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Resources consumption analysis of business process services in cloud computing using Petri Net

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ABSTRACT

Using the cloud for companies can have a positive impact on business process construction because it gives the ability to perceive resources such as unlimited. However, this construction in the cloud still has a lot of problems with resource issues in elasticity, especially after over time, this can be costly expensive for companies when services of business process aren't optimised in resource consumption. Hence, resources perspectives have become important to optimise the business process construction by selecting similar services that have low consumption for each activity. Concretely, the aim of this work is to ensure the consistency feature in resource perspective by using a Petri Nets to verify the right execution of business process with initial allocated resources based on some properties and to select a path of similar services that has a low consumption to minimise cloud elasticity anytime for companies.

Contents

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1. Introduction

In recent years, cloud computing concept has been of major importance in the industrial world (Fox et al., 2009) not only because they offer the possibility of using unlimited resources, but also because they make it possible to pay for resources on a pay-per-use basis (Mell and Grance, 2009). This new concept allows companies to create, manage and optimise their business process (BP) using elasticity. Such as elasticity offers flexible computing resources to meet customer demand.

In fact, BP is a set of activities that consume resources and reflects these consumption perspectives on BP (Mili et al., 2010). Which is considered as a modelling: resources, resource consumption and resources interaction with different BP services.

Nowadays, on the cloud, we can find a significant number of services that offer the same functionalities and that can be used for BP construction. However, with cloud benefits, companies are reluctant to use it because resource elasticity can be out of control by deploying and using BP in the cloud. One of the problems is that after a while (over time), elasticity can be costly for companies, especially when business process services are not optimised in the resources consumption. Thus, these services can be exchanged with other similar services that are optimal in terms of resource consumption. Therefore, this cloud elasticity has become an important problem in terms of selecting services for the BP construction because there are many similar services that have different resource consumption and can be used for this construction. In this way, resource perspectives have become important to optimise the BP construction by choosing similar low-consumption services for each activity. In fact, cloud resources can be elastic and shared between different services of BP. In addition, BP resource consumption modelling in the cloud includes two main features: the first is the specification of resource requirements and the second is the consistency that ensures there is no contradiction (violation of resource consumption) between the different similar services of BP activities.

In this work, we are more interested in the consistency feature from a resource consumption perspective. In additional, we use the Petri Nets model to describe BP with their resource consumption to verify BP properties in cloud computing. In order to verify the efficiency of initial resource provisioning between different BP services and to verify the partial elasticity of BP in cloud computing based on the initial allocation of resources. We suggest a verification methodology based on a formal model to verify resource consumption properties and select services with low resource consumption. In order to reduce the cost of elasticity of BP resources in cloud computing.

This paper is organized as follows: Section 2 provides an overview of some related work. In Section 3, we provide a brief overview of this approach and present the different steps of the transformation model from BPMN to Petri Nets (PN). Moreover, in Section 4, we discuss the methodology for analysing the proprieties on the PN. In Section 5, a case study that shows the applicability of this approach is presented. Section 6 discusses the approach by detailing the contributions of this paper. Finally, Section 7 presents our concluding observations by concluding this paper and presenting future directions.

2. Literature review

In recent years, cloud computing has gained a lot of popularity, due to the unlimited allocation of resources in any area of computing for the proper systems execution. But in the industrial world, the allocation of resources for BP is under consideration to allocate resources for BP activities or services in the cloud. Today, few scientists work in this area of resource allocation for BP, they generally focus on human resource allocation and some work on cloud resource allocation, but none of them on resource consumption. In fact, the authors (Bessai et al., 2013) have proposed a set of scheduling strategies for BP in cloud computing. Three complementary approaches for scheduling BP on distributed cloud resources have been proposed while taking into consideration its business model based on pay as you go and its elastic computing characteristic that allows users to allocate and release compute resources on-demand. The authors (Hoenisch et al., 2013) have presented an approach to automatically renting and releasing resources for workflow executions based on knowledge about the current and future process landscape.

In general, researches focus on non-functional behaviours from the resource perspective in terms of response time and financial cost (Mastelic et al., 2015) or functional behaviours such as correctness of execution based on cloud properties (Graiet et al., 2016). In this work, we consider the two aspects of behaviour: the first is the consistency of the execution of the BP and also the consistency of the BP partial elasticity (functional aspect). The second is non-functional behaviours, more precisely, we focus on financial cost (this is done by choosing services that consume low resources).

Furthermore, works below have used formal methods such as PN, CTL or event-B, but some of them have not taken into account resource perspectives. Many studies have tried to formally verify BP behaviour in terms of the composition of their services by using Event-B as a (Hamel et al., 2011, 2012), authors have presented an approach based on Event-B for a proof, refinement and verification of the structural and behavioural properties of the component service before dynamically integrated into the composition during the execution. The authors (Bersani et al., 2014) have proposed a formalisation, based on the CLTLt(D) temporal logic, of several concepts and properties related to the behaviour of cloud-based elastic systems and preliminary evaluation of the feasibility. In (Klai and Tata, 2013), authors have proposed an approach that supporting elasticity at the service level based on a formal model of PN for describing elasticity mechanisms and their strategies for SBPs (service-based BP). Furthermore, in (Amziani et al., 2013); authors have proposed a formal model for SBPs elasticity in the cloud and have shown that their model preserves the semantics of SBPs when services are duplicated or consolidated based on a formal framework for the evaluation of elasticity strategies. In (Graiet et al., 2016) have presented a formalism based on the Event-B language for specifying cloud resource allocation policies in BP models. In order to formally validate the consistency of cloud resource allocation for process modelling at design time, and to analyse and check its correctness according to user requirements and resource capabilities. In (Boubaker et al., 2015; Boubaker et al., 2016), the authors have also proposed a formalism based on the Event-B for specifying cloud resource allocation policies in BP models. These approaches are used to analyse and check BP correctness according to users' needs and resource properties and to formally validate the consistency of cloud resource allocation for process modelling. In (Cheikhrouhou et al., 2018), the authors have proposed an approach that assisting BP designers to identify necessary cloud resources with respect to temporal and financial restrictions on BP. In (Ben Halima et al., 2016; Ben Halima et al., 2018) the authors address the issue of verifying the resources allocation in the cloud while using Amazon's pricing models and taking into account time constraints of activities. In this work, they first presented a formal specification of the business process model with time constraints on cloud activities and resources. Then, they proposed a mapping step whose objective is to map each cloud pricing strategy in timed automata. In addition, they proposed an automatic generation of timed automata based on this BPMN extensions to check the adequacy between the two-time constraints: Cloud activities and resources.

In (Jlassi et al., 2019) the authors have proposed a formal definition of the resource perspective in FOSS applications as a step towards a correct and consistent allocation of cloud resources in FOSS application modelling. That's why they developed a cloud resource allocation model (CRAM4FOSS) for FOSS applications using the Event-B method. This model is used to formally validate the consistency of cloud resource allocation for "FOSS" applications at conception, and to analyse and verify its accuracy based on user needs and resource capabilities.

3. Transformation approach

Our aims in this work are to verify some properties of BP in cloud computing and to calculate for each BP activity the resource consumption of all similar services discovered by the multi-agent system of our previous work (Lacheheub and Maamri, 2016). In order to choose the best services (which have a low resource consumption) and this can be done by mapping the Business Process Model and Notation (BPMN) to the PN for property verification. In addition, we want to verify if all services are compatible with the resources that were initially allocated to this BP to test the efficient initial resources provisioning property of resources in the cloud computing and verify if this new BP can be combined with other processes to test the partial elasticity of the BP in the cloud computing to support the extension or creation of a new BP.

3.1. Information injection (extended BPMN)

In this paper, we do not illustrate our formal BP model with a set of information injected into the BPMN (similar services for each activity and their resource consumption). We focus on analysing the transformation of the BP to the PN and on the resources consumption of BP in cloud computing. In this phase, additional information from services compatible with BP activities that represent the resource consumption of these services is directly injected into the BPMN model using our BPMN meta model extension.

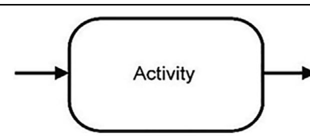
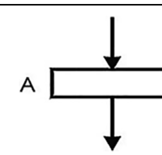
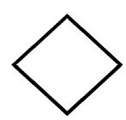
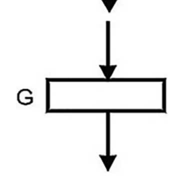
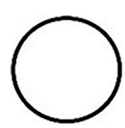
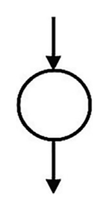
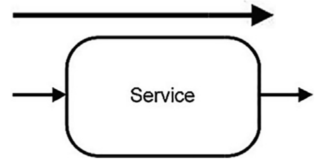
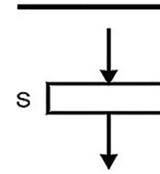
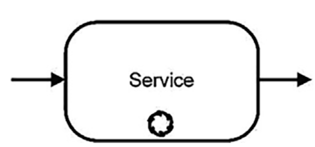
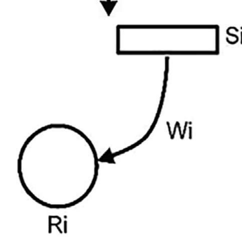
3.2. The transformation (mapping from extended BPMN to Petri Nets)

In this phase, we will see the mapping rules of the extended BPMN model to PN model, this mapping is illustrated in Table 1:

3.3. Refinement of extended BPMN

With each evolution, the company needs to check the BP again in order to check all the properties of the BP in cloud computing. In fact, the BP at each evolution cannot be verified by a BPMN model because it is a standard model based on a semi-formal language, unlike a Petri Nets. For this reason, we use a PN to check the properties of the BP in cloud computing. In addition, the verification and validation of BP are a crucial issue to verify the proper execution of the BP in terms of resource consumption because the company can have economic losses when its BP is not optimised and this can be due to the absence or high consumption.

Table 1
mapping rules of the extended BPMN model into Petri Nets.

Elements	Mapping Description	BPMN Graphical Representation	PN Graphical Representation
Activity	the activity or sub-process is mapped to an abstract transition		
Gateway	is mapped to an elementary transition. Generally, gateways are used to control the divergence and the convergence of sequence activities in the BP		
Events	are mapped to a places in PN. We can find three categories of events: start, intermediate and end events		
Arcs	are arcs in PN that connect transitions to places or vice versa		
Services	are mapped to transitions in PN. Such as, one activity can contain one or more elementary services (which are similar and compatible with this activity)		
Resources	are mapped to a places, arcs and weights of arcs structure in PN (each service has its own resource consumption)		

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One of the solutions proposed is designing a behavioural specification of BP in terms of resource consumption by using a PN for analysing the obtained BP model. Furthermore, our aim is to simulate this consumption of resources and verify whether the resources initial allocated can be available between all activities of BP by minimising the use of elasticity in cloud computing (if we can choose the right similar services for each activity, we can reduce the cost of resource elasticity in cloud computing). But one of major inconvenient is that we can have a complex model in PN with the representation of services discovered and their resource consumption or the representation of other BP as a service. For this reason, we have opted for the refinement or abstraction of extended BP using PN. In addition, each time BP is updated using partial cloud computing elasticity, a new PN model is generated to verify the properties of the new BP.

The verification is done on the first generated PN model (model with abstract transitions that represent a BP as a service) and after properties verification, a refinement step can be repeated on an abstract transition (which introduces an additional level of detail). The model thus refined in PN is then verified and further refinement can be performed on another abstract transition until a sufficient level of description is reached. In order to detect which abstract transition can cause the problem of resource consumption.

3.3.1. Refinement of partial business process elasticity

The refinement of partial BP elasticity is based on the transition that represents another BP in the PN model. That means all abstracted transitions represents another BP that can be analysed and refined. We take an example that is illustrated in Fig. 1 to see this abstraction or refinement of extended BP.

As we can see in Fig. 1, we start by refining and checking first transition A1 (the first verification level). After this, the refinement and verification of extended BP can be performed on the next transition A2 (the second verification level). Such as, transition A1 represents three similar services that can be compatible with activity A1 (only one of the similar services that have been discovered will be selected for activity A1). In addition, the transition A2 represents another BP that contains two parallel activities. So, the refinement and analysis are restarted again on this transition A2 for the verification of the new BP.

4. Analysis of resources consumption in business process

The extended BPMN is transformed or mapped to a classical PN model for property verification. In this section, we explain the analysis phase of each property since they are verified only on the PN. this proprieties are divided into three categories which are illustrated in Table 2:

Thus, to verify the BP properties in the cloud (properties E.R.P and P.E) some properties of PN must be verified, as shown in Table 3.

So, to check these two properties of BP in cloud computing:

- There must be no deadlock in PN.
- In both cases, the soundness and liveliness must be checked.
- The marking place of resources must be $M(p) \leq k$ in both properties. Such as, k in resources places represents the initial allocation of resources for BP.
- In the P.E, the E.R.P property must be checked before the verification of the P.E.

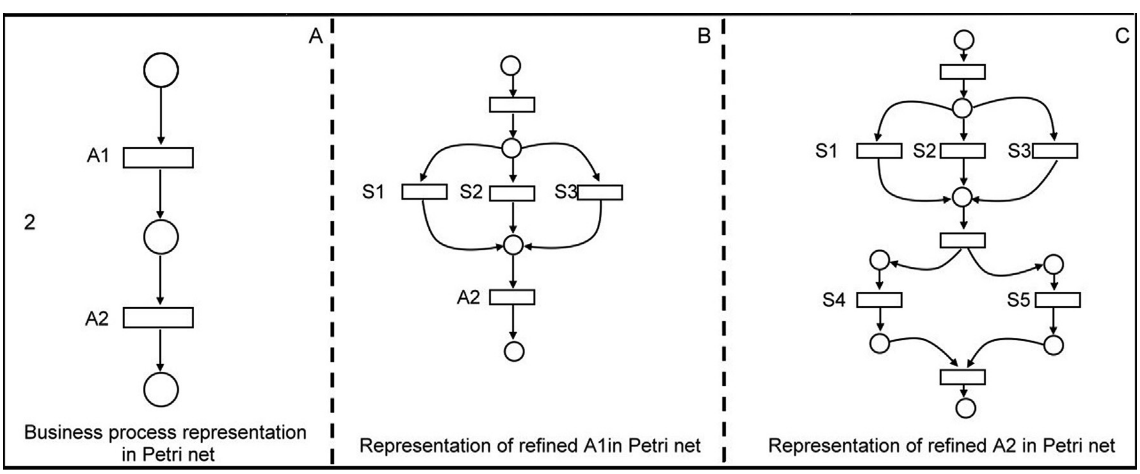

Fig. 1. Example of Transition refinement.

Table 2
Properties of BP in the cloud.

Properties		Description
Business process	correct execution	BP needs to be executed correctly, such as, each activity needs to be executed to achieve the global goal of company. So, to verify this property of the correct execution we use the PN to check (soundness property in PN wich represents correct execution in BP)
Cloud computing	The efficient initial resource provisioning (E.R.P)	This property verifies whether the initial cloud resources allocated to the BP are auto-sufficient for the execution of one BP instance
	The partial business process elasticity (P.E)	This property verifies the combination of two or more BP as service in cloud computing with the initial BP and also it checks the new BP based on the efficient initial resource provisioning and its correct execution
Resources Consumption	Own termination	For each marking accessible from the initial state (the start place contains one token), it is always possible to reach the final marking, Where the only marked place is the end place (all other places must be empty except the resource places)

Table 3
Business process cloud properties.

Properties	Soundness	Liveliness	Boundness	Deadlock	E.R.P
E.R.P	✓	✓	$M(p) \leq k$	×	
P.E	✓	✓	$M(p) \leq k$	×	✓

In this section, we present how simulation and analysis are performed. We start with a simulation of resource consumption in PN, in order to simulate the consumption of services discovered of all BP activities and also to choose the best services for construction or management of the BP in terms of resource consumption. Furthermore, we verify the properties of the efficient initial resource provisioning, soundness and the partial elasticity of BP. In this case, we take examples to see how consumption simulation is done on the properties mentioned above.

4.1. Soundness propriety

The soundness is a property that verifies the correct execution of BP in cloud computing. The BP runs correctly when it ends with a token in place "o" and other tokens in the resources places. In additional, all other places must be empty and there must be no dead activities.

In Fig. 2, the soundness property of the BP is checked in the first scenario "A" because all the places are empty except the end place "o" and the resources places (R1 and R2). On the other hand (the second scenario "B") the soundness property is not checked because there is one token in the place (E1). That means, there is a problem in the event E1 of this BP.

4.2. Consistency property

The consistency property is checked if the resource consumption is less than or equals to the initially allocated resources. Thus, if the resources are sufficient for the correct execution of a BP instance, it means that consistency is verified.

For the analysis of the consistency property, an example is illustrated in Fig. 3: As we can see in this figure, in the first case, the propriety is checked because the resources consumed are equal to the initial resources allocated to the BP and these resources are auto-sufficient for the execution of one BP instance but in the second case, the resource consumed is higher than to the initially allocated resources (meaning that the property is unverified).

4.3. Efficient initial resources provisioning property

The efficient initial resource provisioning property is a checked if all initially allocated resources to the BP can be allocated to other

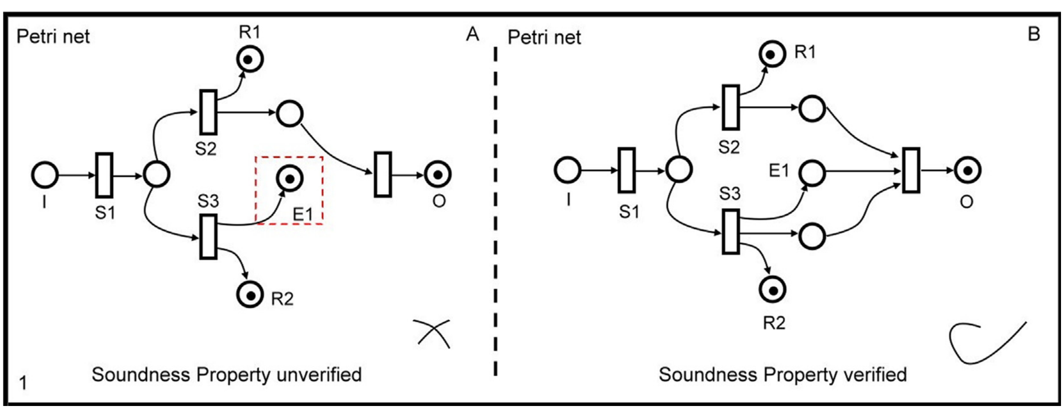

Fig. 2. Soundness property of the business process.

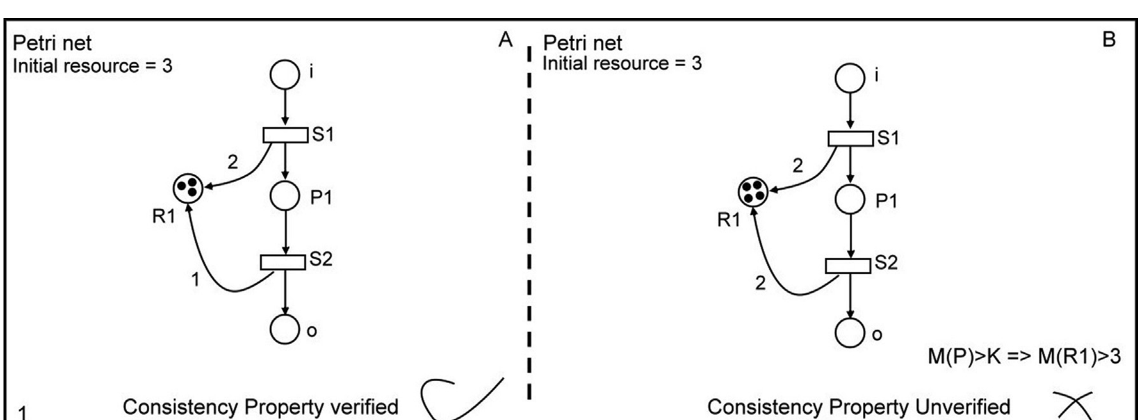

Fig. 3. Consistency property of the business process.

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activities (the partial elasticity of BP can be done without the elasticity of resources in cloud computing) otherwise this property will not be verified. We start by allocating resources between the different activities. An example is illustrated in Fig. 4.

In this example, we take only one service for each activity to reduce the complexity of the simulation. As shown in Fig. 4, (I) represents the input, (O) represents the output of the BP and the activity A1 of BP has two services (S1 and S2). Each service has its own resource consumption (RC) which is represented by the weight function of the arc that connects the transitions (S1 and S2) to the places (R1 and R2). Simulation of this example leads to the marking change in PN. Such as, each transition activation (Si) adds tokens to the Ri place. This operation is related to the resource consumption, e.g. if the S1 consumes two units of R1; two tokens will be represented in place R1 and the function of the arc weight that connects S1 to R1 is also equal to two.

In Fig. 4 the marking of all places equals one token, except for Ri places. In this place the tokens number is constantly evolving, because this place represents the resource consumption of (Si) transition and at the instant (t) this marking stop evolving. This due to the limited instance number of BP that can be executed without cloud elasticity.

The PN analysis is based on the resource consumption of all BP activities and their associated services to verify the resource consumption property. This analysis is done on the marking of all resources places with the initial allocation of resources. The activation of service transition leads to marking change in the resources places of these services. As an example, we take the above description of PN in Fig. 4. In the PN representation, the activation of the transition of service S2 leads to marking change of the resource place (R2). Thus, each time the service is used, it consumes one unit of that resource. For example, the R2 place accumulates tokens each time the S2 transition is activated. Fig. 5 illustrates an example of the efficient initial resources provisioning property.

As shown in Fig. 5, the first case, the efficient initial resource provisioning property is not verified because all initial resources are consumed and in the second case, the efficient initial resource provisioning is verified because the resources allocated initially to the BP is auto-sufficient for the execution of another activity or a BP.

Thus, the property of the efficient initial resource provisioning is verified, if the resources consumed by the BP are exactly lower than the resources initially allocated.

4.4. Business process partial elasticity property

The partial elasticity of BP is represented in BPMN as a new sub-process that contains many activities. Thus, after the transformation from BP to PN, the sub-process of this new BP is represented as an abstracted transition. So, the BP is analysed and verified at

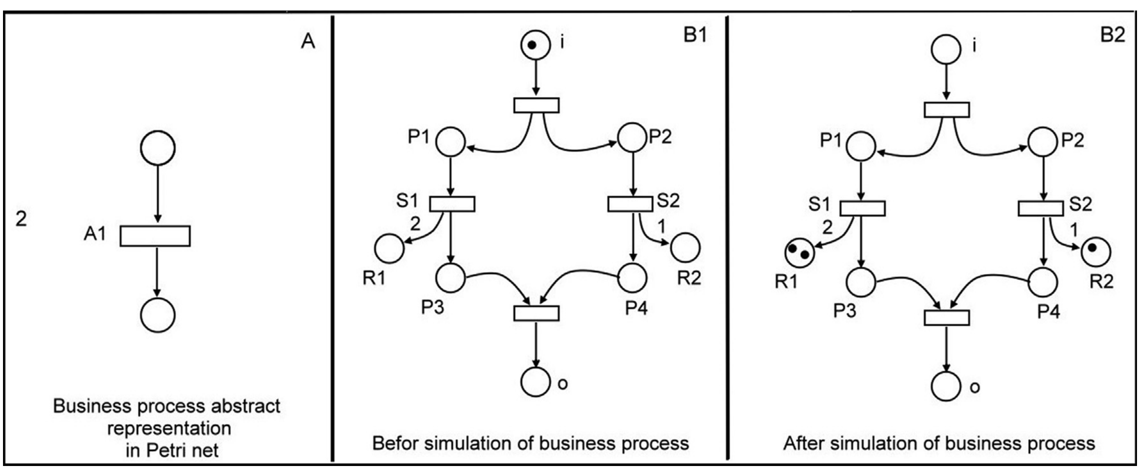

Fig. 4. simulation example.

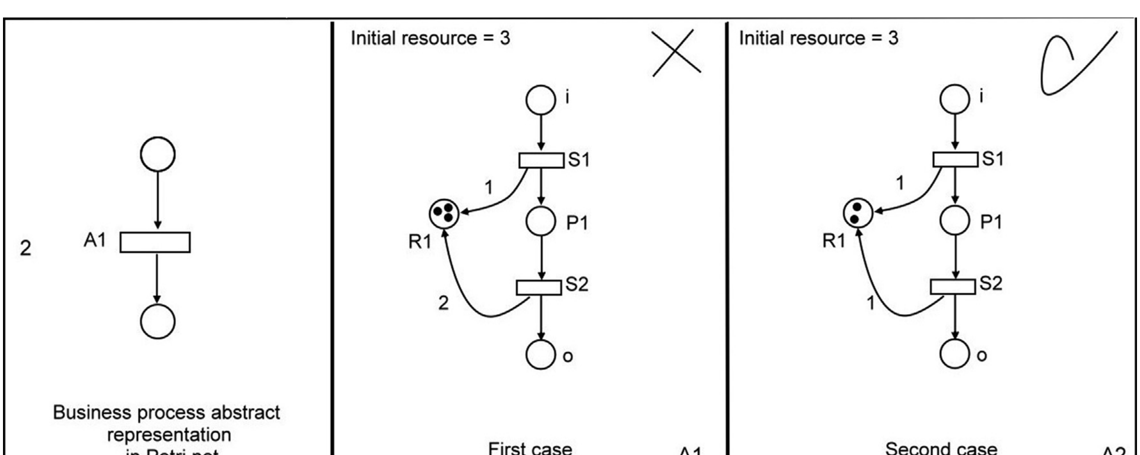

Fig. 5. efficient initial resources provisioning propriety.

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each partial elasticity to create a new complex BP. We take the previous example and add another process to the initial BP. After BPMN transformation, the new process is represented as an abstract transition that contains another BP as services BP2, this is illustrated in Fig. 6.

In this example, we start with testing resource consumption of the first BP to test the efficient initial resource provisioning property. If the first BP verifies this property, the refinement of the abstracted transition that represents the BP2 be started to verify again the efficient initial resource provisioning of all BP and detect if there is a resource over-consumption.

The PN analysis is based on the resource consumption of all activities of the new BP and their associated services to verify resources availability, consistency and soundness proprieties. In order to check the compatibility between the new combination of BP. This analysis, focus on the marking of all resources places and their initial allocation. The activation of service transition leads to marking change in resources places of these services. Thus, with this new model, the analysis of efficient initial resource provisioning is based on all possible combinations of BP. In the previous example, the analysis is performed on the BP1 and after checking all properties, the refinement of the business can start with BP2.

The comparison between the resource consumption is made to choose the best path that consumes fewer resources to create a new BP with low resource consumption.

As shown in Fig. 7, the best path that can be chosen for company after refining all abstract transitions is the first path (S1, S2 and S3) because this path consumes three unities of resource R1, unlike the second path (S1, S2 and S4) that consumes four unities of R1.

5. Case study

We are considering a company that wants to create a new BP to deliver order items to its customers. This BP, which is shown in Fig. 8 is defined as follows: Login (A1); item search v (A2); items selects (A3); credit card information insertion (A4); credit card information saving (A5); items purchasing validation (A6); items sending (A7); items tracking (A8); items receiving confirmation (A9).

NB: In this use case, activities A4 and A7 are abstract activities that represent two other BPs.

To reduce the complexity of this example, we only consider activities that may have many similar services that are compatible with these activities. Such as, The activities that have been taken into consideration are (A2) and (A8). Such as A2 has three cloud services (S1, S2, and S3) that may be compatible with this activity and activity A8 has two compatible services (S4 and S5).

Activities A4 and A7 represent other BP that may have other activities and services from different providers. In this case, these

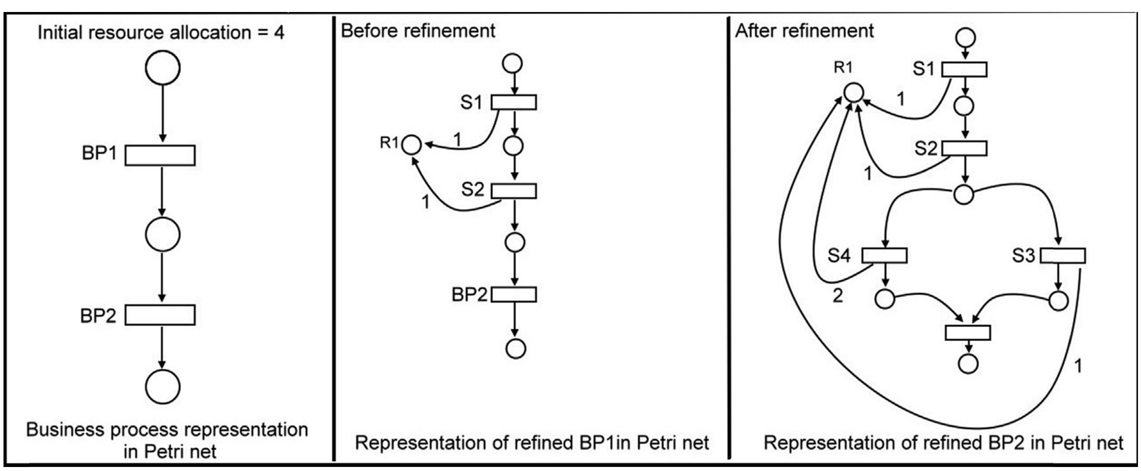

Fig. 6. Business process elasticity.

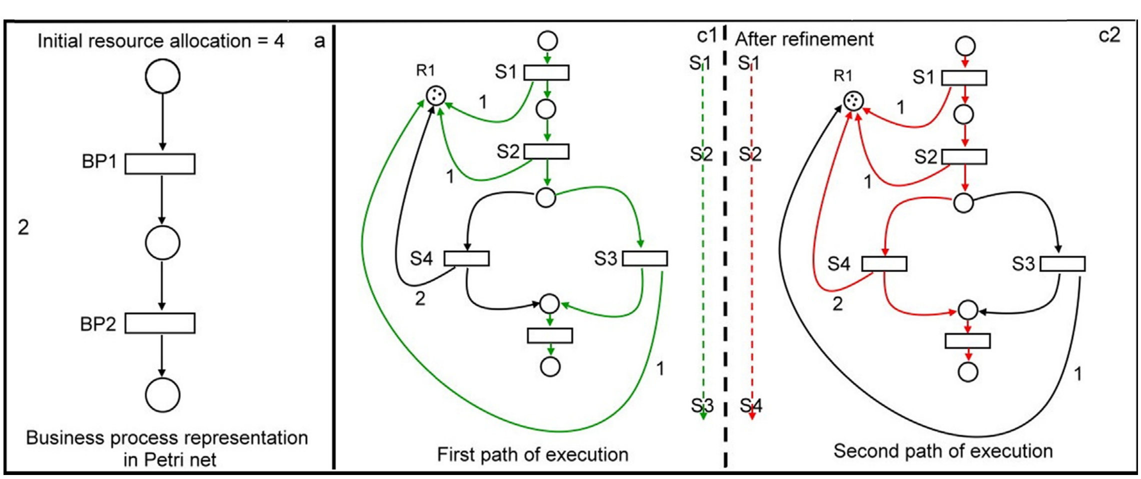

Fig. 7. Business process Path execution.

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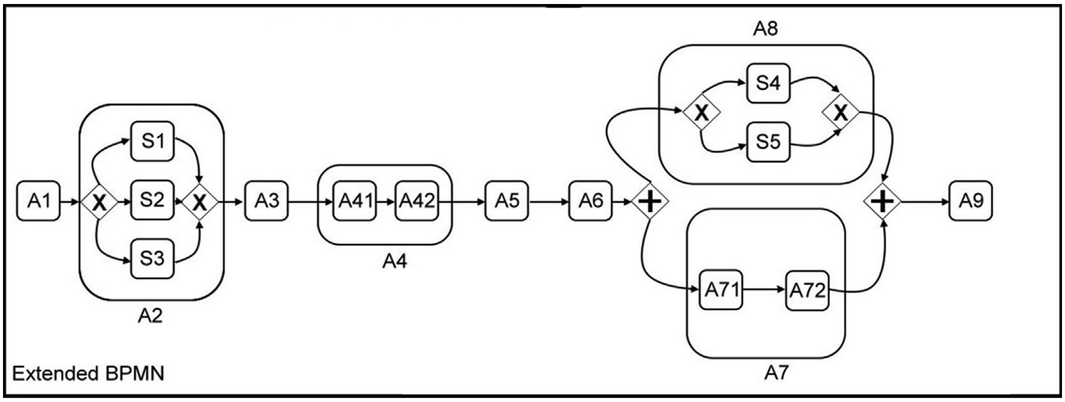

Fig. 8. Example of business process.

two activities will be represented by an abstract transition and information on their resource consumption will not be verified before the verification of the first BP.

Table 4 summarises the resource consumption of each BP activity. As in this table, we can see three categories of resources (CPU, RAM, and Data) that can be consumed in cloud computing by a BP. In addition, both activities A2 and A8 may have different compatible services from cloud computing, with similar functionalities for each activity but different resource consumption.

In this use case, the resources initially allocated to BP in cloud computing that has been defined for the running of a BP instance, are as follows: CPU = 7, RAM = 5 and Data = 5. Fig. 9 illustrates the example described above.

The simulation of this example leads to having multiple execution paths in PN. The number of this path is equalised to six without transition A4 and A7 (they represent the other BP as a service) and each path has its own resource consumption.

The simulation of this example generates six possibilities that can be taken into account. If we compare the two sequence Seq1 and Seq2, we find that RC1 is better than RC2 in terms of data consumption because in RC1_data = 2 and RC2_data = 3. In this use case, we assume that the CPU resource is more important than the RAM resource (the CPU price is more expensive than RAM in cloud computing).

We summarise the result of CPN tool concerning resource consumption of all paths of this use case in Table 5. Thus, in this use

Table 4
Resources consumption of business process elements.

Res\Act	A1	A2	S1	S2	S3	A3	A4	A41	A42	A5	A6	A7	A71	A72	A8	S4	S5	A9
CPU	1		1	2	1	0		0	1	0	0		1	2		1	1	0
RAM	0		1	0	1	2		0	0	0	2		0	0		0	1	0
Data	0		0	0	1	0		2	0	1	0		0	0		0	0	1

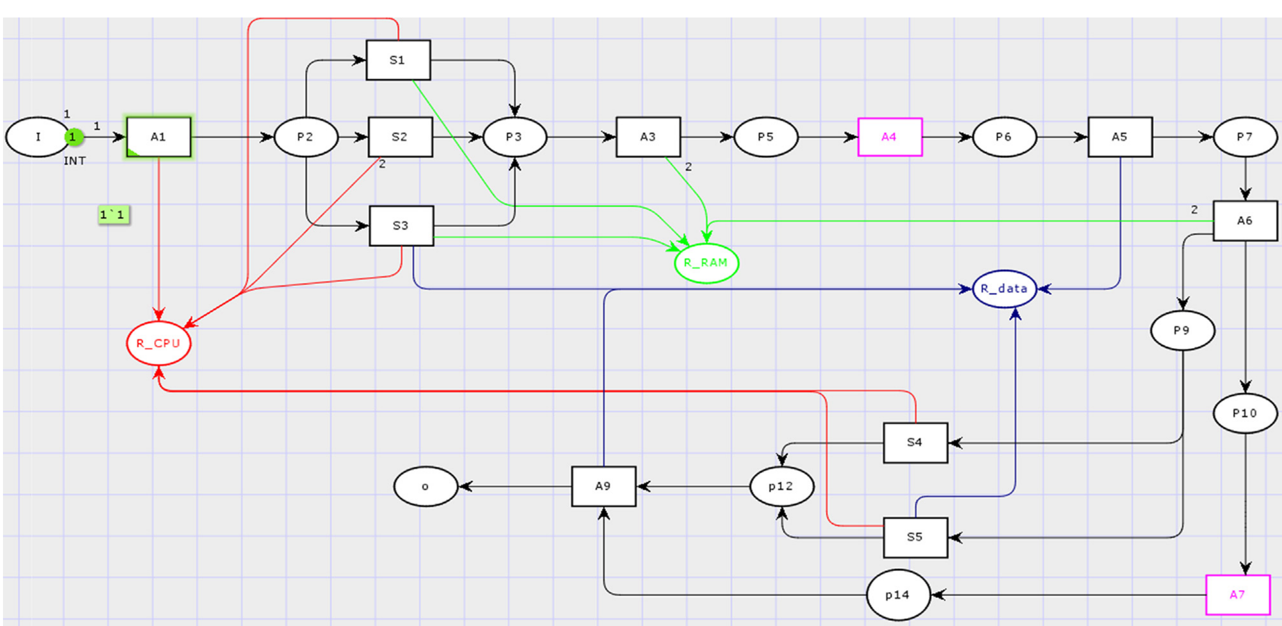

Fig. 9. the Petri Nets model of Business process.

Table 5
Resources Consumption of business process before refinement.

Sequence name	Sequence	Resources Consumption (RC) = (CPU, RAM, DATA)	E.R.P	Soundness Property	consistency
Seq1	A1, S2, A3, A4, A5, A6, A7, S4, A9	(4,4,2)	✓	✓	✓
Seq2	A1, S2, A3, A4, A5, A6, A7, S5, A9	(4,4,3)	✓	✓	✓
Seq3	A1, S1, A3, A4, A5, A6, A7, S4, A9	(3,5,2)	× (ram)	✓	✓
Seq4	A1, S1, A3, A4, A5, A6, A7, S5, A9	(3,5,3)	× (ram)	✓	✓
Seq5	A1, S3, A3, A4, A5, A6, A7, S4, A9	(3,5,3)	× (ram)	✓	✓
Seq6	A1, S3, A3, A4, A5, A6, A7, S5, A9	(3,5,4)	× (ram)	✓	✓

case, there is no deadlock and the Liveliness property is verified, but the verification of Boundness property depends on Resources Consumption (if the Resources Consumption is less than or equals to the resources initially allocated the property is verified).

As can be seen in Table 5, the consistency and soundness properties in all sequences are checked because all resource consumption of these sequences is less than or equals to the initial resources allocated C = (7,5,5) and the last place (o) have a token that indicates that the BP has been executed correctly.

As we can see in Table 5, there are different sequences and each sequence has its own resource consumption. This consumption is illustrated in Fig. 11 of the first phase (resources_Ph1). The same is true for the result of resource consumption of the new BP (after refining the A4 transitions in the PN), this result is illustrated in Fig. 11 in phase two (resources_Ph2).

As we can see in Fig. 10 in phase two, the Seq6 is not available now after the refinement of the A4 transition. Thus, this sequence doesn't check the efficient initial resources provisioning, consistency and partial elasticity of BP because the resource consumption has exceeded the resource initially allocated in data resources, the BP needs more storage resources on this path for adequate performance.

After verification of the previous refinement of the activity A4 (BP as a service that has two activities A41 and A42), the refinement can be applied to the next abstract activity which is A7 and which represents the BPaaS of item delivery. This process includes two activities A71 and A72. Such as A71 represents the selection of delivery option that consumes one unity of the CPU and A72 is product packaging that consumes two unities of the CPU. The refinement of this BP transition is illustrated in Fig. 10.

Table 6 summarises the resource consumption of the A7 transiton refinement.

The result of the last case of all PN transitions refinement is shown in Fig. 11. As shown in this figure only sequence three verify

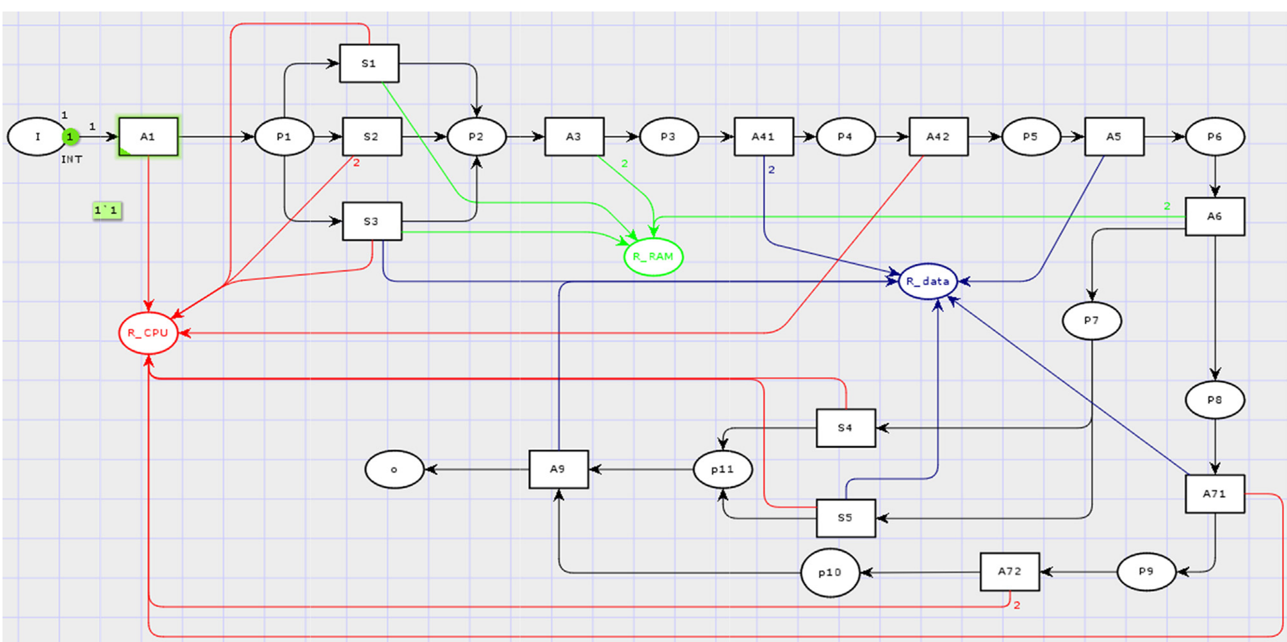

Fig. 10. refinement of business activity A4 and A7.

Table 6
Resources consumption of business process after the refinement of all transition.

Sequence name	Sequence	(RC) = (CPU,RAM,DATA)	E.R.P	Partial Elasticity	Soundness Property	consistency
Seq1	A1, S2, A3, A41, A42, A5, A6, A71, A72, S4, A9	(8,4,5)	×(cpu and data)	×(cpu)	✓	×
Seq2	A1, S2, A3, A41, A42, A5, A6, A71, A72, S5, A9	(8,4,6)	×(cpu and data)	×(cpu and data)	✓	×
Seq3	A1, S1, A3, A41, A42, A5, A6, A71, A72, S4, A9	(7,5,5)	× (all resources)	✓	✓	✓
Seq4	A1, S1, A3, A41, A42, A5, A6, A71, A72, S5, A9	(7,5,6)	×(all resources)	×(data)	✓	×
Seq5	A1, S3, A3, A41, A42, A5, A6, A71, A72, S4, A9	(7,5,6)	×(all resources)	×(data)	✓	
Seq6	A1, S3, A3, A41, A42, A5, A6, A71, A72, S5, A9	(7,5,7)	×(all resources)	×(data)	✓	

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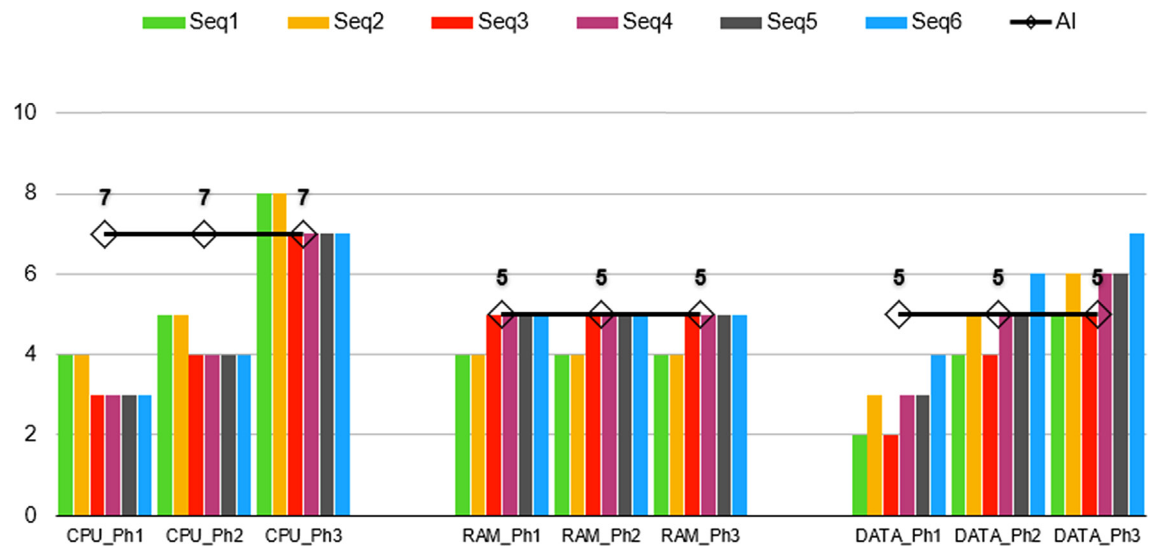

Fig. 11. business process resource consumption.

Table 7
Comparison of a related formal approach.

Approaches\Criteria	Formal Language	Verified Properties	Resources perspective	Cloud Properties
(Klai and Tata, 2013; Amziani et al., 2013)	Petri Nets/WF-net	Soundness property	–	Horizontal elasticity
(Bersani et al., 2014)	LTL and CTL	–	–	Horizontal elasticity
(Boubaker et al., 2015; Boubaker et al., 2016)	Event-B	correctness and consistency	Resources allocation	-
(Graiet et al., 2016)	Event-B	correctness and consistency	Resources allocation	Shareability and vertical elasticity
(Cheikhrouhou et al., 2018)	Petri Nets	temporal constraints	Resources allocation pricing strategies	–
(Ben Halima et al., 2016; Ben Halima et al., 2018)	Automata	temporal constraints	Resources allocation pricing strategies	-
(Jlassi et al., 2019)	Event-B	correctness and consistency	Resources allocation	Shareability
Our Approach	Petri Nets	correctness and consistency	Resources consumption	Resources availability and partial BP elasticity

the proprieties of soundness, consistency and partial elasticity compared to the resources initially allocated (AI). The property of efficient initial resource provisioning is not checked because all resources are consumed by this sequence, but this BP sequence is executed correctly because the initial resources are equal to the resource requirements. The other sequences have exceeded the resource consumption compared to the initial allocation and they don't check any properties of resources perspective (which means that with these sequences, the BP cannot be extended with activities and cannot be executed correctly).

6. Discussion

To summarise all this result, the approach proposed in this paper makes it possible to refine a BP with many sub-process (BpaaS) and detect which process or services can cause a resource overconsumption problem and to detect the process that may be more costly for the company because if the company uses the process that consumes more resources, it means that the resource elasticity of this BP can be very costly.

Furthermore, this approach makes it possible to demonstrate which is the best path for BP in terms of resource consumption. In order to allow the company to choose the best BP as services and to check whether the BP is partially elastic or no.

Table 7 summarises the aforementioned works and describes their differences. In fact, we have compared these works based on property verification, resources perspectives and cloud properties. In our work, we have used a PN model for the BP specification and verification taken into account the resources perspective and some cloud characteristic (cloud characteristics are partially covered).

Furthermore, we consider two cloud properties: the partial elasticity of BP (adding other activities or process from the cloud to the initial BP) and the efficient initial resource provisioning between the different activities of BP with the initial or partial elastic.

In additional, the property of consistency is checked if the resource consumption doesn't exceed the resources initially allocated. Unlike other formal language, the PN accurately describes the structure of BP, provides graphic design support, allows BP to be described in simple elements and describe the structure and dynamics of this BP. Moreover, PN allows the use of the refinement concept of BP and it allows us to formally verify the consistency of BP in both cases; without extended BP (not partial elastic BP) and the with extended BP (partial elastic BP).

7. Conclusion

In this paper, we propose a new approach based on PN that can be considerate as an enterprise solution. This solution can be applied to manage BP resource consumption and can be used to formally verify BP resource consumption in a cloud environment. In addition, it allows the efficient initial resource provisioning between the different activities of a BP with the multiple similar services to be verified in order to choose the best path for activities and their services (services that can consume low resources). Furthermore, the BP soundness property is verified in the PN model simulating resource consumption in the CPN tool by enabling transitions of all services of the BP activities.

Moreover, this approach checks the partial elasticity of BP by adding other BPs as a service to see their compatibility with the initial BP (extension of the initial BP with other BPs of other companies).

This approach is proposed to analyse the BP in terms of resources in order to choose the best service path that has low resource consumption in BP with or without extension, verify the efficient initial resource provisioning property and also verify the soundness and consistency properties of BP in cloud computing and allows to check the compatibility with other BP in order to do the partial BP elasticity in terms of resource consumption.

In this work, we focused only on cloud resources, but in future works, we intend to verify other cloud computing properties such as the elasticity of service instances and verify the resource consumption in vertical and horizontal elasticity in cloud computing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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