BUSTECH 2016

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BUSTECH 2016

Forward

The Sixth International Conference on Business Intelligence and Technology (BUSTECH 2016), held between March 20-24, 2016 in Rome, Italy, continued a series of events covering topics related to business process management and intelligence, integration and interoperability of different approaches, technology-oriented business solutions and specific features to be considered in business/technology development.

The conference had the following tracks:

- Modeling and simulation
- BPM and Intelligence
- Features of business/technology development

Similar to the previous edition, this event attracted excellent contributions and active participation from all over the world. We were very pleased to receive top quality contributions.

We take here the opportunity to warmly thank all the members of the BUSTECH 2016 technical program committee, as well as the numerous reviewers. The creation of such a high quality conference program would not have been possible without their involvement. We also kindly thank all the authors that dedicated much of their time and effort to contribute to BUSTECH 2016. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations and sponsors. We also gratefully thank the members of the BUSTECH 2016 organizing committee for their help in handling the logistics and for their work that made this professional meeting a success.

We hope BUSTECH 2016 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress in the area of business intelligence and technology. We also hope that Rome provided a pleasant environment during the conference and everyone saved some time for exploring this beautiful city.

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Table of Contents

A BSC-Based Method for the Supervision of Business Processes

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Abstract— **Today, companies must be able to supervise the execution of their business processes in real time, what gives a quick adaptation and arising problems or deviations. Thus, it is possible to obtain a current overview over their processes, and subsequently their business performances. One of the difficulties of the supervision is related to the frameworks for building systems enabling a performance analysis of the adequacy of the strategic objectives of the organization. In this paper, we propose a new method for building a Business Supervision System (BSS) covering the three phases: analysis, design and implementation. First, Balanced ScoreCard (BSC) has been extended by adding a public process as a new perspective. The goal of this extension is to provide for the modern companies, a way to consider in their strategy the state of their external business processes, not only on the state of internal business processes. Second, we use Unified Modeling Language (UML) activity diagrams describing the dynamic aspects of the system, such as interaction of private (internal) and public (external) business processes. Third, Business Process Execution Language for Web Services (BPEL4WS) is used for assembling a set of discrete business processes as a set of interactions between web services. The objective is to provide to decision makers a method ensuring the agility property. This property is the ability to change and refine easily a concept of a method without involving their other concepts.**

Keywords-agility; supervision; business process; BSC; BPEL4WS

I. INTRODUCTION

Companies use many business processes to ensure their proper functioning. A business process consists of a set of activities that are coordinated in an organizational and technical environment. These activities realize jointly a business goal. Each business process is enacted by a single organization. But, it may interact with other business processes performed by other organizations [1]. The orchestration and control of all the resources that are involved in a process to achieve a business objective is therefore an important issue.

Successive cycles of development, implementation and monitoring of business processes bring to the organization a way to integrate structural and environmental changes. Supervision of business processes is a measurement, a verification and an analysis activity of observed differences between the expected values and the measured values. Any deviation is sanctioned by conducting corrective actions on business processes [2]. Therefore, the supervision of business processes requires a technical infrastructure implementing the ability to react automatically to some events triggered directly from the instances or its execution environment. Also, supervision permits an interaction with all the key players in the company through the taken decisions: redefinition of a process or a part of activity, interruption of the execution of a running process or improvement of the goals and strategic objectives [3].

Quality and certification management system standards are often inflected concepts in present business practice. The certification to ISO standards is a prerequisite for competitiveness in many sectors of business. These international standards constitute a normative base of Quality Management System (QMS). They create and keep mechanisms that are able of prevent undesirable behavior through internal audits [21]. Indeed, they are able to provide a supervised procedure. These standards are closely connected to Business Process Management (BPM) [17]. BPM is a disciplined approach to identify, design, execute, document, measure, monitor, and control both automated and non-automated business processes to achieve consistent and targeted results that are aligned with the organization's strategic goals. BPM creates an add-value, and enables an organization to meet its business objectives with more agility. It enables an enterprise to align its business processes to its strategy, leading to effective overall company performance through improvements of specific work activities either within a specific department, across the enterprise, or between organizations. Weske [18] states that BPM includes concepts, methods, and techniques to support the design, administration, configuration, enactment, and analysis of business processes. Indeed, our work is included in the BPM field.

Balanced ScoreCard (BSC) [4] is a performance measurement method that includes not only traditional financial measures but also such qualitative measures as employee satisfaction, corporate mission and customer loyalty. It gives a way to translate a vision into a clear set of goals that are then translated into a powerful measurement system, which effectively defines the whole strategic objectives of an organization [5]. In addition, BSC creates a reporting system that allows the progress against the strategy to be supervised and corrective actions to be taken as required. BSC also serves as a link between the operations control process and the learning and control

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process for managing strategy [4]. Therefore, BSC is adopted in our solution because it is among the few methods available for widespread monitoring process. It goes beyond translating strategic objectives into operational plans, to check the alignment of business processes and to provide support to the company's strategy [2].

Web Services (WS) [6] are considered as a dominant standard for distributed application communication over the Internet. Consumer applications can locate and invoke complex functionality, through widespread XML-based protocols, without any concern about technological decisions or implementation details on the side of the service provider. The Business Process Execution Language for Web Services (BPEL4WS) [7] allows designers to orchestrate individual services so as to construct higher level business processes. The specification of the orchestration is expressed in XML-based language and it is deployed in a BPEL execution engine, making thus available for invocation by consumers.

In order to enjoy the utility of these concepts, we propose a method that aims to ensure the agility property. This method permits the development of a BSS during the three phases of its development: analysis, design and implementation. In the analysis phase, the objective is to study the environment and to determine the company’s strategy. We use the UML activity diagram in order to describe the dynamic aspects of the system. In our case, we represent the interaction model of internal and external supervised business processes. After that, we use BPEL4WS as a standard executable language for specifying actions within business processes with WS. In the design phase, our contribution extends the BSC method to “Public Process” as a new perspective because the contemporary enterprises and their business processes are becoming more dynamic, distributed and complex. Thus, even a simple process may cause business transactions across boundaries of numerous business units and trigger interactions of multiple actor sand software applications [20]. Consequently, enterprises need to add also in their strategy the state of the collaborative or external business processes, not only the state of internal ones. Finally, in the implementation phase, we import both the BPEL4WS specification as XML file and the BSC extended strategic as structured table towards the BSS reference.

The rest of this paper is organized as follows. In Section II, we describe a synthesis of some research works in relation to our proposition. Section III is devoted to the definition of the concepts used in our solution. Section IV describes the proposed method description. Section V provides a case study to validate our framework related to the Algeria Gulf Bank (AGB). Section VI is reserved to a conclusion demonstrates the conformity of our solution with the agility property and proposes some prospects.

II. RELATED WORK

The combination of BSC [4] and BPEL4WS [7] is of interest for BPM research and few works combining these two concepts have been found. Derrick et al. [8] addresses

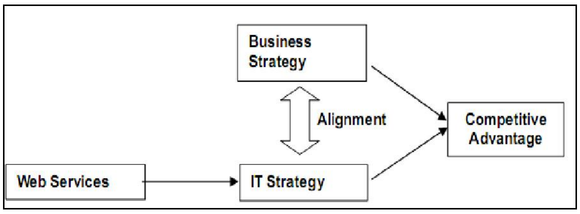

Figure 1. Integrating web services with competitive strategies [8].

the issue of deploying Web services strategically using the concept of a widely accepted management tool, BSC (see Fig. 1). It presents potential benefits of Web services with corporate BSC perspectives. Indeed, this work argues that the strategic benefits of implementing Web services can only be realized if the Web services initiatives are planned and implemented within the framework of an IT strategy that is designed to support the business strategy of a firm.

BSCs have also been used in several companies. Wang et al. [9] defines the major indicators of social sustainability for development of Sustainable Design-centered Manufacturing (SDM). These indicators permit to evaluate the weighting factors among the three pillars and the indicators used to assess each pillar. Lina et al. [10] provides valuable support for successful decision making in network hierarchical structures they adopt the traditional BSC framework that considers importance weights, performance weights and norm values. Lin et al. [11] investigate the current status of BSC application and its impact on hospital performance in China. In this work, the BSC application contributes to the improvement of organizational and personal performances. Such a contributing effect increases with the extension (level) of BSC application. Antonsen [12] shows that using the BSC to strengthen formal control, combined with advisors commitment to serve their customers, seems to contribute to high financial results for the bank. However, this study reveals shortcomings of using the BSC in promoting critically reflective work behavior and commitment among line managers and employees. Wu et al. [13] propose a research model to examine the relationships between a stage-based diffusion structure and the four BSC indicators.

Therefore, the objective of this study is to propose a method building a BSS: first, to present the benefits of BSC by adding for the original structure a new perspective that supports the study of external business processes; second, to elaborate an UML activity diagram describing the interaction of internal and external business processes to supervise; third, to specify the link of these business processes using BPEL4WS. Finally, we will prove that this study ensures the agility property.

III. BACKGROUND

In this section, we briefly provide the basic concepts that are adopted in our framework.

 ISBN: 978-1-61208-467-1

A. Balanced Scorecard

BSC is a method to measure the company's activities [5]. It provides a more global steering with defining a rigorous framework for developing the strategy and methodology for the decline in operational terms [2]. It has evolved in three main generations. However, the third generation refines the others in order to give more relevance and functionality to strategic objectives. Other key components are strategic objectives, strategic linkage model and perspectives, measures and initiatives [16]. In our work, we adopt this last generation whose structure is represented in Fig. 2, respecting the balance in the following four perspectives:

- Financial perspective: the financial performance of an organization is based on its ability to create values by efficiently using capital.
- Customer Perspective: it illustrates the choice of the company in market segmentation, in which it makes sales and generates revenue.
- Internal business processes perspective: it identifies the business processes involved directly in the objectives.
- Learning and Growth perspective: the last of the four perspectives is the sharing and communication of knowledge in the organization leading to the achievement of individual goals. This perspective is closely linked to information from the human resources department.

For each perspective of the BSC, four parameters are controlled: the main objectives such as increasing profitability; the indicators such as observable parameters, which will be used to measure progress towards the objectives to achieve; the targets taking specific targets values to be achieved by measures; the initiatives that are projects or programs launched to meet the objective [3]. The important word in BSC is "balanced" because it equilibrates between short and medium or long-term goals, it equilibrates between financial indicators and non-financial, it equilibrates measuring indicators of past performance and indicators "forward" and it equilibrates between the external perception and conducted internal performances [2].

Thus, BSC presents a new way to monitor the performance of a company measured by the past success and set goals for the future [14]. In our method, we extend the original structure of the BSC, in order to accomplish the distributed and the dynamic companies' requirements. Our proposed contribution adds a new perspective with "Public Process". Then, it is possible to allow a company to think so in its strategy on the status of their public and private business processes.

B. BPEL4WS

BPEL4WS [7] has been designed to model business processes that are fairly stable, and thus it involves the invocation of WS that are known beforehand. Therefore, the BPEL scenario designer specifies, at the time when the scenario is crafted, the exact services to be invoked for the realization of the business process.

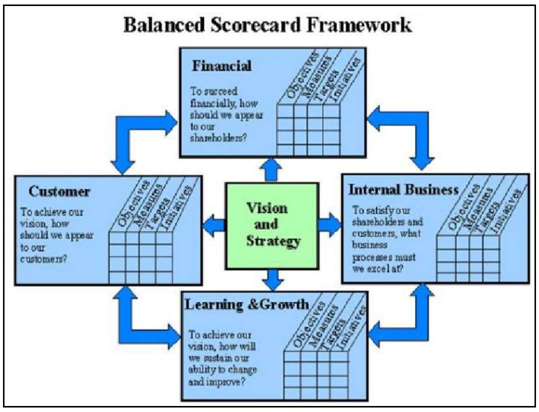

Figure 2. Original structure of BSC [3].

UML [15] UML is the most used specification and the way the world models not only application structure, behavior, and architecture, but also business process and data structure. UML is used in this method because it helps to specify, visualize, and document models of software systems, including their structure and design.

Business Process Model and Notation (BPMN) [19] is a standard that will provide businesses with the capability of understanding their internal business procedures in a graphical notation and will give organizations the ability to communicate these procedures in a standard manner. Thus, BPMN will allow for an easier and quicker move from theory to practice. In our method, and for ease of use, we elaborate an UML activity diagram for modeling the internal and external business processes interaction. According to this diagram, the cooperative behavior that links this supervised business processes as set of WS is specified with BPEL4WS.

IV. The Proposed Method

We recall that our work has as objective the proposition of a new method for building a BSS (Fig. 3), with ensuring the agility property. This method exploits: BSC extended with Public Processes as a new perspective; UML modeling of public and private business processes interaction; and BPEL4WS specification to link this interaction. In this context, our method follows the three phases: analysis, design and implementation:

A. Analysis Phase

This phase provides two activities:

- Identification of the business strategy: the Board of Directors meets to target a business strategy that repents potential of the company in a definite period. In this phase, we also define the format of requested reporting, curves, graphs and statistics, respecting the hierarchical recipients. At this stage, we must also fix the degree of possible alerts, notifications and the causes triggering.
- Analysis of internal and external interaction scenarios of all the business processes to be supervised. For this, we will need to: i) Identify

 ISBN: 978-1-61208-467-1

company internal business processes (private) to supervise; ii) Identify company's external business processes (public) to supervise; iii) Select their supervised WS, and identify their use contract.

B. *Design Phase*

This phase provides four activities:

- Elaborate the dynamic behavior of business process modeling of all the interacted internal and external processes, using UML activity diagrams. The resulted representation shows the interaction from a start point to a finish point, detailing the many decision paths that exist in the progression of events contained in the activity. Activity diagrams are useful for business modeling where they are used for detailing the processes involved in business activities.
- Define the BPEL4WS specification that allows the link between WS of supervised business processes (public and private), according to the UML activity diagram.
- Extend the BSC structure, which consists of adding a fifth perspective in the original structure of BSC is that of "Public Process". This new perspective allows the company to consider its strategy on the status of their collaborative or external business processes, not only on the state of internal ones. As a matter of fact, currently companies publish some services to the outside.
- Build the new BSC, in order to identify the overall objectives of the company according to five dimensions: financial, customer, internal process, external process, learning and growth. For each objective, we should specify performance measures, targets and initiatives to develop.

C. *Implementation phase*

By using the most appropriate software tool, this implements the basic components of our BSS. These components provide the import of BPEL4WS specification as an XML file, and import also the new structure of BSC as a strategy table toward a reference. This system improves business efficiency (via the strategy respect); it reduces a response time to the operations of these internal or external business processes (via BPEL specification); and it allows accesses to real-time process performance indicators (via BSC measures against targets).

V. CASE STUDY: AGB BANK

In order to establish the exploitation of our method, we choose to validate it with a case study in relation with a banking company, named AGB (Algeria Gulf Bank). This choice is made because the banking domain provides the most convenient environment to prove all the aspects of this new method. Our objective is to implement in a company bank a BSS of the various transactions of internal and external business processes. Thus, the company provides the following public services (external) (see Fig. 4): e-Banking system (website), notification system (Fax, SMS and e-mail), Automatic Teller Machines (ATM) via a Card Inter Bank (CIB) and e-Payment through Electronic Payment Terminal (EPT) also via the CIB. The following section gives the application of the proposed method:

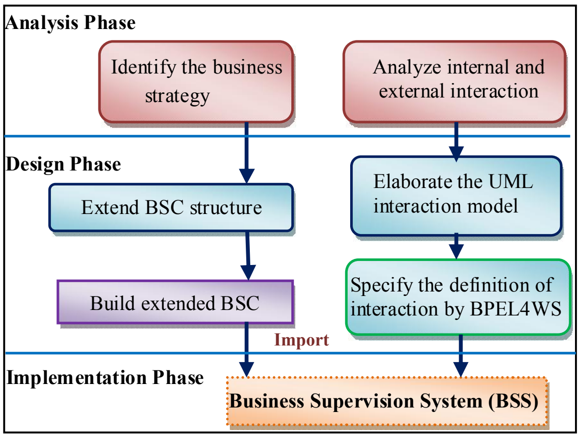

Figure 3. Overview of the proposed method.

A. *Analysis phase*

- Identification of the business strategy: the AGB strategy was defined the first time in early 2009 aims to achieve its mission while being faithful to the values and principles that are hers. Now, this strategy focuses on six areas: to increase profits, to increase the number of clients, to reduce credit risk, to insure qualified employees, to acquire robust equipments and platforms and finally to provide services outside the bank's headquarters boundaries (through the net).
- Analysis of the internal and external interaction:

- Internal company business processes (private) to supervise: Human resources management; Development of balance sheets and reports (monthly, yearly); Customer Service Management.

- External company business processes contain in WS to supervise is: E-Banking (Website); Notification (Fax, SMS, email); E-Payment (EPT) and ATM (CIB). Their user contract or service interface are:

a) The WS e-Banking System: the user contract is the Personnel Identifier Number (PIN) code and the Password.

b) The WS Notification system: the user contract is the Fax number/E-mail address/mobile number and the content of the notification.

c) The WS E-Payment System: the user contract is the PIN code, the Amount to be paid and the CIB.

d) The WS ATM: the user contract is the PIN code, the Amount to retire and the CIB.

B. *Design phase*

According to the AGB environment, Fig. 5 shows a part of UML activity diagram that displays the interaction of these internal and external business processes.

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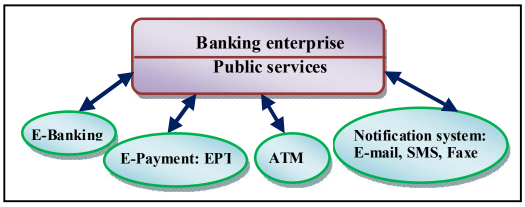

Figure 4. AGB Public Services.

In order to build a BEPL4WS specification that links all the supervised business processes, we choose to present in Fig. 6 the invocation syntax of Notification WS. According to the study of the AGB strategy and the definition of a new structure of BSC, Table 1 shows a part of our overall extended BSC, when the entire line of the new perspective is colored in blue.

In order to implement the BSS, we import the BPEL4WS definition as an XML file and the new BSC structure. This system checks in each supervision cycle the adequacy of data specified in the BSC (measures taking against targets) with the authorized interactions described in the XML file. This system aims to trigger alerts, sends notifications and provides requested reporting.

VI. CONCLUSIONS AND FUTURE WORK

In this paper, we have proposed a new method for developing a BSS, which covers three phases: analysis, design and implementation. The presented method combines the use of strategic BSC, which "Public Process" as a new perspective, the representation with UML activity diagrams for modeling the interaction of supervised private and public business processes and the specification BPEL4WS to define links of these business processes. The provided solution is validated, by applying it to an example related to the supervision of business processes in AGB banking company. Finally, we ensure that this method guarantees the agility property, which gives an added-value to this method. Agility is the ability of easy changes. Thus, we ensure the agility property because of the flexibility to manipulate in BSC objective properties, targets and measures for each dimension dashboard financial, customer, process and learning and growth independently of the other. Agility emerges also in an easy graphic modeling of ULM diagrams, which are flexible to handle and easy to refine. Agility exists also in BPEL4WS abstraction, when the interface is the only visible part of these components. Consequently, we present a new agile solution when it is easy to refine a concept without involving the others. In a future work, we will investigate to find a standard structure for the extended BSC. We also want to develop a global architecture resulting from the proposed method and implementation of all the components depending on the presented case study.

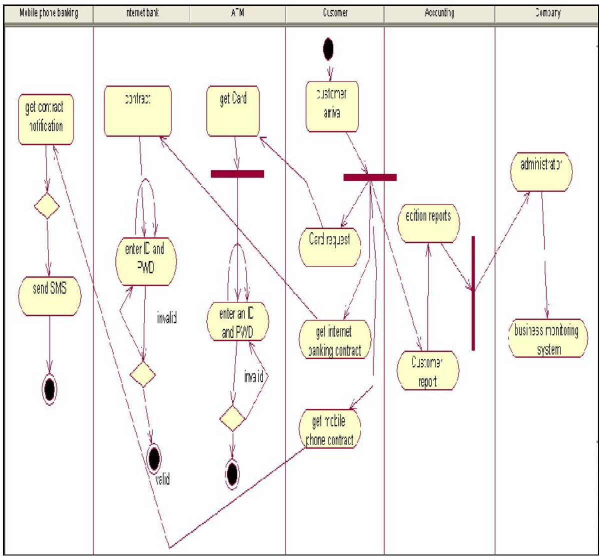

Figure 5. Activity diagram.

TABLE I. AGB EXTENDED BSC.

Perspec-tives	***Strategy Map***	***Balanced Scorecard (BSC)***		***Action Plan***
	Objectives	***Measures***	***Targets***	***Actions / Initiatives***
Financial	Increase in revenues	- Own capital -Total revenues - Charges -Tax	- Social capital: 20% en 2022 -ROA +3% -ROE +2%	-Increase sponsoring - Analyze reports
Customer	Evolve in customer wallet	-Number of customers -Deposits from customers	-Total accounts +5% -Credit total ±3 -Total assets+0,1% -Own Fond+1%	-Align claim with the trade - Provide available and easily service accessible
Private processes	Mark as a reference bank in terms of technology and innovation	-Critical processes -Process failed	-Critical processes = 0.001% -Process failed =<0,00 5%	-Apply information technology -Improve capacity of information systems
Public processes	Optimize the use of published web services	-SW Successfully invoked -SW invoked with failure	- Rate Failure < 0,00001%	- Reinforce the security conditions
Learning and Growth	Improve the performance of current and future collaborator	-Training Organized -Trained employee -Employee productivity	- Rate human failures = 0.5% -80% Employee trained in 202	-Master The existing and new business in the banking industry

```
<invoke partnerLink= " link "
portType="port"
operation="Notification "
inputVariable="Fax number/Adress e_mail/Mobile number,
 Notification "?
outputVariable="code_notification, nbr_notification, date" ? >
<!-- adding guard -->
<catch faultName=" Declined_notification "
faultVariable=" Fax number/adress e_mail/mobile number " ?
activity
</catch>
</catchALL>?
activity
</catchALL>
<!-- compensation mechanisms in case
of cancellation of a transaction -->
<compensationHandler>?
activity
</compensationHandler>
</invoke>
```

Figure 6. Notification BEPL4WS syntax.

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Assessing the Environmental Impact: A Case of Business Process Analysis in the Automotive Industry

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Abstract— **Sustainability management is has been in the focus of the enterprises for several years now. Communal and private organizations are interested in sustainable solutions and practices for their operations. Software systems and their underlying business processes are ubiquitous and fundamental for most of the organizations of our industrial society. Hence, sustainability aspects must be integrated into the information systems architecture and into the business process life cycle. Using the action research approach for the environmentally focused business analysis of an automotive supplier we provide insights on how measuring the environmental effect of a business process can affect its optimization. We also show how a more process aware software can generate enhance environmental indicators beyond its own resource use optimization. By including environmental indicators into the classic process performance measuring this approach allows researchers and practitioners integrating environmental performance goals into the processes and their analysis.**

Keywords- Measuring environmental impact; action research; business process management.

I. INTRODUCTION

The increasing awareness of customers and the general public for sustainability and environmental impact on the one hand and legislative requirements on the other hand motivate more and more organizations to keep track on their environmental impact [1]. Public and private organizations are interested in finding and using sustainable solutions and practices. Thus, sustainability needs to be considered on all organizational levels. To support the transition to sustainability, the organisation need to integrate aspects into the business processes and their management. Past research has indicated that, in order to become green, organizations need to embed sustainability-related targets at all levels of business, starting from the strategy level [2]. Consequently, business analysis needs to accommodate sustainability-related factors to be able to measure and control them. This step not only allows for controlling the accomplishment of sustainability-related targets, but also creates transparency and awareness [3].

Building on this reasoning, the research question here is: What insights can process analysis provide on sustainability-related optimization aspects? Being a research-in-progress, we focus on the environmental aspects of the general set of problems of sustainability. Furthermore, the effects of the derived management actions changed the environmental impact of the enterprise will be addressed in future studies.

In this paper we consider the environmental perspective of a business process and its contributions to achieving the environmental goals of an enterprise. Therefore, we define environmentally relevant process characteristics based on an online survey among environmental officers as well as on the literature review. Furthermore, we develop a list of indicators that includes the “classic” key performance indicators (KPI) as well as KPIs that measure the environmental impact of a business process. Using these indicators we assess a real-life processes from the automotive industry in regard to their environmental impact. Additionally, we suggest process optimization measures. Here, we use action research (AR) paradigm to provide insights on the environmental process assessment. The researchers are “participant observers” as required by Baskerville and Myers [4]. This paper presents the first two stages of the AR in Information Systems (IS) as described by [4]. We define the research problem and position our research in the domain of business analysis with theoretical background of design and action [5], here the soft system methodology [6]. As the second stage, an action needs to result from the research activities. The results of the analysed enterprise and business process were presented to the process owners and sustainability officer inducing the process re-engineering actions but also the social reasoning on the action and its results for the theoretical domain it was initiate from introducing stages three and four of AR. The pragmatic approach of AR provides the researcher with the method that helps explain why things work [4] and thus provides a valuable feedback to the theory the research question is grounded in.

This research contributes to a process-focused discussions between business and IT managers to enable a common understanding of processes and the resulting opportunities to make these processes and thus the organization more sustainable [7]. We focus on the process-oriented techniques, as this view allows leveraging the power of information systems for a transition to a more environmentally friendly process and organization [7]. The defined indicators can be applied by business process managers, sustainability officers, business process analysts as well as researchers in the area of green IS.

To present our research findings we review related work on assessment of environmental process indicators in section two. The research method is describe in section three, while section four describes the studies process and indicator structure followed by the process assessment results and the implications for change. The paper finishes with the discussion of the gained insights and outlook on our future work.

II. Related Work

The information systems (IS) domain addresses sustainability under the aspects of information technology (IT), software and business processes. Also, the notion of the Key environmental indicators (KEI) is gaining popularity in the domain of performance management. Reiter et al. [8] introduce a combined approach of IT and BPM for efficient energy use in a process. Cleven et al. [9] discuss the capabilities required to measure and manage sustainability performance on a process level by providing a capability maturity model (CMM) for green process performance management capabilities. Goldkuhl and Lind [10] address the process design phase by presenting an extended process modelling approach for capturing and documenting the greenhouse gas (GHG) emissions produced during the execution of a business process as well as an accordant analysis method. The calculation methods for the carbon footprint of a process already being explored by e.g. [11]–[15]. Betz [16] describes an approach for a sustainability aware business process management using XML-nets. Among these works, two general measurement approaches can be distinguished: Cooper and Fava (2006) suggest a bottom-up approach from the process analysis perspective, while Pan and Kraines (2001) describe a top-down perspective incorporated in the environmental input-output analysis. Heijungs and Suh (2006) combine the two approaches. Nowak et al. [17] present a methodology and architecture for green BPR, providing a starting point for green process analysis and re-design. Further methods for process analysis towards environmental potentials are presented in [18].

III. Research Method

Following Baskerville et al. [4] our research is based on the pragmatism premise. Thus, we first establish the purpose of the action research and its theoretical background. Given our research question of how and to what level to assess environmental effect of a business process, the theoretical background here is the soft systems methodology [6]. To assure that the problem setting includes practical action [4] we identified business units that are producing the highest environmental effect by distributing an online survey among environmental officers of the enterprises. The survey was sent to 87 enterprises and was designed to answer the question about which business division in the enterprise depending on the amount of greenhouse gas (GHG) emissions. A follow up question was, what business area the sustainability responsible considers to have the highest potential to reduce its environmental impact in future as required by German legislation on GHG emissions for enterprises. The final set consisted of 74 answered surveys.

To compose the evaluation system for environmental and business performance, the environmental indicators where collected from Eco-Management and Audit Scheme [19], an environmental management scheme based on EU-Regulation 1221/2009, as well as from German environmental legislation. They were filtered towards redundancy as well as the relevance and feasibility of process performance evaluation.

To assess the environmental effects, a real-life company, a testing company as automotive supplier, was contacted. The testing division, i.e. quality assurance unit, was chosen as an object analysis. For process identification and documentation interviews with process actors and owners were led. The process was modelled using BPMN and is shown in Fig. 1. The results of the process analysis where communicated back to the process owners and actors as well as the environmental officer. The discussion concerning their realization was initiated with the middle and upper management.

IV. Results

The results of the online survey concerning the definition of the environmentally relevant business divisions resulted in 64% of the respondents identifying the manufacturing division as the business unit with the highest GHG emissions as well as the business area that will be affected by the legislation for emission reduction the most, according to 70% of the respondents. Facility management (11%) as well as logistics (10%) are seen as the business units with high environmental impact. Although, quality assurance was named as one of the emission intensive areas by only 8% of the respondents, 11% considered it to have a reduction potential concerning the future emissions.

A. Environmental Indicators

Based on literature review of sustainability indicators as well as on the environmental standard of EMAS III we identified environmental indicators that can be collected on the process level. Categories included into this KPI structure are listed in Table 1 as: biodiversity, mobility and employee information as well as classic indicators of process performance.

TABLE I. KPI structure including environmental indicators

Category	Indicator (Example)
Energy efficiency	Total energy consumption p.a. in MWh Total energy consumption of renewable energy Percentage of renewable energy consumption on total energy consumption
Resource efficiency	p.a./ without energy and water in t
Water usage	p.a. in m3
Biodiversity	Usage of built-up area in m3
Waste	p.a.in t toxic waste p.a. in t
Emission	Of Green House Gas (GHG) in tCO_2 equivalent p.a.

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Mobility	p.a. in km: transport, business fleet, business travel per person in flight/train, fuel consumption, parking space for cars/bikes per employee
Employee information	Number of sustainability workshops; number of suggested and realized sustainability related improvements
Realization of the Environmental Management System (EMS)	Number of EMS related workshops, number of days and costs related to EMS maintenance
Time	Response, processing, cycle time, set-up time
Cost	Failure, overall. Resources
Quality	Usability, accuracy, life expectancy, reliability
Capacity	Bottle-necks, machine efficiency, throughput
Flexibility	Temporal, structural, volume
Integration	Degree of automation, information flow, information: transparency, granularity, accessibility
Complexity	Degree of: standardization, structure; organizational and process interfaces

B. *Studied Process*

The process chosen for the environmental analysis is situated in the quality assurance domain. The considered enterprise is a service provider for testing of automotive products. Thus, the analysed testing process is a core process for the service provider and is modelled in Fig. 1. The company is situated in several locations, thus for some of the tests the tested object needs to be transported between different locations.

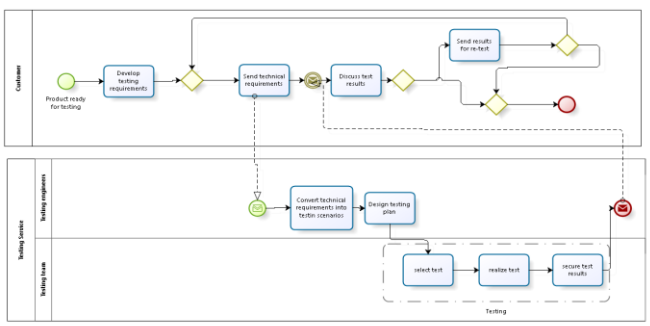

Figure 1. Testing process

The testing process is initiated by the customer. The customer describes the product and the characteristics that need to be tested. According to these requirements, testing scenario/s are chosen and specified in a testing plan by an engineer. The testing team performs the tests using the support of a specific software. Testing engineer and testing manager supervise the tests and communicate with the customer who can change the technical requirements according to the test results. For the process analysis we consider the sub- processes, i.e. the tests: Static/Dynamic Performance Tests (SPT, DPT), the most frequently executed test, Powered Thermal Cycle (PTC), the most energy intensive test, and Running Noise (RN). The testing process is coordination intensive as it implies several decisions being made by different parties. Some of the tests might also require transportation between the locations of the service provider or in case of external testing between a third-party service provider.

C. *Process Assessment Results*

We used the integrated analysis approach for assessing process productivity and environmental effects. Several of the suggested KPIs such as mobility could not be measured in our setting on the process level. Others, indicate possible improvements that can be realized on the process level or location-wide. Table 2 shows an excerpt from the process analysis results.

TABLE II. RESULTS OF PROCESS PERFORMANCE ANALYSIS

Indicator/Process	SPT	DPT	PTC	RN
Power Consumption (in MWh)	0.3	0.43	10.09	0.31
Percentage of energy from renewable sources	24	24	24	24
Emissions (p.a. in tCO_2)	0.17	0.24	5.75	0.16
Built-up area	105	105	175	250
Handling time (in min)	62	62	140	80
Processing time (in min)	62	62	14675	80
Idle time (in min)	0	0	14535	0
Set-up time (in min)	17	17	60	30

Representing the quality assurance domain, the main resources used during the execution of the tests are energy and space. The PTC test uses the highest amount of energy (10.09 kWh per cycle) that is mostly needed for the heating of the testing room, while the RN-test process requires the highest space usage ($250m^3$). The three testing processes generated 6.32 tons of CO_2 per year due to their execution. The exact mobility patterns related to the tests were hard to deduce during the analysis. Also the water usage as well as employee information indicators could not be sufficiently assessed during the process analysis.

D. *Implications for Change*

Being a measurement process, the tests mostly involve the usage of energy and space. Besides using the energy for the IT support of the process the PTC process involves working with high temperatures. Thus, a closer look at the performance number of the PTC process provides optimization potentials. Beside the idle period as well as the set-up time of the testing appliances that can be reduced using a scheduling software that is provided with the exact process description including cycle times and device usage, further potential for change lies in the heterogeneous expertise of the testing team. Since the testing knowledge is not symmetric within the team, tests are scheduled according to their feasibility and not according to the optimal resource usage. Homogenous knowledge level would also result in reduced error rates, leading to less test re-runs requiring resource usage.

Collected environmental indicators imply that changes towards more sustainability will induce changes on the enterprise level or at least location level. Most efficient changes can be achieved by changing the energy provider to enhance the energy mix from currently 24% being from

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renewable energy sources to a higher percentage. An alternative for a more sustainable energy acquisition can be a construction of an on-site energy generator such as photovoltaic facility that could, e.g. cover the parking lot or is located on the roof of the building to provide a renewable energy source for heating. These alternatives would result in a reduction of GHG emissions as well as provide other advantages in terms of employee satisfaction and benefits for facility management. Another large scale action would be the enforcement of commuting of employees by train between locations rather than by cars. A back-of-the-envelope calculation on the change in transportation for the location and testing team in question showed a difference of GHG emission of 18t per year.

Potential for process enhancement bears the focus on test specific equipment. The PTC test uses a climate chamber that needs to be pre-heated for three hours before the test. Thus, the heater runs during the night, resulting in about nine hours of excrescent heating. Furthermore, the heater generates rejected heat that stimulates the air conditioning (AC) to balancing the temperature. A solution would be to position the AC machines in a separate room, making the room temperature gradually adjustable as well as reducing the noise in the testing room. A more efficient planning software would also contribute to a higher energy efficiency by providing the exact times for the optimal room tempering for the tests and automated heater management. These actions would result in a higher energy efficiency and GHG emission reduction of 2.8t per year given the averaged historical data on process execution.

Hence, our assessment of the environmental process performance revealed sustainability potentials on all of the three levels: Enterprise-wide such as the change of the energy provider; location-wide such as instalment of a photovoltaic facility; process-wide such as re-assessing the software features towards planning and facility automation and re-thinking the process tools usage. While the enterprise-wide changes might be difficult to realize due to the complex decision structure, location and process-wide changes can be targeted for short-time realization. Thus, we suggest that the company launches processes to support the environmental officer in realization of location- and process-wide programs to support the environmental thinking and realize the otherwise lost potentials as well as to encourage employees in their awareness of environmentally effective process improvements.

V. Discussion and Outlook

In this paper we presented insights gained from an action research based approach to sustainability assessment on process level by including environmental indicators within the classic process performance measures. The chosen research paradigm of action research allowed us to observe the reactions on the topic of environmental problems in general within the enterprise on different organizational levels as well as the reaction on the suggested optimization measures in particular.

Since the considered enterprise does have an environmental officer, there have already been actions taken to provide more sustainable operations. These have mostly concerned the facility management domain, e.g. automatic light sensors, routine maintenance of the heating, etc. for efficient energy use. These actions are consistent with other research findings of the effects and toeholds of enterprise-wide sustainability initiatives [20].

The performed process analysis revealed a close connection between classic process optimization and enhancement of environmental indicators. Focusing on sustainability additionally allows the process analysis to look deeper not only into the workflows but also into surroundings in which the process is situated. Hence, the results suggest a need for a process analysis framework that includes environmental aspects. The potential effects will be continuous process improvement (CPI) that result in a more efficient technology use and work schedules. Hence, the suggested improvement of the testing software would not only result in a more efficient workflow but would also positively affect the energy use and employee satisfaction. Similar to the classic CPI approach, process owners or managers should encourage process actors to pay attention to more efficient resource usage as well as the exploration of occurring synergies. While big changes towards sustainability can be realized on the enterprise level, gradual improvement as well as personal awareness needs to take place on the process-level in the enterprise. To achieve this goal, enterprises need to invest into supporting education of the workers not only on the CPI techniques but also in environmental topics.

Our future work will focus on development of the sustainable performance management framework that that includes the structuring of enterprise wide aspects, locally changeable issues as well as process wide issues. Furthermore, a process analysis method based on the KPIs described above will be developed to include the potential interdependencies of the performance and environmental indicators. Furthermore, the KPI structure presented here needs to include further indicators of sustainability that go beyond environmental concern. We intend to provide sustainability managers with an evaluated tool that encourages change, incorporates suggestions from process actions and shows the results of their implementation.

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Efficient Calculation and Simulation of Product Cost Leveraging In-Memory Technology and Coprocessors

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***Abstract*—Determination of product cost and resource consumption during manufacturing, is a crucial scenario for manufacturing companies. While enterprises have the required data for these calculations already, the computational complexity makes it still hard to build interactive applications that can be used for end-to-end simulation, from procurement to sales. Nevertheless, these applications are required for collaborative product cost simulations that support business experts to make fact-based and data-driven decisions. Within this paper, we present the generic calculation engine that can calculate product cost and other resource based features of thousands of products within the time-frame requirements for interactive applications efficiently. The engine leverages the potential of today's high-end in-memory databases in combination with the computational power of coprocessors. To solve the problem, we transfer the input drivers and their interdependencies into a system of equations that can be solved by either the coprocessor or a large scale multiprocessor system. For our evaluation, we use actual enterprise data of a Fortune 200 company also providing the scenario. We evaluate the approach based on this data, comparing our enterprise application specific problem solution with standard solution techniques of the same domain.**

***Keywords*–in-memory database; enterprise coprocessing; business data processing; product cost calculation.**

I. Introduction

The knowledge about the costs of products and services offered by a company is mandatory information to guarantee the long-term success of a company. Therefore, the ability to calculate product cost based on product and manufacturing data is an integral part of enterprise systems. Cost drivers, like material prices, labor cost, cost of machinery and others, together with structural data, such as bill of material, and process data, such as routing, influence the cost of a product. Being able to determine the effects of changes of these cost drivers presents an advantage for decision makers, as they can make fact-based and data-driven decisions for the business how to best react to these changes. Enterprise systems already store the majority of the information required to calculate these costs.

State-of-the-art enterprise systems use in-memory databases to store and analyse huge amounts of data [1]. Those database systems are able to handle high volume workloads, while still guaranteeing maximum performance for database queries [2]. With the emerging trend of predictive analytics and complex simulation models requiring more business data, application logic is being transferred to the database execution level to avoid expensive data transfer. In addition, one can benefit from the available computational resources of the database server, reducing requirements on the client's side. SAP's HANA, one of the leading in-memory database systems in the enterprise application market, for example, offers a variety of tools to support developers with algorithms for predictive analytics [3]. While these algorithms benefit from the computational resources of the in-memory database system, they differ in computational complexity from transactional and analytical enterprise database operations.

The calculation of product cost fits into this category of enterprise application logic. To calculate the cost of a product, all relations can be expressed by a set of interdependant equations. The system of equations is then populated with data stored inside the database system and needs to be solved numerically in order to determine the cost of every raw material, semi-finished and finished good.

Within our research, we focused on calculating product features, such as the costs of companies' products, enabling companies to run collaborative planning sessions, including real-time simulation of changes to influential feature drivers. While today's product cost calculation systems focus on the influence of changes on single products, our system aims to provide end-to-end simulation capabilities. Therefore, we use transactional enterprise data to build a matrix representation of the relations between business entities. To solve the calculation problem as fast as possible, we make extensive use of data parallelization techniques and use coprocessors, such as Intel's Xeon Phi [4] and Nvidia's 2nd Generation Maxwell graphic processing units (GPUs) [5]. The use of these coprocessors is beneficial in our scenario for two major reasons: performance-price ratio and additional level of scalability.

These coprocessors offer computational resources for a subset of enterprise problems for lower prices than CPUs. A modern CPU (Intel Xeon E7-8890-v3 [6]) has a theoretical performance peak at 558 GFLOPs for a price of $7,488, while a current coporcessor (Nvida GeForce GTX Titan X[5]) offers 6,600 GFLOPs for $999. Even under the consideration that coprocessors cannot be used for all operations a traditional CPU can execute, the approximately 90 times lower price for performance ratio makes the coprocessor a valid option to add computational resources to the database node.

While the coprocessor calculates the product features, the CPUs of the database server are available for other computational tasks, such as database transactions. This becomes

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even more important, as enterprise systems have to handle the workload of many hundreds and thousands of users. All results in this paper are based on a dataset we got from a Fortune 200 company, manufacturing goods for the consumer packaged goods market.

The remainder of this paper is organized as follows: Section II gives an overview of related work in the area of linear equation system solving, followed by Section III presenting the calculation logic of product cost in detail. Section IV describes the insides of the implemented inversion algorithms and other important parts of the prototype. These implementations are evaluated in Section V. The paper concludes and gives an outlook on future work in Section VI.

II. Related Work

As the costs of a product can be expressed as a system of linear equations, we will present related work in the area of equation solving. The optimization of linear equation solving is a well-established field of research. Linear equations are known to be executable efficiently on GPUs, in either format as sparse or dense matrices [7], [8], [9]. To solve both sides of a linear equation system, matrices need to be inverted. Ezzatti et al. [10] compared CPU only, GPU only and hybrid implementations of matrix inversion, using an LU factorization from LAPACK [11] and the Gauss-Jordan elimination algorithm. Their investigation indicates that the Gauss-Jordan elimination is a well-suited algorithm for parallel computing. Additionally they show that hybrid implementations, exploiting the underlying platform features can still outperform pure GPU versions.

One issue arising with transferring computations to a coprocessor are the memory constraints. In comparison to today's available large main memory systems, the memory of coprocessors is still rather small. To reduce the memory required during the inversion of matrices, DasGupta [12] proposes a modified version of the Gauss-Jordan elimination calculating the inverse within the original matrix space. Another possible approach to solve this issue is to split the calculation into sub matrices [13].

A different approach to solve linear equations in a general form is to use linear solvers instead of an inversion and matrix-vector multiplication. Krüger and Westermann [14] have proposed a framework for implementing linear algebra operators on GPU and used it to implement an efficient sparse conjugate gradient solver. More work on linear solvers on GPU includes Tomov et al. [15], who present solver implementations on hybrid systems, which are GPU accelerated.

For our work, we focused on using the inverse calculation approach, as it is beneficial for our use case in two aspects. Firstly, we only have to calculate the inverse of the matrix once, while the calculation is executed multiple times, either for different input parameters or different features. This reduces the overall application runtime overhead of the inverse calculation in comparison to the interactive simulation process. Lastly, the inverse matrix can be used for fast search of materials and cost center activities, as it condenses all information for specific materials and cost center activities either in its corresponding rows or columns. Thereby the inverse matrix enables fast filtering on materials that is not required by the product cost calculation directly, but it enables an interactive navigation through the material database. The inverted matrix can even be used to reduce the load on the database management system, by providing an index-like structure for the material hierarchy, at the cost of additional memory requirements. The additional memory is also required for the algorithms in any case, which is why it is not considered to be a drawback.

III. Product Cost Calculation

While we aim to calculate multiple product features, including carbon dioxide, water requirements and energy usage, which indicate the environmental impact of a product, we started with the calculation of monetary features of a product within the prototype based on the data obtained. Nevertheless, the calculation of product cost is a common scenario in enterprises and therefore poses a relevant use case to build a prototype on. Based on the data and complexity of today's products, this calculation is computational intensive. We present a solution for the problem, using parallelizable algorithms for modern hardware. All manufacturing and non-manufacturing related expenses of a company determine the costs of a product. The prototype enables a group of experts to change cost drivers according to predictions and to evaluate the influence on product cost instantly. Due to the immediate feedback, these planning sessions become interactive and collaborative.

Within this section, we present the calculation process of the prototype, the equations used for the calculation, and the real dataset provided by our industry partner.

A. Multiphase Product Cost Calculation

To demonstrate the feasibility of using coprocessors to solve enterprise equation systems, we implemented a prototype focusing on manufacturing related product cost of a company. The prototype is split into a lightweight user interface for result visualization and a server application executing all calculations for the requested production periods. We aim to enable the user to calculate and modify product cost and single cost components to support an interactive simulation scenario. The logic executed in the server could be integrated at a later stage into procedures for the database system. At the time of writing, we left this open for future work.

We use the transactional data entered and stored in an enterprise resource planning (ERP) system as a base for the calculation of product cost. The data contains information about raw material prices, operational expenses, product design, production process, foreign currency exchange rates, and many more. These cost drivers are parts of the equation system.

The product cost calculation process is split into three phases: virtual data model creation, data retrieval and homogenization, and cost calculation.

1) Virtual Data Model Creation: The virtual model is created during the design phase of the application. It is required to create a simplified view on the ERP data model to be accessible for the product cost calculation. Within this phase, we create non-materialized views that fit the needs of data granularity, based on tables of an ERP system. These views are a logical description that is populated during query execution time, rather than having a materialized representation inside the database.

A simplified version of these views used within the prototype is depicted in Figure 1. For ease of readability, text fields

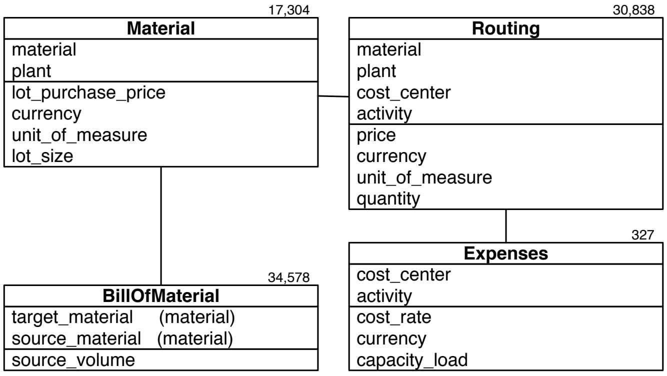

Figure 1. Simplified Virtual Data Schema

and additional information are removed from the illustrated model.

In the simulation prototype, the data is stored within a database and retrieved from it.

a) Material: The *Material* view contains the data of all materials. Information about lot purchase price and corresponding currency, lot size and unit of measure is available in the view.

b) Bill of Material: The *Bill of Material* (BOM) contains the list of all raw materials, parts, intermediates, subassemblies, commodities, semi-finished goods and finished goods required to construct or repair a product. Therefore, it stores the relational network between materials. Specifically, the number of units of a source material that is required to produce a lot of the target material is represented in the table. Furthermore, the BOM can be seen as a directed graph, having nodes representing materials and edges representing amounts required to produce the material at the end of that edge.

c) Routing: Routing describes how many units of a specific cost center activity are required during the manufacturing process of a specific material. In addition, the costs per unit and additional meta-data are stored.

d) Expenses: The *Expenses* view contains all expected expenses by general ledger account for the combination of cost center, activity, and work center. These expenses are not necessarily bound to a specific manufacturing step or material.

2) Data Retrieval and Homogenization Phase: The data retrieval and homogenization phase relies on features available in the in-memory database engine. In this phase, the views are requested and executed to transfer the data to the application. During the query execution, all volumes are translated into their base measure and are unified into a common target size, either lots or units. We decided to convert everything into lots, due to the more meaningful values for business users. Currencies are converted using SAP HANAs currency conversion feature [1]. The majority of the data is retrieved at application start time and is prepared for the feature calculation. At the end of this phase, a block matrix containing multiple weighted adjacency matrices is available inside the server application.

3) Cost Calculation: The Cost Calculation (CC) represents the simulation part of the application. The user changes input drivers for the calculated features. For the prototype, we decided to use monetary values, such as purchase price and cost center activity rates. These can also be replaced by other factors, while a change of the matrix part of the equation is not required. The influence on the costs for all materials is calculated and the result is returned to the client. The fast response time enables an interactive and collaborative use of the application. The calculations are either done on a multi core CPU or preferably on a coprocessor, like Intel's Xeon Phi or a GPGPU. Using the coprocessor for calculation decreases the load in the CPU, making resources available for database query processing. In addition, the simulation benefits from the parallel execution of the calculation on the coprocessor to deliver results within a smaller time-period than the CPU.

B. *Problem Formalization*

Multiple cost drivers, e.g., material prices, labor costs, machinery hours, transportation, and more influence product cost. Based on the calculated cost per unit, the costs of goods sold can be determined, applying this rate to the sales volume.

1) Bill of Material: An entry b_{st} in the bill of material describes how many units of material s are required to produce one unit of material t. Instead of units, lots can be used as well. S_t represents the set of materials required for a target material t, while T represents the set of all materials that are produced. T_s represents all materials t that require s for their production.

2) Routing: Routing A describes how many hours of a specific cost center activity are required during the manufacturing process for one lot of a target material. In particular, a_{it} represents the amount of a specific cost center activity a_i that is required to manufacture material t. The cost center activity rate is determined by r_i.

3) Manufacturing Costs: As an example feature, we calculate the manufacturing costs mc of a product t. These costs describe, how many working hours and how many source materials are required for the production of t. The purchase price pp is part of the equation to cover the manufacturing costs of raw materials.

$$mc_t = pp_t + \sum_{a_i \in A} a_{it} r_i + \sum_{s \in S_t} b_{st} mc_s \tag{1}$$

While 1 uses the purchase price as variable input factor for the cost feature, any other linear factors for other features could also be part of the equation.

4) Capacity Load: The capacity load of a cost center activity is defined by the sum of hours spent for the specific cost center activity during the production process. T_i represents the set of all materials that require cost center activity i.

$$l_i = \sum_{t \in T_i} \big(a_{it}(pd_t + md_t) \big) \tag{2}$$

The demand d_t of a material t is defined by two parts: primary demand and manufacturing demand. The primary demand pd_t determines the amount of material t that is sold to the markets. The manufacturing demand md_s determines the amount of material s that is required to manufacture all demands of materials t that require s during production cycle.

$$md_s = \sum_{t \in T_s} \big(b_{st}(pd_t + md_t) \big) \tag{3}$$

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C. Solving the System of Equations

To solve the system of equations, multiple methods exist: using a linear system solver or by executing matrix operations. General feedback is that using a linear solver, like the funtions provided by Intel's Math Kernel library[16] (`sgetrf` to compute the LU decomposition, followed by `sgetrs` , which solves the linear equations), is preferable for performance reasons, especially if a matrix has to be inverted. This is due to the optimized implementations and reduced number of calculations required to solve an equation system. For the presented use case, we decided to go for the matrix operation path, because we saw benefits for operation parallelization. Based on the previously defined equations, all summations and multiplications can be done using a matrix-vector multiplication.

$$\begin{pmatrix} pp_t \\ pr_i \end{pmatrix} = \begin{pmatrix} b_{st} & a_{it} \\ 0 & l_i \end{pmatrix} \times \begin{pmatrix} mc_s \\ r_i \end{pmatrix} \tag{4}$$

The matrix stores all relevant relations between materials and cost center activities. It stores the adjacencies between these to be used for the calculation and is logically partitioned into four quadrants, as shown in4. For our implementation, we use row major ordering based to early experiences with the Xeon Phi and Intel's Math Kernel Library. In early experiments, we have seen that the usage of a transposed matrix vector multiplication was faster than matrix vector multiplication.

The first quadrant (upper left) represents the BOM. The quadrant is aligned by source materials on the vertical and target materials on the horizontal axis. The entries b_{st} represent the inventory change that will be applied if the specified source material is used for production.

The second quadrant (lower left) contains only 0 and is therefore called Zero.

The third quadrant (upper right) stores the routing information a_{it}. This represents the amount of hours spent during each manufacturing step.

The last quadrant (lower right) contains the capacity load l_i of all cost center activities. It represents the total amount of hours spent by a specific cost center activity in the time period stored inside the matrix. The numbers in this quadrant depend on the material demands and routing data factors of the other quadrants.

IV. Prototype Architecture and Algorithms

To calculate multiple versions of the manufacturing costs, the matrix presented in4 has to be inverted. Matrix inversion is hereby preferred to linear equation solvers, due to the number of different configurations of the equation system. To speed-up the cost intensive inversion process, the implemented inversion algorithm reuses knowledge about the matrix's quadrants and data stored inside the database. Within this section, we present some of the implemented inversion algorithms and other relevant parts of the architecture.

A. Prototype Architecture

To evaluate the approach of using a coprocessor for product feature calculation, we build the prototype depicted in Figure 2. A frontend application is provided to the user, enabling the user to configure and run simulation scenarios. The frontend application communicates via HTTPS with the backend that sends JSON responses. The frontend communicator is written in C++ and uses `mongoose` and `rapidjson` for data serialization. When a user triggers a simulation run, the simulator executes the given simulation scenario. The simulator fetches all required data from the database and sends it to the engine, which is the central computation unit. The engine itself consists of three subparts: the matrix inverter, the demand calculator, and the matrix-vector operator. The matrix inverter is responsible to execute an inversion algorithm and returns the inverse matrix that is used later on for the matrix-vector multiplication executed by the matrix-vector operator. The demand calculator is required to calculate the load for all cost center activities for the given production period, and it is part of the matrix inversion. All elements of the engine can be replaced by different implementations and are either executed on the CPU, the coprocessor, or both. The engine builder is responsible to set the implementations of the engines algorithms, to provide a user defined engine that can be used by the simulator. Within the prototype, the user is able to set different engines to enable a comparison of the implemented execution strategies. The database connector is responsible to fetch the data from the database. For our prototype, we used SAP's HANA in-memory columnar database. The database connector uses `nanodbc` to communicate with the database via ODBC.

B. Inversion Algorithms

To invert the matrix containing the enterprise equation system, we implemented several algorithms: Naiv inversion, AVX inversion, upper triangular transformation, and CUDA inversion. These algorithms are presented in detail within this section.

The current implementations require twice the amount of memory than what is required to store the data in dense matrix format, due to the implemented Gauss-Jordan inversion. The memory is required as space for a temporary working copy and the identity matrix of the same size as the original matrix. Each operation described later on is applied to the temporary copy and the identity matrix. Optimizations for the Gauss-Jordan elimination have been proposed by DasGupta [12] and Amestoy et al. [13] and can be applied in future versions of the inversion.

1) Naiv Inversion: At first, the quadrant containing the cost center load is inverted. Because only the diagonal value is set, the number of cost center activities determines the number of divisions required to finish this step. Based on initial performance measurements, an OpenMP `parallel for` pragma is used to parallelize the operation on a per cost center activity base (row level).

The next quadrant to be modified, contains the routing data. All columns of a row that are not equal to 0 get a multiple of the corresponding load line subtracted. Because the zero quadrant only contains zeros, we do not modify the bill of material quadrant in neither the temporary nor the identity matrix. Thus, additional computations can be eliminated, as the subtraction has to be done on the routing columns only. To speedup the execution, this step gets parallelized with an OpenMP `parallel for` pragma using the rows for parallelization.

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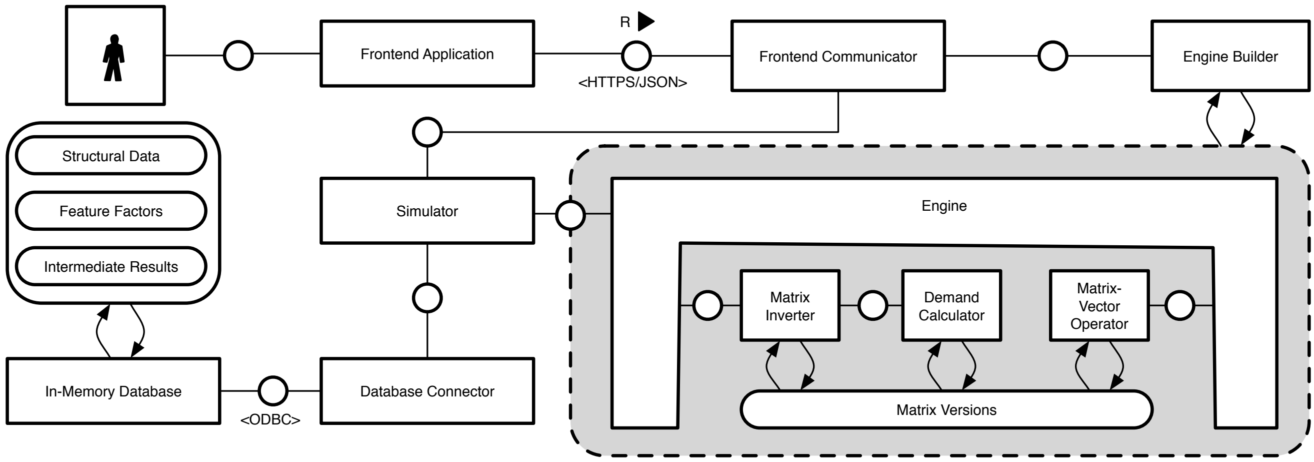

Figure 2. Architecture of the Product Feature Calculation Prototype

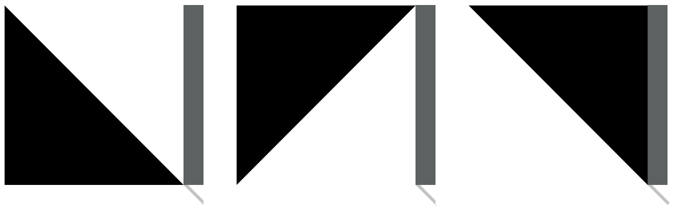

Figure 3. Matrix reordering enables the use of upper triangular matrix inversion

Finally, the BOM quadrant is converted to the identity form. This quadrant has two properties that are beneficial for the inversion process: the diagonal is set to 1.0, due to restrictions we applied during the virtual data model creation phase. This quadrant is also a lower triangular matrix. Thus the inversion can be done iteratively, starting at the first row and subtracting it from all other rows that have a value not equal to 0 at the corresponding position. This is done in parallel on row level, picking one row that can potentially be subtracted from all other rows. After this last step, an inverted matrix is calculated and the temporary copy of the matrix is removed.

2) AVX Inversion: During the second and third step of the naiv inversion, rows are subtracted from each other. This operation had a major performance impact on the inversion and therefore is a subject for performance optimization. To speedup the process, three changes to the initial implementation were made: the algorithm is NUMA aware, all memory is aligned to its AVX requirements, and we make use of Intels AVX instruction set, applying the same operation to multiple values at once. The implementation uses the functions `_mm256_set1_ps`, `_mm256_load_ps`, `_mm256_mul_ps`, `_mm256_sub_ps` and `_mm256_store_ps`, defined in `immintrin.h`.

3) CUDA Inversion: A CUDA-enabled implementation of the matrix inversion allows the execution of the algorithm on the GPU and outperforms a GPU baseline inversion algorithm from the Cula dense library [17]. The implementation focuses on reducing the access to global memory to gain performance. Utilizing the GPU's shared memory during the subtraction in the third step of the naiv inversion achieves the performance improvement.

4) Upper Triangular Transformation: In order to evaluate and compare the performance of our inversion algorithm, we required a baseline we could measure against. Based on the initial matrix format, we evaluated the LAPACK methods for general inversion (`sgetrf` and `sgetri`), which solved the problem. In order to use an optimized inverter implementation, we decided to implement row and column reordering for the inversion process, thus enabling the use of LAPACKs triangular matrix inversion.

The process of reordering is visualized in Figure 3. In the original format (left), the linear equation part of the bill of material quadrant (black) is a lower triangular matrix. During the first phase, the rows of the bill of material and routing (dark grey) are reordered (middle). In a second phase, the columns of the bill of material are reordered to convert the matrix into an upper triangular format (right). The quadrant containing the cost center load (light grey) is not modified during the conversion. White spaces contain only 0 values.

Afterwards we were able to use `strtri` for matrix inversion, which delivered faster results than the general inversion. In all measurements done for this paper, the time of row and column reordering is excluded and thus not part of the inversion time.

C. Scenario Data

Having described the construction of the matrix in detail, we will examine now the data sources for each part and give some characteristics of the dataset used by the current prototype. This dataset will later also provide the basis for the performance evaluation in Section V.

The data is a limited dataset provided by a manufacturing company. It contains data for a single location the company operates in. It consists of 17,304 materials and 327 cost center activities, resulting in a 17,631 $\times$ 17,631 sized matrix. Hence, the dominant part of the matrix is the bill of material, being over 50 times larger than the cost center activity related quadrants. Besides the general size of the matrix, it is also helpful to look at the number of raw materials, which is 6,379 and the number of products 2,978. This leaves 7,947 materials to be semi-finished goods and packaging materials. To get an understanding of the structure of the bill of material and the routing the following measures are helpful. Starting from products moving down the material hierarchy, there is an average depth between two and three levels of intermediate products included, with a maximum of five. This means when not using the matrix structure, but a tree-like structure, it is necessary to calculate the product cost for each of the intermediate products on the different levels, before the product cost for one product could be determined.

Another measure to consider is the ratio of non-zero values compared to zero values. On average, seven different raw materials or semi-finished goods are needed during each manufacturing step, resulting in a rather small number of values other than 0 in the bill of material quadrant. The maximum count is 27. Taking the average results in a ratio of non-zero data fields compared to data fields containing a zero of 1:2,472. Similar for the cost centers an average of six are required during each manufacturing step, with a maximum number of 39. The average ratio of non-zero data fields compared to data fields containing a zero is 1:55 within the routing quadrant. Therefore, the matrix in general is a sparse matrix.

We calculate the inverse of the matrix and it is not guaranteed that an inverse of a sparse matrix is also going to be a sparse matrix. While this may lead to additional overhead for runtime memory allocations for these new non-zero data fields in the inverted matrix, we consider a dense matrix for out implementation. When considering bringing the algorithm on to a GPU, this results in performance loss due to branching within kernels.

V. EVALUATION

Within this section, we will evaluate the central components of our simulation prototype: matrix inversion, and matrix-vector multiplication. To compare our solutions with standard methods, we compare our implementation with LAPACK implementations that are part of Intel's MKL [16]. All experiments were executed on a two-socket server, equiped with Intel Xeon E5-2640 CPUs. For the CUDA inversion, we used an Nvidia K20Xm Tesla card. The matrix-vector multiplication was executed on an Intel Xeon Phi 5110P.

A. Matrix Inversion

To calculate the product features based on different feature drivers, the equation system needs to be transformed. Therefore, the matrix representing the equation system is inverted. An additional inversion might also be necessary, if structural changes, e.g. product design changes or new manufacturing machinery, are part of the simulation process. Therefore, the inversion represents an important step during the feature calculation. The results for the presented algorithms are shown in Figure 4, depicting an average of 20 executions per algorithm.

To make sure to get as close to the theoretical performance as possible, we created a fine-tuned version of the AVX inversion algorithm. As a next step, the coprocessor based implementation needs to be tuned. It has to be noted that the system executed one inversion at a time exclusively, executing no other operations at the same time. Additional background load would decrease the performance of the CPU based inversion. To transfer the data to and from the coprocessor, additional 827 ms are required. In the case that the matrix-vector multiplication is run on the same coprocessor, the data

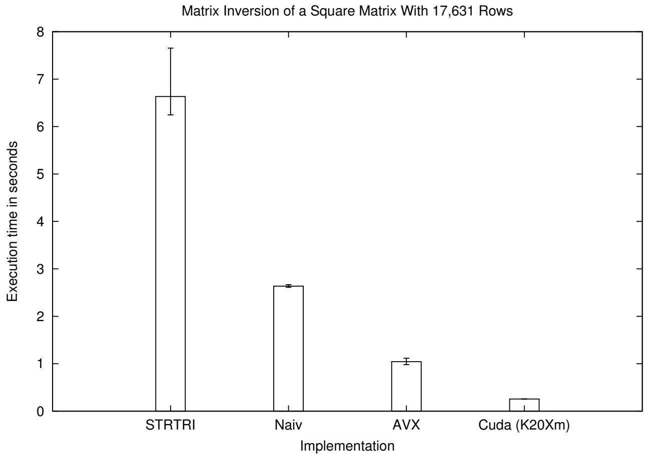

Figure 4. Performance evaluation for the matrix inversion algorithms

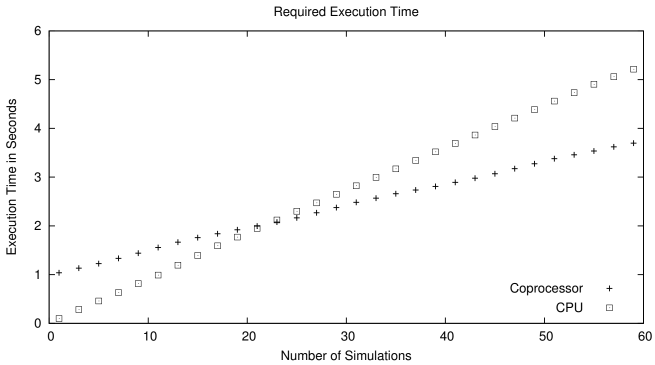

Figure 5. Performance evaluation for the execution of simulations.

can be reused and the transfer time gets amortized. Overall using available business knowledge leverages the performance of the matrix inversion compared to a standard library version and can be further improved by exploiting the underlying hardware.

B. Matrix-Vector Multiplication

The central component for simulating a new set of product feature input parameters is the matrix-vector multiplication. The results can be seen in Figure 5. The initial data placement to the coprocessor is dominating its execution time. The CPU has no off-load attached but the computational performance is lower than on the coprocessor, which is why the initial cost for offloading the inverted matrix gets amortized after 22 simulations.

Using the Intel library `pragma offload_transfer` preprocessor macros, we were able to offload the necessary simulation data in $0.98s$, using the Intel Xeon Phis PCIe 2.0 connection.

Offloading all data for every simulation is inefficient and reduces the performance advantages of the coprocessor. Since base and modified costs are the only changing features in our scenario, they need to be transferred for every single matrix-vector operation, while the inverted matrix has to be offloaded only once. This allows us to reduce the overall transfer overhead.

It has to be noted that there was no additional activity on the server during our tests, which would influence the execution performance of the CPU negatively.

VI. Conclusion and Future Work

With our prototype, we have shown that enterprise systems can benefit from the use of coprocessors. The usage of these specialized hardware components had a benefit from a runtime performance point of view. We showed with this prototype the influence of the increased performance from an application perspective based on actual enterprise data, enabling an interactive product feature simulation. While these results clearly demonstrate how a hybrid architecture, consisting of CPUs and coprocessors, can leverage business scenarios, such as the presented product feature calculation and simulation.

While the nature of database operations as parallelizable operations on sets and the parallel computing resources of coprocessors are a good fit, advanced application logic is different. To use the theoretical performance in an enterprise environment, data and algorithms have to be aligned to make efficient use of these parallel computation resources.

To solve this initial issue, supporting structures have to be defined, which enable the user to determine applications that will benefit from hybrid execution. Based on these findings, data structures have to be modeled that are suitable to deliver a data representation a coprocessor will be able to work on as directly as possible, reducing the upfront cost of execution time and memory during the virtual data model creation and data retrieval and homogenization phases. To avoid further continuous transfer of matrix versions between main memory and the coprocessors memory, the use of different sparse matrix representations might be necessary. Thereby the focus should not only be on memory consumption, but on the cost to construct them from the data fetched from an in-memory columnar database as well. Providing the enterprises with the ability to model different versions of the matrix, compare them with each other and even base their simulations upon them, enriches the foundation for their decision making. This extension requires to calculate the product features for multiple matrices at the same time, requiring additional memory, which will exceed the available memory on a coprocessor. While using sparse matrices relaxes the issue, an investigation on how to create an efficient versioned matrix data structure, which only requires to store a base matrix and the changes to it, is needed.

As enterprise systems tend to be used by hundreds to thousands of users in parallel, access to limited resources like coprocessors needs to be optimized. Multiple users might be able to share the same basic data structure to modify their application needs, such as the structural data used for the presented simulation scenario. This assumption has to be reconsidered once we allow users to alter these shared structures, such as the matrix encapsulating the equation system. To reduce the potential transfer overhead to the coprocessor, an intelligent data placement strategy reducing the effects of data transfers while considering the data of multiple users is required. Summarizing the results, we believe that coprocessors will play an essential role in the development of future enterprise applications.

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