Navigating in Process Model Repositories and Enterprise Process Information*

Markus Hipp
Group Research & Advanced Engineering
Daimler AG, Germany
markus.hipp@daimler.com

Bela Mutschler
and Bernd Michelberger
University of Applied Sciences
Ravensburg-Weingarten, Germany
bela.mutschler@hs-weingarten.de
bernd.michelberger@hs-weingarten.de

Manfred Reichert
Institute of Databases and
Information Systems
University of Ulm, Germany
manfred.reichert@uni-ulm.de

Abstract—Although process-aware information systems have been adopted in enterprises for many years, they still do not properly link the business processes they implement with related enterprise process information (e.g., guidelines, checklists, templates, and e-mails). On one hand, process management technology is used to design, implement, enact, and monitor processes. On the other, enterprise process information is spread over various sources like shared drives, databases, and enterprise information systems. As a consequence, users often manually link process information with particular process objects (e.g., using process portals). What is needed instead, however is an integrated access to both processes and related enterprise process information. This paper establishes such a link by introducing an integrated navigation space for process model collections and related enterprise process information. In particular, this navigation space allows process participants to flexibly navigate within process model collections, single process models, and related process information. In turn, this enables advanced end-user support for process repositories.

I. Introduction

In many domains, large and complex processes can be found [1]. Examples include automotive engineering [2] and patient treatment [3]. Usually, respective processes refer to a variety of enterprise process information (*process information* for short) like, for example, guidelines, checklists, corporate rules, e-mails, forms, and best practices [4].

Process-aware information systems have been adopted in enterprises for many years and large process model repositories have emerged in this context [5]. In general, a process model repository not only comprises process models, but related process information as well. To cope with this information load, various services for querying, comparing and handling process models as well as related process information have been developed [6], [7]. What is missing, however, are advanced concepts enabling an integrated access to both process models and related process information [8]. On one hand, process management technology is used to design, implement, enact, and monitor processes. On the other, relevant process information is spread over various sources like shared drives, databases, and enterprise information systems. To establish a link between the different artifacts, i.e., to provide an integrated view

on business process models and related process information, process portals have been introduced. As an example consider the snapshot of a process portal from the automotive domain as shown in Fig. 1. Process model collections are visualized in terms of colored rectangles (cf. Fig. 1A). Process models of a particular collection may be accessed by double-clicking on the respective rectangle. Finally, process information related to an entire process model collection or a single process model is presented to users through a document list [5] (manually created by an administrator) (cf. Fig. 1B).
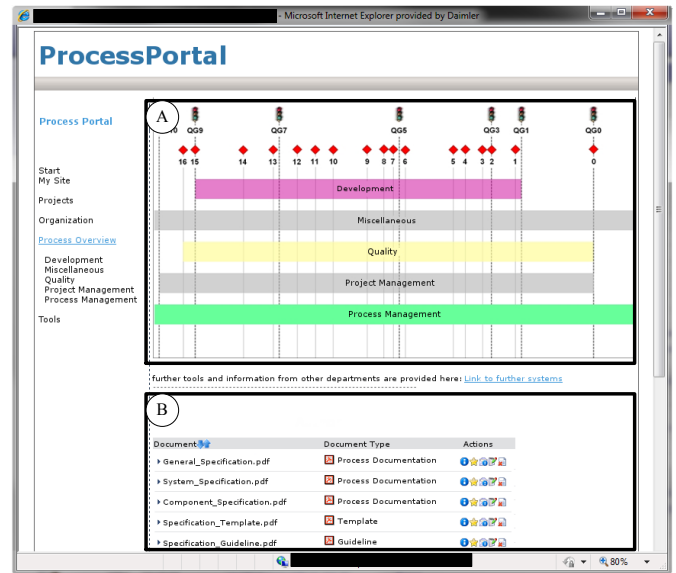
A: Process Model Collection; B: Process Information

Fig. 1. Example of a process portal from the automotive domain.

As a major drawback of such a rigid process portal, the link between process models and process information is defined statically. In two case studies, which we performed in this context (cf. [9], [10]), we showed that this usually leads to large and static process maps [11]. Instead, process participants need intuitive support for navigating in process model collections as well as for accessing related process information. In this context, *navigation* refers to the way, users may interact with a process model repository. For example, a user may want to navigate from the visualization of a process model collection to the one of a single process task enriched

with required process information.

In previous work, we presented the niPRO framework for integrating process models with related process information [12]. Specifically, niPRO comprises two major components: *POIL* (Process-Oriented Information Logistics) [13] and *ProNaVis* (Process Navigation and Visualization) [14], [15]. The former enables the semantic integration, analysis and delivery of process models and related process information, whereas the latter deals with the visualization of and the navigation in process model collections. This paper complements this work by introducing a navigation space that enables users to navigate in process model collections, single process models, and related process information in an integrated and intuitive way.

The remainder of this paper is organized as follows: Section II gives background information required for understanding this paper. Section III introduces an example from the automotive domain and Section IV discusses related requirements. Section V then presents our conceptual approach whose use is illustrated in Section VI. Finally, Section VII discusses related work and Section VIII concludes the paper.

II. THE niPRO FRAMEWORK

To enable an integration of process models with related process information, the niPRO framework was introduced in [12]. Fig. 2 depicts its four architectural layers, which are organized in two components: POIL and ProNaVis.
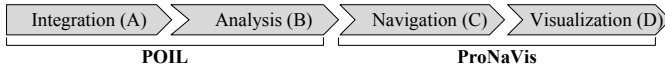

Fig. 2.   The niPRO framework.

The POIL component comprises two layers: *Integration* (A) and *Analysis* (B) [16]. The former layer deals with the semantic integration of process models and related process information that stems from distributed, heterogeneous data sources (cf. Fig. 3a). For this purpose, each *process model* is automatically split into its atomic *process objects*[1] (e.g., all elements provided by the BPMN standard such as tasks, gateways, events, roles, and data objects) [13], [17]. In turn, process information, such as checklists or best practices, is represented through *information objects*.

Process and information objects are then analyzed and linked on layer B (cf. Fig. 3b). During this analysis phase, the relationships between process objects, between information objects, and between process and information objects are identified (cf. Tab. I).

Relationship between	Implicit	Explicit
process objects	semantic analysis	process model
information objects	semantic analysis	manual links
process and information objects	semantic analysis	manual links

TABLE I.   IMPLICIT AND EXPLICIT OBJECT RELATIONSHIPS.

An object relationship may be either *explicit* or *implicit* [13]. Explicit relationships are directly contained in

[1]An open-source plugin for integrating process models is available at http://sourceforge.net/projects/signaviocontent/.

process models. For example, the sequence flow contained in a process model can be directly mapped to *process object relationships* (cf. Fig. 4a). In fact, the entire structure of a process model can be mapped to process object relationships [13]. For example, consider Fig. 4b, which shows a structural relationship between a swimlane and a process task, indicating that the task is contained in the swimlane.
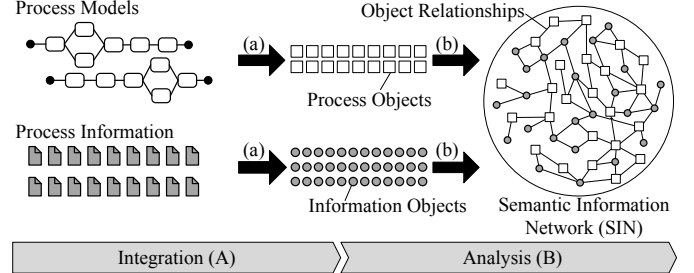

Fig. 3.   Integrating process models and related process information.

In turn, implicit relationships connect objects related to the same topic or used in the same working context (e.g., a guideline similar to another one) (cf. Fig. 4c). Such relations can be determined based on semantic algorithms (cf. [16]).
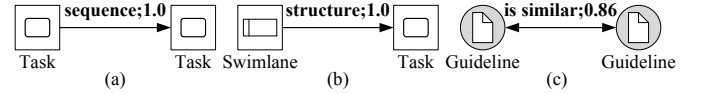

Fig. 4.   Examples of object relationships.

Relationships are both labeled (e.g., "is similar") and weighted. A weight is expressed in terms of a value ranging from 0 to 1: 1 indicates the strongest possible relationship and 0 the weakest one [18]. Note that this allows documenting the semantics as well as the strengths of an object relationship.

As a result of the described integration (layer A) and analysis (layer B), we obtain a *semantic information network* (SIN) [13]. A SIN consists of process models (i.e., sets of process objects), process information (i.e., information objects), and object relationships (cf. Fig. 3). Particularly, it provides a uniform view on process models and related process information, and hence constitutes the interface between the aforementioned POIL and ProNaVis components (cf. Fig. 2).

In the following, we describe how a navigation space for process model collections and related process information can be constructed from a given SIN.

III. ILLUSTRATING EXAMPLE

In order to illustrate our approach, we refer to a real-world scenario from the automotive domain. It consists of a process model collection dealing with the development of electric/electronic systems for cars [2]. In detail, the scenario comprises process models related to *requirements engineering*. We consider a *general specification* process (cf. Fig. 5) that involves 5 roles: *E/E development (R1)*, *Component Responsible (R2)*, *Expert (R3)*, *Project Responsible (R4)*, and *Decision Maker (R5)*. In addition, the process comprises 11 tasks *(i.e., T1-T11)* related to the preparation, creation and validation of a
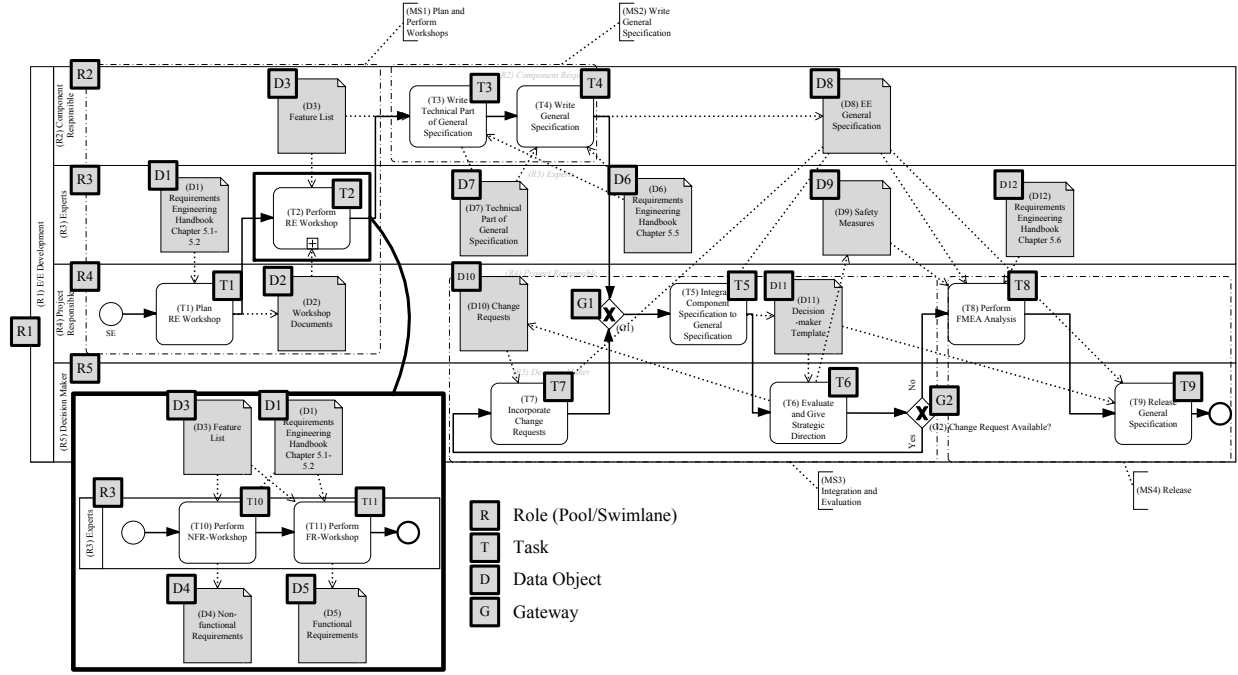
Fig. 5. The *general specification* process.

general specification of a car component. In turn, these process tasks refer to 12 data objects D1-D12.

The SIN representation of this process model that results after completing the integration (layer A) is shown in Fig. 6. We use a shared drive as data source for information objects. These information objects are integrated into the SIN based on semantic and syntactic analyses (layer B). For the sake of simplicity, detailed information on single relationship labels and weights are only illustrated in few examples. Further, note that the SIN from Fig. 6 is simplified regarding its overall size, i.e., it only covers a part of the actual SIN representing the scenario of our running example. Usually, a SIN may comprise hundreds or thousands of linked process and information objects.

IV. REQUIREMENTS

First of all, we summarize fundamental requirements for navigating in process model collections and related process information (cf. Table II). The requirements were identified in the context of two case studies ([9], [10]) in the healthcare and automotive domains as well as a comprehensive literature survey [19]. Both case studies are based on expert interviews and questionnaires. Considering the similar observations made in the two domains, we may assume that these requirements are applicable to other domains as well.

Req #1 (Integration): Process model collections and related process information shall be provided in an integrated manner. For example, an engineering process usually refers to hundreds or thousands of documents. In turn, in healthcare, paper-based medical records should be linked to the tasks emerging during medical ward rounds [20].

Req #2 (Interaction): Process stakeholders must be able to effectively interact with process model collections and related

process information. For example, consider a requirements engineer creating the specification of a car control unit. Usually, an engineer is solely interested in process information related to specific process tasks. Hence, flexible interaction support is required that allows hiding non-relevant process information or switching to preceding/succeeding process tasks.

Req #3 (Personalization): Process stakeholders need to be supported with personalized visualizations of a process model collection and related process information. For example, when a requirements engineer starts creating a specification, certain process information is needed. First, he might be interested in temporal process information (e.g., deadlines). Second, after completing the specification, he might need information on follow-up process tasks or contact persons.

Req #4 (Detail Level): Process model collections and related process information should be presented to users at different levels of detail. For example, a requirements engineer needs detailed process information (e.g., checklists, guidelines, and task description) when working on a particular process task. In turn, a project manager asks for process information on a more abstract level, e.g., a management summary or an overview of the currently executed process tasks.

Req #5 (Consistency): Process model collections and related process information need to be presented in a consistent manner. The use of different formats and tools might distract process stakeholders.

V. THE PRONAVIS NAVIGATION SPACE

This section introduces advanced concepts for constructing a navigation space for a given process model collection and related process information based on a SIN. Section V-A presents our overall vision. Sections V-B and V-C then describe how the navigation space can be constructed.
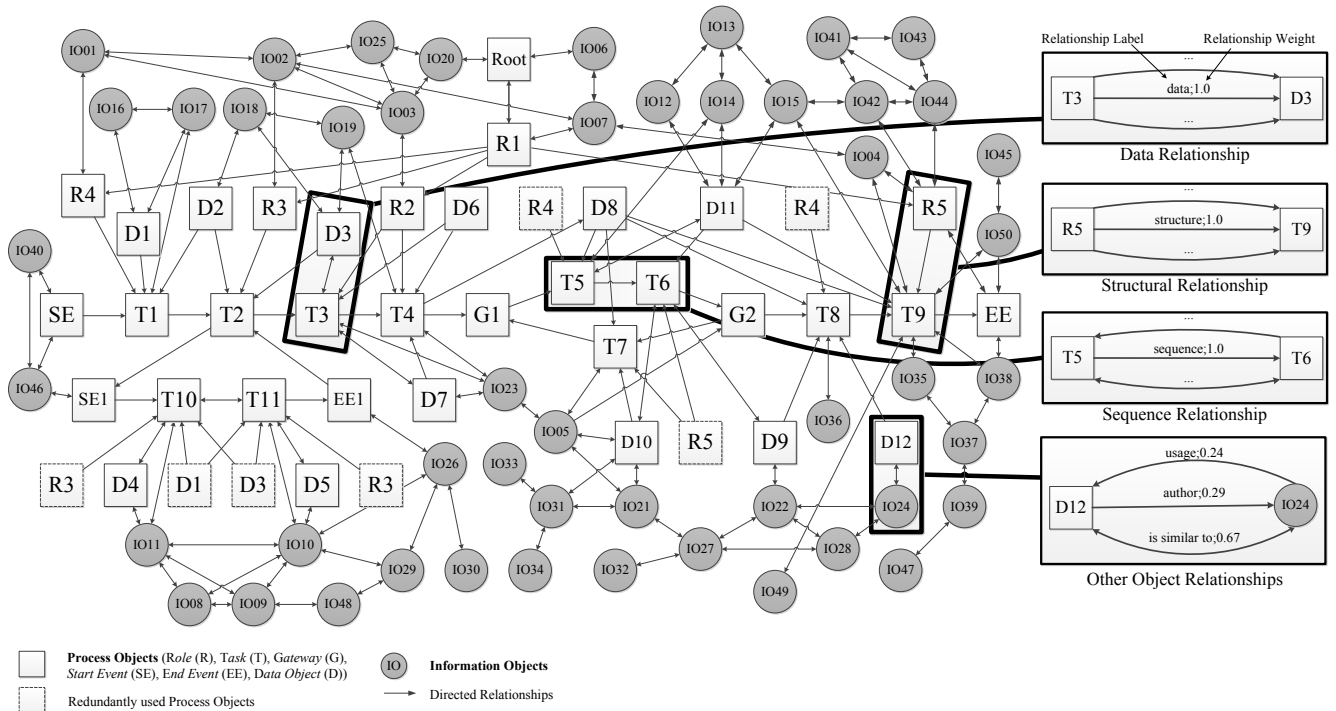
Fig. 6. A SIN representing the *general specification* process from Fig. 5 (partial view).

Req #	Requirement	Source		
		Lit	CS1	CS2
Req #1 Integration	Process model collections and process information should be provided in an integrated manner.		●	●
Req #2 Interaction	Process stakeholders should be enabled to interact with process model collections and related process information.		●	●
Req #3 Personalization	Process stakeholders should be supported with personalized presentations of process model collections and related process information.	●	●	●
Req #4 Detail Level	Process model collections and related process information should be presented to users at different levels of detail.	●		●
Req #5 Consistency	Process model collections and related process information should be presented in a consistent manner.		●	●

Lit: Literature Study; **CS1:** Case Study 1 (healthcare); **CS2:** Case Study 2 (automotive)

TABLE II. MAIN REQUIREMENTS.

A. Vision

In order to construct the *navigation space*, first of all, we reorganize the SIN (cf. Sect. III). Specifically, we transform the existing network into a hierarchical structure that allows us to derive three *navigation dimensions*: the *semantic* dimension, *geographic* dimension, and *view* dimension. The *semantic dimension* allows displaying process and information objects on different levels of detail. The latter range from abstract process information (e.g., names of process tasks) to more detailed one (e.g., all information available for process tasks). The *geographic dimension* enables visual zooming without changing the level of detail. Think of a magnifier while reading a newspaper. Finally, the *view dimension* allows users to

focus on specific process aspects while eliminating others. For example, a temporal view on a process shall enable process participants to easily identify deadlines or other temporal constraints, whereas an organizational view should provide access to information objects like contact persons or documents. Using these three navigation dimensions in combination, the requirements from Table II can be met. Altogether, the three navigation dimensions form the navigation space.

Basically, the navigation space is constructed in two consecutive steps taking a SIN as input:

Step 1 (Process Space) First, the *process space* is constructed. It represents a harmonized, but preliminary data structure that is used to construct the navigation space. For deriving the process space of a SIN, we first extract the objects related to single process models from the SIN (cf. Fig. 7, Step 1.1). Each extracted process model is then represented as a tree-like structure[2]. Then, we compose the extracted models to a single structure representing the entire process model collection (cf. Fig. 7, Step 1.2). Finally, we add the information objects retrieved from the SIN by following the object relationships between the extracted process objects and their related information objects (cf. Fig. 7, Step 1.3). Section V-B explains these sub-steps in detail.

Step 2 (Navigation Space) Taking the process space derived in Step 1 as input, the *navigation space* is constructed in this context. In particular, the already mentioned navigation dimensions (cf. Sect. V-A) need to be covered. First, the semantic dimension is constructed based on the tree *levels* of the process space. Thereby, all process and information objects belonging to the same level constitute a particular *navigation*

---

[2]This structure can be determined based on the structural object relationships of the SIN. i.e., structural relationships.
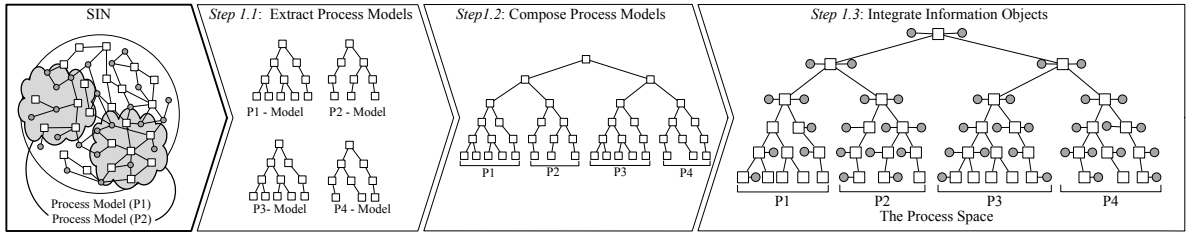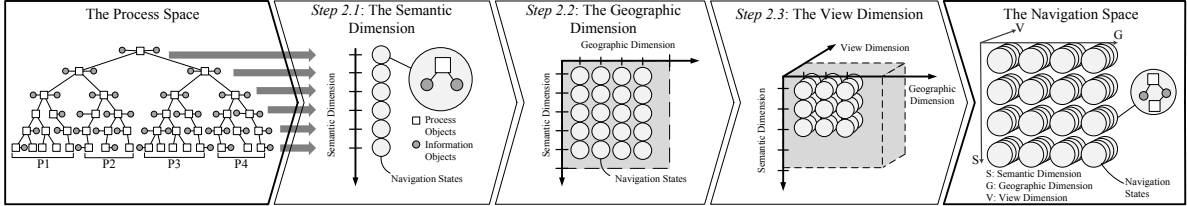
Fig. 7. Constructing the process space (Step 1).

Fig. 8. Constructing the navigation space (Step 2).

state (cf. Fig. 8, Step 2.1). Second, the geographic dimension extends the semantic one by adding zooming functions (cf. Fig. 8, Step 2.2). Third, the view dimension visualizes process and information objects of both the semantic and geographic dimension (cf. Fig. 8, Step 2.3). By combining the three navigation dimensions, we obtain the overall navigation space. Section V-C presents the details regarding the construction of the navigation space.

B. Step 1: Constructing the Process Space

As a first challenge, we need to construct the process space. A process space constitutes a harmonized data structure that provides the basis for deriving the navigation space. The construction of the process space comprises three steps:

Step 1.1 (Extract Process Models from the SIN)

We first extract process models from the SIN and represent each model in terms of a hierarchical data structure. In this context, we introduce a generic *root node* as unique identifier for each process model. Then, we create a hierarchical structure for each process model. For this purpose, we utilize the relations of a SIN, e.g., object relationships (cf. Fig. 9). Note that there exist various types of object relationships (cf. Fig. 4). During Step 1.1, structural and data relationships are taken into account. Sequence relationships, in turn, are ignored in this context.
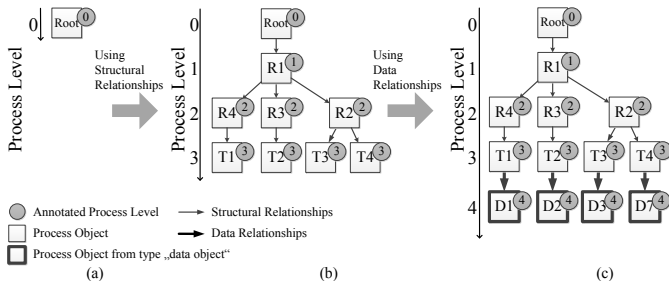

Fig. 9. Extracting process models from the SIN (Step 1.1).

Consider again the *general specification* process we introduced in Section III. In particular, we can extract this process model from the SIN shown in Fig. 6. First, we identify the root node (cf. Fig. 9a), which corresponds to process level 0. Then, we analyze the object relations of the SIN. In our example, only process object $R1$ (i.e., pool *E/E development*) is directly related to the root node through a structural relationship. Thus, we assign $R1$ to process level 1. When considering $R1$, roles $R2$ (i.e., lane *component responsible*), $R3$ (i.e., lane *expert*), and $R4$ (i.e., lane *project responsible*) can be identified as related process objects. Accordingly, these roles are assigned to process level 2. Finally, process objects $T1$, $T2$, $T3$, and $T4$, of which each represents a single process task, are assigned to process level 3. Due to space limitations, Fig. 9b does not show the resulting hierarchical structure entirely, but only a small part of it. Finally, data objects (i.e., $D1$, $D2$, $D3$, and $D7$) are assigned to process level 4 (cf. Fig. 9c) based on their relations.

Based on the data structure so far, users may navigate within a single process model, e.g., starting with the root node and then accessing other process objects (e.g., process tasks or data objects). In order to also enable navigation across different process models within a process model collection, the extracted hierarchical structures of the process models need to be composed.

Step 1.2 (Composing Process Models)

First, the process models referring to the same topic are combined. For this purpose, every topic is represented by a manually or automatically created process object (i.e., a *topic node*). In turn, a topic node belongs to process level -1 and connects all process models exhibiting topical similarity. Finally, an additional meta topic node is added on process level -2 representing the entire process model collection (cf. Fig. 11).

As the SIN from Fig. 6 only covers one process model, for the purpose of illustration, we use a schematic representation of a SIN comprising 4 process models (cf. Fig. 10). In our scenario, two relevant topics can be identified (cf. Fig. 11).
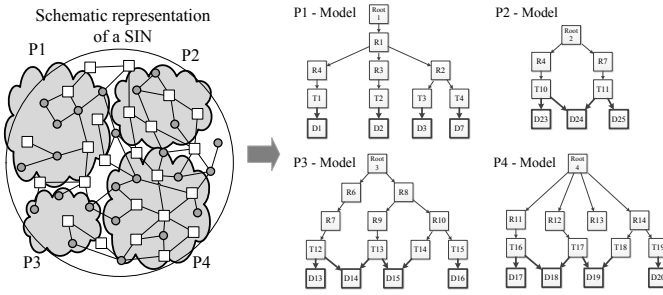
Fig. 10. Four process models extracted from the SIN (Step 1.1).

Both are represented as topic nodes and are assigned to process level -1. In particular, process models P1 and P2 are assigned to topic *component specification*, whereas process models P3 and P4 are assigned to topic *system specification*. Finally, both topic nodes are connected by a generic node on process level -2 representing the entire process model collection. Starting with this generic node, a user may access all process models of the respective collection as well as related information (i.e., process objects such as tasks).

Generally, process participants are not only interested in navigating across process models, but also want to access process information. For example, after navigating to a particular process task, the user wants to access process information (e.g., guidelines or checklists) related to this task. Thus, we have to consider the integration of process and information objects.

Step 1.3 (Integrate Information Objects)

We integrate SIN information objects based on their semantic relations with process objects. As a result, we obtain a hierarchical structure denoted as *process space* (cf. Fig. 12). The latter allows for a centralized and harmonized access to all process models of a given process model collection and its related process information.

As example consider a *requirements engineer* creating a *component specification* for an ABS[3] control unit. In order to perform the task *write general specification* ($T4$ in our process example from Fig. 5), the engineer may access the process model collection on process level -2 (cf. Fig. 12). Then, he navigates via topic node *requirements engineering* to process model *component specification* ($P1$ represented by $Root1$), and via $R1$ (representing pool *E/E development*) and $R2$ (representing role *component responsible*) to the task of interest (i.e., $T4$) on process level 3. At this level, he may further access all information related to $T4$ (cf. Fig. 12a), e.g., a specification guideline ($IO22$).

C. Step 2: Constructing the Navigation Space

Taking the process space resulting from Step 1 as input, the navigation space can now be derived by consecutively constructing the three navigation dimensions (cf. Fig. 8).

Step 2.1 (Deriving the Semantic Dimension)

All process and information objects that belong to a particular process level of the process space correspond to a single *navigation state*. In turn, each navigation state represents a

---

[3]ABS: Anti-lock Braking System.

particular value of the semantic dimension. Accordingly, the process levels of the process space correspond to values on a discrete scale represented by the semantic dimension of the navigation space (cf. Fig. 13a). Note that this approach has been inspired by the concept of semantic zooming as originally introduced in [21].

Due to lack of space, we only consider a small part of the process space from Fig. 12 as shown in Fig. 13a. Assume that a navigation starts with object $R2$ on process level 2, i.e., only process and information objects on process levels 2-4 are considered. Regarding the selected part, the navigation state corresponding to process level 2 includes objects $R2$ and $IO11$. In turn, navigation state $N31$, which corresponds to process level 3, comprises objects $IO10$, $T3$, $IO22$, and $T4$.

Step 2.2 (Deriving the Geographic Dimension)

In general, a navigation state may comprise a large number of process and information objects. To cope with this, the geographic dimension allows users to control the number of process and information objects to be displayed (cf. Fig. 13b). Decreasing the scale of the geographic dimension increases the number of objects displayed (cf. $N31$ in Fig. 13b). In turn, increasing this scale allows users to focus on fewer or even single objects (cf. $N33$ in Fig. 13b). Technically, we apply zooming and panning techniques as proposed in [11] and [22].

Like the semantic dimension, the geographic one is divided into discrete values. Thus, each combination of values of the geographic dimension (i.e., a certain scale) and the semantic one (i.e., a certain process level) may be represented as a navigation state in a 2-dimensional navigation space (cf. Fig. 13b). From a conceptual point of view, the 2-dimensional navigation space corresponds to the matrix depicted in Fig. 13b.

As an example consider navigation state $N31$ in Fig. 13a. It comprises objects $T3$, $T4$, $IO10$, and $IO22$. Assume that a *requirements engineer* who is creating a *component specification* wants to learn more about his current process task (i.e., T4). For this purpose, he selects process level 3 in the semantic dimension, which includes task $T4$ as well as all other objects assigned to this level. By default, the resulting navigation state $N31$ is associated with geographic value 1 (i.e., a small scale). The requirements engineer may now reduce the number of objects included in $N31$ by zooming into this state, i.e., by increasing the scale of the geographic dimension. When selecting $T4$, a state transition to navigation state $N32$ is triggered, which, in turn, focuses on process task $T4$ and its related information objects ($IO22$ in the given case). In order to view details of $IO22$ (i.e., the specification template) another state transition to $N33$ may be performed.

Step 2.3 (Deriving the View Dimension)

The view dimension deals with the visualization of process as well as information objects, i.e., the visualization of navigation states. In particular, the view dimension allows transforming process and information objects into various representations (cf. Fig. 13c). On one hand, a *time-based* view can be used to visualize temporal aspects. Tasks, for example, may be represented by rectangles of different widths indicating their actual durations. On the other, a
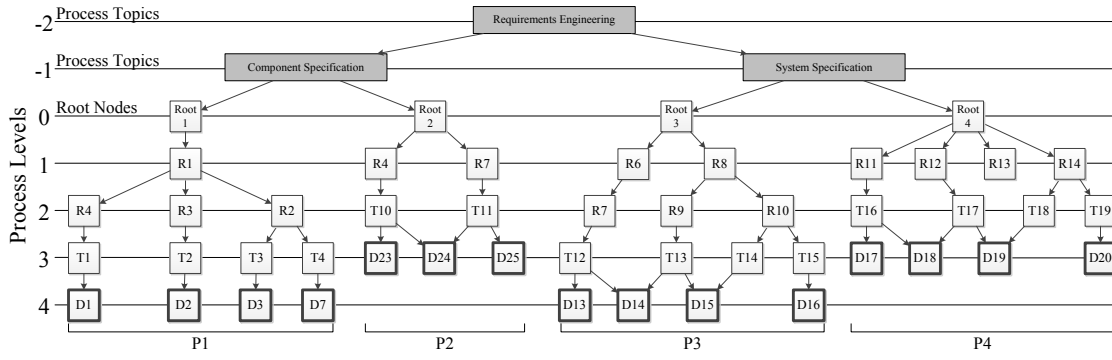
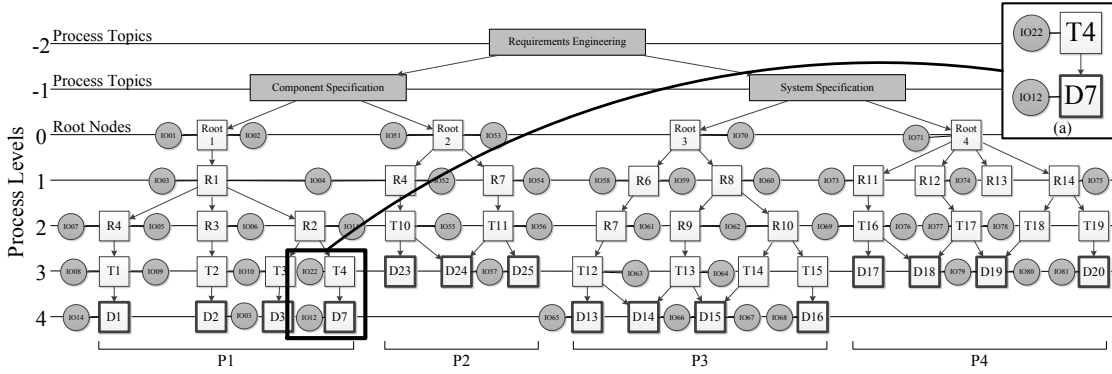Fig. 11. Composed process models (Step 1.2).

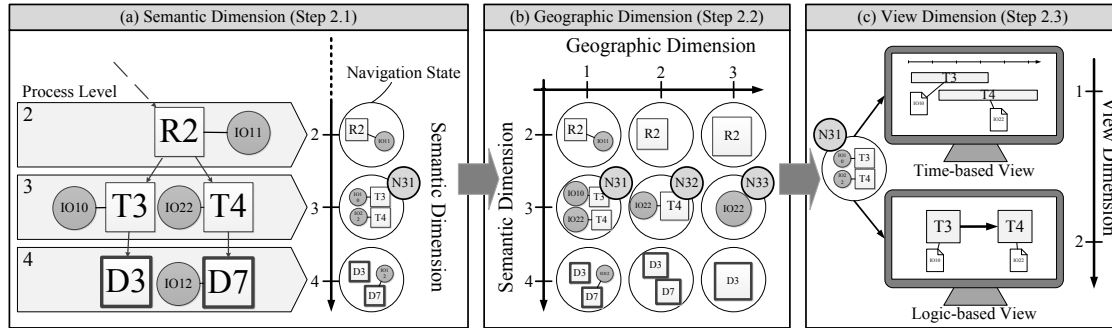Fig. 12. Process space (Step 1.3).

Fig. 13. Constructing navigation dimensions (Step 2).

logic-based view may be used to emphasize logical relations, i.e., predecessor/successor relations between tasks. Other views, not shown in Fig. 13c, might focus on the visualization of information objects (e.g., documents).

Overall, the constructed navigation space allows tailoring the number of displayed process and information objects. The latter can be visualized according to specific user needs based on the view dimension. Accordingly, navigation corresponds to transitions between navigation states. A formal model for representing such transitions is presented in [15].

Table III summarizes how the presented navigation approach meets the requirements discussed in Section IV.

Req #	Requirement	Process Space	Navigation Space		
			S	G	V
Req #1	Integration	✓			
Req #2	Interaction	✓	✓	✓	✓
Req #3	Personalization		✓	✓	✓
Req #4	Detail Level		✓	✓	
Req #5	Consistency	✓			

S: Semantic Dimension; **G:** Geographic Dimension; **V:** View Dimension

TABLE III.   REQUIREMENTS FULFILMENT.

VI. IMPLEMENTATION AND PRELIMINARY VALIDATION

This section presents results from the application of the presented navigation concept in a real-world environment from the automotive domain. Section VI-A introduces *Compass*, a tool implementing our concept with particular focus on processes for developing electric/electronic components of a car [23].

However, we do not only present Compass, but also validate the developed concept. For the latter purpose, we perform a controlled user experiment comparing this navigation concept with the static one used in the process portal depicted in Fig. 1. Section VI-B presents the experiment design, Section VI-C discusses experiment results, and Section VI-D addresses threats of validity.

A. Implementing our Navigation Concept in Compass

Compass is a tool that aims to support knowledge workers who deal with the engineering of electric/electronic components for cars, trucks, and buses. In particular, Compass allows navigating in process model collections based on the navigation space described in Section V.

The Compass user interface comprises three major components (cf. Fig. 14): First, the *process management area* (cf. Fig. 14A) provides management functions (e.g., a breadcrumb navigation and a timeline showing important dates). Second, the *tool area* (cf. Fig. 14B) provides functions for interacting with process model collections. Third, contents (i.e., process models and process information) are depicted in the *content area* (cf. Fig. 14C).

Compass allows integrating process models with relevant process information (Req #1). Further, it supports the interactions between users and process models (Req #2). In the latter context, the tool provides three different views: a time-based view (cf. Fig. 14), a logic-based view (cf. Fig. 15), and a text view (not shown) (Req #3). It also implements the presented navigation dimensions (i.e., semantic, geographic, and view dimension) (Req #4). Finally, Compass enables an integrated access to process models and enterprise process information through a single user interface (Req #5).

Figs. 14 and 15 refer to the example from Section III. Fig. 14 shows the visualization of the *Requirements Engineering* process model collection on process level -1 in the semantic dimension. It comprises three process topics (*Component, System,* and *General Specification*) represented as rectangles in the time-based view. Thereby, different colors indicate different roles involved in these process topics. Increasing the geographic and semantic dimension, in combination with a change of the view dimension, allows the user to display the underlying process model (cf. Fig. 15), i.e., the logic-based view of our *general specification* process from Fig. 5, together with related process information on process level 3. In this context, data objects $D6$ and $D7$ are displayed as icons (cf. Fig. 15A). By clicking on one of these icons, a window on the right hand side is displayed, which provides detailed information about the data object, including a list with related process information (cf. Fig. 15B) (e.g., additional documents such as guidelines or best practices).

Compass is currently run by 4 business units of an automotive manufacturer (cf. Tab. IV) and 364 employees use it during their daily work. Process model collections maintained by Compass comprise between 4 and 50 process models (including between 8 and 37 process tasks) depending on the business unit. 390 documents such as guidelines, checklists, and handbooks are included.

Department	Employees	Process Models	Documents	Area
Business Unit A	257	50	290	Busses
Business Unit B	47	15	60	Trucks
Business Unit C	37	23	30	Cars
Business Unit D	23	4	10	Cars

TABLE IV.   DETAILS ON THE USE OF COMPASS.

B. Experiment Design

In order to validate our navigation concept, we performed a controlled user experiment, involving 18 subjects from the automotive domain. Our goal is to investigate the benefit of the developed navigation concept compared to a static, one-dimensional navigation concept. The research question corresponding to our experiment is as follows:

Is three-dimensional process navigation more suitable for navigating in complex process model collections when compared to a static, one-dimensional navigation concept. If 'yes', how strong is this difference?

On one hand, we assume that provision of three navigation dimensions makes navigation more difficult and less intuitive, since the number of navigation options increases. On the other, a more sophisticated navigation support becomes possible.

When designing our experiment, the following criteria are taken into account [24], [25]:

- The design of an experiment shall allow for the collection of as much data as possible with respect to the major goals of the experiment.

- The collected data should be unambiguous.

- The experiment must be feasible for a given setting.

Considering these design criteria, we conduct a *controlled single factor experiment*. Subjects are randomly divided into two groups with nine subjects each. The *experimental group* works with Compass and thus applies the developed navigation concept (*experimental system*), whereas the *control group* works with an older version of Compass providing solely a static, one-dimensional navigation concept (*control system*).

Prior to the start of the experiment, we inform the subjects about goals and procedures. Afterwards, subjects have to perform three introductory tasks in order to become familiar with their tool (and thus with their navigation concept). Then, the actual experiment starts. Based on three typical use cases for requirements engineers in the electric/electronic domain, we derive 6 specific tasks the subjects have to complete. For example, subjects must navigate to a specific process task and search for a related document. While performing the tasks, all subjects are captured on video and encouraged to give direct feedback during the entire session (*Think Aloud Method* [26]). For each task execution times are captured as well. After finishing all tasks, subjects must fill out a questionnaire concerning their subjective impressions on the navigation concept. In the latter context, they use a 5-step Likert scale reaching from 1 (*I totally disagree*) to 5 (*I totally agree*).

Our results do not show normal distribution (calculated with a *Kolmogorov-Smirnov test* and a *Shapiro-Wilk test*).
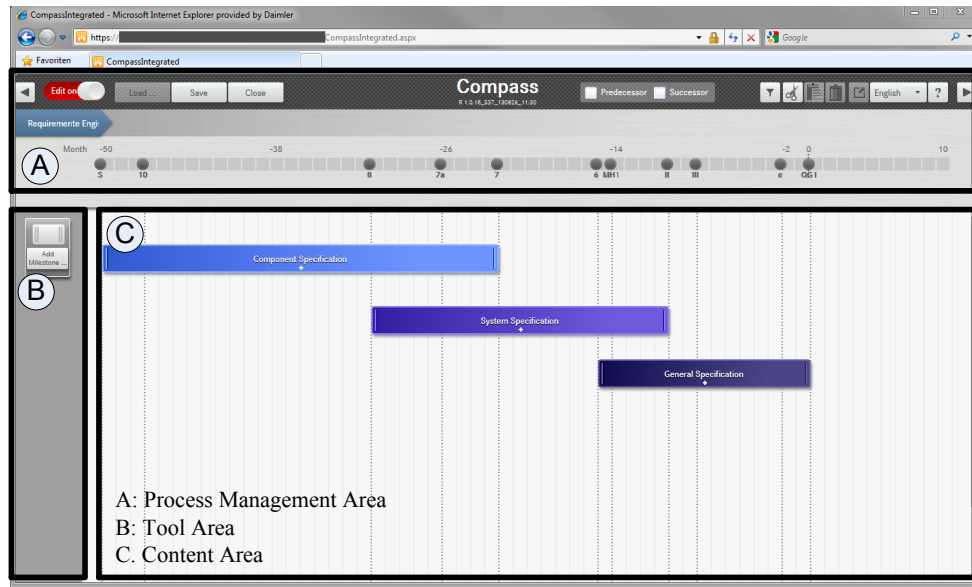
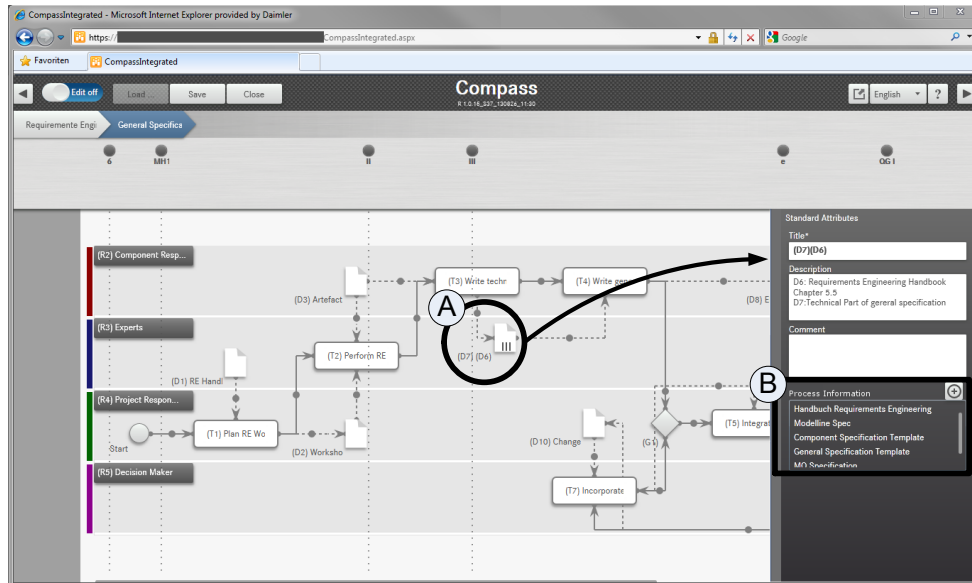Fig. 14. Time-based view on the process model collection.

Fig. 15. Logic-based view on the *general specification* process.

Thus, a *Mann-Whitney U test* is applied to calculate significance values. Applying this test, we are able to assess whether the means of the experimental samples and the control samples are statistically different from each other [27]. All tests are executed based on a 5% significance level ($\alpha = 0.05$).

C. Experiment Results

Fig. 16 shows results of the experiment. Both navigation concepts are considered as equally *interesting*. Even though the experimental system (ES) shows a higher mean (3.89) than the control system (CS) (3.78), the difference is not significant ($p = 0.931$). Further, the experimental system is considered as being more *vivid* (3.78) than the control system (3.22). Again, no significant difference can be identified ($p = 0.297$). All subjects agreed that the navigation in a process model

collection is *traceable* based on both systems (4.22 for the ES, 4.00 for the CS).

The experimental as well as the control system were *easy to learn* for the participants. More precisely, the control system shows a higher mean (4.56 for the CS and 4.33 for the ES). The experimental system is *very understandable* (4.44), even if it provides more navigation possibilities than the control system, which is perceived as *very understandable* (4.11) as well. Subjects agreed that navigation is *easy* with both systems (4.22 for the ES and 4.00 for the CS), though there are no significant differences ($p = 0.863$). Finally, the experimental system is more *intuitive* (4.33) than the control system (3.78), though this difference is not significant ($p = 0.436$). The latter is surprising, considering the complexity of our navigation concept (i.e., three navigation dimensions instead of one).
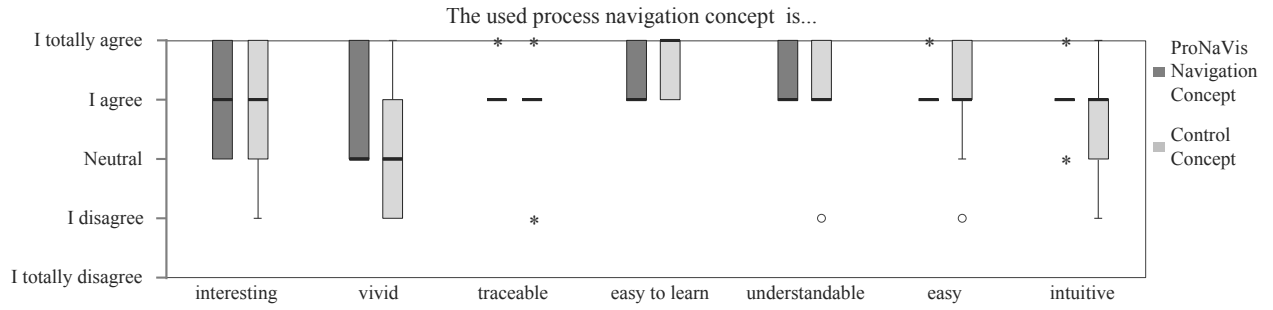
Fig. 16. Comparing two navigation concepts.

Interestingly, subjects using the experimental system were able to perform their tasks by an average of 13.19 seconds faster than subjects working with the control system. However, this result is not significant ($p = 0.370$). Finally, the experimental group made significantly less mistakes (0.778 mistakes per task) than the control group (2.278 mistakes per task) ($p = 0.031^*$).

Furthermore, we investigated the three navigation dimensions. Note that only the experimental group can be considered here. Fig. 17 shows that subjects agreed or even totally agreed that the geographic dimension is *easy to learn*, *intuitive*, *easy*, *important*, and *helpful* for users navigating in process model collections.
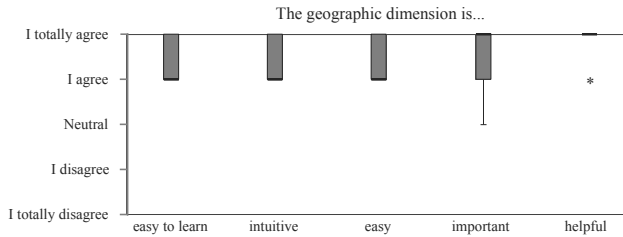

Fig. 17. The geographic dimension.

Subjects further agreed that the semantic dimension is *intuitive*, *important*, and *helpful* for process participants (cf. Fig. 18). Only one out of the 18 subjects disagreed that the navigation concept is *easy to learn*.
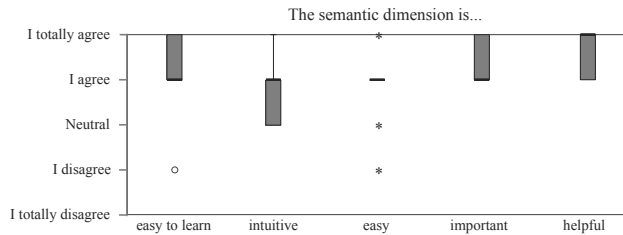

Fig. 18. The semantic dimension.

Experiment results related to the view dimension are presented in Fig. 19. As can be seen, this dimension is very *important* and *helpful* for users. Subjects further agreed that it is *intuitive* and *easy to learn*.

All results of our experiment confirm that the experimental system, which is based on the presented navigation concept,
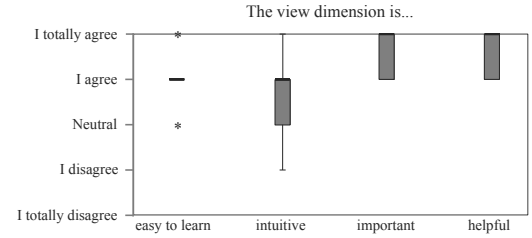

Fig. 19. The view dimension.

is better suitable for navigating in complex process model collections than the control system. Though our experiment mostly did not reveal significant differences, it clearly indicates higher means for all (except one) variables. In particular, despite its increased complexity, the developed navigation concept does not negatively bias user experience. In contrast, subjects perform tasks faster and make fewer mistakes.

The main lessons learned from this experiment as well as the feedback obtained from Compass users are as follows:

- The provision of a geographic dimension allows for a better overview of a process model collection.

- The possibility to either decrease or increase the number of displayed information objects along the semantic dimension facilitates tool usage.

- Navigating across process models allows for a better understanding of the relations thet exist between single process models.

- The provision of different views allows supporting specific demands of users having different roles (e.g., engineers and managers).

D. Threats of Validity

Generally, there might be risks to be taken into account when performing experimental research. In particular, factors threatening the *internal* and *external validity* of the experiment need to be considered. Regarding the described experiment, the threats of internal validity are as follows:

- **Subjects.** Different experience levels of the subjects involve a crucial factor threatening internal validity. To limit this threat, we exclusively choose subjects from the industrial sector, i.e., process experts from the area of electric/electronic development processes

in order to guarantee for the same conditions among subjects. This fact also explains the small number of subjects since these experts are hard to recruit. Finally, we randomly assigned subjects to experiment groups in order to achieve a uniform distribution.

- **Objects.** Objects should not differ in more than one factor in order to make results traceable to this origin. Note that in the context of the experiment, Compass was used for both groups, i.e., both groups were confronted with similar user interfaces, i.e., solely the applied navigation concepts differed.

- **Training.** Subjects have obtained the same amount of training for the respective navigation concepts in order to ensure similar levels of knowledge.

Finally, threats of external validity are as follows:

- **Experience.** In order to guarantee a similar level of experience, all subjects are familiar with the topic of business processes. This might have a negative impact on the external validity since all subjects are experts with respect to the topic of process navigation.

- **Process Models.** To not falsify results due to comprehensibility issues regarding the process models used, we chose process models that are semantically easy to understand.

VII. RELATED WORK

The integration of different enterprise resources is considered in the areas of enterprise resource planning [28], [29] and enterprise engineering [30], [31]. In this context, the integration of process models, e.g., all information and activities related to a supply chain, constitutes a key factor. Though the benefit of integrated processes is discussed, however, neither the automated integration of enterprise process information nor sophisticated navigation and visualization concepts have been addressed so far.

Research on the flexible visualization of process models (i.e., on what we call view dimension) is presented in [32] and [33]. More specifically, these approaches introduce aggregation and reduction techniques to create flexible views on complex business process models. In [34] and [35], a view framework allowing for updatable and user-centered process views as well as the user-centered modeling and visualization of business processes is presented. [36] focuses on timeline visualizations for documenting and visualizing continuously changing process models. Note that all these approaches solely deal with process models, while the combination of process models and related process information as well as the navigation in respective process spaces are neglected.

Challenges related to zooming functionality in user interfaces are addressed in [21], which presents *zoomable user interfaces* for navigating in complex information spaces. The *JAZZ*-framework [37] applies these concepts. Corresponding user interface concepts include *Squidy* [38], *ZOIL* [39], and *ZEUS* [40]. Zooming and moving in a 3D environment is realized by the *Flight Navigator* tool [41], which supports numerous interaction paradigms enabling users to present, inspect and analyze process models in a 3D environment. Similarly,

[42] and [43] use 3D technology to realize a collaborative approach for modeling business processes. An approach for efficient zooming is presented in [22].

Finally, there exists research on the provision of information on different detail levels (according to our semantic dimension). Both [44] and [45] make use of process hierarchies in order to efficiently visualize complex process models on small canvas. Respective approaches allow displaying large process hierarchies in their entirety in a compact manner and thus facilitate the presentation of information on different semantic levels. Furthermore, [46] discusses the representation of detailed information about a single activity without losing the overview of the global structure of an organization. Finally, this approach provides a representation technique embedding charts into cells of a tree map.

VIII. SUMMARY AND OUTLOOK

As business processes are becoming increasingly complex, a static representation of the relationships between process models and process information is no longer sufficient in order to adequately support process stakeholders in their daily work. This paper presents the ProNaVis navigation concept, a 3-dimensional navigation space enabling a repository support for navigating in large process model collections and related process information. We introduce three navigation dimensions (semantic, geographic, and view dimension) upon which we finally construct the navigation space. The latter allows for an integrated access to both process model collections and process information. We further present Compass, an application applying these concepts to complex real-world automotive process model collections. Finally, a user experiment shows that more sophisticated navigation possibilities, as provided by our navigation concept, justify the increased complexity.

Future work will include the full implementation of the mentioned concepts as well as their further evaluation based on Compass. Further, we will investigate the effort to establish such a system in an enterprise, as required effort might be a major obstacle for adopting the approach. Therefore, we plan to run Compass in other departments in the automotive sector in order to gather additional experiences and to optimize efforts. Finally, we will develop and empirically investigate additional view-concepts, e.g., visualization options.

REFERENCES

[1] S. K. Öhgren, A., *Information Overload in Industrial Enterprises - Results of an Empirical Investigation.* in: Proc 2nd European Conf on Information Management and Evaluation (ICIME'08), pp. 343-350, 2008.

[2] D. Müller, J. Herbst, M. Hammori, and M. Reichert, *IT Support for Release Management Processes in the Automotive Industry.* in: Proc 4th Int'l Conf on Business Process Management (BPM'06), pp. 368–377, 2006.

[3] R. Lenz and M. Reichert, *IT Support for Healthcare Processes - Premises, Challenges, Perspectives.* in: J on Data and Knowledge Engineering, 61(1), pp. 39–58, 2007.

[4] A. Edmunds and A. Morris, *The Problem of Information Overload in Business Organisations: A Review of the Literature.* in: Int'l J of Information Management, 20(1), pp. 17–28, 2000.

[5] B. Weber, M. Reichert, J. Mendling, and H. A. Reijers, *Refactoring large process model repositories.* in: J Computers in Industry 62(5), pp. 467–486, 2011.

[6] M. L. Rosa, H. A. Reijers, W. M. P. van der Aalst, R. M. Dijkman, J. Mendling, M. Dumas, and L. García-Bañuelos, *APROMORE: An advanced process model repository*. in: J Expert Sys Appl, pp. 7029–7040, 2011.

[7] M. Kunze and M. Weske, *Metric Trees for Efficient Similarity Search in Process Model Repositories*. in: Proc 1st Int'l Workshop Process in the Large (IW-PL '10), LNBIP 66, pp. 535–546, Springer, 2010.

[8] W. M. P. van der Aalst, *Process-Aware Information Systems: Design, Enactment and Analysis*. in: Wiley Encyclopedia of Computer Science and Engineering, pp. 2221–2233, Wiley & Sons, 2009.

[9] M. Hipp, B. Mutschler, and M. Reichert, *On the Context-aware, Personalized Delivery of Process Information: Viewpoints, Problems, and Requirements*. in: Proc 6th Int'l Conf on Availability, Reliability and Sec (ARES'11), LNCS 6908, pp. 390–397, Springer, 2011.

[10] B. Michelberger, B. Mutschler, and M. Reichert, *On Handling Process Information: Results from Case Studies and a Survey*. in: Proc 2nd Int'l Workshop on Empirical Research in BPM (ER-BPM'11), LNBIP 99, pp. 333–344, Springer, 2011.

[11] J. J. van Wijk and W. A. A. Nuij, *A Model for Smooth Viewing and Navigation of Large 2D Information Spaces*. in: J IEEE Trans Vis Comput Graph, 10(4), pp. 447–458, 2004.

[12] M. Hipp, B. Michelberger, B. Mutschler, and M. Reichert, *A Framework for the Intelligent Delivery and User-adequate Visualization of Process Information*. in: Proc 28th Symp on Applied Computing (SAC2013), ACM, pp.1383–1390, 2013.

[13] B. Michelberger, B. Mutschler, and M. Reichert, *Process-oriented Information Logistics: Aligning Enterprise Information with Business Processes*. in: Proc 16th Int'l EDOC Conf (EDOC'12), pp. 21–30, IEEE, 2012.

[14] M. Hipp, B. Mutschler, and M. Reichert, *Navigating in Process Model Collections: A new Approach Inspired by Google Earth*. in: Proc 1st Int'l Workshop on Process Model Collections (PMC'11), LNBIP 100, pp. 87–98, Springer, 2011.

[15] ——, *Navigating in Complex Business Processes*. in: Proc 23rd Int'l Conf on Database and Expert Systems Applications (DEXA'12), LNCS 7447, pp. 466–480, Springer, 2012.

[16] B. Michelberger, B. Mutschler, M. Hipp, and M. Reichert, *Determining the Link and Rate Popularity of Enterprise Process Information*. in: Proc 21st Int'l Conf on Cooperative Information Systems (CoopIS'13), pp. 112-129, 2013.

[17] B. Michelberger, B. Mutschler, and M. Reichert, *A Context Framework for Process-oriented Information Logistics*. in: Proc 15th Int'l Conf on Business Information Systems (BIS'12), LNBIP 117, pp. 260–271, Springer, 2012.

[18] J. Wurzer and B. Mutschler, *Bringing innovative Semantic Technology to Practice: The iQser Approach and its Use Cases*. in: Proc 4th Int'l Workshop on Applications of Semantic Technologies (AST'09), LNI 154, pp. 3026–3040, 2009.

[19] B. Michelberger, R.-J. Andris, H. Girit, and B. Mutschler, *A Literature Survey on Information Logistics*. in: 16th Int'l Conf on Business Information Systems (BIS'13), LNBIP 157, pp. 138-150, Springer, 2013.

[20] R. Pryss, D. Langer, M. Reichert, and A. Hallerbach, *Mobile Task Management for Medical Ward Rounds - The MEDo Approach*. in: Proc. 1st Int'l Workshop on Adaptive Case Management (ACM'12), BPM'12 Workshops, LNBIP 132, pp. 43–45, Springer, 2012.

[21] H. Reiterer and T. Büring, *Zooming Techniques*. Ency of Database Systems, pp. 3684–3689, 2009.

[22] J. J. V. Wijk and W. A. A. Nuij, *Smooth and Efficient Zooming and Panning*. in: Proc 9th Conf on Inf Visualization (INFOVIS'03), pp. 15–22, IEEE, 2003.

[23] D. Müller, M. Reichert, and J. Herbst, *A New Paradigm for the Enactment and Dynamic Adaptation of Data-driven Process Structures*. 20th Int'l Conf on Advanced Information Systems Engineering (CAiSE'08), LNCS 5074, pp. 48–63, Springer, 2008.

[24] V. R. Basili *et al.*, *Experimentation in Software Engineering*. in: J IEEE Trans Software Engineering, pp. 733 – 743, 1986.

[25] N. J. Juzgado and A. M. Moreno, *Basics of software engineering experimentation*. Kluwer, 2001.

[26] V. Someren, M. W., Barnard, Y. F., and J. Sandberg, *The Think Aloud Method: A Practical Guide to Modelling Cognitive Processes (Knowledge-Based Systems)*. Academic Press, 1994.

[27] H. Coolican, *Research Methods and Statistics in Psychology*. Routledge, 2009.

[28] G. A. Langenwalter, *Enterprise Resources Planning and Beyond: Integrating Your Entire Organization (Resource Management)*. CRC Press, 1999.

[29] E. J. Umble, R. R. Haft, and M. Umble, *Enterprise resource planning: Implementation procedures and critical success factors*. in: European J of Operational Research, 146(2), pp. 241–257, 2003.

[30] K. Kosanke, F. Vernadat, and M. Zelm, *CIMOSA: enterprise engineering and integration*. in: J Computers in Industry, 40(2-3), pp. 83–97, 1999.

[31] F. Vernadat, *Enterprise Modeling and Integration*. Springer, 1996.

[32] R. Bobrik, M. Reichert, and T. Bauer, *View-Based Process Visualization*. in: 5th Int'l Conf on Business Process Management (BPM'07), pp. 88–95, 2007.

[33] S. Smirnov, *Business Process Model Abstraction*. PhD Thesis, Business Process Technology, HPI, Potsdam, 2012.

[34] J. Kolb, M. Reichert, and B. Weber, *Using Concurrent Task Trees for Stakeholder-centered Modeling and Visualization of Business Processes*. in: Proc S-BPM ONE 2012, CCIS 284, pp. 237–251, 2012.

[35] J. Kolb, K. Kammerer, and M. Reichert, *Updatable Process Views for User-centered Adaption of Large Process Models*. in: Proc 10th Int'l Conference on Service Oriented Computing (ICSOC'12), LNCS 7636, pp. 484–498, Springer, 2012.

[36] S. Kabicher-Fuchs, S. Kriglstein, and K. Figl, *Timeline Visualization for Documenting Process Model Change*. in: Proc 5th Int'l Workshop on Enterprise Modelling and Inf Sys Architectures (EMISA'12), CCIS 284, p. 237–251, Springer, 2012.

[37] B. B. Bederson, J. Meyer, and L. Good, *Jazz: An Extensible Zoomable User Interface Graphics Toolkit in Java*. in: Proc 13th ACM Symposium on User Interface Software and Technology (UIST'00), pp. 171–180, 2000.

[38] W. A. König, R. Rädle, and H. Reiterer, *Squidy: a zoomable design environment for natural user interfaces*. in: Proc 27th Int'l Conf on Human Factors in Computing Systems (CHI'09), pp. 4561–4566, ACM, 2009.

[39] M. Zöllner, H.-C. Jetter, and H. Reiterer, *ZOIL: A Design Paradigm and Software Framework for Post-WIMP Distributed User Interfaces*. in: 1st Workshop on Distributed User Interfaces (CHI'11), HCI Series, pp. 87–94, 2011.

[40] F. Gundelsweiler, T. Memmel, and H. Reiterer, *ZEUS - Zoomable Explorative User Interface for Searching and Object Presentation*. in: Proc Symposium on Human Interface (HCI'07), LNCS 4557, pp. 288–297, Springer, 2007.

[41] P. Effinger, *A 3D-Navigator for Business Process Models*. in: Proc 1st Int'l Workshop on Theory and Applications of Process Visualization (TAProViz'12), LNBIP 132, pp.737–743, Springer, 2012.

[42] S. West, R. A. Brown, and J. C. Recker, *Collaborative business process modeling using 3D virtual environments*. in: Proc 16th Americas Conference on Information Systems: Sustainable IT Collaboration around the Globe, Association for Information Systems (AIS), 2010.

[43] R. A. Brown and R. K. Rasmussen, *Virtual environment visualisation of executable business process models*. in: J on Virtual Technologies for Business and Industrial Applications: Innovative and Synergistic Approaches, pp. 68–87, BSR, 2010.

[44] A. Seyfang, K. Kaiser, T. Gschwandtner, and S. Miksch, *Visualizing Complex Process Hierarchies during the Modeling Process*. in: Proc 1st Int'l Workshop on Theory and Applications of Process Visualization (TAProViz'12), LNBIP 132, pp.768–779, Springer, 2012.

[45] B. Shneiderman, *Tree visualization with Tree-maps: A 2-d space-filling approach*. in: J ACM Transactions on Graphics, 11, pp. 92–99, 1991.

[46] K. Misue and S. Yazaki, *Panoramic View for Visual Analysis of Large-Scale Activity Data*. in: Proc 1st Int'l Workshop on Theory and Applications of Process Visualization (TAProViz'12), LNBIP 132, pp.756–767, Springer, 2012.