation model and is shown in Appendix R: *ED Evaluation Method Option Simul8 Simulation Model Results (Scenario I)*.

Summary

This section identifies the two alternative scenarios that are investigated in this chapter. Scenario I represents the Synthetic Fuel plant without the inclusion of the Oxygen Extra plant (*i.e.* the inclusion of an extra oxygen "train") and is used to identify the problem areas or "bottlenecks" in the plant. Scenario II represents the Synthetic Fuel plant with the Oxygen Extra plant incorporated and is used to determine how this addition impacts on the throughput of the plant. An overview of the most important aspects of the results that are presented in the preformatted spreadsheets, is also provided.

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4.2 SCENARIO I RESULTS

In this section the problem areas or "bottlenecks" in the Synthetic Fuel plant are identified by analysing the results of the Scenario I simulation runs that were completed with the ED evaluation method option Arena and Simul8 simulation models.

Table 4.1: *Scenario I Primary "Bottlenecks"* provides the Scenario I results of the ED evaluation method option Arena and Simul8 simulation models for the primary "bottlenecks" in terms of the time (see Equation 2.15) and production lost (see Equation 2.16) criteria. The throughput utilisation values (see Equations 2.13 and 2.14) for the primary "bottlenecks" are also shown.

It is important to note that each of the throughput utilisation values is given as a percentage for the specific point of evaluation while the time and production lost values are given as percentages of the total time and total production lost values.

Table 4.1: Scenario I Primary "Bottlenecks"

No.	Name	Arena Simulation Model			Simul8 Simulation Model		
		ThrUtl (%)	Time (%)	PrdLst (%)	ThrUtl (%)	Time (%)	PrdLst (%)
1	Coal Processing	68,58	0,02	0,02	68,59	0,08	0,09
3	Steam	50,47	0,00	0,00	50,38	0,00	0,00
4	Gas Production	85,58	0,77	0,31	85,65	1,09	0,51
5	Temperature Regulation	80,33	0,00	0,00	80,31	0,00	0,00
6-A	Oxygen-A	90,41	10,96	18,11	90,41	11,17	18,45
6-B	Oxygen-B	88,77	1,14	1,86	88,78	1,32	2,14
6-C	Oxygen-C	77,51	0,18	0,30	77,50	0,19	0,31
8	Plant(I)	93,58	28,63	28,30	93,57	27,91	28,20
9-A	Plant(II)-A	93,82	57,53	47,16	93,90	57,53	46,70
9-B	Plant(II)-B	59,45	0,03	0,08	59,44	0,04	0,10
10	Plant(III)	84,14	0,25	1,32	84,13	0,26	1,34
11	Division Process	84,25	0,49	2,54	84,20	0,41	2,16
12	Recycling	75,82	0,00	0,00	75,80	0,00	0,00

Where:

No.	:	The plant identification number.
ThrUtl	:	The throughput utilisation value of the primary "bottleneck" (%).
Time	:	The time that the primary "bottleneck" is the "bottleneck" (%).
PrdLst	:	The production lost due to each of the primary "bottlenecks" (%).

From Table 4.1 it follows that the three most important primary "bottlenecks", in order of importance, are Plant(II)-A, Plant(I) and Oxygen-A. All three the primary "bottleneck" identification criteria support this finding. According to the throughput utilisation value criterion the three most important primary "bottlenecks" are Plant(II)-A (93,82% - Arena and 93,90% - Simul8), Plant(I) (93,58% - Arena and 93,57% - Simul8) and Oxygen-A (90,41% - Arena and Simul8). According to the time criterion the three most important primary "bottlenecks" are Plant(II)-A (57,53% - Arena and Simul8), Plant(I) (28,63% - Arena and 27,91% - Simul8) and Oxygen-A (10,96% - Arena and 11,17% - Simul8). According to the production lost criterion the three most important primary "bottlenecks" are Plant(II)-A (47,16% - Arena and 46,70% - Simul8), Plant(I) (28,30% - Arena and 28,20% - Simul8) and Oxygen-A (18,11% - Arena and 18,45% - Simul8).

These results are presented in Table 4.2: *Scenario I Primary "Bottlenecks" Prioritised.*

Table 4.2: Scenario I Primary "Bottlenecks" Prioritised

No.	Name	Arena Simulation Model			Simul8 Simulation Model		
		ThrUtl (%)	Time (%)	PrdLst (%)	ThrUtl (%)	Time (%)	PrdLst (%)
9-A	Plant(II)-A	93,82	57,53	47,16	93,90	57,53	46,70
8	Plant(I)	93,58	28,63	28,30	93,57	27,91	28,20
6-A	Oxygen-A	90,41	10,96	18,11	90,41	11,17	18,45

Where:

No. : The plant identification number.
ThrUtl : The throughput utilisation value of the primary "bottleneck" (%).
Time : The time that the primary "bottleneck" is the "bottleneck" (%).
PrdLst : The production lost due to each of the primary "bottlenecks" (%).

A discussion on the interpretation of the throughput utilisation values of Scenario I is provided in the *Magister* dissertation (Albertyn, 1995:84-89). The throughput utilisation values of the Scenario I ED evaluation method option Arena and Simul8 simulation models correlates extremely closely with those of the original simulation model (Albertyn, 1995:88). In this document, however, the time and production lost criteria are the focus of the discussion.

From Table 4.2 it follows that Plant(II)-A is the primary "bottleneck" for approximately 58% of the time and is responsible for approximately 47% of the production that is lost. Plant(I) is the primary "bottleneck" for approximately 28% of the time and is responsible for approximately 28% of the production that is lost. These results thoroughly substantiate the perception of the engineering division of the Synthetic Fuel plant that Plant(II)-A and Plant(I) are the "troublemakers". Oxygen-A is the primary "bottleneck" for approximately 11% of the time but is responsible for approximately 18% of the production that is lost. This indicates that when Oxygen-A is the primary "bottleneck", it has a pronounced effect on the throughput of the Synthetic Fuel plant and therefore Oxygen-A is a valid candidate for increased capacity, even though more production is lost at Plant(II)-A and Plant(I). In this document the addition of an extra oxygen "train" is the proposed change scenario that is under scrutiny, but it should be noted that both Plant(II)-A and Plant(I) are also subjected to continuous improvement drives.

Table 4.3: *Scenario I Secondary "Bottlenecks"* provides the Scenario I results of the ED evaluation method option Arena and Simul8 simulation models for the secondary "bottlenecks" in terms of the total volumes and mean rates of flare at the secondary "bottlenecks".

Table 4.3: Scenario I Secondary "Bottlenecks"

No.	Name	Flare	Arena Simulation Model		Simul8 Simulation Model	
			Volume (m^3, nm^3)	Rate (m^3/h, nm^3/h)	Volume (m^3, nm^3)	Rate (m^3/h, nm^3/h)
13	Plant(IV)	Flare-A	3362,1	0,389	7264,6	0,841
14	Sub(I)	Flare-C1	0,0	0,000	0,0	0,000
15	Sub(II)	Flare-C2	0,0	0,000	0,0	0,000
16	Sub(III)	Flare-C3	0,0	0,000	0,0	0,000
17	Sub(IV)	Flare-C4	0,0	0,000	0,0	0,000
18	Sub(V)	Flare-C5	0,0	0,000	0,0	0,000
19	Sub(VI)	Flare-C6	0,0	0,000	0,0	0,000
20	Plant(V)	Flare-B	17036,7	1,972	17191,2	1,990

Where:

No. : The plant identification number.

From Table 4.3 it is evident that there are only two secondary "bottlenecks", namely: Plant(IV) and Plant(V). The difference in the total volume and mean rate of flare values at Plant(IV), between the results of the Arena and Simul8 simulation models, is immediately noticeable. The total volume and mean rate of flare values of the Arena simulation model are approximately half that of the Simul8 simulation model. This discrepancy warrants further investigation. Closer examination of the rest of the results of the two simulation runs, however, reveals that the mean number of failures created at Plant(IV)-C is 0,15 for the Arena simulation model and 0,30 for the Simul8 simulation model. The higher number of failures created by the Simul8 simulation model implies that Plant(IV)-C was less available in the Simul8 simulation run and therefore a bigger portion of the throughput was flared. There is no discernible difference in the total volume and mean rate of flare values at Plant(V) between the results of the Arena and Simul8 simulation models. A scrutiny of the rest of the results of the two simulation runs reveals that the mean number of failures created at Plant(V) is 11,20 for the Arena simulation model and 11,05 for the Simul8 simulation model.

Summary

In this section the Scenario I results of the ED evaluation method option Arena and Simul8 simulation models are used to identify the primary and secondary "bottlenecks" in the Synthetic Fuel plant. The three most important primary "bottlenecks" are Plant(II)-A, Plant(I) and Oxygen-A (arranged in order of declining importance). Oxygen-A is responsible for approximately 18% of the production that is lost. Plant(IV) and Plant(V) are the only two secondary "bottlenecks" that have to flare portions of their throughput.

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4.3 SCENARIO II RESULTS

In this section the effect of a proposed change (the addition of an extra oxygen "train") on the Synthetic Fuel plant is determined by analysing the results of the Scenario II simulation runs that were completed with the ED evaluation method option Arena and Simul8 simulation models. Simulation runs consisting of 20 replications of a simulated time period of one year (see Appendix L) were completed with the Scenario II simulation models. The input of the Scenario II simulation runs was exactly the same as those of the Scenario I simulation runs that are described in Section 3.7, with the exception that the Oxygen Extra plant was incorporated into the Synthetic Fuel plant.

In Table 4.4: *Verification of the Scenario II Simulation Models* the Scenario II ED evaluation method option Arena and Simul8 simulation models are verified by comparing the time that each of Oxygen-A, -B and -C is the primary "bottleneck" (including the time that they are multiple "bottlenecks") in Scenario I, with the number of modules that is switched on values of each of Oxygen Extra-A, -B and -C in Scenario II. It logically follows that there should be a close correlation between the time that a point of evaluation is the "bottleneck" in Scenario I and the number of additional modules that is switched on in Scenario II. Oxygen Extra-A, -B and -C has only one module each and therefore the number of modules that is switched on values in the Scenario II results also represent the time that the modules were switched on because the modules are only switched on when needed.

Table 4.4: Verification of the Scenario II Simulation Models

No.	Name	Arena Simulation Model		Simul8 Simulation Model	
		Scenario I Time "Btt" (%)	Scenario II No. Swt On	Scenario I Time "Btt" (%)	Scenario II No. Swt On
6-A	Oxygen-A	11,15	-	11,37	-
6-B	Oxygen-B	1,22	-	1,38	-
6-C	Oxygen-C	0,30	-	0,32	-
6E-A	Oxygen Extra-A	-	0,112	-	0,114
6E-B	Oxygen Extra-B	-	0,012	-	0,014
6E-C	Oxygen Extra-C	-	0,003	-	0,003

Where:

No. : The plant identification number.

Time "Btt" : The time that each point of evaluation is the primary "bottleneck" (including the time that they are multiple "bottlenecks").

No. Swt On : The number of modules that is switched on.

A scrutiny of Table 4.4 reveals that there is a 100% correlation between the time that each of Oxygen-A, -B and -C is the primary "bottleneck" (including the time that they are multiple "bottlenecks") in Scenario I and the number of modules that is switched on values of each of Oxygen Extra-A, -B and -C in Scenario II for both the Arena and Simul8 simulation models. It can therefore be concluded that the Scenario II simulation models operate as intended, insofar as Oxygen Extra-A, -B and -C are concerned.

It is interesting to note that the inclusion of an extra oxygen "train" (*i.e.* the Oxygen Extra plant) into the simulation models of the Synthetic Fuel plant is not a straightforward matter. A scrutiny of Table A1 reveals that Oxygen Extra-A and -C are electricity-driven while Oxygen-A and -C are steam-driven. This implies that the ratio of steam that is supplied to the Gas Production plant to steam that is supplied to the Oxygen plant (*i.e.* the steam-division-ratio) changes when Oxygen Extra-A or -C is switched on. Iterative loops are used in the logic engine high-level building block to accommodate this very complex concept. A detail discussion of these iterative loops does not fall within the scope of this document.

Table 4.5: *Comparison of the Scenario I and II Simulation Models* provides a comparison between the Scenario I (see Table 3.7) and II ED evaluation method option Arena and Simul8

simulation models.

Table 4.5: Comparison of the Scenario I and II Simulation Models

Simulation Model	Scn	n_{Rep}	Runtime (min)	GasPro (nm^3/h)	StdDev (nm^3/h)	n_{Sam}	Deviation (%)
Arena (ED)	I	20	8,6	1332471,8	6620,5	11	0,018
Arena (ED)	II	20	8,7	1351034,1	7443,5	13	-
Simul8 (ED)	I	20	6,8	1332253,3	7462,5	13	0,001
Simul8 (ED)	II	20	7,0	1351484,8	8149,1	14	-

Where:

Scn : The scenario number.
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 (%).

The means and the standard deviations from the means of the output throughput values of the Gas Production plant, are calculated from the results of the 20 replications of the simulation runs that were completed with the ED evaluation method option Arena and Simul8 Scenario II simulation models. The standard deviations are used to calculate the corresponding minimum sufficient sample sizes with an allowance for a 0,5% deviation from the real-world mean output throughput value of the Gas Production plant (see Appendix M) and a 99% confidence interval. Section 3.5 provides a detailed explanation of the determination of minimum sufficient sample size. The number of replications completed in both instances should be more than, or equal to, the calculated minimum sufficient sample sizes for the answers to be taken as representative of the simulated scenario. A scrutiny of Columns 3 and 7 of Table 4.5 indicates that this constraint is adhered to.

From Table 4.5 it follows that the simulation runtimes of the Scenario II simulation models are slightly longer than those of the Scenario I simulation models for both the Arena and Simul8 simulation models. This can be attributed to the fact that the Scenario II simulation models complete additional tasks when the Oxygen Extra plant is incorporated. The mean output throughput values of the Gas Production plant of the Scenario II simulation models are also larger than those of the Scenario I simulation models for both the Arena and Simul8 simulation models. This indicates that the addition of the extra oxygen "train" leads to a higher throughput.

Table 4.6: *99% Confidence Intervals for the Output Throughput (Scenario I and II Simulation Models)* provides the 99% confidence intervals for the mean output throughput values of the Scenario I and II ED evaluation method option Arena and Simul8 simulation models. The mean output throughput values of the Gas Production plant are used.

Table 4.6: 99% Confidence Intervals for the Output Throughput (Scenario I and II Simulation Models)

Simulation Model	Scn	GasPro (nm^3/h)	StdDev (nm^3/h)	ConInt (nm^3/h)	Lower ConLmt (nm^3/h)	Upper ConLmt (nm^3/h)
Arena (ED)	I	1332471,8	6620,5	8470,8	1328236,4	1336707,2
Arena (ED)	II	1351034,1	7443,5	9523,8	1346272,2	1355796,0
Simul8 (ED)	I	1332253,3	7462,5	9548,1	1327479,2	1337027,4
Simul8 (ED)	II	1351484,8	8149,1	10426,6	1346271,5	1356698,1

Where:

Scn : The scenario number.

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).

ConInt : The confidence interval (nm^3/h).

ConLmt : The confidence limit (nm^3/h).

Section 3.6 indicates that the confidence intervals should be taken into consideration when alternatives are compared. If the confidence intervals for the mean output throughput values of two scenarios overlap, the two scenarios cannot be differentiated in terms of representing two different outcomes.

A scrutiny of Columns 6 and 7 of Table 4.6 reveals that the 99% confidence intervals for the mean output throughput values of the Scenario I and II Arena simulation models do not overlap and therefore the two scenarios can be assumed to represent two different outcomes. This implies that it is valid to use the delta between the mean output throughput values of the Scenario I and II Arena simulation models to determine the effect of the additional oxygen "train" on the throughput of the Synthetic Fuel plant. Furthermore, the 99% confidence intervals for the mean output throughput values of the Scenario I and II Simul8 simulation models also do not overlap and therefore the two scenarios can be assumed to represent two different outcomes. This implies that it is valid to use the delta between the mean output throughput values of the Scenario I and II Simul8 simulation models to determine the effect of the additional oxygen "train" on the throughput of the Synthetic Fuel plant.

Table 4.7: *Scenario II Primary "Bottlenecks"* provides the Scenario II results of the ED evaluation method option Arena and Simul8 simulation models for the primary "bottlenecks" in terms of the time (see Equation 2.15) and production lost (see Equation2.16) criteria. The throughput utilisation values (see Equations 2.13 and 2.14) for the primary "bottlenecks" are also shown.

Table 4.7: Scenario II Primary "Bottlenecks"

No.	Name	Arena Simulation Model			Simul8 Simulation Model		
		ThrUtl (%)	Time (%)	PrdLst (%)	ThrUtl (%)	Time (%)	PrdLst (%)
1	Coal Processing	69,53	0,02	0,03	69,58	0,09	0,12
3	Steam	50,95	0,00	0,00	50,88	0,00	0,00
4	Gas Production	86,77	1,03	0,47	86,89	1,27	0,71
5	Temperature Regulation	81,45	0,00	0,00	81,47	0,00	0,00
6-A	Oxygen-A	79,10	0,18	0,37	79,14	0,21	0,41
6-B	Oxygen-B	76,45	0,00	0,00	76,49	0,00	0,00
6-C	Oxygen-C	68,14	0,00	0,01	68,17	0,00	0,01
8	Plant(I)	94,88	32,42	33,12	94,92	31,98	33,19
9-A	Plant(II)-A	95,13	65,57	61,40	95,25	65,75	61,32
9-B	Plant(II)-B	60,28	0,03	0,09	60,30	0,04	0,11
10	Plant(III)	85,31	0,25	1,54	85,35	0,26	1,58
11	Division Process	85,45	0,49	2,97	85,42	0,41	2,54
12	Recycling	76,87	0,00	0,00	76,90	0,00	0,00

Where:

No. : The plant identification number.
ThrUtl : The throughput utilisation value of the primary "bottleneck" (%).
Time : The time that the primary "bottleneck" is the "bottleneck" (%).
PrdLst : The production lost due to each of the primary "bottlenecks" (%).

In Section 4.2 the three most important primary "bottlenecks" are identified from the results of the Scenario I simulation runs. They are, in order of importance, Plant(II)-A, Plant(I) and Oxygen-A. Table 4.7 indicates that the Scenario II results for the throughput utilisation values of the most important Scenario I primary "bottlenecks" are the following: 95,13% (Arena) and 95,25% (Simul8) for Plant(II)-A, 94,88% (Arena) and 94,92% (Simul8) for Plant(I) and 79,10% (Arena) and 79,14% (Simul8) for Oxygen-A. The Scenario II results, according to the time criterion, of the most important Scenario I primary "bottlenecks" are the following: 65,57% (Arena) and 65,75% (Simul8) for Plant(II)-A, 32,42% (Arena) and 31,98% (Simul8) for Plant(I) and only 0,18% (Arena) and 0,21% (Simul8) for Oxygen-A. The Scenario II results, according to the production lost criterion, of the most important Scenario I primary "bottlenecks" are the following: 61,40% (Arena) and 61,32% (Simul8) for Plant(II)-A, 33,12% (Arena) and 33,19% (Simul8) for Plant(I) and only 0,37% (Arena) and 0,41% (Simul8) for Oxygen-A.

These results are presented in Table 4.8: *Scenario II Primary "Bottlenecks" Prioritised.*

Table 4.8: Scenario II Primary "Bottlenecks" Prioritised

No.	Name	Arena Simulation Model			Simul8 Simulation Model		
		ThrUtl (%)	Time (%)	PrdLst (%)	ThrUtl (%)	Time (%)	PrdLst (%)
9-A	Plant(II)-A	95,13	65,57	61,40	95,25	65,75	61,32
8	Plant(I)	94,88	32,42	33,12	94,92	31,98	33,19
6-A	Oxygen-A	79,10	0,18	0,37	79,14	0,21	0,41

Where:

No. : The plant identification number.
ThrUtl : The throughput utilisation value of the primary "bottleneck" (%).
Time : The time that the primary "bottleneck" is the "bottleneck" (%).
PrdLst : The production lost due to each of the primary "bottlenecks" (%).

Table 4.8 actually represents the results of the three most important primary "bottlenecks" that are identified from the results of the Scenario I simulation runs in Section 4.2 and not the three most important primary "bottlenecks" of the Scenario II simulation runs. The reason for this is that it allows a direct comparison of the three primary "bottleneck" identification criteria for Oxygen-A between Scenario I and II.

A discussion on the interpretation of the throughput utilisation values of Scenario II is provided in the *Magister* dissertation (Albertyn, 1995:90-94). The throughput utilisation values of the Scenario II ED evaluation method option Arena and Simul8 simulation models correlate extremely closely with those of the original simulation model (Albertyn, 1995:94). In this document, however, the time and production lost criteria are the focus of the discussion.

From Table 4.8 it follows that Plant(II)-A is the primary "bottleneck" for approximately 66% of the time and is responsible for approximately 61% of the production that is lost. Plant(I) is the primary "bottleneck" for approximately 32% of the time and is responsible for approximately 33% of the production that is lost. Oxygen-A is the primary "bottleneck" for less than 1% of the time and is responsible for less than 1% of the production that is lost.

Table 4.9: *Scenario II Secondary "Bottlenecks"* provides the Scenario II results of the ED evaluation method option Arena and Simul8 simulation models for the secondary "bottlenecks" in terms of the total volumes and mean rates of flare at the secondary "bottlenecks".

Table 4.9: Scenario II Secondary "Bottlenecks"

No.	Name	Flare	Arena Simulation Model		Simul8 Simulation Model	
			Volume (m^3, nm^3)	Rate (m^3/h, nm^3/h)	Volume (m^3, nm^3)	Rate (m^3/h, nm^3/h)
13	Plant(IV)	Flare-A	3413,9	0,395	7328,2	0,848
14	Sub(I)	Flare-C1	0,0	0,000	0,0	0,000
15	Sub(II)	Flare-C2	0,0	0,000	0,0	0,000
16	Sub(III)	Flare-C3	0,0	0,000	0,0	0,000
17	Sub(IV)	Flare-C4	0,0	0,000	0,0	0,000
18	Sub(V)	Flare-C5	0,0	0,000	0,0	0,000
19	Sub(VI)	Flare-C6	0,0	0,000	0,0	0,000
20	Plant(V)	Flare-B	19418,8	2,248	19413,0	2,247

Where:

No. : The plant identification number.

From Table 4.9 it is evident that there are only two secondary "bottlenecks", namely: Plant(IV) and Plant(V). The difference in the total volume and mean rate of flare values at Plant(IV) between the results of the Arena and Simul8 simulation models is immediately noticeable. The total volume and mean rate of flare values of the Arena simulation model are approximately half that of the Simul8 simulation model. The explanation for this anomaly in the results is provided in Section 4.2. There is no discernible difference in the total volume and mean rate of flare values at Plant(V) between the results of the Arena and Simul8 simulation models.

Summary

In this section the Scenario I and II results of the ED evaluation method option Arena and Simul8 simulation models are used to verify the Scenario II simulation models, to compare the Scenario I and II simulation models and to establish the 99% confidence intervals for the mean output throughput values of the Scenario I and II simulation models. The confidence intervals do not overlap and therefore the two scenarios can be assumed to represent two different outcomes. The Scenario II results are used to identify the primary and secondary "bottlenecks" and it is indicated that the two most important primary "bottlenecks" are Plant(II)-A and Plant(I). Oxygen-A is only responsible for less than 1% of the production that is lost in Scenario II. The total volume and mean rate of flare values indicate that Plant(IV) and Plant(V) are the only two secondary "bottlenecks" in Scenario II.

* * * * *

4.4 COMPARISON OF THE SCENARIO I AND II RESULTS AND THE CONCLUSIONS

This section compares the Scenario I and II results (see Sections 4.2 and 4.3) of the ED evaluation method option Arena and Simul8 simulation models and presents some logical conclusions that can be derived from these results.

Table 4.10: *Comparison of the Scenario I and II Primary "Bottlenecks"* provides a comparison between the Scenario I and II results of the ED evaluation method option Arena and Simul8 simulation models for the most important primary "bottlenecks" in terms of the time (see Equation 2.15) and production lost (see Equation 2.16) criteria.

Table 4.10: Comparison of the Scenario I and II Primary "Bottlenecks"

No.	Name	Arena Simulation Model				Simul8 Simulation Model			
		Scenario I		Scenario II		Scenario I		Scenario II	
		Time (%)	PrdLst (%)	Time (%)	PrdLst (%)	Time (%)	PrdLst (%)	Time (%)	PrdLst (%)
9-A	Plant(II)-A	57,53	47,16	65,57	61,40	57,53	46,70	65,75	61,32
8	Plant(I)	28,63	28,30	32,42	33,12	27,91	28,20	31,98	33,19
6-A	Oxygen-A	10,96	18,11	0,18	0,37	11,17	18,45	0,21	0,41
	Total	**97,12**	**93,57**	**98,17**	**94,89**	**96,61**	**93,35**	**97,94**	**94,92**

Where:

No. : The plant identification number.

Time : The time that the primary "bottleneck" is the "bottleneck" (%).

PrdLst : The production lost due to each of the primary "bottlenecks" (%).

Table 4.10 indicates that Plant(II)-A, Plant(I) and Oxygen-A (the three most important primary "bottlenecks") are the primary "bottlenecks" for a total of approximately 97% of the time and are responsible for a total of approximately 93% of the production that is lost in Scenario I. Oxygen-A is the primary "bottleneck" for approximately 11% of the time out of the total of 97% for the three most important primary "bottlenecks" and is responsible for approximately 18% of the production that is lost out of the total of 93% in Scenario I. Scenario II, however, presents a different picture. Plant(II)-A, Plant(I) and Oxygen-A are the primary "bottlenecks" for a total of approximately 98% of the time and are responsible for a total of approximately 95% of the production that is lost in Scenario II. Oxygen-A, however, is the primary “bottleneck” for less than 1% of the time out of the total of 98% and is responsible for less than 1% of the production that is lost out of the total of 95% in Scenario II.

The results of the previous paragraph clearly indicate that Oxygen-A does not qualify as an important primary “bottleneck” in Scenario II. In fact, Plant(II)-A and Plant(I) together are the primary “bottlenecks” for most (98%) of the time and are responsible for most (95%) of the production that is lost in Scenario II.

These results are graphically depicted in Figure 4.1: *Comparison of the Scenario I and II Primary “Bottlenecks”* which shows the time (on the left-hand side of the graph) and production lost (on the right-hand side of the graph) of Plant(II)-A, Plant(I) and Oxygen-A.

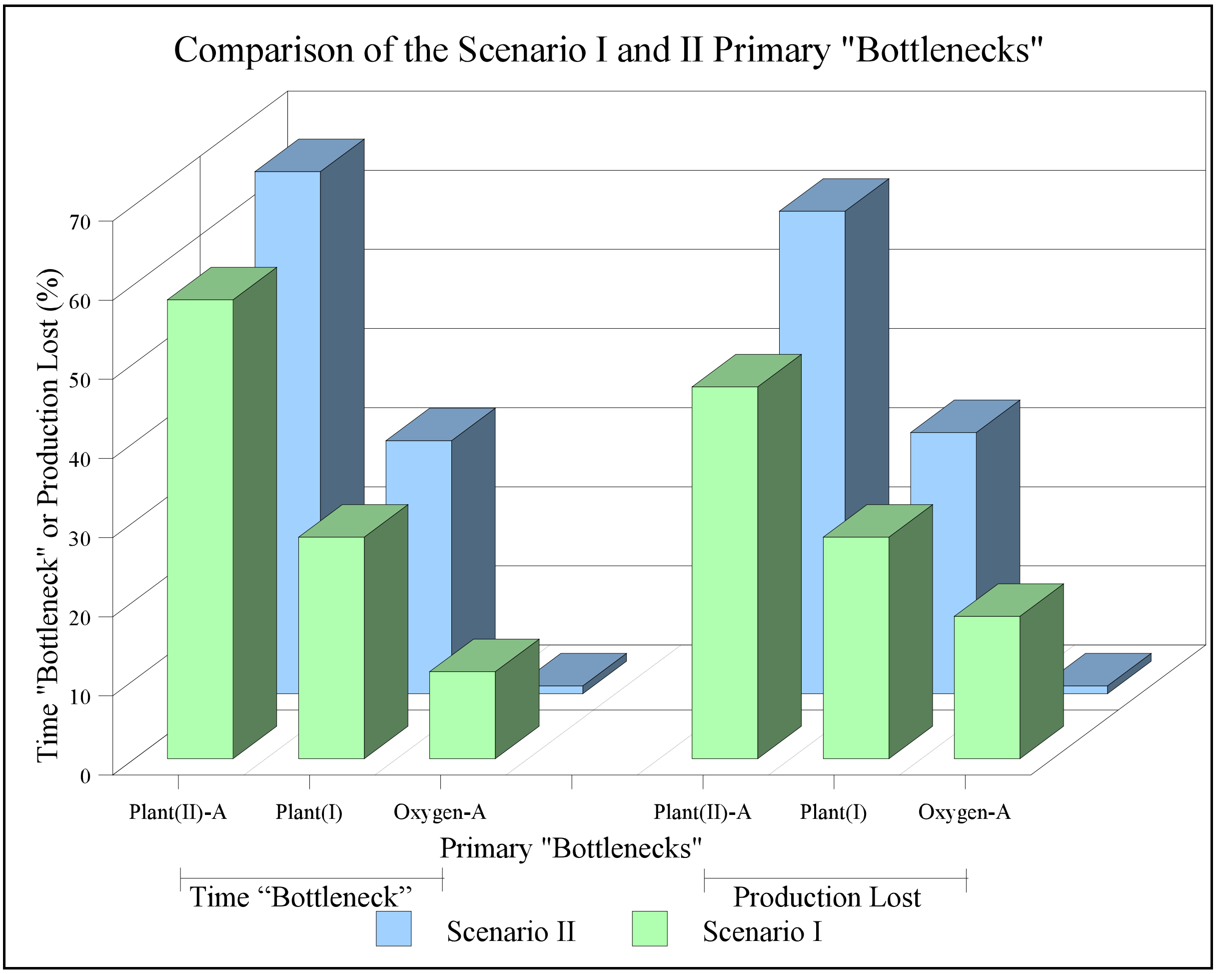

Figure 4.1: Comparison of the Scenario I and II Primary “Bottlenecks”

Oxygen-A does not qualify as an important primary "bottleneck" anymore, when an additional oxygen "train" (the Oxygen Extra plant) is incorporated into the Synthetic Fuel plant in the Scenario II ED evaluation method option Arena and Simul8 simulation models.

Table 4.11: *Comparison of the Scenario I and II Secondary "Bottlenecks"* provides a comparison between the Scenario I and II results of the ED evaluation method option Arena and Simul8 simulation models for the most important secondary "bottlenecks" in terms of the total volumes and mean rates of flare at the secondary "bottlenecks".

Table 4.11: Comparison of the Scenario I and II Secondary "Bottlenecks"

No.	Name	Flare	Arena Simulation Model				Simul8 Simulation Model			
			Scenario I		Scenario II		Scenario I		Scenario II	
			Vol (D1)	Rate (D2)	Vol (D1)	Rate (D2)	Vol (D1)	Rate (D2)	Vol (D1)	Rate (D2)
13	Plant(IV)	Flare-A	3362,1	0,389	3413,9	0,395	7264,6	0,841	7328,2	0,848
20	Plant(V)	Flare-B	17036,7	1,972	19418,8	2,248	17191,2	1,990	19413,0	2,247

Where:

No. : The plant identification number.

Vol (D1) : The total volume flared (m^3, nm^3).

Rate (D2) : The mean rate of flare (m^3/h, nm^3/h).

From Table 4.11 it follows that Plant(IV) and Plant(V) are the only two important secondary "bottlenecks". The difference in the total volume and mean rate of flare values at Plant(IV), between the results of the Scenario I Arena and Simul8 simulation models, is immediately noticeable. The same applies to the Scenario II simulation models. The total volume and rate of flare values of the Scenario I and II Arena simulation models are approximately half that of the Scenario I and II Simul8 simulation models. Section 4.2 indicates that this discrepancy can be attributed to that fact that the mean number of failures created at Plant(IV)-C is 0,15 for the Arena simulation model and 0,30 for the Simul8 simulation model in both Scenario I and II. The higher number of failures created by the Simul8 simulation model implies that Plant(IV)-C was less available in the Simul8 simulation run and therefore a bigger portion of the throughput was flared in both Scenario I and II. There is no discernible difference in the total volume and rate of flare values at Plant(V) between the results of the Scenario I Arena and Simul8 simulation models, and also no discernible difference in the results of the Scenario II Arena and Simul8 simulation models. A scrutiny of the rest of the results of the two simulation runs reveals that the mean number of failures created at Plant(V) is 11,20 for the Arena simulation model and 11,05 for the Simul8 simulation model in both Scenario I and II.

The exposition in the previous paragraph indicates that results that are in any way dependent on low failure rates should be scrutinised more carefully. This view is supported by the discussion in Section 3.6 which shows that a large deviation of the number of failures created by the Arena and Simul8 simulation models and the real-world number of failures that occur is acceptable for a point of evaluation with a low failure rate. When fewer failures occur, the effect of these failures on a system seems to be more pronounced. In such an instance the simulation run should be extended to include more replications. This should have an equalising effect on the results and could present a more balanced picture of what is actually happening at that point in the simulation model.

In Scenario II the total volume and mean rate of flare values at Plant(IV) and Plant(V) are slightly larger than in Scenario I. This result can be explained by the fact that the mean output throughput value of the Gas Production plant in Scenario II is larger than in Scenario I (see Section 4.3). The larger mean output throughput value of the Gas Production plant, in Scenario II, cascades through the simulation model and leads to larger mean throughput values at Plant(IV) and Plant(V). There is no difference between the capacities, service schedules and failure characteristics of the modules of Plant(IV) and Plant(V) in Scenario I and II. It is therefore obvious that the total volume and mean rate of flare values at Plant(IV) and Plant(V) will be larger in Scenario II.

Table 4.12: *Comparison of the Scenario I and II Output Throughput* shows the deltas, the gains and the gains, expressed as production days, of the mean output throughput values of the Gas Production plant between the Scenario I and II results of the ED evaluation method option Arena and Simul8 simulation models.

Section 4.3 indicates that the 99% confidence intervals for the mean output throughput values of the Scenario I and II Arena and Simul8 simulation models do not overlap and therefore the two scenarios can be assumed to represent two different outcomes for both the simulation models. This implies that it is valid to use the deltas between the mean output throughput values of the Scenario I and II Arena and Simul8 simulation models to determine the effect of the additional oxygen "train" on the throughput of the Synthetic Fuel plant.

Table 4.12: Comparison of the Scenario I and II Output Throughput

Simulation Model	Scn	GasPro (nm^3/h)	Delta (nm^3/h)	Gain (%)	Production Days (Day)
Arena (ED)	I	1332471,8	18562,3	1,3931	5,02
Arena (ED)	II	1351034,1			
Simul8 (ED)	I	1332253,3	19231,5	1,4435	5,20
Simul8 (ED)	II	1351484,8			

Where:

Scn : The scenario number.

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

From Table 4.12 it follows that the deltas between the mean output throughput values of the Gas Production plant in Scenario I and II are 18562,3 nm^3/h for the Arena simulation model and 19231,5 nm^3/h for the Simul8 simulation model. The gains between the mean output throughput values of the Gas Production plant in Scenario I and II are 1,3931% for the Arena simulation model and 1,4435% for the Simul8 simulation model. The gains, in terms of production days, between the mean output throughput values of the Gas Production plant in Scenario I and II are 5,02 days for the Arena simulation model and 5,20 days for the Simul8 simulation model. The gains are expressed in terms of the mean output throughput values of Scenario I and in terms of the simulation model year (see Appendix L).

The gains, in terms of production days, between the mean output throughput values of the Gas Production plant in the Scenario I and II ED evaluation method option Arena and Simul8 simulation models, correlate closely with the gain of 5,15 production days of the original simulation model that is determined in the *Magister* dissertation (Albertyn, 1995:96).

The gain, in terms of production days of the Gas Production plant, is approximately five production days, when an additional oxygen "train" (the Oxygen Extra plant) is incorporated into the Synthetic Fuel plant in the Scenario II ED evaluation method option Arena and Simul8 simulation models.

Section 2.6 indicates that both primary and secondary "bottlenecks" are undesirable from the perspectives of increased efficiency and the realisation of profit (see Section 1.3) and therefore have to be managed with circumspection. The secondary "bottlenecks", that flare throughput that cannot be processed, are also undesirable as seen from the environmental perspective.

If the process flow of the Synthetic Fuel plant is assumed to remain unchanged, the following three strategies are available to reduce the effect of primary and secondary "bottlenecks":

a) Increase the capacity at the primary and secondary "bottlenecks".
b) Decrease the time that is lost due to services at the primary and secondary "bottlenecks". This is done by revisiting the service schedules of the relevant modules to see if an increase in cycle time or a decrease in service time, or both, is possible.
c) Decrease the time that is lost due to failures at the primary and secondary "bottlenecks". This is done by embarking on reliability growth programmes that decrease the failure rate (*i.e.* increase the MTBF) of the relevant modules or by decreasing the repair time of the relevant modules, or both simultaneously.

The impact on the Synthetic Fuel plant, when an additional oxygen "train" (the Oxygen Extra plant) is incorporated, is the following:

a) The "bottleneck" effect of Oxygen-A is removed.
b) The output throughput of the Synthetic Fuel plant is increased.

Summary

In this section the Scenario I results of the three most important primary "bottlenecks" (*i.e.* Plant(II)-A, Plant(I) and Oxygen-A) are compared with those of Scenario II. The comparison indicates that Oxygen-A does not qualify as an important primary "bottleneck" in Scenario II. The Scenario I and II results also indicate that the total volume and mean rate of flare values at the two secondary "bottlenecks" (*i.e.* Plant(IV) and Plant(V)) are larger in Scenario II. This can be ascribed to the larger mean output throughput value of the Gas Production plant in Scenario II. The gain in Scenario II, expressed in terms of production days of the Gas Production plant, is approximately five production days. The overall impact, when an additional oxygen "train" (the Oxygen Extra plant) is incorporated into the Synthetic Fuel plant, is that the "bottleneck" effect of Oxygen-A is removed and that the output throughput of the Synthetic Fuel plant is increased.

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