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Enterprise Architecture Intelligence

Combining Enterprise Architecture and Operational Data

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***Abstract*—Combining enterprise architecture and operational data is complex (especially when considering the actual 'matching' of data with enterprise architecture objects), and little has been written on how to do this. Therefore, in this paper we aim to fill this gap and propose a method to combine operational data with enterprise architecture to better support decision-making. Using such a method may result either in an enriched enterprise architecture model (which is very suitable as a basis for model-based architecture analyses), or in a warehouse data model where operational data is enriched with enterprise architecture metadata (which leads to more traceability by easing the retrieval and interpretation of raw data, and of business analytics results). The method is illustrated by means of a case study. Also, a model to store enterprise architecture, operational data and time is presented on which new forms of analysis may be performed.**

Keywords—enterprise architecture; operational data; business intelligence; quantitative analysis; database; model.

I. Introduction

When having to decide about strategy and investments, managers deal with complex situations that could influence their future of their organizations. They often use Business Intelligence (BI) solutions to visualize data for decision support. In a report of Gartner [1], predictions are that BI and analytics will be the top focus of CIO through 2017. According to Gartner, *"the benefits of fact-based decision-making are clear to business managers in a broad range of disciplines, including: marketing, sales, supply chain management, manufacturing, engineering, risk management, finance and HR"*. Typically, facts that underlie decision-making are extracted from various data sources (e.g., back-office systems, big data, etc.), consolidated in a corporate data warehouse and then analyzed using a rich variety of quantitative techniques, with the aim of measuring, monitoring, and visualizing the levels of different key performance indicators (KPIs) and of other variables. Such information is presented to managers in a synthetic form in so-called performance dashboards, and is believed to ease and rationalize the decision making process and lead to better decisions. However, BI solutions do not address the gap that exists between, on one hand, the organization's *structure*, which is typically captured and documented in an enterprise architecture (EA), and, on the other hand, the *data* that is analyzed/visualized using BI applications. This leads to lack of traceability of BI results to enterprise processes and resources. For example, it might be difficult to pinpoint exactly which element in the organization (e.g., process, employee, system, etc.) may be the reason for a low customer retention rate. EA can enable this type of traceability, but is not suitable as data source for BI applications, as most enterprise architecture models do not carry quantitative or operational data about its elements. Their focus is on providing overview and documenting the intricate structure and workings of an organization on different levels (business, software applications and infrastructure) and on the dependencies between these levels.

In this paper we argue that combining these two fields into what we call *enterprise architecture intelligence* may become the solution for compensating for the shortcomings of both EA and BI and so provide a powerful decision support instrument. Combining enterprise architecture and operational data is complex (especially when considering the actual 'matching' of data with enterprise architecture objects), and little has been written on *how* to do this. Therefore, our research goal is to fill this gap and propose a *method* to combine operational data with enterprise architecture to better support decision-making. Using such a method may result either in an enriched enterprise architecture model, or in a warehouse data model where operational data is enriched with enterprise architecture metadata. This has several advantages.

On one hand an enriched enterprise architecture model is very suitable as basis for model-based architecture analyses. Over the last decade, several quantitative techniques of this kind have been proposed (e.g., [11], [12]), but most of them suffer from one weakness: difficulty of obtaining the necessary suitable quantitative input. To overcome this problem, in [12] it is suggested that one way to collect such input is to interview an organization's domain experts and ask them to provide estimates of the measured variables, based on their work experience. Nevertheless, this approach (although good when no other option is available) is time consuming, and far from producing accurate results (in the same study the analysis data resulted from the expert input deviated on average with about 10 - 15% from the measured results, which in certain contexts can be considered as an unacceptable large error). We argue that, by combining BI data sources and EA the most accurate and current available data can be extracted from the organization's data storages, attributed to the various architecture elements, and eventually fed as input for EA analyses for reliable results.

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On the other hand, operational data enriched with architecture metadata, not only provides more traceability by easing the retrieval and interpretation of raw data, and of business analytics results, but can also enable and motivate in an objective fashion the definition and implementation of the business strategies, and justify certain organizational changes.

The above arguments, motivated us to develop our method, called the Enterprise Architecture Intelligence Lifecycle (EAIL), which we position as the main contribution of this paper. While developing the method, we adhered to the design science research methodology [14].

The remainder of the paper is structured as follows. In Section II we give some background for EA and BI. Section III provides a brief description of the proposed method. In Section IV we introduce the Timber case study, which will serve as running example for the illustration of the different EAIL phases. These phases are first explained in detail. We conclude the paper with a discussion, conclusions and some pointers to future work.

II. Background & Related Work

A. EA: modelling, and method

In recent years, EA has evolved into a mature discipline, with well-established methods and modelling techniques, that take a broad business network perspective, and goes beyond just information systems design. ArchiMate, an open standard of The Open Group [3], is becoming widely accepted as the language of choice for expressing EA models and views. The language distinguishes between three layers: the business layer, the application layer, and the infrastructure layer. In addition, the language considers the structural, behavioral, and informational aspects within each layer. It also identifies relationships between and within the layers. For a full description of the language, we refer to [3]. In the EA domain, we rely on the most widely accepted development method, The Open Group Architecture Framework (TOGAF) [13]. The core of TOGAF is formed by the Architecture Development Method (ADM), a step-wise iterative approach for the development and implementation of an enterprise architecture.

B. BI: architecture, and method

Lately, in the field of BI systems, which are typically built on top of a corporate warehouse and enhanced with data visualization, alerts, and performance measurement, business analytics capabilities have become increasingly popular as decision support tools at all organizational levels. BI is an umbrella term that covers architectures, tools, databases, analytical tools, applications, and methodologies [15]. The typical architecture of a BI solution is shown in Fig. 1. Notably, in such solutions the data warehouse, as corporate storage of operational data, may instantiate different architectural patterns [16] and may adhere to different development methods like [17] and [18].

C. Related work

Next to the mentioned literature in the fields of EA and BI, studies have been performed in the field of (automated) EA documentation (e.g. [19][1]) that may contribute to our method by automating recurrent processes and detailing technical aspects that come with combining EA and operational data.

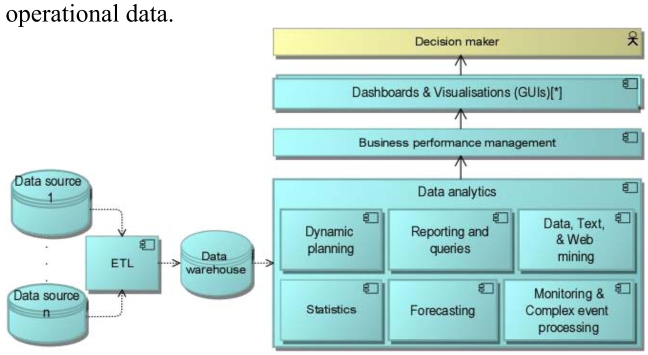

Fig. 1. *BI architecture.*

III. The Enterprise Architecture Intelligence Lifecycle Method

The enterprise architecture intelligence lifecycle method (EAIL method) we propose consists of six phases that enable an organization to combine enterprise architecture and operational data for a specific purpose, which usually originates from a business problem. The combination of enterprise architecture and operational data makes a variety of analyses possible, like allocating types of data to specific architecture elements and then tracing analytical results to organizational entities.

In the following we briefly describe the six phases of EAIL. An overview of the method is shown in Fig. 2 and in TABLE I. a detailed overview of the EAIL is presented. Whenever an organization is motivated (e.g. as a result of a specific concern) to combine an enterprise architecture with operational data, the lifecycle is initiated, starting with the first of six phases. Both enterprise architecture and (operational) data source(s) (DS) are required as input for the EAIL.

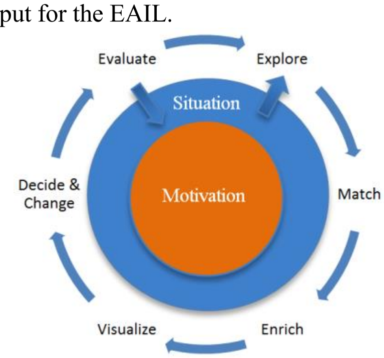

Fig. 2. *Overview of the Enterprise Architecture Intelligence Lifecycle.*

The phases we identified as relevant are: I-*explore,* II-*match,* III-*enrich,* IV-*visualize,* V-*decide & change,* and VI-*evaluate*. In every phase, several activities are carried out. In the *explore* phase the main concern is determined, how it is addressed and which data is available. In the *match* phase relevant subsets of the enterprise architecture and operational data are selected and matched. In the *enrich* phase, the data model is enriched and the determined analysis is performed. In the *visualize* phase the analysis results are visualized. During the *decide & change* phase a decision is made on which organizational change is realized. In the *evaluate* phase the effects of the implemented solution and change are monitored and evaluated, possibly leading to a new EAIL iteration.

IV. Demonstrating EAIL: The Timber Case Study

In this section, the EAIL phases are explained in detail by means of specific process models (e.g., Fig. 3), and then rigorously applied to the Timber case-study. The case concerns the problem of *cost allocation*, which arises because the company needs to make a decision. The Timber case originates from a real life case, which was altered for confidentiality reasons.

A. Case Study Description

Timber is one of the largest firms involved in the production and processing of wood in Sweden. The organization has a few core business units, namely *Forest, Wood, Logistics* and *Sales*, next to the supportive business units *Customer Relations, Human Resources,* and *IT*. Timber deals with several types of costs, namely *manufacturing costs (direct costs)* and *non-manufacturing costs (indirect costs)*, which can be further divided. Manufacturing costs are split into *direct materials* and *direct labor* costs. Non-manufacturing costs are split into *marketing, sales, administrative* and *IT support* costs.

TABLE I. Overview of Phases and Activities with Inputs and Outputs

Phase # / Activity	**Input**	**Output**
I-a / Determine concern	Motivation	Determined concern
I-b / Create source overview	Determined concern	Source overview (possibly outputted in a 'Source overview File'
I-c / Retrieve variables	Source overview	Retrieved variables
I-d / Determine metric(s) & measurement(s)	Retrieved variables	Determined metric(s) & measurement(s) (possibly outputted in a 'Metrics File')
II-a / Determine EA & DS subsets	Determined metric(s) & measurement(s) (possibly outputted in a 'Metrics File') & Source overview	Determined EA & DS subsets
II-b / Match concepts	Determined EA & DS subsets	A match of concepts derived from the enterprise architecture and the determined data sources (e.g. a mapping).
III-a / Determine data model	Information to be able to determine the best choice for a model to be enriched with.	Determined data model (e.g. an enterprise architecture or a data source)
III-b / Enrich data model	Determined data model (e.g. an enterprise architecture or a data source)	An enriched data model (e.g. an enriched enterprise architecture or an enriched data source)
III-c / Perform analysis	An enriched data model (e.g. an enriched enterprise architecture or an enriched data source)	The calculated metric(s) (possibly outputted in an 'Analysis Data'-file)
IV-a / Prepare data visualization	Analysis data (e.g. from an 'Analysis Data'-file)	Prepared analysis data
IV-b / Visualize data	Prepared analysis data	Visualized data
V-a / Make decision	Visualized data	Decision
V-b / Develop solution	Decision	Developed solution
V-c / Implement solution	Developed solution	Implemented solution
VI-a / Monitor effects	Implemented solution	Results of monitoring effects
VI-b / Evaluate solution	Results of monitoring effects	Evaluation (possibly leading to a new EAIL iteration)

Until now, the indirect costs have always been allocated to the organization as a whole. Recently, however, business units became profit and loss responsible. As a consequence, they are now billed with costs by the supportive business units directly. For example, the *Sales* business unit and the *Wood* business unit are billed with server costs coming from the IT business unit. Due to the change, the business units want an IT cost clarification to identify why prices (e.g., of wood and labor) have increased. Timber, however, has no clear view on how IT costs are allocated to the business units. Therefore, they hire a consulting firm (specialized in EA) to clarify the situation.

B. Phase I – Explore

The activities of the Explore phase are shown in Fig. 3. The main goal of this phase is to identify the main concern, determine which sources are available to address this concern, and which metrics and measurements can be used based on concern and available sources.

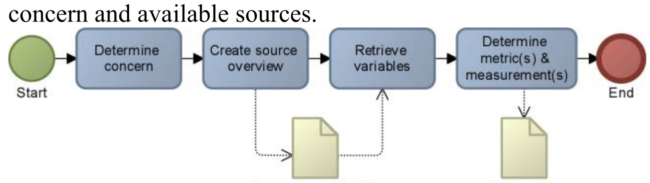

Fig. 3. *Business process of 'phase I – explore', including activities.*

I-a Determine concern – After conducting several interviews with the CIO of Timber, the *concern is determined* that 'there is haziness about why some business unit products have a high price'. The root cause is that 'there is no cost-allocation.

Several techniques may be used to identify the problem or the root cause underlying the business concern. Finding the root cause may eventually help in determining the solution, since it pinpoints a specific issue. The organization may also associate the problem with a measureable goal, which is *"an end state that the stakeholder intends to achieve"* [3]. For example, if the *concern* is that 'profit has decreased', the measureable goal could be 'to lower costs'. The result of this phase (as indicated in TABLE III.) is a business concern possibly motivated by a root cause and associated with a measureable goal.

TABLE II. ROOT CAUSE ANALYSIS OF TIMBER CASE

Motivation	More requests are coming from the business units to clarify *why* some of their products have a high price.
Concern	There is haziness about why some business unit products have a high price.
Problem	Clarity about business unit product pricing is lacking, but is needed to conform to profit and loss responsibility.
Root cause	There is no cost-allocation.

TABLE III. DESCRIPTION OF THE 'DETERMINE CONCERN' ACTIVITY

Phase I-a	**Determine concern**
Actor(s)	CIO and Enterprise Architect (consultant).
Input	Business request of Timber.
Used techniques	Root cause analysis [4], interview techniques [5].
Output	There is no cost-allocation.

I-b Create source overview – In this step, relevant operational data sources in the enterprise architecture are identified and a *source overview* is created. This source overview may be a global interpretation of the enterprise architecture and its data sources, but preferably it is a concise document that can be exchanged and referred to. An example is a mapping table between *sources* and *types of data* stored in them.

The Enterprise Architect (a consultant) asks the CIO to bring him into contact with a Data Specialist to *create a source overview*. The Data Specialist creates the an overview of source systems and cost-related data (TABLE IV.), in which only data sources are listed that *might* help solving the concern to avoid stating irrelevant information. The consultant gives advice to Timber on how to address the concern based on the data available *or* data that may be created using available systems, which is why the source overview is needed.

TABLE IV. SOURCE OVERVIEW FOR THE TIMBER CASE

Source	**Data type**
Financial system	Financial data (costs, revenues)
CRM system	Customer-related data (sales, etc.)
Servers 1 to 8	Utilization data (usage of servers for performing daily operations)

TABLE V. DESCRIPTION OF THE 'CREATE SOURCE OVERVIEW' ACTIVITY

Phase I-b	**Create source overview**
Actor(s)	Enterprise Architect and Data Specialist.
Input	Determined *concern*: 'there is no cost-allocation'.
Used techniques	Interview techniques [5], requirements analysis techniques [6].
Output	An overview of available data sources and a description of data stored in these data sources.

I-c Retrieve variables – Having created a source overview, the next step is to translate the concern, measureable goal *or* root cause into measurable variables that can be found in the data sources. These variables are the smallest elements which are later used to determine metrics. Examples of variables are units or rates like *processing time, costs,* or *workload rate*. The data types (shown in TABLE IV.) help in allocating costs; the overview itself helps in determining variables.

Determining the variables is based on the cost driver which is used to allocate costs (server costs) to cost objects (the business units) [9]. Choosing the cost driver is based on three guidelines: the allocation must be fair, the allocation must be rational and verifiable, and the impact on the people who use or work with this information must be known [8]. Servers are able to perform different tasks using processors to calculate and storage to store data. These servers bring depreciation costs (of the processors and storage hard disks) to the company as well as maintenance and electricity costs. Based on the guidelines stated above and the information explained, the cost driver is determined to be 'server utilization', since this is considered to be fair, rational and verifiable. Moreover, the impact that allocation decisions may have on employees can be analyzed. To define a metric, the data specialist provides cost related data per server (cf. TABLE VI.), which is retrieved from the financial system and the servers 1 to 8 (cf. TABLE IV.).

TABLE VI. SOME VARIABLES TO BUILD A METRIC

Variable name	**Data type**
Electricity (kWh)	Integer (in kilowatt hour (kWh))
Storage (GB)	Integer (in Gigabytes (GB))
Maintenance (hours)	Integer (in hours)
License costs (Euro)	Money (in Euro currency)
Software purchases (Euro)	Money (in Euro currency)
Server usage (percentage)	Real (percentage)

TABLE VII. DESCRIPTION OF THE 'RETRIEVE VARIABLES' ACTIVITY

Phase I-c	**Retrieve variables**
Actor(s)	Stakeholder and Enterprise Architect.
Input	An overview of *available data sources* and *a description of the data* that is stored in these data sources.
Used techniques	Interview techniques [5] , requirements analysis techniques [6].
Output	Retrieved *variables* (cf. TABLE VI.).

I-d Determine metric(s) & measurement(s) – Having found the variables (e.g., 'processing time' or 'workload rate'), we determine a suitable metric (e.g., *resource utilization*). This is an important step since it will be used for combining the EA with DSs. For this purpose, Priyanto [8] provided a metric template that can be used to structurally define the metric (resulting in a 'Metrics File'). Kerzner [9] and Hubbard [10] have provided thorough literature on how these variables and metrics can be determined. Determining a measurement means to determine *how* to measure the metric, e.g. by using a specific algorithm that uses the variables to calculate certain values. There may be multiple ways to calculate a metric, e.g. 'return on investment' (ROI). Defining an algorithm may require mathematical and algorithmic skills [7].

To establish a cost allocation per business unit, the two-stage cost allocation process is used [9], which in our case comprises two steps, namely *(1) calculating product cost* based on server costs and *(2) reallocating product cost to multiple divisions*. The *total costs* metric based on the variables is calculated for each server, based on the amounts of electricity (kWh), storage (GB) and maintenance (FTE) multiplied by the prices for each variable. The prices are retrieved from the financial system. Without the 'determine variables' activity, it would be hard to determine a good metric capable of measuring data available in the organization.

TABLE VIII. DESCRIPTION OF THE 'DETERMINE METRIC(S) AND MEASUREMENT(S)' ACTIVITY

Phase I-d	**Determine metric(s) and measurement(s)**
Actor(s)	Enterprise Architect and Data Specialist.
Input	Retrieved variables (cf. TABLE VI.).
Used techniques	Metrics design [9][10], requirements analysis techniques [6] and algorithm design techniques [7].
Output	An identified *metric 'total costs'* and its *measurement*.

C. *Phase II – Match*

The goal of the Match phase is to match the enterprise architecture with the data sources (cf. Fig. 4). The output of phase I is used as input for this phase.

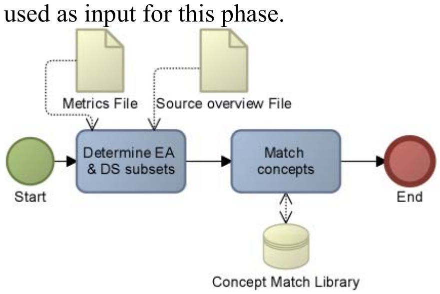

Fig. 4. *Business process of 'phase II – match', including activities.*

II-a Determine EA & DS subsets – The Metrics File and Source overview File are used to determine the subsets of the enterprise architecture (EA) and data sources (DS) that are suitable as a source for further steps. It is critical that the chosen subsets from both EA and DS are relevant for the determined metric; the subsets are combined to better support decision-making in a later phase. An enterprise architect could determine which *EA-concepts* are relevant. If the problem is related to the whole organization, the scope consists of the entire EA. If the problem is related to a division of the organization, the scope is related concepts of the EA (e.g. business functions, processes, application components, and their relations). A data specialist with knowledge about the availability of data could determine which *DS-concepts* are relevant. To determine the subset, a scope is set regarding available data, which is based on the Source overview (cf. TABLE IV.) At the end of this activity, both an EA-subset and a DS-subset are available for the next activity.

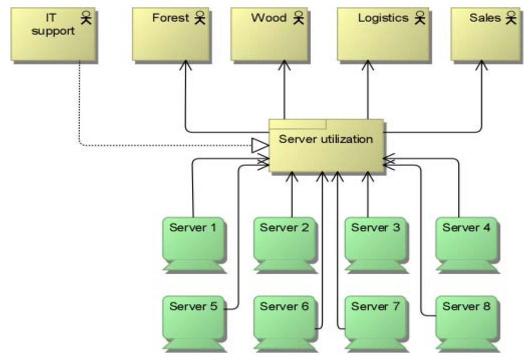

Fig. 5. *The EA subset, representing the relevant objects for the Timber case.*

For Timber, an EA subset is modeled based on the relevant objects needed to address the concern. The servers are modelled along with the business units. A business product 'server utilization' is added to the EA and a realization-relation links it with the IT support business actor, as illustrated in Fig. 5. The DS subset consists of several Excel-files containing operational data, representing the determined variables. These files were delivered by an internal Timber data specialist.

TABLE IX. DESCRIPTION OF THE 'DETERMINE EA & DS SUBSETS' ACTIVITY

Phase II-a	**Determine EA & DS subsets**
Actor(s)	Enterprise Architect and Data Specialist.
Input	A determined metric *'total costs'* and its measurement and a source overview, as support sources to identify the EA & DS subsets.
Used techniques	Requirements analysis techniques [6], data mining techniques, ETL, etc. [17].
Output	Determined EA & DS subsets (cf. Fig. 5). DS subset is not shown here – large size Excel-files.

II-b Match concepts – When the EA-subset and the DS-subset have been determined, both subsets are compared in order to find matches between concepts. In our terminology, a concept is either an object in an enterprise architecture (i.e., concept or relation) or a field in a data source (i.e., a value). An example of a *match* is a certain *business process attribute* within the EA-subset that is related to some *data value* found in the DS-subset. Matching concepts is complex, since it requires an understanding of the DS-subset and the EA-subset. Concept matches can be saved for later use (e.g., for new iterations through the EAIL) in a ‘Concept Match Library’. The library is a mapping between enterprise architecture, operational data and time, illustrated in Fig. 6. The model may serve as a blueprint for a database or even a spreadsheet. Using simple database functionality, *timestamps* that keep track of updates for each concept match are logged. The relations shown in the model are linked via primary keys and foreign keys in the *Concept_match* relation (cf. Fig. 6). To illustrate where external data sources are placed, both the *EA* and *DS* relation are added to the model and linked to the *EA* and *DS subsets*. *EA*, *DS* and *Time* are interlinked using the *Concept_match relation*, which is directly linked to the *Property* and *Record relation*. An application of the model in a snapshot of a spreadsheet with figurative data is added in Fig. 7. For each object in the EA-subset (cf. Fig. 5) attributes are added using a scripting language that is able to define attributes per EA object-type. Then, matches are made for each EA object’s properties that are defined with the data given in the DS subset. The data was manually inserted in the EA subset using an enterprise architecture application called BiZZdesign Architect [1]. The snapshot of data as illustrated in Fig. 7 gives us an overview of some of the matches made for the Timber case. If the matches made were automatically stored in a database with attributes as stated in our model (cf. Fig. 6), more possibilities would arise for data analysis. An example of a new analysis type could be ‘data tracing’, i.e. exactly tracing the EA or DS concepts used in a calculation, based on the ‘accessed’ attribute.

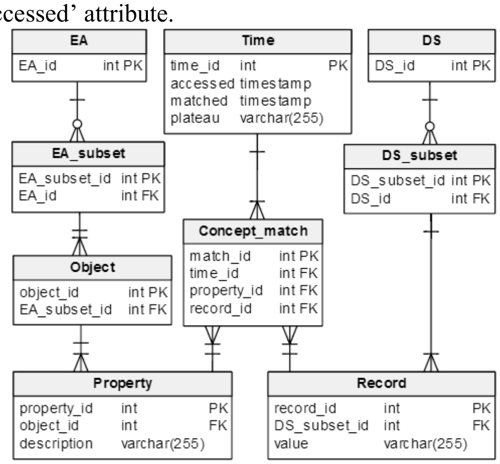

Fig. 6. *A Model to Store Enterprise Architecture, Operational Data & Time.*

Data tracing could address issues like *‘where does the data come from’* for the enterprise architecture field or *‘what does this set of data mean in business terms’* for the business intelligence field. By defining an algorithm [7] that measures the differences between timestamps in the ‘accessed’ attribute, data is traced for a specific analysis.

match_id	property_id	object_id	description	record_id	value	DS_id	time_id	matched	accessed	plateau
11	50	402	amount_kWh	210	7600	1	11	12-9-2014 11:13	12-9-2014 11:17	baseline
12	51	403	amount_kWh	211	7589	2	12	12-9-2014 11:13	12-9-2014 11:17	baseline
13	52	404	amount_kWh	212	7489	3	13	12-9-2014 11:14	12-9-2014 11:17	baseline
14	53	405	amount_kWh	213	7533	4	14	12-9-2014 11:14	12-9-2014 11:17	baseline
15	54	406	amount_kWh	214	7450	5	15	12-9-2014 11:14	12-9-2014 11:18	baseline
16	55	407	amount_kWh	215	7402	6	16	12-9-2014 11:14	12-9-2014 11:18	baseline
17	56	408	amount_kWh	216	7187	7	17	12-9-2014 11:14	12-9-2014 11:18	baseline
18	57	409	amount_kWh	217	3400	8	18	12-9-2014 11:14	12-9-2014 11:18	baseline

Fig. 7. *Snapshot of a possible spreadsheet application of a Model to Store EA, Operational Data & Time, illustrated with figurative data.*

As shown in Fig. 6, *property_id* relates to *record_id*. Match 11 (*match_id* with value 11) describes a property ‘amount_kWh for a certain object (*object_id*) and relates a value of ‘7600’ using *record_id* ‘210’. The record belongs to a data source (*DS_id*) 1, which is a server. When a match is made, a timestamp (*matched*) is added. When the match is accessed (e.g. for a calculation), a timestamp (*accessed*) is updated.

TABLE X. DESCRIPTION OF THE ‘MATCH CONCEPTS’ ACTIVITY

Phase II-b	**Match concepts**
Actor(s)	Enterprise Architect and Data Specialist.
Input	(1) A defined *metric* and its *measurement*. (2) Set of data (both enterprise architecture and operational data).
Used techniques	Requirements analysis techniques [6].
Output	A match of concepts derived from the enterprise architecture and the determined data sources (e.g. a mapping).

D. Phase III – Enrich

The main activities of the Enrich phase are shown in Fig. 8.

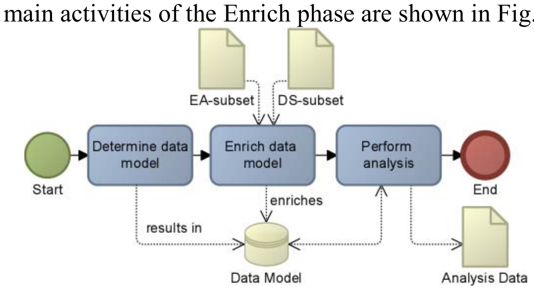

Fig. 8. *Business process of ‘phase III – enrich’, including activities.*

III-a Determine data model – Having matched the concepts from both EA and DS subsets, the next step is to determine the output data model. Depending on the output preferences of stakeholders (e.g. management) and whether the enterprise architecture or the data sources are able to submit to these preferences, a data model is chosen. Using the original enterprise architecture and data sources may be risky, e.g. when data is manipulated and errors are made. Possibly, a different data model is created, e.g. with different dimensions and optimized for business intelligence and other representation solutions. Creating a new enterprise architecture subset may simply be creating a copy of a selection of concepts (business processes, business functions, application components, etc.). Creating a new data source may be creating a direct copy of the most suitable data model to store data, e.g. a data mart. Determining the best data model depends on multiple factors to be taken into account by the consulting firm and the organization: both might influence the choice.

For Timber, the data model is an enterprise architecture. This is due to its ability to graphically represent business concepts understandable by the end users, the employees of Timber.

TABLE XI. DESCRIPTION OF THE 'DETERMINE DATA MODEL' ACTIVITY

Phase III-a	**Determine data model**
Actor(s)	Enterprise Architect.
Input	Information to be able to determine the best choice for a model to be enriched with.
Used techniques	Enterprise Architecture application techniques $_1$.
Output	An enterprise architecture model.

III-b Enrich data model – The data model created in the previous activity is combined (or enriched) with data from the other source. If an enterprise architecture is the data model, it will be combined with data sources. If a data source is the data model, it will be combined with an enterprise architecture. For the enterprise architecture the previously matched DS-subset is used: the data is 'loaded' in the EA, creating an 'enriched enterprise architecture'. For the data source the previously matched EA-subset is used: (meta-)data is loaded in the DS (e.g., descriptive data referring to EA properties and objects). Enriching a data model may be done using query scripts that retrieve data and, provided the matching of concepts is given (e.g., using the previously mentioned 'Concept Match Library'), store data in the new data model. Simply stated, the script uses the locations of data as an input and output source for retrieving, respectively, storing data. The result of enriching an enterprise architecture could be an EA containing operational data as attributes of the architecture elements. The result of enriching a data source could be a data source (e.g. a data warehouse or data mart) with meta-data that describes the location of data in an enterprise architecture.

Timber enriches the enterprise architecture data model as illustrated in Fig. 5. Since this example model is relatively small, data has been inserted manually for each attribute, for each server (1 to 8). The data is retrieved from the DS subset. With the enterprise architecture being enriched, calculations are made using the structure of the EA.

TABLE XII. DESCRIPTION OF THE 'ENRICH DATA MODEL' ACTIVITY

Phase III-b	**Enrich data model**
Actor(s)	Enterprise Architect.
Input	Data or meta-data (descriptive) derived from an EA-subset or a DS-subset.
Used techniques	Enterprise Architecture techniques $_1$, mathematical techniques, analysis techniques $_1$, etc.
Output	Enriched enterprise architecture.

III-c Perform analysis –The enriched data model is analysed. The analysis is performed by an analysis-function [9] in an application (e.g. an enterprise architecture application or a business intelligence application). The analysis is done using algorithms with parameters. The algorithm is based on the *metric* and *variables* described in the 'Metrics File', discussed in phase I. Several types of analysis may be performed, be it qualitative (using quantified measures) or quantitative. Measuring qualitative aspects may require phases like *preparation, coding, analysis* and *reporting* to make them measureable. Software applications like *HyperRESEARCH*, *QSR NVivo* and *ATLAS.ti* may assist in making qualitative data measureable. Information on how to measure qualitative data is explained by [10], amongst others. These applications may assist in phase I to determine variables and metrics as well. Quantitative analysis of data has been discussed in literature [11] and is already widely performed in all kinds of business intelligence applications.

The first analysis to be performed for Timber to come to a total cost for all servers is calculated for each server, based on the amounts of electricity (kWh), storage (GB) and maintenance (FTE), multiplied by the prices for each variable, where prices are retrieved from a financial system. The second analysis to be performed for Timber is to allocate the total costs to each business unit, based on the server usage. Total costs are divided based on the server usage percentage and multiplied by the total server costs. The analysis algorithm is scripted inside BiZZdesign Architect using the EA subset as a data model.

TABLE XIII. DESCRIPTION OF THE 'PERFORM ANALYSIS' ACTIVITY

Phase III-c	**Perform analysis**
Actor(s)	Enterprise Architect.
Input	An enriched model (e.g. an enriched enterprise architecture) or an enriched data source) and a 'Metric File' to determine the analysis to be performed.
Used techniques	Enterprise Architecture scripting techniques $_1$, mathematical techniques, analysis techniques $_1$, etc.
Output	The calculated metric, outputted in an 'Analysis Data'-file (or any other file suitable for visualizing).

E. Phase IV – Visualize

The main activities of the Visualize phase are shown in Fig. 9.

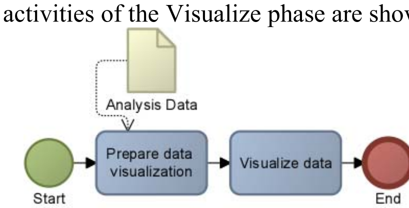

Fig. 9. *Business process of 'phase IV – visualize', including activities.*

IV-a Prepare data visualization – When data has been analyzed and made available for visualization, the dataset may be optimized for the software application that is able to represent the data in a way the decision-maker understands. Different types of decision-makers have different needs to be able to make thought-out decisions. These needs may determine the software application that needs to be selected. Preparing the data for visualization may only be necessary when a change is needed from one format to another. If a format is already optimized for the final representation, this activity may be skipped. The data should then be ready for visualization. For Timber, it is decided that the enterprise architecture application is suitable to show the analysis data. Therefore, the analysis data did not have to be prepared in e.g.

an Excel format, but was calculated ad hoc inside BiZZdesign Architect for each enterprise architecture object.

TABLE XIV. DESCRIPTION OF THE 'PREPARE DATA VISUALIZATION' ACTIVITY

Phase IV-a	**Prepare data visualization**
Actor(s)	Enterprise Architect.
Input	Analysis data (e.g. from an 'Analysis Data'-file).
Used techniques	Business intelligence techniques [15] (determining suitable input format for visualization application) [17], SQL-techniques, etc.
Output	Prepared analysis-data.

IV-b Visualize data – In this step, the dataset is ready for representation. Depending on the data model and the format the data was tailored to, a visualization application should be selected to represent the data in a manner the decision-maker understands. As we briefly mentioned, different types of decision-makers exist (e.g., data-driven or structure-driven). The data that is shown should be understood (i.e. well-interpreted) by the decision-maker. For data visualization, literature about user interface design may be applied or best practices may be used as long as the organization is satisfied with the way data is presented. Priyanto [8] explained different options that may be taken into account when developing for these business needs. The end result of this activity is data being visualized in a software application fulfilling the decision-maker's needs.

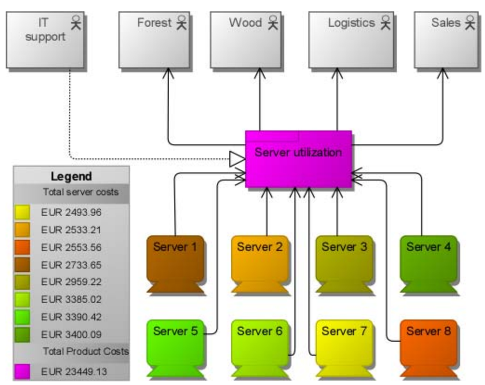

Fig. 10. *Step 1 – Calculating the Product Cost for 'Server utilization'.*

The analysis data being calculated in the enterprise architecture, several ways to visualize the data are possible. Fig. 10 and 0 show a 'color view' and a 'compare view', of which the first is used to show differences between servers and business products, and the latter to show the differences between cost allocations.

TABLE XV. DESCRIPTION OF THE 'VISUALIZE DATA' ACTIVITY

Phase IV-b	**Visualize data**
Actor(s)	Enterprise Architect.
Input	Prepared analysis-data (e.g. from an 'Analysis Data'-file), in our case inside in an EA.
Used techniques	Business intelligence techniques [17], enterprise architecture techniques 1, scripting techniques 1.
Output	Visualized data.

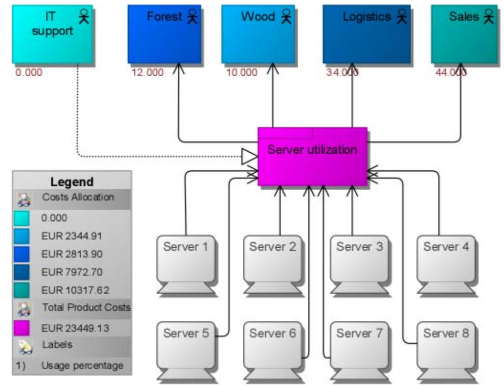

Fig. 11. *Step 2 – Reallocating the Product Costs to Multiple Divisions.*

F. *Phase V - Decide & Change*

The main activities of the Decide & Change phase are shown in Fig. 12.

Fig. 12. *Business process of 'phase V – decide & change', including activities.*

V-a Make decision – Until now we have discussed the steps that have led towards the visualization of data. In phase V, the organization makes a decision based on the represented data that leads to the implementation of a solution for the initial concern. Decision-making is done based on the data that was represented and interpreted by the decision-maker, which leads to information the decision-maker derives out of the data. Timber decides that costs will be allocated based on business unit goal satisfaction.

TABLE XVI. DESCRIPTION OF THE 'MAKE DECISION' ACTIVITY

Phase V-a	**Make decision**
Actor(s)	Timber's Board of Directors.
Input	Visualized data.
Used techniques	Decision-making techniques, scenario comparison techniques [2], etc.
Output	Costs will be allocated according to business goals.

V-b Develop solution – Having decided upon a certain concern, the organization is able to take action in order to minimize the concern. The result of an action for a specific concern is a *solution* to that concern: it tries to solve or minimize the problem. Multiple solutions may exist to a specific concern, all attempting to assist in heading to a better situation for the organization. Determining the best solution may need different opinions and scenarios to take into account, as mentioned by [2]. A solution may be a set of actions to be taken, resulting in e.g. an action plan, but may also be a product or a service that needs to be created.

TABLE XVII. DESCRIPTION OF THE ‘DEVELOP SOLUTION’ ACTIVITY

Phase V-b	**Develop solution**
Actor(s)	Timber’s middle management together with an Enterprise Architect.
Input	Costs will be allocated according to business goals.
Used techniques	e.g. tactical and operational skills for creating the most suitable solution for the current situation.
Output	The Enterprise Architect changes the enterprise architecture, so that goals are reached and costs are allocated accordingly to the business units.

V-c Implement solution – When a solution has been determined and developed, the organization may implement (or execute) the solution in the organization. Before a solution is implemented, it could be tested in a *test-environment* to be able to predict its behavior in the *real environment*. A test-environment may be a representation of the real environment or even an extreme environment to be able to see how the solution reacts to extreme situations. When the behavior of the solution is acceptable, the solution may be transferred to the real environment.

TABLE XVIII. DESCRIPTION OF THE ‘IMPLEMENT SOLUTION’ ACTIVITY

Phase V-c	**Implement solution**
Actor(s)	Timber’s Board of Directors & Enterprise Architect.
Input	The Enterprise Architect changes the enterprise architecture, so that goals are reached and costs are allocated accordingly to the business units.
Used techniques	Enterprise architecture techniques [1].
Output	Implemented solution.

G. *Phase VI – Evaluate*

The main activities of the Evaluate phase are shown in Fig. 13.

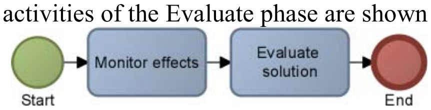

Fig. 13. *Business process of ‘phase VI – evaluate, including activities.*

VI-a Monitor effects – The solution being implemented in the organization does not necessarily mean the organization is relieved from the ‘pain’ the concern was causing, initially. It may be that the solution has helped to minimize the concern, but did not manage to eliminate the concern. To be able to determine whether a solution has helped to minimize the initial concern means that the concern and solution should be monitored to determine the effects the solution has brought to the organization. These effects may have come at a certain point and disappeared at a later point in time. This is the reason why effects need to be monitored for a period of time; the effects may not be permanent, making a final evaluation of the solution based solely on a ‘snapshot’ of a situation inappropriate. However, the effects should be taken into account when discussing the positive and negative effects of the solution. Examples of effects are *customer sales increase/decline* or *business leads increase/decline*.

TABLE XIX. DESCRIPTION OF THE ‘MONITOR EFFECTS’ ACTIVITY

Phase VI-a	**Monitor effects**
Actor(s)	Timber’s Board of Directors & Enterprise Architect.
Input	Implemented solution.
Used techniques	Business intelligence techniques [15], enterprise architecture techniques [1], scripting techniques [1].
Output	Results of monitoring effects.

VI-b Evaluate solution - When the situation has come to an equilibrium, which is a stable moment when most temporary effects have appeared, the solution and situation are ready to be evaluated. Here, the organization and consulting firm discuss the way the solution has (hopefully) helped in minimizing the concern. The developed solution may completely solve the initial concern, but may also solve a part of it. When the organization decides that the concern should be minimized even more, the approach starts again in phase I, explore. The new situation becomes the ‘current situation’ and the EAIL starts all over again.

TABLE XX. DESCRIPTION OF THE ‘EVALUATE SOLUTION’ ACTIVITY

Phase VI-b	**Evaluate solution**
Actor(s)	Timber’s Board of Directors & Enterprise Architect.
Input	Results of monitoring effects.
Used techniques	Decision-making skills, evaluation skills.
Output	Evaluation, possibly leading to a new EAIL iteration.

V. DISCUSSION

For all activities mentioned in the phases of our approach we acknowledge that sidesteps might be useful, like dividing tasks between an internal organization’s actor (e.g., a data specialist) and a consulting firm’s actor (e.g., an enterprise architect). Also, it might be useful to refine some steps, through the splitting of activities into smaller activities, and/or customizing the proposed method for the specific needs of the company under analysis. In EAIL we have left the assignment of roles to method activities unspecified. However, it should be noted that this is a critical issue in some of the method activities. For example, the definition of ‘concept matches’, essentially entails the specification of a model transformation between the EA and the data model of the data source. Such specifications are never a trivial exercise and require intimate knowledge of both the EA and the DS. Most probable, domain experts from both areas should be involved and collaborate. This is usually a one-time effort investment, which will pay-off, as such transformations (i.e., concept matches) can be re-used in future analyses, as suggested by the principles of model-driven development. Basically, both relations and concepts in an EA could be enriched with quantitative data to be used for BI purposes. The method proposed in our research comes with both architecture and BI tool support, to be included in the 2014 spring release of BiZZdesign Architect[1].

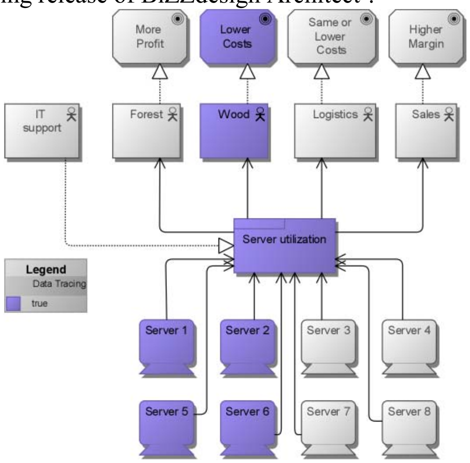

Fig. 14. *Illustration of a 'data tracing' analysis for the enterprise architecture field. Blue objects (goal, server utilization and servers) represent objects that were used for a specific calculation. All objects have a 'timestamp' attribute that is used to visualize the data trace.*

Our approach opens new possibilities in the field of enterprise architecture and business intelligence. New forms of analysis may be created, like the tracing of data based on 'timestamps' (illustrated in Fig. 14). Many other analytical models and techniques (e.g., risk analysis, stochastic simulations, etc.) can be thus transferred from BI tools to the realm of EA. Also, visualization of analysis results for EAs can be enhanced with common charting techniques from BI.

VI. CONCLUSION

In this paper we have proposed a method to combine enterprise architecture and operational data. We argue that our approach provides support for decision making, while facilitating the traceability of analytical outcomes to the architectural elements involved in the respective decision. Our method is illustrated by means of a real-life case study. In order to reap the full benefits of this method the following issues should become subject of future research.

- The most technically cumbersome steps in the EAIL method are the model transformations necessary for the concept matching and the subsequent model enrichment. It should be investigated to what extent these steps can be automated.
- Regarding types of quantitative analysis, it is interesting to investigate the possibilities for both the field of EA and BI combined. Future work can address these possibilities while showing the value for the business.
- We argued that our method opens new possibilities for EA model-based quantitative analysis methods. It is interesting to investigate which BI analytical tools are suitable for being transferred to EA. In the future, such tools should become part of a standard analysis toolbox of any EA modelling tool.
- With respect to visualization of analytical results, it remains to be determined what are the most suitable architecture views to effectively convey information to *other* target groups than just regular enterprise architects. In our opinion, one of the most important visualization challenges is concerned with bringing EA into the board room of an organization.

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