# Business Process Simulation - A Tool Survey

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**Abstract.** In the nineties, more and more attention was raised for process oriented analysis of the performance of companies. Nowadays, many process aware information systems are implemented (e.g., workflow management systems) and business processes are evaluated and redesigned. The discipline related to this field of study is called Business Process Management (BPM). An important part of the evaluation of designed and redesigned business processes is Business Process Simulation (BPS). Although an abundance of simulation tools exist, the applicability of these tools is diverse. In this paper we discuss a number of simulation tools that are relevant for the BPM field, we evaluate their applicability for BPS and formulate recommendations for further research.

**Keywords**: Business Process Management, Simulation, Petri nets.

## 1 Introduction

Business Process Management (BPM) is attracting attention more than a decade now, and its attention is now shifting from the enactment of business processes towards improving business processes. The field of BPM now supports the design, enactment, control, and analysis of business processes [6]. Companies are improving their performance by a constant evaluation of the value added in all parts of their processes. Business processes are in a continuous improvement cycle in which design and redesign play an important role. Various possibilities to change a process are present and the best alternative design should replace the current process. Making an intuitive choice may lead to unpleasant surprises and lower process performance instead of yielding the expected gains. In [16] simulation is mentioned as one of the techniques suitable for the support of redesign. The simulation of business processes helps in understanding, analyzing, and designing processes. With the use of simulation the (re)designed processes can be evaluated and compared. Simulation provides quantitative estimates of the impact that a process design is likely to have on process performance and a quantitatively supported choice for the best design can be made.

Simulating business processes is, to a large extent, overlapping with the simulation of other discrete event systems. In [32] an overview is provided of the steps that are carried out in the context of Business Process Simulation (BPS).

Regarding the simulation of business processes a number of steps can be distinguished.

First the business process is mapped onto a process model, possibly supplemented with process documentation facilities. Then the sub processes and activities are identified. The control flow definition is created by identifying the entities that flow through the system and describing the connectors that link the different parts of the process. Lastly, the resources are identified and assigned to the activities where they are necessary. The process model should be verified to ensure that the model does not contain errors.

Before simulation of a business process, the performance characteristics, such as throughput time and resource utilization, need to be included. For statistically valid simulation results a simulation run should consists of multiple sub runs and each of these sub runs should have a sufficient run length. During the simulation, the simulation clock advances. The simulation tool may show an animated picture of the process flow or real-time fluctuations in the key performance measures. When the simulation has been finished, the simulation results can be analyzed. To draw useful and correct conclusions from these results, statistical input and output data analysis is performed.

Although the steps in BPS will be the same irrespective of the simulation tool used, each simulation tool will have a different applicability. There is an abundance of simulation tools available of which some are applicable to the BPM field. In this paper we discuss several simulation tools taken from three relevant areas: business process modelling, business process management and general simulation tools. We evaluate the modelling, simulation and output analysis capabilities and we aim at providing insights in the advantages and disadvantages of each simulation tool.

The remainder of this paper is organized as follows. First, we discuss related work on evaluation criteria of BPM tools. Then, in Section 3, we describe tools for BPS. The criteria used for the evaluation of BPS tools are listed and explained in Section 4. In Section 5 we compare the described BPS tools, and in Section 6 we present our conclusions.

## 2 Related work

In this paper, we aim to evaluate several software packages for suitability of BPS. Hardly any package explicitly advertises as BPS tool, however, many of them provide simulation functionality and may be suitable. Bradley *et al* defined seven different categories to evaluate business process re-engineering software tools [8]. The seven categories are as follows:

1. Tool capabilities, including a rough indication of modelling, simulation and analysis capabilities.
2. Tool hardware and software, including, e.g., the type of platform, languages, external links and system performance.

3. Tool documentation, covering the availability of several guides, online-help and information about the learning curve of the tool.
4. User features: amongst others user friendliness, level of expertise required, and existence of a graphical user interface.
5. Modelling capabilities, such as identification of different roles, model integrity analysis, model flexibility and level of detail.
6. Simulation capabilities, summarizing the nature of simulation (discrete vs. continuous), handling of time and cost aspects and statistical distributions.
7. Output analysis capabilities such as output analysis and BPR expertise.

In this paper we elaborate on the categories as defined by Bradley *et al* in the direction of BPS. Especially the last three categories are of interest when evaluating BPS.

With respect to modelling capabilities, the patterns research is used to evaluate the possibility to model various control flow patterns [5], data patterns [26] and resource patterns [27]. The patterns research is used to evaluate the modelling capabilities of a tool with respect to complexity.

The complexity of modern business processes is increasing. In order to manage this complexity, Becker *et al* have formulated six main quality criteria for business process models [7]. These criteria are:

1. Correctness, the model needs to be syntactically and semantically correct.
2. Relevance, the model should not contain irrelevant details.
3. Economic efficiency, the model should serve a particular purpose that outweighs the cost of modelling.
4. Clarity, the model should be (intuitively) understandable by the reader.
5. Comparability, the models should be based on the same modelling conventions within and between models.
6. Systematic design, the model should have well-defined interfaces to other types of models such as organizational charts and data models.

Many authors have proposed requirements for business process modelling tools (for example [10, 24, 31, 35]) or have tested these requirements empirically [11, 16]. Although this requirement building frequently took place in the context of BPS only one explicit list with evaluation criteria for simulation or output analysis capabilities is present. Law and Kelton describe desirable software features for the selection of general purpose simulation software [19]. They identify the following groups of features:

1. General capabilities, including modelling flexibility and ease of use.
2. Hardware and software considerations.
3. Animation, including default animation, library of standard icons, controllable speed of animation, and zoom in and out.
4. Statistical capabilities, including random number generator, probability distributions, independent runs (or replications), determination of warm up period, and specification of performance measures.

5. Customer support and documentation.
6. Output reports and plots, including standard reports for the estimated performance measures, customization of reports, presentation of average, minimum and maximum values and standard deviation, storage and export of the results, and a variety of (static) graphics like histograms, time plots, and pie charts.

## 3 Tools for Business Process Simulation

Many software tools exist to simulate processes. When simulating business processes, some specific requirements are applicable. The nature of the business process requires sufficient modelling power of the tool. When particular choices or a synchronization cannot be implemented, the simulation result loosens its strengths. On the other hand, simulation of business processes aims to support process owners or process managers. When the tool or the simulation output can hardly be understood by the client, the tool overreaches itself. In this section, we describe three different categories of software tools that may be applicable for BPS:

- business process modelling tools,
- business process management tools,
- general purpose simulation tools.

For each type a general introduction and the description of two specific tools are given.

### 3.1 Business process modelling tools

Business Process Modelling tools are developed to describe and analyze business processes. The analysis part may provide data useful for the management of these processes. The tool supports the process to establish the control flow of business processes, the resource roles involved, documents being used and it documents instructions for the execution of steps in the business process. As a result, reports can be generated for process documentation, manuals, instructions, functional specifications, etc. For the evaluation of the simulation functionality we consider two different tools, one based on Petri Nets (Protos) and one based on Event-driven Process Chains (ARIS Toolset).

**Protos**
Protos is a modelling and analysis tool developed by Pallas Athena and it is mainly applied for the specification of in-house business processes. Protos is suitable to model well-defined Petri Net structures. Nevertheless, it also permits free hand specifications of business processes without formal semantics, e.g. to support initial and conceptual modelling [34]. When formal Petri Net semantics have been applied, translation to various other process-based systems is feasible as well, e.g. to the workflow management system COSA and the workflow analyzer Woflan [33].

The main use of Protos is to define models of business processes as a step towards either the implementation of quality management systems, the redesign of a business process, communication enhancement between process stake holders or the implementation of workflow management systems. The process can be analyzed with respect to data, user and control logic perspective, and by making use of simulation [34].

The simulation engine is implemented in Protos version 7.0. The existing engine of the Petri Net based tool ExSpect has been integrated in the Protos environment and it facilitates the simulation of the business process as has been specified in the Protos model before. In addition to the standard process specification, simulation data can be added for tasks, connections and resources such as the (stochastic) processing time and the number of resources required. Furthermore, process characteristics are added such as the arrival pattern for cases and the number and length of simulation runs. The simulation result can be obtained from an Excel spreadsheet and includes mean and 90% and 99% confidence interval of utilization rates, waiting times, service times, throughput times and costs.

**ARIS**

ARIS Simulation is a professional tool for the dynamic analysis of business processes. It is an integral part of the ARIS Toolset; processes recorded in the ARIS Toolset are used as the data basis for business process simulation. ARIS Toolset is developed by IDS Scheer AG (see www.ids-scheer.nl) and can be classified as an enterprise modelling tool with a strong emphasis on business processes. Enterprise modelling is supported by a number of different views (process, function, data, organization and product) and the modelling approach called ARIS House [30, 29].

The process modelling part supports the definition of business processes represented in Event-driven Process Chains (EPCs). Other modelling techniques supported in the ARIS House are, e.g. value chains (also to model the control flow), organization charts (to model relationships between resources), EPCs and and function allocation diagrams (for supplementary information such as data and systems). The simulation functionality shows whether the specified processes are executable at all and it answers questions about throughput times and utilization levels of the resources, etc.

When starting a simulation, the simulation module of the tool is started and the model is transferred. The simulation toolbar shows buttons for start and stop, one time step and simulation steps and options for animations. The simulation results are available in Excel spreadsheets and include statistics on events, functions, resources, processes and costs. Only raw data is available.

### 3.2 Business process management tools

Business process management (BPM) systems can be seen as successors of Workflow Management (WFM) systems. The core functionality of a WFM system is automating the "flow of work". With the introduction of BPM the functionality is broadened to support the whole proces life-cycle. BPM is defined as *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* [6]. Some BPM tools offer a simulation tool to support the design phase. Most BPM tools, however, do not provide simulation facilities and we use FLOW*er* as a representative of this group of BPM tools. Further, we will evaluate FileNet, one of the most advanced BPM tools. FileNet is evaluated to show what most likely will be the best simulation functionality provided by a BPM tool. The FLOW*er* tool is evaluated, regardless his lack of simulation facilities, to illustrate the other end of the simulation spectrum of BPM tools.

**FLOW*er***

FLOW*er* is a flexible, case-based BPM system. When handling cases the system only prevents actions for which it is specified that these are not allowed. This results in a flexible process where activities for a case can be executed, skipped or redone.

The FLOW*er* systems consists of a FLOW*er* Studio, FLOW*er* Case Guide, FLOW*er* CFM (Configuration Management), FLOW*er* Integration Facility, and FLOW*er* Management Information and Case History Logging.

The graphical design environment, Studio, is used to define processes, activities, precedences, data objects and forms. Work queues are used to provide work to users (defined with CFM) and to find cases satisfying specified search criteria. Case Guide is the client application which is used to handle individual cases. FLOW*er* Integration Facility provides the functionality to interface with other applications. FLOW*er* Management Information and Case History Logging can be used to store and retrieve management information at various levels of detail.

BPM systems, like FLOW*er*, focus on the configuration of the system, and the execution and control of the workflow. Additional features like the FLOW*er* Management Information and the FLOW*er* Integration Facility are provided. However, FLOW*er* does not provide explicit simulation or output analysis functionality. We will not be able to evaluate the simulation and output analysis capabilities of FLOW*er*, but we can evaluate the modelling capabilities [3, 5].

**FileNet**

FileNet is considered to be one of the leading commercial BPM systems[1]. We have evaluated the strengths and weaknesses of the FileNet P8 BPM Suite and its ability to support the various parts of the process life-cycle [23].

The FileNet system includes a FileNet Process Designer, a FileNet Process Simulator, a FileNet Process Engine, a FileNet Process Administrator, and a FileNet Analysis Engine.

First, a process structure is modelled graphically with the Process Designer and tasks are assigned to work queues. These work queues and the associated users are created outside the Process Designer. Then, the created process defini-

[1] www.gartner.com

tion is feeded to the Process Engine to start the execution of the workflow. The execution data for individual cases is logged by the Process Engine and can be accessed with the Process Administrator. Further, execution data is aggregated and parsed to the Analysis Engine. Reporting and analysis of the aggregated data is facilitated by twenty out-of-the-box reports; each graphically presenting the data related to one performance indicator.

The Process Simulator in FileNet can be used to evaluate the performance of a created design. The Process Simulator is a separate tool, which can partly import the created process definition. Other parts of the process definition have to be reentered. Simple arrival patterns of cases are defined, i.e. a fixed number of cases arrives at fixed time points. Also historic, execution arrival data can be used. Other performance characteristics should be added manually and can only have constant values. After simulation an animation and a summary of the simulation results are provided. Simulation data can also be presented in Excel reports. However, performing what-if analysis (comparing scenarios) is not possible.

### 3.3 General purpose simulation tools

Simulation tools may be tailored towards a specific domain, such as logistics (e.g., Enterprise Dynamics) or SPEEDES in the military domain. In this section we consider simulation tools that are not tailored towards a particular domain and we evaluate their suitability for the domain of business processes. The first tool, Arena, has an industrial background and shows industry successes in manufacturing, supply chain management, military/defense, health care, contact centers and process reengineering (see www.arenasimulation.com). The second tool, CPN Tools, has been developed in a university environment and has been applied in more technical engineering domains (see http://www.daimi.au.dk/CPnets/).

**Arena**

Arena is a general purpose simulation tool developed by Rockwell Automation. The Arena product family consists of a Basic Edition for uncomplicated processes and a Professional Edition for more complex large scale projects in manufacturing, distribution, processes, logistics, etc. The Professional Edition also provides (and allows definition of) templates for complex repetitive logic, e.g., for packaging and contact centers.

When opening the tool, a number of process panels are available, e.g., for basic and advanced processes and for reporting. The model can be created by drag and drop from the process panel to the model window. By double-clicking on the icons, options for the different building blocks can be set such as delay types, time units and the possibility to report statistics. Many more building blocks are available and can be attached when necessary.

When a model has been created and is completely specified (from the Arena viewpoint) and it is syntactically correct, it can be simulated. Warm-up and cool-down periods can be specified, as well as run length and confidence intervals.

Several statistics are provided by default, but the larger part needs to be added manually by adding record building blocks where necessary [15].

In a previous study, de Vreede et al considered the suitability of Arena to simulate business processes [35]. They stated that a weak point in simulating business processes is the time consuming and complicated process to create simulation models. They took advantage of the possibility to develop their own template with predefined building blocks, which they considered to be successful in several simulation studies they carried out.

**CPN Tools**
CPN Tools is developed by the computing science group of Aarhus University in Denmark. CPN Tools is a tool for editing, simulating and analyzing Colored Petri Nets. The tool attracts attention with respect to its user interface which has been designed in cooperation with leading HCI experts, and includes a number of novel interaction mechanisms such as the use of two-handed input by means of a mouse and a trackball. During editing a net (a process model), feedback facilities provide contextual error messages and indicate dependency relationships between net elements. The tool features incremental syntax checking and code generation which take place while a net is being constructed. A fast simulator efficiently handles both untimed and timed nets. Untimed nets are generally not applicable for modelling and simulation of (realistic) business processes, but several earlier projects already showed that timed CP-nets can model business processes [20, 13, 22]. Correctness of the developed model can be researched by existing Petri Net techniques such as the generation of state spaces and the analysis of boundedness and liveness properties, which are all implemented in CPN Tools.

The industrial use of CPN Tools (and its predecessor Design CPN) can be found starting from the home page (http://www.daimi.au.dk/CPnets/). Design CPN is the most widespread software package for modelling and analysis by means of Colored Petri Nets. The overview shows a wide variety of mainly technical domain areas such as protocols and networks, hardware and control systems. Also some projects are listed with a more business oriented focus, though these are exceptions.

## 4 Evaluation criteria for BPS Tools

When evaluating BPS tools, the modelling, simulation and output analysis capabilities of the tool are important. In this section we present our view on these capabilities and specify criteria to evaluate each capability in detail.

### 4.1 Modelling capabilities

The purpose of the modelling capabilities criteria is to evaluate how well and how precise a business process can be represented. The modelling evaluation criteria are:

– Ease of model building [8, 19]
  Model building should be easy to allow users to be involved in the modelling of their processes. A graphical user interface with predefined business objects which can be dragged and dropped facilitates the model building. The hard coding of process parts is hard to perform or understand for users and should be avoided.

– Formal semantics [4] and verification of correctness [21, 33]
  Formal semantics provide a precise and unambiguous description of the behavior of the modelled process. Van der Aalst concludes that many modelling techniques lack formal semantics and thus powerful analysis methods and tools [4]. In [2] he summarizes three good reasons for using a Petri-net based workflow management system which appear to be critical in large BPM projects. These reasons are: (1) the existence of formal semantics despite the graphical nature, (2) the state based diagrams instead of event based diagrams (as can be encountered in many workflow products) and (3) the abundance of analysis techniques.

– Workflow patterns [5]
  The workflow patterns [5], or control flow patterns, are used to evaluate the expressive power of modelling languages. The patterns identify both basic and complex modelling constructs. The number of supported patterns indicate how well a modelling language can give a good representation of the actual business process.

– Resource and data perspective [8, 26, 27]
  The process model should include the resource and data perspective and not just the process structure to provide a good representation of the real world situation. Resource and data patterns capture the various ways in which respectively resources and data are represented and utilized in processes [26, 27].

– Level of detail, transparency and suitability for communication [7, 8]
  Both senior management as well as end users need to be informed about the process (alternatives), they shoulddddd be able to validate the model and should be able to make decisions based on these models. These stake holders have a different need for information, senior management wants a high level overview, while the end users need detailed work descriptions. Through the use of, for instance, hierarchical layers processes are be modelled in detail, but without loosing overview.

### 4.2 Simulation capabilities

The purpose of the simulation capabilities is to evaluate in which way a simulation can be carried out and which parameter settings can be made. The simulation evaluation criteria are:

– Performance dimensions [8, 25, 19]
A simulation model should incorporate the performance dimensions one is interested in. In most cases it should be possible to simulate several different time and/or costs aspects. Other relevant performance dimensions are quality and flexibility [25].

– Distributions [19, 24]
The average performance of a simulated process may seem fine while in real life many problems would occur because of its variability. Queues may be empty at some moments and overloaded at other moments, creating employee and customer dissatisfaction [24]. Taking into account the distributions of performance characteristics will not only show the average behavior of the process, but also its extremities.

– Animation [19, 35]
With simulation not only the final simulation results but also the simulation itself can give useful insights in the simulated process. A replay or animation of the simulation will show the states the simulation model has been in during simulation. This visualization might reveal bottlenecks and other problems in the execution of the process.

– Scenarios [14, 18]
With the use of scenarios the consequences of changes can be investigated. While the process stays the same, different configurations of the simulation model reflect potential changes in, i.e., the arrival pattern or resource availability. With the use of scenarios the effects of changes can be predicted and counter measures can be taken to avoid bad performance once the change occurs in reality.

### 4.3 Output analysis capabilities

The output analysis capabilities aim to evaluate the outcome of a simulation, which data can be analyzed and which representation styles are provided. The output analysis evaluation criteria are:

– Statistics [17, 19]
Simulation should provide statistically proper results and it should be clear how these results are calculated. Simulation settings (e.g. simulation length, number of replications, start and stop conditions [9, 24]) should be indicated to or even better be set by the user. A random generator should be used for the generation of cases. For each performance measure not only the mean, but also the standard deviation and confidence intervals should be presented.

– Format [8, 19]
The tool should have an easy to read format for the presentation of the re-

sults and possibilities for animation, storing and reuse of results.

– What-if analysis [18, 9, 14]
  Before a process design is chosen what-if analysis is performed. In this analysis different scenarios (of the same simulation model) are compared. The comparison of confidence intervals of a performance measure shows which scenarios perform significantly better than others on this measure. It also indicates under which conditions a certain process design will perform within its requirements and under which conditions a performance level can not be reached.

– Conclusion-making support [8, 35]
  Conclusion-making support facilitates the interpretation of the simulation results. Useful support is the identification of trends, the slicing and dicing of data and the tracking of the cause of specific outcomes.

## 5 Comparison of BPS Tools

In Section 3 we described six different tools which may be applicable for BPS, and which have been developed from various viewpoints: process modelling, process execution and simulation. In Section 4 we developed a framework with a set of evaluation criteria to find strengths and weaknesses of these tools. In this section, we report our findings. We will score the BPS tools for each of the evaluation criteria ranging from good (++) and neutral (+/–) to bad (– –).

### 5.1 Modelling capabilities

In this section we evaluate how well and how precise a business process can be modelled in the tools. We provide a short overview per tool and at the end of the section we summarize the findings in Table 1.

**Protos**

The control flow of a business process and the resources can very easily be specified in Protos, as may be expected from a process modelling tool. Also the data perspective and instructions for the execution of tasks can be specified. The tool allows freehand specifications, however it also allows well-defined Petri Net structures, thus opening possibilities for further verification (e.g., in Woflan) and analysis (based on the ExSpect tool). The application of sub models allows for a transparent process model and handling of resources which can very well be communicated with process owners. Points for improvement are the possibility to assign different roles to one task and to specify part time work and overtime. This could be specified, e.g., in histograms (which can already be handled by the simulation engine but is not (yet) allowed in the Protos interface).

**ARIS**

The control flow part is being modelled in EPCs. This is an informal modelling language, and the simulation relies on the given semantics when the EPC language has been implemented in the ARIS Toolset. It appears that these semantics are not completely clear, which may result in unforseen behavior when using (X)OR connectors. The models can be conveniently arranged, has functional use of colors for different model elements and supports hierarchy. Due to the informal language, several workflow patterns cannot be modelled conveniently. Model verification is not supported by the tool.

**FLOW*er***

With FLOW*er* it is, on the one hand, possible to handle exceptions and on the other hand, to force a sequential order handling. Due to this flexibility FLOW*er* supports most of the workflow patterns. FLOW*er* is data driven, giving it a strong data perspective and also the resource perspective is taken into account. Both the process and role graph can be modelled in several layers of detail.

**FileNet**

Most BPM tools, including FileNet, use a simple graphical representation of process models without formal semantics and verification of correctness. With this, users can create and discuss process models without difficulties. More advanced workflow patterns and also the resource and the data perspective need to be hard coded in FileNet.

**Arena**

Arena models can be created very easily, though to specify exactly those things you would like to model is more difficult. When browsing through a model, the level of detail is very convenient, due to the use of sub models and the fact that many details are hidden in the icon properties. When creating models, good knowledge about all necessary building blocks and their exact specification is required. Frequently used control flow patterns are supported, but some more advanced patterns require a bit more indirect modelling [12].

**CPN Tools**

The tool is based on Petri Net modelling techniques, and both benefits and suffers from this property: it has formal semantics, allows for most control flow patterns [5] and can be verified, but the price to be paid is that the models may be quite detailed and technical.

This level of detail is required to model resource handling and corresponding timing aspects, which is crucial in most business process models. Also, some constructs can only be modelled indirectly, thus resulting in model parts that can hardly be understood by business process owners. As a result, models cannot be built easily. Though very powerful, the Petri Net formalism appears to be more difficult to understand than informal modelling languages [28].

In Table 1 our score for the modelling capability criteria for each of the tools is presented.

**Table 1.** Modelling capabilities

| Feature | Protos | ARIS | FLOW*er* | FileNet | Arena | CPN Tools |
|---|---|---|---|---|---|---|
| Ease of model building | ++ | + | + | + | + | − − |
| Formal semantics/verif. | + | − | − − | − − | +/− | ++ |
| Workflow patterns | + | − | + | +/− | + | + |
| Resources and data | + | ++ | ++ | +/− | + | +/− |
| Level of detail | ++ | ++ | ++ | + | ++ | − − |

### 5.2 Simulation capabilities

In this section, we evaluate in which way a simulation can be carried out and which parameter settings can be made. We provide a short overview per tool and at the end of the section we summarize the findings in Table 2.

**Protos**

The simulation engine in Protos seems to be working fine. A more detailed look, however, reveals some weaknesses of the simulation. Apparently, these weaknesses seem to be introduced by the interface between Protos and ExSpect as the simulation engine of ExSpect itself does not suffer from this. The suggestion of the Protos/ExSpect simulation tool is that all data specified in the process, task and resource properties are taken into account in the simulation. It appeared that this is not the case for the number of resources and the data required for a task. As a result, decisions in the process cannot be made based on data (but instead a probability is calculated based on the weight of outgoing arcs or follow-up tasks). In addition, problems may occur when using subprocess; in some cases an OR-split can be changed into an AND-split (though this seems to be a bug instead of a design issue).

All important (standard) performance dimensions are predefined, but it is not possible to add any other dimension. The same holds true for the possible distributions. The most well-known distributions are available but these cannot be extended. In the future, distributions based on histograms may be provided to be more flexible in this aspect. Facilities for animation and scenarios are not available.

**ARIS**

Before running a simulation, several simulation parameters need to be set: average processing times and distributions, number of cases being generated, case arrival distribution and probabilities of outgoing arcs from XOR-split connectors. It is possible to use animation during the simulation and an animation icon can be selected. ARIS is based on an informal process modelling language. Since the simulation models can be executed, a semantic is chosen for constructs which leave room for interpretation, i.e. (X)OR splits and joins. An example of this is the choice for a waiting time for incoming branches: if the waiting time has been exceeded, it is assumed that the data that has arrived already will be processed and that no other data will reach the connector for this particular case. It is unclear what exactly happens beneath the surface.

**FLOW*er***

Most BPM tools, including FLOW*er*, only provide the possibility to test or play with the workflow by launching some cases and execute them manually. In this sense the workflow engine is used as a runtime simulation engine. This, however, does not provide explicit simulation functionality.

**FileNet**

After simulation with FileNet the flow of cases can be replayed in an animation. Both time and costs aspects are taken into account but without fluctuations because only constant performance measures are used in the simulation. It is possible to create scenarios of a simulation model, but it is not possible to change the process structure in the process simulator itself.

**Arena**

In Arena a model can be simulated by pressing the go-button in the toolbar. The model then enters the simulation mode and cannot be edited anymore. The simulation can be done step-by-step and in normal and fast-forward modes. All performance dimensions and frequently used distributions can be added on those places necessary in the model. Animations are obtained by icons flowing through the model or 3D animations (in a post-processing tool). Alternative models can be defined and evaluated in the Process Analyzer.

**CPN Tools**

CPN Tools has been developed for simulation purposes, and this shows in the simulation capabilities. When a model (part) has been created, it can be simulated directly, making use of a step-by-step simulation, or a chosen number of steps. All performance dimensions can be measured in the monitoring part of the tool. A number of standard monitors are pre-programmed, but most monitors need to be programmed manually. Animation facilities are not available in the standard tool, but an additional tool (BRITNeY) aims at building and deploying visualizations of Colored Petri Net Models, see e.g. [37]. Scenarios can be implemented quite easily by creating model versions with adapted model parameters.

In Table 2 our score for the simulation capability criteria for each of the tools is presented.

**Table 2.** Simulation capabilities

| Feature | Protos | ARIS | FLOW*er* | FileNet | Arena | CPN Tools |
|---|---|---|---|---|---|---|
| Performance dimensions | − − | ++ | − − | + | ++ | ++ |
| Distributions | + | + | − − | − − | ++ | ++ |
| Animation | − − | + | − − | + | ++ | + |
| Scenarios | − − | − | − − | +/− | + | + |

### 5.3 Output analysis capabilities

In this section, we evaluate how well the simulations statistically can be carried out, how well they match the situation in real life and how the user is supported in the evaluation of the simulation results. We provide a short overview per tool and at the end of the section we summarize the findings in Table 3.

**Protos**
The simulation results are made available in a very basic spreadsheet, but all important performance dimensions are listed and supplemented with means and 90% and 99% confidence intervals. However, depending on the data specified in the process model, the simulation results may be incorrect (see 5.1).

**ARIS**
The output format is (a set of) Excel spreadsheets, with raw detailed and/or cumulative data. Statistics need to be calculated manually and support for what-if analysis and scenarios is not directly available in the tool. ARIS Toolset however has a good interface with other ARIS tools which can provide these, e.g., ARIS Process Performance Manager or ARIS Business Optimizer.

**FLOW*er***
Most BPM tools, including FLOW*er*, do not provided simulation functionality and output analysis functionality.

**FileNet**
The first impression of the performance reports provided by FileNet is a good one. Nice graphics are shown for different performance indicators and more detailed views are easy to realize. However, a closer look shows that it is unclear what is presented and how the performance indicator should be interpreted. It is hard to come to conclusions and there are only averages presented. It is impossible to view the results of one scenario or to compare scenarios, because the results for all scenarios for a certain simulation model are aggregated.

**Arena**
Arena provides standard statistics for all performance indicators specified. For each statistic, the minimum and maximum value is given, as well as mean and half length of the 95% confidence interval. When a simulation has run to com-

pletion, you can see the results in a standard report, it can be analyzed later in the output analyzer (in the advanced process panel) or it can be written to an Excel file (by inserting the read-write module). Conclusion making support is provided in the process analyzer.

**CPN Tools**
Strong point of the tool is the statistically correct output of the simulation. All aspects specified in the process model are taken into account, thus resulting in good simulation results. The standard output format gives 90, 95 and 99% confidence intervals. In addition other confidence intervals can be calculated making use of the raw simulation data. Weak point of the tool is the lack of support when drawing conclusions on the simulations. The output is provided on a html-page and any further processing should be done manually, e.g. when comparing different scenarios.

In Table 3 our score for the output analysis capability criteria for each of the tools is presented.

**Table 3.** Output analysis capabilities

| Feature | Protos | ARIS | FLOW*er* | FileNet | Arena | CPN Tools |
|---|---|---|---|---|---|---|
| Statistics | – | – – | – – | – | ++ | ++ |
| Format | – | +/– | – – | +/– | + | +/– |
| What-if analysis | – – | + | – – | – – | – | – |
| Conclusion-making support | – – | + | – – | – | + | – – |

## 6 Conclusion

In this paper we considered a number of software tools on their suitability for BPS. The tools have been evaluated on their modelling capabilities, simulation capabilities and possibilities for output analysis. The tools were selected for different reasons. Protos and ARIS were selected because of their strong background in process modelling. The modelling power, transparency for business users and the ability to model data and resource perspectives met our expectations. Filenet and Flower were selected because of their usage in business process management, i.e. their strong support of workflow processes. Filenet and Flower appeared to be strong in this respect. Finally, CPN Tools and Arena were selected because of their excellent track record in simulation. Both tools performed well on this aspect.

The above mentioned tools, however, were not only evaluated on their respective “known” strong points, but of course also on all other aspects relevant when modelling and simulating business processes. Both business process management tools fel short on their simulation capabilities; Flower did not support simulation at all (like most business process management tools) and Filenet did support simulation though without stochastic functions and statistical analysis. The process modelling tool Protos provides a simulation module based on the ExSpect simulation engine. However, the interface between the two modules omits important details with respect to data and resources, thus making the outcome of a simulation unreliable. Flower, Filenet and Protos are considered to be unsuitable for solid BPS studies.

The three remaining tools, ARIS, Arena and CPN Tools, all three qualify for BPS studies. These tools have different principles that determine the suitability of the tool for a particular simulation study. ARIS is based on the informal process modelling language of EPCs and has difficulty to model workflow patterns. However, its strong point is the suitability for communication with process owners, which frequently is an important condition in such simulation studies. Arena is a strong simulation tool that proved to be appropriate for BPS. The modelling with this tool is based on predefined building blocks, which can be adapted and extended if necessary. In this tool, it is important to have a profound knowledge about the building blocks that are available and about the exact mode of operation. Finally, CPN Tools is based on the formal modelling techniques of Petri Nets. This opens many possibilities for the formal verification of the simulation model. The price to be paid however, is high. Like modelling in Arena, a profound knowledge is required on modelling Petri Nets, but CPN Tools differs from Arena in that respect that the resulting models are hard to understand by general process owners who should be able to understand and validate the models.

## 7 Future work

In our research, e.g. on the quantification of business process redesign heuristics, we benefit a lot from the formal verification techniques. Based on this and the results of the evaluation, we choose CPN Tools as a basis for further development. Further BPS research points towards elaboration on CPN Tools. We foresee two possible directions: (1) making the process of modelling business processes easier and (2) making simulation output more transparent for business process owners.

As future work in the direction of process modelling, we consider the development of a library of building blocks dedicated for business process modelling. This library may cover, for instance, resource handling, some timing aspects and statistical output analysis. As a starting point we will consider the strong points of ARIS and Arena as described above and the work previously done in the Petri net community, e.g., the development of the ExSpect libraries [1].

In ExSpect, for example, building blocks have been defined dedicated for e.g., logistic analysis. A difference between CPN Tools and ExSpect, however, is the fact that the logic of an ExSpect transition is hidden in the transition whereas the logic of a CPN Tools transition is derived from the logic on input and output arcs. Furthermore, ExSpect knows a strong separation of the definition of a transition and its actual installation. As a result, it is more straightforward to define a library of ExSpect transitions than a library of CPN Tools transitions. A possible solution can be found in the creation of subpages in CPN Tools. Each subpage represents a particular building block, that can be applied in a new CP net. For instance we consider a resource building block as an important component [22]. The number of input and output arcs, as well as the transition logic of the corresponding substitution transition in the CP net is defined. Apart from the selection and definition of such building blocks, we should also consider how to create a library of building blocks/subpages and how to call a building block from a library.

Future work in the direction of simulation output includes visualization of the simulation: tokens are moving over the arcs during the processing of a task instead of being consumed and produced with a delay. Furthermore, output statistics are captured both statically and dynamically, e.g. in performance dashboards, e.g. as in Arena or ExSpect. Finally, we will consider the addition of what-if analysis support to compare several different scenario's. Recent developments in the BRITNeY Suite [36, 37] will also be considered here.

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## References

1. W.M.P. van der Aalst. Modelling and Analysis of Complex Logistic Systems. In *Proceedings of the IFIP WG 5.7 Working Conference on Integration in Production Management Systems*, pages 203–218, Eindhoven, the Netherlands, 1992.
2. 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, Camebridge, Massachusetts, Nov 1996.
3. 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.
4. W.M.P. van der Aalst and K.M. van Hee. Business Process Redesign: A Petri-net-based approach. *Computers in Industry*, 29(1-2):15–26, 1996.
5. W.M.P. van der Aalst, A.H.M. ter Hofstede, B. Kiepuszewski, and A.P. Barros. Workflow Patterns. *Distributed and Parallel Databases*, 14(1):5–51, 2003.
6. W.M.P. van der Aalst, A.H.M. ter Hofstede, and M. Weske. Business Process Management: A Survey. In W.M.P. van der Aalst, A.H.M. ter Hofstede, and M. Weske, editors, *International Conference on Business Process Management (BPM 2003)*, volume 2678 of *Lecture Notes in Computer Science*, pages 1–12. Springer-Verlag, Berlin, 2003.

7. J. Becker, M. Kugeler, and M. Rosemann. *Process Management - A guide for the design of business processes*. Springer-Verlag: Berlin, 2003.
8. P. Bradley, J. Browne, S. Jackson, and H. Jagdev. Business Process Reengineering (BPR)– A study of the software tools currently available. *Computers in Industry*, 25(3):309–330, 1995.
9. M.A. Centeno and M.F. Reyes. So you have your model: What to do next. A tutorial on simulation output analysis. In D.J. Medeiros, E.F. Watson, J.S. Carson, and M.S. Manivannan, editors, *Proceedings of the 1998 Winter Simulation Conference*, pages 23–29. IEEE Computer Society Press, Los Alamitos, 1998.
10. T.H. Davenport. *Process innovation : reengineering work through information technology*. Harvard Business School Press, Boston, 1993.
11. V. Hlupic and S. Robinson. Business process modeling and analysis using discrete-event simulation. In D.J. Medeiros, E.F. Watson, J.S. Carson, and M.S. Manivannan, editors, *Proceedings of the 1998 Winter Simulation Conference*, pages 1363–1369. IEEE Computer Society Press, Los Alamitos, 1998.
12. M.H. Jansen-Vullers, R. IJpelaar, and M. Loosschilder. Workflow patterns modelled in arena. Technical Report BETA Working Paper Series, WP 176, Eindhoven University of Technology, The Netherlands, 2006.
13. M.H. Jansen-Vullers and H.A. Reijers. Business Process Redesign at a Mental Healthcare Institute: A Coloured Petri Net Approach. In K. Jensen, editor, *Proceedings of the Sixth Workshop and Tutorial on Practical Use of Coloured Petri Nets and the CPN Tools (PB-576)*, pages 21–38, Department of Computer Science, University of Aarhus, Oct. 2005.
14. W.D. Kelton. Analysis of Output Data. In J.D. Tew, S. Manivannan, D.A. Sadowski, and A.F. Seila, editors, *Proceedings of the 1994 Winter Simulation Conference*, pages 62–68. Society for Computer Simulation International, San Diego, 1994.
15. W.D. Kelton, R.P. Sadowski, and D.T. Sturrock. *Simulation with Arena*. McGrawHill, 2004.
16. W.J. Kettinger, J.T.C. Teng, and S. Guha. Business Process Change: A Study of Methodologies, Techniques, and Tools. *MIS Quarterly*, 21(1):55–80, 1997.
17. J.P.C. Kleijnen and W.J.H. van Groenendaal. *Simulation: a statistical perspective*. Wiley, Chichester, 1992.
18. M. Laguna and J. Marklund. *Business Process Modeling, Simulation, and Design*. Pearson Prentice Hall, New Jersey, 2005.
19. A.M. Law and W.D. Kelton, editors. *Simulation modeling and analysis*. McGraw-Hill, New York, 2000.
20. D. Makajic-Nikolic, B. Panic, and M. Vujosevic. Bullwhip Effect and Supply Chain Modelling and Analysis using CPN Tools. In K. Jensen, editor, *Proceedings of the Fifth Workshop and Tutorial on Practical Use of Coloured Petri Nets and the CPN Tools (PB-570)*, pages 219–234, Department of Computer Science, University of Aarhus, Oct. 2004.
21. J. Mendling, M. Moser, G. Neuman, H.M.W. Verbeek, B.F. van Dongen, and W.M.P. van der Aalst. A quantitative analysis of faulty EPCs in the SAP Reference Model. In *Proceedings of the fourth International Conference on Business Process Management (BPM 2006)*, page (to appear), Vienna, Sept. 2006.
22. M. Netjes, W.M.P. van der Aalst, and H.A. Reijers. Analysis of Resource-Constrained Processes with Colored Petri Nets. In K. Jensen, editor, *Proceedings of the Sixth Workshop and Tutorial on Practical Use of Coloured Petri Nets and the CPN Tools (PB-576)*, pages 251–265, Department of Computer Science, University of Aarhus, Oct. 2005.

23. M. Netjes, H.A. Reijers, and W.M.P. van der Aalst. Supporting the BPM life-cycle with FileNet. In T. Latour and M. Petit, editors, *Proceedings of the CAiSE'06 Workshops and Doctoral Consortium*, pages 497–508, Luxembourg, June 2006.
24. R.J. Paul, G.M. Giaglis, and V. Hlupic. Simulation of Business Processes. *The American Behavioral Scientist*, 42(10):1551–1576, 1999.
25. H. Reijers. *Design and Control of Workflow Processes: Business Process Management for the Service Industry*, volume 2617 of *Lecture Notes in Computer Science*. Springer-Verlag, Berlin, 2003.
26. N. Russell, A.H.M. ter Hofstede, D. Edmond, and W.M.P. van der Aalst. Workflow data patterns. Technical Report QUT Technical report, FIT-TR-2004-01, Queensland University of Technology, Brisbane, 2004.
27. N. Russell, A.H.M. ter Hofstede, D. Edmond, and W.M.P. van der Aalst. Workflow resource patterns. Technical Report BETA Working Paper Series, WP 127, Eindhoven University of Technology, The Netherlands, 2004.
28. K. Sarshar and P. Loos. Comparing the control-flow of epc and petri net from the end-user perspective. In *Business Process Management*, pages 434–439, 2005.
29. A.W. Scheer. *ARIS: Business Process Frameworks*. Springer-Verlag, Berlin, 1998.
30. A.W. Scheer. *ARIS: Business Process Modelling*. Springer-Verlag, Berlin, 1998.
31. K. Spurr, P. Layzell, L. Jennison, and N. Richards, editors. *Software assistance for business re-engineering*. Wiley, Chichester, 1993.
32. K. Tumay. Business Process Simulation. In J.M. Charnes, D.J. Morrice, D.T. Brunner, and J.J. Swain, editors, *Proceedings of the 1996 Winter Simulation Conference*, pages 93–98. ACM Press, 1996.
33. H.M.W. Verbeek, T. Basten, and W.M.P. van der Aalst. Diagnosing workflow processes processes using Woflan. *The Computer Journal*, 44(4):246–279, 2001.
34. H.M.W. Verbeek, M. van Hattem, H.A. Reijers, and W. de Munk. Protos 7.0: Simulation Made Accessible. In G. Ciardo and P. Darondeau, editors, *International Conference on Application and Theory of Petri Nets (ICATPN 2005)*, volume 3536 of *Lecture Notes in Computer Science*, pages 465–474. Springer-Verlag, Berlin, 2005.
35. G.J. de Vreede, A. Verbraeck, and D.T.T. van Eijck. Integrating the Conceptualization and Simulation of Business Processes: A Modelling Method and an Arena Template. *SIMULATION*, 79(1):43–55, 2003.
36. M. Westergaard. BRITNeY Suite: Experimental Test-bed for New Features for CPN Tools. http://wiki.daimi.au.dk/britney/britney.wiki, last access 04/10/2006.
37. M. Westergaard and K. Bisgaard Lassen. Building and Deploying Visualizations of Coloured Petri Net Models Using BRITNeY Animation and CPN Tools. In K. Jensen, editor, *Proceedings of the Sixth Workshop and Tutorial on Practical Use of Coloured Petri Nets and the CPN Tools (PB-576)*, pages 119–135, Department of Computer Science, University of Aarhus, Oct. 2005.