An Architecture and Methodology for a Four-Phased Approach to Green Business Process Reengineering

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Abstract. Sustainability and responsible resource exposure has become a major issue in everyday life. Government, customers, and increasing social responsibility force more and more organizations to positively optimize their environmental impact towards a better, livable planet. In this paper we propose a four-layered architecture and corresponding four-phased methodology to enable organizations to (1) define ecological characteristics, (2) sense and measure these ecological characteristics, (3) identify, localize and visualize their environmental impact, and (4) help them to develop appropriate adaptation strategies in order to optimize their environmental impact without neglecting the organization's competitiveness.

Keywords: Business Processes, Process Views, Process Monitoring, Adaptation, Environmental Impact, Green Business Process Reengineering

1 Introduction

The growing interest in environmental topics and discussions reflects that sustainability in general has become a major issue for organizations over the last years. 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 [1,2]. Based on this demand organizations are forced to design environmentally aware business processes and therefore trace the environmental impact caused by them. However, this first postulates that organizations *know* which environmental impact (e.g., carbon footprint [3]) their business processes have in order to *adapt* more sustainable solutions to their processes [4]. As complex business processes may consist of several hundred activities [5] it is not easy to identify the relevant parts of the process that mainly drive the overall environmental impact due to the various influence factors relevant to the processes. Therefore, organizations need adequate technologies and methodologies to make their business processes more transparent with respect to their environmental impact. Subsequently, adaptation techniques need to be employed to decrease the overall environmental impact while ensuring not to significantly worsen the organizations economic objectives.

In previous work [4] we have discussed initial concepts and techniques focusing on *green Business Process Reengineering (gBPR)* which extends the *Business Process Reengineering (BPR)* originally proposed by [6] and [7]. They describe BPR as the analysis and design of work flows and processes within and between organizations. In [7], BPR is also promoted as fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance. The problem is that currently neither BPR formerly described in [6] and [7] nor modern approaches like [9] do cope with green requirements adequately. This leads to a gap of missing interconnection between existing standalone solutions for efficient resource usage and a holistic optimization of an organization's environmental impact. In most cases, the information gathered for traditional *Key Performance Indicators (KPIs)* provides insufficient data with respect to environmental aspects. Consequently, there is a need for concepts and technologies to define and monitor green efficiency metrics and to provide this information for analyzing and optimizing the processes properly. Given this information these approaches are faced with a further issue. Green requirements may end up in a trade-off with existing KPIs like costs or time and may change the current "best practices" when considering both KEI and KPI dimensions. In order to support the complex types of business objectives containing economic *and* ecological objectives we need to extended traditional BPR by introducing two novel perspectives in our gBPR approach. The first one contains the so called *Key Ecological Indicators (KEIs)*. Using these KEIs allows measuring the environmental impact of business processes and parts thereof. This concerns for example the energy consumption, water consumption, CO_2 emission, carbon footprint, recycling, or regulatory compliance and thus forms the motivation for changing the business processes. The second added perspective covers additional management activities emerging from the integration and interaction of the KEI, process, and infrastructure perspectives [4]. This concerns for instance the mutual influences of the process structure and its underlying infrastructure.

In this paper we propose an architecture and methodology to address the current lack of supporting green requirements adequately. Consequently, the contribution of this paper is twofold: Firstly, we introduce an architecture that includes four layers to serve the different aspects of gBPR: (1) Strategy, (2) Sensing & Monitoring, (3) Analysis & Management, and (4) Adaptation. This architecture covers the proper monitoring, analysis and adaptation of green reengineering approaches and thus helps organizations to identify the relevant aspects for optimizing their environmental impact. The implementation of this architecture in a service-oriented environment is ongoing work. Secondly, we introduce a methodology to enable the process stakeholders to reduce the environmental impact utilizing the proposed architecture. The remainder of this paper is structured according to the phases of gBPR: Section 2 introduces the architecture in general. Section 3 explicitly describes the four architecture layers and their corresponding methodology support. In Section 4, the key concepts are applied to a concrete scenario. Section 5 positions our approach to the existing literature. Finally, Section 6 concludes the paper and outlines future work.

2 Architecture

Business processes of organizations are dependent on various internal and external parameters, such as the organizational structure or legislative regulations. Thus, in order to achieve best possible decrease in its environmental impact, it is essential to consider business processes from an end-to-end perspective, including their underlying infrastructure as well as the people or other resources that perform the associated activities. To best fit these requirements and to provide a holistic perspective on organizations' processes we propose an extended BPR architecture and a four-phased methodology based on the initial gBPR concepts [4]. Our architecture comprises four major layers which are shown in Fig. 1: (1) Strategy, (2) Sensing & Monitoring, (3) Analysis & Management, and (4) Adaptation. The arrows between the different layers indicate that relevant data is provided from each layer to its successive layer. Details are explained in Section 3.

The first layer "Strategy" is used to identify and define appropriate KEIs which reflect the ecological objectives and traditional KPIs which reflect the economic objectives of an organization. KEIs are defined based on a set of ecological metrics (e.g., CO_2 emission, water consumption etc.) to be measured and the specific thresholds that apply for a complete process or single activity, respectively.

The measurement of KEIs is performed in the "Sensing & Monitoring" layer. At this level we assume that monitoring of KPIs is done in an appropriate way using given methodologies and technologies, e.g., [11]. However, due to the wide range of possible KEIs that one might consider, the information gathered for determining those KPIs may be insufficient and additional information for determining the KEIs is needed. For the measurement of KEIs, the ecological characteristics of processes and activities have to be determined explicitly. In some cases, that information can be extracted from service or product specifications at design time. In the general case, however, special sensors are needed which monitor the ecological characteristics of, for instance, IT systems, manufacturing operations, human activities, ecosystems, facilities and buildings, or logistics at process runtime. That sensor information has to be correlated with process instances and activities which use the corresponding resources. As a result, the process instances and activities contained in them are annotated with sensed ecological metrics.

The third layer "Analysis & Management" forms the heart of making processes "greener" as it allows us to analyze processes and subsequently identify the parts of a process that cause the highest negative environmental impact. To reveal this information, we utilize *process views* as introduced in [10]. By means of augmenting the process model with ecological information from layer two (Sensing & Monitoring) we are able to build virtual views on a process and identify and visualize the KEIs of either the complete process or specific activities of interest. This enables analyzing the current environmental impact of a process model, identifying the main cause of defined KEI violations, and finally revealing the room for ecological improvement.

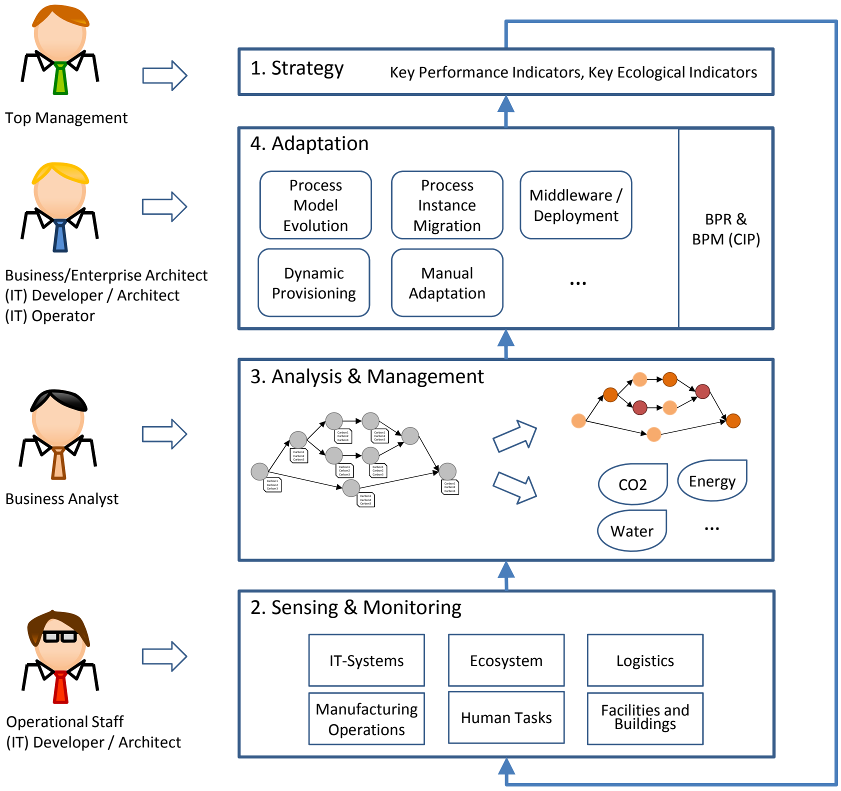

Fig. 1. Architecture of an Environmental Impact Management

If the room for ecological improvement is identified, a business process can then be reengineered in different ways. This is represented in layer four "Adaptation". For example, an organization may decide to use a cloud infrastructure instead of their on-premise solution, or to use a new truck (i.e., resource) performing a specific delivery activity. An organization may also decide to introduce a new structure of the process model, rethinking the existing organizational structure [7]. At this point, a very important issue concerning the reengineering of process models is to keep track on given KPIs and economic objectives. An organization mainly focusing on cost aspects, for example, may be limited in adopting different services or substituting resources. As economic KPIs are also augmented to the process model we are able to directly compare the impacts of modifications through generating different process views. Based on these different views, a decision for reengineering the process in the analyzed way can either be made automatically or manually. Consequently, the concrete restructuring of the process model can be performed. Again, based on the variety of the KEIs, the restructuring can be manifold. Depending on the kind of restructuring we can utilize approaches common in the field of adaptability, like (1) changing the flows of a process model, (2) changing the underlying infrastructure or resources, (3) add, remove or modify (groups of) activities, or (4) introduce dynamic provisioning of activities.

3 Four-Phased Environmental Impact Management

To illustrate our proposed architecture and methodology we use a motivating example describing the company *Auto Inc.* that manufactures premium cars. Due to internal policies *Auto Inc.* would like to decrease their CO_2 emissions caused by the manufacturing of each car of a series. Based on this information *Auto Inc.* must buy a proper amount of emission permits. If they exceed these emission permits, they need to buy an additional contingent from companies that require fewer permits, otherwise if they use less they can sell their permits, respectively. This is also known as "emission trading" [12]. This regulation provides a significant economic incentive for reducing an organizations collective CO_2 emission. In the following, we first use an abstract process to better describe the methodology and different steps the various process stakeholders (see Fig. 1) of *Auto Inc.* need to perform in order to "green" a process. A use case describing a simplified but concrete process is shown in Section 4.

3.1 Strategy and Sensing & Monitoring

The environmental impact of a business process can be assessed in terms of a set of KEIs. These KEIs are defined based on so called *Ecological Characteristics (ECs)* such as energy consumption, water consumption, CO_2 emission, recycling, or regulatory compliance. We define KEIs as a tuple consisting of an EC metric and a target value function based on the ecological goals one wants to achieve (defined by business strategy). For example, a KEI for a particular business process could be specified as "*max CO_2 emission (of a process instance) < X_1*". Therefore, the definition of a KEI is very similar to KPIs; the difference is that the underlying metric definition is based on EC characteristics and involves new information sources, while in case of KPIs the underlying metrics concern time, quality, or cost perspectives [11]. In order to assess the KEIs, the underlying metrics have to be measured for the performed business process instances in the "Sensing & Monitoring" layer. For the calculation of an EC referring the whole business process, we need to collect the needed data of each process activity. For example, in order to assess the CO_2 emission of a whole business process instance, we need to know the CO_2 emissions of each executed process activity in that process instance and then sum up those emissions. The collection of the needed measurement data per activity can be performed in different ways. In the simple case, a process activity has always the same EC metric value across all process instances and that value can be obtained dynamically from a service specification or a *Service Level Agreement (SLA)* if, for example, the process activity implementation is provided by an external service provider. Otherwise it can also be obtained statically from previous experiences or existing know-how. In that case no monitoring is needed.

If the EC metric value of an activity is not known at design time, it has to be monitored while performing the process instance. Therefore, we first have to determine the resources which are used by that activity and affect the needed EC. Then, at runtime we need to obtain and aggregate sensor data which reflects the EC consumption of those resources and correlate it with the process activity of the specific instance. A specific correlation and differentiation has to be done if resources (e.g., IT infrastructure or transportation vehicles) are shared between different process instances and different process activities. The Sensor data can be provided in an automated fashion, in particular if sensors are able to emit events to an event bus. In that case, complex event processing technology can be used to correlate sensor events with process instance events in a timely fashion. Sensor data can also be provided manually by humans who e.g. manually determine how much water an activity has consumed; this analysis can happen after the process instance is already finished (post-mortem).

After having performed measurements for a certain number of process instances, we can determine which EC value each activity is dedicated to: (1) a static value or (2) a dynamic value, whereby the value depends on the data input to the process activity and/or the duration of the process activity, e.g., the emissions of a printer depend on the number of pages that should be printed (data input). In this case the monitoring in future can be performed on process level only, because a static factor (EC metric value / page) is combined with a dynamic factor (number of pages) obtained on the process level. The calculation function can then be determined by using regression analysis. Additionally, we have identified two more types of EC values, namely (3) a mixed value as a combination of (1) and (2), and (4) a dynamic value which depends on external factors and always should take into account appropriate sensor data. That information can be saved in a repository and used later, for example, if those activities are re-used in other processes. This would imply a change in the type of EC value of a specific activity or process fragment [13]. In order to use these different types of EC values in the subsequent analysis phase, we calculate average values based on the available process instances.

3.2 Analysis & Management

The information collected in Section 3.1 provides the basis for analyzing and managing the existing organizational processes by facilitating the identification and localization of vital KEI violations. In order to localize and finally visualize the cause of a KEI violation we use the concept of process views introduced in [10]. A Process view results from one or more specific transformations applied to a process model and therefore enables the analysis of processes from different perspectives. The transformations can be of an augmentation, structural or visual type, for example. Depending on the underlying information, the use of process views is one promising approach to address various important questions: Which activities make a significant contribution to the overall carbon footprint and energy consumption? What is the overall environmental impact and how would it change due to particular modifications of the process model? Which parts of the model are allowed to change? How can inter-organizational savings be achieved? To answer these questions we combine different transformations performed in several succeeding steps. Referring to our running example, the steps and their corresponding transformations *Auto Inc.* needs to perform in order to analyze a specific manufacturing process are described in the following. We now assume that *Auto Inc.* tries to achieve a more sustainable process and therefore the top management announces the decrease of CO_2 emission of

Process P which consists of nine activities, A_1 to A_9 (see Fig. 2, left). The management has further defined the new CO_2 emission thresholds X_1 to X_9 for each activity A_1 to A_9. Based on this information the process stakeholders from the architecture layer two (Sensing & Monitoring) provide the required information to support the KEI "CO_2 emission". However, the data provided comprises both, economic and ecological information that are properly correlated to the process model. So, this data can also be used for the enrichment of existing business dashboards that represent the current state of the process instances and enables stakeholders to initiate proper actions when detecting KPI or KEI violations.

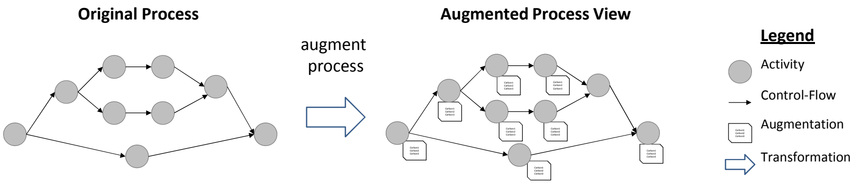

Fig. 2. Process Augmentation

Now, as a first step when detecting a KEI violation the given process model needs to be augmented with related data (see Fig. 2, center). This is a fundamental step which is a prerequisite for all further steps or view transformations in general. The augmented process model now contains all relevant information about the processes' KPIs and KEIs to proceed with the next step. In our example we will first use the information provided by the KEI data in order to identify which activities exceed the thresholds defined from the management. To visualize the activities with the highest amount of CO_2 emission we perform another transformation. First, we use a visual transformation that omits all activities where the augmented CO_2 emission is below their dedicated threshold X_n. As a next step, we additionally omit all activities that cannot be changed or outsourced per se. This can, for instance, be due to privacy concerns or legislative requirements and varies in each particular use case. The result of the omission of the activities is shown in Fig. 3 (center).

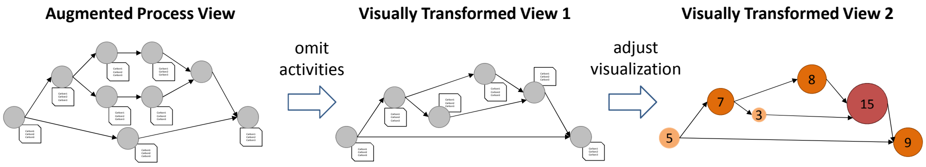

Fig. 3 Visual Process Transformation

Based on the activities left, *Auto Inc.* can begin to identify and localize the activities with the highest amount of CO_2 emission. We can support the human readability by generating a so called heat-map, for example. This visual transformation changes the color of the shapes of the process view depending on their augmented CO_2 emission. A dark red color is equivalent to a high CO_2 emission and a light orange is equivalent to a lower CO_2 emission, respectively. Within this transformation step, we can also change the size of the activities and add the percentage value each activity exceeds their threshold. The performed transformation steps and corresponding views are shown in Fig. 3.

Auto Inc. can now locate the activities with the highest CO_2 emission, represented by the corresponding colors, the size of the shape, and the CO_2 emission values inside the shapes. However, it might be feasible to "zoom in" deeper, i.e. to collapse activities for allowing to view or directly change the interior of an activity. As an example, we want to have a more detailed look at the big red activity in the left side of Fig. 4 which exceeds their CO_2 threshold by 15 percent. After performing the drill-down transformation the right side of Fig. 4 shows the sub-activities that are performed within the big red activity on the left side and their contribution to the overall CO_2 emission. Of course, the sub-activities can also be further sub-processes that are again shown in an aggregated way. Note that a viewing scenario that supports collapsing requires the augmentation of the process with runtime or deployment information about the actual implementation of an activity. Consequently, the visualization function could then visualize the information about the interior in resulting graph-like structures (see Fig. 4) or even drill down to the bits (in case of an IT process). An important issue concerning the drill-down methodology is to provide sufficient technologies for disaggregating and aggregating the overall KEI or KPI values. First approaches in this area are proposed by [14,15].

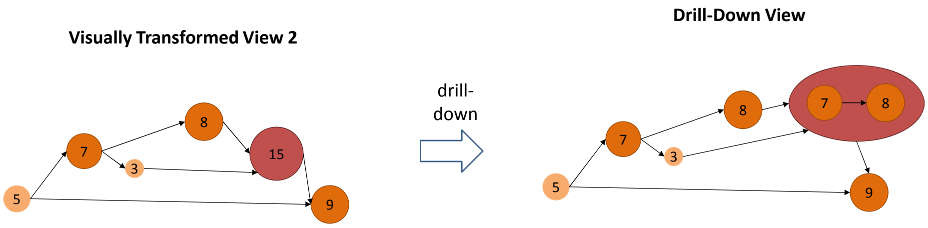

Fig. 4. Activity Drill-Down

3.3 Adaptation

Knowing the most dissipative activities with respect to the observed KEIs we can develop appropriate adaptation strategies that optimize these KEIs. In market environments, however, we need to ensure the competitiveness of an organization beyond the adaptations for "greener" and more sustainable processes. Ecological characteristics are often in sharp contrast to strategic and economic objectives. However, there may also occur situations that influence traditional KPIs, i.e., cost, quality, and time in a positive manner, sometimes even without extensive upfront investments. Using a computer-based e-Fax solution for supplier contact, for example, makes *Auto Inc.* reduce their CO_2 emission due to the abdication of extra hardware, but at the same time reduce their costs and time using this service. So, this trade-off is no novel appearance and can also be found at traditional KPI research, but now we have to consider a fourth dimension: the environment.

In our approach, process views also provide the means to develop and visualize different adaptation strategies. Within the development of adaptation strategies we first want to distinguish between structural and non-structural adaptations. A non-structural adaptation does not influence the structure or logic of an observed process model, but has influence on the augmented information (e.g., the attributes, resources, or underlying infrastructure of the activities). The change to a supplier of electric energy providing green electricity, for example, may lower the CO_2 emission of particular activities without changing or restructuring them. However, the attributes augmented to the activities change. Structural adaptations on the other hand are dependent on the range and characteristics of the planned reengineering. Thereby, several process optimization techniques known from BPR are feasible to optimize the KEIs of the observed process. These include, but are not limited to: (1) New binding of services implementing a process activity, (2) changing the underlying infrastructure which better adapts the process characteristics, (3) changing the flows of a process model, (4) rearrange activities, i.e., add, remove or modify (groups of) activities, or (5) introduce dynamic provisioning of activities. Utilizing these techniques provides a wealth of opportunities for making a business process more sustainable and can therefore be fully applied to our approach. So, the adaptation strategies we may use here can constitute either of a complete reengineering approach including the creation of a new process model, the modification of specific activities or resources, or an arbitrary combination in-between. Furthermore, structural and non-structural adaptations can also be combined.

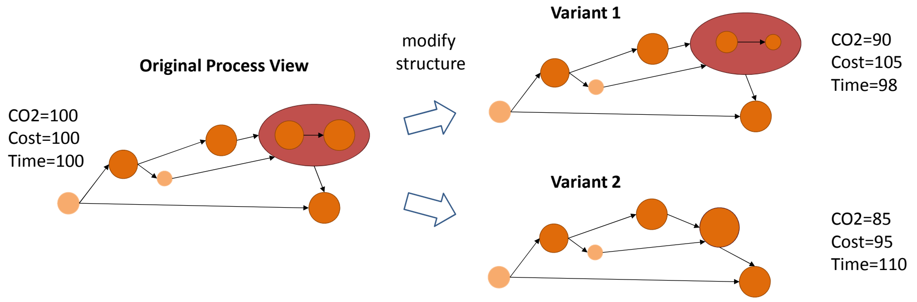

Fig. 5. Adaptation Strategies

In order to determine the impact of an adaptation strategy we need to calculate the aggregated values of both, the corresponding KEIs as well as the corresponding KPIs for each adaptation strategy. The KPI values can be determined in an analogous manner and provide the means to compare the different adaptation strategies. In our running example, *Auto Inc.* decided to substitute the activities with the highest CO_2 emission by activities from external providers with a lower CO_2 emission. In this case, we may also consider constraints when exchanging activities. For example, a specific activity that improves the CO_2 emission might exceed a given cost threshold and therefore cannot be used as substitute. Two different adaptation strategies are shown in Fig. 5. The upper one substitutes the two activities identified at the drill-down, the lower one substitutes the complete activity identified before drill-down.

The numbers shown exemplarily depict the impact of each adaptation strategy based on KEIs and KPIs.

In these adaptation scenarios, the information needed for the augmentation of the substitute activities needs to be provided either by previous analysis, certain know-how, information provided by business partners offering the alternative service (SLA), or other estimations. Note, that the comparison of different adaptation strategies is only as valid as its underlying estimations. Therefore, it is crucial that the data used for the augmentation is as accurate and current as possible. When comparing different strategies with one another, equivalent data is necessary for both processes in question. Otherwise, the comparison might lead to non-representative results. If the information concerning KEIs and KPIs is in a proper shape, a concrete adaptation strategy can be chosen. Considering the given thresholds for economic and ecological objectives an organization, for instance, can choose a strategy that satisfies the economic and even optimizes the ecological objectives. So, in our running example, *Auto Inc.* compares their adaptation strategies from Fig. 5 to one another, deliberates about which strategy best fits their overall economic and ecological objectives (i.e., their business strategy) and finally decides in which way to adapt the observed process model. Depending on the process characteristics (i.e., whether the observed process is an automated process or an undocumented process, for example) proper adaptation mechanisms may be selected to support the adaptation strategy in detail. In general, we are faced with similar issues known from *Life Cycle Assessment (LCA)* [17]. LCA is also a methodology for analyzing commensurable aspects of quantifiable systems. However, not every KEI value can be reduced to a number and augmented to a process model. In our approach this holds for recycling aspects or soil pollution, for example.

4 Use Case

To illustrate the practicability of our approach we use a concrete business process example from a car manufacturer. In order to apply our methodology, we use the *car finishing process* depicted in BPMN notation [18] in
Fig. **6**. This process is performed every time a new car has been assembled and leaves the assembly line. In the first step of the finishing process the car is put into operation making sure all systems are working. Then, in the regular case a quick check based on a predefined checklist is performed. In some cases a detailed check is performed. This part of the process first includes the transportation of the car to the test center and the preparation of the test procedure. The test procedure then starts with an engine test which is followed by a detailed visual check of interior and exterior. After the test run on a test track in the next process step, the water density is checked and the car gets cleaned and prepared for delivery or refinishing, respectively. Finally, in both cases a detailed report of the test results is created and sent to the operations management. Performing the finishing process either with a quick or a detailed test run results in different cost, quality, and duration characteristics of the complete process depending on the specific weights of those dimensions, e.g. the percentage of detailed tests that can be managed.

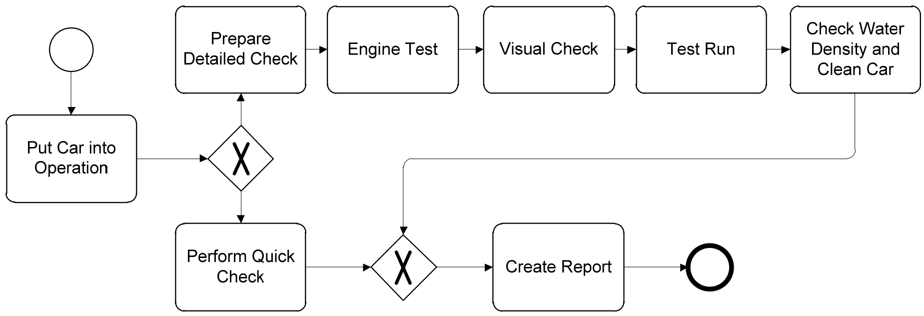

Fig. 6 Car Finishing Process

Now, an additional dimension, namely KEIs, is added. In the first step towards improving the environmental impact of this process we need to monitor and sense the required information in order to analyze and subsequently achieve the strategic objectives of decreasing both the CO_2 emissions and the water consumption by a certain percentage. The CO_2 emission can be estimated by identifying the means for the car transport to the test center, the fuel burned during the engine test and the test run, the electricity needed for light and apparatus of the visual check and during the water density check and cleaning, for example (note that concrete measuring methods are out of the scope of this paper). The water consumption can be estimated by water meters, respectively. The complete environmental information, beside other KPIs like cycle time and process costs, is then augmented to the process model and can be used for further process analysis.

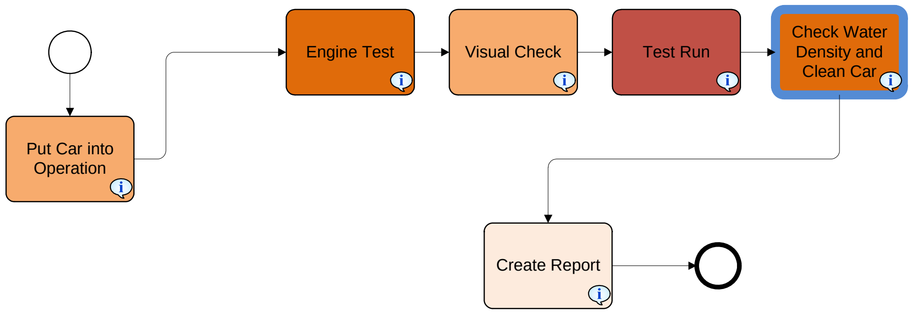

Fig. 7 Augmented and Re-Shaped Process View

Analyzing the augmented data we are noticing that our KEI targets are not reached with this process. To identify the activities that cause the main environmental impact we create a new process view. Therefore, we first omit those activities that must be performed as modeled according to internal guidelines. This includes the activities *Prepare Detailed Check* and *Perform Quick Check*. In order to provide a better readability we also perform a transformation that repaints the shapes depending on their CO_2 emission and water consumption. The result is depicted in Fig. 7. The intensity of the background colors indicates the amount of CO_2 emissions caused by the corresponding activity. The thickness of the blue border line indicates the total water consumption of the corresponding activity. In Fig. 7 we can see, that the *Engine Test* as well as the *Test Run* activities produce a high amount of CO_2 emissions while the *Check Water Density and Clean Car* activity indicates both, a high CO_2 emission and water consumption. The information sign in the bottom right corner of each activity is used to display all information augmented to this activity (mouse-over). Based on this information we can identify the problematic activities and derive potential process alternatives.

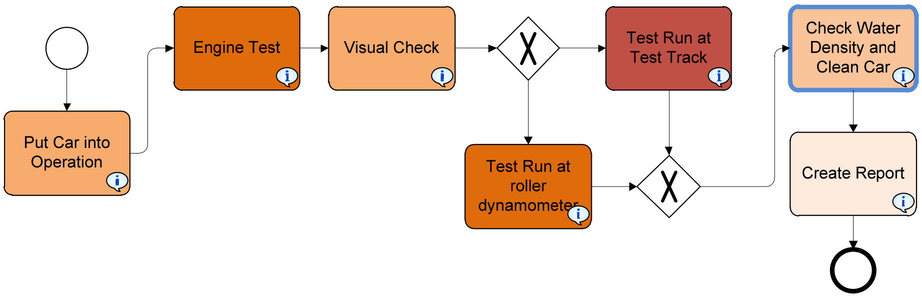

Fig. 8 Process Alternative

In order to achieve the strategic objectives we decide to perform a structural adaptation of the process as depicted in Fig. 8. We include a new test run activity which performs the test at an existing roller dynamometer test bench and is executed as an alternative to the original test run activity. The test run is now performed in equal parts at both the test track and at the existing roller dynamometer test bench. The latter one allows a more efficient test run with respect to the test run duration and therefore reduces the fuel burned, for example. The alternative test run also eliminates the transport of the cars to the test track. Additionally, the cars are just handled indoors which reduces the amount of water and cleaning supplies for washing the cars. In order to visualize the total environmental impact of this process alternative, the augmented information of the related activities is overwritten, i.e. a new process view containing the new process model and its related information is generated. Within this use case, the information can be gathered either by some test runs of the specific activities or based on existing knowledge. Next, we also need to consider the process costs of the restructured process as well as the corresponding time and quality impacts. Before, the roller dynamometer test bench has not been used within the finishing process because it had worse impact on the KPI dimension cost and quality than the other test types. This now changes with adding the KEI dimension because we are faced to a new trade-off situation. Within the new case, the costs will slightly increase due to the higher costs of a test run at the roller dynamometer test bench. On the other side, we will save a significant amount of time for not transporting the car to the test track and the more efficient test run. What is important now is that we can also achieve savings at the water consumption and CO_2 emission. Based on the weights strategically set for those four dimensions we can try to determine the percentage of tests which should go to the new roller dynamometer test activity and configure the branching activity accordingly.

5 Related Work

Within the cross-cutting concern of this work different approaches considering the specific parts and areas of interest of this approach can be found in literature. Following [8], these approaches can be distinguished in Green IT and Green IS approaches. The green information technology (IT) is mainly focused on energy efficiency and resource utilization. Here, we can distinguish different approaches considering two main perspectives: (1) the hardware perspective [19,20] that covers the efficient use of resources, e.g., proper allocation of resources, and (2) the infrastructure perspective [21,22] that covers the efficient and target-oriented usage of an underlying infrastructure, e.g., proper management of cloud environments. Green information systems (IS), in contrast, "refer to the design and implementation of information systems that contribute to sustainable business processes" [8]. Consequently, the literature considers the software and process perspective. In [23] and [16] the authors have developed first concepts on how business processes can be optimized in a green manner. They focus on a classification of resources that influence the environmental impact and how they can be reduced during design-time of a business process. Additionally, they introduced a formal model dealing with the combination of quantitative and qualitative QoS in order to also consider non-numbered QoS. Subsequently, in [24] they focus on how these resources can be modeled. This approach contains interesting aspects regarding the green optimization of processes, however, considers only design time and is not focusing on an organization's complete environment including the organizational structure, the processes, and the used infrastructure and resources.

A more general approach to assess environmental and social damages assignable to products and services is Life Cycle Assessment (LCA) [17] which is part of the ISO 14000 family "environmental management standards" [25]. It provides a technique to assess all impacts of a process from cradle-to-grave, i.e. from raw material to disposal or recycling. While it covers the whole product lifecycle, it can be used to optimize the environmental impact of a product or of a whole company. LCA provides a good basis for optimizing the environmental impact of an organization, however, does not focus on business processes in particular and the underlying infrastructure in general. Another interesting viewpoint is the research work done in "ecological information science" (in Germany this research area is called "Umweltinformatik"). Ecological IS deals with the modeling, simulation and analysis of ecosystems. They provide a lot of information on how harmful substances may spread or how control systems should behave to minimize the impact on ecosystems, for example. They also provide first ideas on business information systems considering ecological information in order to support operational decisions. However, so far they lack in applying their research results to the (IT) business processes layer and especially how business processes can be designed or adapted in order to prevent a negative impact on ecosystems.

6 Conclusion

The architecture presented in this paper describes fundamental layers needed to achieve more sustainable organizational environments in the cross-cutting concern of green Business Process Reengineering. We described each layer in detail, identified the roles within an organization responsible for each layer and sketched the main issues of each layer. Moreover, the corresponding methodology presented in this work describes a walk through this architecture. It helps organizations to plan and define their ecological objectives in form of Key Ecological Indicators (KEIs) and to identify and localize the most dissipative parts of their processes based on these KEIs. To realize the *Analysis & Management* as centerpiece layer of the architecture we used the approach of “process views” that enables a proper visualization of the process model utilizing so-called view transformations. Consequently, in the *Adaptation* layer organizations can derive adaptation strategies to optimize their collective environmental impact while considering both, their ecological and economic objectives. Finally, we presented a use case from automotive industry that shows the practicability of the proposed architecture and methodology. Our approach bridges the gap of missing interconnection between existing Green IT and Green IS approaches towards a holistic environmental impact analysis and optimization in organizational structures. In our future work we will investigate a classification for KEIs and their application in intra-organizational and cross-partner environments. Within this work we will also address the problem of how to sense and monitor the environmental influence factors on a per task basis. We will further develop different process view patterns that allow organizations the application of process views in a re-usable fashion and will devise algorithms that support the trade-off between KPIs and KEIs.

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