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Process Modeling and Problem Solving: Connecting Two Worlds by BPMN

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Abstract**—**Business Processes (BPs) are the key instrument to understand how companies operate at an organizational level, taking an *as-is* view of the workflow, and how to address their issues by identifying a *to-be* model. In last year's, the BP Model and Notation (BPMN) has become a *de-facto* standard for modeling processes. However, this standard does not incorporate explicitly the Problem-Solving (PS) knowledge in the Process Modeling (PM) results. Thus, such knowledge cannot be shared or reused. To narrow this gap is today a challenging research area. In this paper we present a framework able to capture the PS knowledge and to improve a workflow. This framework extends the BPMN specification by incorporating new general-purpose elements. A pilot scenario is also presented and discussed.

Keywords**—**Business Process Management, BPMN, Problem Solving, Process mapping.

I. Introduction

PROBLEM SOLVING (PS) strategies in engineering are applied when products or processes fail, to take corrective actions and then preventing further failures. PS can also be applied to a product or process prior to an actual fail event. For instance, when a potential problem can be predicted, analyzed, and mitigation applied to avoid new occurrences of it. To support the improvement of processes methodologies, many techniques and tools has been developed [1], [4], [5], together with a number of languages specifications for describing processes or workflows [4], [6]. Such languages represent a workflow on the basis of its control structure (i.e., where the execution control of the activities is defined) and its participants (i.e., which agents execute the workflow activities). However, these approaches do not incorporate explicitly the PS knowledge in the workflow definition: this knowledge is implicitly used and then it cannot be shared or reused. For dealing with this drawback, workflows need to be specified as a view at the knowledge level.

In this paper a framework, which captures the PS knowledge used to define and execute a workflow, is developed and proposed. The framework extends the Business Process Model and Notation (BPMN) [8] specification, by incorporating new executable components. More specifically, the proposed BPMN-PS approach supports the conventional three phases used in workflow modeling [1]–[3]:

1: *Frame the process:* to develop an overall process map, the so-called "landscape", clarifying what is in and what is out of scope; to establish the scope of the target process to be studied; to perform an initial process assessment; to determine the process goals and performance objectives.

2: *Understand the current (as-is) process*: to map the current process workflow; to document important observations about all enablers;

3: *Design the new (to-be) process*: to characterize the to-be process; to design the to-be workflow.

Fig. 1 represents the three-phases via a BPMN diagram. Here, a circle represents an *event*, denoting something that happens, whereas a rounded-corner rectangle with a plus sign against the bottom line represents a *sub-process*, describing the kind of work at a high level of business process detail. Finally the *sequence flow* is represented by a solid black-headed arrow, showing the source and target work units and how the work is flowing.

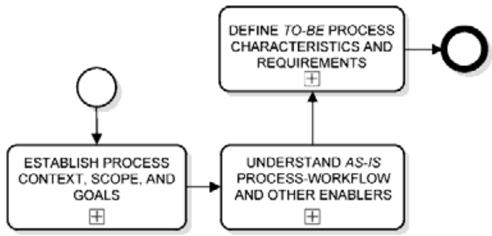

Fig. 1 A BPMN diagram representing the conventional three-phases used in workflow modeling

An overall ontological view of our BPMN-PS approach is depicted in Fig. 2, where concepts (enclosed in ovals) are connected by properties (represented by black arrows) or by specialized properties (the general-to-specific property, represented by white arrows). The right side of the diagram pertains to process modeling, where solutions to problems are represented. Here, a *business process* is aimed at delivering *products or services* which can have a *problem*. A problem is characterized by an *as-is business process* and solved by a *to-be business process*. A business process can be mapped by a *workflow*, expressed as a *BPMN model*, which in turn can be deployed and executed by means of a Business Process Management (BPM) platform. The left side of the diagram pertains to PS, where knowledge generating solutions to problems is represented. In our BPMN-PS approach the PS knowledge is defined by means of six *enablers*, i.e., central factors that determine how the process (mis-)behaves [3].

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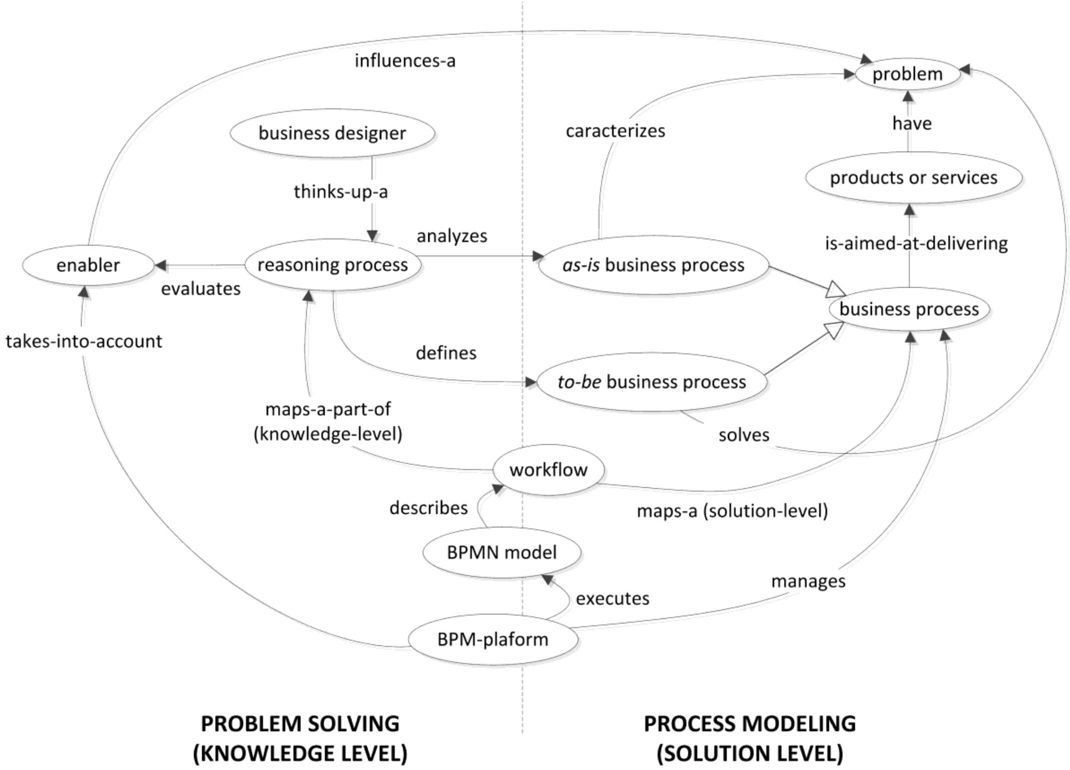

Fig. 2 An ontological view of our problem-solving approach (BPMN-PS)

As such, an *enabler* can influence a p roblem. More specifically for each enab ler a method details th e *reasoning process* (thought up by a *business designer*) able to anal yze the *as-is process* and to define the *to-be process*. Such reasoning process can be partially modeled by BPMN, deployed and executed by means of a BPM platform. The BPM platform takes into account each enabler thus supporting the reasoning process. Thus, the BPM pl atform acts as an infrastructure for the execution of knowledge-enriched workflows [4], [7].

The paper is structu red as f ollows. In Sectio n II, a conceptual framework for process enab lers is specified. Section III defines our BPMN extension for supporting PS. In Section IV t he details of a supporting IT infrastructure are reported. Section V describes a pilot scenario to show an actual application of the proposed approach. The m ain strengths and weaknesses of the BPMN-PS ar e discusses in the conclusive section.

II. A Conceptual Framework for Process Enablers

An *enabler* is a factor that can be adjusted to impact process performance. Much of the work o f process modeling and analysis is directed at finding the cases where the enablers are hindering the process, in order to improve it appropriately [2].

Fig. 3 repr esents an Ishikawa fishbone diagram of the six enablers influencing a business process. The co mplete framework includes six enablers:

A. workflow design;
B. information systems;
C. motivation and measurement;
D. human resources;
E. policies and rules;
F. facilities.

Enablers are how we make the process working. No process will work optimally until all the enablers are correctly acting. For instance, improvements in workflow design and information systems will ha ve little i mpact if personnel are untrained (an aspect of the h uman-resources enabler) or are not motivated by appropriate measures and rewards (an aspect of the motivation-and-measurement enabler). Each enabler addresses a specific aspect of the total process, which can be assessed by means of Critical-To-Quality (CTQ) characteristics, as detailed in next subsections.

A. Workflow-Design Enabler

The process workflow design shows the sequence of steps, decisions, and handoffs carried out by the process participants between the i nitial event and the final result. A participant could be a person, an organization, an information system, a piece of machinery, or anything else that "holds the work" [1]. Having a wo rkflow model supports also the asses sment the other enablers in an organized fashion, step by step and actor by actor. Table I shows some example of important CTQ characteristics of the workflow-design enabler.

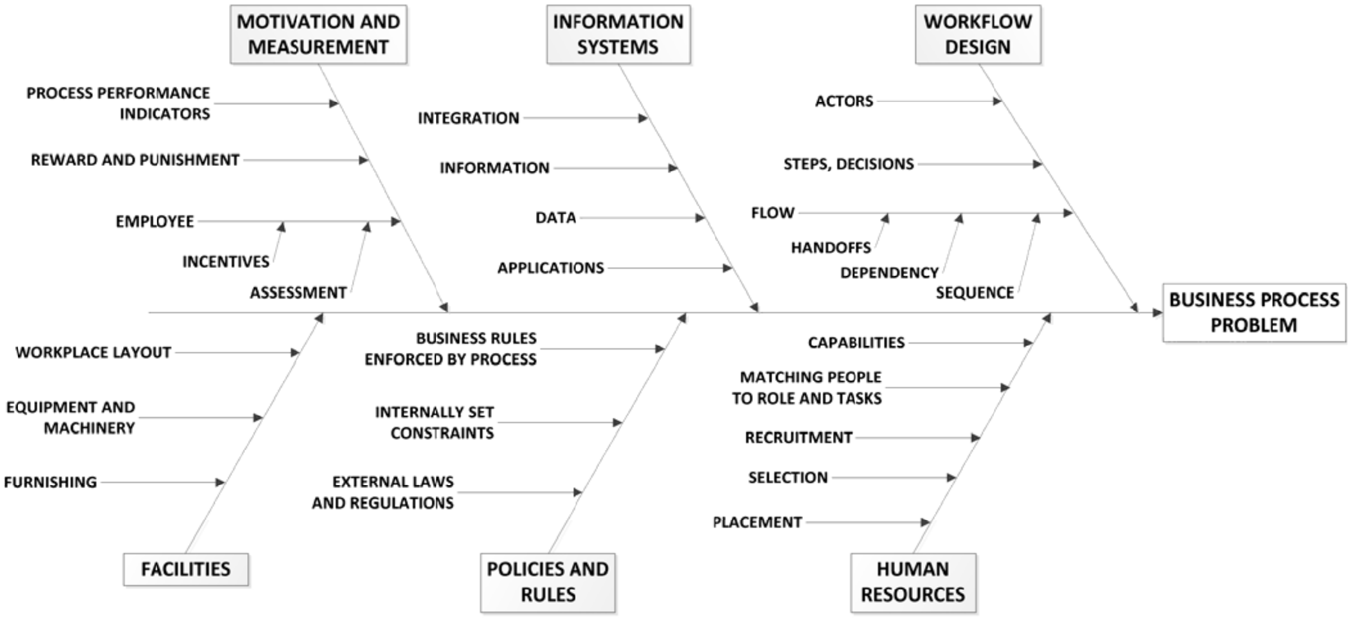

Fig. 3 An Ishikawa fishbone diagram of the six enablers influencing a business process

TABLE I
EXAMPLES OF CTQ FOR THE WORKFLOW-DESIGN ENABLER

Quantity to assess	Example of CTQ
Adding value	Steps that are not adding value
Number of approvals	Too many approval/inspection steps interfering with the main flow Too many handoffs Escalating approval of information loop
Duplication	Activities duplicated by different actors throughout the process Non critical steps holding up the main flow, rekeying information or reconciling different sources
High delay, error, expense	Delay, error, expense in the transport of work or handoff between actors
Sequential steps	Flow excessively sequential when steps could be done in parallel
Resources per task	Too many actors doing minor tasks that could be easily be handled by one of them
Bottleneck	Under-resourced steps Role that coordinates other roles or tasks
Exception occurrence	Exceptions occur too frequently
Roles definition level	Roles are poorly defined, leading to confusion about who is responsible for what
Cause-effect separation	Work and inspection are not separated: delay, rework of intermediate steps, poor learning

B. Information-Systems Enabler

Information systems include platforms, applications, and databases that provide specific capabilities and that are managed and referred to as a whole, such as a booking system or a reverse logistics system [2]. Information systems enable a process by automating or supporting steps, capturing or presenting information, or managing and expediting the workflow. Increasingly important is the role of a business process management system (BPMS), which provides many capabilities for the execution, monitoring, and management of business processes as t hey flow through multiple systems. Table II shows some example of important CTQ characteristics of the Information-system enabler.

TABLE II
EXAMPLES OF CTQ FOR THE INFORMATION-SYSTEMS ENABLER

Quantity to assess	Example of CTQ
Data quality	Quality data maintained in the data management layer
Information accuracy	Useful information captured from and presented to each step receiving automated support
Importance of activity	Important activities are automated or receive automated support
Importance of functionality	Important functionalities are in place and available as services
Usability	User interfaces, reports, queries, are appropriate for the task and the user
Service availability	Services available to the right user interfaces (browser, mobile phone, kiosk, etc.)
Automation level	Flow of work is automated wherever possible and appropriate
Monitoring level	Flow of work is actively monitored to deal with errors and exceptions
Traceability	There is no a tracking mechanism Process undocumented

C. Motivation-and-Measurement Enabler

Motivation and measurement comprise the explicit and implicit reward systems of the organization. Their concern is how people, organizations, and processes are measured, assessed, and rewarded. Experience shows that people do what they are measured on and rewarded for, and if the measures do not align with the goals of a redesigned process, failure is virtually certain [3]. A frequent problem is that performance targets are badly designed, and then encourage people and organizations to behave against the actual goals of the process. Table III sh ows some example of important CTQ characteristics of the Motivation-and-measurement enabler.

D. Human Resources

The human-resource enabler covers th e knowledge, skills, and experience of the w orkforce, how they are recruited, trained, and assigned within the organization, the design of the organization and individual jobs, and so on [2]. A process requires the right people with the right skills in the right job. Important problems occur when the wrong people have responsibility for critical tasks. A very bad case is when expensive professional staff does work that could be performed better, at lower cost, by clerical, administrative, or support staff. TABLE IV shows some example of important CTQ characteristics of the Human-resources enabler.

TABLE III
EXAMPLES OF CTQ FOR THE MOTIVATION-AND-MEASUREMENT ENABLER

Quantity to assess	Example of CTQ
Number of advertise orders	Sales representatives are measured and rewarded for the number of order that they get
Non monetary measures Responsibility level Pressure level	Incentives to customer service representatives when meet new responsibilities and under higher pressure
Number of discovered defects	Quality Control group is measured on the number of defects they discovered
Uncooperative attitude	Poor attitude of people to corporative plans

TABLE IV
EXAMPLES OF CTQ FOR THE HUMAN-RESOURCES ENABLER

Quantity to assess	Example of CTQ
Attitude, skills	Hire for attitude, then train for skills
Correspondence salary-to-type of work	Scarce resource of highly paid employee doing clerical/support work
Abilities to an intended role	The Peter principle: the selection of a candidate for a position is based on his performance in the current role rather than on the abilities relevant to the intended role
Level of handoff Level of division of responsibility	A reorganization introduces segmentation leading to excess of handoffs and division of responsibility
Skill dilution	Skill dilution from excessive specialization and fragmentation

E. Policies and Rules

This enabler includes the rules and policies established by the enterprise to guide or constrain business processes, as well as applicable laws and regulations [9]. Many problems occur when additional work is included to enforce obsolete, contradictory, or overly complex rules or regulations. Other problems occur when policy are poorly documented, because assumptions have been perpetuated over time. Table V shows some example of important CTQ characteristics of the Policies-and-rules enabler.

TABLE V
EXAMPLES OF CTQ FOR THE POLICIES-AND-RULES ENABLER

Quantity to assess	Example of CTQ
Rule complexity	Requisition: over $ 1,000 must be approved by a department head, over $ 5,000 must be approved by a department head and a vice president
Rule obsolescence	A software program still executes an hard coded rule that is supposed to have ended some year ago
Missing requirements	Non conformities (concerning design, process, customer, supplier)
Maintenance effort	Reliability, Maintenance costs

F. Facilities

Facilities are the workplace design and physical infrastructure such as equ ipment, furnishings, machinery, lighting, air quality, and ambient noise [10]. There is a growing trend to recognize the importance of facilities as enablers to effectiveness, productivity, and well being. Table VI shows some example of important CTQ characteristics of the Facilities enabler.

TABLE VI
EXAMPLES OF CTQ FOR THE FACILITIES ENABLER

Quantity to assess	Example of CTQ
Space, quiet level	Too much noise and interruption of work requiring intense concentration
Privacy level	Cubicle gives no privacy, everyone can hear your conversation
Distance between collaborating people	Too much distance between people whose tasks are linked
Ventilation, glare	The physical environment is unpleasant

III. THE PROPOSED BPMN EXTENSION

In any process- based methodology quantifiable measurements must be defined, so-called Key Performance Indicators (KPIs). In the case of the PS process, KPIs should be related to CTQs and associated with enablers rather than with specific process. A KPI may have a target and allowable bounds, or low er and upper limits, forming a r ange of performance that the process should achieve [10]. KPIs can be made up of one or more CTQs. The calculated results of the metrics during pr ocess monitoring are used to determine whether the t arget of the KPI has been met. For example, waiting time, processing time, cycle tim e, process cost, resource utilization are commonly used KPIs. Choo sing the right KPIs of the PS process requires go od understanding of what is important to the organization. Business Activity Monitoring discipline attends this topic in d epth. Table II shows some of the commonly used KPIs for assessing the six enablers [9], [10].

TABLE VII
COMMONLY USED KPIS FOR ASSESSING ENABLERS

Type of measure	Example of KPIs
Counting	Total volume, total frequency Proportion of different cases Proportion of different paths (accepted versus rejected) Proportion of different results (accepted versus rejected)
Duration	Cycle time Work time Time worked Peaks and valleys in seasonal/weekly/daily variations Idle time Transit time Queue time Setup time
Respon-sibility	People (number of) Job classifications (number of) Departments (number of) Known handoffs (number of) Labor unions (number of) Locations (number of) Languages (number of) Countries and cultures (number of)
Efficiency	Percentage of scrap or rework Percentage of errors Number of non-conformities and where, which cycle How soon defects and non-conformities are discovered How much interaction to solve How many customer to complete the process How many approvals and/or complaints received

A. Core Concepts of BPMN

In order to define a BPMN extension able to allow the specification of measurement of the above KPIs, let us first introduce the basic BPMN elements. To describe business processes, BPMN offers the Business Process Diagram (BPD. A BPD consists of four basic elements categories [8]: *flow objects*, *connecting objects*, *swim lanes*, and *artifacts*, as shown in Fig. 4.

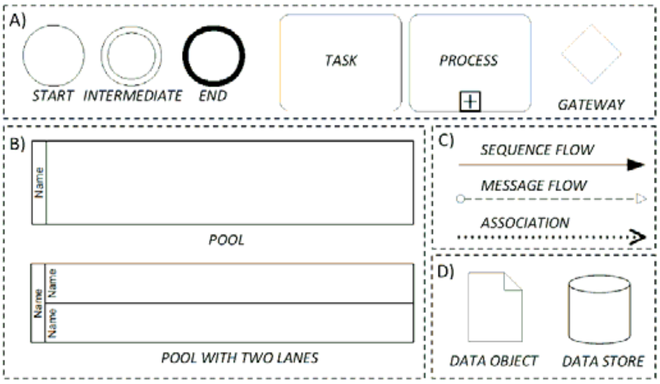

Fig. 4 Basic elements in BPMN: (A) flow objects; (B) swim lanes; (C) connecting objects; (D) artifacts

Key concepts are briefly defined in the following. *Events* are representations of something that can happen during the business process; *business flow* is activated by a *start event* and terminated by an *end event*, while *intermediate events* can occur anywhere within the flow. Business activities can be atomic (*tasks*) or compound (*processes*, as connection of tasks); *gateways* represent decision points to control the business flow. *Data objects* model any information required or provided by activities, whereas *data store* model permanent data. Connecting objects connect flow objects together: *sequence flows* show the order of execution of activities in the business process, *message flows* represent messages exchanged between business entities, and *associations* highlight inputs and outputs of activities. A *pool* represents a participant in a business process and *lanes* allow detailed categorization of activities within a pool.

B. Extended Concepts of BPMN

The proposed BPMN extension is aimed at defining the PS knowledge perspective in an event-driven workflow, by using the extension mechanism provided by the BPMN metamodel. This mechanism consists in a set of extension components which allow the attachment of additional attributes and elements to the BPMN features [8]. The UML class diagram of Fig. 5 shows the conceptual model of the proposed extension. Here, the core BPMN elements are depicted in gray color, in contrast with the extended (white) elements. In particular, the BPMN Task element is enriched (as a new Monitored Task element) with the specification of KPIs with the related conformity conditions and data sources. The extension is thus divided into two aspects (packages): the specification of a KPI, on the right, and the specification of the data sources necessary to feed the indicator, on the left. More specifically, in the *Data Source* package, a KPI can be connected to a collection of *Features*, each representing a different type of numerical or categorical data source. Indeed, the abstract class *Feature* can be specialized as a *Categorical Feature* or *Numerical Feature*, i.e., concrete classes implementing features that can assume, respectively, a categorical or numerical value. The latter is qualified by a *name*, a *value* and a *unit name* (for instance, “kg” for weight), whereas the former is characterized by a *name* and a *value*, which belongs to a set of possible values modeled by the class *Categorical Value*. Each *Categorical Value* is characterized by a *value*, a *description*, and an *ordering*. This last item can be used whenever ordered categorical values are needed. This class organization allows dealing uniformly with the most quality features.

In the *Conformity Condition* package, a *Key Performance Indicator* is characterized by a *name* and a *value*, and should be associated to a *Target*. More specifically, a *Target* represents a desired range of values. A *Numerical Target* and a *Sortable Categorical Target* are defined in terms of *lower* and *upper bounds*, whereas a *Non-sortable Categorical Target* is defined in terms of allowed values. In all cases, a value of the KPI which is not within bounds or within the allowed values causes the conformity condition to fail, thus triggering a BPMN exception.

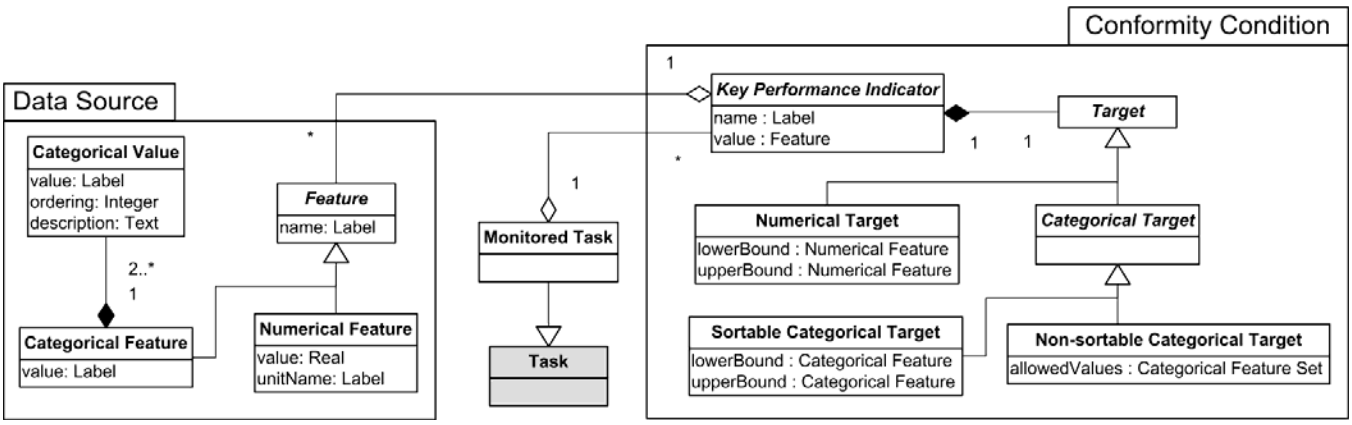

Fig. 5 The conceptual model of the proposed BPMN extension

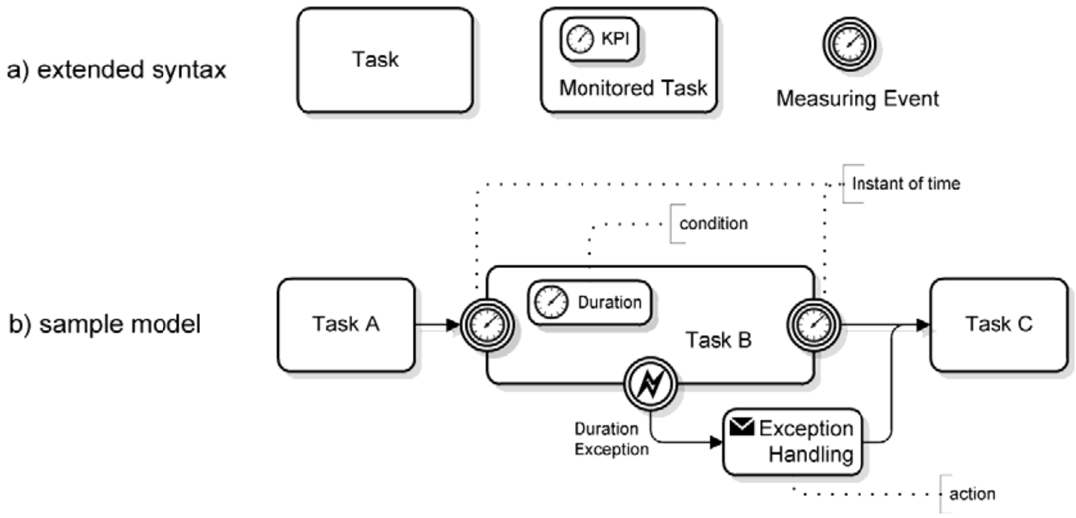

Fig. 6 The extended syntax of the proposed BPMN extension

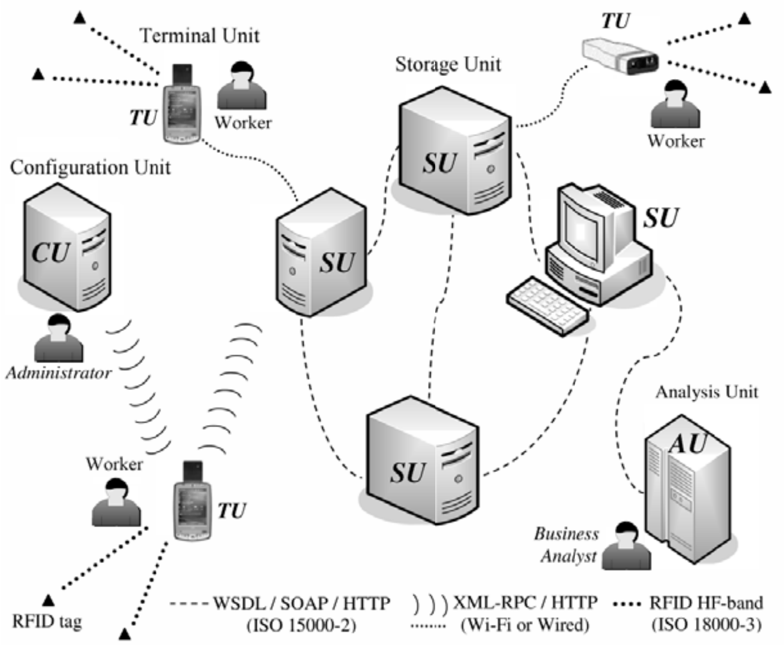

Fig. 7 An example of supporting IT infrastructure

In order to create graphical models with the extended BPMN, the extended syntax has to be specified by providing visual representations, i.e., graphical symbols and textual labels that express their behavior. The proposed notation is depicted in Fig. 6. Fig. 6 (a) shows: (i) a core BPMN Task, (ii) a Monitored Task, and (iii) a Measuring Event which can be connected to a data source. Fig. 6 (b) shows a sample of Monitored Task, which is measured in terms of total duration. The data sources are connected to the KPI via two measuring events attached at the beginning and the end of the activity. Each event provides the instant of time. In case of a KPI value which does not satisfy the conformity condition, a duration exception event is triggered, and an exception handling activity can be executed, as the corresponding action.

IV. A Supporting IT Infrastructure

The strength of BPMN resides in two important aspects: First, its simplicity which is due to the abstraction level provided by the standard. Second, the possibility of being translated (in an automatic manner) into a business execution language, and then to generate a machine-readable prototype of business processes [11]. Indeed, BPMN is supported with an internal model that enables the generation of executable programs in Web Service Business Process Execution Language (WSBPEL), a language for specifying business process behavior based on web services. Thus, BPMN represents a standardized bridge for the gap between the business process design and implementation.

In this section, we introduce an IT infrastructure to support our PS approach. To this aim, let us consider the architectural view shown in Fig. 7. Here, different Terminal Units (TU) are comprised, equipped with RFID readers, to serve as data source. Indeed, a TU gathers data and transmits them to a Storage Unit (SU). SUs keep data supplied by TUs, according to defined KPIs. Analysis Units (AUs) harvest data supplied by SUs and compute the KPIs. TUs can be hosted by a mobile device (e.g., PDA or smart phone equipped with an RFID reader), or fixed device (e.g., bank reader, door gate reader). TUs are configured on the basis of the deployed BPMN model, via some Configuration Units (CUs). CUs contain also the definitions of the quality features requested by AUs. Thus, for instance, when quality attributes have to be inserted, the TU is automatically configured by the corresponding CU so as to show appropriate interface widgets.

The presented IT infrastructure is based on a distributed architecture in which data is managed according to a "pull" model, in which data is stored according to computation of particular KPIs. According to the service-oriented paradigm, the communication between SUs and AUs relies on an asynchronous message-centric protocol, which provides a robust interaction mechanism among peers, based on the SOAP/HTTP stack (ISO 15000-2). On the other hand, the communication between TU and the other units can be proficiently achieved using a more efficient and lightweight XML-RPC/HTTP based interaction. Finally, the communication between RFID readers and tags is based on the EPC standard (e.g., ISO 18000-3) [12].

V. A Pilot Scenario

To show an example of our PS approach, in this section we introduce an excerpt of a Wine Production process taken from a real-world case study. To this purpose, we take the perspective of a wine manufacturing company that provides products on stock and operates in a business-to-business supply chain environment. Fig. 8 represents the macro processes in BPMN language, for two distinct lanes: raisin and white wine. More specifically, the start event in the *Raisin Wine Processor* lane indicates that the process starts at the half of August (timing event). Then, three activities are performed on the grasp: *early harvesting*, *sun-withering*, and *storage in wooden boxes*. The second activity is characterized by a duration of 20-30 days (lower and upper bounds, respectively). The start event in the *White Wine Processor* lane indicates that the process starts in September-October (the period of vintage) and performs four activities on the grasp: *harvesting*, *crushing*, *maceration* and *pressing*. The third activity is characterized by a duration of 24-48 hours (lower and upper bounds, respectively). At this point, in the *Raisin Wine Processor* lane the raising wine-must is mixed with part of the white wine-must to allow the subsequent activity: *maceration in base-must*, during the next 30-40 days.

Subsequently, the base-must is processed by *fermentation*, *pressing* (at 4-5°C) and *decantation*. Then, it is mixed with the white wine-must, which in the meanwhile has been processed, in turn, by *fermentation* (with 50 gr./hl of Bentonite) and *clarifying*. The mixed-must is later processed via *aging* (36-42 months) and *bottling*. Finally, *quality check and packing* activity is carried out, including the control of the color intensity of the raisin wine, which should be between 5.3 and 6.6 in (intensity). The end event indicates where the process ends and where final product is made. Fig. 9 shows the packing room (on the left) and two IT devices used to collect data source: an RFID reader for tracking the instant of time when each box is completed (on the top-right), and a mobile device to report non conformities related to the *quality check and packing* task. Fig. 10 shows the BPMN extended data objects related to two KPIs of the *quality check and packing* task: Average Wine Rating and Average Color Intensity. The former is a sortable categorical feature, ranging from "one star" to "five star" and expressing the quality of the wine, whereas the latter is a numerical feature. The target values of the features are four-five stars and 5.3-6.6 in, respectively.

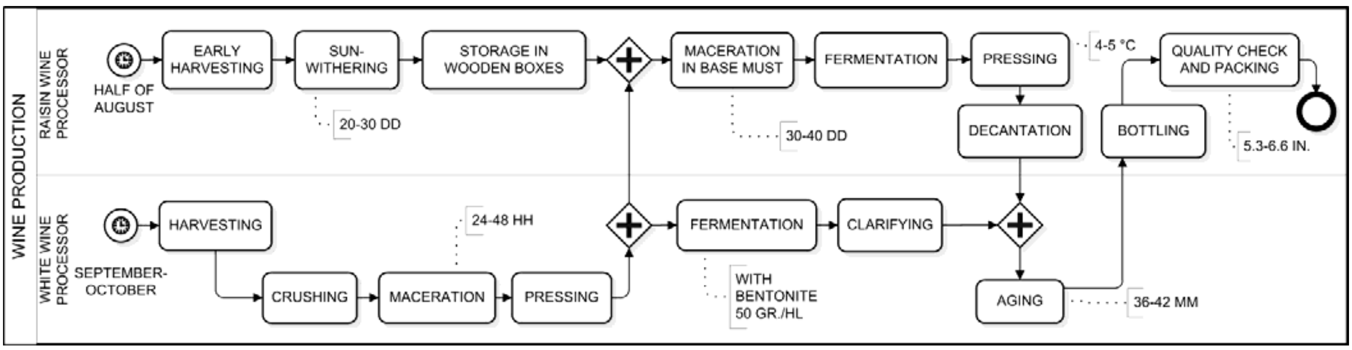

Fig. 8 The Wine Production process sample

Fig. 9 Wine Production process: the packing room (on the left) and some RFID-based IT device for data sourcing

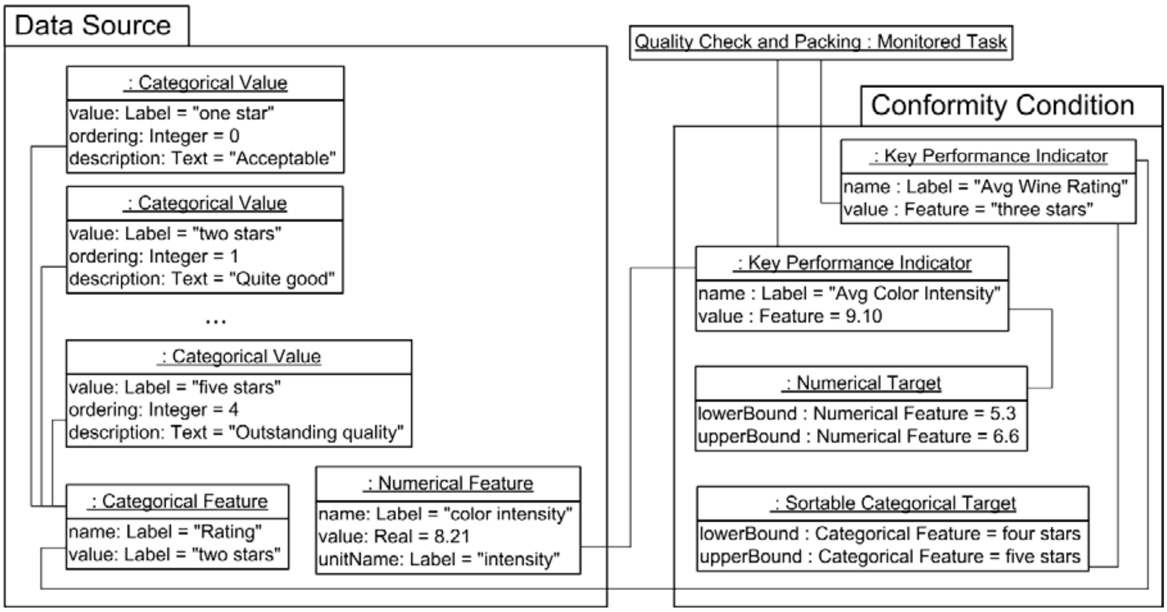

Fig. 10 Wine Production process: objects related to two KPIs of the “Quality check and packing” activity

Under the above conditions, the following pilot scenario shows how the Wine Production Company can be supported by our BPMN-PS approach:

I. The indicator “Rating”, modeled in Fig. 10, is the main process performance, i.e., the main KPI. We can assume that rating lower than “four stars” is the problem.
II. In order to monitor the factors that can be adjusted to impact this kind of problem, all the enablers have been considered and prioritized in terms of CTQs.
III. The prior KPIs connected with the above CTQs are the following: duration of the *sun-withering*, *maceration*, *fermentation (white wine must)*, *maceration in base must*, and *aging* activities; temperature of the *decantation* activity; quantity of Bentonite in the *fermentation* activity. See Fig. 8.
IV. Each KPI has been modeled in terms of data sources and conformity conditions, on the basis of the lower and upper bounds specified in Fig. 8, as in the sample of Fig. 10.
V. The workflow of Fig. 8 has been enriched with PS knowledge, which comprises conditions and related actions, as in the sample of Fig. 6.
VI. Each KPI, together with the related conformity conditions and actions, are deployed on the Configuration Unit (See Fig. 7).
VII. The Configuration Unit enables the related Terminal Units and Storage Units to gathers and record source data on the

process. The related Analysis Unit calculates the KPIs.

VIII. A problem occurs with some lots at the *Maceration in base- must* task: it lasts 26 days, i.e., lower than the bound.

IX. A related exception handling task sends a message to the Business Analyst for each non conformity. Let us imagine that no actions are performed at this time.

X. After some months, a problem occurs at the *Quality Check and Packing* task: the rating of some lots is "two stars" because of the poor color intensity of the wine (value lower than the bound).

XI. A related exception handling task sends a message to the Business Analyst for each non conformity.

Hence, in the above scenario, the system alerts the Business Analyst to two non conformity conditions. Such conditions are connected in terms of cause-effect and represent a fundamental aid for the reasoning process (see Fig. 2). Thus, the to-be business process design can be proficiently driven by the knowledge provided by the system.

VI. Conclusion

The above pilot scenario has been a first realization of the proposed BPMN-PS method, and demonstrated its potential of being used. More specifically, the main strengths of the approach are: (i) the expressiveness of the BPMN extension, supporting the definition of event triggered when types of KPIs exhibit critical values, as well as the specification of reactions to be taken in terms of workflow; (ii) the agile execution of such enriched workflows, deployed from the high-level BPMN extended models to a service-oriented IT infrastructure. However, the presented approach is subject to two main limitations: (i) the PS knowledge should be expressed at the handoff and service level of a workflow, i.e., at the core of the workflow modeling. Domain specific (task level) knowledge could be very expensive to be managed in terms of total life-cycle of the approach; (ii) due to the strict focus on BPMN, only process-related KPIs can be easily expressed. Other categories of KPIs which might also be of interest (e.g., financial) cannot be tested. Thus, external data which is not handled within a business process cannot be used for the definition of measures.

To model more complex cause-effect relationships in the workflow perspective is considered a key investigation activity for future work.

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