Business Process Management: A Survey

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Abstract. Business Process Management (BPM) includes methods, techniques, and tools to support the design, enactment, management, and analysis of operational business processes. It can be considered as an extension of classical Workflow Management (WFM) systems and approaches. Although the practical relevance of BPM is undisputed, a clear definition of BPM and related acronyms such as BAM, BPA, and STP are missing. Moreover, a clear scientific foundation is missing. In this paper, we try to demystify the acronyms in this domain, describe the state-of-the-art technology, and argue that BPM could benefit from formal methods/languages (cf. Petri nets, process algebras, etc.).

Keywords: Business Process Management, Workflow Management, Formal Methods.

1 Introduction

This volume of Springer Lecture Notes in Computer Science is devoted to the "Conference on Business Process Management: On the Application of Formal Methods to Process-Aware Information Systems" taking place in Eindhoven (The Netherlands) in June 2003. To put the contributions to this conference into perspective, we discuss the ideas, technology, and foundations hidden behind acronyms like WFM, BPM, BAM, BPA, STP, etc. The goal of this paper is to provide an overview of the scientific and practical issues in the context of business process management systems. This way we hope to trigger researchers and practitioners to address the challenges in this domain. The definition of a business process management system used throughout this paper is: *a generic software system that is driven by explicit process designs to enact and manage operational business processes*. The system should be process-aware and generic in the sense that it is possible to modify the processes it supports. The process designs are often graphical and the focus is on structured processes that need to handle many cases.

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To show the relevance of business process management systems, it is interesting to put them in a historical perspective. Consider Figure 1, which shows some of the ongoing trends in information systems [3]. This figure shows that today's information systems consist of a number of layers. The center is formed by the operating system, i.e., the software that makes the hardware work. The second layer consists of generic applications that can be used in a wide range of enterprises. Moreover, these applications are typically used within multiple departments within the same enterprise. Examples of such generic applications are a database management system, a text editor, and a spreadsheet program. The third layer consists of domain specific applications. These applications are only used within specific types of enterprises and departments. Examples are decision support systems for vehicle routing, call center software, and human resource management software. The fourth layer consists of tailor-made applications. These applications are developed for specific organizations.

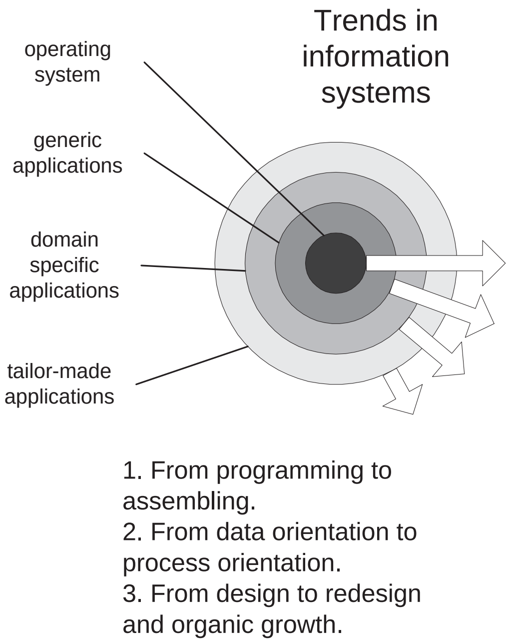

Fig. 1. Trends relevant for business process management [3].

In the sixties the second and third layer were missing. Information systems were built on top of a small operating system with limited functionality. Since no generic nor domain specific software was available, these systems mainly consisted of tailor-made applications. Since then, the second and third layer have developed and the ongoing trend is that the four circles are increasing in size, i.e., they are moving to the outside while absorbing new functionality. Today's operating systems offer much more functionality. Database management systems that reside in the second layer offer functionality which used to be in tailor-made applications. As a result of this trend, the emphasis shifted from programming to assembling of complex software systems. The challenge no longer is the coding of individual modules but orchestrating and gluing together pieces of software from each of the four layers.

Another trend is the shift from data to processes. The seventies and eighties were dominated by data-driven approaches. The focus of information technology was on storing and retrieving information and as a result data modeling was the starting point for building an information system. The modeling of business processes was often neglected and processes had to adapt to information technology. Management trends such as business process reengineering illustrate the increased emphasis on processes. As a result, system engineers are resorting to a more process driven approach.

The last trend we would like to mention is the shift from carefully planned designs to redesign and organic growth. Due to the omnipresence of the Internet and its standards, information systems change on-the-fly. As a result, fewer systems are built from scratch. In many cases existing applications are partly used in the new system. Although component-based software development still has its problems, the goal is clear and it is easy to see that software development has become more dynamic.

The trends shown in Figure 1 provide a historical context for business process management systems. Business process management systems are either separate applications residing in the second layer or are integrated components in the domain specific applications, i.e., the third layer. Notable examples of business process management systems residing in the second layer are workflow management systems [6,19,22,23,24] such as Staffware, MQSeries, and COSA, and case handling systems such as FLOWer. Note that leading enterprise resource planning systems populating the third layer also offer a workflow management module. The workflow engines of SAP, Baan, PeopleSoft, Oracle, and JD Edwards can be considered as integrated business process management systems. The idea to isolate the management of business processes in a separate component is consistent with the three trends identified. Business process management systems can be used to avoid hard-coding the work processes into tailor-made applications and thus support the shift from programming to assembling. Moreover, process orientation, redesign, and organic growth are supported. For example, today's workflow management systems can be used to integrate existing applications and support process change by merely changing the workflow diagram. Isolating the management of business processes in a separate component is also consistent with recent developments in the domain of web services: Web services composition languages such as BPEL4WS, BPML, WSCI, XLANG, and WSFL can be used to glue services defined using WSDL together.

An interesting starting point from a scientific perspective is the early work on office information systems. In the seventies, people like Skip Ellis [13], Anatol Holt [17], and Michael Zisman [28] already worked on so-called office information systems, which were driven by explicit process models. It is interesting to see that the three pioneers in this area independently used Petri-net variants to model office procedures. During the seventies and eighties there was great optimism about the applicability of office information systems. Unfortunately, few applications succeeded. As a result of these experiences, both the application of this technology and research almost stopped for a decade. Consequently, hardly any advances were made in the eighties. In the nineties, there again was a huge interest in these systems. The number of workflow management systems developed in the past decade and the many papers on workflow technology illustrate the revival of office information systems. Today workflow management systems are readily available [22]. However, their application is still limited to specific industries such as banking and insurance. As was indicated by Skip Ellis it is important to learn from these ups and downs [14]. The failures in the eighties can be explained by both technical and conceptual problems. In the eighties, networks were slow or not present at all, there were no suitable graphical interfaces, and proper development software was missing. However, there were also more fundamental problems: a unified way of modeling processes was missing and the systems were too rigid to be used by people in the workplace. Most of the technical problems have been resolved by now. However, the more conceptual problems remain. Good standards for business process modeling are still missing and even today's workflow management systems enforce unnecessary constraints on the process logic (e.g., processes are made more sequential).

2 Business Process Management Demystified

Many people consider Business Process Management (BPM) to be the "next step" after the workflow wave of the nineties. Therefore, we use workflow terminology to define BPM. The Workflow Management Coalition (WfMC) defines workflow as: "The automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules." [22]. A Workflow Management System (WFMS) is defined as: "A system that defines, creates and manages the execution of workflows through the use of software, running on one or more workflow engines, which is able to interpret the process definition, interact with workflow participants and, where required, invoke the use of IT tools and applications." [22]. Note that both definitions emphasize the focus on enactment, i.e., the use of software to support the execution of operational processes. In the last couple of years, many researchers and practitioners started to realize that the traditional focus on enactment is too restrictive. As a result new terms like BPM have been coined. There exist many definitions of BPM but in most cases it clearly includes Workflow Management (WFM). We define BPM as follows: *Supporting business processes using methods, techniques, and software to design, enact, control, and analyze operational processes involving humans, organizations, applications, documents and other sources of information*. Note that this definition restricts BPM to operational processes, i.e., processes at the strategic level or processes that cannot be made explicit are excluded. Note that systems supporting BPM need to be "process aware", i.e., without information about the operational processes at hand little support is possible.

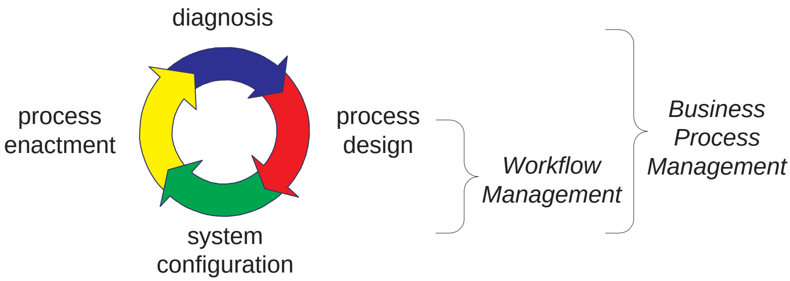

Fig. 2. The BPM lifecyle to compare Workflow Management and Business Process Management.

Figure 2 shows the relationship between WFM and BPM using the BPM lifecyle. The BPM lifecyle describes the various phases in support of operational business processes. In the design phase, the processes are (re)designed. In the configuration phase, designs are implemented by configuring a process aware information system (e.g., a WFMS). After configuration, the enactment phase starts where the operational business processes are executed using the system configured. In the diagnosis phase, the operational processes are analyzed to identify problems and to find things that can be improved. The focus of traditional workflow management (systems) is on the lower half of the BPM lifecyle. As a result there is little support for the diagnosis phase. Moreover, support in the design phase is limited to providing an editor and analysis and real design support are missing. It is remarkable that few WFM systems support simulation, verification, and validation of process designs. It is also remarkable that few systems support the collection and interpretation of real-time data. Note that most WFM systems log data on cases and tasks executed. However, no tools to support any form of diagnosis are offered by the traditional systems.

Currently, many workflow vendors are positioning their systems as BPM systems. Gartner expects the BPM market to grow and also identifies *Business Process Analysis* (BPA) as an important aspect [16]. It is expected that the BPA market will continue to grow. Note that BPA covers aspects neglected by traditional workflow products (e.g., diagnosis, simulation, etc.). *Business Activity Monitoring* (BAM) is one of the emerging areas in BPA. The goal of BAM tools is to use data logged by the information system to diagnose the operational processes. An example is the ARIS Process Performance Manager (PPM) of IDS Scheer [18]. ARIS PPM extracts information from audit trails (i.e., information logged during the execution of cases) and displays this information in a graphical way (e.g., flow times, bottlenecks, utilization, etc.). BAM also includes process mining, i.e., extracting process models from logs [10]. BAM creates a number of scientific and practical challenges (e.g., which processes can be discovered and how much data is needed to provide useful information).

When it comes to redesigning operational processes two trends can be identified: *Straight Through Processing* (STP) and *Case Handling* (CH). STP refers to the complete automation of a business process, i.e., handling cases without human involvement. STP is often only possible if the process is redesigned. Moreover, STP is often only possible for a selected set of cases. The latter means that cases are split into two groups: (1) cases that can be handled automatically (in Dutch these cases are called “Gladde gevallen”) and (2) cases that require human involvement. By separating both groups it is often possible to reduce flow time and cut costs. While STP strives for more automation, CH addresses the problem that many processes are much too variable or too complex to capture in a process diagram [4]. In CH the normal route of a case is modeled but at the same time other routes are allowed if not explicitly excluded. One way to do this is to make workflows data-driven rather than process-driven and allow for authorizations to skip or undo activities. Also the focus is on the case as a whole rather than on individual work-items distributed over work-lists.

To summarize: BPM extends the traditional WFM approach by support for the diagnosis phase (cf. BPA and BAM software) and allowing for new ways to support operational processes (cf. CH and STP). In the remainder, we focus on the scientific foundations and current technology.

3 On the Interplay between Business Process Management and Formal Methods

Business Process Models should have a formal foundation. Well-known reasons (see e.g. [1]) include: 1) formal models do not leave any scope for ambiguity, and 2) formal models increase the potential for analysis (see also e.g. [26]).

It is desirable that a Business Process Model can be understood by the various stakeholders involved in an as straightforward manner as possible. This could e.g. be achieved through the use of graphical representations. At the same time, these stakeholders should assign the same meaning to such a model, there should not be any scope for alternative interpretations. Business Process Models can be quite complex and the use of a formal language for their specification is the only sure way to guarantee that alternative interpretations are ruled out. After consensus among the stakeholders has been reached, a business process model can be deployed and if a formal language was used, its behavior can be explained in terms of the formal semantics of that specification language. As remarked in [21], the lack of a formal semantics has resulted in different interpretations by vendors of even basic control flow constructs, definitions in natural language such as provided by the Workflow Management Coalition are not precise enough.

As always, it is preferable to identify any problems in software before it is actually deployed. In the case of Business Process Models this is especially important as they may involve core business and/or complex business transactions.

To reduce the risk of costly corrections, a thorough analysis of a Business Process Model can be beneficial. Analysis of Business Process Models can also be used to investigate ways of improving processes (e.g. reducing their cost). Formal languages may have associated analysis techniques which can be used for investigating properties of specifications. These techniques can then be relied upon to provide insight into the behavior and characteristics of a Business Process Model specified in such a language.

In [1] three reasons are stated arguing the benefits of the use of Petri nets for the specification of workflows. The reasons brought forward are the fact that Petri nets are formal, have associated analysis techniques, and are state-based rather than event-based. The development of Woflan (see e.g. [25]) demonstrates that workflows specified as workflow nets [2], a subclass of Petri nets, can be analyzed in order to determine whether they are e.g. deadlock free. In the context of UML activity diagrams, tool support for verification is discussed in [15].

Through the notion of place, Petri nets provide natural support for modeling the stages in between processing. State-based patterns such as *deferred choice*, *interleaved paralled routing*, and *milestone* can therefore be specified straightforwardly. A description of these patterns can be found in [9]. Petri nets though also have some deficiencies when it comes to the specification of certain control flow dependencies (see [7]). This observation has led to the development of YAWL [8] (Yet Another Workflow Language) of which the formal semantics is specified as a transition system.

It is interesting to observe that a concept such as the deferred choice, while easily captured in terms of Petri nets, is not often supported in languages of "classical" workflow management systems (see [9]). Two recently proposed standards for web service composition, BPEL4WS and BPML, however, provide direct support for this construct (see [27]) and [5] resp.). In web services composition it is important to capture the interactions between the various services and a formalism such as the π-calculus seems to be a natural candidate to provide a formal foundation for such interactions. While it is sometimes claimed that BPML is based on the π-calculus, there does not seem to be a precise definition of this relation (note that in [12], it is stated that "there is currently no evidence that BPEL4WS is based on a formal semantics"). We believe that it is important that such relations are fully formalized.

Formally defined Business Process Modeling Languages can be compared in terms of their expressive power. For some classes of workflow modeling languages, abstractions of some existing approaches, comparative expressiveness has been studied in [21,20]. These results are in the context of a specific notion of equivalence, addressing the issue of when two workflow models can be considered expressing the same workflow. Expressiveness results give insight into what can and cannot be expressed in some approaches and more research is needed in this area as it could provide more guidance for language development.

4 Available Technology and Emerging Standards

Based on the definition of Business Process Management proposed in Section 2, a characterization of its main concepts is provided, and the technology currently available or on the horizon is discussed. Some of the key aspects of business process management already mentioned in Sections 1 and 2 are re-visited, and the current state of available technology and emerging standards are discussed.

One of the main aspects and certainly an activity typically carried out in early phases of business process management projects is the design of business processes. There is a close relationship between business process design and business process modeling, where the former refers to the overall design process involving multiple steps and the latter refers to the actual representation of the business process in terms of a business process model using a process language. To this end, the term business process modeling is used to characterize the identification and (typically rather informal) specification of the business processes at hand. This phase includes modeling of activities and their causal and temporal relationships as well as specific business rules that process executions have to comply with.

Business process modeling has a decade long tradition, and a variety of products are commercially available to support this phase, based on different process languages. Given this situation, it is not surprising that the selection of a particular product is an important step in many BPM projects, and, consequently, appropriate selection criteria have been studied extensively. Besides organizational, economical, and aspects related to the overall IT infrastructure of the enterprise at hand, the expressive power of the process language as well as interfaces to related software systems are important criteria, most prominently interfaces to process enactment systems (such as workflow management systems) and to software responsible for modeling personnel and organizational structures of the enterprise. Not only the expressive power but also a well-defined semantics of the process language deserves a central role during product selection. However, this aspect is considered only in a small number of recent business process management projects.

Business process analysis aims at investigating properties of business processes that are neither obvious nor trivial. To this end, the term analysis is used with a rather broad meaning, including for example simulation and diagnosis, verification and performance analysis. Process simulation facilitates process diagnosis in the sense that by simulating real-world cases, domain experts can acknowledge correct modeling or propose modifications of the original process model. If business process models are expressed in process languages with a clear semantics, their structural properties can be analyzed. If, for example, certain parts of processes can never be reached, an obvious modeling mistake occurred that should be fixed. While basic structural properties of process models have been studied for some time, it is remarkable that few software products actually support them. However structural analysis of process models requires a clear formal semantics of the underlying process language, which might not be present. In some products, a pragmatic approach to process modeling is preferred to a formal one; especially if the main goal of process modeling is discussion with domain experts rather than process analysis or process enactment. However, we mention that formal semantics of process languages and intuitiveness and ease of use are no contradicting goals, and recent approaches seem to support this observation.

The next aspect of BPM and traditionally a very strong one is process enactment. However, before process enactment is discussed, we provide a coarse classification of business processes that paves the way for a discussion of different types of process enactment systems. In the early days of BPM when in the application side business process modeling and in the IT enactment side workflow management were the only options, processes with a static structure were focused. The main reason behind this obvious limitation was as follows: Modeling a process and providing infrastructure for its enactment incurs considerable effort. To provide satisfactory return on investment, a large number of individual cases have to benefit from this new technology. This type of straight-through-process is also called production workflow [23]. While there are successful workflow projects on this type of straight-through processes, this restriction of workflow technology proved fatal for applications in more dynamic environments. In some cases where traditional workflow technology was used in these advanced settings, new workflow solutions were partly circumvented or even neglected. As a response to this situation, considerable work in ad-hoc, flexible and case-based workflow was (and is being) conducted, both in academia and in industry. Recently, case handling is studied in depth as a new paradigm for supporting knowledge-intensive business processes with loose structuring. Based on the brief characterization of case handling provided above, we mention that in the case handling paradigm knowledge workers enjoy a great degree of freedom in organizing and performing their work which they are knowledgeable about. Some of the concepts of case handling are already present in commercial case handling systems.

Standardization has a long history in workflow management. Fueled by information system heterogeneity that also includes workflow management systems, organizations started to form interest groups aiming at standardizing interfaces between workflow management systems and components, with the goal of enhancing interoperability and fostering the workflow market. The most prominent organization in this context is the Workflow Management Coalition (WfMC) that was formed in 1993 and today has over 300 member organizations, including all major workflow vendors as well as workflow users and interested academia [22]. The basis of WfMC activities is the so called WfMC Reference Architecture that defines standard workflow system components interfaces. Despite the fact that all major vendors are organized in WfMC and a number of important contributions on practical workflow aspects have been made, many people feel that WfMC's ambitious goals have yet to be reached.

A more recent standardization effort in the BPM context is related to the current momentum of XML and Web services technology. Web services is a promising technology to foster interoperability between information system based –

conceptually – on the service oriented architecture paradigm [11] and – technologically – on open standards and light-weight protocols and systems. While Web services technology has not yet reached maturity level, there is considerable effort under way by literally all major software vendors. The need for standardization is clearly acknowledged in this context, and important contributions have been made. However, as sketched in Section 2, recently a trend of new standards proposals as well as merging of proposals can be experienced in the Web services context. Besides these recent developments, Web services are seen as an important infrastructure to foster business processes by composing individual Web services to represent complex processes, which can even span multiple organizations. While Web services composition is a young discipline and a number of proposals are being discussed, we currently experience what seems to be a slow consolidation of recent standardization effort around Web services composition, based on the BPEL4WS and associated proposals. However, at this point industry seems more involved in standardization than in systems design and development. While there is some controversy on these upcoming standards, it seems that at least industry goes with the flow. In any case, Web services in general and Web services composition in particular can be expected to play an important role in future business process systems technology. This will include both processes within organizations and, more strongly, between organizations.

5 Conclusion

This paper provides an overview of Business Process Management (BPM) and serves as an introduction to this volume of Springer Lecture Notes in Computer Science devoted to the "Conference on Business Process Management: On the Application of Formal Methods to Process-Aware Information Systems". The goal is to put the contributions to this conference into perspective. Section 1 puts BPM in its historical perspective going back to the late seventies. Section 2 defines BPM and compares it with workflow management. Based on this the paper zooms into the formal foundations of BPM on the one hand (Section 3) and technology and emerging standards for BPM on the other hand (Section 4). This way, the paper reflects the objective of this conference: Bringing together (computer) scientists and practitioners to work on advancing BPM methods, techniques, and tools.

References

1. W.M.P. van der Aalst. Three Good Reasons for Using a Petri-net-based Workflow Management System. In S. Navathe and T. Wakayama, editors, *Proceedings of the International Working Conference on Information and Process Integration in Enterprises (IPIC'96)*, pages 179–201, Cambridge, Massachusetts, Nov 1996.
2. W.M.P. van der Aalst. The Application of Petri Nets to Workflow Management. *The Journal of Circuits, Systems and Computers*, 8(1):21–66, 1998.

3. W.M.P. van der Aalst. Making Work Flow: On the Application of Petri nets to Business Process Management. In J. Esparza and C. Lakos, editors, *Application and Theory of Petri Nets 2002*, volume 2360 of *Lecture Notes in Computer Science*, pages 1–22. Springer-Verlag, Berlin, 2002.
4. W.M.P. van der Aalst and P.J.S. Berens. Beyond Workflow Management: Product-Driven Case Handling. In S. Ellis, T. Rodden, and I. Zigurs, editors, *International ACM SIGGROUP Conference on Supporting Group Work (GROUP 2001)*, pages 42–51. ACM Press, New York, 2001.
5. W.M.P. van der Aalst, M. Dumas, A.H.M. ter Hofstede, and P. Wohed. Pattern-Based Analysis of BPML (and WSCI). QUT Technical report, FIT-TR-2002-05, Queensland University of Technology, Brisbane, 2002.
6. W.M.P. van der Aalst and K.M. van Hee. *Workflow Management: Models, Methods, and Systems.* MIT press, Cambridge, MA, 2002.
7. W.M.P. van der Aalst and A.H.M. ter Hofstede. Workflow Patterns: On the Expressive Power of (Petri-net-based) Workflow Languages. In K. Jensen, editor, *Proceedings of the Fourth Workshop on the Practical Use of Coloured Petri Nets and CPN Tools (CPN 2002)*, volume 560 of *DAIMI*, pages 1–20, Aarhus, Denmark, August 2002. University of Aarhus.
8. W.M.P. van der Aalst and A.H.M. ter Hofstede. YAWL: Yet Another Workflow Language. QUT Technical report, FIT-TR-2002-06, Queensland University of Technology, Brisbane, 2002.
9. W.M.P. van der Aalst, A.H.M. ter Hofstede, B. Kiepuszewski, and A.P. Barros. Workflow Patterns. QUT Technical report, FIT-TR-2002-02, Queensland University of Technology, Brisbane, 2002. (Also see http://www.tm.tue.nl/it/research/patterns.) To appear in *Distributed and Parallel Databases.*
10. W.M.P. van der Aalst, B.F. van Dongen, J. Herbst, L. Maruster, G. Schimm, and A.J.M.M. Weijters. Workflow Mining: A Survey of Issues and Approaches. *Data and Knowledge Engineering*, 2003 (to appear).
11. S. Burbeck. The Tao of e-Business Services. IBM Corporation, http://www-4.ibm.com/software/developer/library/ws-tao/index.html, 2000.
12. DAML-S and Related Technologies. www.daml.org/services/daml-s/0.7/survey.pdf, 2003.
13. C.A. Ellis. Information Control Nets: A Mathematical Model of Office Information Flow. In *Proceedings of the Conference on Simulation, Measurement and Modeling of Computer Systems*, pages 225–240, Boulder, Colorado, 1979. ACM Press.
14. C.A. Ellis and G. Nutt. Workflow: The Process Spectrum. In A. Sheth, editor, *Proceedings of the NSF Workshop on Workflow and Process Automation in Information Systems*, pages 140–145, Athens, Georgia, May 1996.
15. H. Eshuis. *Semantics and Verification of UML Activity Diagrams for Workflow Modelling.* PhD thesis, University of Twente, Enschede, The Netherlands, 2002.
16. Gartner. Gartner's Application Development and Maintenance Research Note M-16-8153, The BPA Market Cathes another Major Updraft. http://www.gartner.com, 2002.
17. A. W. Holt. Coordination Technology and Petri Nets. In G. Rozenberg, editor, *Advances in Petri Nets 1985*, volume 222 of *Lecture Notes in Computer Science*, pages 278–296. Springer-Verlag, Berlin, 1985.
18. IDS Scheer. ARIS Process Performance Manager (ARIS PPM). http://www.ids-scheer.com, 2002.

19. S. Jablonski and C. Bussler. *Workflow Management: Modeling Concepts, Architecture, and Implementation.* International Thomson Computer Press, London, UK, 1996.
20. B. Kiepuszewski. *Expressiveness and Suitability of Languages for Control Flow Modelling in Workflows.* PhD thesis, Queensland University of Technology, Brisbane, Australia, 2003. Available via http://www.tm.tue.nl/it/research/patterns.
21. B. Kiepuszewski, A.H.M. ter Hofstede, and W.M.P. van der Aalst. Fundamentals of Control Flow in Workflows (Revised version). QUT Technical report, FIT-TR-2002-03, Queensland University of Technology, Brisbane, 2002. (Also see http://www.tm.tue.nl/it/research/patterns.) To appear in *Acta Informatica.*
22. P. Lawrence, editor. *Workflow Handbook 1997, Workflow Management Coalition.* John Wiley and Sons, New York, 1997.
23. F. Leymann and D. Roller. *Production Workflow: Concepts and Techniques.* Prentice-Hall PTR, Upper Saddle River, New Jersey, USA, 1999.
24. D.C. Marinescu. *Internet-Based Workflow Management: Towards a Semantic Web*, volume 40 of *Wiley Series on Parallel and Distributed Computing.* Wiley-Interscience, New York, 2002.
25. H.M.W. Verbeek, T. Basten, and W.M.P. van der Aalst. Diagnosing Workflow Processes using Woflan. *The Computer Journal*, 44(4):246–279, 2001.
26. Dirk Wodtke and Gerhard Weikum. A formal foundation for distributed workflow execution based on state charts. In Foto N. Afrati and Phokion G. Kolaitis, editors, *Proceedings of the 6th International Conference on Database Theory – ICDT '97, Delphi, Greece, January 8–10, 1997*, volume 1186 of *Lecture Notes in Computer Science*, pages 230–246. Springer, 1997.
27. P. Wohed, W.M.P. van der Aalst, M. Dumas, and A.H.M. ter Hofstede. Pattern-Based Analysis of BPEL4WS. QUT Technical report, FIT-TR-2002-04, Queensland University of Technology, Brisbane, 2002.
28. M.D. Zisman. *Representation, Specification and Automation of Office Procedures.* PhD thesis, University of Pennsylvania, Warton School of Business, 1977.