

5 CONCLUSIONS AND IMPLICATIONS

5.1 Introduction

This thesis has been organised into five chapters which were structured, unified, and focused on solving one research problem (see Chapter 1.3). The first chapter set the scene by introducing the core research problem and outlined the path that the reader will travel towards its conclusion. Chapter 2 identified from the existing body of knowledge, research gaps and advanced hypotheses. Then, by using various methods, Chapter 3 brings answers to these hypotheses and practically demonstrated them in Chapter 4 by developing 6 software prototypes. Finally, chapter 5 briefly summarises the previous chapters, and then, prior to making conclusions about the research, it explains how the new and the old pieces fit to make the whole picture clear (Figure 5.1).

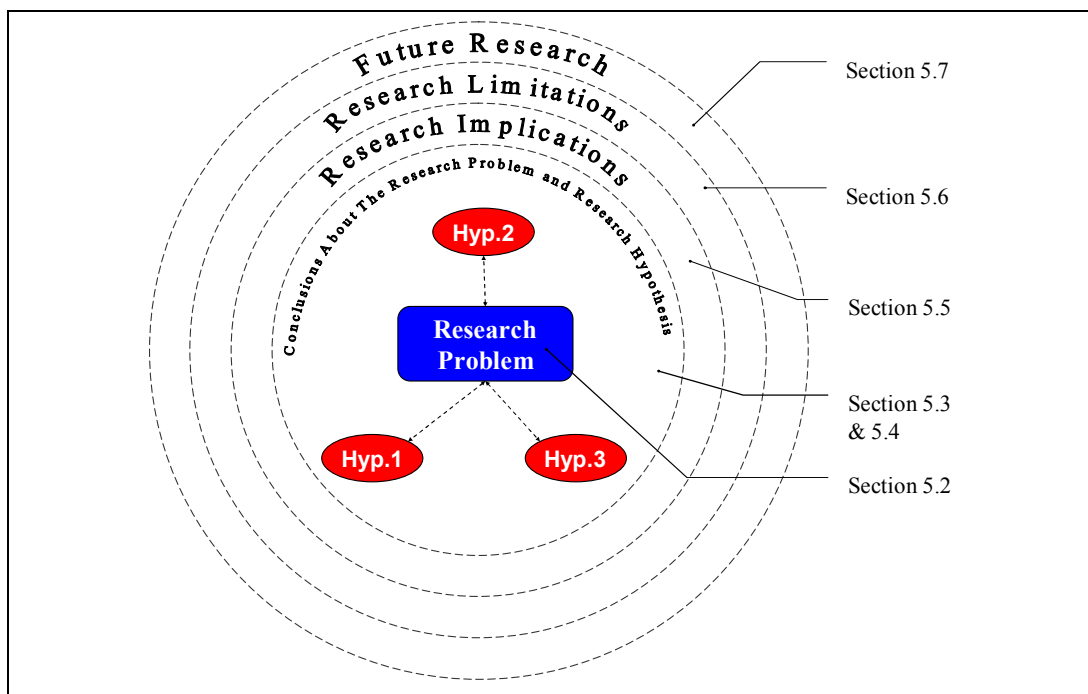


Figure 5.1 Chapter's map

5.2 A Brief Overview of Previous Chapters

In order to find the answer to the research problem of **how can the architecture of a CAPP system be effectively and successfully integrated into a manufacturing enterprise**, the literature survey focused on the issues of CAPP systems, but also considered complex, multifaceted, and cross-disciplinary directly related disciplines that arise in combining these fields within the process of developing a new CAPP software system.

As a result of the research, it has been found that the process planning complex activities required many scientific, engineering, and economics abilities, and so, its automation was required. But, CAPP, considered one of the most important and most complicated computer aided systems (Maropoulos 1995, Feng and Zhang 1998, Huang and Xu 2003), had a limited positive impact in the real industry (ElMaraghy 1993, Luo et al. 1997), was hardly a success story (Huang and Xu, 2003), and did not meet the requirements of modern manufacturing (Feng and Zhang, 1998), because the systems were large, monolithic, and complex (Law and Tam, 2000), with low-level of integration with other applications, and high development and maintenance costs (Feng and Zhang, 1998). Therefore, new CAPP approaches were required to establish the relationship between the requirements of the new manufacturing paradigms, the computerised automation systems, and the people which should use them (Kryssanov et al. 1998).

Consequently, the shortcomings in CAD/CAPP communication have been analysed and found out that CAD surface models were too complex to interpret, and only suitable for parts produced by one process (Rozenfeld and Kerry, 1999); the solid models were non-unique in nature (Jain and Kumar, 1998b) and only useful for subtractive volumes to be cut out (Rozenfeld and Kerry, 1999); and features were still a bottleneck (Kang et al., 2003), a nightmare (AAAI, 1997), and a challenging research area (Feng et al. 1999, Feng and Song 2000b), because their recognising was a complex, cumbersome, and problematic process (Jain and Kumar 1998, Jang et al. 2003) that led to different descriptions of the product

(Martino et al., 1998), and so, with an insignificant practical impact (Kang et al., 2003). With all these, although the CAD knowledge was hard to manage and access (OMG, 1996) because its detailed data geometry (Feng and Song, 2000b) that made the automated reasoning highly complex to implement (AAAI, 1997), most academic research and developers attempted to recognize very detailed design information (Feng et al. 1999, Chang and Chang 2000, Feng and Song, 2000b) that was believed a waste of time, cost, efficiency, and can even affect the correctness of process planning (Chang and Chang, 2000). Additionally, the tolerance and surface finish data were not real attributes of CAD models, but simply text representations on the drawing, the same as technical notes (Kang et al., 2003) that made the actual CAD systems inconvenient for most manufacturing applications (Abdalla and Knight, 1994). In these conditions, it was observed that the engineering drawings were not only represented by geometry elements but also drafting symbols and text that provided the designer with an added flexibility in design (AAAI 1997, Kuric and Janec 1998), and that yielded enough input to determine many of the characteristics of the manufacturing process (Feng et al., 1999, Feng and Song, 2000a). Finally, although an experienced human planner does not use every design feature but utilizes only important features that would influence the process planning (Chang and Chang, 2000), the CAD/CAM systems were not available at this high level of integration (Zhao et al. 2002, Kang et al. 2003) considered crucial for mapping traditional CAD data on the process planning systems (Feng et al., 1999). These led to the:

First hypothesis: A CAD system that uses common designs and manufacturing objects and preserves most of the actual design representations will enhance CAD/CAPP communication, and lead to the development and implementation of a better CAPP software system.

Furthermore, the manufacturing enterprise, with their historically inflexible, centralised, and monolithic organizational structure (OMG, 1996), in order to cope with the changing circumstances and support their business processes, applied a number of manufacturing concepts, used the advanced technology, such

as FMS, that increased its flexibility but also its complexity (Ndiaye et al. 2002, Shukla and Chen 1997), and involved the IT, which also evolved towards being process-centric which is based on what an organisation does. All these led to the:

Second hypothesis: Decomposing CAPP's complex problems into smaller more manageable sub-problems, keeping human in the systems loop, and better alignment of the architecture of a new modular CAPP software system with the organizational structure of the engineering company, its characteristics, manufacturing concepts used in practice, new technologies, business practices, manufacturing processes, the need for information, and the new trends in the IT infrastructure, will lead to the development and implementation of a better aggregate CAPP software system.

Moreover, also CIM was viewed as a computerised integration and information sharing (Sun, 2000) to improve manufacturing operations (Love and Barton 1996, Liu et al. 1998), shortcomings such as its inflexible hierarchical control made it unsuitable for small production batches in a dynamically changing environment (Davies 1997, Volchkov 2002, Ryu and Jung 2003). As a result, CIM was merely applied (Prasad, 2000), and a fully computerised integration in the manufacturing system was considered unlikely to be the main model in the near future (Sun, 2000). Therefore, over the years, the idealistic vision about a fully integrated company was changed to a more moderate view in line with the real company's circumstances and available equipment (Cubonova and Kumicakova, 1998). These led to the:

Third hypothesis: Simplifying information complexity, use of automation principles and strategies, and the inclusion of CAD, CAPP, and other categories of data in the communication part of CIM will lead to the development and implementation of a better CAPP software system.

Then, chapter 3 described the major methodologies used to answer the above hypothesis and the research question of **how to develop the architecture of a**

new CAPP software system that takes into consideration the specific application requirements, the enabling technologies, the existing company resources and culture, and also minimises the software development risks and time. Also, chapter 3 was the starting point of a new CAPP software project called SACAPP where, it was considered that the organisational and managerial aspects of software development were at least as important as its technical aspects (van Vliet, 2000). Hence, the SACAPP project was spanned by a structured organisation that provided the assurance that appropriate procedures were followed. In addition, because SACAPP followed the RUP iterative and risk-driven process model (Jacobson et al., 1999), chapter 3 was also spanned by phases and iterations intended to keep the focus on the scope of the project and minimise its risks. As a result, at the end of the Inception phase, the Lifecycle Objectives milestone was reached and so, it was understood that it was both possible and desirable to develop the new software system. By using the same fashion, the end of the Elaboration phase reached its Lifecycle Architecture milestone and so, it was understood that it was created a software executable, resilient, and robust architecture baseline which can evolve over the life of the product. As a result, chapter 4 with the last two of the RUP phases, namely the Construction and the Transitions, presented the prototype systems together with their GUI interfaces, UML diagrams, the input frames, and the automatically generated outputs. Finally, chapter 4 ended with the analysis of prototype systems that focused on how the research hypotheses have been applied to their development, but without drawing conclusions about the results that will be discussed next.

5.3 Conclusions about the Hypothesis and Research Questions

In this section, the agreement or disagreement of the results from chapter 4 with the literature is made clear and the reason for disagreement explained. Furthermore, in sections 5.3.1 to 5.3.9 that follow, each part of the hypotheses in chapter 2 has its own subsection, and references are used to illustrate how the findings in the chapter 4 fit into the body of knowledge.

5.3.1 Align both CAD and CAPP with the software architectural elements used in practice, and enhance CAD/CAPP communication

SADwO and SACAPP systems considered, as another direction for CAD/CAPP integration (Chang and Chang, 2000), a limited number of important design and manufacturing features that provided sufficient information for other applications (Abdalla and Knight, 1994), interpreted CAD data directly to the CAPP system (Rozenfeld and Kerry, 1999, Zhao et al., 2002), and achieved an integrated product model in which geometry data and manufacturing information were stored together (Kang et al., 2003). Therefore, SADwO and SACAPP followed the actual trend to unify and simplify size tolerances and surface finishes (Voelcker 1997, Kumar and Roman 1997) because the most CAD/CAM packages couldn't "understand", interpret, analyse, or make decisions about the tolerance/surface finish information stored in them (Kumar and Roman, 1997), and because tolerances on the work-piece were almost always dependent on the detailed knowledge of the machine-tool operator (Whybrew and Britton, 1997). As a result, in SADwO and SACAPP it was possible to employ features inter-relationships rather than just feature-by-feature planning (Naish, 1996), use the surface finish as a direct link between the designs and the machining sequence (Kumar and Roman 1997, Xu and Hinduja 1997), and so, construct the process plan's operations sequence considered process planner's most critical activity (Esawi and Ashby, 1998) because it involved knowledge about facts, procedures, and "if-then" rules (Wong and Siu, 1995).

5.3.2 Decompose the CAPP complex problems into smaller, more manageable sub-problems

The complexity was considered a notion of an inherent difficulty of a problem, a solution, or an approach (Szyperski et al., 2002), and also a consequence of the pursuit of features and performance (Sha, 2001), unnecessary requirements (Szyperski et al., 2002), and the belief that complex systems require complex

systems to manage them (Morley, 1998). In this context, because CAPP was one of the most complicated computer aided systems (Maropoulos 1995, Feng and Zhang 1998, Huang and Xu 2003) and its actual solutions were large and complex (Law and Tam, 2000), this thesis solved the CAPP complexity through simplicity, because simplicity led to reliability (Sha, 2001), minimised the number of rules (Morley, 1998), relaxed some constraints while it emphasised particular aspects of the problem (Freuder and Wallace, 2000), and used data structure as one of the simplest tools to structure and control the complexity of a large system (Budd, 2001). Consequently, the thesis proposed and practically developed a system of systems that automatically generate the CAPP output (Figure 5.2).

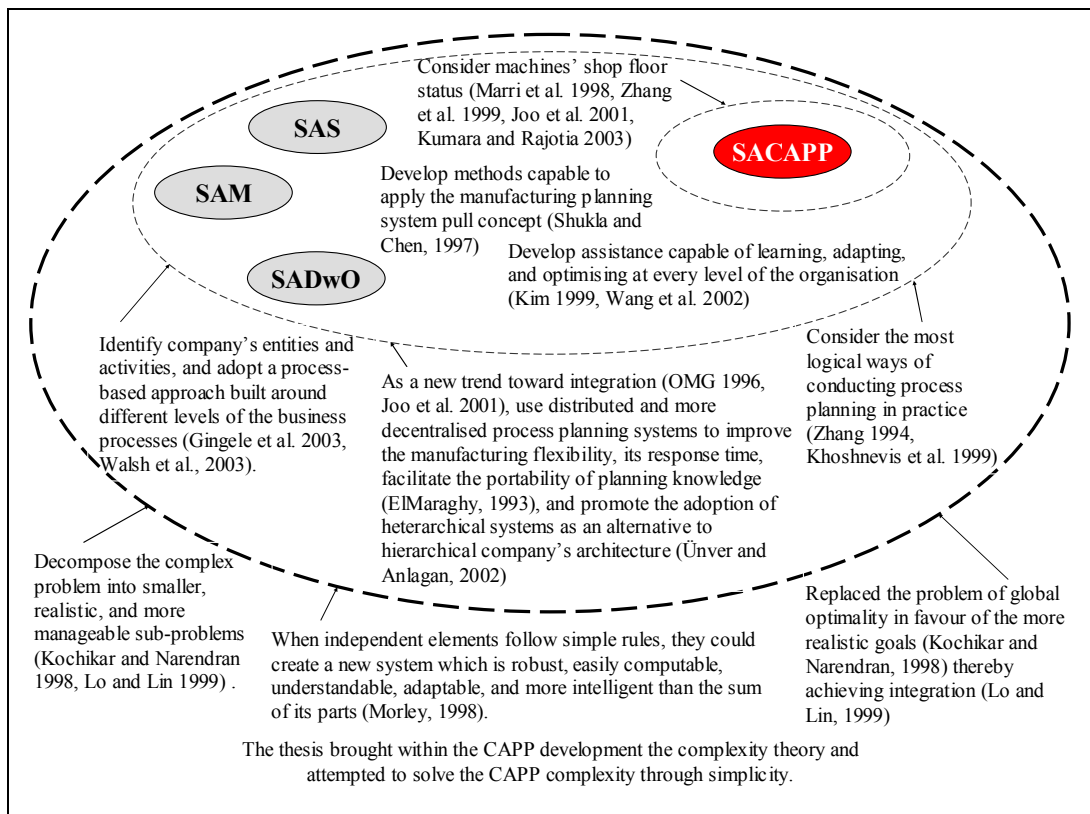


Figure 5.2 Decompose the CAPP complex problems into smaller more manageable sub-problems

5.3.3 Keep human in the systems loop

Cultural issues received less attention while they were as important as technical issues (Petrarolo 1995, AAAI 1997, Price 1998). Therefore, the thesis considered that, irrespective of the degree of automation and computerisation, the human should be a focus (Kusiak, 2000), and so, be explicitly incorporated in the model as a component at the design stage (Sreeram and Chawdhry, 1999) (Figure 5.3).

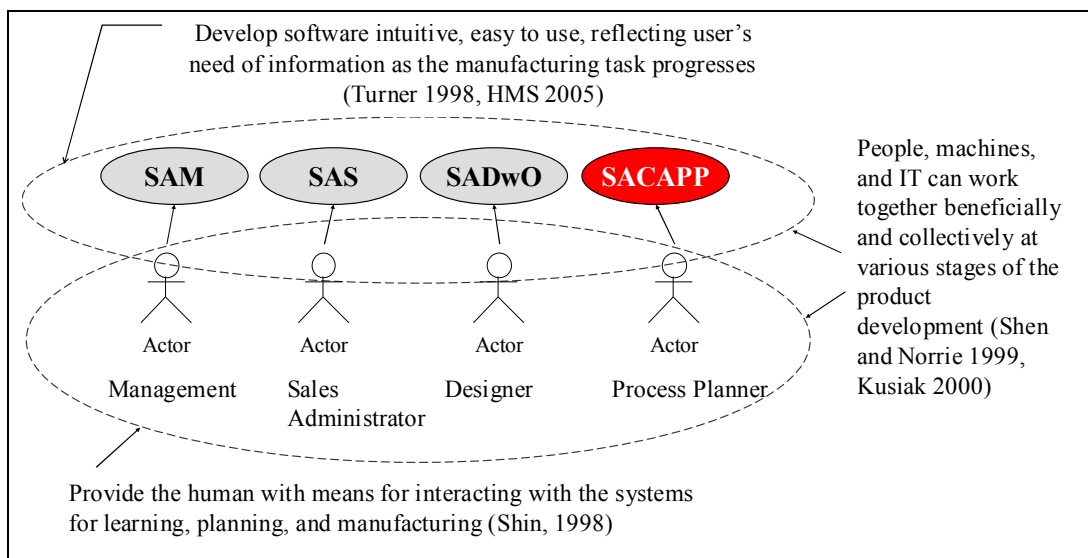


Figure 5.3 Developed systems and how the human was kept in the loop

5.3.4 Better align the architecture of a modular CAPP software system with the organizational structure of the engineering company and manufacturing concepts used in practice

The thesis divided the usually large, complex, and monolithic CAPP system (Feng and Zhang 1998, Law and Tam 2000), in a number of smaller, independent, and co-operative sub-systems which managed complexity in an efficient manner (Marshall and Leaney, 1999), and offered a powerful framework for identifying, building, and using organisation's knowledge assets (Sanchez, 2002). Furthermore, SACAPP's approach was aligned with the organizational structure of the engineering company, business practices, and a number of manufacturing concepts used in practice such as modularity – when it used small and

independent sub-systems; concurrent engineering – when it used systems that reasoned about a common product model (OMG 1996, Han and Requicha 1998, Prasad 2000); flexibility - which required a modular-based working practices (Marshall and Leaney, 1999); and agility - that integrated organisations, people and technologies into a meaningful highly responsive unit (Gupta et al., 1996) and leveraged people and information (Gunasekaran and Yusuf, 2002a). Therefore, SACAPP’s approach contributed towards process planning becoming a candidate for enhancing manufacturing systems’ adaptability and flexibility of (Joo et al., 2001).

5.3.5 Simplify information complexity

In the conditions in which the heart of CIM has been considered data management (Zhang, 2001) and information integration (Lo and Lin, 1999), and CIM was considered unlikely to be the main model to be used in the near future (Sun, 2000), SACAPP’s initial concern of how to automate the process planning shifted towards its integration with design, shop floor control and business functions (ElMaraghy, 1993) (Figure 5.4).

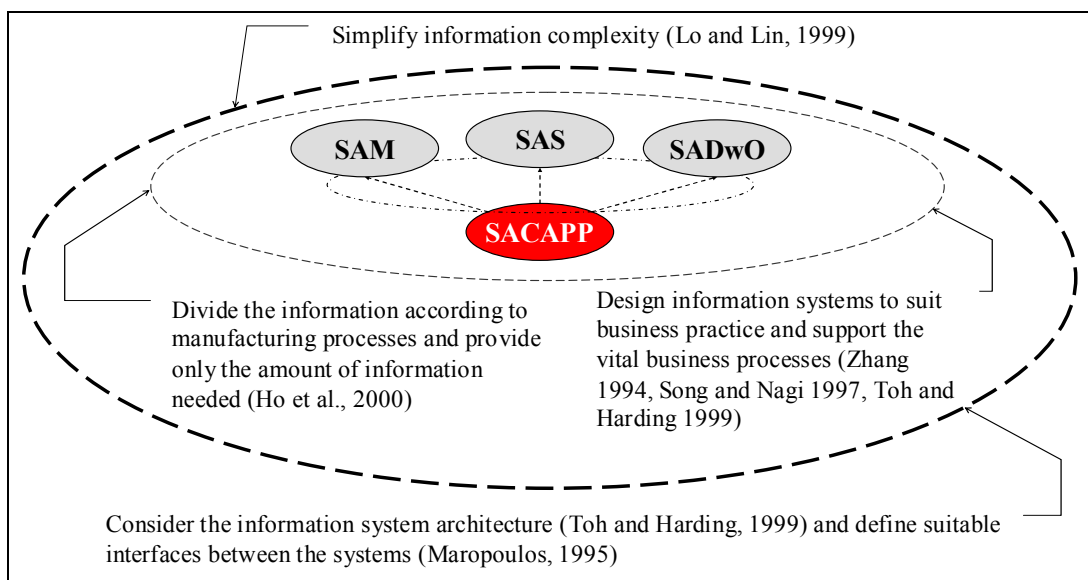


Figure 5.4 Simplify information complexity

5.3.6 Include CAD, CAPP, and other categories of data in the communication part of CIM

CAPP, although a bottleneck in the whole CIM system (Yan et al., 2001), has had a fundamental and increasingly crucial role in CIM (Davies 1997, Cay and Chassapis 1997, Ming et al. 1999, Yan et al. 2001, Kang et al. 2003, Kumara and Rajotia 2003). Therefore, the thesis transformed CAD from a design tool to a data exchange (Prasad, 2000); included in communication part of CIM different categories of data including CAD, CAM, CAPP, and Internet ((Prasad 2000, Brissaud 2002); and moved from a “technology push” situation to a “requirement pull situation”, which represented the move from CIM to Intelligent Manufacturing Systems (IMS) (Jung et al., 2001)

5.3.7 Use of automation principles and strategies

When dealing with automation systems, wider issues should be considered that focus on people and systems that would maximise peoples’ capabilities, opportunities, and participation (Turner 1998, Shafto and Hoffman 2002). Therefore, in conditions in which one normally associated automation with the individual production machines, the scope of SACAPP project was to automate and improve the accuracy of process plans’ generation, and simplify the effort and improve the process planner’s productivity. So, it was essential to understand the fundamental philosophies of the improvement journey (Hollingum, 1999), and employ automation principles and strategies such as the USA principle (Groover, 2001), which, according to the author’s knowledge, have never been applied before. Also, because no single formalism, technique, or tool generated useful decisions in a modern enterprise (Kusiak, 2000), the thesis considered that the human planner was still irreplaceable (Kryssanov et al., 1998) and a critical component (Shin, 1998), and so, SACAPP software solution was viewed as a vehicle to assist in achieving various manufacturing goals, rather than to replace humans (Sreeram and Chawdhry, 1999).

5.3.8 Cautious use of the AI

The thesis was cautious in using AI because few expert systems had significant impact on manufacturing industries (Kryssanov et al. 1998, Ming et al. 1999), GA was far from having an impact in practice (Aytug et al., 2003), and it was unusual to see reports about successful general CAPP solutions based on AI (Rozenfeld and Kerry, 1999). In addition, the research literature was confusing, with some considering that CAPP greatly benefited from AI methods (Cay and Chassapis, 1997), and others considering that AI had great success in manufacturing only where it was deployed as “intelligent amplification” and not when it tried to tackle problems in the area of CAD/CAM automation (AAAI, 1997). Consequently, the thesis proposed the use of NNs only at machine-tool level where the operator referred to nothing but catalogues and handbooks (Whybrew and Britton 1997, Yan et al. 2001), and where NNs could support his specific activities and capture manufacturing process characteristics (Figure 3.17).

5.3.9 SACAPP, Object-Oriented programming, RUP, UML, and Java

Although object-oriented programming was recognised as a new way of thinking about solving problems (Luo et al., 1997) and a promising alternative to other techniques (Lo and Lin, 1999), it received little attention in CAPP (Liang and O’Grady, 1998). Therefore, the thesis developed for the first time according to the author’s knowledge, a CAPP software system written completely in Java. Consequently, CAPP’s problem domain was decomposed into objects and their relationships, and then achieved self-contained sub-systems in terms of their operations, data, and communication (van Vliet, 2000), and able to capture, describe, understand, and analyse the problem better (Jackson, 2001). Also, the thesis brought into CAPP’s development the RUP’s software engineering philosophy of iterative and risk-driven process measured against clear milestones characterised by the availability of sets of artifacts such as models or documents. Consequently, SACAPP moved CAPP’s development within a new three dimensional functionality space where, in addition to its technical functions,

important social, organisational, managerial, and business implications factors have been considered.

5.4 Conclusions about the Research Problem

Based on the thesis' qualitative findings, the research problem of **how can the architecture of a CAPP system be effectively and successfully integrated into a manufacturing enterprise** can now receive a concise answer. Essentially, it is argued that CAPP's architecture should be considered a framework for problem solving that should:

- be aligned with the business practices and the ways in which the companies are run,
- promote the simplification of information, and
- support the human which should be an integrated part of the system.

Also, it has been concluded that CAPP system, as a multi-perspective activity, should focus on:

- CAD-CAPP-Company Resources-Sales-Quotation integration, and
- the generation of the process plans' sequence of operations,
- while at machine-tool level, the focus should be on improving the human-automata integration.

Finally, all these led to a CAPP system of systems which was architectural-centric, process-centric, human-centric, and in line with the IT infrastructure trends.

5.5 Research Implications

This section provides the theoretical implications of the research and supports the facts that the thesis not only made a significant contribution to knowledge in its

immediate discipline, but also it has had implications for the wider body of knowledge where other disciplines could benefit from its findings.

5.5.1 Implications for theory

Presented in a concise graphical format, Figure 5.5 represents the summary of the thesis contribution to knowledge. The term “New” indicates that a specific approach has been applied for the first time in CAPP, based on the author’s knowledge.

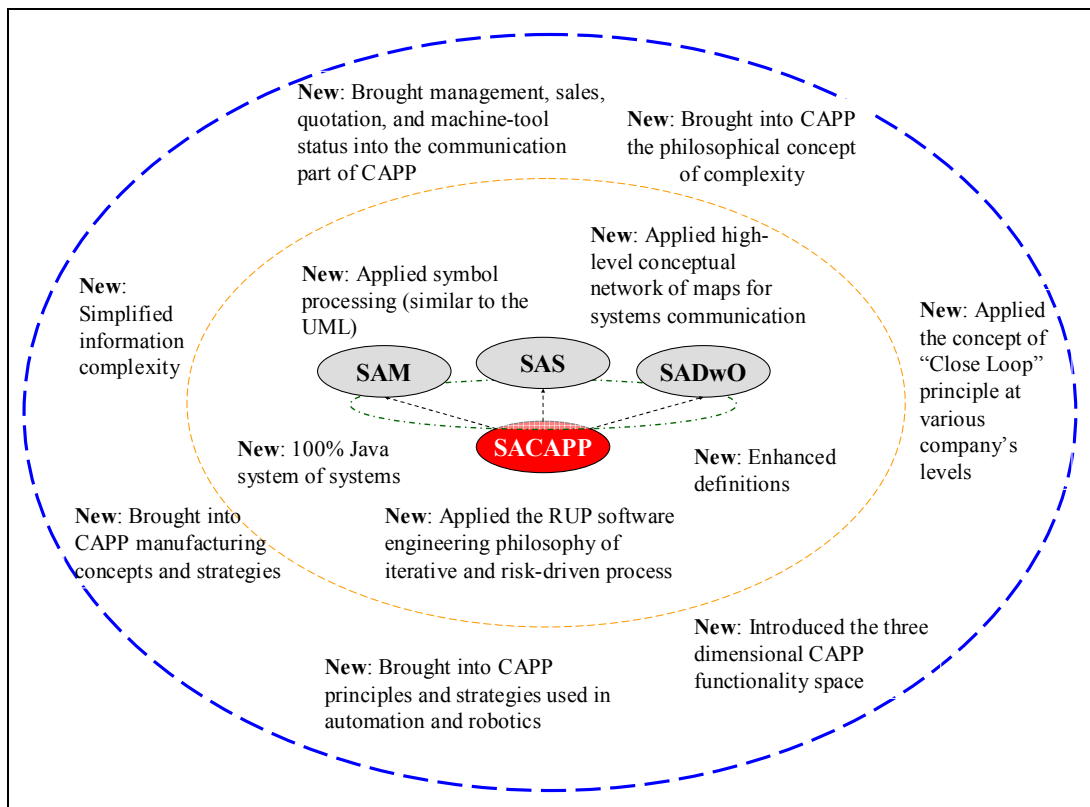


Figure 5.5 Thesis contributions to knowledge

It is also worth being highlighted that this thesis was the first interdisciplinary CAPP research in South Africa.

5.5.2 Implications for practice

The research literature has shown that CAPP introduction bring benefits, which combined could improve not only the productivity, consistency, clarity, accuracy, and quality of the process planning activity itself, but also improve various related activities such as production lead-time, production scheduling, and capacity utilization.

The research findings showed that the application of object-oriented programming techniques, a suitable data structure and interfaces with other systems, and the right balance between manual user interaction and automation of tasks, could facilitate CAPP's functionalities of the various company levels. As a result of this increased flexibility, CAPP's scope of application will become wider and in line with the new demands in product development practices that require a direct link with other activities and systems, including the engineering release system, product data management (PDM), or enterprise resource planning (ERP) system. Consequently, CAPP could facilitate data exchange, promote company integration, and contribute towards implementation of the concurrent manufacturing concept.

5.6 Research Limitations

The thesis has aimed to:

- develop an original CAPP software architecture,
- develop a CAPP software system to generate high-level process plans, and
- evaluate the concepts and software through case studies applied to machined parts within a discrete manufacturing environment

The research focused on the industrial processes that involved metal removal because the machining domain was still a major bottleneck to CAPP implementation. Also, the research focused on CAPP's essential goals considered

to be the reduction of the clerical load of the process plans preparation, the process selection, and the generation of process plans sequence of operations.

Some of the thesis limitations acknowledged by the author, that do not detract the significance of the thesis' findings, refer to the need to extend the research findings to include other manufacturing processes such as sheet metal forming and assembling operations, and the need to develop a number of machine-tool gauges for detailed operation planning, including tool selection and machine-tool set-up.

5.7 Further Research

This final section is written to help students and other researchers in selection and design of future research directions that could be foreseen (Figure 5.6).

Finally, the research literature suggested that CAPP is one of the most important and unsolved manufacturing problems. This thesis showed that it is both theoretically and practically possible to find solutions to CAPP's problems and set a foundation for further research.

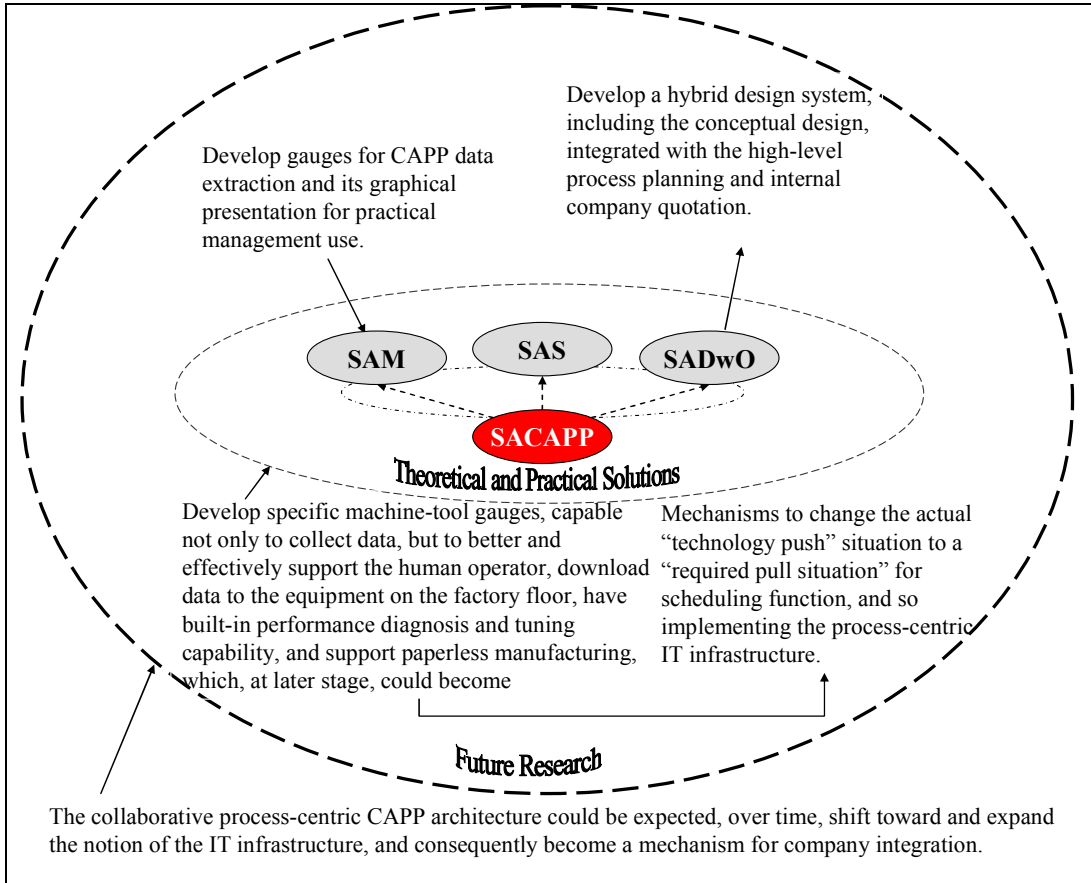


Figure 5.6 Future research

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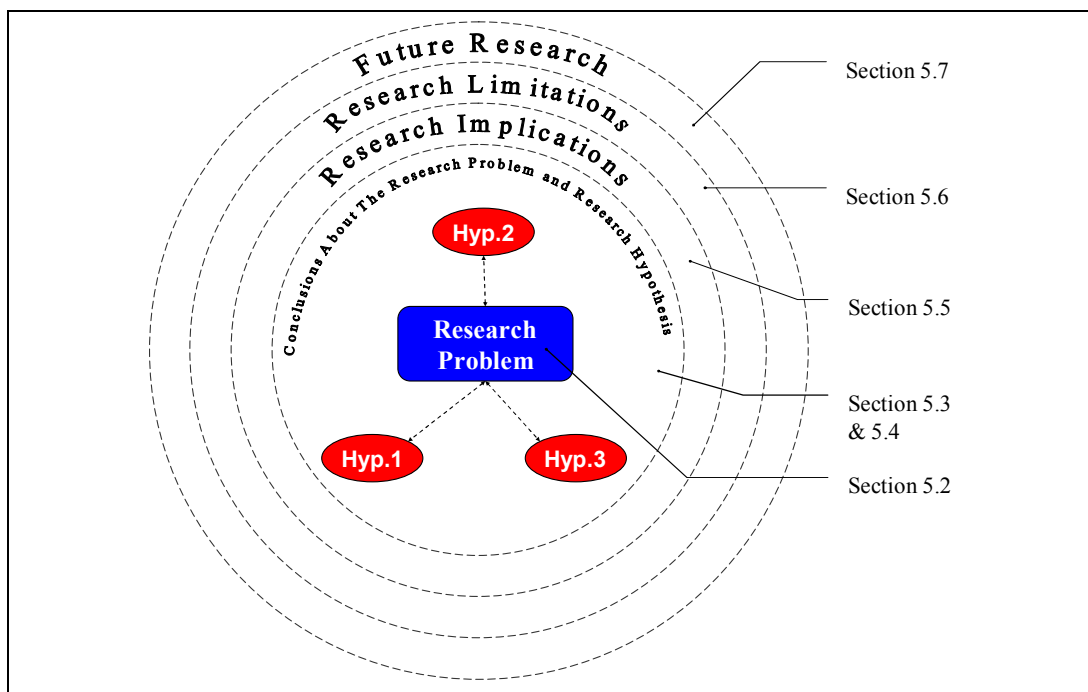


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systems to manage them (Morley, 1998). In this context, because CAPP was one of the most complicated computer aided systems (Maropoulos 1995, Feng and Zhang 1998, Huang and Xu 2003) and its actual solutions were large and complex (Law and Tam, 2000), this thesis solved the CAPP complexity through simplicity, because simplicity led to reliability (Sha, 2001), minimised the number of rules (Morley, 1998), relaxed some constraints while it emphasised particular aspects of the problem (Freuder and Wallace, 2000), and used data structure as one of the simplest tools to structure and control the complexity of a large system (Budd, 2001). Consequently, the thesis proposed and practically developed a system of systems that automatically generate the CAPP output (Figure 5.2).

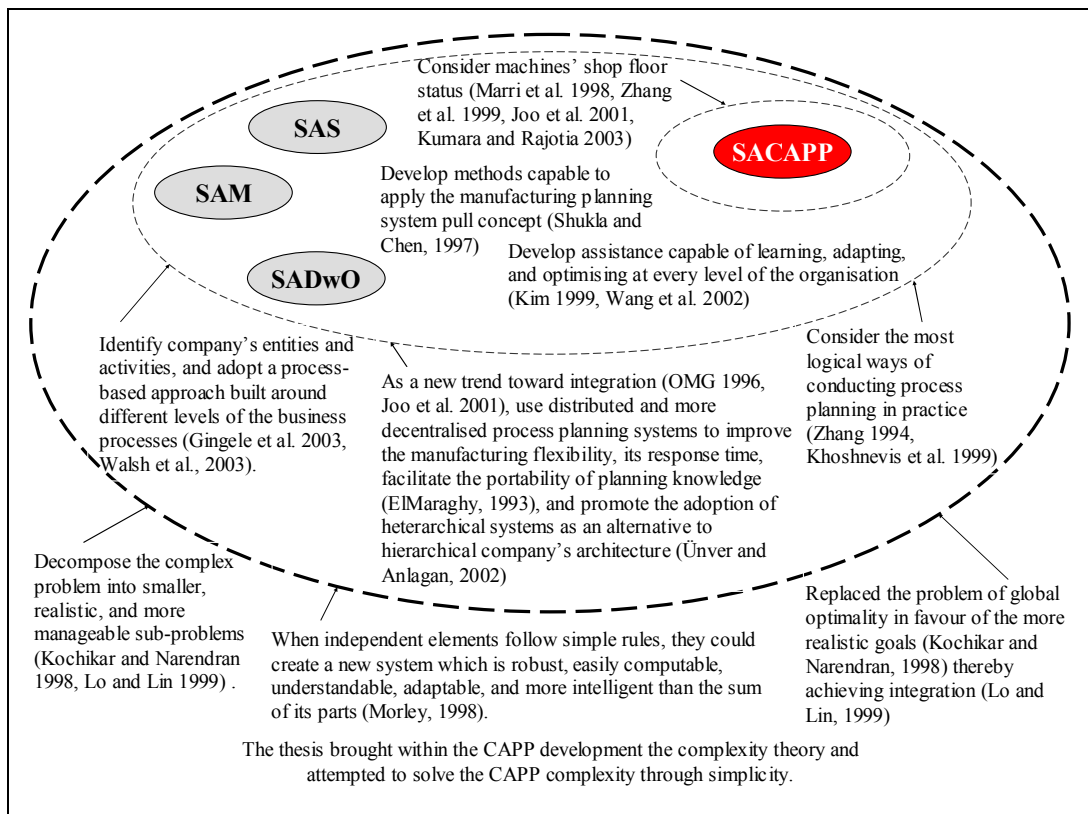


Figure 5.2 Decompose the CAPP complex problems into smaller more manageable sub-problems

5.3.3 Keep human in the systems loop

Cultural issues received less attention while they were as important as technical issues (Petrarolo 1995, AAAI 1997, Price 1998). Therefore, the thesis considered that, irrespective of the degree of automation and computerisation, the human should be a focus (Kusiak, 2000), and so, be explicitly incorporated in the model as a component at the design stage (Sreeram and Chawdhry, 1999) (Figure 5.3).

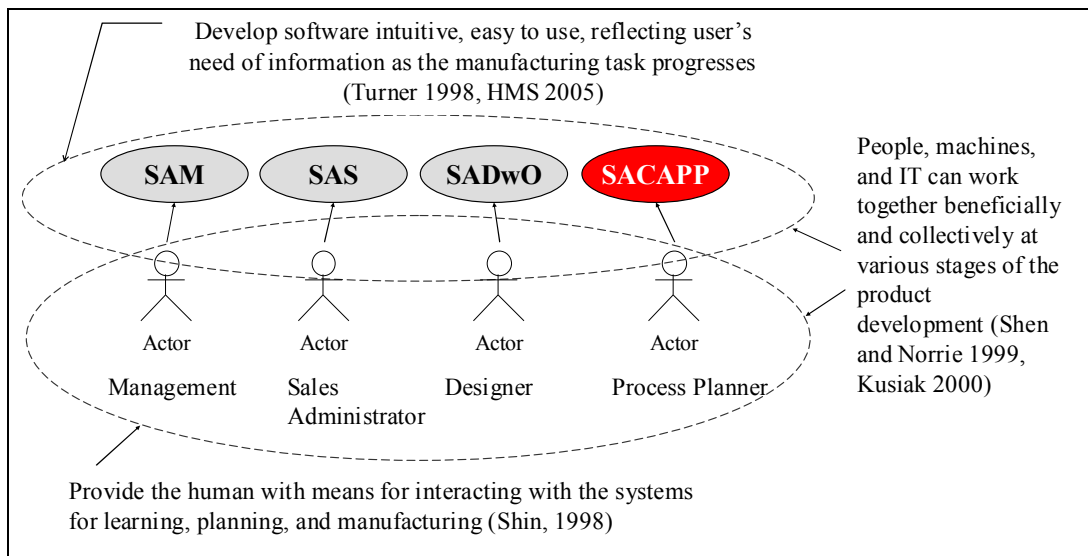


Figure 5.3 Developed systems and how the human was kept in the loop

5.3.4 Better align the architecture of a modular CAPP software system with the organizational structure of the engineering company and manufacturing concepts used in practice

The thesis divided the usually large, complex, and monolithic CAPP system (Feng and Zhang 1998, Law and Tam 2000), in a number of smaller, independent, and co-operative sub-systems which managed complexity in an efficient manner (Marshall and Leaney, 1999), and offered a powerful framework for identifying, building, and using organisation's knowledge assets (Sanchez, 2002). Furthermore, SACAPP's approach was aligned with the organizational structure of the engineering company, business practices, and a number of manufacturing concepts used in practice such as modularity – when it used small and

independent sub-systems; concurrent engineering – when it used systems that reasoned about a common product model (OMG 1996, Han and Requicha 1998, Prasad 2000); flexibility - which required a modular-based working practices (Marshall and Leaney, 1999); and agility - that integrated organisations, people and technologies into a meaningful highly responsive unit (Gupta et al., 1996) and leveraged people and information (Gunasekaran and Yusuf, 2002a). Therefore, SACAPP’s approach contributed towards process planning becoming a candidate for enhancing manufacturing systems’ adaptability and flexibility of (Joo et al., 2001).

5.3.5 Simplify information complexity

In the conditions in which the heart of CIM has been considered data management (Zhang, 2001) and information integration (Lo and Lin, 1999), and CIM was considered unlikely to be the main model to be used in the near future (Sun, 2000), SACAPP’s initial concern of how to automate the process planning shifted towards its integration with design, shop floor control and business functions (ElMaraghy, 1993) (Figure 5.4).

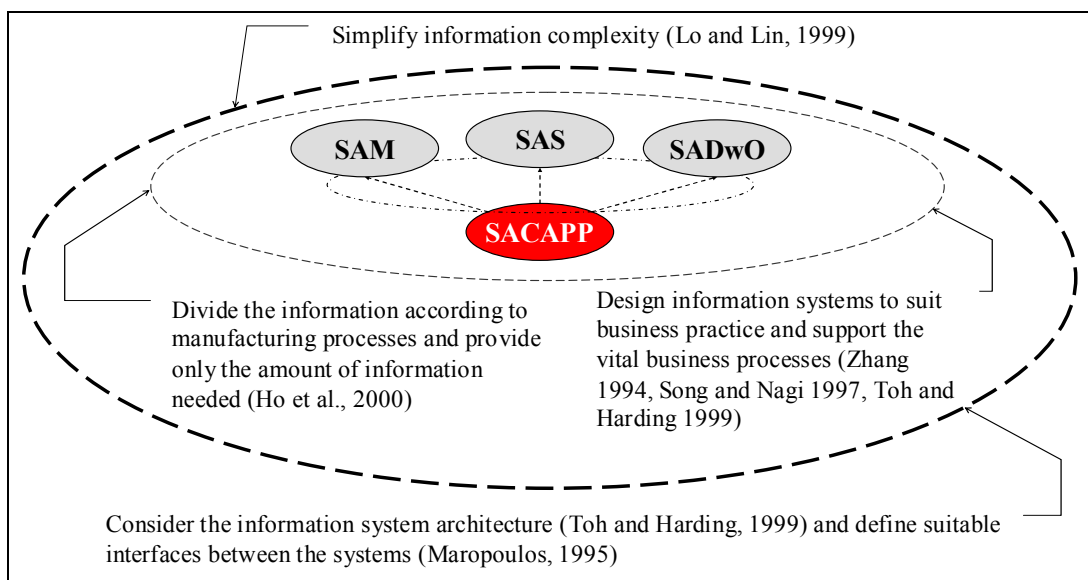


Figure 5.4 Simplify information complexity

5.3.6 Include CAD, CAPP, and other categories of data in the communication part of CIM

CAPP, although a bottleneck in the whole CIM system (Yan et al., 2001), has had a fundamental and increasingly crucial role in CIM (Davies 1997, Cay and Chassapis 1997, Ming et al. 1999, Yan et al. 2001, Kang et al. 2003, Kumara and Rajotia 2003). Therefore, the thesis transformed CAD from a design tool to a data exchange (Prasad, 2000); included in communication part of CIM different categories of data including CAD, CAM, CAPP, and Internet ((Prasad 2000, Brissaud 2002); and moved from a “technology push” situation to a “requirement pull situation”, which represented the move from CIM to Intelligent Manufacturing Systems (IMS) (Jung et al., 2001)

5.3.7 Use of automation principles and strategies

When dealing with automation systems, wider issues should be considered that focus on people and systems that would maximise peoples’ capabilities, opportunities, and participation (Turner 1998, Shafto and Hoffman 2002). Therefore, in conditions in which one normally associated automation with the individual production machines, the scope of SACAPP project was to automate and improve the accuracy of process plans’ generation, and simplify the effort and improve the process planner’s productivity. So, it was essential to understand the fundamental philosophies of the improvement journey (Hollingum, 1999), and employ automation principles and strategies such as the USA principle (Groover, 2001), which, according to the author’s knowledge, have never been applied before. Also, because no single formalism, technique, or tool generated useful decisions in a modern enterprise (Kusiak, 2000), the thesis considered that the human planner was still irreplaceable (Kryssanov et al., 1998) and a critical component (Shin, 1998), and so, SACAPP software solution was viewed as a vehicle to assist in achieving various manufacturing goals, rather than to replace humans (Sreeram and Chawdhry, 1999).

5.3.8 Cautious use of the AI

The thesis was cautious in using AI because few expert systems had significant impact on manufacturing industries (Kryssanov et al. 1998, Ming et al. 1999), GA was far from having an impact in practice (Aytug et al., 2003), and it was unusual to see reports about successful general CAPP solutions based on AI (Rozenfeld and Kerry, 1999). In addition, the research literature was confusing, with some considering that CAPP greatly benefited from AI methods (Cay and Chassapis, 1997), and others considering that AI had great success in manufacturing only where it was deployed as “intelligent amplification” and not when it tried to tackle problems in the area of CAD/CAM automation (AAAI, 1997). Consequently, the thesis proposed the use of NNs only at machine-tool level where the operator referred to nothing but catalogues and handbooks (Whybrew and Britton 1997, Yan et al. 2001), and where NNs could support his specific activities and capture manufacturing process characteristics (Figure 3.17).

5.3.9 SACAPP, Object-Oriented programming, RUP, UML, and Java

Although object-oriented programming was recognised as a new way of thinking about solving problems (Luo et al., 1997) and a promising alternative to other techniques (Lo and Lin, 1999), it received little attention in CAPP (Liang and O’Grady, 1998). Therefore, the thesis developed for the first time according to the author’s knowledge, a CAPP software system written completely in Java. Consequently, CAPP’s problem domain was decomposed into objects and their relationships, and then achieved self-contained sub-systems in terms of their operations, data, and communication (van Vliet, 2000), and able to capture, describe, understand, and analyse the problem better (Jackson, 2001). Also, the thesis brought into CAPP’s development the RUP’s software engineering philosophy of iterative and risk-driven process measured against clear milestones characterised by the availability of sets of artifacts such as models or documents. Consequently, SACAPP moved CAPP’s development within a new three dimensional functionality space where, in addition to its technical functions,

important social, organisational, managerial, and business implications factors have been considered.

5.4 Conclusions about the Research Problem

Based on the thesis' qualitative findings, the research problem of **how can the architecture of a CAPP system be effectively and successfully integrated into a manufacturing enterprise** can now receive a concise answer. Essentially, it is argued that CAPP's architecture should be considered a framework for problem solving that should:

- be aligned with the business practices and the ways in which the companies are run,
- promote the simplification of information, and
- support the human which should be an integrated part of the system.

Also, it has been concluded that CAPP system, as a multi-perspective activity, should focus on:

- CAD-CAPP-Company Resources-Sales-Quotation integration, and
- the generation of the process plans' sequence of operations,
- while at machine-tool level, the focus should be on improving the human-automata integration.

Finally, all these led to a CAPP system of systems which was architectural-centric, process-centric, human-centric, and in line with the IT infrastructure trends.

5.5 Research Implications

This section provides the theoretical implications of the research and supports the facts that the thesis not only made a significant contribution to knowledge in its

immediate discipline, but also it has had implications for the wider body of knowledge where other disciplines could benefit from its findings.

5.5.1 Implications for theory

Presented in a concise graphical format, Figure 5.5 represents the summary of the thesis contribution to knowledge. The term “New” indicates that a specific approach has been applied for the first time in CAPP, based on the author’s knowledge.

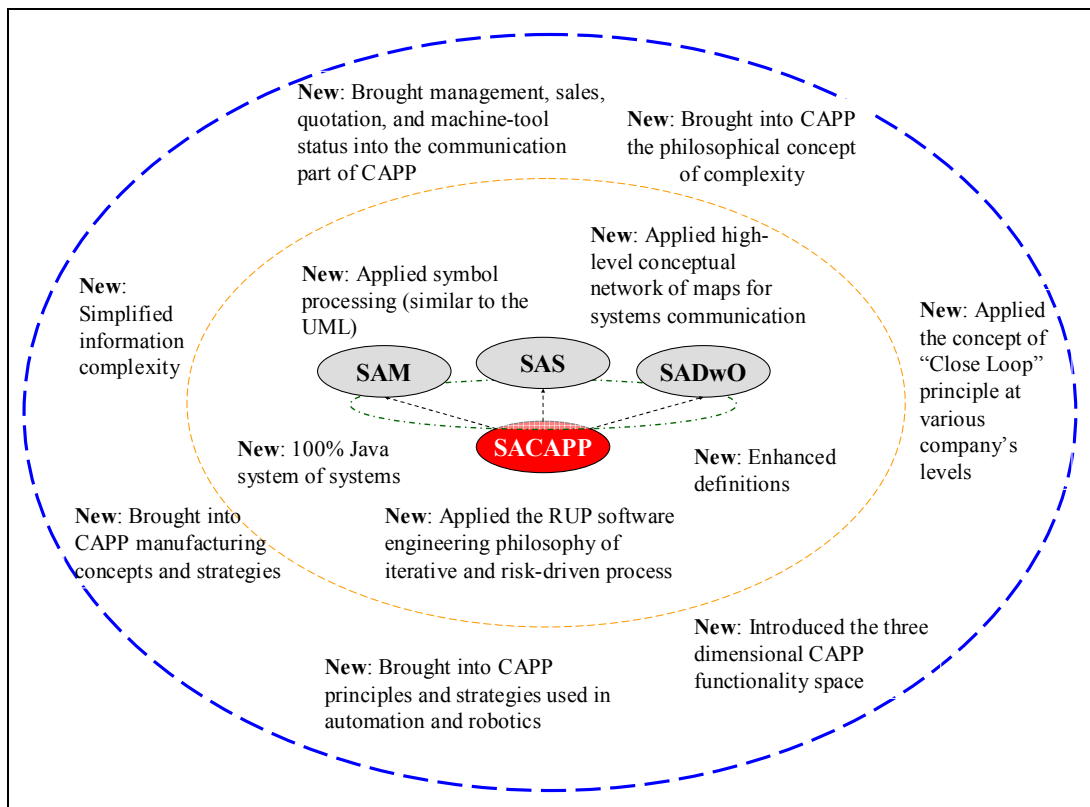


Figure 5.5 Thesis contributions to knowledge

It is also worth being highlighted that this thesis was the first interdisciplinary CAPP research in South Africa.

5.5.2 Implications for practice

The research literature has shown that CAPP introduction bring benefits, which combined could improve not only the productivity, consistency, clarity, accuracy, and quality of the process planning activity itself, but also improve various related activities such as production lead-time, production scheduling, and capacity utilization.

The research findings showed that the application of object-oriented programming techniques, a suitable data structure and interfaces with other systems, and the right balance between manual user interaction and automation of tasks, could facilitate CAPP's functionalities of the various company levels. As a result of this increased flexibility, CAPP's scope of application will become wider and in line with the new demands in product development practices that require a direct link with other activities and systems, including the engineering release system, product data management (PDM), or enterprise resource planning (ERP) system. Consequently, CAPP could facilitate data exchange, promote company integration, and contribute towards implementation of the concurrent manufacturing concept.

5.6 Research Limitations

The thesis has aimed to:

- develop an original CAPP software architecture,
- develop a CAPP software system to generate high-level process plans, and
- evaluate the concepts and software through case studies applied to machined parts within a discrete manufacturing environment

The research focused on the industrial processes that involved metal removal because the machining domain was still a major bottleneck to CAPP implementation. Also, the research focused on CAPP's essential goals considered

to be the reduction of the clerical load of the process plans preparation, the process selection, and the generation of process plans sequence of operations.

Some of the thesis limitations acknowledged by the author, that do not detract the significance of the thesis' findings, refer to the need to extend the research findings to include other manufacturing processes such as sheet metal forming and assembling operations, and the need to develop a number of machine-tool gauges for detailed operation planning, including tool selection and machine-tool set-up.

5.7 Further Research

This final section is written to help students and other researchers in selection and design of future research directions that could be foreseen (Figure 5.6).

Finally, the research literature suggested that CAPP is one of the most important and unsolved manufacturing problems. This thesis showed that it is both theoretically and practically possible to find solutions to CAPP's problems and set a foundation for further research.

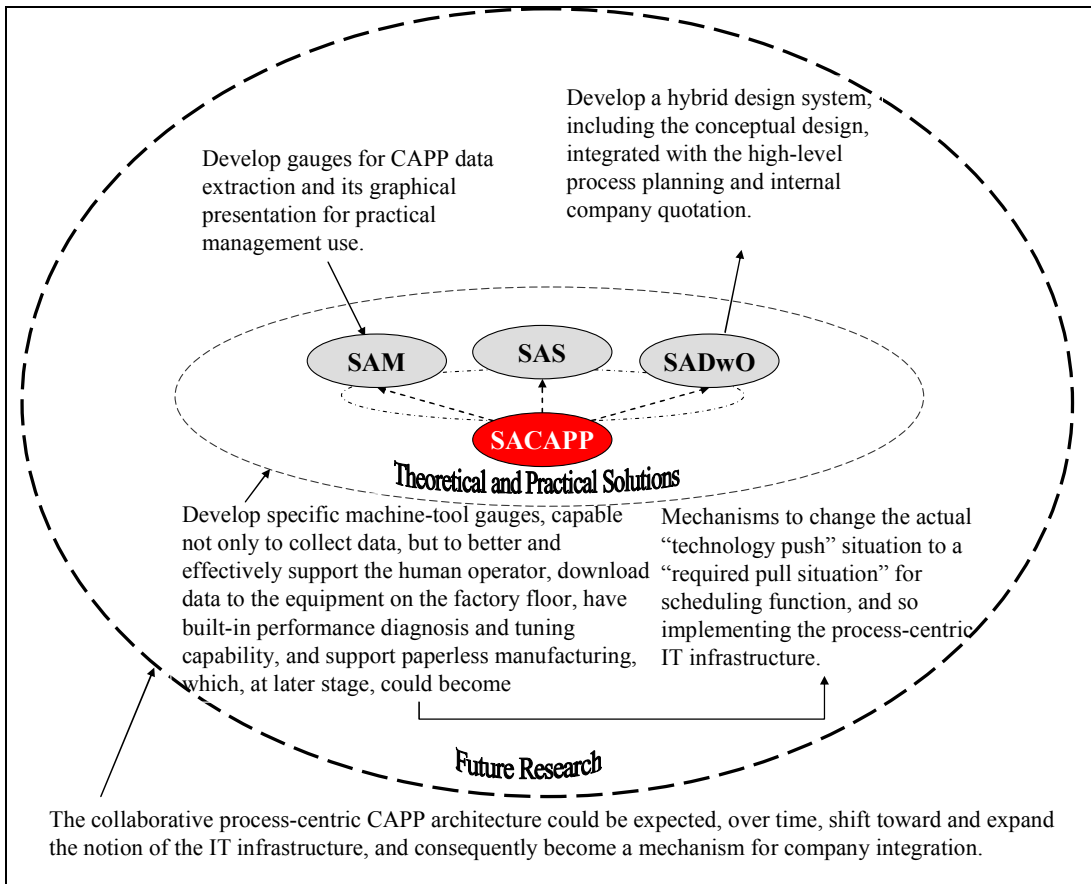


Figure 5.6 Future research