A General Solution for Business Process Model Extension with Cost Perspective based on Process Mining

Dhafer Thabet, Sonia Ayachi Ghannouchi, Henda Hajjami Ben Ghezala
RIADI Laboratory
National School for Computer Sciences
Mannouba, Tunisia
e-mail: dhafer.thabet@isetso.rnu.tn, sonia.ayachi@isgs.rnu.tn, henda.benghezala@ensi.rnu.tn

***Abstract*—Several organizations look for improving their business processes in order to enhance their efficiency and competitiveness. Business process management approach includes techniques allowing continuous business process improvement. Process mining is a business process management technique allowing to extract knowledge from event logs commonly available in today's information systems. Business process model extension is a process mining technique enriching a business process model with different perspectives useful for decision making support. Furthermore, financial costs incurred during business process execution is prominent information needed for business process improvement decision making in terms of cost reduction. We propose a solution for business process model extension with cost perspective based on process mining. The solution is based on cost extension of the high-level process structure, which is a meta-model enabling the integration of different perspectives into one model independently of its notation. However, the cost extension is designed only at the activity level and the general approach needs to be validated. In this paper, on one hand, we propose an improved version of the proposed approach providing cost extension including cost data description and analysis at both activity and business process levels, and on the other hand, we present implementation and tests of the improved solution on three simplified business process model notations: Petri Net, Event-driven Process Chain and Business Process Model and Notation.**

Keywords-Business Process Management; Business Process Improvement; Process Mining; Business Process Model Cost Extension; Cost Extended High Level Process Structure.

I. INTRODUCTION

The main concern of several organizations is to enhance their efficiency and competitiveness [3]. The Business Process Management (BPM) approach aims at, continuously, improving organizations' business processes [1][22]. The Process Mining (PMining) technique is used to analyze business processes based on event logs commonly available in today's information systems [1][22]. Event logs can be used to conduct three types of PMining [13][23][28]: (1) discovery: produces a BP model using event logs; (2) conformance: an existing process model is compared with the corresponding event logs to identify the eventual deviations; (3) enhancement: includes two sub-types: repair (improving the model to better reflect reality) and extension. The latter type allows to enrich the BP model with additional perspectives useful for BP improvement decision making support (examples: organizational, case and time perspectives).

Furthermore, organizations look to reduce the financial costs incurred during the execution of their business processes using different techniques. Management Accounting (MA) is the field defining how cost (and other information) should be used for planning, controlling, continuous improvement and decision making [10][30]. It includes several techniques such as: Activity-Based Costing/Management (ABC/M) [10][30]; Time-Driven ABC (TDABC) [14]; and Resource Consumption Accounting (RCA) [7][21]. The goal of these techniques is to measure costs incurred during process execution and to allocate them to the BP operations.

In order to facilitate access and interpretation of cost information for decision makers, it would be interesting to have these information associated to the corresponding BP model. Indeed, this enables decision makers to easily obtain accurate cost information about their business processes. Thus, we considered the issue of BP model extension with cost information based on PMining extension technique. In [24][25], we started by studying this issue for business processes modeled with Petri Nets. Thus, we proposed an approach and its implementation for Petri Net cost extension based on PMining extension technique. Furthermore, in [27], the proposed solution was improved according to recommendations we drew from interviews we conducted with experts in MA. Moreover, in [28], we proposed a generalized version of the proposed approach in order to make it independent of the BP modeling notation (not only Petri Nets).

The main research goal is BP model extension with cost perspective using PMining extension technique in order to support decision makers in their improvement decisions for cost reduction. The solution we proposed in [24][25] ensures a Petri Net model cost extension based on PMining extension technique. In [26], we improved the proposed solution with respect to recommendations drew from interviews with experts in terms of MA. The considered improvements concern three main levels: cost data structure, cost data description and cost data analysis. Besides, in [27], we generalized the proposed approach in order to support different BP modeling notations.

However, the generalized approach provides cost extension, cost data description and analysis, only at the activity level. Thus, it would be useful for decision makers to also get insight on cost information and knowledge at the BP level. For instance, this would provide information about the activities which incurred the highest cost value among the considered BP activities. Therefore, in this paper, the considered main research question is about the way to improve the proposed approach so that it provides cost extension, cost data description and analysis at both activity and BP levels. Moreover, this paper presents an overview about the implementation as well as the tests of the improved approach on three simplified BP modeling notations: PN, EPC and BPMN.

In the remainder of this paper, we give an overview about the related works, in Section II. Section III presents the proposed solution design, implementation and tests. Finally, a summary of the contribution, its limits and the future works are presented in Section IV.

II. Related Work

The work of Nauta in [18] is a proposal of an architecture to support cost-awareness in PMining. Nauta's solution, mainly, consists in annotating the initial event log -in eXtensible Event Stream (XES) format [12] - with cost information using a cost model. The cost annotation is performed, per cost type, in the final event of each task instance. Then, the obtained cost annotated event log -in XES format- is used to create cost reports [18].

The work of Wynn et al. [32][33] was motivated by the work of Nauta. Wynn et al. proposed a cost mining framework allowing cost reports generation and cost prediction. The cost report can be customized in different ways. The cost prediction looks for cost patterns so that it would be possible to predict cost consumption of an ongoing BP case [33]. The cost prediction is performed by proposing a cost extension of the transition system approach [29] to produce a cost-annotated transition system.

The technique proposed by Conforti et al. in [5] aims at predicting faults related to three dimensions of a BP, which are time, cost and reputation. It allows process participants to make risk-informed decisions when taking part in a BP. The technique relies on risk estimator trained using data extracted from event logs. For each state of a process execution where input is required from a participant, the estimator determines the severity and likelihood that a fault will occur if that input is going to be used to carry on the process execution. The technique offers the considered participant risk-based recommendations for reducing the number of faults and their severities [5].

Although cost reports, which are produced by the solution of Nauta, are used by management accountants to have details about the costs incurred by BP execution, they are not sufficient for better decision making support. Moreover, the generation of only tabular cost reports does not facilitate decision making. In the work of Wynn et al., cost reports are generated separately from the BP model, which may not facilitate support for decision makers with no MA background. Furthermore, the proposed cost prediction is mainly based on activities and resources of the considered BP while different other attributes could influence cost values. In addition, cost prediction aims at cost reduction for the current BP case but does not support improvement decisions for the whole BP. Similarly, in the work of Conforti et al., cost-related risk prediction is used to provide recommendations supporting reduction of cost-related faults for the current BP case but not for the whole BP improvement. Besides, all of the mentioned works do not provide BP model cost extension at different levels (particularly activity and BP levels) while it is important to present BP-related cost information from different points of view. Moreover, each of these works focus on a particular type of BP models, although the diversity of BP modeling notations.

Therefore, in this paper, we propose a solution using the cost annotated event logs, produced by the solution of Nauta, in order to extend BP models with cost perspective at BP and activity levels. Besides, the proposed solution takes into account the diversity of BP modeling notations.

III. Proposed Solution

In [27], we introduced the first version of the generalized approach for BP model cost extension based on PMining. In order to provide better support for decision makers in their improvement decisions, we considered to further improve the previous version of the proposed approach so that cost extension covers the activity level as well as the BP level. Moreover, the improved solution should be implemented and tested in order to be validated. In the following, we present the improved solution design, implementation and tests.

A. Proposed Solution Design

In the following, we present an overview about the proposed approach and the adopted general meta-model allowing cost extension at activity and BP levels.

1) Proposed Approach Overview: Fig. 1 shows an overview about the proposed approach. The BP model and the corresponding cost annotated event log are the inputs of the generalized approach. The BP model is extended with cost data extracted from the cost annotated event log. Thus, the obtained output of this step is a cost extended BP model. Then, the output is graphically displayed with respect to the corresponding notation. The following step is to handle the cost extended BP model in such a way to further support decision makers in BP cost reduction. Cost data can be handled at two different levels: the activity level and the BP level.

Firstly, activity level cost data is handled whether by description or analysis for each user-selected activity. On one hand, cost data description allows decision makers to get insight about each activity of the BP model from a cost point of view. Cost description is performed using user-customizable tables and graphics. Tables are used to present cost values with respect to the user-specified options. Graphics are used to represent views of average cost values based on different factors (resource, cost types, instances) and to visualize a comparison between recorded cost values and the user-expected ones. The user-defined cost values could be provided whether by a single cost expected value or a cost expected interval representing a cost value range between expected minimum and maximum cost values. On the other hand, cost data analysis supports decision makers to find out factors influencing on incurred cost values. Two cost analysis methods are considered. The first method consists in classifying resources into two groups by comparing resource-based average cost corresponding to the selected activity with a user-defined cost value or interval. This method supports decision makers to determine resources involved in incurring higher/lower cost values than the user-expected one for the selected activity. The second cost data analysis method deals with how to support decision makers to know which activity-related attributes (resource, time and other data attributes) influence activity cost values, and how. The method is based on using Machine Learning (ML) classification algorithms [9][23][31], which allow to extract knowledge about the influence of selected attributes on activity cost values. The inputs of a ML classification algorithm are: training examples, attributes and classes. In our case, for each selected activity of the BP model, training examples are the activity instances contained in the cost annotated event log. The attributes are the activity-related ones including resource, time and data attributes. If the user provides a single expected cost value, two classes are defined: C1 (respectively C2) represents activity instances having an average cost value (cost type is selected by the user) higher (respectively lower) than a user-estimated cost value. If an expected cost interval is provided (expected maximum and minimum cost values), in addition to C1 and C2 classes, a third class C3 is added to represent activity instances having an average cost value (cost type is selected by the user) between the user-expected cost interval bounds. The outputs are the inferred structural patterns represented, for instance, in the form of a list of classification rules, which represent a simple and expressive way to understand which attributes influence cost values, and how [27].

Secondly, BP cost data can be handled with two main ways. On one hand, the first way provides BP cost data description using tables or graphics. Tables represent numeric cost data values calculated according to user-customized options (computation modes and cost types). Graphics provide cost-related views based on different factors (BP instances, activities and cost types) and are also used to represent comparisons between recorded cost values and user-defined cost value or interval. On the other hand, the second way consists in analyzing BP cost data in order to support decision makers determining factors influencing cost values at the BP level. Cost data analysis includes two methods. The first method provides statistics about BP instances that incurred costs more/less than a user-defined cost value or interval. If the user chooses to provide a single cost value, the cost data analysis consists in calculating the percentages of BP instances that incurred costs more and less than the user-defined one. If the user provides an interval (expected maximum and minimum cost values), the cost data analysis consists in computing percentages of BP instances that incurred costs higher, in and lower than the user-defined cost interval. Then, the obtained percentages are displayed textually and/or graphically. The second BP cost analysis method aims at extracting knowledge about BP-related attributes (time and other data attributes) that influence BP cost values using ML classification algorithms. The input data include training examples, which are the BP instances (traces) contained in the cost annotated event log; attributes which are BP instances-related attributes including time and (if any) other data attributes; and classes which depend on the cost expected value(s) provided by the user. If a single value is provided, two classes are generated: C1 (respectively C2) represents BP instances with average costs higher (respectively lower) than the user-expected one. If an interval is provided, a third class C3 is generated representing BP instances with average costs within the provided interval. The outputs of this method are structural patterns representing knowledge about factors that influence BP-related cost values.

2) Cost-extended High-Level Process Structure: The high-level process structure is a general meta-model designed to embed information from different perspectives into the control flow and to make them as generic and reusable as possible [23]. As our goal is to incorporate cost information into the BP model, we considered to extend the high-level process structure with the data structure representing the cost perspective. The cost extended high-level process core data structure is shown in Fig. 2 as a UML class diagram. The yellow-colored classes together with their relationships represent the high-level process structure. The HLProcess is the central class and holds the high-level information independently of the BP model type. It holds a list of process elements (HLProcessElement) such as activities (HLActivity) for the process. Besides, each high-level process element is identified using the HLID class. The HLGlobal class holds information that is globally relevant for the BP. The HLModel class enables to match the nodes of an actual BP model to their corresponding elements in the HLProcess structure. The ModelGraph class represents the actual BP model. These classes represent the common elements that will be shared by all high-level processes, regardless of whether they refer to some Petri net model, or YAWL model, etc. [23][27].

As shown in Fig. 2, the cost data structure is represented by the grey-colored classes together with their relationships. The HLProcessCost class and the corresponding relationships represent cost information at BP level. It consists of a list of process instances costs each of which is represented by the ProcessInstanceCost class. Moreover, as HLProcessCost class represents cost information at BP level, it is associated to the HLProcess class. Each process instance cost consists of a list of activity instances costs (ActivityInstanceCost class).

Each activity instance cost consists in turn of elementary costs (ElementaryCost class). Each elementary cost has a value, a currency and a cost type (CostType class). Furthermore, each process instance cost is related to a process instance (ProcessInstance class) and each activity instance cost is related to an activity instance (ActivityInstance class). The ProcessInstance and ActivityInstance classes are generalized using the abstract Instance class so that for each process instance and activity instance, we retain the resources involved in its execution (Resource class), the corresponding time information (Time class) and, if any, other related data attributes (DataAttribute class). This way, HLProcessCost class holds cost information related to the whole BP and to each one of its activities independently of the BP model notation. Thus, the cost-extended HLPS shown in Fig. 2 allows to get cost information at both BP and activity levels.

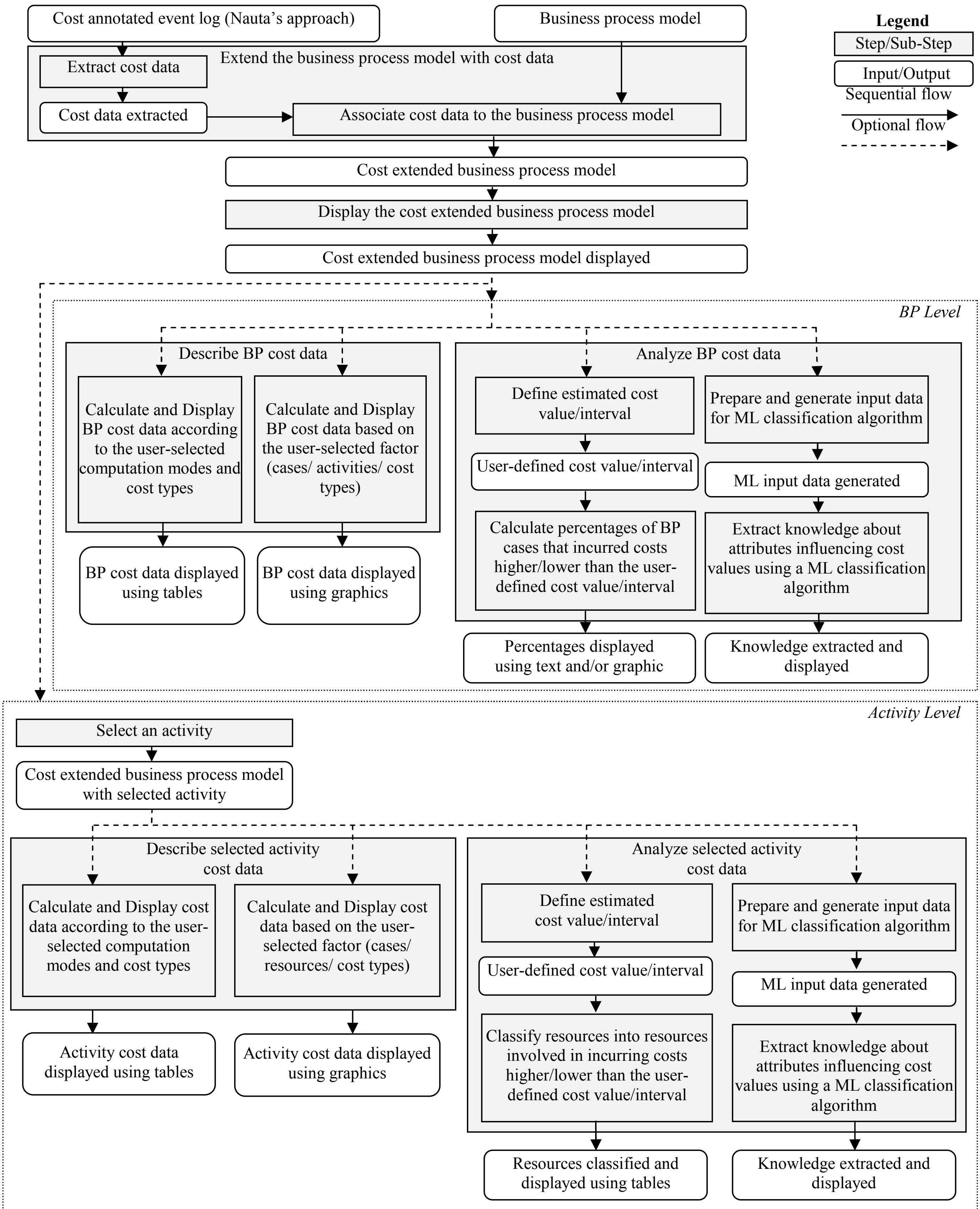


Figure 1. Improved approach overview.

B. Proposed Solution Implementation

The proposed approach is implemented as a tool for BP model cost extension. Table 1 shows the general architecture of the implemented tool. The left side column of Table 1 represents the required inputs for the implemented tool. The first input is the BP model file (PN or EPC or BPMN, etc.), which meets the corresponding meta-model (format). For this moment, the PNML [15], the EPML [17] and simplified BPMN [19] meta-models are implemented. Thus, the implemented tool supports PN, EPC and BPMN models corresponding, respectively, to the above mentioned meta-models. The second input is the corresponding cost annotated event log file, which meets XES format - the standard event log meta-model for PMining [12]. The central column of Table 1 shows the internal tool structure, which is represented by a UML component diagram. It is composed of three packages: CostExtendedHLPS, GUI and Main.

The CostExtendedHLPS package contains three sub-packages: HLProcess, HLModel and ModelGraph. The HLProcess sub-package consists of the high level process information classes and their relationships (HLProcess and related classes in Fig. 2) including cost data structure. The HLProcess sub-package uses the OpenXES plugin to import cost data from cost extended event log files. The HLModel sub-package contains the HLModel class and its sub-classes as shown in Fig. 2. The ModelGraph sub-package consists of the ModelGraph class and its sub-classes, which represent the different BP meta-models. For this moment, we implemented PN, EPC and BPMN meta-models using (respectively) the PNML framework [15], EPCTools [6] and BPMN Camunda [4] plugins. The GUI package contains all graphical user interfaces and their related classes whose role is to import input files and display processed results. Orchestration of the different packages is ensured by the Main package.

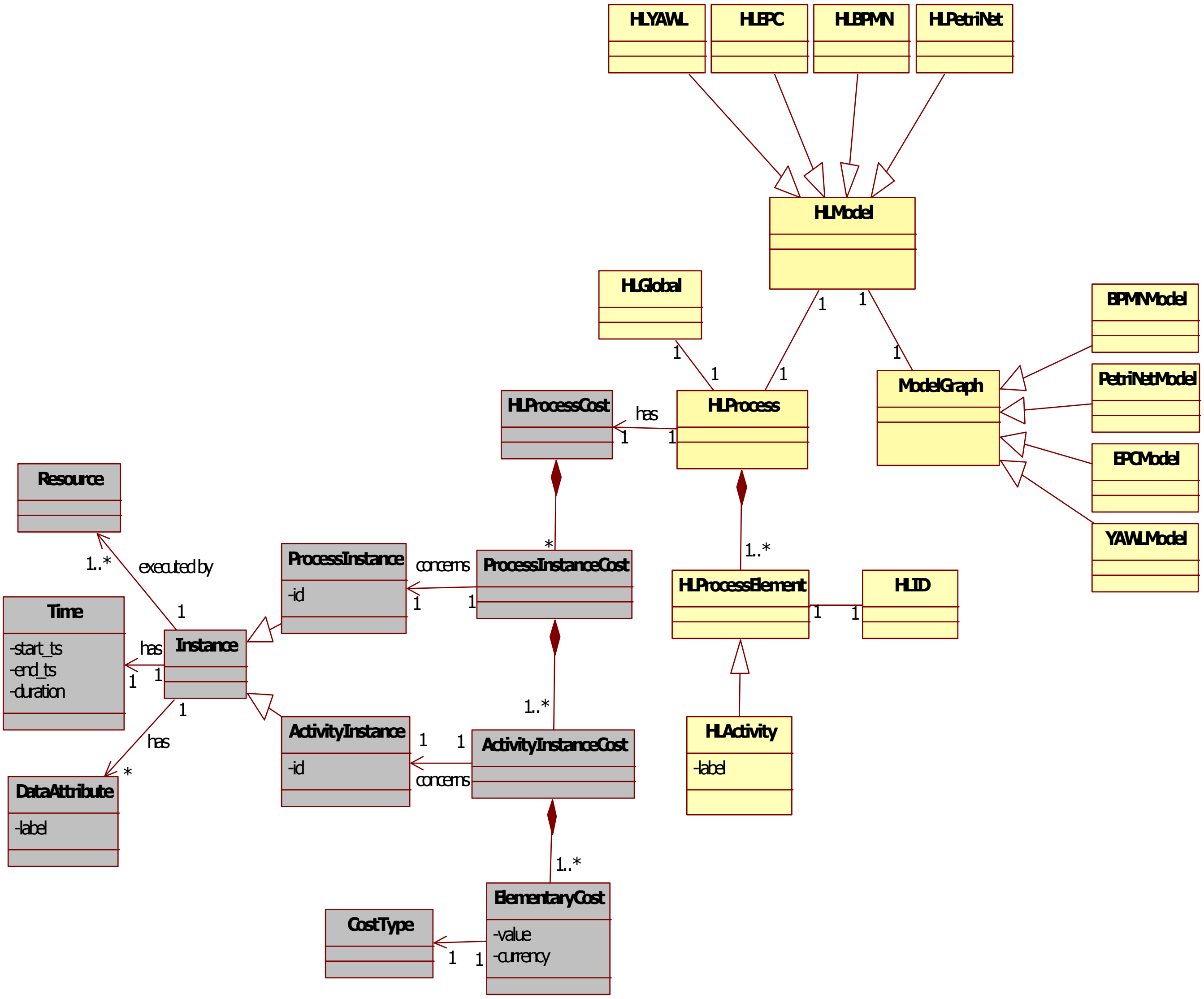
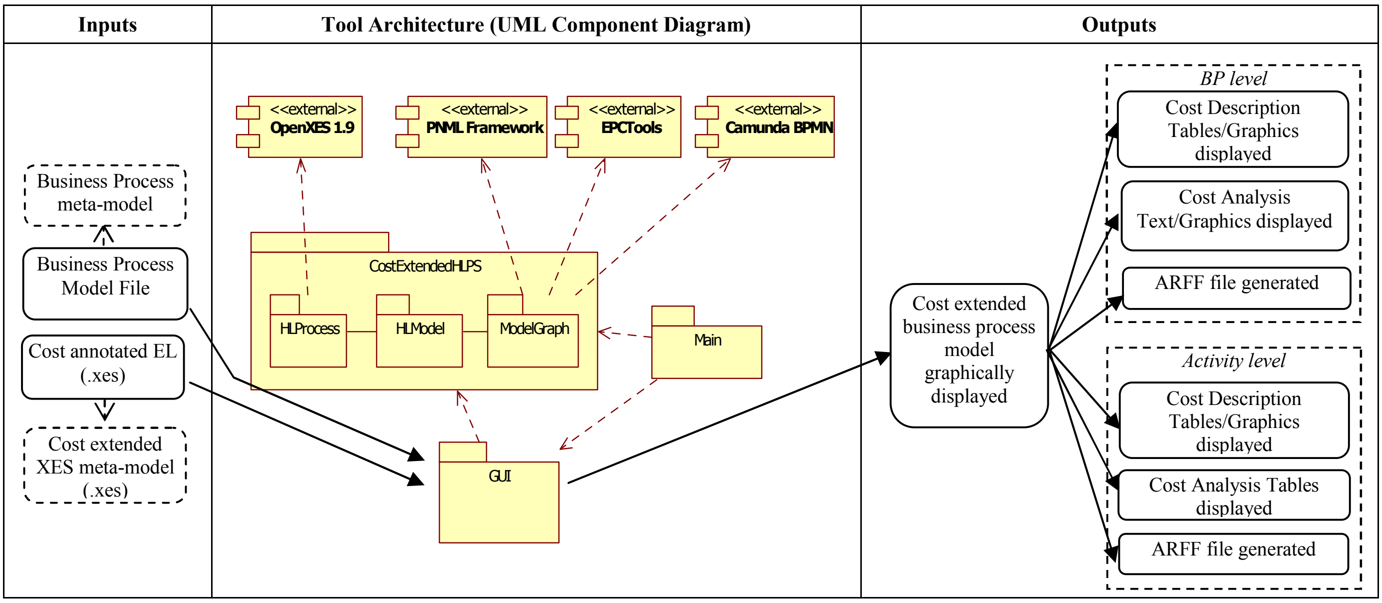


Figure 2. Improved cost-extended HLPS.

TABLE I. GENERAL ARCHITECTURE OF THE BP MODEL COST EXTENSION TOOL.



Depending on the user-selected option, the produced output concerns whether the BP level or the activity level. On one hand, the BP level outputs are computed for the whole BP and may be: (1) cost description results displayed whether with tables or graphics, or (2) cost analysis results displayed using text and/or graphics for BP instances costs statistics method and are generated as Attribute-Relation File Format (ARFF) file [31] for the ML classification-based method at BP level. Each generated ARFF file consists of attributes values and classes as presented in section III.A.1. Thus, the generated ARFF file can be easily imported into the Waikato Environment for Knowledge Analysis (Weka) system [31], which allows to pre-process the input data and provides several algorithms to apply for extracting knowledge about factors influencing cost values of the whole BP in different forms such as classification rules or decision trees. On the other hand, activity level outputs are calculated for each selected activity and may be: (1) cost description results displayed using tables or graphics, or (2) cost analysis results, which are displayed using tables for the cost-based resource classification method and are generated as ARFF files for the ML classification-based method at activity level. The generated ARFF file can be imported in Weka and classification algorithms can be applied to extract knowledge about factors influencing cost values of the selected activity.

C. Proposed Solution Tests

In order to validate the improved solution, we carried out tests using the same BP example with three different modeling notations: PN, EPC and BPMN. The test example is a simple phone repair process. The considered BP modeled with Petri Net notation is presented in [18][24]. The BP begins by the registration of the broken phone and then it is analyzed to determine the defect type. Depending on the severity of the defect, a simple repair or a complex repair is carried out. Then, the phone is tested to check whether it is fixed. If so, the repair details are archived and it is returned to the customer. If it is not fixed, the repair and then the test are restarted again. If the phone is still broken after the fifth repair test, the repair details are archived and the phone is returned to the customer. Otherwise, the customer is informed about the defect type after the defect analysis and before archiving the repair details [18][23].

This process example was already used as a test case example in Nauta's solution. We used the produced cost annotated event log (1000 cases obtained by simulation) together with its corresponding BP model (in PN, EPC and BPMN notations) as inputs for our tool test phase. In the following two sub-sections, the obtained results of the carried out tests are presented for each of the BP and the activity levels cost extensions with different BP modeling notations.

1) Tests Results of the Business Process Level Cost Extension: Fig. 3 (respectively Fig. 4) shows the obtained results after importing the BP example Petri Net (respectively BPMN) model file and the corresponding cost annotated event log file. The background frame of Fig. 3 (respectively Fig. 4) represents the main tool frame, which displays the corresponding Petri Net (respectively BPMN) model. The foreground frames of Fig. 3 illustrate cost data description at the BP level. The top left frame represents the BP level related cost description table with different computation modes (average, maximum and minimum) for all cost types (total, fixed, labour, variable overhead and material costs). The top right frame shows average total cost incurred by each activity of the BP using a pie chart indicating the activity that incurred the highest cost among them ("Repair (Complex)" activity in Fig. 3). The bottom right frame shows BP level related average cost per cost type: total cost is yellow-colored and other cost types are green-colored. The bottom left frame illustrates BP level related average cost based on BP cases together with two horizontal lines representing minimum (blue line) and maximum (green line) cost values provided by the user as the expected cost interval boundaries.

The foreground frames of Fig. 4 provide cost statistics about BP instances. As shown in the foreground left frame of Fig. 4, the selected cost type to be analyzed is "Total Cost" and the user chooses to enter an expected cost interval (500..800 AUD) instead of an expected cost value. Moreover, both textual and graphical display modes are selected. Then, when validating, BP cost statistics results are displayed. Textual results are displayed in the bottom of the foreground left frame of Fig. 4. The red (respectively blue, green)-colored text represents number and percentage of BP instances that incurred higher (respectively in interval, lower) average total costs than the user-provided cost interval. The foreground right frame of Fig. 4 represents graphically the obtained results using a pie chart. As shown in both foreground frames, 7.7% of BP instances incurred total costs more than 800 AUD, 7.2% of them incurred total costs less than 500 AUD and 85.1% of them incurred total costs between 500 and 800 AUD. Tests of ML-based cost analysis for the BP level is left for other BP examples as for the considered test example, there is no data attributes related to the BP instances (traces). The tests results of the BP level cost extension, presented in Fig. 3 and Fig. 4, remain valid for the three considered BP notations (PN, EPC and BPMN).

Figure 3. Cost data description (BP level) with PN notation.

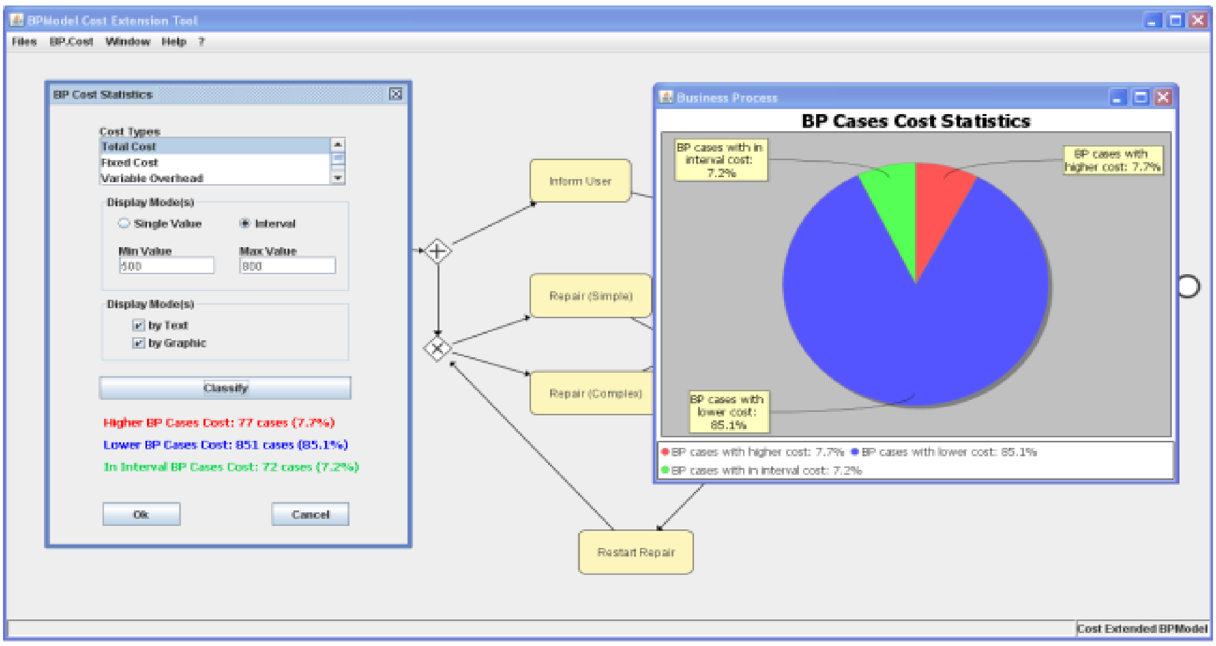


Figure 4. BP cases cost statistics (BP level) with BPMN notation.

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2) Tests Results of the Activity Level Cost Extension: As shown in Fig. 5 (respectively Fig. 6), the background frame displays the obtained EPC (respectively BPMN) model after importing the corresponding BP model and cost extended event log files. The foreground frames of Fig. 5 show cost data description corresponding to the “Analyze Defect” function. The top left frame illustrates cost data description table corresponding to the “Analyze Defect” function with average, maximum and minimum computation modes and total, variable overhead, fixed and labour cost types. The top right frame shows blue bars each of which representing the average of total costs related to “Analyze Defect” function instances executed by a resource. The bottom right frame illustrates a curve representing the average total costs of the “Analyze Defect” function based on its instances and two lines representing the user-expected cost interval boundaries: minimum (blue line) and maximum (green line) cost values. The bottom left frame shows average cost per cost type for the “Analyze Defect” function: yellow-colored bar represents total cost and green-colored bars represent others cost types.

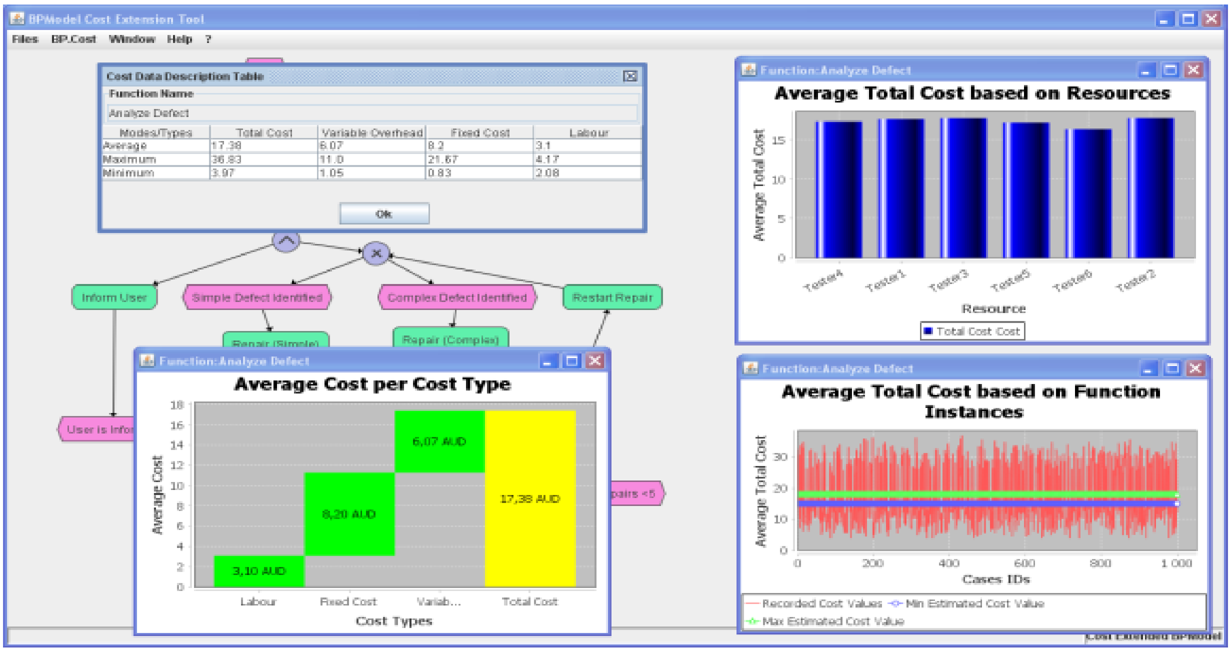

Figure 5. Cost data description for “Analyze Defect” function (activity level) with EPC notation.

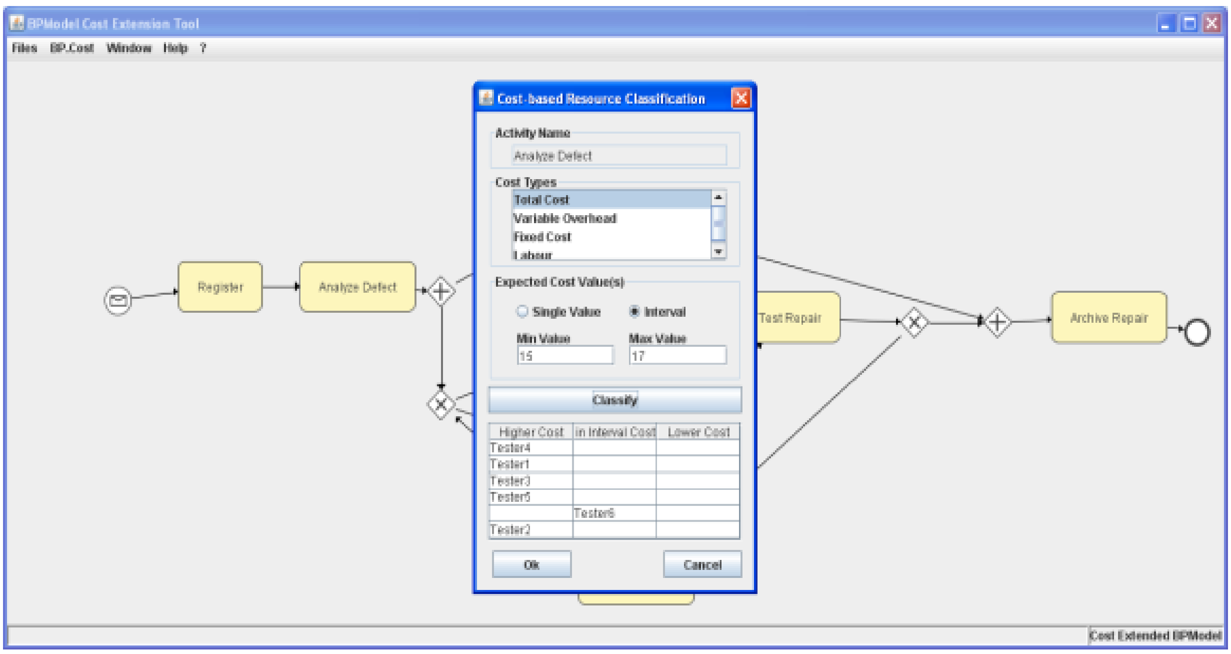

Figure 6. Resource classification based on total cost of “Analyze Defect” activity (activity level) with BPMN notation.

The foreground right frame of Fig. 6 shows test results of the first activity level cost analysis method, which is a cost-based resource classification for the "Analyze Defect" activity. As it is illustrated in Fig. 6, the user selected the "Total Cost" as the cost type to be analyzed. The provided expected cost interval for the considered activity ranges from 15 AUD to 17 AUD. Then, the provided result is displayed using a table showing three columns. The first column (respectively second, third) lists resources, which executed "Analyze Defect" activity instances with average total cost higher (respectively in interval, lower) than the user-expected cost interval. As shown in Fig. 6, the average total cost of "Analyze Defect" activity instances executed by "Tester6" is within the user-expected cost interval. However, the other resources are involved in incurring higher total costs than 17 AUD and no resources incurred lower total costs than 15 AUD. Furthermore, the second activity-level cost analysis (ML-based) method is tested on the "Analyze Defect" activity by selecting the total cost as a cost type and 17 AUD as the expected cost value. An ARFF file is automatically generated according to details presented in section III.A.1. Afterwards, the ARFF file is imported using Weka system. The selected attributes are: "resource", "duration", "phone type" and "defect type" attributes for the activity in hand. Then, we applied different classification algorithms among which we retained the J48 algorithm [31] as it provided the highest rate of correctly classified instances (100%). The obtained result is presented by the following classification rules:

```
If (phoneType = T1) Then
    Cost is lower
If (phoneType = T2) Then
    Cost is lower
If (phoneType = T3) Then
    Cost is higher
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The obtained classification rules show that if the phone type is T1 or T2, the incurred total cost of the "Analyze Defect" activity is lower than the expected cost value (17 AUD). However, if the phone type is T3, the total cost exceeds the expected cost value. Then, it can be concluded that the total cost incurred during the execution of this activity depends on the "phone type" attribute and the influence of the other attributes on the corresponding total cost is not prominent. This indicates to decision makers that reviewing the repair of T3 phones is likely to lead to a solution to reduce costs incurred by the execution of "Analyze Defect" activity. The tests results, presented in Fig. 5 and Fig. 6 about the activity level cost extension, remain valid for the three implemented BP notations (PN, EPC and BPMN).

IV. Conclusion and Future Works

In this paper, we proposed an improved solution providing BP model cost extension at the activity level as well as the BP level based on Process Mining. In fact, we extended the proposed approach so that it offers cost description and analysis at both activity and BP levels. Besides, we improved the proposed meta-model (HLPS) in order to represent cost data at activity and BP levels. Moreover, we presented the implementation of the improved approach. Additionally, we described the obtained results of tests that we carried out on the implemented tool using a simple phone repair process as test example with three simplified modeling notations: PN, EPC and BPMN. Furthermore, the tests results show that the solution is extensible to cover different other business modeling notations. Therefore, the obtained proposal is a general BP model cost extension solution providing cost extension, description and analysis at activity and BP levels, which further improve decision making support for BP cost reduction.

However, the proposed solution has some limits especially for the ML-based cost data analysis. First, the provided BP level cost analysis does not include the influence of resources on BP costs while it may be important in cost reduction decision making. Second, selection of the classification algorithm is left for the user, which may be enhanced by guiding the selection in order to improve the quality of the generated results. Third, the proposed solution does not include means to simulate the impacts, of changes brought to the BP, on its incurred costs before applying real actions on the BP.

Currently, we are studying further cost data analysis improvements in such a way to provide more guidance for better decision making support. These improvements will be proposed and validated by coordination with data mining experts. In future works, we consider to carry out real world case studies in order to evaluate the proposed solution performances.

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