Challenges of Applying Adaptive Processes to Enable Variability in Sustainability Data Collection

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Abstract. Nowadays, demanding legal regulations as well as sophisticated customer needs force companies in electronics and automotive industries to provide a multitude of different sustainability indicators. Since their products usually contain numerous components and sub-components, companies must deal with complex, intransparent data collection processes along their supply chains in order to finally deliver valuable data. A myriad of different automatic and manual tasks, potentially long-running processes, and quickly changing situations result in great variability that is hard to handle. In the SustainHub project, a dedicated information system for supporting data collection processes is developed. Thereby, core challenges as well as state-of-the-art were systematically gathered, consolidated as well as assessed. The condensed results are presented in this paper.

Key words: Business Process Variability, Data Collection, Sustainability, Supply Chain

1 Introduction

These days, companies of the electronics and automotive industry face steadily growing demands for sustainability compliance triggered by authorities, customers and public opinion. As products often consist of numerous individual components, which, in turn, also comprise sub-components, heterogeneous sustainability data need to be collected along intertwined and intransparent supply chains. Thereby, highly complex, cross-organizational data collection processes are required, featuring a high variability, e.g., through dynamically integrating companies' employees and information systems (ISs). Further issues include incompleteness and varying quality of provided data, heterogeneity of data formats, or changing situations and requirements. Until today, there is no dedicated IS supporting companies in creating, managing and optimizing such data collection processes. Within the SustainHub[1] project, such a dedicated information system is being developed. In this context, use cases, delivered by industry partners from the automotive and the electronics domain, have been intensively studied in order to consolidate core challenges and essential requirements regarding the IT-support of data collection processes. In relation, state-of-the-art has also been deeply studied to assess whether existing approaches and solutions satisfy the requirements. As a result, this paper systematically presents the condensed core challenges and state-of-the-art considering complex sustainability data collection process along today's supply chains. This domain is well suited for eliciting such challenges because of the complexity of the supply chains on the one hand and the requirements imposed by emerging laws and regulations on the other. However, they can be transferred to many other domains as well. Thus, this contribution identifies 7 core challenges for data exchange and collection in complex distributed environments and also reviews approaches in place to solve these challenges. Thereupon, future research in the area of adaptive business process management can be aligned to extend existing approaches for supporting more variability and dynamics in today's business processes.

Therefore, the fundamentals and an illustrating example are introduced in section 2. Subsequently, seven data collection challenges are unveiled in section 3, exposing concrete findings, identified problems and derived requirements. In section 4, the current state-of-the-art is presented based on its origin. Finally, section 5 rounds out this paper giving a conclusion and an outlook.

2 Sustainable Supply Chains

This section elaborates on the domain of sustainable supply chains and gives background information.

2.1 Fundamentals

In today's globalized industry, the development and production of many products is based on intransparent, complex supply chains with dozens of interconnected companies distributed around the globe. To ensure and extend competitiveness, complex communication tasks must be managed properly for effective and efficient interorganizational processes. Generally, such cross-organizational collaboration involves a variety of different manual and automated tasks. Involved companies significantly differ in size and industry background, and they use various different ISs, which are not able to intercommunicate easily. Due to this heterogeneity, neither federated data schemes, unifying tools nor other concepts can be realistically introduced without considerable effort [1].

As sustainability is is an emerging trend, companies even face a new challenge in their supply chains: sustainable development and production. The incentives

[1] SustainHub (Project No.283130) is a collaborative project within the 7th Framework Programme of the European Commission (Topic ENV.2011.3.1.9-1, Eco-innovation).

are given by two parties: On one hand, legal regulations, increasingly issued by authorities, force companies to publish more and more sustainability indicators (like greenhouse gas emissions in production or gender issues) on an obligatory basis. On the other hand, public opinion and customers compel companies to provide sustainability information (e.g., organic food) as an important base for their purchase decisions.

Examples include ISO 14000 standard for environmental factors in production, GRI[2] covering sustainability factors or regulations like REACH[3] and RoHS[4]. Overall, sustainability information involve a myriad of different indicators. It relates to social issues (e.g., employment conditions or gender issues), to environmental issues (e.g., hazardous substances or greenhouse gas (GHG) emissions), or to managerial issues (e.g., compliance issues).

There already exist tools at market providing support for the management and transfer of sustainability data: IMDS[5] (International Material Data System), for instance, is used in the automotive industry and allows for material declaration by creating and sharing bills of materials (BOM). A similar system exists for the electronics industry (Environ BOMcheck[6]). Despite providing useful support in basic data declaration and exchange tasks, these tools clearly fall short in providing dedicated support for the sustainability data collection and exchange along the supply chains.

2.2 Illustrating Example

To illustrate the complexity of sustainability data collection processes in a distributed supply chain, we provide an example. The latter was composed with the problems and requirements provided by SustainHub's partner companies for the automotive and electronics industry by formal and informal surveys and interviews. Please mind that data collection in such a complex environment does not have the characteristics of a simple query. It is rather a varying, long-running process incorporating various activities and involving different participants.

The example illustrated in Fig. 1, depicts the following situation: Imposed by regulations, an automotive manufacturer (requester) has to provide sustainability data considering its production. This data is captured by two sustainability indicators, one dealing with the greenhouse gas emissions relating to the production of a certain product, the other addressing the REACH regulation. The latter concerns the whole company as companies usually declare compliance to that regulation on a company basis.

To provide data regarding these two indicators, the manufacturer has to gather related information from his suppliers (answerer). Hence, it requests a

[2] Global Reporting Initiative: `https://www.globalreporting.org`

[3] Regulation (EC) No 1907/2006: Registration, Evaluation, Authorisation and Restriction of Chemicals

[4] Directive 2002/95/EC: Restriction of (the use of certain) Hazardous Substances

[5] `http://www.mdsystem.com`

[6] `https://www.bomcheck.net`

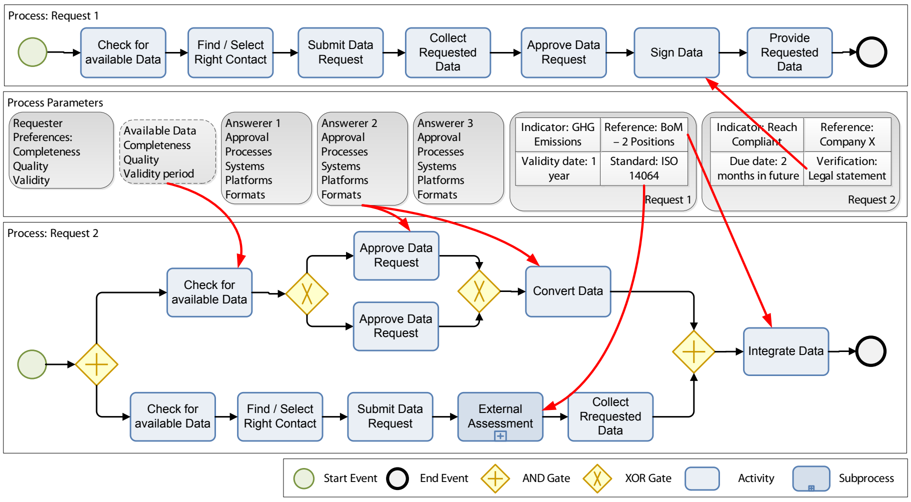

Fig. 1: Examples of Two Data Collection Processes

REACH compliance statement from one of its suppliers. To get the information, the activities shown in the process *Request 1* have to be executed. Furthermore, the product for which the greenhouse gas emissions shall be indicated has a BoM with two positions coming from external suppliers. Thus, the request, depicted by the second workflow, has to be split up into two requests, one for each supplier.

Hence, the basic scenario involves a set of activities as part of the data collection processes. Some of these are common for the requests, e.g., on the requester side, checking available data that might satisfy the request, selecting the company and contact person, and the submitting the request. On the answerer side, data must be collected and provided. The other process activities are specifically selected for each case. Thereby, the selection of the right activities is strongly driven by data (process parameters) coming from the requester, the answerer, the requests and indicators, and possible already available data.

For example, *Request 1* implies a legally binding statement considering REACH compliance. Therefore, a designated representative (e.g., the CEO) must sign the data. In many cases, companies have special authorization procedures for releasing of such data, e.g., that one or more responsible persons have to approve the request (cf. two parallel approval activities (*Approve Data Request*) at *Request 2*, *four-eyes-principle*). In some cases, data may be already available in a company and does not have to be manually gathered (cf. *Request 2*, *Check of available Data*). However, every time the company-internal format of the answerer does not match the requester's one, a conversion must be applied. Further, some indicators and requests also directly relate to a given standard (e.g., ISO 14064 for greenhouse gases) where this can directly trigger an assessment of the answerer if he cannot exhibit the fulfillment of the standard (cf. *Request 2*, *External Assessment*).

Finally, another important aspect for often long-running data collection processes is that process parameters might change over time and, hence, exceptional situations could occur. Even in this very simple example, many variations and deviations might occur: for example, if the CEO was not available, activity *Sign Data* could be delayed. In turn, this might become a problem if there are defined deadlines for the query answer.

3 Data Collection Challenges

Following first insights provided in Section 2, this section presents seven concrete challenges for an information system supporting sustainability data collection processes along a supply chain (IS-DCP). The results are based on findings from case studies conducted with industrial partners in the SustainHub project. Three figures serve for illustration purposes: Fig. 2 illustrates data collection challenges (DCC) 1 and 2, Fig. 3 illustrates DCC 3 and 4, and Fig. 4 illustrates DCC 5-7.

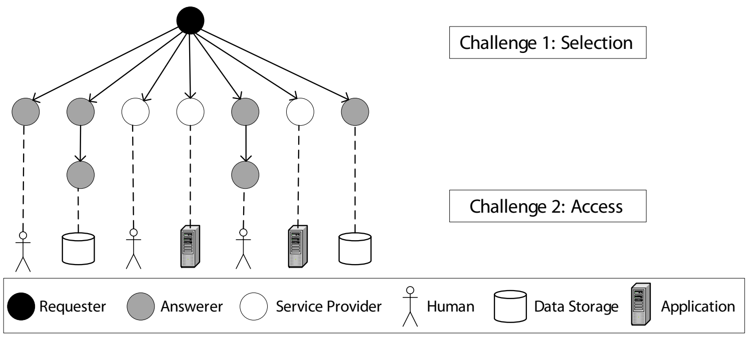

Fig. 2: Data Collection Challenges 1 and 2

3.1 DCC 1: Dynamic Selection of Involved Parties

Findings Sustainability data collection in a supply chain involves various parties. A single request may depend on the timely delivery of data from different companies. For manual tasks, this mostly has to be done by a specific person with sustainability knowledge or authority. In big companies, it can be even difficult to find the right contact person to answer a specific request. In relation, contact persons may change from time to time. Furthermore, as the requested data is often complex, has to be computed, or relates to legal requirements, external service providers may be involved in the data collection request as well. Finally, regarding the timely answering of a request, many requests are adjusted and forwarded to further suppliers (cf. Fig. 2) – thus answering times can multiply.

Problems The contemporary approach to such requests heavily relies on individuals conducting manual tasks and interacting individually. There are tools (e.g., email) which can provide support for some of these and partly automate them. However, much work is still coordinated manually. As a request can be forwarded down the supply chain, it is quite difficult to predict, who exactly will be involved in its processing. Resulting from that, answering times of requests can be hardly estimated in a reliable manner as well.
Requirements An IS-DCP need to enable companies to centrally create and manage data collection requests. Thereby, it must be possible to simplify the dynamic selection process of involved parties and contact persons regarding the request answerers as well as potentially needed service providers. This is a basic requirement for enabling efficient request answering, data management, and monitoring.

3.2 DCC 2: Access to Requested Data

Findings In a supply chain different parties follow different approaches to data management. Big companies mostly have implemented a higher level of automation while SMEs heavily rely on the work of individual persons. Furthermore, sustainability reporting is a relatively new area and a unified reporting method is not implemented along supply chains. This implies great variability when it comes to accessing companies' internal data. Some companies have advanced software solutions for their data management, some manage their data in generic databases, some store it in specific files (e.g., Excel), and some have even not started to manage sustainability data yet.
Problems The contemporary approach to sustainability reporting is managed manually to a large extend. This involves manual requests from one party to another and different data collection tasks on the answerer side. This can impose large delays in data collection processes as sustainability data must be manually gathered from systems, databases or specific files before it can be compiled, prepared and authorized in preparation to the delivery to the requester.
Requirements An IS-DCP must accelerate and facilitate the access to requested sustainability data. On the one hand, this includes guiding users in manual data collection as well as automizing data-related activities (e.g., data approval, data transformation) as far as possible. On the other hand, automatic data collection should be enabled whenever possible. This involves accessing the systems containing the data automatically (e.g., via the provision of appropriate interfaces) and including such activities with manual approval activities when needed. Finally, data conversion between different formats ought to be supported as a basis for data aggregation.

3.3 DCC 3: Meta Data Management

Findings The management and configuration of sustainability data requests in a supply chain relies on a myriad of different data sets. As aforementioned,

this data comes from various sources. Examples of such parameters include the preferences of the requester as well as the answerers (including approval processes and data formats) or the properties of the sustainability indicators (e.g., relations to standards) (cf. Fig. 3). As a result, potentially matching data might be already available in some cases but exposing different properties as requested.
Problems As requests rely on heterogeneous data, they are difficult to manage. Requirements are partially presumed by the requester and often implicit. Hence, answerers might be unaware of all requirements and deliver data not matching them. Moreover, it is difficult to determine whether data, which has been collected before, fits the requirements of a new request. Finally, as a supply chain might involve a large number of requesters and answerers, this problem multiplies as crucial request data is scattered along the entire supply chain.
Requirements To be able to consistently and effectively manage data collection processes, an IS-DCP must centrally implement, manage and provide an understandable meta data schema addressing relevant request parameters. Thereby, instanced data based on the uniform meta data schema can be effectively used to directly derive and adjust variants of data collection processes.

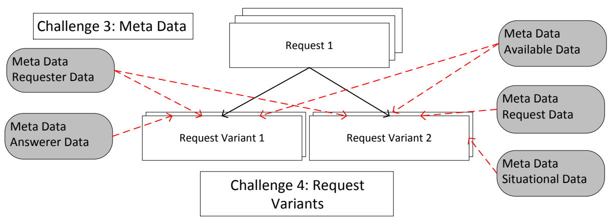

Fig. 3: Data Collection Challenges 3 and 4

3.4 DCC 4: Request Variants

Findings As mentioned, sustainability data exchange in a supply chain involves a considerable number of different manual and automated tasks aligned to the current data request. Hence, execution differs greatly among different data requests, highly influenced by parameters and data and distributed on many sources (cf. DCC 3 and Fig. 3). Moreover, the reuse of provided data is problematic as well as the reuse of knowledge about conducted data requests: persons in charge, managing a data collection, might not be aware of which approach matches the current parameter set.
Problems This makes the whole data collection procedure tedious and error prone. Based on the gained insights, to each data request a data collection process is manually defined initially, and evolves stepwise afterwards. Relying on the various influencing parameters, every request has to be treated individually – there is no applicable uniform approach to a data request, instead a high

number of variants of data collection processes exist. So far, there is no system or approach in place that allows structuring or even governing such varying processes along a supply chain.

Requirements An IS-DCP needs not only to be capable of explicitly defining the process of data collection. Due to the great variability in this domain, it must also be capable of managing numerous variants of each data request relating to a given parameter set. This includes the effective and efficient modeling, management, storage and executing of data collection request processes.

3.5 DCC 5: Incompleteness and Quality

Findings Sustainability data requests are demanding and their complex data collection processes evolve based on delivered data and forwarded requests to other parties (i.e., suppliers of the suppliers) (cf. Fig. 4). Furthermore, they are often tied to regulative requirements and laws as well as involve mandatory deadlines. Therefore, situations might occur, in which not all needed data is present, but the request answer must still be delivered due to a deadline. As another case, needed data might be available, but on different quality levels and/or in different formats.

Problems Contemporary sustainability data collection in supply chains is plagued by quality problems relating to the delivered data. Not only that requests are incompletely answered, the requester also has no awareness of the completeness and quality of the data stemming from multiple answerers. Moreover, answerers have no approach to data delivery in place when being unable to provide the requested data entirely, or their data does not match the request's quality requirements. Missing a unified approach, definitive assertions or statements to the quality of the data of one request can often not be made and requests might even fail due to that fact.

Requirements An IS-DCP must be able to deal with incomplete data and quality problems. It must be possible that a request can be answered despite missing or low quality data. Furthermore, such a system must be able to make assumptions about the quality of the data that answers a request.

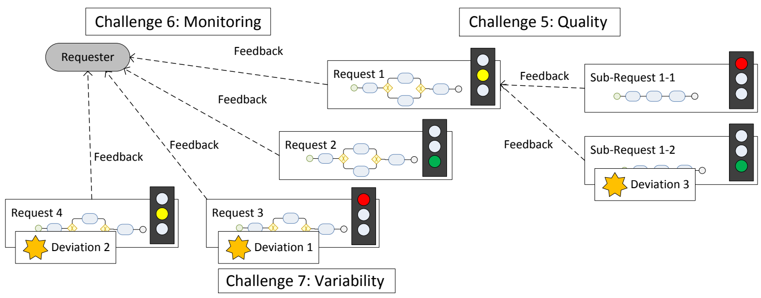

Fig. 4: Data Collection Challenges 5-7

3.6 DCC 6: Monitoring

Findings Sustainability data collection along the supply chain involves many parties and logically may take a long time. The requests exist in many variants and the quality and completeness of the provided data differ greatly (cf. DCC 5). The contemporary approach to such requests does not provide any information about the state of the request to requesters before the latter is answered (cf. Fig. 4). This includes missing statements about delivered data as well as the intermediate requests along the supply chain. If request processing is delayed at the side of one or more answerers, the initial requester cannot access such information without huge effort.

Problems As a requester has no information about the state and potential data delivery problems of his requests, problems only become apparent when deadlines are approaching. However, at that time, it is mostly too late to apply countermeasures to low quality, incomplete data, or answerers that simple deliver no data at all.

Requirements An IS-DCP must be capable of monitoring complex requests spanning multiple answerers as well as various different manual and automatic activities. A requester must have the option to get actively or passively informed about the state of the activities along the data collection process as well as the state of the delivered data.

3.7 DCC 7: Run Time Variability

Findings Data collection requests can take a long time to answer as they dynamically involve a great number of different parties. Further, they expose manual and automatic activities, different kinds of data and data formats, and various unforeseen influences on the data collection process. This implies that parameters, applied at the beginning of the request influencing data collection, may change during the run time of a data collection process. Exceptional situation handling occurs as a result of expiring deadlines or answerers not delivering data.

Problems The variability relating to sustainability data collection processes constitute a great challenge for companies. Running requests might become invalidated due to the aforementioned issues. However, there is no common sense or standard approach to this. Instead, requesters and answerers must manually find solutions to still get requests answered in time. This includes much additional effort and delays. Another issue are external assessments: they could not only be delayed but also completely fail, leaving the answerer without a required certification. The final problem touched by this example concerns mostly long-running data collection processes: data, that was available at the beginning of the query, could get invalid during the long-term process (e.g., if it has a defined validity period).

Requirements An IS-DCP must cope with run-time variability occurring in today's sophisticated sustainability data collection processes. As soon as issues are detected, data collection processes must be timely adapted to the changing situation in order to keep the impact of these issues as considerable as possible.

This requests a system which is able to dynamically adapt already running data collection processes without invalidating or breaking the existing process flow.

4 State of the art

This section gives insights on the state of the art in scientific approaches relating to the issues shown in this paper. It starts with a broader overview and proceeds with more closely related work including three subsections.

Section 3 underlines that exchanging data between different companies along a supply chain in an efficient and effective way has always been a challenge. Nonetheless, this exchange is not only necessary—it is now a crucial success factor and a competitive advantage, these days. However, many influencing factors hamper the realization of a data exchange being automated and homogeneous. In particular for those companies aiming to address holistic sustainability management, the inability to implement automated and consistent data exchange is a big obstacle. Please remind that these companies need to take into account existing and even emerging laws as well as regulations requesting to gather and distribute information about their produced goods. Furthermore, that requested information need be gathered from their their suppliers as well. Hence, complex data collection processes, involving a multitude of different companies and systems, have to be designed, conducted, and monitored to ensure compliance. So far, we could not locate any related work that completely addresses the aforementioned challenges (cf. Section 3).

For complex data collection processes, IS support in the supply chain is desirable supporting communication and enabling automated data collection. The importance and impact of an IS for supply chain communication has already been highlighted in literature various times. In [2], for instance, a literature review is conducted showing a tremendous influence of ISs on achieving effective SCM. The authors also propose a theoretical framework for implementing ISs in the supply chain. Therefore, they identify the following core areas: strategic planning, virtual enterprise, e-commerce, infrastructure, knowledge management, and implementation. However, their findings also include that great flexibility in the IS and the companies is necessary and that IS-enabled SCM often requires major changes in the way companies deal with SCM. As another example, [3] presents an empirical study to evaluate alternative technical approaches to support collaboration in SCM. These alternatives are a centralized web platform, classical electronic data interchange (EDI) approaches, and a decentralized, web service based solution. The author assesses the suitability of the different approaches with regard to the complexity of the processes and the exchanged information. Concluding, the relating work in this area shows or evaluates novel approaches to SCM management, which are, however, mostly theoretic, very general, and not applicable to the specific topic of sustainability data collection processes.

As automation can be a way to deal with various issues for sustainability data collection, various approaches addressing that topic can be found in literature. However, none of them applies to the domain and specific requirements of sustainable supply chain communication. For example, [4] presents an approach to semi-automatic data collection, analysis, and model generation for performance analysis of computer networks. The approach incorporates a graphical user interface and a data pipeline for transforming network data into organized hash tables and spread sheets for usage in simulation tools. As it primarily deals with a specific type of data transformation, it is not suitable in our context. Such approaches deal with automated data collection; yet they are not related to sustainability or SCM and the problems arising in this setting.

There also exist approaches addressing sustainability reporting (e.g., [5], [6],[7], and [8]). However, they do not suggest technical solutions for automatic data collection. They rather address the topic theoretically by analyzing the importance of corporate sustainability reporting, evaluating sustainability indicators or the process of sustainability reporting as a whole, or aiming at building a sustainability model by analyzing case studies.

Besides approaches targeting generic sustainability, SCM and data collection issues, there are three closer areas that are mainly related to our problem statement and issues. As discussed, sustainability data collection processes involve numerous tasks to be orchestrated. Data requests may exist in many different variants based on a myriad of different data sources and may be subjected to dynamic changes during run-time (cf. DCC 7). This sub-section reviews approaches for process configuration (Section 4.1), data- and user-driven processes (Section 4.2), and dynamic processes (Section 4.3).

4.1 Process Configuration

Behaviour-based configuration approaches enable the process modeler to specify pre-defined adaptations to the process behaviour. One option for realizing this is hiding and blocking as described by [9]. By blocking, this approach allows disabling the occurrence of a single activity/event. The other option enabled by this approach is hiding enabling a single activity to be hidden. That activity is then executed silently but succeeding activities in that path are still accessible.

Another way to enable process model configuration for different situations is to incorporate configurable elements into the process models as described in [10] or [11]. An example of this approach is a configurable activity, which may be integrated, omitted, or optionally integrated surrounded by XOR gateways. Another approach enabling process model configuration is ADOM [12] that builds on software engineering principles and allows for the specification of guidelines and constraints with the process model. A different approach to process configuration is taken by structural configuration, which is based on the observation that process variants are often created by users by simply copying a process model and then applying situational adaptations to it. A sophisticated approach dealing with such cases is Provop [13], which enables process variants by storing a base process models and pre-configured adaptations to it. The later can also be related to context variables to enable the application of changes matching to different situations. Finally, [14] provides a comprehensive overview of existing approaches targeting process variability.

Process configuration approaches are a promising option to the problem presented in this paper. Nevertheless, that approaches do not completely match the requirements for flexible data collection workflows in such a dynamic and heterogeneous environment, as many different data sources must be considered and request can be subjected to change even while they are running.

4.2 Data- and User-driven Processes

In contrast to classical process management approaches focusing on the sequencing of activities, the case handling paradigm [15] focuses on the objective of the process that is called case. In relation, the product-based workflow approach focuses on the interconnection between product specification and derived workflows [16]. The Business Artifacts approach [17] is a data driven methodology that focuses on business artifacts rather than activities. These artifacts hold the information about the current situation and thus determine how the process shall be executed. In particular, all executed activities are tied to the life-cycle of the business artifacts. Another data-driven process approach is provided by Core-Pro [18]. It enables process coordination based on objects and their relations. In particular, it provides a means for generating process structures out of the object life cycles of connected objects and their interactions. The creation of concepts, methods, and tools for object- and process-aware applications is the goal of the PHILharmonic Flows framework [19]. Thus, flexible integration of business data and business processes shall be achieved and the limitations known from activity-centered Workflow Management Systems shall be overcome.

The approaches shown in this sub-section facilitate processes that are more user- or data-centric and aware. The creation of processes from certain objects could be interesting for SustainHub, however in the dynamic supply chain environment processes rather rely on context parameters than objects and are also continuously influenced by their changes while executing.

4.3 Dynamic Processes

In current literature, there are two main options for making the automatically supported execution of workflows dynamic: Normal, imperative workflows that are dynamic or adaptive or constraint based declarative workflows that are less rigid by design. This sub-section briefly reviews both kinds of approaches starting with adaptive imperative workflows.

Adaptive PAIS have been developed that incorporate the ability to change a running process instance to conform to a changing situation. Examples of such systems are ADEPT2 [20], Breeze [21], WASA [22], and SPADE [23]. All of these only permit manual adaptation carried out by a user. An important issue in this case is that the exceptional situations leading to the adaptation can occur more than once. In that case, knowledge about the previous changes should be exploited to extend effectiveness and efficiency of the current change [24][25].

In case a human shall apply the adaptations, approaches like ProCycle [26] or CAKE2 [27] aim at supporting him with that knowledge. In the situation described in this paper, these approaches are not suitable since the creation and adaptation of process instances has to incorporate various potentially new information and has to be applied before humans are involved or incorporate knowledge the issuer of a workflow does not possess. Automated creation and adaptation of the data collection workflows will be favourable. In this area, only a small number of contemporary approaches exist, like AgentWork [28] and SmartPM [29] Unfortunately, these are limited to rule based detection of exceptions and application of countermeasures.

As mentioned before, another way to enables flexibility into workflows is by specifying them in a declaring way. By such specification, a strict activity sequencing is not rigidly prescribed. Instead of this, a number of different constraints can be used to specify certain facts that the workflow execution must conform to. This could be the mutual exclusion of two activities or a sequencing relation between two distinct activities. Based on this, all activities specified can be executed at any time as long as no constraint is violated. Examples for such approaches are DECLARE [30] and ALASKA [31]. However, such approaches have specific shortcomings relating to understandability. Furthermore and even more important in our context, if no clear activity sequencing is specified, all activities relating to monitoring are difficult to satisfy and monitoring is a crucial requirement for the industry in this case.

5 Conclusion

This paper motivated the topic of sustainability data exchange along supply chains to subsequently present core challenges as well as state of the art in this area. We have clearly identified seven core challenges for today's data collection processes based on intensive interaction with our SustainHub partners most of them relating to variability issues. Especially, design time as well as run time flexibility are clear requirements for any approach supporting companies aiming at sustainable development and production. The presented challenges can serve as starting point for applications developed to support today's complicated supply chain communication. The challenges are expressed in terms of sustainability data collection, however they describe generic problems that may occur in many domains. Thus the results can be easily transferred and be used for other domains. There exists a substantial amount of related work in different areas touching these topics. Yet, none of these approaches or tools succeeds in providing holistic support for the process of sustainability data exchange in a supply chain. The support of data collection requests and processes along today's complex supply chains is a challenge in the literal sense. Nonetheless, SustainHub is actively working on a process-based solution to deal with, and successfully manage the high variability occurring during design and run time. Future work will describe the exact approach, combination of technologies, and the architecture of the system to cope with the aforementioned challenges.

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