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SLAs, KPIs and BPMN Standard for the Digital Transformation of the Enterprises' IT Business Processes

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KEYWORDS

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Business Analytics

ABSTRACT

Business processes are at the heart of the enterprises' operations and management. Business Process Model and Notation (BPMN) standard is considered to be the state-of-the-art business process modeling standard in enterprises. To further regulate the business process operations, Service Level Agreements (SLAs) are applied by the enterprises so as to guarantee the service level of their own operations. An SLA, which is a contract agreement, consists of Service Level Objectives (SLOs) and Key Performance Indicators (KPIs), which are the SLA measurable characteristics and the SLA quantitative means to assess and benchmark the provided service levels. In the light of the digital transformation of today's enterprises, the primary objective of this paper is the evolution of today's enterprises' business processes to the next generation SLA – aware business processes that are based on the BPMN standard, SLAs, SLOs and KPIs so that: (a) an accurate and elaborate business process modeling could be achieved; and (b) the continuous improvement and the easier change management of the enterprises' business processes could be ensured. To implement the aforementioned evolution for the enterprises' Information Technology (IT) business processes, two methodologies are proposed in this paper, namely: (i) The SLA-aware BPMN IT business process lifecycle; and (ii) The interdepartmental SLA definition framework. The MATLAB / Octave simulation results of a real enterprise's BPMN IT business process, which is regulated by an SLA of two main SLOs with the corresponding KPIs, are provided. The simulation results are discussed to support design concept, effectiveness and benefits of the proposed methodologies. The MATLAB / Octave simulation code is freely distributed with the Supplementary Material file of the paper. Finally, a number of operations and management issues, that rises from the application of the proposed methodologies, is examined, namely: (1) The interdepartmental SLA responsibility; (2) The internal KPI evaluation system for the enterprises' personnel; (3) The IT service outsourcing based on SLAs, SLOs and KPIs; and (4) The wave of the enterprises' digital transformation.

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1.0 Introduction

In the light of the digital transformation of today's enterprises, business processes are at the heart of their operations and management (Ahmad et al, 2020; Cho et al, 2017; Harmon, 2010). By adopting a business process management strategy, continuous improvement and easier change adaptation can be ensured during the operation of the enterprises while activities such as modelling, automation, execution, monitoring and benchmarking of enterprises' business processes can be integrated (Zarour et al, 2019).

Despite the existence of several business process modelling languages, Business Process Model and Notation (BPMN) is the state-of-the-art business process modeling standard in enterprises and is treated as the default standard of this paper (Lazaropoulos, 2021a; Saputra & Jayadi, 2022). In fact, BPMN standard provides graphical notations and diagrams for meticulously describing enterprises' business processes and workflows in an expressive, formal but yet understandable language in a less verbal way by final users (Chinosi & Trombetta, 2012). BPMN standard has been developed by the Object Management Group (OMG) and is now specified as the International Organization for Standardization (ISO) / International Electrotechnical Commission (IEC) 19510:2013 standard (Object Management Group, 2011; White, 2004a; ISO, 2013). Except for the traditional functional requirements, OMG has extended BPMN in (Object Management Group, 2013) so that domain-specific business processes –e.g., Information Technology (IT) services and manufacturing– and Non-Functional Requirements (NFRs) can be supported (Object Management Group, 2013). In a similar way to OMG, business process designers prefer extending the existing BPMN standard by exploiting the simplicity and the semantic richness of its kernel design instead of inventing Domain-Specific Modelling Languages (DSMLs) due to the required higher costs in money and time (Zarour et al, 2019; Braun & Esswein, 2014; Braun & Esswein, 2015; Rademacher, 2022). By following the previous BPMN extension concept, the BPMN basic elements have been modified in (Lazaropoulos, 2021a) so that BPMN diagrams can be notationally aligned with other business process modeling standards, which may be used for business process modelling across the different departments of the same enterprise or the external partners. In any case, BPMN standard can regulate the operation of business processes, simply denoted as BPMN business processes, that has an impact on the enterprise's deliverable quality and on the satisfaction of the external and / or internal customers.

To further regulate their business process operation, Service Level Agreements (SLAs) are applied by the enterprises so as to guarantee their own operations in a business perspective. Actually, SLAs are contracts that may define the business process operation while the enterprise provides SLAs to the external and / or internal customers, by detailing: (i) the agreement; (ii) terms used; (iii) parties involved; (iv) performance targets; (v) means for measuring performance; (vi) penalties or bonuses for under- or over-performance, respectively; (vii) customer's obligations; and (viii) ways in which disagreements or changes are negotiated (Ahmad et al, 2020). The inverse procedure occurs in the case of the outsourced business operations of the enterprises. In total, Service Level Management (SLM), which is part of the broader framework of Information Technology Service Management (ITSM) of the enterprises, defines and monitors the outgoing and incoming SLAs (Ahmad et al, 2020; ITIL3Sm, 2007). Furthermore, an SLA consists of Service Level Objectives (SLOs) that act as the SLA measurable characteristics and, thus, the quantitative means to assess and benchmark the provided service level in terms of: (i) the availability; (ii) the throughput; (iii) the response time; and (iv) the Quality of Service (QoS) (Rastegari & Shams, 2015). Moreover, each SLO is based on corresponding Key Performance Indicators (KPIs) that are deployed by the enterprises across their business processes in order to monitor the performance of different areas of each business process; KPIs provide various measurements and progress overviews during the operation of business processes (Maté et al, 2017; Marr et al, 2004; Parmenter, 2009; Efkarpidis et al, 2022; Yaghmaei, 2018; Cruz Villazón et al, 2020). In fact, KPIs can be defined on one business process instance or on multiple business process instances or by exploiting the measurements of other KPIs (Wetzstein et al, 2008; Domínguez et al, 2019; Río Ortega & Resinas, 2009; Hübner-Bloder & Ammenwerth, 2009). Anyway, standardized frameworks, such as Information Technology Infrastructure Library (ITIL), Capability Maturity Model Integration for Services (CMMI-SVC) and Control Objectives for Information and Related Technologies (COBIT), that are validated all over the world in IT governance and ITSM may assist the enterprises to easier define and monitor their KPIs during the operation of their business processes (Widiyaningrum et al, 2015; Arias & Monroy, 2007; Rusman et al., 2022). Regardless of their definition and monitoring method, SLOs and KPIs can be stored, analyzed and combined with statistical analysis by the business analysts thus offering significant value add for the enterprises (Borges, 2019; Engel et al., 2022). The careful study of SLAs, SLOs and KPIs of business processes may pave the road towards the further exploitation of the KPI performance evaluation system by the management inside the enterprises and towards an assessment tool for the examination of potential IT service outsourcing (Gong et al, 2021; Tairova & Niyazov, 2021; Schneider & Sunyaev, 2016). In addition, the simultaneous awareness of BPMN diagrams of the enterprise's services and of KPIs / SLOs may offer further value add to enterprises not only to more wisely place their KPIs at the exact basic elements of the examined IT business processes but to simulate, predict and optimize the behavior of their KPIs and, thus, of SLOs and, finally, of SLAs without exhaustive in real-life situ service measurement trials or sophisticated frameworks and software (Mukherjee et all, 2017; Mabe & Bwalya, 2022).

The main contribution of this paper is the proposal of: (i) the SLA-aware BPMN IT business process lifecycle; and (ii) the interdepartmental SLA definition framework. The motivation of this paper is that enterprises may exploit the proposed theory so that the testing and preparation of the SLAs for their BPMN IT business processes could be refined while the cooperation of the enterprises' department / subdepartments and external partners can be regulated on the basis of the new SLA – SLO – KPI procedures. To assess the performance of the proposed theory, a real enterprise's BPMN IT business process, which is regulated by an SLA of two main SLOs with the corresponding KPIs, is going to be simulated. The MATLAB / Octave simulation results of this paper are investigated in terms of the proposed BPMN basic element attributes of KPI, SLO and SLA within the context of the SLA-aware BPMN IT business process lifecycle and the interdepartmental SLA definition framework. On the basis of the simulation results of MATLAB / Octave simulation methodology, the contribution and the SLA / SLO responsibilities of the external partners and different departments and / or subdepartments that cooperate in the same BPMN IT business process is expected to be clearly highlighted while the required SLO / KPI improvement actions can be studied, safely negotiated, tested and benchmarked in a computer simulation environment prior to apply them in the harsh real-word conditions. The SLA-aware BPMN IT business process lifecycle and the interdepartmental SLA definition framework are both proposed in this paper while their combined operation and their interaction with the simulation module are analyzed. During the analysis of the simulation results, a number of operations and management issues, such as the interdepartmental SLA responsibility, the IT service outsourcing based on SLAs, SLOs and KPIs, the internal KPI evaluation system for the enterprises' personnel and the enterprises' digital transformation, is going to be discussed.

The rest of this paper is organized as follows: In Section 2, the relevant literature in SLA and IT services is reported with reference to: (i) the SLA-aware BPMN IT business process lifecycle; and (ii) the interdepartmental SLA definition framework. Special attention is given to the definition of suitable SLOs and KPIs for BPMN IT business processes. Section 3 briefly presents the BPMN standard and its corresponding diagrams as well as a set of popular BPMN basic elements that is further extended with SLO and KPI attributes. In Section 4, simulation results and discussion of a representative real IT business process are given in terms of the BPMN basic element attributes of KPI, SLO and SLA within the context of the SLA-aware BPMN IT business process lifecycle and the interdepartmental SLA definition framework. Thoughts and steps about the future's research direction of the paper are provided. Section 5 concludes this paper.

2.0 SLA and IT Services – Definition of Suitable SLOs and KPIs for BPMN IT Business Processes

In this Section, the SLA-aware business process lifecycle and the interdepartmental SLA definition framework for BPMN IT business processes are first presented so that suitable SLAs, SLOs and KPIs can be defined for the BPMN IT business processes. Apart from the definition of the SLOs and the KPIs, the role of the simulation module is highlighted in the interdepartmental SLA definition framework while certain issues such as the stepwise approach of SLA management, the interdepartmental responsibility, the KPI personnel evaluation system and the SLO / KPI improvement actions are raised for the first time.

2.1 SLA and IT Services – SLA - Aware BPMN IT Business Process Lifecycle

Before the enterprise offers the SLAs for its respective IT services to the external and / or internal customers, the enterprise should be able to initially assess the performance of its IT services. In this paper, IT service is defined as the service provided to one or more external and / or internal customers by the enterprise, based on the use of enterprise's IT resources (personnel, hardware, software and supporting infrastructure) in order to support the customer's business processes (Ahmad et al, 2020). As the definition of SLAs of IT services is concerned, SLA is the formal negotiated agreement between the enterprise that offers its IT services and the external and / or internal customer that receives the enterprise's IT services analyzing the delivered IT service and IT service level targets in order to create a common understanding about QoS, priorities and responsibilities of the stakeholders (Ahmad et al, 2020; Ahmad & Shamsudin, 2013; Beloglazov et al, 2015). When the provided IT service stands for a BPMN IT business process, its performance can be reflected on the SLOs and the KPIs of its BPMN basic elements while the overall SLOs of the BPMN IT business process can be computed by aggregating the respective SLOs and KPIs of the involved BPMN basic elements (Barros et al, 2014; Borges, 2019; Wetzstein et al, 2008). SLOs can exploit KPIs, which are defined either from scratch or selected from a set of KPI libraries, that are deployed by the enterprises across their BPMN IT business processes to monitor the performance of different areas of the BPMN IT business processes (Maté et al, 2017; Aksu et al, 2019; Marr et al, 2004; Parmenter, 2009). The KPIs may measure the progress of the achievement of a business strategy and its objectives. Two different KPI types are supported, say, atomic KPIs and composite ones while KPI values can be collected on one business process instance or on multiple business process instances (Maté et al, 2017; Wetzstein et al, 2008; Aksu et al, 2019). In fact, the SLOs exploit and set constraints only on specific KPIs that are of interest for the provided IT service while the plethora of other KPIs can still measure and control the operation of the BPMN IT business processes.

With reference to (Wetzstein et al, 2008), the SLA-aware business process lifecycle is here modified to the SLA-aware BPMN IT business process lifecycle in order to set a compass and give a start signal to the enterprises prior to offer their SLOs (and their corresponding SLAs) to the external and / or internal customers when their BPMN IT business processes occur. The SLA-aware BPMN IT business process lifecycle, which is a rather self-awareness task for the enterprises, describes an initial stepwise approach that consists of three major phases:

- *Modeling*: During this first phase, the enterprises are required to follow three steps, namely: (i) List their supported IT services and detail the respective IT business processes; (ii) Apply the BPMN standard to their IT business processes and outline the involvement of the different enterprise's departments and / or subdepartments and external partners; and (iii) Specify the SLA performance requirements for their BPMN IT business processes. The SLA performance requirements come from the enterprise's strategy concerning the competition, the enterprise's desired position to the IT service market and the current enterprise's worldview regarding its customer target groups, policies and regulations (Wetzstein et al, 2008). The enterprise's SLA performance requirements that are prepared during this phase have a direct impact on the selection and definition of SLOs and KPIs as well as the SLO and KPI positioning across the BPMN diagrams of the BPMN IT business processes.

- *Configuration*: This phase follows the initial modeling phase and theoretically investigates whether the SLO and KPI of the examined BPMN IT business process may reach the desired SLO and KPI requirements of the modeling phase. By studying the BPMN diagrams of the examined BPMN IT business process, the overall SLOs and KPIs of the BPMN IT business process can be theoretically approximated by aggregating the SLOs of the involved BPMN basic elements following the BPMN diagram dependencies (BPMN flow and connecting objects, which define the BPMN diagram dependencies, are detailed in the following Section). In this phase, the primitive interdepartmental responsibility issue rises since the guarantee for SLOs between different departments in the same enterprise implies inner-SLAs between the department provider and the department customer. It is obvious that: (i) partners cooperating in the enterprise's BPMN IT business processes must guarantee their IT services through SLAs; and (ii) the selection of enterprise's partners has as a result that their IT services with corresponding KPIs and SLOs are concatenated in such a way that after aggregating their performance values, the overall respective target KPIs and SLOs are satisfied.

- *Execution*: During this final phase, BPMN IT business processes start to operate; and the SLOs and KPIs are in the operation phase too. The overall BPMN IT business process performance is monitored by SLOs and KPIs. In the current phase, that is the first trial and error phase, the target values of SLOs and KPIs are challenged. Not to have significant deviations from the target values of SLOs and KPIs, a strong theory and practical background is required that is based on measurement data and statistical analysis (Alves et al, 2010; Fotrousi et al, 2014). The SLO and KPI mapped dependencies from the BPMN diagrams, which have been revealed during the configuration phase, are here analyzed so that the deviation of SLO and KPI target values can be explained and further investigated (Wetzstein et al, 2008). Anyway, the execution phase creates the big data of BPMN IT business processes that are the feed data for the proposed interdepartmental SLA definition framework for BPMN IT business processes and its simulation module.

Actually, the SLA-aware BPMN IT business process lifecycle, which has been presented, is the introductory movement towards the digital transformation of BPMN IT business processes where the first big data concerning the SLA, the SLOs and the KPIs are collected, stored, analyzed and combined with the business analytics. The big data of the SLA-aware BPMN IT business process lifecycle are going to feed the interdepartmental SLA definition framework that is the permanent and systematic approach towards defining the optimized SLAs, the SLOs and the KPIs in terms of the respective target values.

2.2 SLOs and KPIs for BPMN IT Business Processes – Interdepartmental SLA Definition Framework

To ensure the success of executing the SLA-aware BPMN IT business process lifecycle of Section 2.1, QoS attributes, priorities, dependencies and responsibilities of the BPMN IT business processes should be considered during the proper definition of the SLOs and the KPIs. Towards that direction, a detailed dictionary of QoS requirements for IT business processes that is adopted for the BPMN IT business process of this paper is reported in (Castro & Fantinato, 2018); say, the main references of this dictionary are categorized into three research subjects, namely:

- QoS attributes for software and web services (International Organization for Standardization, 2002; International Organization for Standardization, 2010; Sommerville, 2010; Lee et al, 2003);
- Web services discovery using NFRs (Alrifai & Risse, 2009; Liu et al, 2004; Zeng et al, 2003; Borges et al, 2019); and
- Other IT service subjects (Abramowicz et al, 2006; Garcia & de Toledo, 2008).

On the basis of the aforementioned three research subjects and the QoS characteristics of ISO/IEC 25010 product quality model (International Organization for Standardization, 2010), eight IT business process QoS requirement categories have been assumed in (Castro & Fantinato, 2018), namely: (1) Performance efficiency; (2) Compatibility; (3) Usability; (4) Reliability; (5) Security; (6) Maintainability; (7) Portability; and (8) Compliance. It is evident that the previous QoS requirement categories may also act as the main application areas of the SLOs and the KPIs that should be deployed across the BPMN IT business processes and further taken into account during the SLA preparation. More specifically, with reference to the previous eight IT business process QoS requirement categories, 93 IT business process QoS requirement subcategories have been proposed in (Castro & Fantinato, 2018) that further facilitate the anyway difficult task of the definition of the suitable SLOs and KPIs for BPMN IT business processes. With reference to (Castro et al, 2019; Castro & Fantinato, 2018), an excerpt of the 93 IT business process QoS requirement subcategories that is going to be used in the following analysis is reported in Table 1; apart from the title and the definition of the applied IT business process QoS requirement subcategory, case studies of suitable and popular SLOs of the literature for the enterprises are added in each subcategory as well as the required measurement period. As the applied KPIs of Table 1 are concerned, their title, operation and type are reported for the corresponding SLO case studies.

From Table 1, it is clear that the following general principles from the literature have been followed while developing SLOs and KPIs, namely (Alomary, 2020): (i) Accountability and performance measurement; (ii) Reliability and validity; (iii) Improvement; (iv) Benchmarking; (v) Relevance; and (vi) Clarity and consistency. The operation of the SLOs and KPIs remain the same (with slight improvements) during the execution phase of the SLA - aware BPMN IT business process lifecycle thus providing the first big data concerning the current behavior of the BPMN IT business processes. Anyway, the optimization of SLA technical terms of the BPMN IT business processes is going to be implemented during the operation of the interdepartmental SLA definition framework that is the permanent and systematic approach towards defining optimized SLOs and KPIs for the SLA preparation in terms of the respective desired values.

With reference to (Cho et al, 2017), the interdepartmental SLA definition framework is here proposed and illustrated in Figure 1. The proposed framework describes the phases from the management decision to prepare for the first time an SLA (or to improve an SLA for a BPMN IT business process) till its final preparation and the update of the BPMN IT business process. Note that the interdepartmental SLA definition framework of Figure 1 describes a general BPMN IT business process in which various departments and external partners of the enterprises cooperate.

With reference to Figure 1, after the management decision to prepare the new SLA, all the stakeholders of the BPMN IT business process (i.e., Department A, other Departments and External Partners) are informed about the Managers' intentions. After the SLO / KPI discussions and the agreement with the Department A, the Managers' intentions have to do with the desired SLOs and KPIs that are going to be part of the new SLA regarding the operation of the examined IT service. Note that all the deliverables about the SLOs and the KPIs are illustrated in Figure 1 in cyan color across the interdepartmental SLA definition framework. By exploiting the big data from the operation of either the SLA-aware BPMN IT business process lifecycle (when the first SLA preparation for the BPMN IT business process occurs) or the interdepartmental SLA definition framework (after the first SLA preparation for its improvement); and the business analysis, the current SLOs and KPIs of the BPMN IT business process may be retrieved as well as its BPMN diagram with the extended BPMN basic elements with SLO and KPI attributes, which are illustrated in green color and analyzed in the following Section. Since the desired SLOs and KPIs may hold respective changes for the other departments and the external partners that are involved in during the BPMN IT business process, their SLO and KPI proposals are received. Being available: (i) the desired SLOs and KPIs; (ii) the current SLOs and KPIs; (iii) the SLOs and KPIs proposals from those involved in the process; and (iv) the BPMN diagram with the extended BPMN basic elements with SLO and KPI attributes, the simulation module, which is shown in yellow color in the Decision Group, can benchmark and test all the desired scenarios while continuous negotiations among the stakeholders can occur thus aiming at the best SLO and KPI compromise. The compromise result of the stakeholders in the Decision Group is reflected on the optimized SLOs, the optimized KPIs and the optimized extended BPMN diagram with SLO and KPI attributes. At the same time, the other departments and the external partners are also informed about their respective optimized SLOs and KPIs. Of course, new SLAs, which are shown in red color, are defined, agreed and signed that can guarantee the performance of the entire BPMN IT business and the performance of the other departments and the external partners among them. After the required update of the business process operation of all the stakeholders, the new BPMN IT business process enters in the execution phase. Note that the optimized SLOs, the optimized KPIs, the SLAs and the optimized extended BPMN diagram are the output big data of the interdepartmental SLA definition framework that are going to be exploited not only during the operation of the BPMN IT business process but when the need for its SLA preparation improvement appears.

From Figure 1, several interesting remarks concerning the interdepartmental SLA definition framework can be pointed out. More specifically:

Table 1. Indicative SLOs and KPIs for the preparation of BPMN IT business process SLAs

IT Business Process QoS Requirement Subcategory in SLA		**SLO**				**Applied KPIs**		
Title (ID in (Castro & Fantinato, 2018)	**Definition**	**Title**	**Measurement Period**	**Scenario**	**ID**	**Title**	**Operation**	**Type**
Availability (11)	Proportion of total time (or of total number of executions) during which a service is operational and accessible when required for use (Castro & Fantinato, 2018; International Organization for Standardization, 2010)	Availability	Over a year	The business process will be available 95% of the time (or of the number of executions)	A	Counter_A_1	Counter at the Start Event (Timer Trigger) of the BPMN IT business process	atomic | multiple business process instances
						Counter_A_2	Counter at the End Event of the BPMN IT business process	atomic | multiple business process instances
						Mathematical Operator_A_1	(Counter_A_2 divided by Counter_A_1) times 100%	composite | one business process instance (every year)
						Flag_A_1	1 if MathematicalOperator_A_1 is equal or greater than 95%	composite | one business process instance (every year)
Response Time (69)	Time necessary to complete a certain service request, from the moment it is dispatched until a response is received (Castro & Fantinato, 2018; Lee et al, 2003)	Response Time (Generic case - prerequisite)			B	Counter_B_1	Counter at the Start Event (Timer Trigger) of the BPMN IT business process	atomic | multiple business process instances
						Counter_B_2	Counter at the End Event of the BPMN IT business process	atomic | multiple business process instances
						Duration_B_1	Time duration from the Start Event to the End Event of the BPMN IT business process	atomic | multiple business process instances
		Response Time 1	Over a month	85% of completion of the entire business process within 11h of receiving a request	B1	Flag_B1_1	1 if Duration_B_1 is equal or lower than 11h	composite | multiple business process instances
						Counter_B1_1	Counter at the End Event of the BPMN IT business process if Flag_B1_1 is equal to 1	composite | multiple business process instances
						Mathematical Operator_B1_1	(Counter_B1_1 divided by Counter_B_1) times 100%	composite | one business process instance (every month)
						Flag_B1_2	1 if MathematicalOperator_B1_1 is equal or greater than 85%	composite | one business process instance (every month)
		Response Time 2	Over a month	99.5% of completion of the entire business process within 23h of receiving a request	B2	Flag_B2_1	1 if Duration_B_1 is equal or lower than 23h	composite | multiple business process instances
						Counter_B2_1	Counter at the end Event of the BPMN IT business process if Flag_B2_1 is equal to 1	composite | multiple business process instances
						Mathematical Operator_B2_1	(Counter_B2_1 divided by Counter_B_1) times 100%	composite | one business process instance (every month)
						Flag_B2_2	1 if MathematicalOperator_B2_1 is equal or greater than 99.5%	composite | one business process instance (every month)

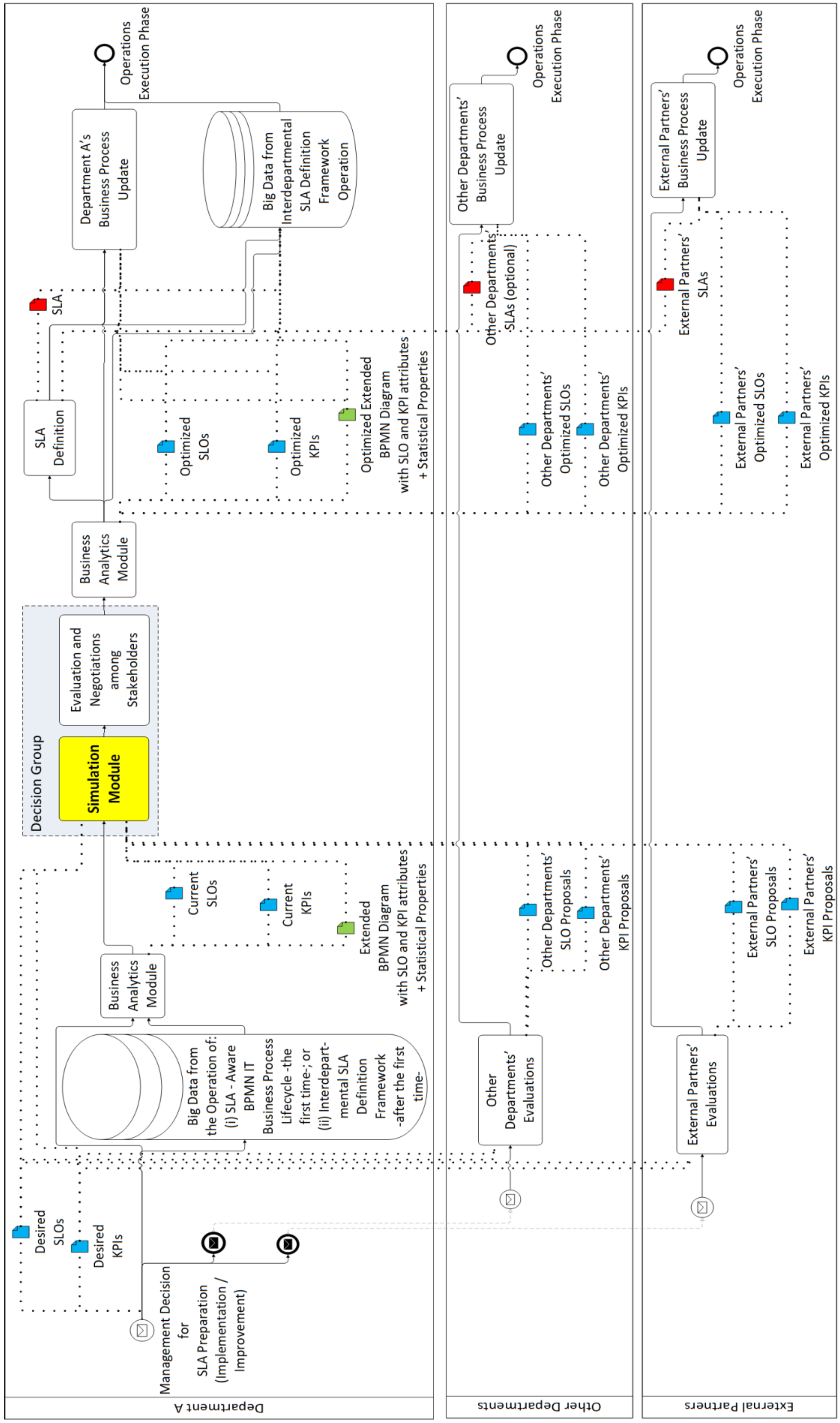


Figure 1. The interdepartmental SLA definition framework for a BPMN IT business process.

- The simulation module stands as the heart of the interdepartmental SLA definition framework. Here, it should also be praised the role of the business analytics module that prepares the input and the output of the simulation module; say, SLOs, KPIs, extended BPMN diagrams and the statistical properties of the basic elements of the BPMN IT process. Apart from the business analytics module, the simulation module cooperates with Evaluation and Negotiations among Stakeholders module in the Decision Group; negotiations among the stakeholders inevitably create technology trade-offs and SLO / KPI scenarios that further involve the Department A, the other Departments of the enterprise and the external partners so that a compromise among their optimized SLOs and KPIs can be achieved (see Figure 1). Except for the SLO / KPI scenarios due to the stakeholders' negotiations, SLO / KPI improvement actions, which may improve the statistical properties of the basic elements and the QoS performance of the BPMN IT process, can also be treated as SLO / KPI scenarios and are examined by exploiting the stepwise approach of the interdepartmental SLA definition framework, the available big data from the operation of either the SLA-aware BPMN IT business process lifecycle or the interdepartmental SLA definition framework and the statistical analysis of the business analytics module. Therefore, a great number of SLO / KPI scenarios can be studied, safely negotiated, quickly tested and benchmarked only in a computer simulation environment prior to apply and validate them during the operations execution phase of the BPMN IT business process.

- The richness and the quality of the big data from either the SLA-aware BPMN IT business process lifecycle or the interdepartmental SLA definition framework help the simulation module to perform more accurate and more realistic optimizations. Towards that direction, the further integration of big data analytics from other fields of the enterprise's operations, the high performance computing and the adoption of cloud computing solutions, which are among the virtues of the enterprise's digital transformation, can benefit the simulation module (Xu et al, 2015). In addition, Artificial Intelligence (AI), Machine Learning (ML) and neural networks, which are also a today's trend of the enterprises' digital transformation, can significantly uplift the performance of the business analytics and simulation modules by further exploiting the available big data collected by the enterprise's general operations and the change behavior of the BPMN IT business process towards the derivation of until now unknown input-output relations and the provision of real-time, short-term and medium-term predictions for SLOs and KPIs (Lazaropoulos, 2021b).

- The interdepartmental SLA definition framework highlights the general partnership characteristics of the SLA-aware business processes though the SLA deliverables of the SLA definition module for the stakeholders. Indeed, the QoS responsibilities among the departments and the external partners for the SLA guaranteed BPMN IT business process are negotiated, agreed and signed in the respective SLAs. Actually, the signed SLAs, even at the level among different Departments within the same enterprise, act as the back to back contract agreements where the stakeholders among them are reliant on their actions in order to fulfil the QoS obligations of the BPMN IT business process (Adels et al, 1997).

- Although the optimized SLOs and KPIs define the performance and responsibilities among the stakeholders during the short-term and medium-term operation of the BPMN IT business process, a great deviation between the optimized SLOs and KPIs and the respective desired ones should concern the management, IT department and supplier & third-party department. To mitigate high SLO / KPI deviations and ensure higher future's services, decisions, such as the IT service outsourcing or the change of external partners, may be the arrows in the administration's quiver that must be carefully considered after assessing their benefits and advantages (Routroy & Pradhan, 2014; Schneider & Sunyaev, 2016; Wan & Chan, 2007).

- These next-generation SLA-aware business processes that are based on the BPMN standard and KPIs imply that the enterprises, enterprise's departments and the external partners may have continuously and over time available their performance records in all the BPMN IT business processes in which they are participating in terms of SLAs, SLOs and KPIs. The aforementioned records of SLOs and KPIs can become the scientific performance appraisal system for the management personnel to enhance the competitiveness and achieve the development goals of the enterprises and enterprise's departments (Peng, 2022). Indeed, the KPI management can: (i) stimulate the internal potentials of departments, subdepartments and their employees; (ii) demonstrate the rationality of the operations and the evaluation; (iii) help towards the achievement of the enterprise's development goals; (iv) improve the management decisions; and (v) enhance the enterprise's market competitiveness (Gong et al, 2021; Tairova & Niyazov, 2021).

Already been mentioned, the simulation module stands as the heart of the interdepartmental SLA definition framework. The way that the simulation module handles the extended BPMN diagrams of the BPMN IT business processes and the statistical properties of the basic elements of the BPMN diagrams are discussed in the next Section.

3.0 Extended BPMN Diagrams, BPMN Simulation Equivalence Table and Simulation Module

In this Section, three critical internal factors that concern the simulation operation and performance of the interdepartmental SLA definition framework are analyzed. First, a brief synopsis of the BPMN standard is given with emphasis on its most popular basic elements in the enterprise's documentation as well as their categorization. Second, the modified BPMN basic elements of (Lazaropoulos, 2021a) are further extended with SLO and KPI attributes in the BPMN simulation equivalence table. Third, this Section concludes with the examination of the simulation module where: (i) additional features are given for the applied KPIs and the general simulation operation; and (ii) certain aspects are touched upon that have to do with the simulation module interaction with the enterprise's business analytics and the interdepartmental SLA definition framework.

3.1 BPMN Standard and its Basic Elements

In accordance with (Lazaropoulos, 2021a; Chinosi & Trombetta, 2012; Object Management Group, 2011; Allweyer, 2016; Wohed et al., 2006), the BPMN standard aims at quickly describing complex business processes via appropriate diagrams that can be easily and intuitively understandable. Similarly to other business process modeling standards of the literature, say, classic flowcharts, Gantt charts and Petri nets, BPMN diagrams are characterized by their flowchart nature while BPMN diagrams can be mapped to business execution languages and cooperate with Enterprise Resource Planning (ERP) systems (Lazaropoulos, 2021a). Already been mentioned, the BPMN standard has been proposed and maintained by the OMG and has now evolved into the ISO / IEC 19510:2013 standard (Object Management Group, 2011; White, 2004a; ISO, 2013)

According to (Lazaropoulos, 2021a; White, 2004b), a BPMN diagram consists of four element categories; say, the flow objects, the connecting objects, the swimlanes and the artifacts. Each of the four categories comprises subcategories with the corresponding BPMN basic elements. The four categories with their subcategories and the corresponding BPMN basic elements are reported in Table 2. Note that not all the BPMN basic elements have been reported but a number of the most popular ones with reference to the enterprise's documentation. The description of the BPMN basic elements applied in this paper is given in (Lazaropoulos, 2021a).

From Table 2, the rich portfolio of BPMN basic elements allows the BPMN standard to describe the operations of the enterprise's IT business processes in a simple and understandable way even if high complexities may occur and require to be expressed. Of course, the already rich portfolio of BPMN diagram basic elements may further be modified by business process designers with internal markers so as to avoid DSMLs and better satisfy their domain-specific needs. With this thought, the basic BPMN elements of Table 2 have been modified in (Lazaropoulos, 2021a) so that the BPMN diagrams can cooperate with classic flowcharts, Gantt charts and Petri nets in a notational alignment concept. In this paper, the already modified BPMN basic elements of (Lazaropoulos, 2021a) are further extended with SLO and KPI attributes in the following subsection so that the BPMN simulation equivalence table can be presented. The definition of the enterprise's BPMN IT business processes is fundamental prerequisite so that the SLA-aware BPMN IT business process lifecycle and the interdepartmental SLA definition framework can operate.

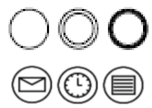
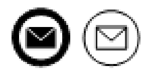
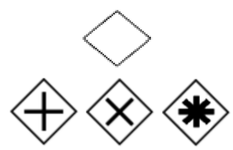
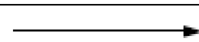
3.2 BPMN Simulation Equivalence Table

In general, not only do modeling and simulation may allow the better understanding of the operations and performance of the real-life systems, they also enable the stakeholders to predict system behavior before a system is actually launched and accurately examine systems under varying operations scenarios. Software platforms, such as MATLAB / Octave and Simulink software, may provide comprehensive state-of-the-art coverage of modeling and simulating issues while a myriad of physical, conceptual and real-life systems can be modeled and simulated by effectively using code principles and techniques (Anița, 2011; Chaturvedi, 2017; Kaisare, 2017).

In this paper, the BPMN simulation equivalence table is the result of a straightforward and simplified process that can correspond each extended BPMN basic element with SLO and KPI attributes to respective code fragment so that the simulation code that runs in the simulation module of the interdepartmental SLA definition framework can be considered to be almost ready after the step of the BPMN simulation equivalence table (see the Supplementary Material of this paper).

Prior to prepare the BPMN simulation equivalence table, the SLO and KPI attributes that are required for the extension of the BPMN basic elements should be defined by also considering the existing BPMN basic element modifications of (Lazaropoulos, 2021a). In accordance with (Lazaropoulos, 2021a), the category, the name and the symbol of the modified BPMN basic elements are demonstrated in the first three columns of Table 3 while the additions of the modified BPMN basic elements to the original ones are presented in red color. After the consideration of the BPMN basic element modifications, SLO and KPI attributes should be taken into account; the SLO and KPI attributes may literally come from the title and definition of the IT business process QoS requirement subcategories of interest and their corresponding SLOs and applied KPIs are shown in Table 1. Note that during the preparation of the SLO and KPI attributes of the extended BPMN basic elements, their statistical nature should be kept in the mind of the business process designers. With reference to the IT business process QoS requirement subcategories of Table 1, the following SLO and KPI attributes should be taken into consideration during the preparation of the extended BPMN basic elements of this paper:

Table 2. Original basic elements in BPMN diagrams (Lazaropoulos, 2021a; White, 2004b)

Category of BPMN Basic Elements	**Subcategory of BPMN Basic Elements**	**BPMN Basic Element Symbols**	**BPMN Basic Element Name**
Flow Objects	Event		*First row*: Start Event; Intermediate Event; End Event *Second row*: Message Trigger; Timer Trigger; Business Rule
	Message Event		Sending Message Event; Receiving Message Event
	Activity		(Generic) Activity
	Gateway		*First row*: (Generic) Gateway *Second row*: Parallel Flow Gateway; Exclusive Flow Gateway; Event-Based Flow
Swimlanes	Pool		Pool
	Lane		Lanes
Artifacts	Data Object		Data
	Database		Database
	Group		Group
	Text Annotation		Text Annotation (comments)
Connecting Objects	Sequence Flow Line		Sequence Flow line
	Message Flow Line		Message Flow line
	Association Line		Association line

- *Availability*: In accordance with the definition of Table 1, SLO A of Table 1 and the modified BPMN basic elements of Table 3, the availability may be affected by planned and unplanned downtimes. The availability probability p_{av} should be statistically computed and considered for a number of extended BPMN basic elements regardless of the nature of the downtimes. Since an availability probability statistical computation is required, the categories / subcategories of the extended BPMN basic elements that are affected by this extension are those of the Flow Objects, the Artifacts / Data Object and the Artifacts / Database. The availability probability can be ignored in all the remaining extended BPMN basic elements.

- *Response Time*: By studying the response time definition and the SLO B, B1 and B2 of Table 1, it is evident that the response time is required to be computed for the entire BPMN IT business process and for this reason the temporal characteristics of the extended BPMN basic elements should be statistically computed and considered across the entire BPMN IT business process. More specifically, assuming that the temporal characteristics of the BPMN basic elements follow normal distributions in this paper, the duration mean d_{μ} and the duration variance $d_{\sigma 2}$ should be computed for the extended BPMN basic elements of the following categories / subcategories: the Flow Objects, the Artifacts / Data Object and the Artifacts / Database. The duration mean and duration variance can be neglected in all the remaining extended BPMN basic elements. Note that the duration mean is already available for the Activities from the BPMN basic element modifications of (Lazaropoulos, 2021a) thus proposing a rough approximation for deterministic simulations where duration variance is assumed to be equal to zero and the only time-consuming parts of the BPMN IT business processes are assumed to be the Activities.

From the previous analysis concerning the SLO and KPI attributes that should be taken into consideration during the preparation of the extended BPMN basic elements of this paper, the role of big data and business analytics module, as shown in the interdepartmental SLA definition framework, remains crucial. Indeed, the big data module offers the required pool of data for the statistical analysis, which is performed by the business analytics module, so that: (i) all the required distribution parameters for the duration (i.e., duration mean and duration variance); and (ii) the availability probabilities; for the extended BPMN basic elements can be safely calculated (i.e., a high population of samples implies safer results during the simulation process). Synoptically, the fourth column of Table 3 presents the extended BPMN basic element symbols of interest in this paper where the modifications of (Lazaropoulos, 2021a) and the SLO / KPI attributes are added in red and green color, respectively. Note that the SLO and KPI attributes for each of the extended BPMN basic element symbol follows the pattern of $[p_{\mathrm{av}} \quad d_{\mu} \quad d_{\sigma 2}]$ by taking into account the findings of the previous analysis. Of course, the assumed SLO and KPI attributes for the extended BPMN basic elements permit the handling of a decent number of the 93 IT business process QoS requirement subcategories of (Castro & Fantinato, 2018), especially those that are related with time and availability. In the fifth column, the IDentity (ID) of each of the extended BPMN basic element is given. With reference to Table 3 and the Supplementary Material of this paper, the proposed BPMN simulation equivalence table can further allow the one-to-one correspondence of the extended BPMN basic elements of the fourth column with code fragments, namely:

- Through a common code fragment that may act as the code fragment basis, the handling of the extended BPMN basic element symbols can remain the same to a certain extent. In fact, the basic object MATLAB / Octave code fragment is sufficient for the operation description of ID01-ID11 and ID18-ID19 extended BPMN basic element symbols.

- In accordance with (Lazaropoulos, 2021a) and Table 2, the Gateways represent the decisions that need to be taken during the BPMN IT business process thus controlling the Sequence Flow lines through forking, merging and joining in the

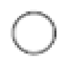
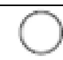
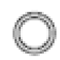
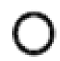
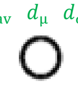
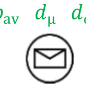
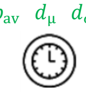
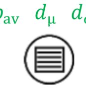
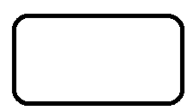
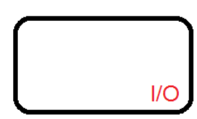
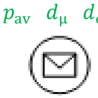
BPMN diagram. The Internal markers further specialize the use of the generic Gateway symbol as presented in Table 3 where 5 specialized Gateways are assumed in this paper. Since the extended BPMN basic element symbols of Gateways initially comprise same SLO and KPI attributes with the ID1-ID11 and ID18-ID19 ones, the basic object code fragment also remains valid. To take into account the control of the Sequence Flow lines through forking, merging and joining during the simulation operation, additional special attributes and corresponding code fragments are required to be added in each case of Gateways. The additional special attributes are added in dark green color inside and below the extended BPMN basic element symbols. More specifically:

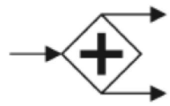
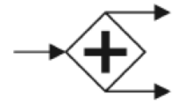
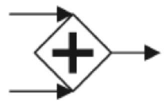
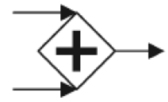
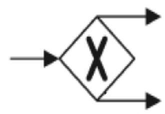
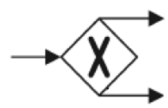
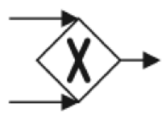
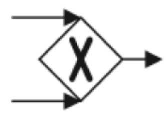
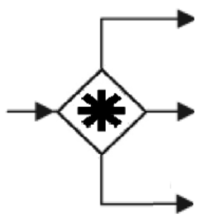
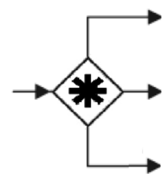
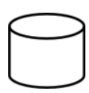
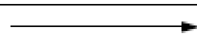
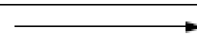
- *Gateway (Parallel Fork)*: In this type of Gateway, all the outgoing sequence flows are followed in parallel thus creating a concurrent execution for each of the sequence flows (Mahrous, 2017). By taking into account the definition of the Gateway (Parallel Fork), the following extensions are required: (i) No additional special attributes are required to be added in the extended BPMN basic element symbol; and (ii) Multiple Tokens are required for the outgoing sequence flows.

- *Gateway (Parallel Join)*: In this type of Gateway, all concurrent sequence flows arriving at the Gateway (Parallel Join) wait at the gateway until an execution activation arrives for each of the incoming sequence flows. Then the process continues passing the Gateway (Parallel Join) (Mahrous, 2017). By taking into account the definition of the Gateway (Parallel Join), the following extensions are required: (i) No additional special attributes are required to be added in the extended BPMN basic element symbol; (ii) Multiple Tokens come from the incoming sequence flows while the basic object starts to run when all the incoming Tokens are activated; and (iii) The duration of the BPMN IT business process comes from the maximum of the computed durations of the incoming sequence flows.

- *Gateway (Data-based XOR Decision) and Gateway (Event-based XOR Decision)*: Although differences occur during the operation of the two gateways in the BPMN diagrams (i.e., the first one is data-based one whereas the second-one is event-based one), their operation remains the same during the simulation of this paper. In this type of Gateway, the only one outgoing sequence flow depends on the input data or the input event for the Gateway (Data-based XOR Decision) or the Gateway (Event-based XOR Decision), respectively. By taking into account the definition of the Gateway (Data-based XOR Decision), the following extensions are required: (i) The different decisions (e.g., D1 and D2) are added as text in dark green color in the extended BPMN basic element symbol; (ii) For the sake of the simulation, each decision has its appearance probability (e.g., p_{D1} and p_{D2} for decisions D1 and D2, respectively). The aforementioned appearance probabilities are added in dark green color with the other SLO and KPI attributes following the pattern of $[p_{\mathrm{av}} \quad d_{\mu} \quad d_{\sigma 2} \quad p_{\mathrm{D1}} \quad p_{\mathrm{D2}}]$; (iii) A random number generator concerning the simulated decision is applied by taking under consideration the decision appearance probabilities p_{D1} and p_{D2}; and (iv) For the continuation of the simulation process, depending on the output of the decision random number generator, the token may pass either to decision D1 or to decision D2. Already been discussed, similar object code applies in the case of the Gateway (Event-based XOR Decision) that is the ID15 extended BPMN basic element of the Table 3. In a similar way, more than three decisions can be programmatically considered.

Table 3. The proposed BPMN simulation equivalence table

1st column **Category of Modified BPMN Basic Elements**	2nd column **Subcategory and Modified BPMN Basic Element Name in (Lazaropoulos, 2021a)**	3rd column **Modified BPMN Basic Element Symbol in (Lazaropoulos, 2021a)**	4th column **Extended BPMN Basic Element Symbol**	5th column **Conversion Case ID**
	Event (Start)		 $[\, p_{av} \;\; d_{\mu} \;\; d_{\sigma 2} \,]$	ID01
	Event (Inter-mediate)		 $[\, p_{av} \;\; d_{\mu} \;\; d_{\sigma 2} \,]$	ID02
	Event (End)		 $[\, p_{av} \;\; d_{\mu} \;\; d_{\sigma 2} \,]$	ID03
	Event (Message Trigger)		 $[\, p_{av} \;\; d_{\mu} \;\; d_{\sigma 2} \,]$	ID04
	Event (Timer Trigger)		 $[\, p_{av} \;\; d_{\mu} \;\; d_{\sigma 2} \,]$	ID05
	Event (Business Rule)		 $[\, p_{av} \;\; d_{\mu} \;\; d_{\sigma 2} \,]$	ID06
Flow Objects	Activity (Generic Use)	 Activity start date/time, Activity duration and Activity end date/time inside the associated Activity	 Activity start date/time, Activity duration and Activity end date/time inside the associated Activity $[\, p_{av} \;\; d_{\mu} \;\; d_{\sigma 2} \,]$	ID07
	Activity (for Input / Output)	 Activity start date/time, Activity duration and Activity end date/time inside the associated Activity	 Activity start date/time, Activity duration and Activity end date/time inside the associated Activity $[\, p_{av} \;\; d_{\mu} \;\; d_{\sigma 2} \,]$	ID08
	Message Event (Send Message)		 $[\, p_{av} \;\; d_{\mu} \;\; d_{\sigma 2} \,]$	ID09
	Message Event (Receive Message)		 $[\, p_{av} \;\; d_{\mu} \;\; d_{\sigma 2} \,]$	ID10

	Gateway (Parallel Fork)		 [p_{av} d_{μ} $d_{\sigma 2}$]	ID11
	Gateway (Parallel Join)		 [p_{av} d_{μ} $d_{\sigma 2}$]	ID12
	Gateway (Data-based XOR Decision)		 D1 D2 [p_{av} d_{μ} $d_{\sigma 2}$ p_{D1} p_{D2}]	ID13
	Gateway (XOR Merge)		 [p_{av} d_{μ} $d_{\sigma 2}$]	ID14
	Gateway (Event-based XOR Decision)		 D1 D2 D3 [p_{av} d_{μ} $d_{\sigma 2}$ p_{D1} p_{D2} p_{D3}]	ID15
Swimlanes	Pool			ID16
	Lane			ID17
Artifacts	Data Object		 [p_{av} d_{μ} $d_{\sigma 2}$]	ID18
	Database		 [p_{av} d_{μ} $d_{\sigma 2}$]	ID19
	Group			ID20
	Text Annotation			ID21
Connecting Objects	Sequence Flow Line			ID22
	Message Flow Line			ID23
	Association Line			ID24

- *Gateway (XOR Merge)*: The gateway (XOR Merge) presents similarities with the Gateway (Parallel Join). However, at the gateway (XOR Merge), a single incoming sequence flow may activate the Gateway while an outgoing sequence flow may occur each time an incoming sequence flow arrives (Corradini et al, 2015). By taking into account the definition of the Gateway (XOR Merge), the following extensions are required: (i) No additional special attributes are required to be added in the extended BPMN basic element symbol; (ii) Multiple Tokens come from the incoming sequence flows while the basic object starts to run when only one (boolean XOR) of the incoming Tokens is activated; and (iii) Depending on the incoming sequence flow, the duration of the BPMN IT business process comes from the maximum duration of the incoming sequence flow in a similar way to the duration computation of the Gateway (Parallel Join).

The operation of the remaining extended BPMN basic elements, say, ID16-17 and ID20-24 ones, does not directly affect the simulation operation and results.

The proposed BPMN simulation equivalence table achieves in a straightforward and simplified way to: (i) incorporate SLO and KPI attributes in the extended BPMN basic elements; and (ii) may correspond the extended BPMN basic elements with respective code fragments. In the following section, the simulation module is going to act as the integrator towards the simulation operation in the interdepartmental SLA definition framework.

3.3 Simulation Module

In this subsection, the simulation module, which is part of the interdepartmental SLA definition framework, is here analysed. Issues concerning the integrator role of the simulation module and the simulation module interaction with the enterprise's business analytics and the interdepartmental SLA definition framework are discussed.

Apart from the code fragments of the extended BPMN basic elements of Table 3 and of the SLO/KPIs of Table 1 (see the Supplementary Material of this paper), the simulation module acts as the integrator of the aforementioned code fragments into the complete simulation code. Towards that direction, the simulation module is responsible for regulating the following code issues:

- *Counter declaration and initialization*: All the counters that are used in the simulation code are initialized prior to the start of the simulation. These counters, which are initialized prior to the start of the simulation process, are mainly exploited by the SLOs and KPIs during the simulation process.

- *Start of the simulation process*: The simulation process consists of multiple iterations (simulations) so that a high population of samples can be reached while safe conclusions can be supported. Here, it should be highlighted the difference between the real life and the simulation; for each of the examined SLOs of this paper, a measurement period is recommended in Table 2. Depending on the nature of the BPMN IT business process, the recommended measurement periods may be short enough for deducing safe conclusions. For the same previous BPMN IT business process, the huge number of simulations by the simulation module of the interdepartmental SLA definition framework of Figure 1 can unravel any weak point of the BPMN IT business process thus bypassing the measurement period suggestion of Table 2. Therefore, the simulation module: (i) defines the number of simulations by using a for-loop; (ii) sets the master counter (i.e., the

Simulation_Counter) of the entire simulation process; and (iii) renders active each simulation.

- *Token management*: The token management and the duration timer management are the two essential management tools of the simulation module that transform the initially isolated code fragments of the extended BPMN basic elements into the entity of the simulation code. Tokens are the flow regulators across the simulation. With reference to the flow of Petri nets of (Lazaropoulos, 2021a; Rajabi & Lee, 2009; Bauskar & Mikolajczak, 2006), the simulation module is responsible for the following modifications in the simulation code: (i) When two or more flows come out of an extended BPMN basic element –except for the Gateway (Data-based XOR decision) and Gateway (Event-based XOR decision)–, each flow carries its own active token with reference to its BPMN basic element source; (ii) For the Gateway (Data-based XOR decision) and Gateway (Event-based XOR decision), each decision sequence flow again carries its own token but each token is conditionally activated; (iii) When two or more flows enter in an extended BPMN basic element –except for the Gateway (XOR merge)–, the insertion of a Boolean AND restriction among the incoming active tokens is required; and (iv) For the Gateway (XOR merge), one active token of the incoming sequence flows is only required so that the Gateway (XOR merge) starts to run. Except for the sequence flow lines, message and association flow lines can also deliver tokens. At the start of each simulation, the simulation module deactivates all the tokens except for the first one (e.g., the token of the Timer Trigger that is the first extended BPMN basic element of the BPMN diagram).

- *Duration timer management*: Similarly to the token management, duration timer handling is a crucial task since it affects the measurement of the overall duration of the simulation that is a critical KPI for a great number of SLOs. Actually, the duration timers are applied by the simulation module to the different flows that start / finish from / to the extended BPMN basic elements, respectively. The simulation module regarding the insertion and handling of the duration timers is responsible for the following modifications in the simulation code: (i) When the examined BPMN basic element is part of a concatenation of flows that comes from either a decision or a set of outgoing flows a duration timer is required during this concatenation of flows; (ii) One concatenation of flows that connects the Start Event with the End one may keep the simulation duration timer that indicates the simulation duration; (iii) Except for the Gateway (XOR Merge), the concatenation of the flows with the highest value of its duration timer defines the value of the duration timer of the BPMN basic element where different concatenations of flows are concentrated in; and (iv) In the case of the Gateway (XOR Merge), the value of its duration timer is determined by the duration timer maximization of the active and inactive concatenations of flows that enter in the Gateway. Except for the sequence flow lines, message and association flow lines can also deliver tokens. At the start of each simulation, the simulation module resets all the duration timers including the simulation duration timer.

- *Gateway counter deployment and initialization*: For the Gateways (Data-based XOR decision) and Gateways (Event-based XOR decision), their decisions can critically affect the values of KPIs and SLOs. For that reason, the simulation module may selectively deploy counters after the aforementioned Gateways so as to collect valuable operations information. Similarly to the other counters and timers, the initialization of the gateway counters is the responsibility of the simulation module right after the start of each simulation.

The simulation integrates all the aforementioned code fragments of given SLO and KPI attributes so that the simulation process can start and generate its results. With reference to Figure 1, the module of the Evaluation and Negotiations Stakeholders can affect the SLO and KPI attributes of the BPMN basic elements of the BPMN IT business process and, thus, the results of the new simulation process. By comparing the simulation process results, trade-offs among the SLO / KPI attributes and stakeholders may occur.

With reference to Figure 1, the simulation module that is the cornerstone of the interdepartmental SLA definition framework cannot operate without the presence and the preparations of an efficient business analytics module. In fact, the business analytics module represents the platform of the business intelligence and data mining while analyzing the complex business information from the operation of BPMN IT business processes (Chang et al, 2020; Cameron & Raman, 2005; Kohavi et al, 2002; Trkman et al, 2010). The business analytics module provides the input data for the simulation module but also the processing of the output results of the decision group by blending together statistics, domain expertise and result visualization (Chang, 2008; Lazaropoulos, 2020c; Lazaropoulos, 2020a; Lazaropoulos, 2020b).

In the following Section where the simulation results and discussion are given, the simulation module is operationally combined with the business analytics module ensuring that the stakeholders can better understand the operation and the simulation results of real BPMN IT business processes. Towards that direction, a real enterprise's IT business process is shown (Lazaropoulos, 2021a). During this daily IT business process, two Departments of the same enterprise cooperate while two Subderpartments of the same Department complete the process.

4.0 SLA – Aware Business Process Based on BPMN Standard and KPIs – Simulation Results and Discussion

In this Section, the simulation results of the combined operation of the SLA-aware BPMN IT business process lifecycle, the interdepartmental SLA definition framework and the MATLAB / Octave simulation methodology are demonstrated with reference to a representative real BPMN IT business process. First, the BPMN diagram of the IT business process is going to be upgraded with the extended BPMN basic elements of SLO and KPI attributes. Prior to the start of the simulation, the default operation settings of the simulation process are reported while the role of the simulation module regarding the token management and duration timer management of the indicative real BPMN IT business process is studied. Second, the progress of the examined SLA of this paper is evaluated; under the aegis of the simulation module and business analytic modules, the values of the applied SLOs and KPIs are assessed after the simulation of the representative real BPMN IT business process. Discussion follows commenting the SLO and KPI values while SLO / KPI improvement actions that may be implemented towards the mitigation of the problematic SLO and KPI values are investigated. Third, issues such as the stepwise approach of SLA management, the interdepartmental responsibility, the internal KPI evaluation system and the dynamics of the digital transformation towards more robust and efficient SLAs are now discussed in a more practical basis.

4.1 A Real BPMN IT Business Process (Case Study) – Extended BPMN Diagram, Default Operation Settings of the Simulation Process and Simulation Module

First, a real enterprise's BPMN IT business process, which acts as the case study of this paper, is explained and discussed. More specifically, In Figure 2, the extended BPMN diagram of a real enterprise's IT business process is shown. The initial BPMN IT business process, which has been modified in (Lazaropoulos, 2021a) and its modifications are shown in red color, consists of the following modified BPMN basic elements: 1 Start Event (Timer Trigger), 5 Activities (Activity01-05), 4 Data Objects (DataObject01-04), 6 Messages (Message01-06), 1 Database (Database01), 1 Gateway XOR Merge (Gateway01), 1 Gateway Event-based XOR Decision (Gateway02) and 1 End Event (Event End); say, 20 BPMN basic elements of interest. During this daily IT business process, two Departments of the same enterprise (say, Department A and B) cooperate while two Subderpartments of the same Department (say, Subdepartment A and B of Department B) complete the process. The QoS control between the two involved Departments is performed in Gateway02 by the Department A where there are two possible decisions; say, OK and NOT OK. The decision NOT OK implies that the IT business process must practically restart from the Activity02 while the decision OK allows the normal flow of the IT business process towards the Activity05. The extension of the modified BPMN basic elements of Figure 2 with SLO / KPI attributes is shown in green color. Already been mentioned in Section 3.2, the pattern of $[p_{\mathrm{av}} \quad d_{\mu} \quad d_{\sigma 2}]$ is applied for the SLO / KPI attribute extension of the modified BPMN basic elements of Figure 2 whereas the special pattern of $[p_{\mathrm{av}} \quad d_{\mu} \quad d_{\sigma 2} \quad p_{\mathrm{OK}} \quad p_{\mathrm{NOT\,OK}}]$ is exclusively applied in the case of the Gateway02. The SLO / KPI attributes of the extended BPMN basic elements of Figure 2 are updated by the business analytic module of the interdepartmental SLA definition framework that processes the available operations big data of the SLA - aware BPMN IT business process lifecycle. The today's average duration of the BPMN IT business process is approximately 9.5h and the business process must be completed within the working day. Note that the SQL database (Database01) is on-premises.

Prior to the preparation of the MATLAB / Octave simulation code of the simulation module, the operation settings are determined as follows:

- The number of simulations is assumed to be equal to 100,000 in this paper. If each simulation represents one working day in the real-world conditions of the examined business process, this implies that the simulation process collects data of approximately 386.6 years of operations (260 working days in a year). Practically, the SLO and KPI measurement periods of Table 1 can be neglected since the high population of samples can provide the steady state and safe results concerning the SLOs and KPIs of this paper.

- For the sake of simplicity, the duration mean and the duration variance of the start event, end event, gateways, message exchange and data object exchange are assumed to be negligible during the simulation process of this Section (i.e., d_{μ}=0h and $d_{\sigma 2}$=0h). Also, the aforementioned BPMN elements are assumed to be always available without failures or faults.

- All the durations of the other extended BPMN basic elements are assumed to follow the normal distribution with a duration mean d_{μ} and a duration variance $d_{\sigma 2}$ computed by the business analytics module of the interdepartmental SLA definition framework and presented in Figure 2. The availability of the extended BPMN basic elements has been computed by exploiting the big data of the SLA - aware BPMN IT business process lifecycle.

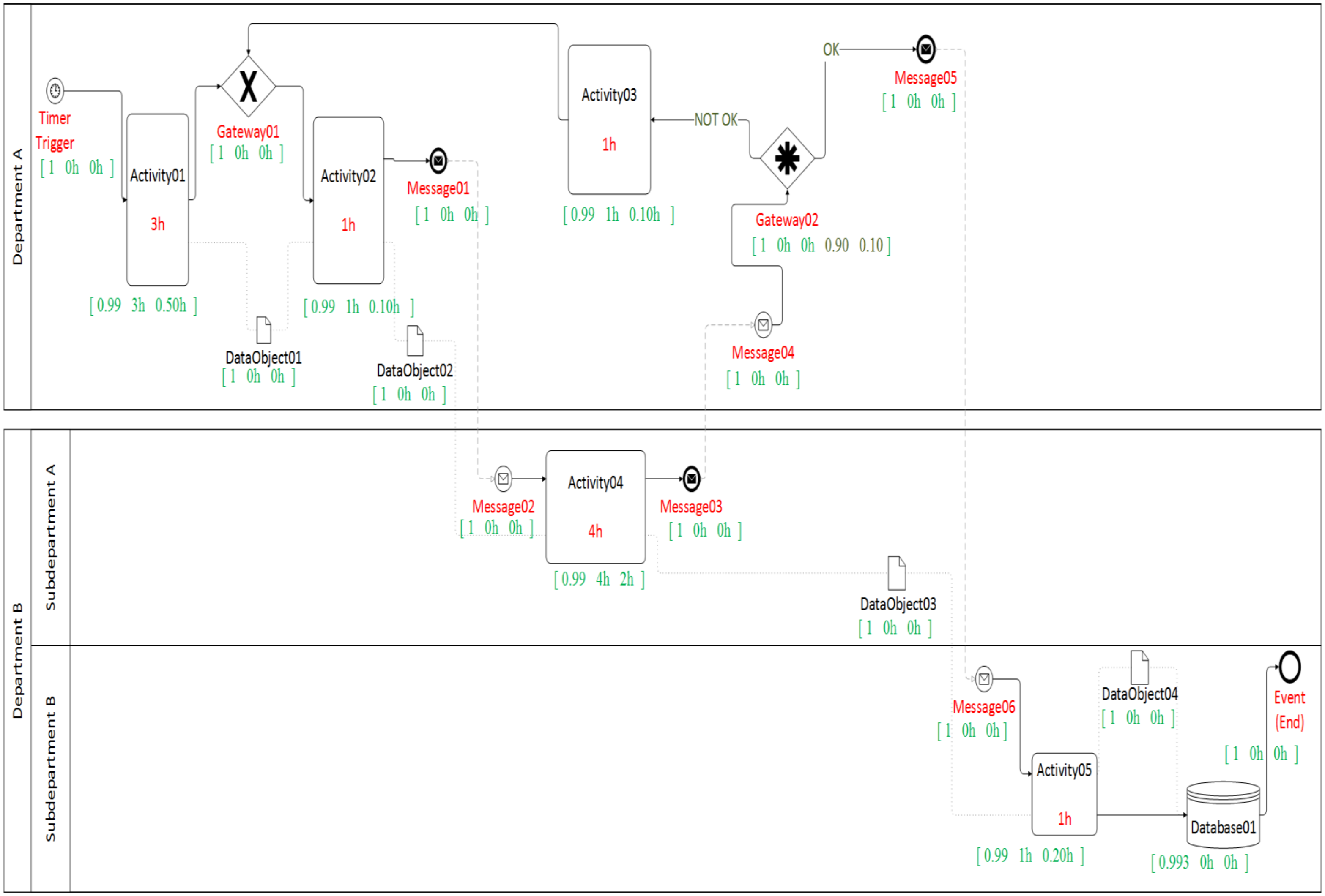


Figure 2. The extended BPMN diagram of the real enterprise's IT business process.

- A gateway counter that acts as a QoS KPI is deployed by the simulation module in Gateway02 so that the different decisions concerning the interdepartmental cooperation can be followed. For the sake of simplicity of the simulation code, the number of NOT OK decisions is saved but only the analytics of the successful flow from the Start to the End Event of the last NOT OK flow are stored. Note that the decision probabilities of the Gateway02 have been computed by exploiting the big data of the SLA - aware BPMN IT business process lifecycle and the daily experience.

It should be noted that as the value range of the operation settings of Figure 2 is concerned, the duration mean, the duration variance and the availability probability of the used extended BPMN basic elements are calculated by exploiting the big data pool of Figure 1 from the operation of the SLA-aware BPMN IT business process lifecycle and the interdepartmental SLA definition framework. As the value range of the SLOs is discussed, their target values are reported in Table 1 and come from the corresponding literature in each SLO case.

Apart from the operation settings for the preparation of the simulation code of the simulation module, the token management and the duration timer management should be fulfilled by the simulation module prior to the start of the simulation process. In Table 4, the token management and the duration timer management are reported with reference to the BPMN IT business process of Figure 2. It is evident that the simulation module simulates the flow of the BPMN diagram via the tokens that connect the extended BPMN basic elements of the simulation code of the simulation process. In addition, the simulation module accurately provides the progress across the BPMN IT business process by continuously keeping the time even though parallel tasks occur. Since all the prerequisites for developing the simulation code of the simulation process have been analyzed, the entire MATLAB / Octave simulation code is provided in the Supplementary Material of this paper. The researcher and the potential reader can freely experiment with the code in (Tutorialspoint, 2022).

In the following subsections, the progress of achieving the SLA that contains the SLOs and KPIs of Table 1 is analytically examined by exploiting the simulation code of the Supplementary Material of this paper.

4.2 Simulation Results Concerning the Progress of the Paper SLA

With reference to Table 1, this paper SLA includes two popular IT business process QoS requirement subcategories (say, availability and response time). For the purpose of this paper SLA and its two IT business process QoS requirement subcategories, two main SLOs with their three SLO variances (i.e., SLO A, B1 and B2) are going to be monitored and benchmarked. For each SLO, corresponding KPIs have already been deployed across the simulation code in order to assist the SLO computations. Apart from the SLO computation, the business analytics module may exploit the simulation results from the applied KPIs so that a continuous monitoring and visualized results can be available either to the enterprise's management or to this paper. For assessing the progress of this paper SLA, two sub-subsections that separately treat the two IT business process QoS requirement subcategories with their corresponding SLOs are examined.

4.2.1 Availability – SLO A

With reference to Table 1, the availability expresses the proportion of the total number of simulations during which the BPMN IT business process is operational and accessible (Castro & Fantinato, 2018; International Organization for Standardization, 2010). Quantitatively and in accordance with SLO A, the BPMN IT business process of this paper is expected to be available 95% of the number of simulations; say, at least 95,000 successful simulations when the simulation process consists of 100,000 simulations. By studying the available applied KPIs of SLO A, MathematicalOperator_A_1 KPI may compute the availability of the BPMN IT business process while Flag_A_1 KPIs examines whether the availability of the BPMN IT business process exceeds 95%, which is the target value of the SLO A. Furthermore, the simulation results of the MathematicalOperator_A_1 and Flag_A_1 KPIs are stored in T_MathematicalOperator_A_1 and T_Flag_A_1 KPI arrays, respectively, so that the time course of the results related to the availability can be examined and further processed during the simulation process.

Table 4. Token management and duration timer management for the BPMN IT business process of Figure 2 by the simulation module

ID	Extended BPMN Basic Element Title in Figure 2	Token Management				Duration Timer Management		
		Incoming Tokens	Boolean Check between Incoming Tokens	Outcoming Tokens	Selective Activation of Outcoming Tokens	Incoming Duration Timer	Computation Method of the Outcoming Duration Timer	Outcoming Duration Timer
BE01	Timer Trigger	1 (by default)	-	Token_Activity01	NO	T (by default)	-	T
BE02	Activity01	Token_Activity01	-	Token_Gateway01a Token_DataObject01	NO	T	-	T_Gateway01a
BE03	DataObject01	Token_DataObject01	-	Token_Activity02a	NO	T_Gateway01a	-	T_Activity02
BE04	Gateway01	Token_Gateway01a Token_Gateway01b	XOR	Token_Activity02b	NO	Token_Gateway01a Token_Gateway01b	Maximum	T
BE05	Activity02	Token_Activity02a Token_Activity02b	AND	Token_Message01 Token_DataObject02	NO	T T_Activity02a	Maximum	T
BE06	Message01	Token_Message01	-	Token_Message02	NO	T	-	T_Activity04a
BE07	DataObject02	Token_DataObject02	-	Token_Activity04a	NO	T	-	T_Activity04b
BE08	Message02	Token_Message02	-	Token_Activity04b	NO	T_Activity04a	-	T_Activity04a
BE09	Activity04	Token_Activity04a Token_Activity04b	AND	Token_Message03 Token_DataObject03	NO	T_Activity04a T_Activity04b	Maximum	T
BE10	Message03	Token_Message03	-	Token_Message04	NO	T	-	T_Activity05a
BE11	DataObject03	Token_DataObject03	-	Token_Activity05a	NO	T	-	T_Activity05b
BE12	Message04	Token_Message04	-	Token_Gateway02	NO	T_Activity05a	-	T_Activity05a
BE13	Gateway02	Token_Gateway02	-	Token_Message05 Token_Activity03	YES	T_Activity05a	-	T_Activity05a
BE14	Activity03	Token_Activity03	-	Token_Gateway01b	NO	T_Activity05a	-	T_Activity05a
BE15	Message05	Token_Message05	-	Token_Message06	NO	T_Activity05a	-	T_Activity05a
BE16	Message06	Token_Message06	-	Token_Activity05b	NO	T_Activity05a	-	T_Activity05a
BE17	Activity05	Token_Activity05a Token_Activity05b	AND	Token_Database01a Token_DataObject04	NO	T_Activity05a T_Activity05b	Maximum	T
BE18	DataObject04	Token_DataObject04	-	Token_Database01b	NO	T	-	T_Database01a
BE19	Database01	Token_Database01a Token_Database01b	AND	Token_EventEnd	NO	T T_Database01a	Maximum	T
BE20	Event (End)	Token_EventEnd	-	-	-	T	-	T

In Figure 3, the availability of the BPMN IT business process is plotted with respect to the number of the successful simulations when the default operation settings are assumed. In the same Figure, the accomplishment progress of the SLO A is also shown. From Figure 3, it is evident that the BPMN IT business process of Figure 2 marginally satisfies the SLO A while availability fluctuations are observed especially at the start of the simulation process. Indeed, the availability of the BPMN IT business process is equal to 95.111% after the completion of the simulation process when the default operation settings are assumed. By examining the achievement progress of the SLO A, it is shown that the steady state, where the availability curve practically becomes steady without significant fluctuations, is achieved after the 30k successful simulations. From 0 to 35k, fluctuations of the achievement of the SLO A are observed indicating that the simulation process remains in a transient state and safe conclusions cannot be deduced there.

Although the SLO A availability target value is marginally achieved, the impact of the availability probability of the different Activities of the BPMN IT business process on the overall availability requires further investigation so as to: (i) achieve to improve the current availability of the BPMN IT business process; and (ii) give attention and improve the Activities that are crucial for the overall availability. In order to assess the aforementioned impact, the availability of the BPMN IT business process (i.e., the overall availability) is plotted in Figure 4 when the availability probability of the Activity01 takes the values 97%, 98%, 99%, 99.5% and 100%. In the same Figure, the availability of the BPMN IT business process is also given with respect to the availability probabilities of the Activity02, Activity03 and Activity05. It should be reminded that the default availability probabilities of all the examined Activities of the BPMN IT business process of Figure 2 are equal to 99%.

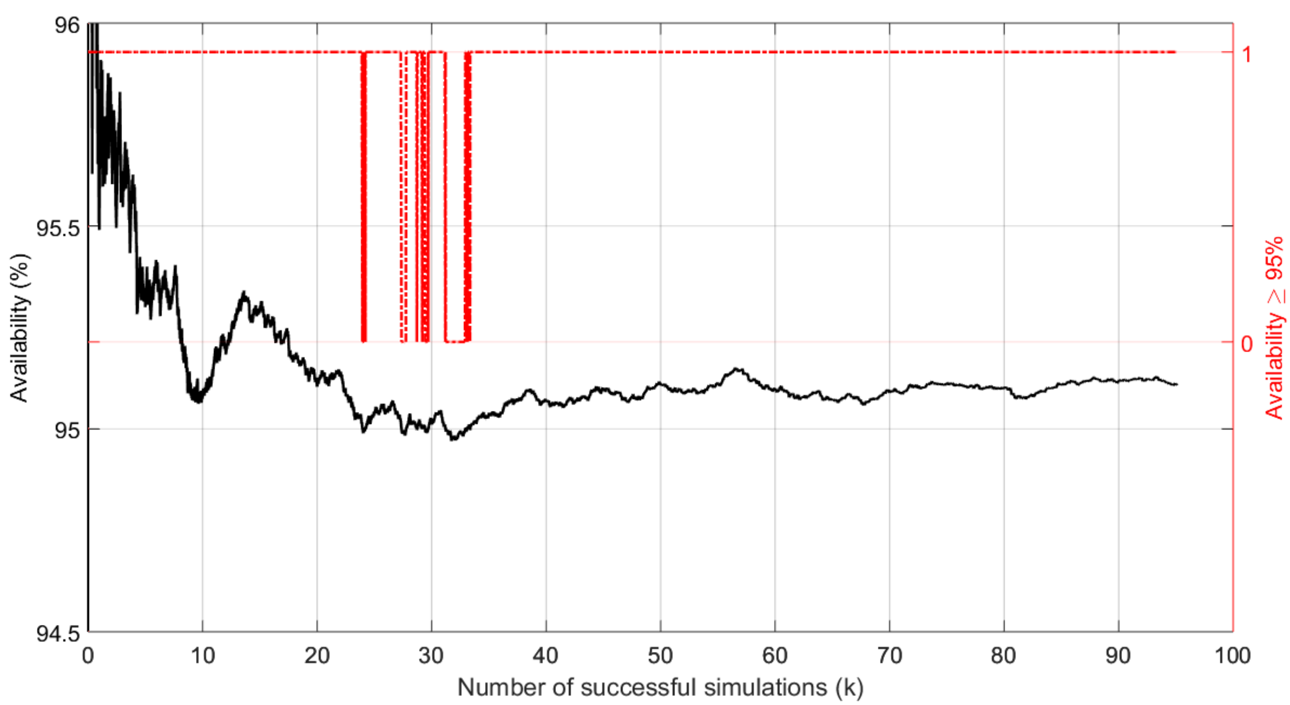


Figure 3. The availability of the BPMN IT business process (▬) and the progress of the SLO A (-▪-) (SLO A target value: ≥95%).

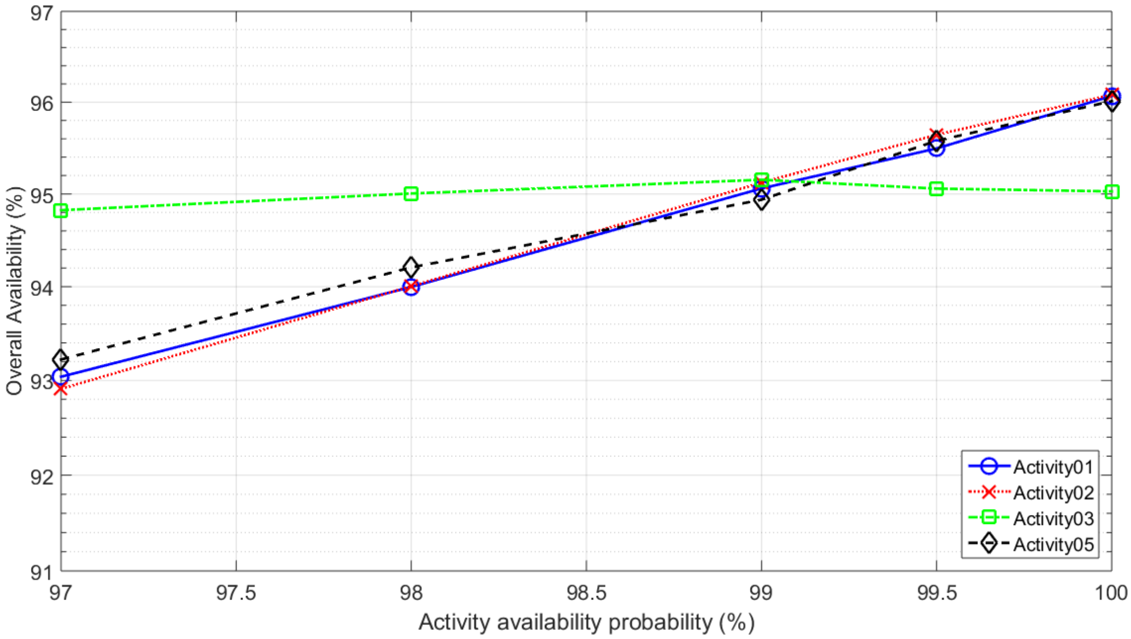


Figure 4. The availability of the BPMN IT business process with respect to the availability probabilities of Activities (SLO A target value: ≥95%).

From Figure 4, the impact of the different activity availability probabilities of the BPMN IT business process on the overall availability differs, namely:

- The impact of the availability probability of Activity03 on the overall availability is weak in comparison with the one of the availability probabilities of the other examined Activities; by observing Figure 2, the weak impact of Activity03 is due to the fact that the Activity03 is only activated when the decision “NOT OK” of the Gateway02 is taken (the “NOT OK” decision probability is equal to 10% by default). Hence, the improvement of the increase of the Activity03 availability probability from 99% (default) to 100% has an impact of $+1\% \times 10\% = +0.1\%$ on the overall availability that can be barely identified in a simulation environment. The opposite occurs when the Activity03 availability probability decreases from 99% (default) to 98%. The combination of the previous results explains the almost stable behavior of the overall availability when changes of Activity03 availability probability occur.

- The impact of the availability probabilities of Activity01, Activity02 and Activity05 on the overall availability remains strong in comparison with the one of availability probability of the Activity03. Conversely to Activity03, Activity01, Activity02 and Activity05 lie on the main flow of the BPMN IT business process. Actually, Activity02 can be activated more than once depending on the decision “NOT OK” of the Gateway02, which may create loops in the BPMN diagram but with low decision probability. In order to assess the impact of the three Activities, let assume an increase of the Activities availability probability from 99% (default) to 100%. The previous +1% increase of the availability probability has an impact of $+1\% \times 100\% = +1\%$ on the overall availability that can be verified for the

Activity01, Activity02 and Activity05 in Figure 4. The opposite occurs when the availability probability of the aforementioned Activities decreases from 99% (default) to 98%. Therefore, an almost linear dependence between the overall availability and availability probabilities of the Activity01, Activity02 and Activity05 with inclination of 45 degrees is demonstrated.

From the previous analysis, the critical role of the Activities that lie across the main flow of the BPMN IT business process has been highlighted since their availability directly affects the availability of the BPMN IT business process thus defining an availability critical path for the enterprise's management. Regardless of the involved department and / or subdepartment and / or external partner, the common commitment to the high availability of each Activity being part of the availability critical path is imperative because availability discounts on each of the aforementioned Activities carry over to equal discounts on the BPMN IT business process overall availability.

Although enterprises have chosen the availability as the most important SLO which should be included in their SLAs (Park & Choi, 2003), the response time of the business processes influences the enterprise's deliverable quality and the satisfaction of the external and / or internal customers. In the next sub-subsection, the response time of the real BPMN IT business process of this paper is assessed as well as its compliance with SLO B requirements.

4.2.2 Response Time – SLO B

With reference to Table 1, the response time is the duration time that is necessary for the completion of the BPMN IT business process of Figure 2, i.e., from the moment that the business process is dispatched from the Timer Trigger until its completion at the End Event (Castro & Fantinato, 2018; Lee et al, 2003). SLO B that deals with the response time of the BPMN IT business process consists of two objectives: SLO B1 and SLO B2. Quantitatively and in accordance with SLO B1, the BPMN IT business process of Figure 2 is expected to finish within 11h in the 85% of the successful simulations. Similarly to SLO B1, SLO B2 demands that the BPMN IT business process finishes within 23h in the 99.5% of the successful simulations. Here, it should be noted that the study of the big data by the business analytics module offers the duration mean and duration variance of all the involved extended BPMN basic elements of Figure 2 that are the crucial SLO and KPI attributes for the evaluation of the response time of the BPMN IT business process. By reviewing the available applied KPIs of SLOs B and B1, Duration_B_1 KPI, which is a general purpose KPI for the SLO B, can count the time duration of the BPMN IT business process, MathematicalOperator_B1_1 computes the percentage of the successful simulations whose time duration is equal or lower than 11h and Flag_B1_2 KPI examines whether the average time duration is equal or lower than 11h in equal or greater than 85% of the successful simulations. In a similar way to the KPIs of SLO B1, Duration_B_1 KPI, MathematicalOperator_B2_1 KPI and Flag_B2_2 KPI are deployed by the SLO B2; MathematicalOperator_B2_1 KPI computes the percentage of the successful simulations whose time duration is equal or lower than 23h while Flag_B2_2 KPI examines whether the average time duration is equal or lower than 23h in equal or greater than 99.5% of the successful simulations. By processing the aforementioned KPIs, the business analytics module may further provide statistical properties of the response time, such as its Power Density Function (pdf) and Cumulative Density Function (cdf).

In Figure 5, the percentage of the successful simulations whose time duration is equal or lower than 11h, which is computed by the MathematicalOperator_B1_1 KPI of SLO B1, is plotted with respect to the number of the successful simulations when the default operation settings are assumed. In the same Figure, the accomplishment progress of the SLO B1, which is computed by the Flag_B1_2 KPI of SLO B1, is also shown when the target value is equal to 85%. Figure 6 is the same with Figure 5, but for time duration threshold and target value being equal to 23h and 99.5%, respectively.

From Figures 5 and 6, it is obvious that the BPMN IT business process of Figure 2 fails to satisfy the SLO B1, which focuses on keeping the BPMN IT business process in a half-day schedule, while it easily satisfies the SLO B2, which aims at securing the daily operation of the BPMN IT business process (one hour safety margin is given in both SLOs). Indeed, the percentages of the successful simulations of the BPMN IT business process whose time duration is equal or lower than 11h (SLO B1) and 23h (SLO B2) are equal to 75.97% and 99.68%, respectively, after the completion of the simulation process. Since SLO B1 is not satisfied, SLO / KPI improvement actions are required for the improvement of the statistical properties of specific extended BPMN basic elements and of the QoS performance of the BPMN IT business process (e.g., SLO / KPI scenarios for Activity04). Anyway, the SLO / KPI improvement actions for SLO B1 will beneficially act for SLO B2.

By investigating the BPMN IT business process of Figure 2, Activity04 is characterized by high duration mean (SLO / KPI scenario B.A) and high duration variance (SLO / KPI scenario B.B) while its QoS performance affects the “OK” decision probability of Gateway02 (SLO / KPI scenario B.C). In order to assess the previous three SLO / KPI scenarios, the response time pdf and the response time cdf that are output metrics of the business analytics module are going to be exploited in this sub-subsection. More specifically, in Figure 7(a), the response time pdf is plotted when the duration mean of Activity04 is equal to 2h, 3h, 3.5h, 4h (default) and 5h. In Figures 8(a) and 9(a), same plots with Figure 7(a) are demonstrated but for different values of the duration variance -i.e., 0h, 0.5h, 1h, 1.5h, 2h (default) and 3h- and different values of the “OK” decision probability of Gateway02 -i.e., 30%, 60%, 90% (default), 95% and 100%-, respectively. In Figures 7(b)-9(b), same plots with the respective Figures 7(a)-9(a) are shown but for the response time cdf. Labels that indicate the percentages of the successful simulations of the BPMN IT business process whose time duration is equal or lower than 11h (SLO B1) and 23h (SLO B2) in each of the examined cases in Figures 7-9 are added on the plots. Note that small differences between the values of the same KPIs among Figures 5-9 are expected due to the nature of the simulation process.

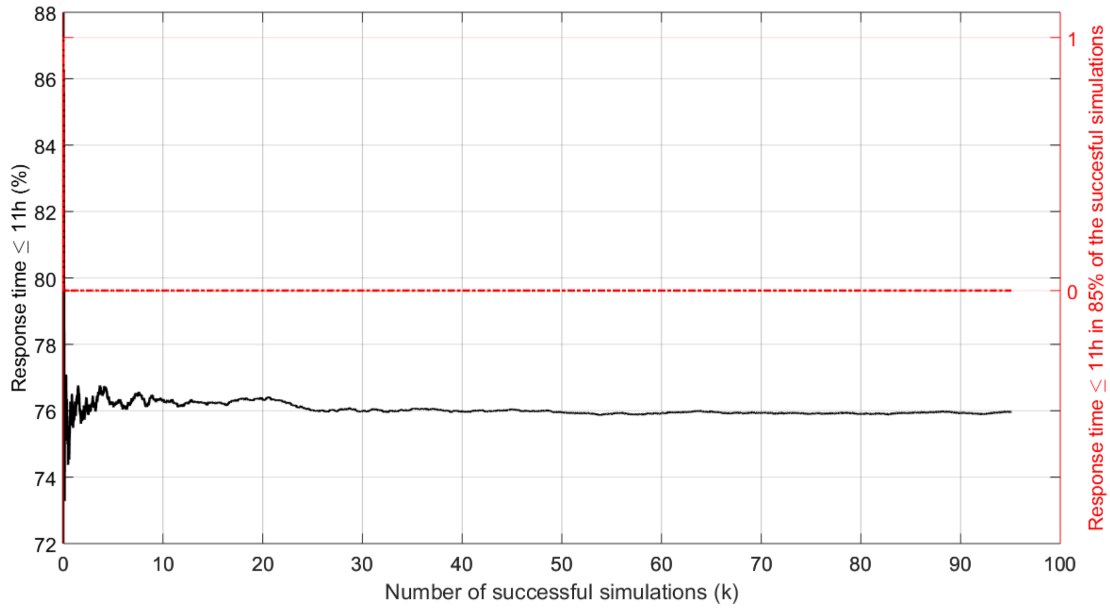


Figure 5. The percentage of the successful simulations of the BPMN IT business process whose time duration is equal or lower than 11h (▬) and the progress of the SLO B1 (--)(SLO B1 target value: ≥85%).

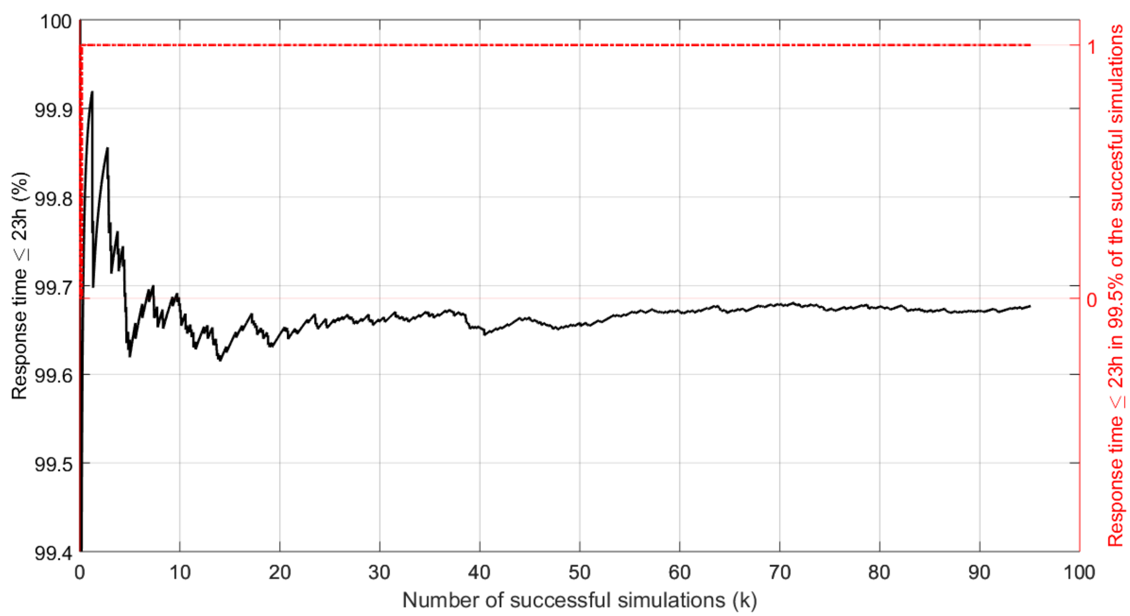


Figure 6. The percentage of the successful simulations of the BPMN IT business process whose time duration is equal or lower than 23h (▬) and the progress of the SLO B2 (--)(SLO B2 target value: ≥99.5%).

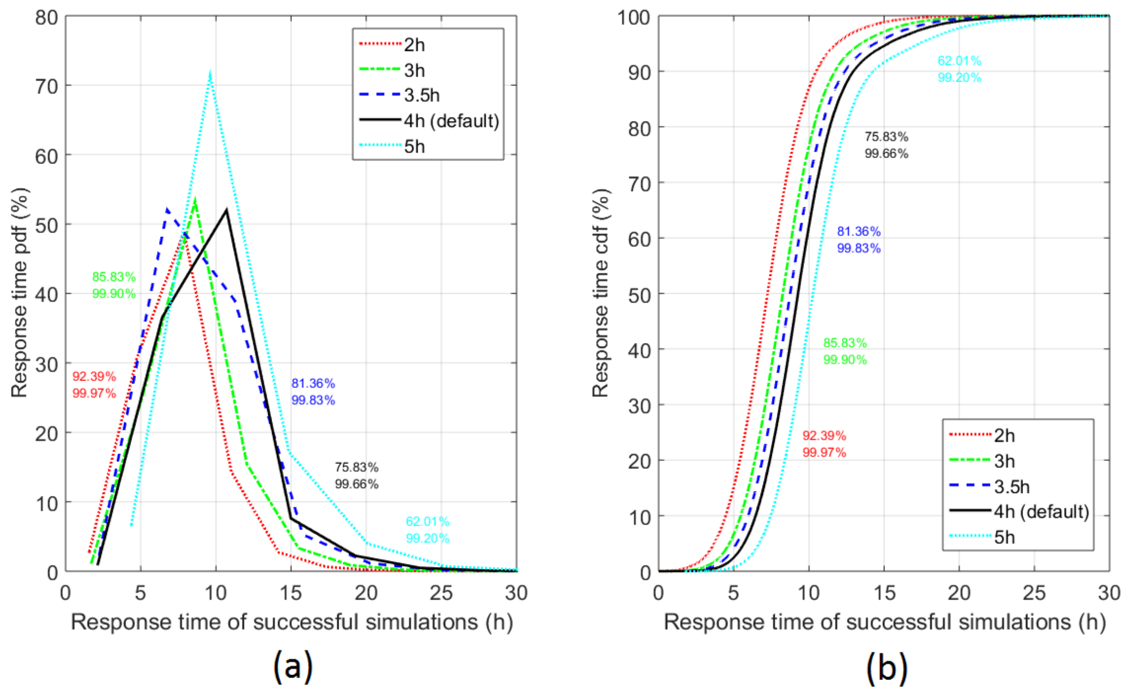


Figure 7. The response time density functions of the successful simulations of the BPMN IT business process for different values of Activity04 duration mean with labels of progress achievement of SLO B1 and SLO B2. (a) pdf. (b) cdf.

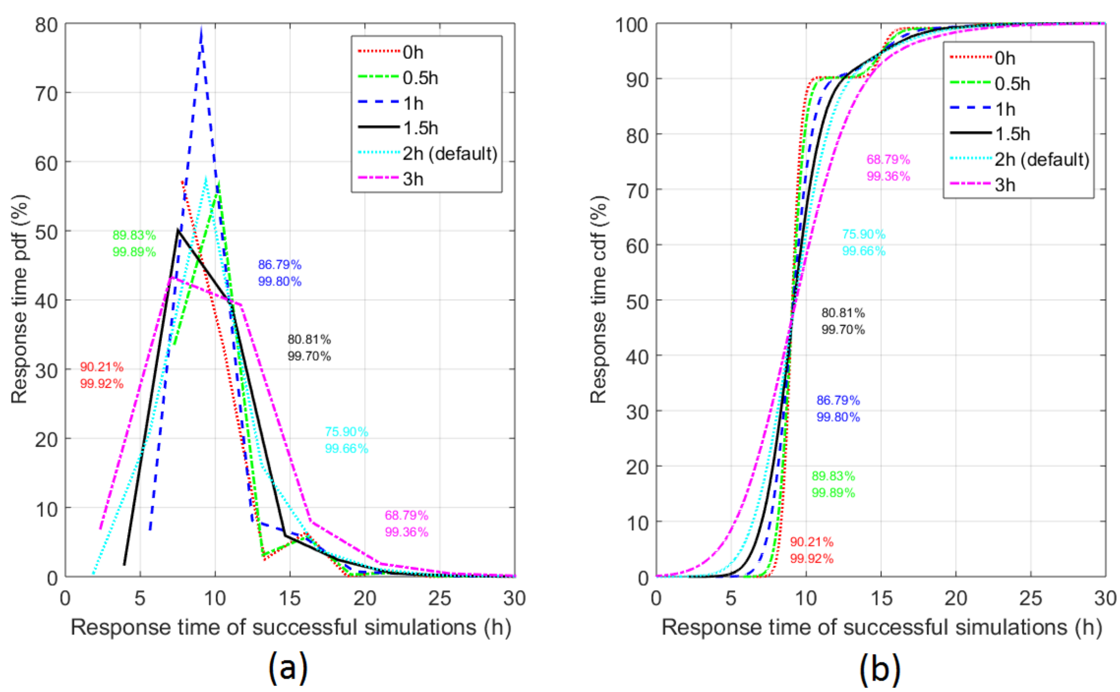


Figure 8. The same curves with Figure 7 but for different values of Activity04 duration variance.

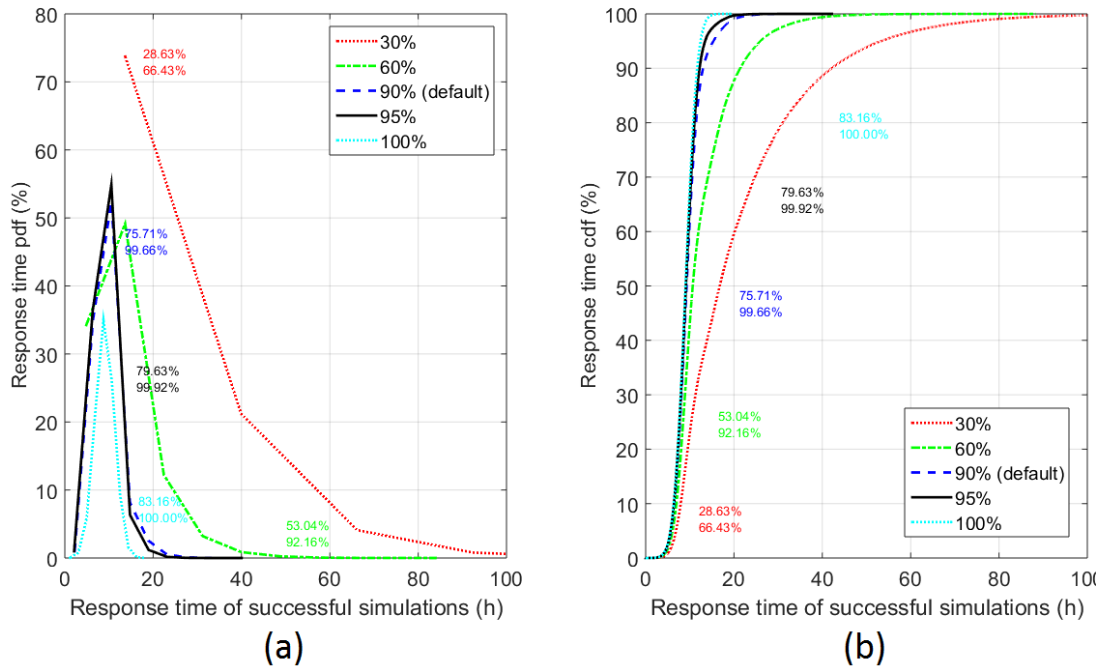


Figure 9. The same curves with Figure 7 but for different values of "OK" decision probability of Gateway02.

From Figures 7-9, it is clear that the impacts of the duration mean, duration variance and the "OK" decision probability of Gateway02 on the response time of the BPMN IT business process of Figure 2 and the SLO B satisfaction have different degrees of importance. More specifically:

- As the SLO / KPI scenario B.A is concerned, in Figures 7(a) and 7(b), when the default operation setting of the duration mean is applied (i.e., 4h), SLO B1 fails whereas SLO B2 succeeds, that is already known from Figures 5 and 6. Let assume that the duration mean of the Activity04 is reduced by 1h by adopting SLO / KPI improvement actions (i.e., 3h instead of 4h). In the case of the 3h duration mean of Activity04, both SLO Bs succeed. The SLO B1 and B2 achievement progress becomes even more improved when the duration mean is further reduced to 2h; the percentages of the successful simulations of the BPMN IT business process whose time duration is equal or lower than 11h (SLO B1) and 23h (SLO B2) are equal to 92.39% (with target value 85%) and 99.97% (with target value 99.5%), respectively, after the completion of the simulation process. In contrast, when the duration mean of the Activity04 increases by 1h to 5h, both SLO Bs fail. Therefore, the decrease of the duration mean of the Activity04 by at least 1h is crucial for the achievement of SLO B1 and SLO B2.

- As the SLO / KPI scenario B.B is concerned, in Figures 8(a) and 8(b), when the default operation setting of the duration variance is applied (i.e., 2h), SLO B1 fails whereas SLO B2 succeeds, that is already known from Figures 5 and 6. Let assume that the duration variance of the Activity04 is reduced by 1h by adopting appropriate SLO / KPI improvement actions (i.e., 1h instead of 2h). In the case of the 1h duration variance of Activity04, both SLO Bs succeed. The SLO B1 and B2 achievement progress becomes even more improved when the duration variance is further reduced to 0h; the percentages of the successful simulations of the BPMN IT business process whose time duration is equal or lower than 11h (SLO B1) and 23h (SLO B2) are equal to 90.21% (with target value 85%) and 99.92% (with target value 99.5%), respectively, after the completion of the simulation process. In contrast, when the duration variance of the Activity04 increases by 1h to 3h, both SLO Bs fail. Therefore, the decrease of the duration variance of the Activity04 by at least 1h is crucial for the achievement of SLO B1 and SLO B2.

As the SLO / KPI scenario B.C is concerned, in Figures 9(a) and 9(b), when the default operation setting of the "OK" decision probability of Gateway02 is applied (i.e., 90%), SLO B1 fails whereas SLO B2 succeeds, that is already known from Figures 5 and 6. Here, it should be noticed that the Gateway02 checks the deliverable QoS of the Activity04 output that is anyway high due to the long time experience of the BPMN IT business process in the enterprise's operations. Let assume that the "OK" decision probability of Gateway02 is increased to 100% by adopting SLO/KPI improvement actions. In the case of the 100% "OK" decision probability of Gateway02, SLO B2 still succeeds (100% from 99.68%) but SLO B1 marginally fails (83.16% from 75.97% with target value 85%). In contrast, when the "OK" decision probability of Gateway02 decreases to 60%, both SLO Bs fail. Therefore, the increase of the "OK" decision probability of Gateway02 is desirable for the achievement of SLO B1 and SLO B2 while a combined action of the "OK" decision probability of Gateway02 with the duration mean and duration variance is required so that both SLO Bs can succeed.

From the previous analysis concerning the SLO and KPI attributes of Activity04 and Gateway02, the guaranteed operation of the Activity04 remains important for the current operation of the BPMN IT business process of Figure 2 and the SLO B2 achievement but its further improvement remains urgent so that the SLO B1 can achieved in the future. Actually, Activity04 is executed in the Department B / Subdepartment A while its input feed and the QoS check of its output are performed by the Department A. On the occasion of the Activity04, the interdepartmental responsibility and the internal KPI evaluation system should be here practically discussed. In fact, the guarantee for the SLO A, SLO B1 and SLO B2 fulfillment between the Department A and B in the same enterprise implies an inner-SLA between these two Departments. In fact, the Department B must guarantee its Activity04 IT services through an SLA that consists of the following KPIs, namely: (i) Activity04 duration mean at most 3h when the current default duration mean is equal to 4h; (ii) Activity04 duration variance at most 1h while the current default duration variance is equal to 2h; and (iii) Since the improvement of the "OK" decision probability of Gateway02 as shown in Figure 9, which depends on the output deliverable QoS of Activity04, has little effect on SLO B1 and SLO B2 achievement, the QoS of the output deliverable of Activity04 is required to stay unchanged or get improved by +5% (i.e., the "OK" decision probability of Gateway02 is equal to 90% or 95%, respectively). In other words, by exploiting the theory of the normal distribution, an SLO could be worded as follows: (i) the 84.1% of the executions of the Activity04 should not last more than 3h + 1h = 4h; (ii) the 97.7% of the executions of the Activity04 should not last more than 3h+2 × 1h=5h; (iii) the 99.8% of the executions of the Activity04 should not last more than 3h+3 × 1h=6h; and (iv) the text fragment for the improvement of the "OK" decision probability of Gateway02 remains the same with the previous KPI text fragment. Actually, the signed SLA between Departments A and B may act as a back to back contract agreement and, at the same time, as a considerable SLO / KPI improvement action where the two Departments are reliant on their actions in order to fulfil the SLO A and B obligations of the BPMN IT business process of Figure 2 (Adels et al, 1997). The aforementioned SLO and KPI requirements of the Department B can also contribute to an interior KPI evaluation system of the personnel involved within the operations of the Activity04. In fact, the liaison between the KPI evaluation of the Activity04 and the internal KPI evaluation of the involved personnel demonstrates the rationality between the operations and the evaluation while helping towards the achievement of the inner-SLA between the Department A and B and of the SLA of the BPMN IT business process, in general.

4.3 Discussion and Future Research

The scope of the proposed SLA-aware BPMN IT business process lifecycle, interdepartmental SLA definition framework and BPMN simulation equivalence table is to be used by the enterprises so that the testing and preparation of SLAs for their IT services could be accelerated while the cooperation of the enterprises' department / subdepartments and external partners may be evolving on a new SLA - SLOs - KPIs basis. To facilitate the accomplishment of the aforementioned scope, enterprises should invest in the virtues of the digital transformation, say: (i) *Digital and IT technology infrastructure*: All the necessary software and applications should be available to the specialized and well trained enterprise's personnel. In addition, to further accelerate the business process integration, cloud-based solutions and collaborative suites that focus on the better communication of the involved personnel may allow the instant file access/sharing and the co-authoring. Anyway, open source software solutions or cloud-based platforms of enterprises' collaboration may be encouraged; (ii) *Expansion of the proposed SLA – aware business process approach based on BPMN standard and KPIs to other services*: For example, an IT department of a power utility may supervise processes such as the smart grid operation, microgrids, power trading, fault localization, electric vehicles, Customer Relationship Management (CRM), Content Management System (CMS), telecommunications, etc (Lazaropoulos, 2019; Lazaropoulos & Lazaropoulos, 2015; Lazaropoulos, 2017; Lazaropoulos, 2020c). Apart from the IT services of this paper, the optimization of the proposed approach may become a systematic strategic enterprise's management decision tool for all the IT department business processes; and (iii) *The upgraded role of the Supplier & Third-party department*: The next-generation SLA-aware business processes that are based on the BPMN standard and KPIs imply that the enterprises, enterprise's departments and the external partners are subjected to a continuous monitoring and control of their SLAs. Towards that direction, the role of the Supplier & Third-party department is crucial for the supervision of the existing SLAs, the preparation of the future's SLAs with the enterprise's suppliers and third-parties by exploiting the big data and experience and the selection of the applied SLOs and KPIs in the future's SLAs. With reference to the Decision Group of the interdepartmental SLA definition framework of Figure 1, the Supplier & Third-party department represents, based on its knowledge and experience, the enterprise's interests during the operation of the Evaluation and Negotiations among Stakeholders module.

Future's research steps can be pursued on the basis of the theoretical and practical refinement of the BPMN simulation equivalence table and the simulation result Section. More specifically:

- The proposed BPMN simulation equivalence table of Table 3, which is an extended version of the simplified business educational equivalence table of (Lazaropoulos, 2021a), offers the correspondence and the equivalence rules between the extended BPMN basic elements and code fragments so that the straightforward MATLAB / Octave simulation code development of Supplementary Material of this paper can occur. In this field, the future research may include the insertion of all the BPMN elements with their corresponding MATLAB / Octave code fragments of the BPMN standard.

- Except for the extended BPMN basic elements, the MATLAB / Octave simulation code of the Supplementary Material of this paper also consists of the MATLAB / Octave code fragments of the applied SLOs and KPIs of Table 1. Actually, the simulation module supports the code fragments of the applied SLOs and KPIs. Here, the future research may include the extension of Table 1 so as to comprise more IT business process QoS requirement subcategories of (Castro et al, 2019; Castro & Fantinato, 2018).

- As the assumptions of the simulation process of Section 4 are concerned, these can be further queried, namely: (i) The temporal characteristics of the extended BPMN basic elements have been assumed to follow normal distributions. However, various distributions can be applied depending on the nature of the examined BPMN basic element. For example, the Poisson distribution can model the number of the expected calls per hour for potential call center activities during the simulation process; (ii) Queue and prioritization properties, which have been ignored for the IT service desk in this paper, can be applied during the simulation process. This may affect the computation of the availability probability, which are assumed to be fixed numbers in this paper; (iii) Temporal and QoS characteristics for the messages and the data objects of the BPMN IT business processes that have been neglected during the simulation process of this paper can be taken into account; and (iv) More detailed recording of the loop flows of the BPMN IT business processes can be fulfilled. For the sake of simplicity, only the analytics of the last successful BPMN IT business process flow are stored during the simulation process of this paper.

5.0 Conclusions

In this paper, the SLA – aware business processes based on BPMN standard and KPIs have been proposed for the enterprises' IT services. With reference to the proposed SLA - aware BPMN IT business process lifecycle, the interdepartmental SLA definition framework and the MATLAB / Octave simulation methodology, a complete transformation from the management decision to prepare a BPMN IT business process SLA till its final preparation after a rigorous simulation process and business analytics session has been outlined. On the basis of a real enterprise's BPMN IT business process, an SLA of two main SLOs with the corresponding KPIs has been examined while the MATLAB / Octave code of the simulation process, which had been developed in accordance with the MATLAB / Octave simulation methodology, is freely distributed in the Supplementary Material of this paper of this paper. During the simulation process, SLO / KPI improvement actions have been applied so that all the SLOs of the enterprise's BPMN IT business process SLA may succeed in all the examined scenarios. On the occasion of the SLO / KPI improvement actions, the following operations and management issues have been addressed in theoretical and practical bases: (i) The interdepartmental SLA responsibility; (ii) The internal KPI evaluation system for the enterprises' personnel; and (iii) The enterprises' digital transformation with reference to the ITSM systems and the cloud-based concept. Future research directions are given for the further elaboration of the proposed theory on the basis of the mitigation of the present's theory limitations (i.e., larger portfolio of BPMN elements, additional SLOs and KPIs, more accurate temporal / queue / prioritization / QoS characteristics of the BPMN elements). The practical implication of the proposed SLA-aware BPMN IT business process lifecycle, interdepartmental SLA definition framework and MATLAB / Octave simulation methodology is that enterprises may exploit the proposed theory so that the testing and preparation of their SLAs for the IT services could be accelerated while the cooperation of the enterprises' department / subdepartments and external partners may be evolving on a new SLA – SLO – KPI environment. Concluding this paper, the next generation SLA – aware BPMN IT business processes may ensure higher and guaranteed QoS performance for the enterprises' BPMN IT business processes, better SLA-based professional relationships among the enterprises' departments and external partners towards the common business-process-oriented goal, the upgraded role of the supplier & third-party department towards the simulation and preparation of better future SLAs and more accurate management decision by imparting the spirit of the enterprises' digital transformation.

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