Modelling Business Process Performance[1]

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Abstract: We present a business process performance evaluation approach based on a hierarchy of interacting analytical performance models from semantic-oriented key performance indicator model through to the resource allocation optimisation model. Discussion of the human-centric process performance evaluation supported by the state-of-the-art presentation provides the motivation for our research work. Presentation of the hierarchical performance modelling architecture is followed by the detailed presentation of the component models representing respective performance evaluation perspectives.

1 Introduction

1.1 Motivation

The growing maturity of the BPM field has resulted in an increasing number of mission critical information systems relying on process-oriented software architectures. Although the workflow management discipline has primarily emerged as a collaboration platform, it has evolved into the ubiquitous enterprise application integration platform and finally has become the critical layer of the service-oriented architecture (SOA). Although the BPM research and development efforts have been attracted by these new aspects of the business process technology, the human-centric workflow management remains still the key critical success area for an overwhelming majority of advanced information systems. In fact, the current development trend shows that multi-paradigm business processes integrating human participants, often supported by application functions invoked by the workflow management platform, with intra- and inter-organization services, published as web services, are becoming the preferred information system solutions.

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The result of the above technological trend is the invasive character of business informatics with respect to the organizational environments supported by the advanced ICT solutions. Sound business process design methodologies are based on an interdisciplinary analysis and design approach providing new quality in information system architectures seamlessly integrated with the organization structures. Hence, the business process performance issues, in particular those pertaining to the process key performance indicators (KPI's), are distributed over the traditional boundaries dividing the information system and management sciences. This is particularly true for knowledge worker and administrative environments, where orchestration of human resource collaborations is the key to organization's success.

Our approach to process-oriented ICT solution development and deployment is based on the proprietary OfficeObjects® BPM methodology [OO05] as well as on workflow management techniques supporting adaptive business processes. An adaptive business process, sometimes called a dynamic business process, in order to support processing of many distinct transaction types, must have first of all the "runtime process rule binding" property coupled with the "dynamic process modification" features exploiting externally defined ontology representing application semantics of the process organizational environment. The process adaptability issues pertaining to the eGovernment application domain are extensively discussed in [eGB06]. An interoperable document management system developed with the use of the adaptive business process management techniques spanning over 30 central government agencies and supporting over 3 thousand users has been presented in [BM05].

Although adaptive business processes tend to be much more robust in withholding change in the process environment in comparison to tailor-made process solutions, the principal challenge is still managing instability of business process environments. Managing dynamic transformations of the business process environments entails among others such issues as:

1. Change in service requests (relative composition of transaction types)

2. Change in human resource availability within the business process role model

3. Change in process constraints:

    a. Time (response time , cycle time)

    b. Costs (human resource number and qualifications)

The business performance characteristics represented by assorted KPI's, designed to reflect the application semantics and constraints of business processes, are defined in terms of statistical values accumulated for a population of business processes over an observation period. They are usually reported by the balanced scorecard-like process dashboards selectively available to authorised business managers. Note, the one should not confuse the statistical KPI values with business process constraints and exception conditions, that should be reported instantaneously to interested parties over a customised messaging system.

The principal objective of the research and development work presented in the paper is to develop a business process methodology and tools supporting the performance-oriented business process design and improvement. This usually requires capability to analyse ex ante the process performance metrics and KPI's under the varying workload and resource constrain conditions.

Note, that such analysis is sometimes referred to as the "what if" analysis. The fact, that advanced workflow management platforms are capable of providing most of the performance metrics performing the ex post analysis of workflow logs, only strengthens our approach by facilitating sound calibration of the analytic business process performance models.

1.2 State-of-the-Art

Pursuing our research and development objectives in the area of business process performance modelling we have parted from the following baseline assumptions pertaining to the business process management field:

1. The human–centric and service-centric process paradigms may be reconciled and a mixed process work participant assignment approach may be adopted. Yet the human-centric focus is justified by the need to resolve hard human resource allocation problems in highly dynamic organizational environments.

2. Business processes embody relevant procedural, legal, and regulatory knowledge, therefore they should be profitably reused and adopted as "best practice" solutions. The adaptable business process technology coupled with robust performance modelling features are key to successful application of the adaptable business process solutions.

3. Analytic queuing network models may be used to model utilisation of process participant resources, both represented by human participants or information system services. The latter may be made available as web services or callable application components.

The focus on human-centric resource utilization analysis stems from our extensive experience in the area of administrative process management [BM05, RD07] as well as that pertaining to management of knowledge processes [IC04]. Significance of the human-centric business process management has been thoroughly presented by Michael zur Muehlen in [zM06]. In particular, discussion of the human workflow participant role models and scheduling disciplines are relevant both to our process workload as well as resource performance modelling approaches. The invasive character of the process-oriented business informatics has been strongly supported and discussed in [BPM05, OO05, S02, and SF03]. Simulation of human-centric workflows has been reported in [JP95].

Methodology and tools for development of adaptable business processes based on ontologies representing declarative procedural knowledge have been developed as principal results of the ICONS project [IC04] and they have been further expanded and presented in [OO05, eGB05, and eGB06]. The use of the Topic Maps standard [ISO00] for constructing domain ontologies have been presented in depth in [eGB06, IC04, OO05, P00, PM01]. The mapping of document meta-data to the business process meta-model to provide process control information constitutes and important part of the emerging document engineering field amply discussed in [GM05]. The use of externally specified business process ontology defined in OWL has been reported in [MR05]. Process adaptability coupled with an automatic process re-engineering model based on the external process performance knowledge base have been discussed in [JP95]. Logic rules for analysis of process performance data developed as a special-purpose language WPQL used for specification of the process performance ontology and the workflow log data mining have been presented in [AE02]. The use of externally specified business process semantics (i.e. the business process ontology) within a process design tool has been reported in [BM95].

Analytic queuing network models (QNM), in particular the Mean Value Analysis (MVA), have extensively been used for modelling of business process performance. All of the reported work concentrated on modelling performance of service-centric business processes mostly developed within the realm of BPEL and WS specification standards. The distributed workflow management and application software deployment configurations have extensively been modelled with the use of the layered MVA models. Results of this work have been reported in [AB07, JC01, KE01, and KE01a]. Management of service quality agreements with the use of analytic performance models has been discussed in [GW02]. Extensive bibliography of the analytical modelling solutions applied to business process performance evaluation has been assembled in [AB07].

The use of process performance parameters, both measured and predicted, for evaluation of key performance indicators (i.e. business process semantic performance metrics) has been thoroughly discussed in [BO5, GW02, LM04, and MR05]

2 Overview of the Business Process Performance Models

2.1 The Hierarchy of the business process performance models

The hierarchy of business process performance models presented in figure 1 facilitates separation of performance evaluation domains and their respective analysis methods and algorithms. The top level represented by the **business process enactment model** provides means to establish the workload metrics and key performance indicators for each business process class. The KPI's provide input to the **business process dashboard** designed to facilitate monitoring of organization's performance from the business process perspective.

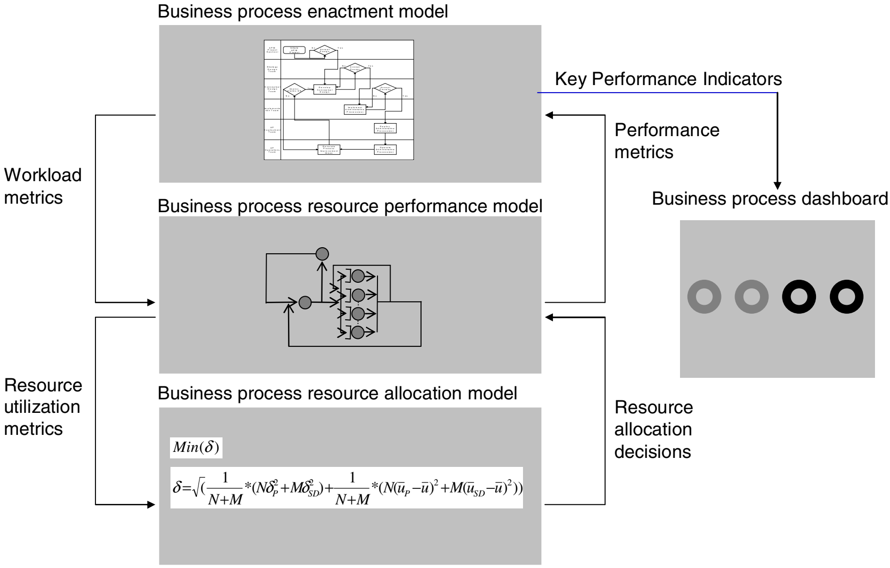

Figure 1. Hierarchy of business process performance models

The **business process resource performance model** represents the human resource configuration within the role model underlying the evaluated business processes and it provides algorithms to calculate the required performance metrics under the given workload characteristics. Thus obtained performance metrics are utilized by the upper level model to compute the KPI's for the business process classes composing the system workload.

The **business process resource allocation model** represents design and management decisions pertaining to the configuration of human resources within the organisation's role model used by the work participant assignment rules controlling the business process instance executions. The resource allocation model may be represented by an optimisation algorithm generating human role configurations optimal for a given goal function under the resource allocation constraints.

3 The Business Process Enactment Model

3.1 Anatomy of an adaptable business process

The adaptable business process enactment model presented in figure 2 includes all software and meta-data components representing the underlying application semantics necessary to execute instances of a given business process class. It also provides sufficient information to establish the workload metrics for a business process class. Typically an adaptable business process class may handle many transaction types processed by the corresponding human participant role configurations.

The **Business Process Topology** component includes the graphical process model specification and the corresponding busness process meta-model extension definition. The BPMN graphical notation [OM06] is used as the business process topology model representation paradigm integrated with the execution rules and the standard process meta-model, i.e. the **Workflow Management Specific**, representation following the WorkFlow Management Coalition [WC95] recommendations. The **Process Application Semantics Specific** part of the process **Meta-data** model, defined during the process design phase, is the key feature enabling extensibility of the business process meta-model. A thorough discussion of workflow management architectures may be found in [AH02].

The meta-data modelled by the application specific part of the meta-model comprises attributes to be populated with values during the business process instance execution. Typically, such meta-data is derived either by mapping selected content of information objects, such as documents, XML files, relational databases, and HTML web pages, or represents meta-model attributes to contain the business process application specific behavioural characteristics, e.g. the business process KPI values, generated during the process instance execution.

The meta-data attribute values derived from documents referenced and/or supported by a business process instance are created manually, usually during input of scanned textual documents, or they may be automatically mappings according to the mapping specifications maintained within the process ontology. In the former case the manual process may be eliminated, or substantially assisted, by the automatic text categorization features generating corresponding meta-data attribute values.

The meta-data attributes are **operated on** by the Business Process Query Language (BPQL) expressions executed by the workflow management platform **Rule Engine** [OfficeObjects2005, OfficeObjects2006]. The business process execution rules control the process routing behaviour as well as the work participant assignment functions executed during instantiation of the business process activities.

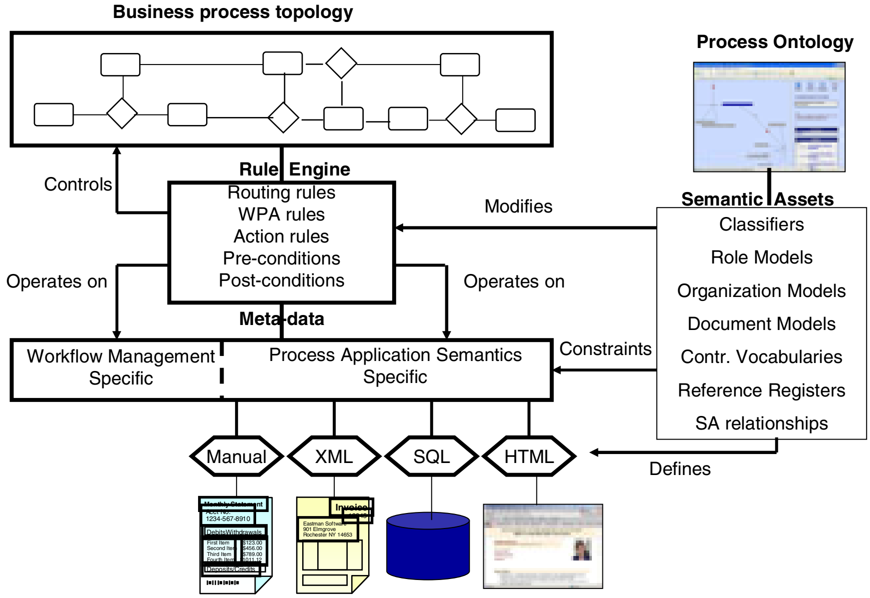

Figure 2. The business process enactment model

In order to achieve the business process adaptability, i.e. the capability to dynamically adjust the process behaviour to the specific application environment, one requires formal knowledge representation mechanisms to represent the appropriate meta-data. Since such information usually may serve many business process classes utilising the **Semantic Assets** to adapt behaviour of their instances, a separate **Process Ontology** module is the principal component enabling business process adaptability. The process ontology specification is supported by an extensible Topic Maps ontology language [ISO00, OO05, P00, PM01]. The semantic assets are either constraining the value domains of the business process meta-model, e.g. by the use of a controlled vocabulary to specify the corresponding attribute value domain, or they may comprise transaction categorisation trees designating the process execution rules to be used for dynamic process modification. The formal specification of the dynamic process modification technique is presented in [eGov-Bus2006].

Business process key performance indicators (KPI's) are statistical metrics pertaining to an adaptable business process class and, if required, to the specific transaction class supported by process instances. In order to represent the application semantics inherent in the KPI's interpretation, the process rules generating respective KPI values must be specified together with the corresponding meta-model attributes storing values of the BPQL predicate variables .

3.2 Business Process Workload Evaluation

We have already established that the business process role model represents the human resource configuration underlying the business process to be executed during the information system operations. For the sake of this discussion, we define a role to be a set of business process participants potentially performing tasks pertaining to a specific process activity. The business process instances are bound to the role model on two distinct levels; (1) the business process class definition level, where roles are represented by the BPMN graph swim lanes, and (2) the business process activity enactment level, where roles are specified by the work participant assignment rules. We call the first role type the **abstract role**, and the latter type the **concrete role**.

We define the family **abstract role participant sets** R_i where $1 \leq i \leq N$, and N is the number of human roles defined in the BPMN diagram The semantics of the BPMN diagram are such that the abstract role participant set R_i includes all potential participants of the i-th role meeting the participation criteria regardless of the transaction type processed within a specific business process instance.

The abstract roles defined in process topology diagrams partition the stakeholders of the analysed business processes into generic subsets (or participant groups) of process activity participants endowed with competences and authorisations. An example, may be all employees with competences to authorise supply invoices received by an organisation.

In order to reflect the effects of the work participant assignment rules defined within the business process specification, we define a family of **concrete role participant sets** CR_j, where $1 \leq j \leq M$, and M is the number of activities in the process graph. The concrete role participant sets are designated by the corresponding work participant assignment functions wpa_j, such that $CR_j = wpa_j(R_i)$, and $CR_j \quad 2^{R_i}$ (the powerset of R_i). Note, that the j-th process activity must be specified in the i-th swim lane of the BPMN diagram.

The concrete role sets further partition the business process stakeholders, or rather the abstract role sets defined for the given process activity, into the potential activity participant groups. An example may be a subset of all employees with competences to authorise supply invoices received by an organisation who may only handle invoices above a certain amount. For adaptable processes such role partitioning is usually defined in the process ontology within the transaction categorisation trees used by the dynamic process modification algorithms.

The business process class workload to be processed by the resource performance model is characterised by the visit vector $V = \langle v_1, \ldots v_j, \ldots v_M \rangle$, where v_j = the number of executions of the process activity A_j for one execution of the corresponding process instance. We further define a service requirement vector $S = \langle s_1 \ldots s_j \ldots s_M \rangle$, where s_j is the average time to perform process activity A_j by resources CR_j. Finally, N_k is the number of concurrent transactions within the k-th transaction type, where $N = \sum_{k=1}^{K} N_k$, where N is the number of all concurrent transactions handled by the business process class and K is the number of transaction type.

The workload characteristics may be established for each business process class to be concurrently processed by the human resources partitioned into the respective concrete role sets within the organisation. Composition of the business process workloads to be input to the lower level models depends on the performance evaluation objectives and the human resource participation characteristics.

The hard part of performance modelling projects is to achieve proper calibration of performance evaluation models, in particular establishing the sound system workload characteristics. In the case of business process management systems, all of the above workload metrics may usually be obtained by statistical analysis of the process execution logs. The ex ante performance analysis may be performed with the use of current real workload characteristics varied by the workload change assumptions to be evaluated from the resource utilisation vantage point. This would be a typical approach to study variations in transaction type composition and their relative frequencies.

Performance evaluation of business processes still in the design and implementation stage requires a more complex workload modelling approach based on the probabilistic evaluation of process graphs producing the routing probability values for each of the process graph transitions. A matrix of routing probabilities allows for computation of the activity visit rates. A similar approach to workload evaluation applied to data base programming languages has been presented in [S83].

4 Business Process Resource Performance Model

The business process resource performance model is represented by a closed queuing network model (figure 3), such that:

- A service center SC_j is a bi-directional mapping of the concrete role participant set CR_j
- A service center SC_j is modelled as multi-service center with the number of processors $p_j = Cardinality(CR_j)$.

- The $(M+1)th$ service center is a delay centre with the service time $s_{M+1} = 0$ and the visit rate $v_{M+1} = \sum_{j=1}^{M} v_j$. We call this service center the "WPA Dispacher"

- The $(M+2)th$ service center is a delay center with the service time $s_{M+2} = 0$ and the visit rate $v_{M+2} = 1$. We call this service center the "Process Initiator/Terminator".

- The service demand at the $j\text{-}th$ service center $D_j = v_j * s_j/p_j$

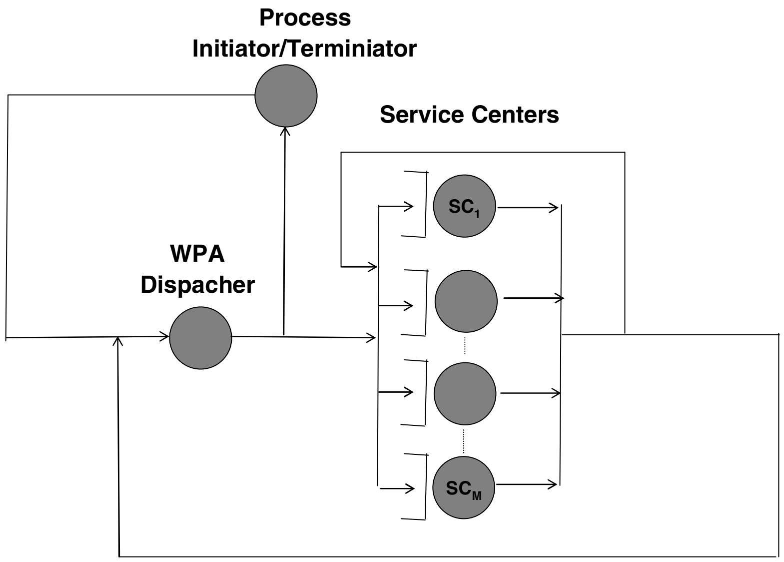

Figure 3. Business process resource performance QNA model

The performance metrics are computed with the use of the Mean Value Analysis algorithm [LZ84] producing the following performance metrics for each service center SC_j :

- Utilization $U_j = B_j / T$, where B_j is the number of time unites the $j\text{-}th$ service center is busy, T is the observation period

- Average residence time $Rj=(time\ in\ service + time\ in\ queue)$ at the $j\text{-}th$ service center

- Average queue length Q_j = *(number of requests in queue + number of requests in service)* at the *j-th* service center

The use of queuing network models (QNM), and in particular application of the MVA performance evaluation algorithms, are constrained by formal requirements, i.e. the queuing network model separability constraints, that must be met to obtain mathematically tractable models. The following discussion shows that our process resource performance model meets the QNM separability assumptions defined in [LZ84]:

- *Service center flow balance assumption* – the number of arrivals at each center is equal to the number of completions there. This requirement is met by all workflow management systems, since all enacted process activities must be completed.

- *One step behaviour assumption* – no two processes in the system "change state" at exactly the same time. This is clearly a characteristic of all centralised computer systems and also holds for the workflow management systems. In the case of distributed workflow management platforms, we assume such system behaviour, due to the order of magnitute difference of the human service times with respect to state transition functions of the workflow management platform.

- *Routing homogeneity assumption* – the proportion of times that a process completing service at the *j-th* center proceeds directly to the *k-th* center is independent of the current queue lengths at any of the service centers, for all j and k. The assumption holds for workflow routing algorithms, which enact the process rules independently of the current business process workload in the system.

- *Service center homogeneity assumption* - the rate of completion of process activities may vary with the number of tasks at that center, but otherwise may not be dependent on the number of placements of tasks within the service center network. The load dependent behaviour usually occurs at service centers below a certain request threshold level, and clearly such behaviour is independent of workflow situation (i.e. workflow task lists) pertaining to other concrete role participant sets (service centers).

- *Homogeneous external arrival assumption* – the times at which arrivals from outside the network occur may not depend on the number of processes in the network. This is clearly a characteristic of workflow management systems, where the number of process instance enactments is always independent of the current system workload.

We would like to stress, that even models that violate the above assumptions may be tractable by the general queuing theory or stochastic simulation techniques. In such situations, one must resort to hierarchical modelling with the use of flow equivalent centers [LZ84].

5 Business Process Resource Allocation Model

The resource allocation optimisation goals aim usually at increasing system throughput by removing the resource bottlenecks or at minimising the business process handling costs by re-assigning resources. In the latter case, a change in process rules, in particular in the work participant assignment rules determining the configuration of the process role models, must be introduced. Resource allocation optimisation problems may be solved with the use of a whole spectrum of allocation design techniques, from optimisation algorithms, thru solution search heuristics, to the manual design procedures.

The process performance analysis in the resource allocation context usually concentrates on such variations of business process workload characteristics as the change of transaction volumes and relative frequencies, as well as the change of transaction service requirements. The latter usually results from modification of the role model configuration, usually represented by variations of the role participant set cardinalities.

The typical business process constraints limiting the resource allocation decision space are the business process temporal constraints, such as the process cycle time or average activity times, or the resource cost constraints. An example of a straightforward process throughput optimisation problem aiming at removing, or rather balancing, the resource bottlenecks is presented in figure 4. The optimisation goal function smoothes the service center utilisation metrics, thus balancing their respective. throughputs. The cost constraints do not allow exceeding costs of the *j-th* and *k-th* service centers to *1000* and *500* units respectively.

$$Min\ (\delta_{SC})\ where:$$

$$\delta_{SC} = \sqrt{\frac{1}{M}\sum_{j=1}^{M}(u_j^{SC} - \overline{u}_{SC})}$$

$$and$$

$$\mu(SC_j) \leq 1000$$

$$\mu(SC_k) \leq 500$$

M - the number of service centers SC

δ_{SC} - standard deviation of the set of service centre SC utilisation metrics

u_j^{SC} - utilisation of the service center SC_j

$\overline{u}_{SC}$ - the average utilisation metric of the set of service centers SC utilisations

$\overline{u}$ - the average utilisation metric for the sum of processing and data storage centre utilisation metric sets

μ - The cost evaluation function defined for service centers SC_j, where 1≤j≤M. The cost evaluation function computes a product of the number of visits to service center SC_j and the average cost of servicing a task at this center.

Figure 4. The throughput optimisation problem with process cost constraints

6 Business Process KPI Model

We defined the key performance indicators to be metrics representing the application semantics of business processes. Such metrics are computed as statistical values providing behavioural characteristics of a population of process instances belonging to a process class over an observation period. Analogically to the balanced scorecard indicators, the business KPI's are of interest to organisation's management and they are usually reported by graphic diagrams presented by the business process dashboard managed by the workflow management system platform.

The KPI's are usually defined as the process exception conditions metrics reporting such process class behavioural characteristics as incidence of process compensating activities, incidence of delayed process activities, or incidence of delayed processes. KPI's representing complex application semantics may be defined with the use of the business process rule language action rules and the extensible process meta-model features [OO05, OO06].

A family of cost-based KPI's may also be defined for a business process class provided that appropriate cost coefficients are maintained within the process transaction categorisation trees comprising the role specifications externally stored in the process ontology. Such KPI's are commonly used to track usage data pertaining to scarce or over-utilized resources, to detect unproductive business process cycles, or peaks in high-cost transaction arrival frequencies.

7 Conclusions

Business process performance monitoring and modelling are key factors enabling continuous management improvement. In particular, business processes invoked by published services constrained by the corresponding service level agreement require sound performance-oriented design methodologies as well as the continuous performance monitoring features.

The business process performance hierarchical models provide a robust and consistent platform representing process monitoring and modelling perspectives, both with respect to the resource utilisation metrics and the process temporal characteristics, as well as the KPI's representing complex application semantics.

Analytical models coupled with resource allocation optimisation algorithms may be incorporated in the business process design tools to facilitate performance-oriented design supported by the sound ex ante performance analysis of new or modified business process models.

Further research is required to exploit the advanced performance modelling results in the business process monitoring and modelling context. A promising research area seems to be hierarchical modelling of business process resource performance models exploiting available performance modelling techniques from QNM, thru general queuing theory, to stochastic simulation. The hierarchical performance models must be coupled with sound business process workload evaluation techniques and algorithms reflecting complexities of advances business process specification features.

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