Association for Information Systems
AIS Electronic Library (AISeL)

ECIS 2002 Proceedings

European Conference on Information Systems (ECIS)

2002

Perceived Ontological Weaknesses of Process Modeling Techniques: Further Evidence

Peter F. Green
The University of Queensland, p.green@mailbox.uq.edu.au

Michael Rosemann
Queensland University of Technology, m.rosemann@qut.edu.au

PERCEIVED ONTOLOGICAL WEAKNESSES OF PROCESS MODELING TECHNIQUES: FURTHER EVIDENCE

Peter F. Green

School of Commerce, The University of Queensland, Ipswich Australia
Phone: 61 7 3381 1029 Fax: 61 7 3381 1227
p.green@mailbox.uq.edu.au

Michael Rosemann

School of Information Systems, Queensland University of Technology, Brisbane Australia
Phone: 61 7 3864 9473 Fax: 61 7 3864 9390
m.rosemann@qut.edu.au

ABSTRACT

The Architecture of Integrated Information Systems (ARIS) is a popular framework for integrated process modeling. Previous research analysed ARIS using an ontology developed by Bunge, Wand and Weber. The results of this study have been summarized in six propositions. This paper reports on insights gained from an empirical study testing these evaluative propositions. The study is conducted with post-graduate students as well as with experienced users of ARIS. Even when considering all five views of ARIS, modelers have problems representing business rules and the scope and boundary of systems. Surprisingly, even though it is completely ontologically redundant, users still find the function view useful in modeling.

1. RESEARCH OBJECTIVES

Over the last decade, process management has received increased attention within the business administration and information systems communities. This attention derives from the fact that managing processes is critical to achieving benefits from Total Quality Management, Activity-based Costing, or Business Process Re-engineering (Hammer 1990; Davenport 1993). Accordingly, integrated process modeling as a means of documenting, analyzing, and evaluating processes has also risen to prominence in organizations. One of the most popular approaches for process modeling is ARIS (Architecture of Integrated Information Systems), which has been developed by Scheer (1999). Scheer's ARIS framework was selected for this research as the example for a number of reasons. First, it integrates five views of the enterprise (data, function, organization, output, and process) to provide the user with a comprehensive modeling framework. The core of ARIS is the Event-driven Process Chain methodology, which is used to describe business processes. Second, its implementation through the ARIS Collaborative Business Suite claims in excess of 26,000 licenses worldwide. Accordingly, there appears to be a large, mature user base against which analytical propositions can be tested. Finally, ARIS underlies the reference models provided in one of the world's most popular ERP solution (SAP R/3).

Previous research analysed the completeness and clarity of ARIS based on an ontology developed by Bunge, Wand and Weber, the so-called BWW-model (Green and Rosemann, 2000). This paper is motivated by the desire to develop and test the propositions generated by Green and Rosemann (2000). From the results, we can begin providing some insights into the usefulness of the ontological evaluation for process modelers using ARIS. This paper presents the results of empirical studies with experienced ARIS users from two companies and post-graduate information systems students studying process modeling.

The paper unfolds in the following way. First, further background is provided on ontologies and how the ontological evaluation was performed. Next, Green and Rosemann's (2000) propositions are briefly summarized. Then, the research methodology used in this work is explained. Following that explanation, the results of this study are presented and discussed. Finally, it will be explained how this work will progress in the future.

2. THEORETICAL FOUNDATION

Wand and Weber (1989a, 1989b, 1990a, 1990b, 1993, 1995) have investigated the branch of philosophy known as ontology as a foundation for understanding the process in developing an information system. Ontology is a well-established theoretical domain within philosophy dealing with models of reality. Wand and Weber (1989b, 1990a, 1990b, 1993, 1995) and Weber (1997) have extended an ontology presented by Bunge (1977) and applied it to the modeling of information systems. Their fundamental premise is that any modeling grammar (Information Systems Analysis and Design - ISAD) must be able to represent all things in the real world that might be of interest to users of information systems; otherwise, the resultant model is incomplete. If the model is incomplete, the analyst/designer will somehow have to augment the model(s) to ensure that the final computerized information system adequately reflects that portion of the real world it is intended to support. This work focuses on the representation model, which defines a set of constructs that are thought to be necessary and sufficient to describe the structure and behavior of the real world.

Weber (1997) clarifies two major situations that may occur when an ISAD grammar is analyzed. Predictions on the modeling strengths and weaknesses of the grammar can be made according to whether some or any of these situations arise out of the analysis.

1. *Ontological Incompleteness* exists unless there is at least one ISAD grammatical construct for each ontological construct.

2. *Ontological Clarity* is determined by the extent to which the grammar does not exhibit one or more of the following deficiencies:

- *Construct Overload* exists in an ISAD grammar if one ISAD grammatical construct represents more than one ontological construct.
- *Construct Redundancy* exists if more than one ISAD grammatical construct represents the same ontological construct.
- *Construct Excess* exists in an ISAD grammar when a grammatical construct is present that does not map into any ontological construct.

3. PREVIOUS ONTOLOGICAL ANALYSIS

Green and Rosemann (2000) analysed in detail the completeness and clarity of ARIS using the constructs of the BWW representation model (Green and Rosemann 2000). For a detailed description of the all the constructs in the representation model, see Weber (1997). They derived, examining only the process view, the following propositions:

1. Because there are no direct representations for *thing, class*, and/or *kind*, users will lack conceptual clarity regarding the object(s) in the real world to which the process model in ARIS relates. A process model in ARIS can represent indirectly attributes of the thing as attributes of the function type but not the thing itself. Accordingly, some other symbol will be needed in conjunction with the process view to overcome this ontological deficiency.
2. Because the process view does not have representations for *conceivable state space*, *lawful state space*, *conceivable event space*, and *lawful event space*, a sufficient focus to identify all important state and transformation laws may not be present during modeling. These laws are the basis of what are known in systems analysis as business rules. Accordingly, problems may be encountered in capturing all the important business rules of the situation. Again, some other symbol may be employed in combination with the process view to overcome this deficiency.
3. Because the process view does not have representations for *system, system composition, system environment, system structure, system decomposition*, and *coupling*, the process view's usefulness for defining the scope and boundaries of the system being analyzed is undermined. For the modeler using the process view, questions arise as to how to structure and factor the complexity of large projects into constituent models. Again, the use of some other symbol seems necessary to overcome this deficiency.

When the analysis of all five ARIS views combined is considered, interesting propositions issue.

4. Even across the five views, no representations exist for *conceivable state space, lawful state space, conceivable event space*, or *lawful event space*. Again, a sufficient focus to identify all important state and transformation laws may not be present during modeling. Thus, problems may be encountered in capturing all the potentially important business rules of the situation. For example, in ARIS, it is not clear how to specify which organizational units are responsible for a function under certain conditions without having to split the function type.
5. Across the five views, no representations exist for *system, system environment, system structure,* and *system decomposition.* Again, its usefulness for defining the scope and boundaries of the system being analyzed is undermined and the usefulness of integrated process modeling for undertaking "good decompositions" would seem questionable. For example, there is no requirement in ARIS to perform corresponding decompositions between the interrelated process view and data view of a model.
6. Because the function view is ontologically redundant when compared to the combination of process view, data view, and either organizational view or output view, its use with the other views will undermine clarity and may cause confusion to users. For example, it is not clear whether function types should be entered in the function view or in the process view first. This situation can lead to inconsistency, if a tool with an integrated repository is not available. Limited usefulness and use of the function view is expected.

4. RESEARCH METHODOLOGY

We created a questionnaire to gather data on the propositions outlined above. In the first instance in 2000, we conducted a limited empirical study by administering this instrument to students from a postgraduate subject (Green and Rosemann 2001). In this way, we achieved two goals. First, we could pilot test the raw instrument with a group of respondents. Second, we could gather some initial data on which we could gain some insight into our propositions. Based on the results of this initial testing, we made a reasoned decision as to the usefulness of persisting with further, more comprehensive testing. We also modified the questionnaire based on the feedback we gathered. In the first semester 2001, we conducted a second survey with post-graduate students (- the results are reported in this paper). Moreover, we also used the refined instrument to form the basis of a structured interview protocol that we administered to four practitioners working in the process modeling area using ARIS in two large organizations. By employing more than one method to obtain data, we were able to mitigate the effects of method bias, obtain richer feedback on the items of interest through the opportunities in the interviews for the participants to expand their reasoning, provide a cross-check between the results obtained in the interviews and those obtained through the questionnaires, and obtain further feedback on the understandability of the survey instrument. In the longer term, we intend to administer our refined instrument to a significant sample of process modeling practitioners and academics both in Australia and internationally.

4.1. Design of the Questionnaire

The original questionnaire consisted of 11 pages and was divided in three sections – A, B, and C. The purpose of section A was to collect information about the background of the respondents. This information included such items as years of general work experience, years of process modeling experience, years of experience with the ARIS, and the general purpose of the activities for which the integrated process modeling tool was used - documentation of organizational or IT processes. As an example of a modification within our questionnaire, we also asked for a more detailed response regarding the purposes of process modeling. The list of possible answers included documentation of the organization, redesign of the organization, support continuous process management, certification, benchmarking of processes, knowledge management, selection of ERP software, specification of software requirements, workflow management, process simulation, process calculation and others. Section B was constructed to gather data about the specific propositions. Moreover, it focused on how respondents working individually used process models in the ARIS. Section C by contrast asked for feedback regarding the use of integrated process modeling techniques when using ARIS as a member in project teams.

Because there was no well-accepted, validated instrument known to the researchers for gathering data on such propositions, a new, raw instrument had to be created. Green (1996) developed and validated a similar instrument for gathering data on ontologically-based hypotheses involving the use of ISAD grammars in combination by analysts/designers when using structured upper CASE tools. This validated instrument was used as the initial basis for the formulation of the instrument for this study.

The refined questionnaire maintained the same structure as its predecessor. Because of the re-sequencing required and the clarification of the wording, the instrument now extends over 14 pages (A copy of the complete instrument can be obtained from the authors on request). The structured interview protocol was based completely on the refined survey instrument. The major difference was that an opportunity was provided for the participant to expand on the reasoning for their answers to each question and/or for them to explain any ambiguity they found in the question wording. The structured interviews were administered by the researchers and they were taped (A copy of the transcripts of the interviews is available from the authors on request).

4.2. The Participants

The participants of the pilot survey were identified because of their enrolment in an advanced post-graduate subject dealing with ARIS at an Australian university in early 2001. Twelve post-graduate students were identified. These students had significant prior training in the purposes of process modeling and the ARIS framework. The students had designed sizable "as-is" and "to-be" process models for selected real-world cases (Rosemann et al. 2000). For example, organized in two teams of six students each, over a period of 13 weeks, they analyzed two processes at a Queensland Government department - Travel Management and Asset Management. The students used ARIS-Toolset 5.01 for the design of the "as-is" and "to-be" models. All process models were presented to the contact people from the government department, to consultants from PricewaterhouseCoopers, and to representatives from SAP Australia.

Students (or "novices") were considered to be appropriate subjects for this refined testing. In the words of Vessey and Conger (1994), students might actually be more appropriate subjects when comparing/evaluating analysis techniques for two reasons:

> "*First,…it is easier to teach them (novices) to apply a specific methodology than it is to teach new methods to people who may already be experts in developing systems…Second, examining expert problem solving can be quite difficult, since experts automate their processes to the point at which they are no longer able to articulate what they are doing.*"

Furthermore, we followed the main guidelines of Rein (1994) regarding the use of students as substitutes for business teams. The selected task was a real project for the student and it accounted for a significant portion of each student's grade. Moreover, we had the results of the interviews with practitioners to cross-reference against those achieved from the "novices".

To extend this research into a multi-method scheme, we approached real users of process modeling (using ARIS) in Australia and New Zealand to participate in structured interviews based on the pilot survey instrument. Because we were concerned to find users who had real experience in using process modeling, we were limited to four interviewees. The multi-method approach however provided us with richer responses and it allowed us to cross-validate the findings in the limited empirical survey.

5. RESULTS

The questionnaire was distributed in the middle of the semester (April 2001). Nine of the 12 students present at the seminar returned the questionnaire, giving a response rate of 75 percent.

All participating students were post-graduate students with significant work experience. Fifty-five percent of the students had more than 5 years experience. Most of the students were involved in process modeling for less than one year. However, 33 percent had more than one year of modeling experience. Similarly, most students had less than one year's experience with the conceptual ARIS framework as well as with the corresponding ARIS-Toolset. Nearly all students (88 percent) identified the redesign of organizational processes as their main modeling purpose. One student saw his objectives rather in the redesign of IT processes. Similarly, the documentation and redesign of organizational processes were the dominant purposes for process modeling. Further important purposes were benchmarking and workflow management (44 percent each) as well as ERP configuration and continuous process management (33 percent each).

Table 1 provides a summary of background information on the four structured interviewees.

Item	Percentage Response
Working in business:	
< 2 years	0
2-5 years	0
5-15 years	25
> 15 years	75
Involved in process modeling:	
< 1 year	0
1-2 years	50
2-5 years	0
> 5 years	50

Used ARIS-Toolset:	
< 1 year	50
1-3 years	50
Most recent version of ARIS-Toolset used:	
ARIS-Toolset 5	100
Primary purpose of process modeling:	
Organizational processes	100
IT processes	25
Specific purpose of process modeling:	
Documentation of the organization	50
Redesign of the organization	50
Workflow management	50
Configuration of ERP software	50
Continuous process management	25
Requirements engineering for software development	50
My organization:	
Public sector	100
Private sector	0

Table 1. Summary of Interviewees' Background.

Forty-four percent (four of the nine) of the survey participants answered that they only used one view - the process view - to design business processes with the ARIS-Toolset. These respondents all indicated that the process view included a sufficient set of symbols to represent all the concepts they needed. All four respondents pointed out that using only one view minimizes the amount of maintenance for the models and helps to avoid inconsistencies between models of different views. Only one of the four (25 percent) indicated that he/she created new symbols within the one view to enhance the modeling capabilities. Thus, this group of process models seemed to be rather satisfied with the functionality of the process view in ARIS. Those who used more than one view (55 percent) always started with the process view. The models were usually completed with models derived from the organizational view. This combination of views - the process view and the organizational view - was used also by 75 percent of the interviewees. Indeed, 100 percent of the interviewees found the need to use more than one view only. Asked which models they are likely to use for their future modeling, respondents selected all remaining three views (data, function and output). This was the case for the interviewees as well.

Overall, 66 % of all survey respondents wanted to model directly real-world objects or things when modeling processes. Of the five respondents who used more than one view for their modeling, three students saw a need to model real-world objects ("things"). The answers to how they actually modelled things varied significantly. They used either free-form text (two answers), used an existing symbol provided in the process view only and changed its meaning (one answer) or created a new symbol within the process view (two answers). Asked what other view besides the process view they would consider to use for the depiction of real-world objects, they selected the data (two answers) and the organizational view (two answers). In the context of the process view only, three of in total four respondents saw a need to model things. However, they all answered that they cannot model directly real-world objects or things using the symbols provided in the process view and any of the four other views. Seventy-five percent of the interviewees also saw a need to model real-world objects directly. Seventy-five percent of the interviewees use an existing symbol and change its meaning for this purpose. Furthermore, seventy-five percent also felt that there were no symbols in the process or any of the other four views to enable direct modeling of real-world objects.

Fifty-five percent (five of the nine) of the survey respondents saw limitations in incorporating all the different business rules of the situation being modelled, if only the process view can be used. They solved this problem in very different ways. They modelled dedicated additional processes capturing the business rules, used existing symbols provided in the process view, changed the meaning of existing symbols within the process view, used free form text, created a new symbol, or stated that they cannot model directly all the different types of business rules (two answers). Only two answers indicated that the data view (one answer) or the organizational view (one answer) might be relevant from the other views to depict business rules. Thus, an interest in modeling business rules within the process view exists, but there is no dominating solution used. Only one of the four interviewees spoke of limitations in representing all the different types of business rules required. It is interesting to note that this was the same person who reported modeling low level or IT processes as opposed to enterprise or high-level organizational processes.

Four of the nine survey respondents wanted to represent directly the scope and boundary of the system, when doing process modeling with the process view only. Again, the answers regarding how to model the system's scope and boundary varied significantly. Their responses included that existing symbols in the process view can be used, that they added free form text, that a redefinition of existing symbols in the process view is sufficient ad that they inserted new symbols. Asked whether symbols from other views might be helpful to defining the scope and boundary of a system, three responses suggested the use of symbols from the data and the organizational view. Three of the four interviewees saw the need to be able to model the scope and boundary of the system. However, one of the three felt that existing symbols were sufficient, one felt that there was no symbol in the process or any of the other views that enabled this representation, while the third person used a completely separate tool - VISIO - to overcome the deficiency in ARIS.

Eighty-eight percent of the survey respondents (eight of nine) agreed that a decomposition of models into more detailed models is required. All five students who are using more than one view, where interested in this decomposition. Seven of these eight answers indicated that they do no have any problem identifying the parent model from which the decomposed model was derived. Those participants, who modelled in more than one view also all stated that they do not have any problems decomposing interrelated models of different views into constituent, more detailed, component models. These results were supported in the main by the interviewees and their responses.

All five multi-view survey respondents perceived the function view as useful. In addition, also two of the participants, who only work within the process view thought that the function view is useful. The two students, who do not perceive the function view as useful stated that they do not know how and when to use the function view. Three of the four interviewees found the function view to be useful in modeling. Again, the one participant who did not find it useful was the one who was principally involved in modeling low level, IT processes. More usefully, discussion from two of the participants indicated that the function view for useful to them more in their role of reviewing processes to see how they could be fine tuned. Focusing on the function view of the event-driven process chains allowed them to reduce the complexity of the diagrams and it assisted them in quickly understanding and reviewing the processes.

All survey respondents (nine out of nine) responded that they were working in a project team while doing process modeling. Only thirty-three percent of the respondents indicated that they share the models developed using different views. All these answers stated that the process, data, functional and organizational view were used.

6. DISCUSSION OF RESULTS

In the light of the derived propositions, this study gives some initial valuable feedback. Green and Rosemann (2000) proposed that the ontological weakness of a missing symbol for *things*, *class* or *kind* leads to a lack of clarity, if real-world objects are supposed to be modeled. However, only one of three multi-view respondents saw a need at all to model real-world objects. Thus, this situation could be a case in which a theoretically derived ontological weakness is of only minor consequence for practical use. This implication would appear to be contradicted by the interviews with three of the four participants recognising the need to directly model real-world objects. It was predicted that, because of the fact that the process view does not have representations for *conceivable state space*, *lawful state space*, *conceivable event space*, and *lawful event space*, a sufficient capability to identify and model all relevant business rules might not be given in ARIS. This proposition was supported by 66 % of the multi-view respondents. More importantly, even when all five views of ARIS were taken into account, respondents still maintained they could not model all necessary business rules. Hence, this situation could possibly be a weakness of ARIS. This implication was supported only by one of the views of the interviewees. Again, this was the person who was involved in low level modeling tasks.

It was proposed that, because of the missing representations for *system, system composition, system environment, system structure, system decomposition*, and *coupling*, the process view's usefulness for defining the scope and boundaries of a system is undermined. Moreover, the usefulness of the process view for undertaking "good decompositions" during analysis is degraded. The fact that all multi-view respondents stressed the importance of defining precisely the scope and boundaries of a system and the opportunity to further decompose a model indicates that ARIS does not support this capability sufficiently. The strategies suggested by the respondents to overcome this problem vary significantly and further investigations are necessary. This outcome was strongly supported by the views of the interviewees. Finally, Green and Rosemann (2000) proposed that the function view is completely ontologically redundant when compared to the combination of process view, data view, and either organizational view or output view. Surprisingly, all three multi-view respondents saw the function view as far from useless. As the functions of the function view are also described in the context of the business processes in the process view, the function view does not seem to add value. One possible explanation for the contrary response received here could be that the user of ARIS appreciates redundancy as a mechanism to handle complexity in modeling. Moreover, insight gained from the interviews on this issue would indicate that, for people reviewing processes particularly, the function view allows them to reduce complexity so that they can quickly gain an understanding of the processes and fine tune them accordingly. So, the *role* of the person involved in the modeling process needs to be considered when evaluating the ontological completeness requirements of the tool (see Rosemann and Green 2000). Table 2 summarizes the insights gained on the propositions.

PROPOSITION	INSIGHT
Process view only:	
P1 – another symbol/view for thing, class/kind	Little support
P2 – another symbol/view for business rules	Supported
P3 – another symbol/view for scope and boundary of system, and to assist in decompositions	Supported
More than one view in combination:	
P4 – another symbol/view for business rules	Supported
P5 – another symbol/view for scope and boundary of system, and to assist in decompositions	Supported
P6 – function view is of limited use	Unsupported – perhaps ontological redundancy helps manage complexity

Table 2. Summary of Results.

7. LIMITATIONS, SUMMARY, AND FUTURE WORK

This study gives some further valuable feedback regarding the Green and Rosemann (2000) propositions. Nevertheless, the selection number of post-graduate students, their modest experience in ARIS and the number of interviews conducted (four) make it obvious that any inferences from this study are necessarily limited. Accordingly, further investigations with professional (practitioner and academic) ARIS users are indispensable.

Furthermore, the feedback from the responses indicates that,

- the need to model real-world objects was not generally perceived. Where the need was perceived, it was accomplished by using an existing symbol and changing its meaning.
- It was generally perceived that within the process view, and even when other views were added to the process view, severe limitations existed in the modeling of all necessary business rules.
- There is a strong perceived need to represent the scope and boundary of a system, and to be able to decompose the system when using integrated process modeling. Within the process view, and across the five views in combination, the respondents either could not model the scope and boundary of a system, or they used existing symbols and changed their meaning to meet their purposes.
- The proposition that, because the function view is completely ontologically redundant when compared to the combination of process, data, and either organizational or output views, the function is of limited use is generally unsupported.

In further work, we will administer the questionnaire to users of ARIS world-wide. This expanded, more experienced sample will provide sufficient data to dramatically improve the inferences that may be made about the propositions and the generalization of the results.

REFERENCES

Bunge, M. (1977) *Treatise on Basic Philosophy: Volume 3: Ontology I: The Furniture of the World.* Reidel, Boston.

Davenport, T. H. (1993) *Process Innovation. Reengineering Work through Information Technology.* Boston.

Green, P. (1996) *An Ontological Analysis of ISAD Grammars in Upper CASE Tools*, Unpublished PhD Thesis, University of Queensland, Brisbane.

Green, P. (1997) Use of Information Systems Analysis and Design (ISAD) Grammars in Combination in Upper CASE Tools – An Ontological Evaluation. In *Proceedings of the 2nd CAiSE/IFIP8.1 International Workshop on the Evaluation of Modeling Methods in Systems Analysis and Design.* Barcelona, 1-12.

Green P. and Rosemann M. (2000) Integrated Process Modeling: An Ontological Evaluation, *Information Systems*, 25(2), 73-87.

Green P. and Rosemann M. (2001) Ontological Analysis of Integrated Process Models: Testing Hypotheses, *Australian Journal of Information Systems*, 9(1), 30-38.

Hammer, M. (1990) Reengineering Work: Don't Automate, Obliterate, *Harvard Business Review,* 68(7-8), 104-112.

Rein, G. L. (1994) A Prolegomena on the Use of Student Subjects in Group Work Research, *Working Paper 775*, State University of New York.

Rosemann, M. and Green, P. (2000) Integrating Multi-Perspective Views into Ontological Analysis. In *Proceedings of the 21st International Conference on Information Systems (ICIS 2000),* eds. W. J. Orlikowski et al., Brisbane.

Rosemann, M., Sedera, W. and Sedera, D. (2000) Industry-oriented Education in Enterprise Systems. In *Proceedings of the 11th Australasian Conference on Information Systems,* eds. G G Gable and M. Vitale. Brisbane.

Scheer, A.-W. (1999) *ARIS – Business Process Frameworks,* 2nd ed., Springer, Berlin.

Vessey, I. and Conger, S. (1994) Requirements Specification: Learning Object, Process, and Data Methodologies, *Communications of the ACM*, 37(5), 102-113.

Wand, Y. and Weber, R. (1989a) A model of control and audit procedure change in evolving data processing systems, *The Accounting Review,* LXIV(1), 87-107.

Wand, Y. and Weber, R. (1989b) An ontological evaluation of systems analysis and design methods. In *Information System Concepts: An In-depth Analysis,* eds. E. D. Falkenberg, P. Lindgreen, North-Holland, 79-107.

Wand, Y. and Weber, R. (1990a) An ontological model of an information system, *IEEE Transactions on Software Engineering,* 16(11), 1281-1291.

Wand, Y. and Weber, R. (1990b) Mario Bunge's Ontology as a formal foundation for information systems concepts, In *Studies on Mario Bunge's Treatise,* eds. P. Weingartner, G. J. W. Dorn, Rodopi. Atlanta, 123-149.

Wand, Y. and Weber, R. (1993) On the ontological expressiveness of information systems analysis and design grammars, *Journal of Information Systems,* 3(4), 217-237.

Wand, Y. and Weber, R. (1995) On the deep structure of information systems, *Information Systems Journal,* 5, 203-223.

Weber, R. (1997) *Ontological Foundations of Information Systems.* Melbourne.