4 ANALYSIS OF DATA

4.1 Introduction

Chapter 3 started the SACAPP software project and reached the Lifecycle Objectives and the Lifecycle Architecture RUP milestones. As a result, Chapter 4 describes the last two of the RUP phases, namely the Construction and the Transitions phases (Figure 4.1).

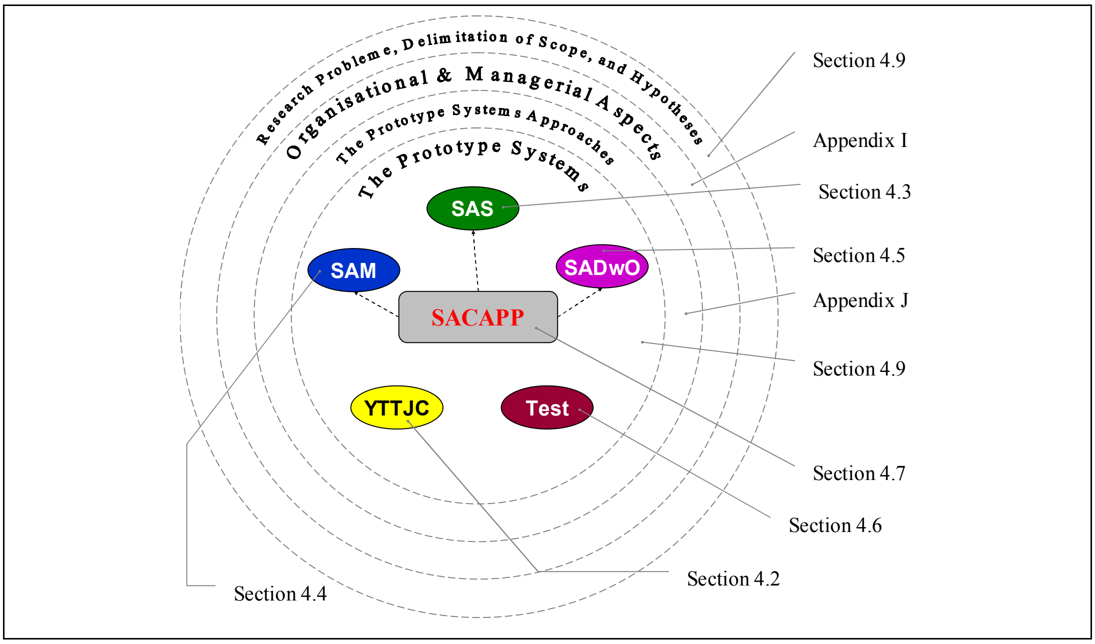

Figure 4.1 The chapter's map

Where the Inception and Elaboration phases were compared to research, the Construction phase is considered analogous to development (West, 2002), so, the emphasis shifts from the accumulation of knowledge needed to build the system to the actual construction of the system. Then, in the Transition phase, components produced in the Construction phase are packaged into deployable units and made available for user assessment.

After the introduction, the chapter continues with the SACAPP roadmap (Appendix I), followed by the prototype systems approaches (Appendix J). Then, sections 4.2 to 4.9 present 6 prototype systems, their implementation, testing, and analysis. The chapter finally ends with section 3.11., conclusions. Furthermore, to separate the results from their significance, Chapter 4 is restricted to presenting and analysing the results for their relevance to the research question and hypotheses, and in doing so it will draw no conclusions or compare the results to those of other researchers.

4.2 The YTTJC System

The YTTJC system, not required for the SACAPP system, was developed in order to have a centre-command for all developed systems.

Figure 4.2 The YTTJC system interface shows the company's pyramid structure and the SACAPP system strategic position.

4.3 The SAS System

The sales administrator represented the company's interface with the customer, therefore the SAS system GUI interface focussed on IWO (Figures 4.3 and 4.4), and its MVC pattern with IWO.java, IWOInfo.java, and IWOHandler.java classes introduced and discussed in detail in Appendix K.

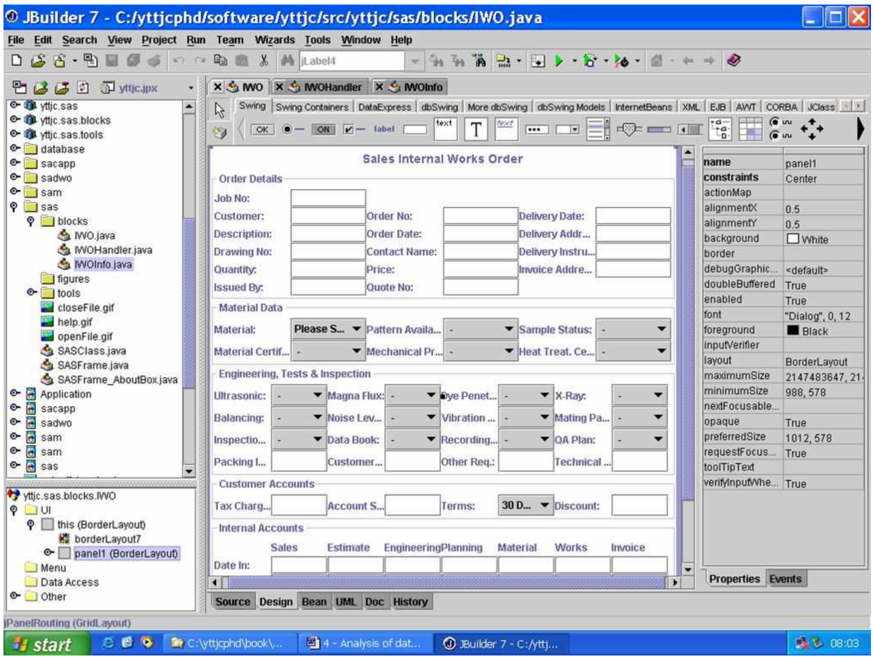

Figure 4.3 IWO during its development using JBuilder

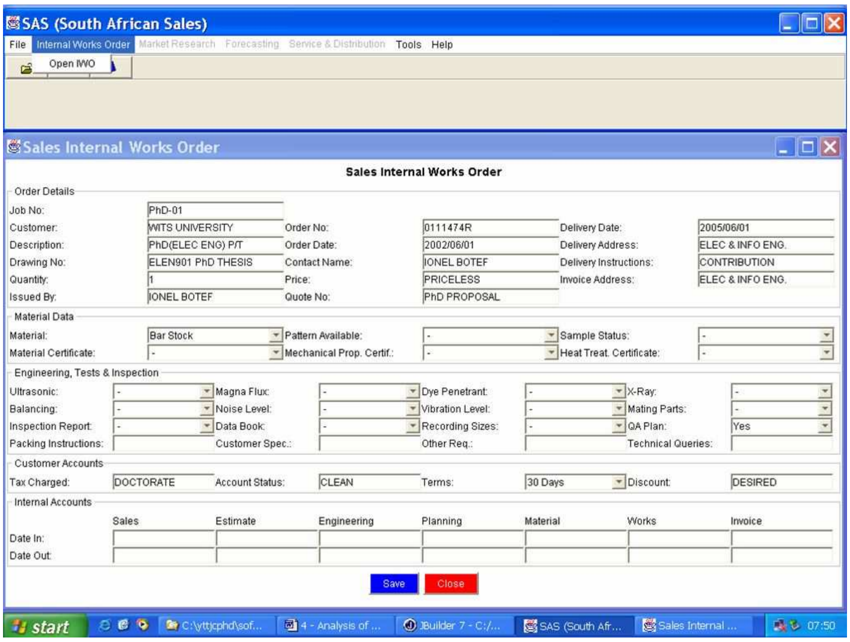

Figure 4.4 SAS and IWO view

4.4 The SAM System

The SAM system focused on reflecting the management decisions to make available or not manufacturing process within the company (Figure 4.5).

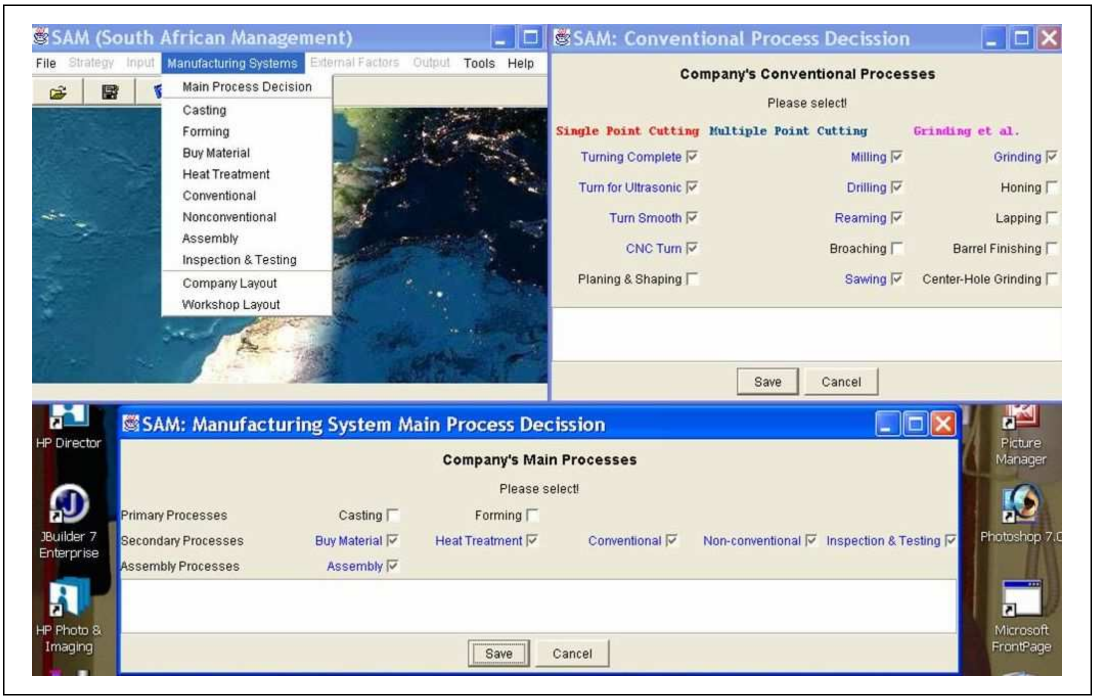

Figure 4.5 The SAM system frames. A selected JCheckBox indicated the availability of the process within the company, whereas a not selected box determines the SACAPP system to automatically indicate an outside co-operation with a sub-contractor.

4.5 The SADwO System

The SADwO resembled a CAD system, so, wire, surface, or solid modelling techniques were possible to be used. In addition, it had a limited number of selected design and manufacturing objects used to design but also communicate with the SACAPP system (Figure 4.6). When a specific drawing file was retrieved from the database, the objects were set-up first, and then, printed on the screen, the drawing was possible to be edited, and saved under the same or a different drawing number (see Appendix L - SADwO UML diagrams).

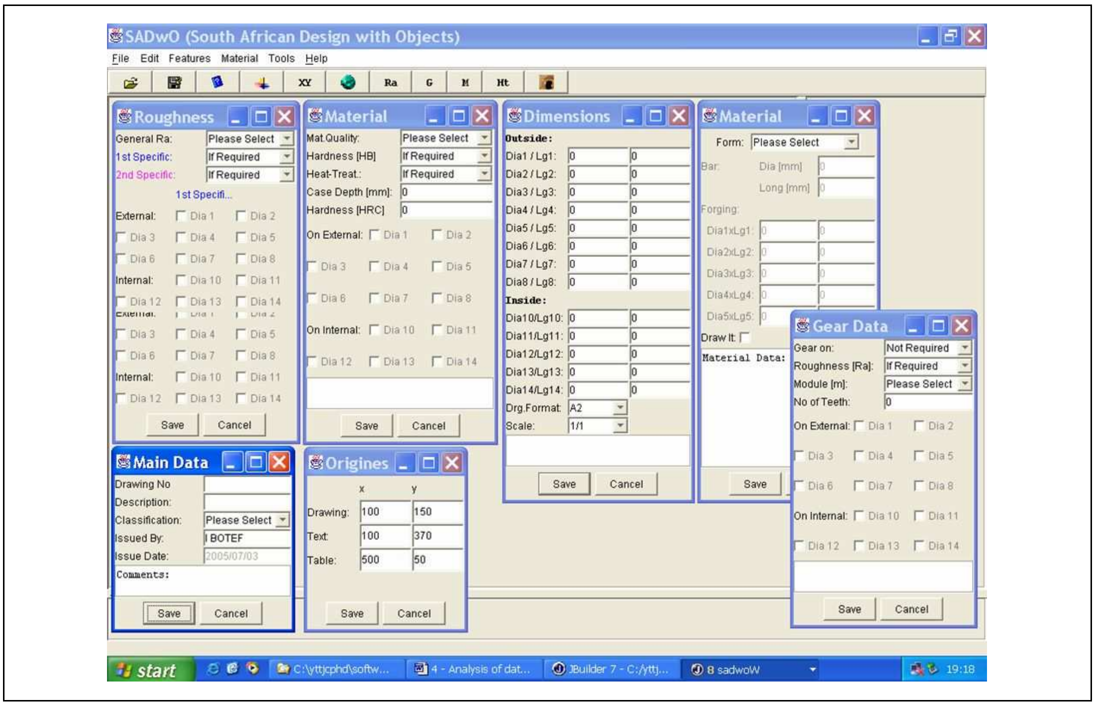

Figure 4.6 SADwO with a number of opened frames

4.6 Object Design Test

The Object Design system was developed in order to test and validate how the process plans were generated. (Figures 4.7 to 4.9). Consequently, the next step was the development of a much more complex prototype, the SACAPP system.

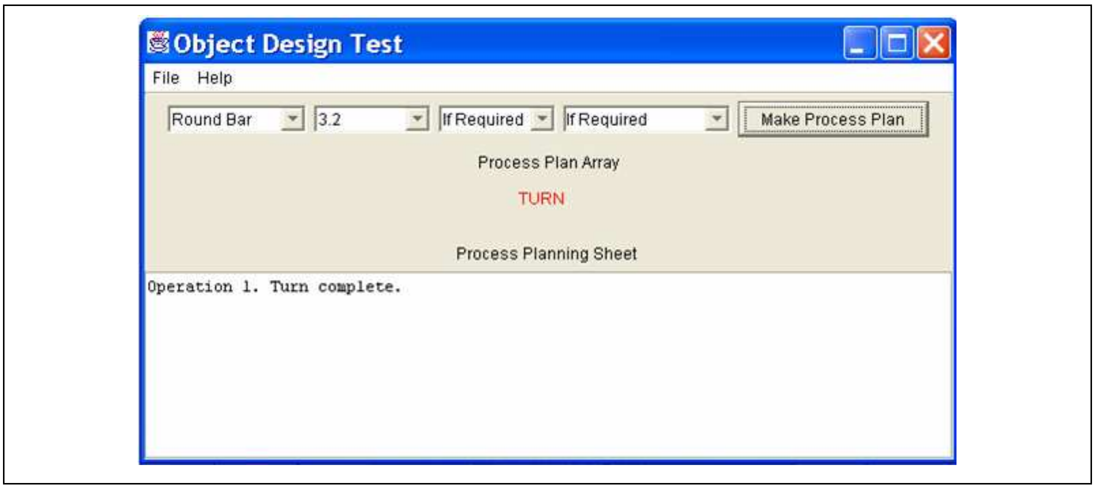

Figure 4.7 Object design test 1

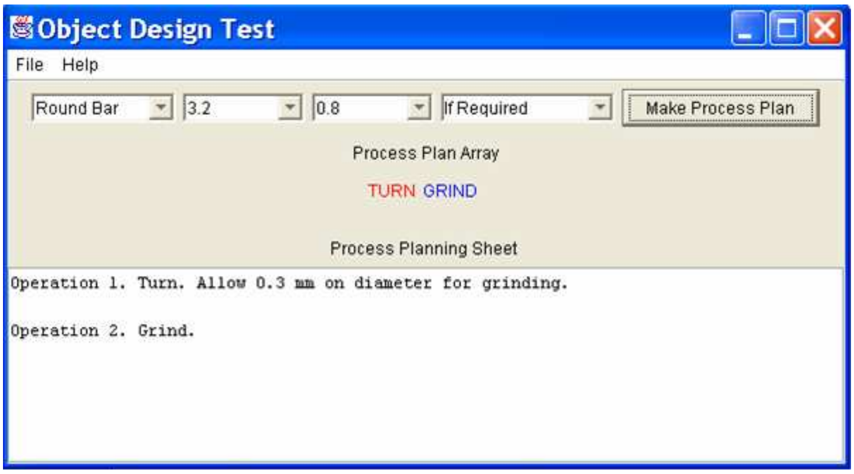

Figure 4.8 Object design test 2

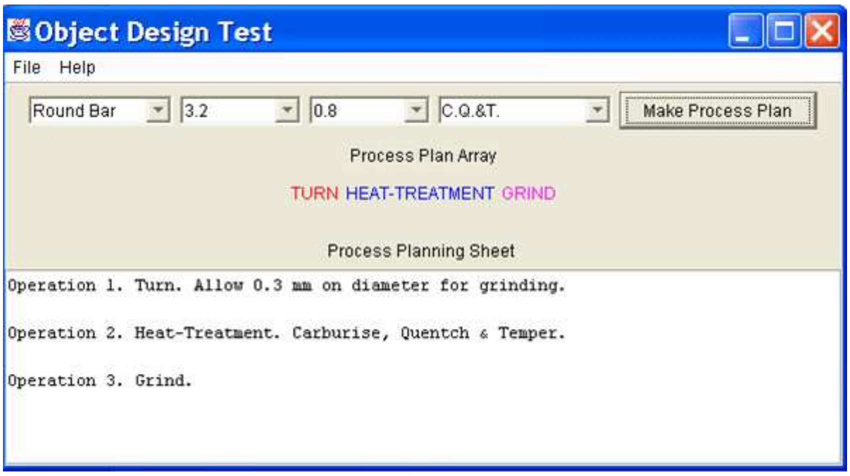

Figure 4.9 Object design test 3. The system had only 4 design objects (the material form, general and special surface roughness, and the heat-treatment)

4.7 The SACAPP System

The SACAPP system (Figure 4.10) automatically generated the process plans based on the input data extracted from the sales (Figure 4.11), engineering drawing (Figure 3.12), management, and the SACAPP system's own settings for operation description (Figure 4.13) and constraints (Figure 4.14). If the process was available within the company, the SACAPP operator's pre-set process description was reflected in the process plan. If the process was not available within the company, an "outside cooperation" was automatically inserted in the process plan. Also, the selection or not of constraints checkboxes were used to reflect in the process plans the company's specific ways to carry-out various manufacturing processes.

Figure 4.10 SACAPP main window

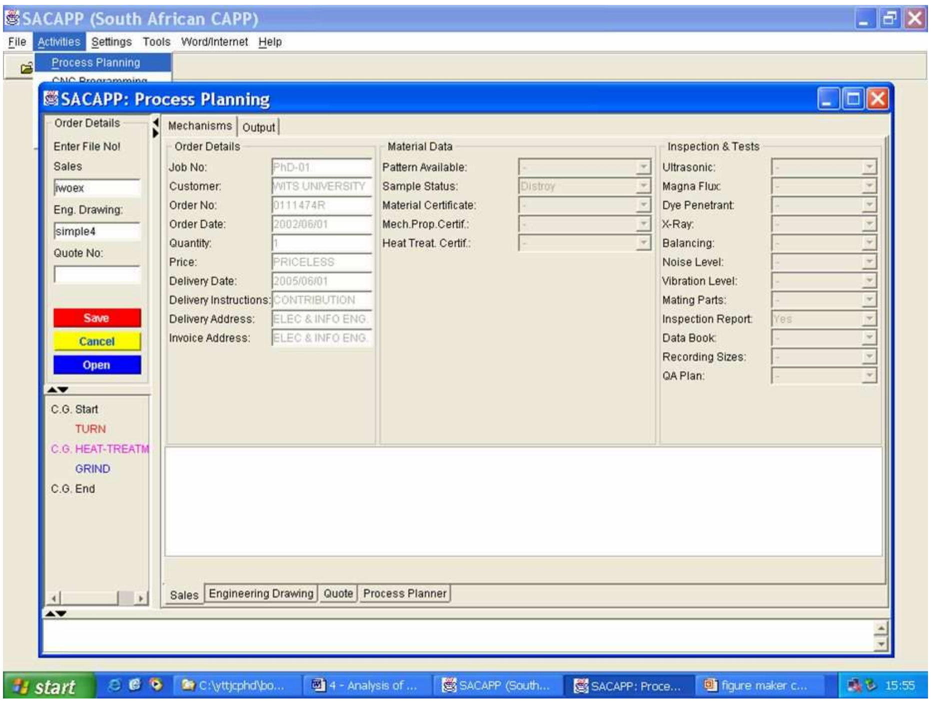

Figure 4.11 SACAPP – sales input window

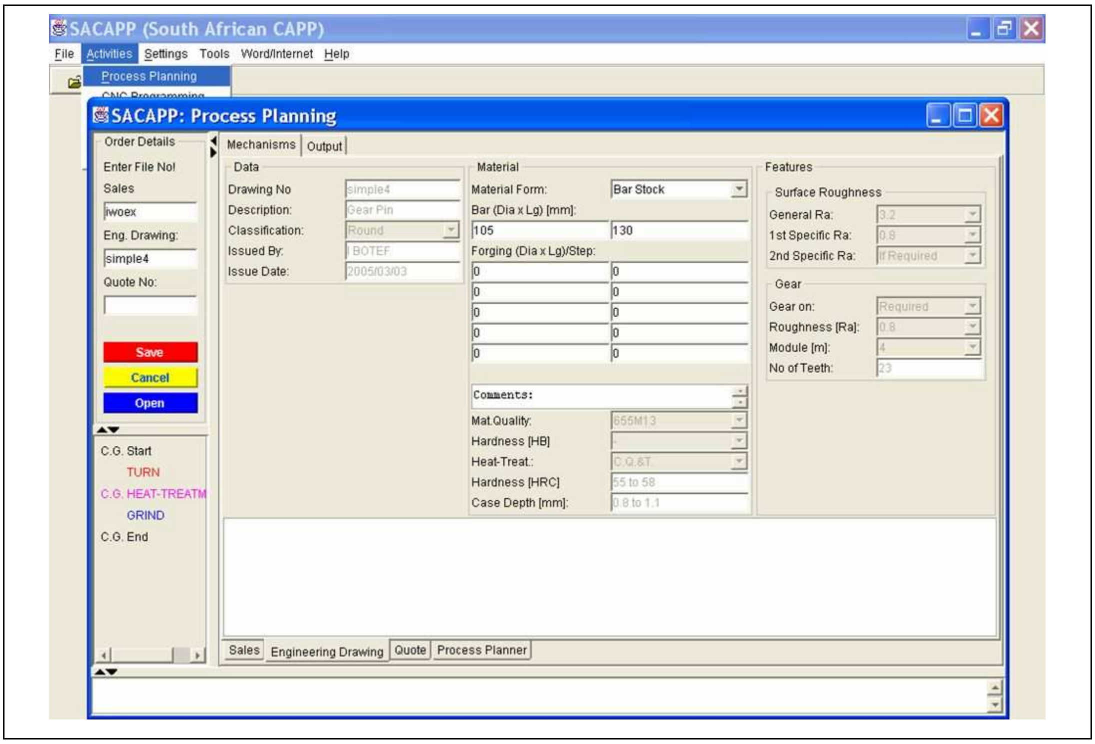

Figure 4.12 SACAPP – engineering drawing input window

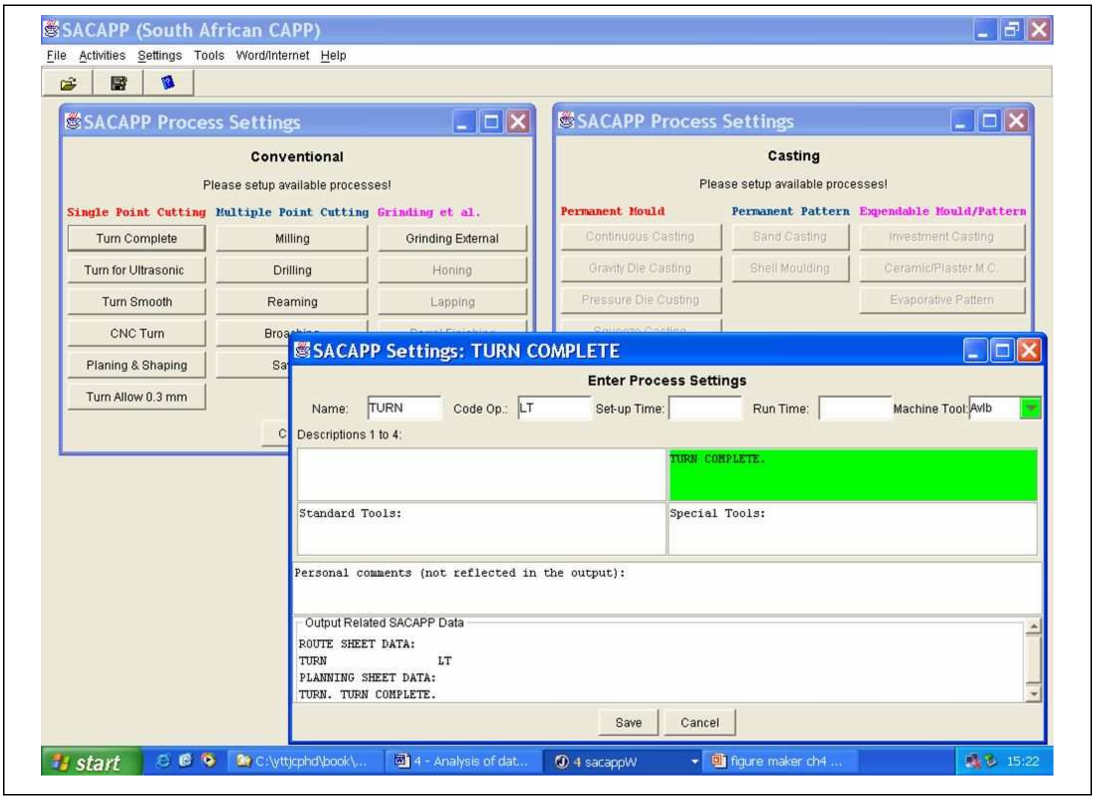

Figure 4.13 SACAPP manufacturing operation description setting

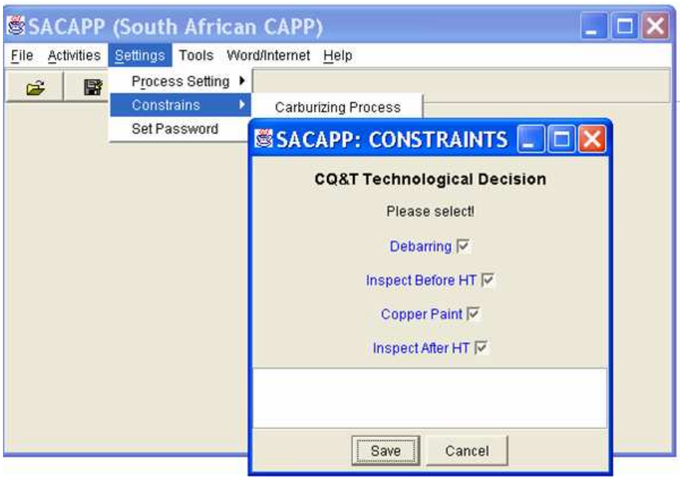

Figure 4.14 SACAPP constraints setting for the carburising process

Then, automatically, by only considering the input data and the system's own setting, the Process Planning Sheet and the Route Sheet were generated (Figures 4.15 and 4.16). After that, before their printing or electronic delivery to production, the human planner could inspect these documents, and make small alterations in the SACAPP's enabled text windows. Furthermore, a limited number of UML diagrams were shown (Figures 4.17 and 4.18), and finally, a few Java codes, shown how the centres of gravity were created and organised.

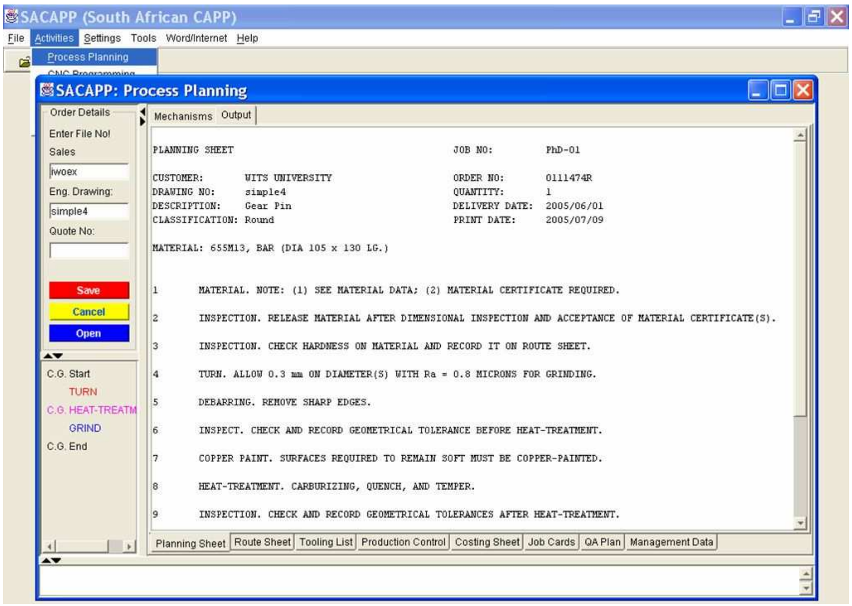

Figure 4.15 SACAPP output window Process Plan Sheet

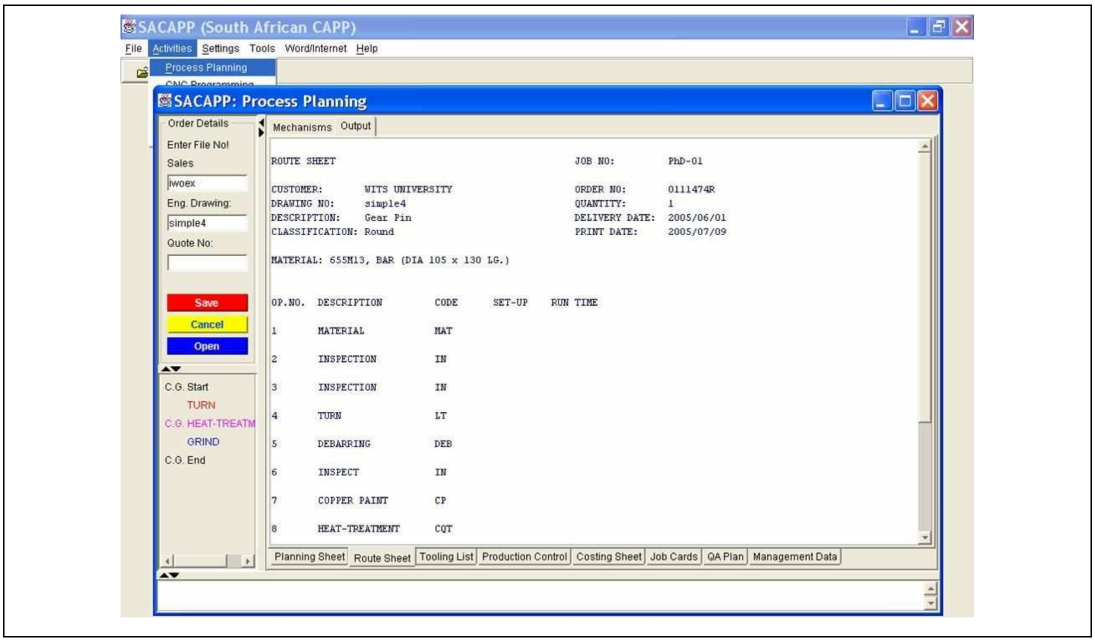

Figure 4.16 SACAPP output window Route Sheet

```
// Import Java Collection classes
import java.util.collections.*;
…
// Create two Java Collections ArrayList (one for the process plan and one for the
// route sheet) that represent the centre of gravity for the end of the plan.
ArrayList end_gPS = new ArrayList();
ArrayList end_gRS = new ArrayList();
…
// EndPlanGravityList() method
public void writeEndPlanGravityList() {
   G_EndPlan g_end = new G_EndPlan();
   end_gPS.add(g_end.getInspStampPS()); // adds operations to the ArrayList
   end_gRS.add(g_end.getInspStampRS());
   if (comboDataBook.getSelectedIndex() == 1)   {
     end_gPS.add(g_end.getInspDataBookPS());
     end_gRS.add(g_end.getInspDataBookRS());   }
   if (comboRecordSize.getSelectedIndex() == 1)  {
     end_gPS.add(g_end.getInspRecordSizePS());
```

```
    end_gRS.add(g_end.getInspRecordSizeRS()); }
  if (comboInspReport.getSelectedIndex() == 1)  {
    end_gPS.add(g_end.getInspReportPS());
    end_gRS.add(g_end.getInspStampRS());       }
  end_gPS.add(g_end.getInspStoresPS());
  end_gRS.add(g_end.getInspStoresRS());
}//end centre of gravity end plan
```

The final process plans and route sheets are built in the same way. For example:

```
// Create two Java Collection ArrayList that collects all centres of gravity
ArrayList mergePS = new ArrayList();
ArrayList mergeRS = new ArrayList(); …
// The inference method
public void newInference() { …
 writeEndPlanGravityList();  …
// the "addAll" method is used to add centres of gravity to the ArrayList
mergePS.addAll(0,start_gPS);
mergePS.addAll(end_gPS);
```

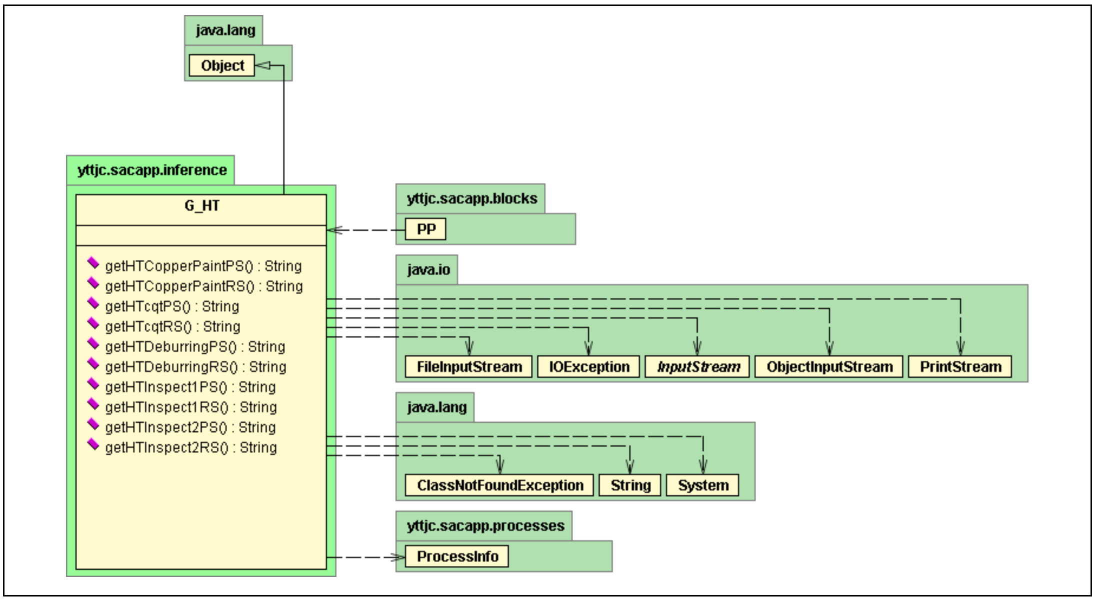

Figure 4.17 SACAPP Centre of Gravity for the heat-treatment

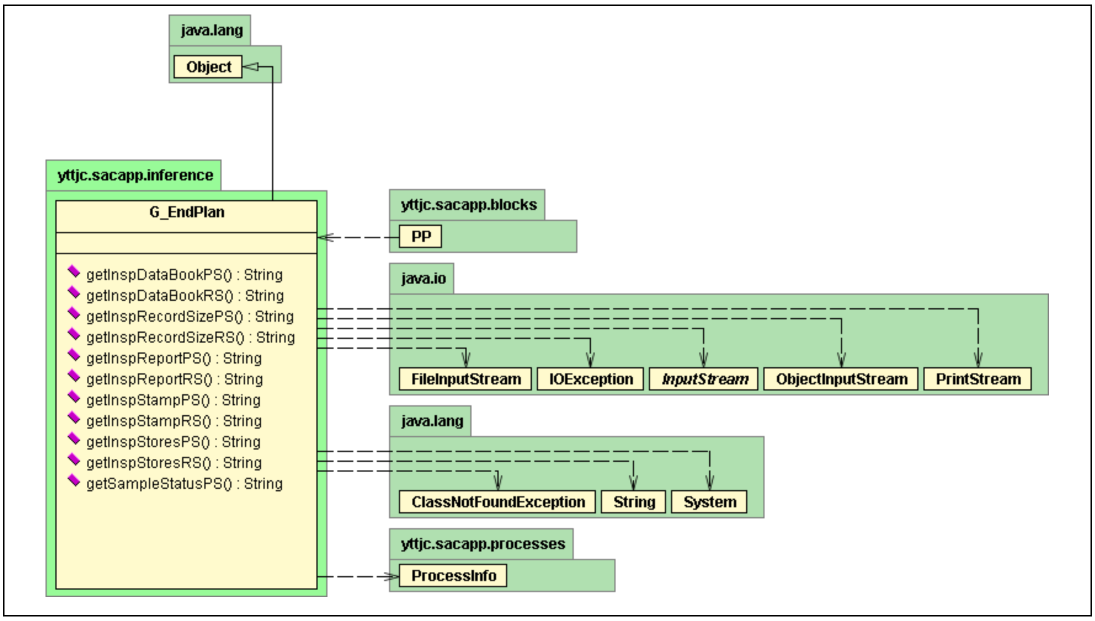

Figure 4.18 SACAPP Centre of Gravity for the End of the process plan

4.8 Systems Testing

The results of the following tests, for a number of simple and complex machined parts, were produced completely automatically by using the SACAPP system.

4.8.1 Simple machined part

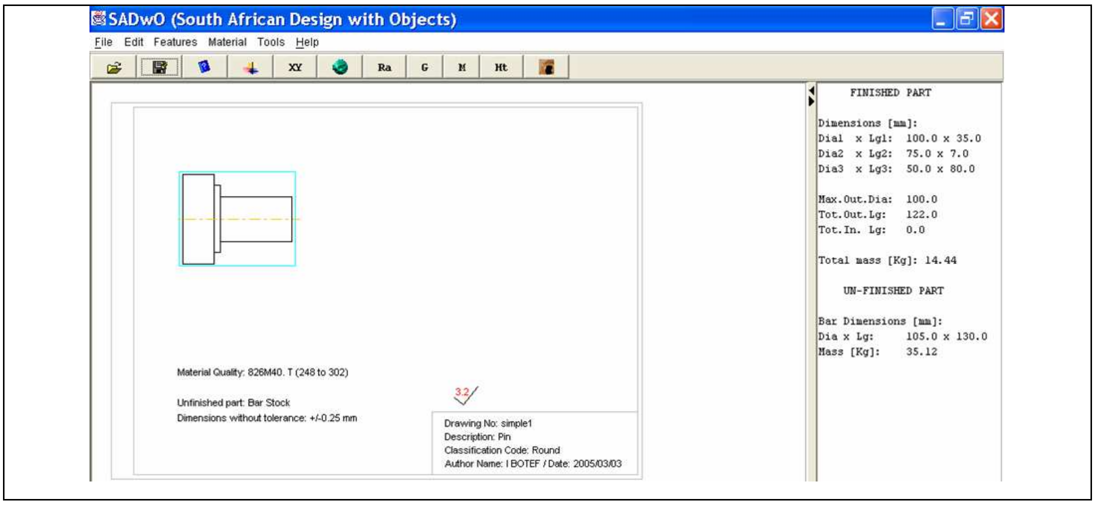

Figure 4.19 Simple item created with the SADwO system

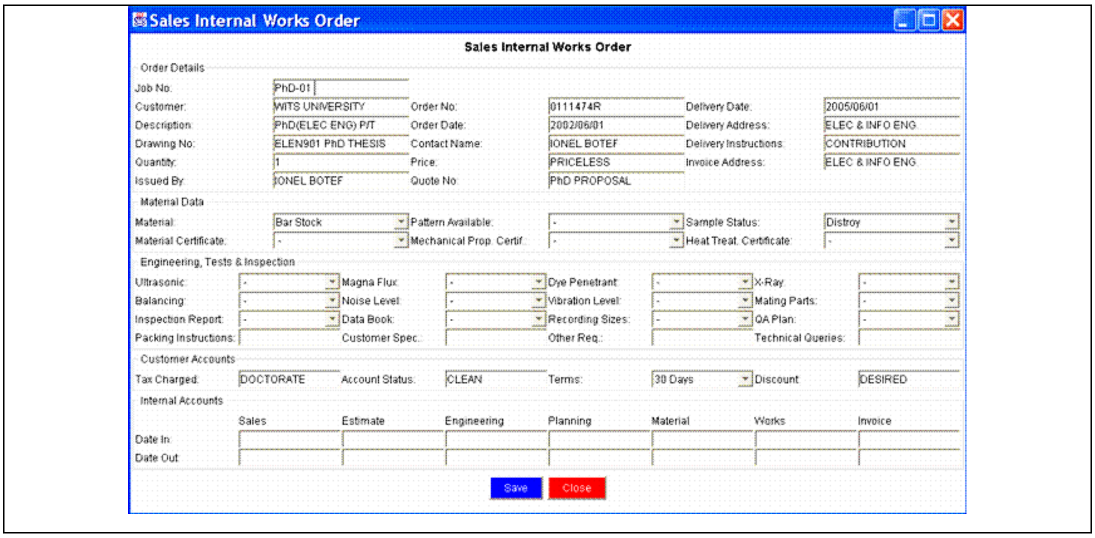

Figure 4.20 IWO created with the SAS system

PLANNING SHEET JOB NO: PhD-01

CUSTOMER: WITS UNIVERSITY ORDER NO: 0111474R
DRAWING NO: simple1 QUANTITY: 1
DESCRIPTION: Pin DELIVERY DATE: 2005/06/01
CLASSIFICATION: Round PRINT DATE: 2005/07/09

MATERIAL: 826M40, BAR (DIA 105 x 130 LG.)

1 MATERIAL. NOTE: (1) SEE MATERIAL DATA; (2) MATERIAL CERTIFICATE REQUIRED.

2 INSPECTION. RELEASE MATERIAL AFTER DIMENSIONAL INSPECTION AND ACCEPTANCE OF MATERIAL CERTIFICATE(S).

3 INSPECTION. CHECK HARDNESS ON MATERIAL AND RECORD IT ON ROUTE SHEET.

4 TURN. TURN COMPLETE.

5 INSPECTION. STAMP ITEM(S) WITH OUR JOB AND SERIAL NUMBER.

6 STORES. THE ITEM(S) MUST BE PROTECTED AGAINST RUST & SUITABLY CRATED TO PREVENT ANY DAMAGE.

NOTE: DESTROY SAMPLE.

ROUTE SHEET JOB NO: PhD-01

CUSTOMER: WITS UNIVERSITY ORDER NO: 0111474R
DRAWING NO: simple1 QUANTITY: 1
DESCRIPTION: Pin DELIVERY DATE: 005/06/01
CLASSIFICATION: Round PRINT DATE: 005/07/09

MATERIAL: 826M40, BAR (DIA 105 x 130 LG.)

OP.NO	DESCRIPTION	CODE	SET-UP	RUN TIME
1	MATERIAL	MAT		
2	INSPECTION	IN		
3	INSPECTION	IN		
4	TURN	LT		
5	INSPECTION	IN		
6	STORES	STO		

4.8.2 Another simple machined part

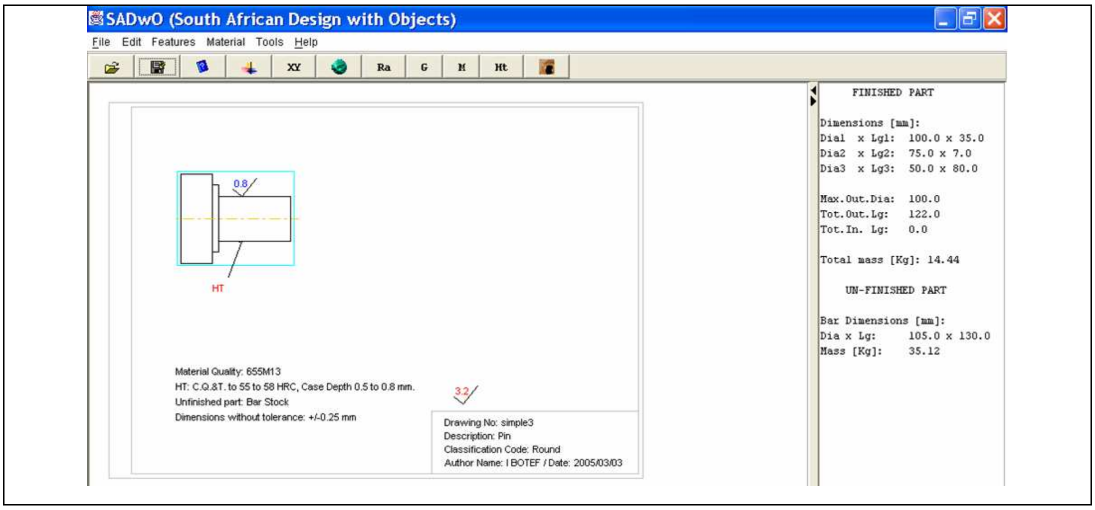

Figure 4.21 Another simple item created with the SADwO system

PLANNING SHEET JOB NO: PhD-01

CUSTOMER:	WITS UNIVERSITY	ORDER NO:	0111474R
DRAWING NO:	simple3	QUANTITY:	1
DESCRIPTION:	Pin	DELIVERY DATE:	2005/06/01
CLASSIFICATION:	Round	PRINT DATE:	2005/07/09

MATERIAL: 655M13, BAR (DIA 105 x 130 LG.)

1 MATERIAL. NOTE: (1) SEE MATERIAL DATA; (2) MATERIAL CERTIFICATE REQUIRED.

2 INSPECTION. RELEASE MATERIAL AFTER DIMENSIONAL INSPECTION AND ACCEPTANCE OF MATERIAL CERTIFICATE(S).

3 INSPECTION. CHECK HARDNESS ON MATERIAL AND RECORD IT ON ROUTE SHEET.

4 TURN. ALLOW 0.3 mm ON DIAMETER(S) WITH Ra = 0.8 MICRONS FOR GRINDING.

5 DEBARRING. REMOVE SHARP EDGES.

6 INSPECT. CHECK AND RECORD GEOMETRICAL TOLERANCE BEFORE HEAT-TREATMENT.

7 COPPER PAINT. SURFACES REQUIRED TO REMAIN SOFT MUST BE COPPER-PAINTED.

8 HEAT-TREATMENT. CARBURIZING, QUENCH, AND TEMPER.

9 INSPECTION. CHECK AND RECORD GEOMETRICAL TOLERANCES AFTER HEAT-TREATMENT.

10 GRIND. GRIND EXTERNAL DIAMETER(S)

11 INSPECTION. STAMP ITEM(S) WITH OUR JOB AND SERIAL NUMBER.

12 STORES. THE ITEM(S) MUST BE PROTECTED AGAINST RUST & SUITABLY CRATED TO PREVENT ANY DAMAGE.

NOTE: DESTROY SAMPLE.

ROUTE SHEET JOB NO: PhD-01

CUSTOMER:	WITS UNIVERSITY	ORDER NO:	0111474R
DRAWING NO:	simple3	QUANTITY:	1
DESCRIPTION:	Pin	DELIVERY DATE:	2005/06/01
CLASSIFICATION:	Round	PRINT DATE:	2005/07/09

MATERIAL: 655M13, BAR (DIA 105 x 130 LG.)

OP.NO	DESCRIPTION	CODE	SET-UP	RUN TIME
1	MATERIAL	MAT		
2	INSPECTION	IN		
3	INSPECTION	IN		
4	TURN	LT		
5	DEBARRING	DEB		
6	INSPECT	IN		
7	COPPER PAINT	CP		
8	HEAT-TREATMENT	CQT		
9	INSPECTION	IN		
10	GRIND	EG	15	
11	INSPECTION	IN		

12   STORES   STO

4.8.3 A complex part

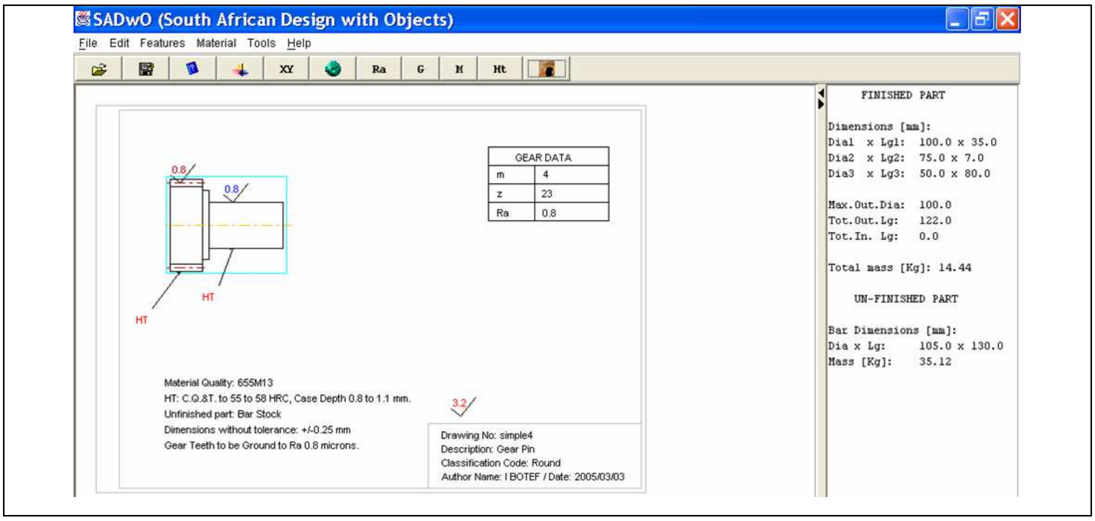

Figure 4.22 Complex item created with the SADwO system

PLANNING SHEET JOB NO: PhD-01

CUSTOMER:	WITS UNIVERSITY	ORDER NO:	0111474R
DRAWING NO:	simple4	QUANTITY:	1
DESCRIPTION:	Gear Pin	DELIVERY DATE:	2005/06/01
CLASSIFICATION:	Round	PRINT DATE:	2005/07/10

MATERIAL: 655M13, BAR (DIA 105 x 130 LG.)

1 MATERIAL. NOTE: (1) SEE MATERIAL DATA; (2) MATERIAL CERTIFICATE REQUIRED.

2 INSPECTION. RELEASE MATERIAL AFTER DIMENSIONAL INSPECTION AND ACCEPTANCE OF MATERIAL CERTIFICATE(S).

3 INSPECTION. CHECK HARDNESS ON MATERIAL AND RECORD IT ON ROUTE SHEET.

4 TURN. ALLOW 0.3 mm ON THE DIAMETER(S) WITH Ra 0.8 FOR GRINDING.

5 GEAR-CUT. CUT TEETH. ALLOW 0.3 mm ALLOWANCE FOR GEAR GRINDING.

6 DEBARRING. REMOVE SHARP EDGES.

7 INSPECT. CHECK AND RECORD GEOMETRICAL TOLERANCE BEFORE HEAT-TREATMENT.

8 COPPER PAINT. SURFACES REQUIRED TO REMAIN SOFT MUST BE COPPER-PAINTED.

9 HEAT-TREATMENT. CARBURIZING, QUENCH, AND TEMPER.

10 INSPECTION. CHECK AND RECORD GEOMETRICAL TOLERANCES AFTER HEAT-TREATMENT.

11 GRIND. GRIND EXTERNAL DIAMETER(S)

12 GEAR-GRIND. GRIND TEETH.

13 INSPECTION. STAMP ITEM(S) WITH OUR JOB AND SERIAL NUMBER.

14 STORES. THE ITEM(S) MUST BE PROTECTED AGAINST RUST & SUITABLY CRATED TO PREVENT ANY DAMAGE.

NOTE: DESTROY SAMPLE.

ROUTE SHEET JOB NO: PhD-01

CUSTOMER:	WITS UNIVERSITY	ORDER NO:	0111474R
DRAWING NO:	simple4	QUANTITY:	1
DESCRIPTION:	Gear Pin	DELIVERY DATE:	2005/06/01
CLASSIFICATION:	Round	PRINT DATE:	2005/07/10

MATERIAL: 655M13, BAR (DIA 105 x 130 LG.)

OP.NO	DESCRIPTION	CODE	SET-UP	RUN TIME
1	MATERIAL	MAT		
2	INSPECTION	IN		
3	INSPECTION	IN		
4	TURN	LT		
5	GEAR-CUT	GC	30	
6	DEBARRING	DEB		
7	INSPECT	IN		
8	COPPER PAINT	CP		
9	HEAT-TREATMENT	CQT		
10	INSPECTION	IN		
11	GRIND	EG	15	
12	GEAR-GRIND	GG	45	
13	INSPECTION	IN		
14	STORES	STO		

4.8.4 Another complex machined part

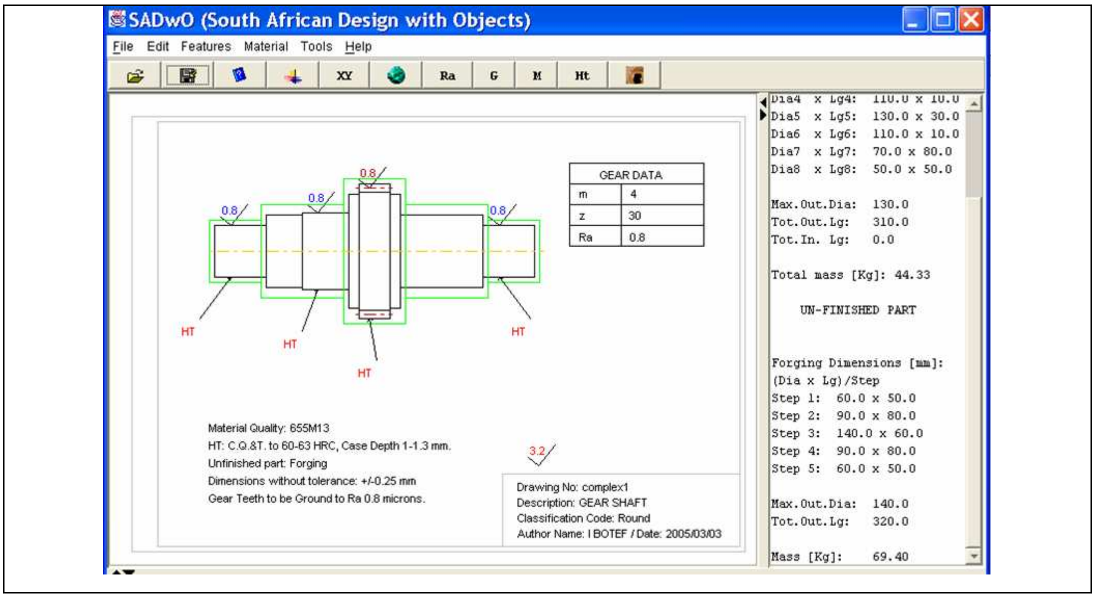

Figure 4.23 Another complex item created with the SADwO system

PLANNING SHEET JOB NO: PhD-01

CUSTOMER:	WITS UNIVERSITY	ORDER NO:	0111474R
DRAWING NO:	complex1	QUANTITY:	1
DESCRIPTION:	GEAR SHAFT	DELIVERY DATE:	2005/06/01
CLASSIFICATION:	Round	PRINT DATE:	2005/07/10

MATERIAL: 655M13, FORGING: (Dia60 x 50 LG) x (Dia 90 x 80 LG) x (Dia 140 x 60 LG) x (Dia 90 x 80 LG) x (Dia 60 x 50 LG)

1 MATERIAL. NOTE: (1) SEE MATERIAL DATA; (2) MATERIAL CERTIFICATE REQUIRED.

2 INSPECTION. RELEASE MATERIAL AFTER DIMENSIONAL INSPECTION AND ACCEPTANCE OF MATERIAL CERTIFICATE(S).

3 INSPECTION. CHECK HARDNESS ON MATERIAL AND RECORD IT ON ROUTE SHEET.

4 TURN. ALLOW 0.3 mm ON THE DIAMETER(S) WITH Ra 0.8 FOR GRINDING.

5 GEAR-CUT. CUT TEETH. ALLOW 0.3 mm ALLOWANCE FOR GEAR GRINDING.

6 DEBARRING. REMOVE SHARP EDGES.

7 INSPECT. CHECK AND RECORD GEOMETRICAL TOLERANCE BEFORE HEAT-TREATMENT.

8 COPPER PAINT. SURFACES REQUIRED TO REMAIN SOFT MUST BE COPPER-PAINTED.

9 HEAT-TREATMENT. CARBURIZING, QUENCH, AND TEMPER (60-63 HRC, 1-1.3 mm DEPTH.)

10 INSPECTION. CHECK AND RECORD GEOMETRICAL TOLERANCES AFTER HEAT-TREATMENT.

11 GRIND. GRIND EXTERNAL DIAMETER(S)

12 GEAR-GRIND. GRIND TEETH (30 TEETH, 4 MODULE)

13 TEST. INVOLUTE, HELIX ANGLE, RUNOUT & PITCH TO PITCH ERROR TO BE CHECKED ON HOFLER TESTER. NOTE: GRAPH REQUIRED.

14 TEST. CARRY OUT MAGNETIC PARTICLE TEST TO AAC 999/6 SPECIFICATION. NOTE: CERTIFICATE REQUIRED.

15 INSPECTION. STAMP ITEM(S) WITH OUR JOB AND SERIAL NUMBER.

16 INSPECTION. INSPECTION REPORT WITH ALL INSPECTION CERTIFICATES TO BE DELIVERED WITH THE ITEM(S).

17 STORES. THE ITEM(S) MUST BE PROTECTED AGAINST RUST & SUITABLY CRATED TO PREVENT ANY DAMAGE.

NOTE: RETURN SAMPLE TO CUSTOMER.

ROUTE SHEET JOB NO: PhD-01

CUSTOMER:	WITS UNIVERSITY	ORDER NO:	0111474R
DRAWING NO:	complex1	QUANTITY:	1
DESCRIPTION:	GEAR SHAFT	DELIVERY DATE:	2005/06/01
CLASSIFICATION:	Round	PRINT DATE:	2005/07/10

MATERIAL: 655M13, FORGING: (Dia60 x 50 LG) x (Dia 90 x 80 LG) x (Dia 140 x 60 LG) x (Dia 90 x 80 LG) x (Dia 60 x 50 LG)

OP.NO	DESCRIPTION	CODE	SET-UP	RUN TIME
1	MATERIAL	MAT		
2	INSPECTION	IN		
3	INSPECTION	IN		
4	TURN	LT		
5	GEAR-CUT	GC	30	
6	DEBARRING	DEB		
7	INSPECT	IN		

8	COPPER PAINT	CP	
9	HEAT-TREATMENT	CQT	
10	INSPECTION	IN	
11	GRIND	EG	15
12	GEAR-GRIND	GG	45
13	TEST	TE	
14	TEST	TE	
15	INSPECTION	IN	
16	INSPECTION	IN	
17	STORES	STO	

4.8.5 Very complex machined part with Inspection Test Plan

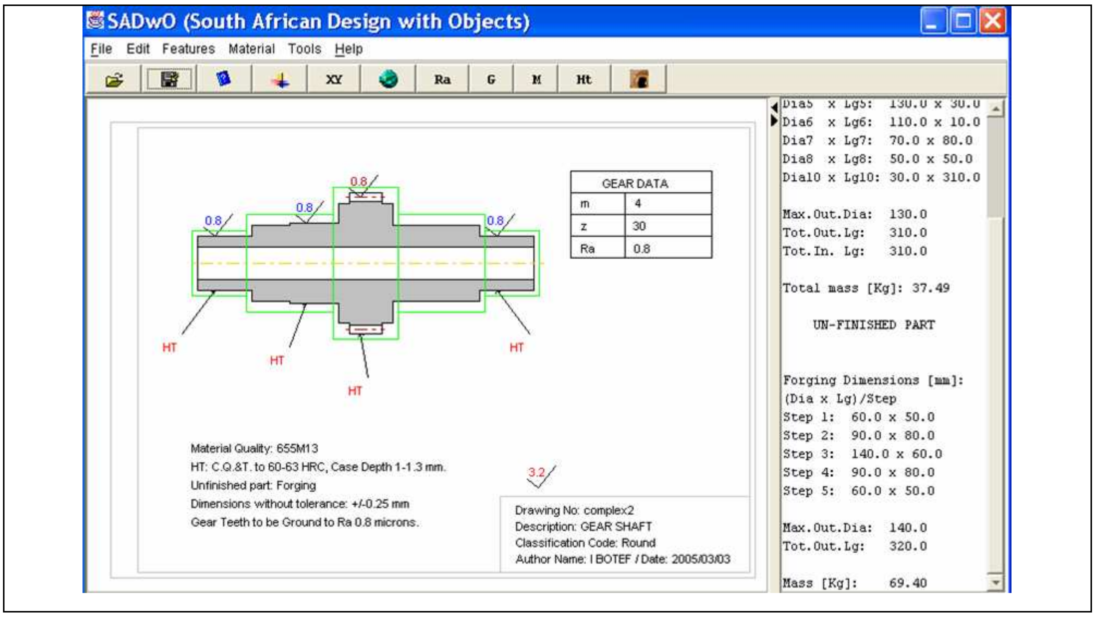

Figure 4.24 A very complex item which, only according to the IWO, requires material's mechanical property certificates, sizes inspection record, and test plan

PLANNING SHEET		JOB NO:	PhD-01
CUSTOMER:	WITS UNIVERSITY	ORDER NO:	0111474R
DRAWING NO:	complex3	QUANTITY:	1
DESCRIPTION:	GEAR SHAFT	DELIVERY DATE:	2005/06/01
CLASSIFICATION:	Round	PRINT DATE:	2005/07/10

MATERIAL: 655M13, FORGING: (Dia60 x 50 LG) x (Dia 90 x 80 LG) x (Dia 140 x 60 LG) x (Dia 90 x 80 LG) x (Dia 60 x 50 LG)

NOTE: I.T.P. TEST PLAN NO. 0111474R MUST BE STRICTLY ADHERED TO & MUST BE SIGNED OFF AFTER EACH STEP.

1 INSPECTION. NOTE: WOODEN BOX MANUFACTURED ON THIS JOB NUMBER MUST BE USED TO TRANSPORT THE ITEM FROM ONE OPERATION TO THE NEXT TO PREVENT DAMAGE.

2 MATERIAL. ITEM 1: MATERIAL CERTIFICATES REFLECTING CHEMICAL ANALYSIS, FULL MECHANICAL PROPERTIES INCLUDING IMPACT & CAST NUMBER REQUIRED. NOTE: ONE TEST PIECE 160 mm LONG & ONE TEST PIECE 12 mm LONG WITH SAME CAST NUMBER TO BE SENT FOR THE FOLLOWING TESTS ACCORDING TO BS 970 PART 1/1991 BY SUPPLIER:
ITEM 2: 160 mm LONG TEST PIECE FOR FULL MECHANICAL PROPERTIES TEST INCLUDING IMPACT TEST. NOTE: CERTIFICATE REQUIRED.
ITEM 3: 12 mm LONG TEST PIECE FOR CHEMICAL ANALYSIS & CLEANLINESS TEST. NOTE: CERTIFICATE REQUIRED.

3 INSPECTION. NOTE: 1) VERIFY ALL CERTIFICATION IN ACCORDANCE WITH REQUIREMENTS OF THE I.T.P. PLAN ATTACHED & PASS ONTO PRODUCTION CONTROL. 2) CHECK MATERIAL DIMENSIONS ACCORDING TO THE DRAWING AND ROUTE SHEET & RELEASE FOR MACHINING PURPOSES

4 CAST NO. RECORD ON ROUTE SHEET.

5 INSPECTION. CHECK HARDNESS ON MATERIAL AND RECORD IT ON ROUTE SHEET.

6 TEST. OUTSIDE OPERATION: SEND TEST PIECE 160 mm LONG FOR FULL MECHANICAL PROPERTIES TESTS INCLUDING IMPACT. 2) SEND TEST PIECE 12 mm LONG FOR CHEMICAL ANALYSIS.

7 TURN. CLEAN UP O.DIA'S ON FULL LENGTH FOR ULTRASONIC TEST PURPOSES.

8 TEST. ULTRASONIC TEST TO AAC 999/6. NOTE: CERTIFICATE REQUIRED.

9 TURN. ALLOW 0.3 mm ON THE DIAMETER(S) WITH Ra 0.8 FOR GRINDING.

10 GEAR-CUT. CUT TEETH. ALLOW 0.3 mm ALLOWANCE FOR GEAR GRINDING.

11 DEBARRING. REMOVE SHARP EDGES.

12 INSPECT. CHECK AND RECORD GEOMETRICAL TOLERANCE BEFORE HEAT-TREATMENT.

13 COPPER PAINT. SURFACES REQUIRED TO REMAIN SOFT MUST BE COPPER-PAINTED.

14 HEAT-TREATMENT. CARBURIZING, QUENCH, AND TEMPER (60-63 HRC, 1-1.3 mm DEPTH.)

15 INSPECTION. CHECK AND RECORD GEOMETRICAL TOLERANCES AFTER HEAT-TREATMENT.

16 GRIND. GRIND EXTERNAL DIAMETER(S)

17 GEAR-GRIND. GRIND TEETH (30 TEETH, 4 MODULE)

18 TEST. INVOLUTE, HELIX ANGLE, RUNOUT & PITCH TO PITCH ERROR TO BE CHECKED ON HOFLER TESTER. NOTE: GRAPH REQUIRED.

19 TEST. CARRY OUT MAGNETIC PARTICLE TEST TO AAC 999/6 SPECIFICATION. NOTE: CERTIFICATE REQUIRED.

20 INSPECTION. STAMP ITEM(S) WITH OUR JOB AND SERIAL NUMBER.

21 INSPECTION. DATA PACK OF ALL CERTIFICATION, COMPLETED PROCESS PLANNING SHEET AND FULL INSPECTION CERTIFICATE TO BE DELIVERED WITH THE ITEM(S).

22 STORES. THE ITEM(S) MUST BE PROTECTED AGAINST RUST & SUITABLY CRATED TO PREVENT ANY DAMAGE.

NOTE: RETURN SAMPLE TO CUSTOMER.

ROUTE SHEET JOB NO: PhD-01

CUSTOMER:	WITS UNIVERSITY	ORDER NO:	0111474R
DRAWING NO:	complex3	QUANTITY:	1
DESCRIPTION:	GEAR SHAFT	DELIVERY DATE:	2005/06/01
CLASSIFICATION:	Round	PRINT DATE:	2005/07/10

MATERIAL: 655M13, FORGING: (Dia60 x 50 LG) x (Dia 90 x 80 LG) x (Dia 140 x 60 LG) x (Dia 90 x 80 LG) x (Dia 60 x 50 LG)

OP.NO	DESCRIPTION	CODE	SET-UP	RUN TIME
1	INSPECTION	IN		
2	MATERIAL	MA		
3	INSPECTION	IN		
4	CAST NO	CAN		
5	INSPECTION	IN		
6	TEST	TE	OUTSIDE COOPERATION	
7	TURN	LT		
8	TEST	TE		
9	TURN	LT		

10	GEAR-CUT	GC	30
11	DEBARRING	DEB	
12	INSPECT	IN	
13	COPPER PAINT	CP	
14	HEAT-TREATMENT	CQT	
15	INSPECTION	IN	
16	GRIND	EG	15
17	GEAR-GRIND	GG	45
18	TEST	TE	
19	TEST	TE	
20	INSPECTION	IN	
21	INSPECTION	IN	
22	STORES	STO	

4.9 Analysis of the Prototype Systems

The analyses of the prototype systems was characterised by a structured approach focused on the research question and hypothesis, and, without drawing conclusions, it used as support the evidence unearthed by the procedures described in chapter 3. Therefore, to cover all their pertaining aspects, the hypothesis and research question have been broken down into smaller manageable pieces (Table 4.1), then their evolution showed throughout the thesis (Table 4.2), and, finally, used them to analyse each developed prototype system. The result of this analysis was presented by using a number of notes.

Table 4.1 Hypothesis and research questions

Hypothesis		The broken down hypothesis and research questions
First hypothesis	1A	Align both CAD and CAPP with software architectural elements used in practice
	1B	Enhance CAD/CAPP communication
	1C	Mainly preserves the actual way to design (e.g. wire, surfaces or solids) and only enhance the CAD system with important designs and manufacturing objects
Second hypothesis	2A	Decompose the CAPP complex problems into smaller more manageable sub-problems
	2B	Keep the human in the systems loop
	2C	Align SACAPP architecture with the organizational structure of the engineering company, its characteristics, manufacturing concepts used in practice, business practices, and manufacturing processes
	2D	Align SACAPP architecture with the need for information, the new technologies, and the new trends in IT infrastructure
Third hypothesis	3A	Simplifying information complexity
	3B	Apply automation principles and strategies
	3C	Include CAD, CAPP, and other categories of data in the communication part of CIM
Research problem	RP	How can the architecture of a CAPP system be effectively and successfully integrated into a manufacturing enterprise?

Table 4.2 Hypothesis, research problem, and systems analysis

Hypothesis	Table 4.10	Chapter 1	Chapter 2	Chapter 3	SAM System	SAS System	SADwO System	SACAPP System
Second hypothesis	2A	-	2.8	3.8	Note 1	Note 1	Note 1	Note 1
	2B	-	2. 8	3.8	Note 2	Note 2	Note 2	Note 2
	2C	-	2.4	3.4	Note 3	Note 3	Note 3	Note 3
	2D	-	2.5	3. 5	Note 4	Note 4	Note 4	Note 4
Third hypothesis	3A	-	2.6	3.6	Note 5	Note 5	Note 5	Note 5
	3B	-	2.7 and 2.8	3.7	Note 6	Note 6	Note 6	Note 6
	3C	-	2.6	3.3	Note 7	Note 7	Note 7	Note 7
First hypothesis	1A	-	2.3	3.3	-	-	Note 8	Note 8
	1B	-	2.3	3.3	-	-	Note 9	Note 9
	1C	-	2.3	3.3	-	-	Note 10	-
Research problem	RP	1.3.1 and 1.3.3	2.2	3.9 and 3.10	Note 11			

Note1: The CAPP complex system was decomposed into smaller and more manageable individual systems focused on realistic specific goals that supported various company levels functionalities. For example, the SAS system focused on the issue of the IWO and Material Data Sheet; the SAM system focused on defining company's resources; and the SACAPP system focused on the generation of the process sequencing; however, when operated together, they were able to accurately generate the process plans, and so, demonstrating their collective intelligence.

Note 2: The prototype systems provided the right balance between the manual and automated tasks; explicitly incorporated the human at the design stage; and allowed the individuals to simply and efficiently interact with the systems for settings, learning, and doing their jobs.

Note 3: The prototype systems were aligned with company's structure, its characteristics, manufacturing concepts and processes, and business practices.

Note 4: The prototype system, were structured to support the performance of the vital business processes and, because the IT infrastructure had evolved towards being process-centric based on what an organisation does, the prototype systems and the information they handled were aligned with the actual practices in the manufacturing industry.

Note 5: The prototype systems simplified information complexity, implemented the "Closed Loop" principle, and used for their communication the minimum necessary information expressed in the most basic and practical way.

Note 6: The prototype systems applied automation and robotics principles and strategies, and used both manual and automated approaches, because the manual methods offered accuracy and control but lack the efficiency of automated methods, and the automated methods offered efficiency but lack the accuracy and control of manual methods.

Note 7: The new approach included CAD, CAPP, and other categories of data in the communication part of CIM, and showed that the CAD system could be transformed from a design tool to a data exchange tool.

Note 8: The SADwO and SACAPP systems were aligned with the software architectural elements used in practice.

Note 9: The CAD/CAPP communication was enhanced with simple, practical, familiar, and common design and manufacturing objects.

Note 10: The SADwO system mainly preserved the actual CAD wire, surfaces, or solids way to design, but was enhanced with a limited number of important designs and manufacturing objects such as surface roughness, material quality, or heat-treatment conditions.

Note 11: The integrated set of prototype systems were built around the main functions of the company, and linked according its information flow. Also, the tests performed, showed that the SACAPP automated generated process plans were according to the manual generated industrial documents, and so, proved that the CAPP system could be effectively and successfully integrated into a manufacturing enterprise environment.

4.10 Conclusions

Chapter 4 was characterised by a number of focus actions, such as RUP's Construction and the Transitions phases with their prototype systems development and testing, and the analysis of the ways the systems applied the research hypothesis. As a result, Chapter 5 will discuss the findings of chapter 4 within the context of the literature, draw the thesis final conclusions, highlight the research implications and limitations, and bring about some ideas for future research.