Enterprise Information Integration: People, Automation, and Complexity Concerns

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Abstract: - The purpose of this paper is to explore how people, automation, and complexity can be effectively and successfully integrated into a manufacturing enterprise information system. This exploration is required because various studies showed that manufacturing enterprise information integration faces complex organisational, technical, and social shortcomings. Based on the paper's qualitative findings supported by authorities, evidence, or logic, essentially, it is argued that automation and information systems should focus, incorporate, and assist human, and that wisdom of simplicity in order to control complexity should prevail against the attempt to develop complex systems that usually are a consequence of unnecessary requirements. This also leads to the need for a multi-perspective research approach for solving enterprise integration problems.

Key-Words: - People, Automation, Complexity, Information, Integration.

1 Introduction

The manufacturing enterprise uses the information, information systems, and Information Technology (IT) infrastructure to support its business processes. Information, defined as any data or knowledge, acquired or supplied, and necessary for an activity [1], has been used by the information systems to interconnect and integrate manufacturing process equipments with other systems and to support the manufacturing enterprise functions. In order to better link the information structures to the operations of the enterprise, the IT infrastructure, defined as a set of IT resources and organisational capabilities, evolved towards being process-centric which is based on what an organisation does [62] (Figure 1).

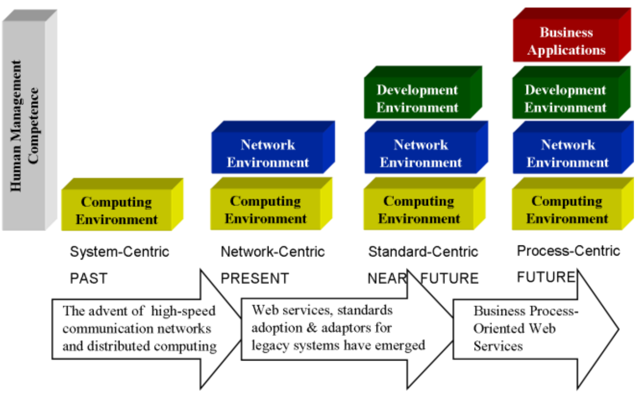

Figure 1. IT infrastructure trends, [62] reorganised.

Therefore, the new information systems should be designed to:

- support and suit business practices [15],
- remove irrelevant and redundant information [63],
- divide complex information and provide only the amount of information needed according to manufacturing processes [64], and
- have a modular and hybrid structure to reduce application complexity and lower application development [7].

In this context, in order to better link the information structures to the operations of the enterprise, a simple computational technique for CAD-CAPP integration was developed by [2]. The model made use of a limited number of important design and manufacturing features to achieve an integrated product model in which geometry data and manufacturing information were stored together.

Furthermore, the approach provided not only a direct interpretation of CAD data to the CAPP system, but also supplied sufficient information for the generation of the correct process plan's operations sequence, considered to be the process planner's most critical activity because it involved knowledge about facts, procedures, and 'if-then' rules.

Finally, the approach simplified engineering drawing's information complexity, and offered better computability, reusability, and improved communication between CAD and CAPP. However, in spite of this, there are still many shortcomings affecting the information integration within a manufacturing enterprise.

Therefore, this paper focuses on people, automation, and complexity issues for the information integration within a manufacturing enterprise. Subsequently, section 2 formulates the problem, research gaps, and constructs the research question. Section 3 presents the methodology. Then, in section 4, hypotheses are advanced and, based on the existing body of knowledge, the paper answers to the hypotheses. Finally, section 5 draws conclusions about the hypotheses and highlights its theoretical and practical implications.

2 Problem Formulation

Manufacturing was considered information and knowledge intensive [7], therefore, the motivation behind Computer Integrated Manufacturing (CIM) development, described as a comprehensive measure of computerised integration and information sharing [8], or a superimposition of an information system and decision support system over the manufacturing infrastructure, facilities, products, and material flows [65] in order to coordinate the production activities [66] and improve company's operational performance [67]. CIM has been concerned with the integration of commercial, financial and engineering systems in order to improve their responsiveness, quality, cost, and competitiveness.

The CIM vision has been one of total business integration, where no data is duplicated unnecessarily, and with no barriers between different departmental functions.

However CIM, that carried the concept of CE to the scale of the whole company [3], has faced important organisational, technical, and social shortcomings. For example, CIM was considered:

- unsuitable for small business server-based applications [4],
- its hierarchical control was too inflexible for small production batches in a dynamically changing environment [5], and
- not flexible in reconfiguring the shop layout [6].

As a result of these shortcomings, CIM was merely applied to integration of data, communication, and processes [7], and a fully computerised integration in the manufacturing system was considered unlikely to be the main model in the near future [8].

Therefore, over the years, the idealistic vision about a fully integrated company was changed to a more moderate view in line with the company's real circumstances and available equipment [9].

Consequently, the new information systems should:

- consider company's real individual condition along with the various enabling technologies [68],
- transform CAD from a design tool to a data exchange tool [7],
- consider the system architecture a model to simplify the information complexity [25],
- handle the knowledge, the communication between different categories of data including CAD and CAPP, and the extended enterprise [7] \cite{brissaud02a},
- move from a 'technology push' situation to a 'requirement pull situation', which represents the move from CIM to Intelligent Manufacturing Systems (IMS) [70], and so
- design information systems to suit business practice [15].

However, the suggestions for the new information systems did not properly consider in their approaches very crucial aspects such as people, automation, and the ways to control manufacturing complexity.

These lead to the following

Research Question: *How can people, automation, and complexity be effectively and successfully integrated into a manufacturing enterprise information system?*

3 Methodology

The scientific method is a process for experimentation used to explore observations and answer questions. The scientific method starts when you ask a question about a problem that you observed and ends with a solution to the problem, so it forms a cycle (Figure 2). The problem statement is therefore the axis which the whole research revolves around, because the problem explains in short the aim of the research. Also, the statement of the problem involves the demarcation and formulation of the problem.

Dividing the main problem into sub-problems is of the utmost importance. Sub-problems flow from the main problem and make up the main problem. Sub-problems approach is the means to reach the set goal in a manageable way and contribute to solving the problem.

Furthermore, to find answers to the research problem and sub-problems, a number of specific hypotheses are used in order to gather data about and so, satisfactorily solve the research problem. The term hypothesis derives from the Greek 'hypotithenai' meaning 'to put under' or 'to suppose'. Therefore, a hypothesis is:

- a preliminary or tentative explanation for an observable phenomenon of what the researcher considers the outcome of an investigation will be,
- a reasoned proposal predicting a possible causal correlation among two or more phenomena/variables that can be empirically tested,
- an informed/educated guess based on previous observations/scientific theories whose merit requires evaluation because it provides a suggested solution to the problem,
- furnishing proof that the researcher has sufficient background knowledge to enable him/her to make suggestions in order to extend existing knowledge, and
- a tool to give direction/structure to the next phase in the investigation and therefore furnishes continuity to the examination of the problem.

A hypothesis differs from a problem. A problem serves as the basis or origin from which a hypothesis is derived. A hypothesis is a suggested solution to a problem. A problem (question) cannot be directly tested, whereas the scientific method requires that a hypothesis can be tested and verified. A hypothesis could be true or false.

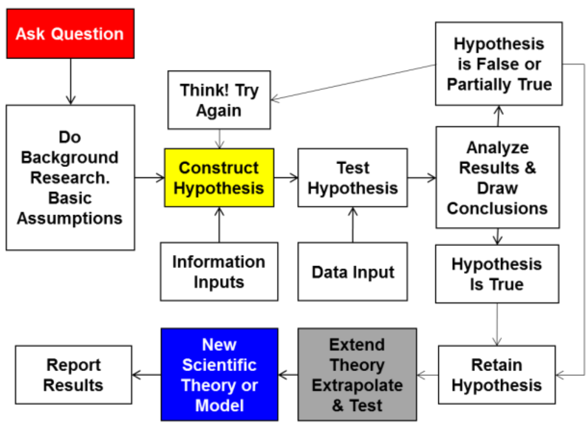

Figure 2. Methodology approach

Finally, in order for the scientific method to answer the research question, it must be about something that you can measure, preferably with a number. However, because of the manufacturing's research lack of mathematical models, this paper answers hypotheses and research question using support from authorities (research literature published by reputable international journals), evidence, or logic.

4 Problem Solution

Based on the research methodology, this section divides the main problem into two sub-problems of the utmost importance, namely:

1. human-automation interaction, and
2. human and complexity.

The two sub-problems flow from the main problem. Also, dividing the main problem into sub-problems, advancing hypotheses, and testing these hypotheses represent the means to find an answer to the research question in a manageable way, and so contributing to the solving of the problem.

4.1 Human-automation interaction

Hypothesis 1: *Automation and information systems that focus, incorporate, and assist humans will lead to the development and implementation of better manufacturing enterprise information systems.*

Automation, defined as the technology concerned with the application of mechanical, electrical, and computer-based systems, aimed to reduce the amount of manual and clerical effort in production [31].

However, situations in which manual labour was usually preferred over automation have been included customised products with short life cycle, and tasks too technological to automate.

Therefore, it was considered essential to understand the fundamental philosophies of the improvement journey [32], and apply a number of automation principles and strategies to find ways to avoid, or at least to mitigate, the spiralling complexity, and therefore making humans and automata real partners with shared goals and a mutual understanding of each other's capabilities and limitations [33].

In this context, the Understand, Simplify, Automate (USA) principle was considered so general that nearly any automation project could apply it [31] because, understanding the details of the existing business process may in fact reveal that simplifying the process is sufficient and automation is not necessary.

Consequently, human-automation interaction has entailed a great deal of new important research [10]. Automated production machinery and systems have improved productivity and increased manufacturing accuracy, but many times the anticipated increase in flexibility and adaptability did not materialise [11]. As a result, direct relationships have been noticed among requirements of the new manufacturing paradigms, computerised automation systems, and people who should use these systems.

In this context, new concepts and computational approaches suggested to consider how people learn and use their past experience [12] and so, determine how people, machines, and information technology can work together beneficially [13] and collectively at various stages of the product development [14].

Also, as co-operation was the philosophy behind agile manufacturing strategy [15], the sub-systems developed at every level of the organisation should be capable of learning, adapting, optimising, reconfiguring [16], and should demonstrate their collective intelligence by following simple rules that could create a new system which is robust, easily computable, adaptable, and probably more intelligent than the sum of its parts [17].

In addition, the new automation and information systems solutions should be viewed as vehicles to assist in achieving various manufacturing goals rather than to replace humans [18] which, irrespective of the degree of automation and computerization, should be the focus, and explicitly incorporated as components at the system design stage [19].

Therefore, to have a realistic approach, the new manufacturing enterprise information systems should:

- focus and incorporate humans as an explicit component at the system design stage,
- follow simple rules such as how people learn, and
- view automation and information systems solutions as vehicles to assist in achieving various manufacturing goals rather than to replace humans.

The above conclusions to the gathered data satisfactorily tested Hypothesis 1 and proved it as true.

Therefore, automation and information systems that focus, incorporate, and assist humans will lead to the development and implementation of better manufacturing enterprise information systems.

4.2 Humans and complexity

Hypothesis 2: *Information systems that use the wisdom of simplicity in order to control complexity and incorporate and assist humans will lead to the development and implementation of better manufacturing enterprise information systems.*

Complex systems is a new field of science studying how parts of a system give rise to the collective behaviours of the system, and how the system interacts with its environment. Problems that are difficult to solve are often hard to understand because the causes and effects are not obviously related. This has become more and more apparent in the efforts to solve societal problems or avoid ecological disasters caused by our own actions. The field of complex systems cuts across all traditional disciplines of science, as well as engineering, management, and medicine, and is considered as the ultimate of interdisciplinary fields [26]. Breaking down the barriers between disciplines, complex systems also provides a scientific framework for understanding complex engineering projects.

People, the economy's most important asset [13], usually and fundamentally used only a few simple tools to create, understand, or manage complex systems in real life [20]. With all these, because the actual professional fields were considered complex and no one could learn about them rapidly [20], people pursued system features and performance and, in this way, pushed the technology envelope and stretched the limits of their own understanding [21]. Sometimes, even when there was no solution to the problem as formally stated [22], people attempted to develop complex systems, usually a consequence of unnecessary requirements [23], due to the belief that complex systems require complex control systems to manage them [17].

Therefore, new concepts suggested the use of wisdom of simplicity in order to control complexity [17] [20] [21], separate critical requirements from desirable properties [21], find solutions by relaxing some constraints [22], and replace the problem of global optimality in favour of the more realistic goals that decompose the complex problem into smaller more manageable sub-problems [24][25].

In addition, with complexity, considered a notion of inherent difficulty of a problem, a solution, or an approach [23], and with no single formalism, technique, or tool capable of generating useful decisions in a modern enterprise [19], unless the human factor is included, the representation of any collaborative systems will be unrealistic and not useful for manufacturing [13]. Therefore, the human planner should be considered still irreplaceable [27] and a critical component [13].

Therefore, to have a realistic approach, the new manufacturing enterprise information systems should:

- decompose complex problems into smaller more manageable sub-problems,
- separate critical requirements from desirable properties,
- simplify information complexity by aligning the need for information and the new trends in the IT, and
- keep the human in the system's loop.

The above conclusions to the gathered data satisfactorily tested Hypothesis 2 and proved it as true.

Therefore, information systems that use the wisdom of simplicity in order to control complexity and incorporate and assist humans will lead to the development and implementation of better manufacturing enterprise information systems.

4.3 Case study

In manufacturing automation, which must not be associated only with the individual production machines, wider issues should be considered such as product design, Computer Aided Process Planning (CAPP), production control, and education and training.

In this context, manufacturing process planning was defined as the transformation of detailed engineering drawing specifications into manufacturing operating instructions for an overall effective production [35], or a technical activity that establishes the process and resources that transforms the raw material into the desired final part in a cost effective manner [34] [36].

However, process planning, documented into planning sheets or route plans, required many kinds of human abilities [37] with a scientific, engineering, and economics background [38] manifested within a company's limitations factors such as product configuration, available processes and equipment, prevalent culture, organisational structure, and technological systems [39][40].

Therefore, in conditions of process planners shortage [41], CAPP, the umbrella term for process planning automated approaches [42], has evolved and diversified to simplify and improve process planning and to achieve more effective use of manufacturing resources [11] (Figure 3, where acronyms indicate 'M' for Machining, 'GT' for Group Technology, 'QA' for Quality Assurance, and 'CE' for Concurrent Engineering).

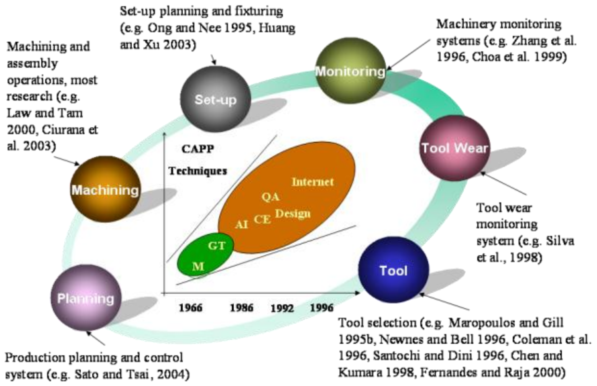

Figure 3. CAPP evolution and diversification.

As a result, CAPP research, an extremely varied subject area [43] that spans over several other scientific and technological domains [44], has generated great interest and quite a lot controversy with its various approaches, implementation techniques, knowledge acquisition and representations, and attempts to identify the data that links design, CAPP, and manufacturing.

CAPP used AI as a major technique because process planning activities was believed highly knowledge intensive, complex, and dynamic in nature [45], and because process-planning was predominantly an open-ended problem that accepted multiple solutions based on the preferences, experience and domain knowledge of the planner [46].

Various AI techniques applied in CAPP included the knowledge-based systems (KBS) [27] [47] [48], case-based reasoning (CBR) system [49] [50] [51], neural networks (NNs) [52] [53], Petri nets [54], fussy logic [55], Genetic Algorithms (GA) [56] [57], or hybrid systems [34] [58] [45].

There was no doubt that the introduction of AI techniques has boosted both the interest in the problem and the capability of the CAPP systems, but its benefits were considered disputable. Research carried out in the last twenty years showed that the classical techniques of developing expert systems did not created a complete CAPP expert system [27], few expert systems had significant impact on manufacturing industries [45], Genetic Algorithms (GA) were far from having an impact in practice [59], and it was unusual to see reports about successful general CAPP solutions based on AI [34], therefore AI results were far from desirable [60].

Furthermore, from an AI standpoint, manufacturing was seen as a rich, research driver, application area, and too often work has proceeded without good understanding of the actual manufacturing problems and so with only marginal practical gain. From the manufacturing side, there was general recognition that AI has had important contributions to make, but there was limited understanding of AI technologies and their relevance [61]

Therefore, the long development and implementation time required to build the knowledge base of a CAPP systems could be avoided by considering a lower degree of CAPP automation in the early stages [34], and increase the level of its automation by following the organisational improvements in the company.

Consequently, this case study highlights how SACAPP (South African CAPP) system developed at the University of the Witwatersrand, Johannesburg, approached the topics discussed in the present paper. More details of this development could be found in [28] [29] [30].

For example, for an actor, which is anyone or anything that interacts with the new system, SACAPP considers that it will be a mistake to make an assumption that the actor is a superman or a super-system, and so can cover lots of bases.

Consequently, considering a use-case a piece of functionality in the system that gives the user a result of value, an actor that participates in a coherent set of use cases to accomplish an overall purpose will require the design of system's interfaces based on the actors' different roles, skills, knowledge, and comprehension levels (Figure 4).

Based on these, Figure 5 defines SACAPP's general architecture and functionality using the Unified Modelling Language (UML) showing the dependencies between architectural layers that flow from the user interface layer to the business logic, to the database communications layer, and to the database itself.

Furthermore, at high level, SACAPP is considered an extension not only of the CAD system, but also of the Management, Sales, and Quotation systems (Figures 6), so being aligned with the activities in an existing industrial company.

For example, SACAPP considered machines' shop floor status, apply manufacturing planning pull concept, and developed assistance capable of learning, adapting, and optimising at every level of the organisation (Figure 7 – where SAS means South African Sales module, SAM means South African Management module, and SADwO means South African Design with Objects module).

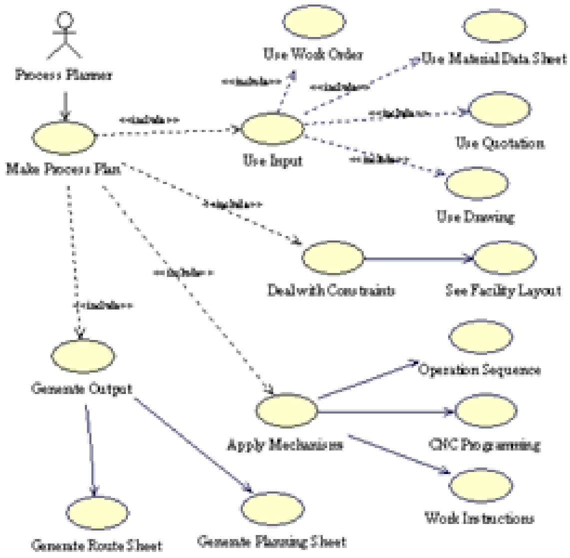

Figure 4. SACAPP actor and its interfaces..

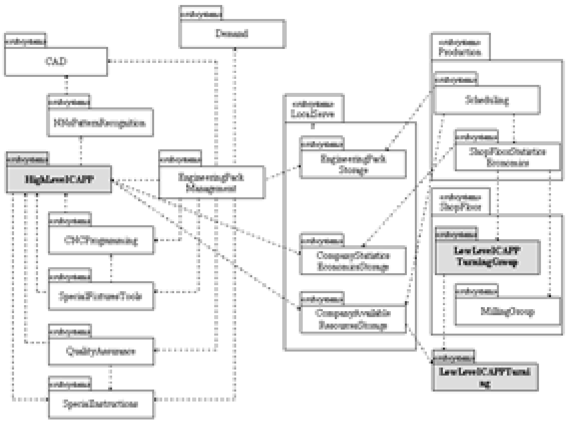

Figure 5. SACAPP architecture with UML.

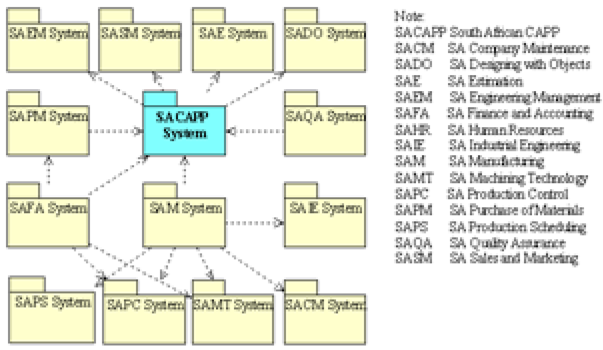

Figure 6. SACAPP, a system of systems.

At company level, SACAPP identified company's entities and activities, used distributed and more decentralised process planning systems, applied the closed loop principle of information at as many levels was possible, and considered the most logical and practical ways to achieve the requirements.

At complexity level, SACAPP decomposed the complex problem into smaller, realistic, and more manageable sub-problems, followed simple rules to create a system which is robust, easily computable, understandable, adaptable, and more intelligent than the sum of its parts, and replaced global optimality in favour of the more realistic goals thereby achieving integration.

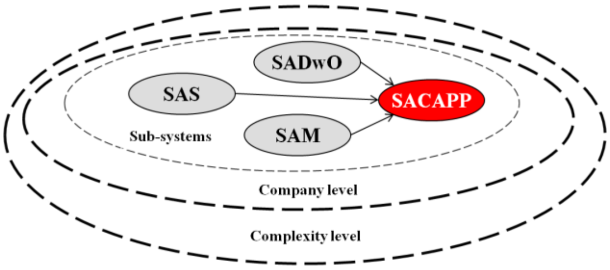

Figure 7. Decomposition of the CAPP complex problems into smaller, more manageable sub-problems.

Also, SACAPP considered the user's need of information as the manufacturing task progresses (Figure 8). In this context, people, machines, and IT were designed to work together beneficially and collectively at various stages of the product development, and the human was provided with means for interacting with the systems for learning, planning, and manufacturing.

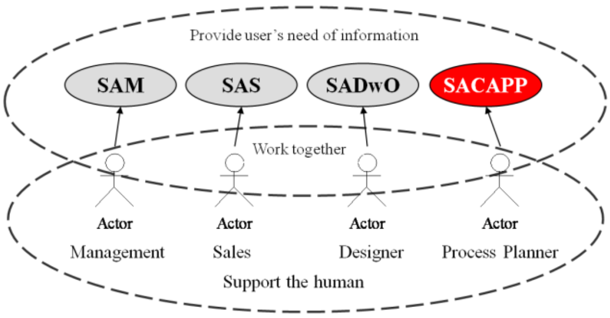

Figure 8. Human interacts with the systems for learning, planning, and manufacturing.

Finally, the information complexity was simplified by dividing the information according to manufacturing processes that received only the amount of information needed to suit business practice and support the vital business processes (Figure 9).

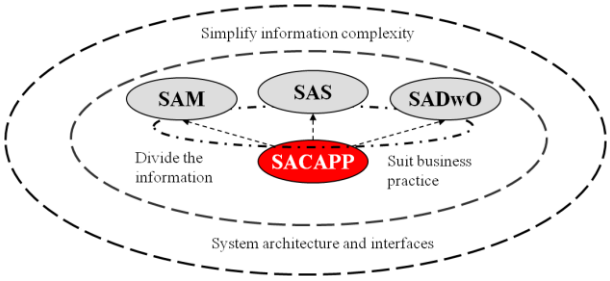

Figure 9. Simplify information complexity.

5 Conclusion and Implications

This paper showed that it is both theoretically and practically possible to find solutions to the problems concerning manufacturing enterprise information integration. Also, it challenged the traditional engineering approaches, and so drew the attention to the need for new approaches.

Based on the paper's qualitative findings, the research problem of how people, automation, and complexity can be effectively and successfully integrated into a manufacturing enterprise information system can now receive a concise answer.

Essentially, it is argued that automation and information systems should focus, incorporate, and assist the humans, and that the use the wisdom of simplicity in order to control complexity should prevail against the attempt to develop complex systems that usually are a consequence of unnecessary requirements.

Also, the case study indicated that when dealing with automation systems, wider issues should be considered that focus on people and systems that would maximise peoples' capabilities, opportunities, and participation.

Therefore, in conditions in which one normally associates 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. To reach such objectives, it was essential to understand the fundamental philosophies of the improvement journey, and employ automation principles and strategies such as the USA principle.

Also, because no single formalism, technique, or tool generated useful decisions in a modern enterprise, the case study considered that the human planner was still irreplaceable and a critical component, and so, SACAPP software solution was viewed as a vehicle to assist in achieving various manufacturing goals, rather than to replace humans.

Finally, it could be concluded that manufacturing enterprise information integration system development should be a multi-perspective activity focused on a variety of interdisciplinary research areas. Their architecture should be considered a framework for problem solving, and so be aligned with the business practices and the ways in which the companies are run, that finally leads to a system of systems which is architectural-centric, process-centric, human-centric, and in line with the IT infrastructure trends.

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