An Evaluation of Process Warehousing Approaches for Business Process Analysis

Khurram Shahzad, Paul Johannesson

Department of Computer and Systems Science (DSV),
Royal Institute of Technology (KTH)/ Stockholm University (SU),
Stockholm, Sweden.
{mks,pajo}@dsv.su.se

Abstract. Execution of a process model produces data that can be used for analysis and optimization of business processes. For several years, data warehouse (DW) technology has been used for analysis and decision making. A data warehouse developed for business processes is called a process warehouse. The capabilities of a process warehouse are seldom evaluated, since a generic framework that can be used for the evaluation is missing. Therefore, in this paper, we develop a generic framework called Process Analysis Framework (PAF) that can be used for evaluating analysis capabilities of a process warehouse. Furthermore, the framework has been used to evaluate various process warehousing approaches, collected through a comprehensive survey.

Keywords: Business process management, Business process monitoring, Business process analysis, Process warehouse.

1 Introduction

Process analysis is a feedback phase of business process management in which reviewing of process execution takes place. Interest for business process analysis is increasing in order to monitor, evaluate and optimize business processes [1, 2]. The data collected during process execution is used for process analysis [3]. Process analysis can: effectively improve efficiency, reduce cost and increase the productivity of process execution [1, 3]. This is done by optimizing resources, activities and actors [4].

For more than a decade, data warehouse (DW) technology has been used by enterprises for analysis and decision support purposes. DW presents the analytical data integrated from different sources in multi dimensional form in order to support analyses not only from different perspectives but also at different levels of granularity [5]. For some years, data warehouse technology has been proposed to be used for business process analysis [7, 8], called process warehouse [6]. Also, some studies [8, 9, 10, 11] have been conducted on designing data warehouses for business processes. In this paper, the two terms process warehouse and data warehouse for processes are used alternatively.

To the best of our knowledge, no study has been conducted to evaluate the capabilities of a process warehouse. There are some studies (like [8, 9, 12]) that partly includes some sort of evaluation, but a comprehensive evaluation of the capabilities of process warehouse is still missing. This is due to the fact that a generic framework that can be used for analysis of process warehouse is missing.

The purpose of this study is to evaluate capabilities of process warehousing approaches. However, no generic framework is available that can be used for this purpose. Therefore, at first we develop a 'Process Analysis Framework' (PAF) and then use it for the evaluation of eleven process warehousing approaches that were selected through a comprehensive survey. The framework is based on the simple logic that if processes are modeled from four perspectives [13] they should also be analyzed from these four perspectives. These are functional, behavioral, organizational and informational perspectives. However, the important aspects about goals and design challenges are not covered in these four perspectives. Therefore, PAF is extended by including these two perspectives, goals and modeling challenges.

The contributions of this study are: a) a framework for the evaluation of process warehouse, b) identification of major process warehousing approaches, c) a comprehensive evaluation of process warehousing approaches and d) identification of deficiencies of process warehousing approaches.

The rest of the paper is organized as follows. Section 2 introduces the Process Analysis Framework. Section 3 contains a brief introduction to process warehouse designing approaches. In section 4, results of the evaluation of process warehousing approaches are given. A discussion about evaluation of approaches along with conclusions and future research directions is given in section 5.

2 The Process Analysis Framework (PAF)

In this section, we present a process analysis framework that is used (in section 4) for the evaluation of process warehousing approaches. Primarily, the process analysis framework consists of five perspectives (functional, behavioral, organizational and informational and goals perspectives). Furthermore modeling challenges are also part of PAF.

It is an established fact that process modeling takes place from four perspectives, functional, behavioral, organizational and informational perspectives [13]. Therefore, it is logical to say that a data warehouse developed for processes should support the analysis of business processes from these four perspectives. For that reason, the four perspectives are the main parts of the Process Analysis Framework.

The four perspectives do not capture important aspects of process analysis like goals, and goals have been extensively emphasized by a number of researchers as an important perspective [14, 15, 16]. For that reason, the goals perspective is included in the Process Analysis Framework. Designing a process warehouse is a challenging task and a number of issues must be considered while designing process warehouse [6, 7]. Therefore, modeling challenges are also included in PAF as an important perspective for the evaluation of process warehousing approaches.

Here, we define the perspectives and a set of analysis parameters (APs), for each perspective. In order to support a perspective, an approach must fulfill the requirements of the analysis parameters, as defined below. Mainly, the analysis parameters are elicited from the generic meta-model of business processes [14] that captures multiple perspectives of a business process.

- ***Functional perspective*:** This perspective represents *'what'* elements of a process model are performed and flows of entities relevant to these process elements [13]. For studying functional perspective process warehouse should support the following analysis parameters *a) Activity analysis,* this analysis answers questions like which activities are executed, which are failed, which activities are not executed, etc. This parameter checks whether activities analysis can be done by a process warehouse or not. *b) flows of informational entities,* this analysis answers questions like what information flows between elements of a process and which elements are involved in the flows [14]. *c) subprocess analysis,* this analysis answers questions like how a process is decomposed and collectively how the subprocess work together to achieve a single goal.
- ***Behavioral perspective*:** This perspective represents *'when'* and *'how'* elements of a process are performed and their execution within the process [13]. For studying the behavioral perspective, a process warehouse should support the following, *a) execution order analysis,* this analysis answers questions like which elements can be executed in series or in parallel etc. *b) cycle-time analysis,* the analysis answers questions related to the amount of time consumed by each process, start time and stop time of a process. *c) anomalous behavior analysis,* this analysis answers questions like anomalies in execution of a process, *d) path analysis,* this analysis answers questions like which path is followed in parallel flows against an event, *e) deadline analysis,* this analysis answers questions like how many time deadlocks were occurred during process execution.
- ***Organizational perspective*:** This perspective represents *'where'* and *'by whom'* process elements are performed and presence or absence of resource triggers a task [13]. For studying the organizational perspective, the following analysis must be supported: a) *resource analysis*: this analysis answers questions like which resources are available, consumed etc. *b) organizational unit analysis,* this analysis answers questions like the processes associated with an organizational unit etc. *c) Participant analysis,* this analysis answers questions like amount of participants associated with a process and the number of processes associated with a participants, *d) software or service analysis,* this analysis answers questions like the software associated with a process and the role of each software in a process.
- ***Informational perspective*:** This perspective is about data imparted, consumed and produced by elements of a process. Also, it is about informational entities produced or manipulated by a process, structure of information entities and relationships among them [13]. For studying informational perspective following analysis must be supported, *a) input analysis,* the analysis answers questions related to, the amount of input required to trigger a process etc., *b) consumption analysis*, this analysis answers questions related to, the resources consumed during a process execution, *c) output analysis,* this analysis answers questions like the number of times a process was successfully executed etc.

- ***Goal*:** A process model includes a set of activities that are used to achieve a certain business goal [15]. This perspective represents the extent to which the goal of a process model is achieved.
- ***Modeling challenges*:** Modeling challenges are also known as design challenges. There are some challenges [5] of developing a data warehouse in general. However, we here discuss only challenges that are specific for process warehouses. The following is a list of challenges collected from different sources [6, 7, 8, 14, 17, 18] that must be addressed by a process warehouse. a) M:M relation between dimension and fact, b) Heterogeneity of fact entries (multi-leveled), c) Interchangeability of fact and dimension roles, d) Conceptually complex aggregations, e) Diversity & evolution management, f) Business process context addition.

3 Process Warehousing Approaches

In this study, we have evaluated a number of process warehousing approaches that can be used for process analysis. The choice of these approaches is based on a comprehensive search through major databases like (Springelink, ACM DL, IEEE Xplore) by using several keywords and phrases like process warehousing, data warehouse for business processes, process analysis, designing process warehouse, data warehouse for workflows, workflow analysis and designing multidimensional schema for business processes. A total of 29 studies related to process warehousing were found during the survey. From these approaches, 11 were included in the study, as only these approaches covered design aspects of process warehousing. A brief description of these approaches is as follows:

- ***Goal driven DW design (GD) [11]:*** The approach is based on GQ(I)M [28] to define goals and questions for identifying indicators. According to this approach, at first goals are defined and then analyzed to produce subgoals and measurement goals. Questions (which can identify achievement of the goals) are developed for measurement goals. Later, these questions are used to identify indicators. The indicators are finalized through refinement, to design DW model. The developed data warehouse is used for process measurement i.e. for 'recognition of the business process execution results using indicators' [11]. Common logical modeling technique is used for conceptual modeling of process warehouse.
- ***Data warehousing designing approach (DWD) [12]:*** According to this approach, as a preparation to the identification of relevant dimension, entire surgical workflow-recording-scheme is developed by using extended entity relationship (EER) notations. Multidimensional schema can be derived from the EER by examining relationship cardinalities and functional dependencies between attributes. Some guidelines developed by Lechtenbrger et al. [19] are used for this purpose. The developed DW is used for surgical workflow analysis. In this approach, 'dimensional fact model' [20] is used for conceptual modeling process warehouse.

- ***Multidimensional modeling approach (MDM) [8]:*** The approach is based on recording scheme of a process as a UML class diagram. According to this approach, structure of cubes is designed by applying vertical and horizontal decomposition. Vertical decomposition determines two granularity levels of fact structures, whereas, dimensions are determined by horizontal decomposition. The obtained dimensions are refined by developing dimensional hierarchies. The approach is developed for surgical process model. In this approach, 'dimensional fact model' is used for conceptual modeling of process warehouse.
- ***Generic warehousing solution (GDW) [17]:*** This approach develops a generic data warehouse for business process models. There is no formal procedure of designing DW however the key solutions of the approach are, 'i) single granularity for each step, ii) single fact table for any step of any process with aggregation of most common measures, iii) correlation with previous step data handled via additional column, iv) separate business data tables per each process types, v) blind links to handle step process correlation with business data' [17]. Common logical modeling technique is used for conceptual modeling of process warehouse.
- ***Data warehouse for logs (DWL) [9]:*** The approach is based on generic workflow metamodel and the typical information needed for process managers. According to this approach, explicitly collected queries (which should be answered) are collected and these queries work as a requirements. Dimensions are collected directly from workflow metamodel. Since time is not available in the metamodel therefore, it is added. DW is designed in such a way that it answers all the formulate queries. The developed DW is used for aggregating, analyzing and comparing data and discovering irregularities. In this approach, 'ADAPT notations' [22] are used for modeling of process warehouse.
- ***Concept-centric Process Data warehouse (CDW) [6]:*** This approach extends DWQ project [21] to the case of process data warehouse. However, no method for designing process warehouse is presented. According to this approach, partial models are produced which provides a view of concepts and relationships of an enterprise. The models are transformed to description logic formalism and enriched through intramodel assertions in order to identify constraints. The approach is applicable for processes in chemical engineering domain. Conceptual model of process warehouse is not presented.
- ***Performance data warehouse (PDW) [23]:*** Application design for analytical processing technologies (ADAPT) approach is used for data warehouse. No formal methodology is used for designing data warehouse. The developed data warehouse can be used to facilitate business process improvement that is based on holistic performance measurement. In this approach, 'ADAPT notations' are used for modeling of process warehouse.
- ***Goal-oriented data warehouse design (GoD) [10]:*** The focus of this approach is a goal oriented methodology for requirement analysis in order to design a data warehouse. The goal oriented methodology is used within a demand-driven and mixed supply driven design framework to produce data warehouse design. According to GoD approach two different perspectives (organizational modeling and decisional modeling) are integrated for requirement analysis. From the two perspectives, goal analysis, fact analysis and attribute identification takes place. Requirements are then mapped onto source schema and hierarchies are constructed

and refined. In this approach, 'dimensional fact model' is used for conceptual modeling of process warehouse.

- ***Process Data Store (PDS) [24]:*** The process data store provides nearly real-time access to critical performance indicators of business processes. There is no formal modeling method proposed in the study and common logical modeling technique is used for conceptual modeling of process data store (DS). The process data store has two types of data, a) very detailed event data, b) detailed up-to-date process data at various granularity levels. DS provides real time access to critical process performance indicators to improve the speed and effectiveness of workflows. Common logical modeling technique is used for conceptual modeling of process warehouse.
- ***Process oriented DW structures (PoWS) [25]:*** The approach is adopted with modification of comprehensive business engineering methodology SOM of Ferstl/Sinz [26]. According to this approach, goals, subgoals relationship between then and services are identified. Main processes are marked off by analyzing business process. Afterwards, conceptual object schema (COS) is developed from interaction and task-event schema. Finally, initial DW structures i.e. metrics, dimension and constraints are identified. Common logical modeling technique is used for conceptual modeling of DW.
- ***Data Warehouse for audit trial (DWM) [27]:*** According to this approach, a data model is developed for capturing workflow audit trial data, relevant to process performance evaluation. After that, a logical model is constructed that characterize derivation of evaluation data from workflow audit trails. The logical model is used to develop dimensional model of data warehouse. The data warehouse is used for business process performance evaluation towards accessing and improving e-business operations. Common logical modeling technique is used for modeling process warehouse.

4 Evaluation

Using the Process Analysis Framework presented in the previous (section 2), we evaluate the eleven approaches from section 3. We study whether each approach supports the analysis of a business process from the functional, behavioral, organizational, and information perspectives. Furthermore, we evaluate whether goals perspective and modeling challenges are considered while designing process warehouse.

The evaluation results of the analysis parameters (recall that each perspective includes a number of analysis parameters) are represented on a scale, where the possible values are: emphasized, included, considered, ignored or no information. The value of an analysis parameter is a) emphasized, if the analysis parameter is the focus of the approach, b) included, if the analysis parameter is covered by the approach, c) considered, if either some aspects of the analysis parameters are present directly or some aspects are not conceived, d) ignored, if the analysis parameter is not supported, e) no information (no info), if we could not define whether the analysis parameter is

included or not. The reasons for no info are that the information is not complete, or it is not understandable.

For the analysis of a business process from the functional perspective, a process warehouse should support activity analysis, information flow analysis and analysis of sub processes, if any. Activity analysis is 'included' or 'considered' by most of the approaches with the exception of GDW. In the GDW approach. instead of activities, tasks are emphasized. Therefore, the value in table 1 is 'emphasis on tasks'. Flows of informational entities are ignored by DWL, PDW and PoWS, whereas it is supported by CDW, GoD, DWM approaches is not understandable, due to absence of any discussion about information entities. The GoD approach does not provide any schema of data warehouse therefore inclusion of sub process analysis could not be understood. Also, DWD does not have any clear discussion about the analysis of sub processes, therefore the value is 'no info'. Results of the evaluation of each approach from the functional perspective are given in table 1.

Table 1. Functional Perspective

	Activities Analysis	Flows of informational entities Analysis	Subprocess Analysis
GD	Considered	Considered	Ignored
DWD	Included	Included	No Info
MDM	Included	Included	Included
GDW	Emphasis on Tasks	Included	Ignored
DWL	Included	Ignored	Included
CDW	Considered	No Info	Considered
PDW	Included	Ignored	Included
GoD	Included	No Info	No Info
PDS	Included	Considered	Included
PoWS	Included	Ignored	Ignored
DWM	Included	No Info	Ignored

From behavioral perspective, GD approach only supports cycle-time analysis of a business process. Deadlock or exceptions analysis is ignored by most of the approaches. Since there is no schema or discussion about execution order therefore from CDW and PDW we could not understand whether analysis of execution order is supported or not. Anamalous behavior is not included in any approaches, however GDW, DWL, PDS considers this analysis. GDW approach is the only approach that supports path analysis. Results of evaluation of each approach from behavioral perspective are given in table 2.

Table 2. Behavioral Perspective

	Execution Order	Cycletime	Anamolous behavior	Path	Deadlock/Exception

GD	Ignored	Considered	Ignored	Ignored	Ignored
DWD	Included	Included	Ignored	Ignored	Ignored
MDM	Included	Included	Ignored	Considered	Ignored
GDW	Included	Included	Considered	Included	Included
DWL	Included	Included	Considered	Ignored	Ignored
CDW	No Info	No Info	No Info	No Info	No Info
PDW	No Info	Included	Ignored	Ignored	Included
GoD	Considered	Considered	No Info	No Info	No Info
PDS	Included	Included	Considered	Considered	No Info
PoWS	Considered	Included	Ignored	Ignored	Ignored
DWM	Included	Included	Ignored	Ignored	Included

The results of evaluation of process warehousing approaches from the organizational perspective are given in table 3. Resource analysis is ignored by DWL, PDW, PoWS and DWM. GoD approach since it is not clear whether participant discussion is included or not, because it seems that author has some assumptions about participants, therefore 'no info' is market for GoD approach. GDW schema is not complete therefore it is difficult to decide whether organizational unit analysis and software system analysis is supported or not. Similarly, due to absence of schema in CDW support of organizational unit and software systems cannot be evaluated. DWL is the only approach that contains information about softwares/service.

Table 3. Organizational Perspective

	Resource	Participant	Organizational Unit	Software system & services
GD	Considered	Included	Ignored	Ignored
DWD	Included	Considered	Included	Ignored
MDM	Included	Included	Included	Considered
GDW	Included	Included	No Info	No Info
DWL	Ignored	Included	Included	Included
CDW	Considered	Considered	No Info	No Info
PDW	Ignored	Included	Included	No info
GoD	Considered	No Info	Considered	No Info
PDS	Included	Included	Considered	Ignored
PoWS	Ignored	Considered	Ignored	Ignored
DWM	Ignored	Included	No Info	Ignored

For analysis of a process from information perspective, input analysis, data consumed and output analysis should be analyzed. Input analysis is ignored in most of the

approaches. Data about consumed elements in a process are not included by processes. About output, some approaches like MDM, GDW, PDS and DWM, support output analysis. Results of evaluation of each approach from behavioral perspective are given in table 4.

Table 4. Information Perspective

	Input Analysis	Consumption Analysis	Output Analysis
GD	Considered	Ignored	Considered
DWD	Included	Ignored	Ignored
MDM	Included	Included	Included
GDW	Included	Considered	Included
DWL	Ignored	Ignored	Considered
CDW	No Info	No Info	No Info
PDW	No Info	Ignored	Ignored
GoD	No Info	No Info	No Info
PDS	No Info	Ignored	Included
PoWS	Ignored	Ignored	Considered
DWM	Ignored	Considered	Included

In some of the process warehousing approaches, goals are a part of process warehouse design approach, but they are not included in the design of the process warehouse produced by the approach. Therefore, instead of using key words (like emphasis, considered etc.) a small explanation about involvement of goals by each approach is given in table 5.

Table 5. Goals Perspective

	Goals Analysis
GD	Goals driven approach is used for designing process warehouse. Goals and subgoals are defined by GQ(I)M [28] and analyzed to define measurement goals. Measurement goals are latterly used for notational model from which dimensions and facts are derived. However, goals are not included in the final process warehouse design.
DWD	The concept of goal is completely ignored during the development of conceptual model for PW. Also the concept of goals is completely missing from the dimensional schema of PW.
MDM	The concept of goal is completely ignored during the development of conceptual model for PW. Also the concept of goals is completely missing from the dimensional schema of PW.
GDW	The concept of goal is completely ignored during the development of conceptual model for PW. Also the concept of goals is completely missing from the dimensional schema of PW.

DWL	The concept of goal is completely ignored during the development of conceptual model for PW. Also the concept of goals is completely missing from the dimensional schema of PW.
CDW	The concept of goal is completely ignored during the development of conceptual model for PW. No dimensional model is presented therefore inclusion of goals in the dimension schema cannot be identified.
PDW	According to this approach, goals are included as a part of auxiliary data, in the form of a goal tree. Individual goals are specified by key performance indicators and for each indicator target and actual performance [23].
GoD	GoD technique adopts two perspectives for requirement analysis i.e. organizational and decision modeling. In both perspectives, goals analysis is the starting point for collecting and analyzing requirements. Later, these requirements are mapped and refined for process warehouse design.
PDS	The concept of goal is completely ignored during the development of conceptual model for PW. Also the concept of goals is completely missing from the schema of data store.
PoWS	This approach consists of four steps. In the first step, goals are identified followed by deep understanding of each goal in the form of subgoals and their relationships. Also, services and subservices are identified that fulfill these goals. In the remaining steps, business processes are analyzed conceptual object schema is derived and finally DW structures are defined.
DWM	The concept of goal is completely ignored during the development of conceptual model for PW. Also the concept of goals is completely missing from the dimensional schema of PW.

In table 6 and 7 results of evaluation of process warehousing approaches, interms of their ability to meet modeling challenges, are presented. The possible values are, yes, no, no discussion (ND). If there is an explicit discussion on the problem and solution, the value is 'yes'. The value is 'no' if there is a discussion on some designing challenges, but the specific challenge is not addressed. Whereas, if there is no discussion in the approach, about any design challenge, the value is 'ND'.

GD, CDW, GoD, PoWS and DWD approaches presents a process warehouse without any consideration of design challenges. Whereas the remaining approaches presents some solutions against a set of challenges. Table 6 and 7 presents the detailed evaluation of each approach.

Table 6. Challenges of process warehousing A

Challenges	GD	DWD	MDM	GDW	DWL
M:M relation between dimension and fact	ND	ND	Yes	No	No
Heterogeneity of fact entries (multileveled)	ND	ND	Yes	Yes	No
Interchangeability of fact and dimension roles	ND	ND	Yes	No	Yes
Conceptually complex aggregations	ND	ND	No	No	No
Diversity & evolution management	ND	ND	No	No	No

Business process context addition	ND	ND	No	Yes	Yes

Table 7. Challenges of process warehousing B

Challenges	CDW	PDW	GoD	PDS	PoWS	DWM
M:M relation between dimension and fact	ND	No	ND	No	ND	Yes
Heterogeneity of fact entries	ND	No	ND	No	ND	No
Interchangeability of fact and dimension roles	ND	No	ND	No	ND	No
Conceptually complex aggregations	ND	No	ND	No	ND	Yes
Diversity & evolution management	ND	No	ND	No	ND	No
Business process context addition	ND	No	ND	Yes	ND	No

5 Discussion and Conclusions

In this paper we have evaluated the analytical capabilities of eleven process warehousing approaches. A comprehensive framework that can be used for evaluation of process warehousing approaches is not available. Therefore, we have developed a Process Analysis Framework (PAF). This framework is primarily based on four established perspectives (functional, behavioral, organizational and informational) from which a process model is developed. Furthermore, the framework was used to evaluate the capabilities of process warehousing approaches.

MDM and PDS approaches support analysis of a process from the functional perspective, whereas, GDW, DWL, CDW, PDW approaches allow the analysis of a process significantly. There are some approaches (e.g. DWD, CDW, GOD DWM) that support the analysis of a process to some degree. However due to the absence of accurate and complete description it is difficult to precisely determine the degree to which the functional perspective analysis is supported by the approaches.

GDW andDWM support analysis of a process from the behavioral perspective to a large extent, however, some aspects of behavioral analysis are missing. Most of the approaches (e.g. DWD, MDM, DWL, PDW, PDS) support the analysis to some degree. The remaining four approaches do not support analysis of processes behavioral perspective.

There are some approach (e.g. MDM, DWL) that support the organizational perspective. Furthermore, there are approaches (DWD, GDW, PDW, PDS) that cover the organizational perspective to some degree. However, the remaining approaches either ignore organizational perspective or the information about supporting or not supporting of the analysis is not complete.

The information perspective is supported by three approaches (MDM, GDW, DWL). However, either the perspective is not supported or the description is not complete for the CDW, PDW and GoD approaches. DWD, PDS, PDWS approaches slightly support analysis of a process from information perspective. To some degree,

GD and DWM approaches support the analysis of a process from the functional perspective.

Most of the approaches (DWD, MDM, GDW, DWL, CDW, PDS, DWM) ignore the goals perspective while designing process warehouse. Furthermore, the remaining approaches consider goals while defining requirements or while designing process warehouses.

The challenges of designing process warehouse are not defined in half of the approaches (GD, DWD, CDW, GoD, PoWS). The approaches like GDW, DWL, PDW, PDS or DWM ignored most of the challenges or at least some challenges, while designing a process warehouse.

Based on the Process Analysis Framework, our study shows the following: a) it is possible to evaluate the capability of a process warehouse, b) often the challenges of designing process warehouses are not addressed, c) a very small number of the studied approaches consider goals while designing process warehouses, d) a design of a process warehouse that supports comprehensive analysis of processes is missing, e) there is a need of a process warehouse that entirely supports the analysis of processes from all the perspectives that are used for designing business processes.

Future research aims to identify a method for collecting requirements of a process warehouse that supports the analysis of business processes from various perspectives. Also, it is planned to develop a method and guidelines for developing a comprehensive process warehouse design. To test the applicability of the proposed method, we also plan to conduct a case study related to a real-time healthcare process. Nonetheless, we aim to quantify the affect of using process warehouse for business process analysis.

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