UNIVERSIDADE ABERTA

Towards a simulation interoperability framework between an agent-based simulator and a BPMN engine using REST protocol

Jacint Duduka

Masters In Information and Enterprise Systems

(Masters in Association)

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RESUMO

O paradigma atual de um modelo de processo de negócio é que é uma representação de uma sequência de tarefas que atuam sobre um “input” de dados, para produzir uma “output”, visando a produção de um novo serviço ou produto. Embora esta seja uma forma válida de interpretar um processo de negócio, ela não considera em pormenor a influência de fenómenos externos, por exemplo, comportamento humano, comunicação, interações sociais, a cultura organizacional que pode ter um efeito significativo na eficiência um processo de negócio.

Como a dinâmica destes fenómenos externos não é linear, eles podem ser interpretados como um sistema complexo, que são sistemas que se comportam de tal forma que não podem ser explicados simplesmente olhando para o comportamento das suas partes individuais. Esta forma holística de pensar sobre os processos de negócio abre as portas à possibilidade de combinar diferentes métodos de simulação para modelar diferentes aspetos que influenciam um processo.

A simulação baseada em agentes (ABS) e BPMN são escolhidas como os dois métodos de simulação para estudar o potencial dessa integração em processos de negócio, e a nossa abordagem para os combinar consiste em modelar o comportamento do utilizador em ABS e o próprio processo de negócio utilizando o BPMN. Por fim, a integração entre os dois motores de simulação acontece durante o decurso da simulação através da invocação de APIs usando o protocolo REST, onde os agentes controlam a dinâmica de execução do processo no BPMN. Esta abordagem de integração é validada através da construção de uma experiência, com o objetivo de determinar se os resultados de simulação obtidos são estatisticamente coerentes.

Palavras-chave: BPMN, processos de negócio, simulação baseada em agentes, agent-based simulation

ABSTRACT

The current paradigm of a business process model is that it is a representation of a sequence of tasks that act upon some data input, to produce an output, aiming the production of a new service or product to be delivered from a producer to a customer. Although this is a valid way of thinking, it neglects to consider in enough detail the influence of some phenomenon on inputs, e.g. human behaviour, communication, social interactions, the organisational culture which can have a significant effect on the output delivered by a business process. As the dynamics of these phenomena are non-linear, they can be interpreted as a complex system. This holistic way of thinking about business processes opens the doors to the possibility of combining different simulation methods to model different aspects that influence a process. A BPMN engine and an agent-based simulation (ABS) engine are chosen to serve the basis of our framework. In its conception, we not only consider the technical aspects of the framework but also delve into exploring its management and organizational dimensions, with the intent of facilitating its adoption in enterprises, as a tool to support decision support systems. We analyse how accurate the simulation results can be when using these two tools as well as what considerations need to be considered within organizations.

Keywords: BPMN, simulation, agent-based modelling, agent-based simulation, business process

Dedicatory

To mother, who made me discover the truth.

Acknowledgements

To all who directly or indirectly helped me through this difficult journey.

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List Of Abbreviations

BPMN: Business process modelling notation

ABS: Agent-Based Simulation

ABM: Agent-Based Modelling

STS: Socio-Technical System

REST: Representational State Transfer

API: Application Programming Interface

RCS: Real Case Study

1 Introduction

In our dissertation we focus on understanding how technology can enable distributed simulation frameworks, considering its implementation feasibility in the enterprise. We begin by describing the problem in chapter 1 and present our hypothesis on how to solve it, define the objectives and delineate the scope of the work being performed. In chapter 2 we specify some key concepts and ideas used across our study to enable the reader to contextualize the topics being discussed. This is followed by a state-of-the-art review, that allowed us to find the most recent developments in the topic. The methodological choices are discussed in chapter 4, where we describe our experiment in detail, how data was collected and evaluated. This is followed by the justification of our solution proposal in chapter 5, were we cover the reasons why we believe our solution solves the problem. Finally, the results of the study are presented in chapter 6 followed by the main conclusions in chapter 7 where the main conclusions are drawn, and future work is proposed.

Today rapid technological change is being driven by the information revolution, as we live in environments that are increasingly technology-saturated(Kadar et al., 2015). This saturation makes the question of the relationship between people and technology more explicit than ever, to the extent that this relationship between the two is widely reported and extensively studied in the literature in the domain of socio-technical systems(Bider, n.d.; Gregoriades & Sutcliffe, 2008; Henda et al., 2016; Ibl & Čapek, 2017; Norta et al., 2014; *The-Evolution-ofSocio-Technical-Systems-Trist.Pdf*, n.d.; Tropmann-Frick & Thalheim, 2015; Vespignani, 2012).

Socio-technical systems are an approach to the understanding and design of complex organisations and technologies that recognise the relationship between people and technology(Kloeckner & Birkmeier, 2010). The study of socio-technical systems (STS) is not only limited to the understanding influence of people in technology at a micro level, for instance, how an individual interacts with a website perceives the interface design, but also on the macro level referring to the complex interactions between society's infrastructure and its socio-cultural domains, an example of this would be how organisational culture influences performance of automated business processes(Geels & Kemp, 2007).

(Pinheiro Martinelli et al., 2013) also notes that looking at systems from this holistic point of view, brings to light some properties that would otherwise be unknown:

- Emergence: refers to features and phenomena born from the interrelationship between components of a system, which cannot be explained by the workings of its parts;
- Recursivity: refers to the idea that a system is contained inside another system, which in turn inside other systems;
- Communication and control: features related to the survival of the system, enabling it to self-correct and adapt to pressures of the environment;

By looking at business processes as STS, one aspect that can't be ignored is the importance of people, as it been pointed out by several authors (Gregoriades & Sutcliffe, 2008) (Dumas, 2013; Harrison-Broninski, 2005; Norling, 1996; Ostadi et al., 2011; Rosemann & Brocke, 2015; Subramanian, 2015) that, their interactions, culture, behaviour, and relationships are a fundamental component of any efficient process, and, simulation plays a vital role in the understanding phenomenon within these social systems.

With the observations above, our dissertation endeavours into looking at business processes as socio-technical systems and tries to shed some light on how combining different simulation engines can create an alternative method for studying the influence of complex phenomena on business processes and therefore create an ecosystem of tools that enable process modelling. Our study has been accepted as a full paper in the KEOD 2020 conference, with title *"Systemic Business Process Simulation using Agent-Based Simulation and BPMN",* due to be presented between 2-4th of November 2020

1.1. The Problem

Despite the realisation of the importance of humans in business processes, as far as we know, there has been little focus on how agent-based simulators can be used to enable business process simulation. The majority of the studies(Haiyan Zhao & Jian Cao, 2007; Halaška & Šperka, 2018; Liu & Iijima, 2015; Sulis & Di Leva, 2018; Tan et al., 2009) focus on using discrete event simulation(DES) as the business process simulator and this can pose some challenges for organizations due to extra investment required to procure software, hire workforce with DES knowledge and time to redesign existing business processes as DES models.

Although this approach is suitable in some cases, it is less likely to be adopted in organizations because of the time and effort commitments it requires. Our assumption of what constitutes a successful information system implementation is based on the information systems analysis framework depicted by (Laudon & Laudon, 2013) that state that there should always be three dimensions to any successful information system.

The first is management, where there should be tasks performed at a management level of the organization for the implementation of the system. These include but not limited to reflecting about what knowledge acquisition, retention strategies, training strategies and budget plans are suitable for the project. The second dimension is organization, where they state that there should be a reflection on how issues such as organizations hierarchy, functional specialties, business processes, organizational culture and pollical interest groups impact an information system. Lastly there is the technology dimension, where hardware, software, data management and networking issues should be considered.

If we contrast the Laudon framework with current simulation frameworks involving ABS and BPS, we notice that current approaches lack on the management and organization dimensions, for the reasons stated above.

The importance of creating a solution that encompasses all three dimensions of the Laundon framework, lies in the possibility it would create to enhance decision support systems, i.e., it would allow modelling and simulating problems in the enterprise that require studying both actor behaviour and process models. Some examples of such questions are as follows: "What employee profile we need for our new team, which will be performing XXX type of activities? Do we need proactive, reactive or both types of behaviour?" or "At which level in the organisation do we need to focus our behavioural change training, so that it results in improvements of at least 10% in these five processes". To better portray the utility of our framework, let us illustrate a use-case with the following example:

Suppose a decision-maker needs to understand how to best place an investment at a fleet of five hospitals, to fast-track the patient registration process, given that patients are from a highly diverse cultural background, and different groups speak different languages. His team managed to narrow down the solution to two final options, first is to purchase a digital assistant in the form of a kiosk, that would help with the entire process, including translation to any of the idioms' patients speak.

The second option is to hire dedicated translators to help with part of the process, and he can't tell which option is the best. For a smaller number of patients, it would be simpler to decide as to which option to choose; however, due to a large number of variables, finding a simple solution is more challenging. One possible solution could be to try to solve the problem mathematically, i.e., create a set of equations to describe user preferences towards technology and people and solve them for the business process in question. Depending on the behaviour to model, this approach can be difficult to implement due to the complexity of the equations(Castiglione, 2006; Epstein, 2006). Using agent-based modelling instead, provides a way to reduce potential model complexity issues and hence, in our example, the affinity of different age groups and language groups towards using digital kiosks or human translators, could be modelled in an agent-based simulator. The patient registration process can be modelled in a BPMN engine or simply reuse any existing model of the process and run a simulation where actors will run according to the set of rules defined in the agent model. Each agent would then signal the BPMN engine, of the completion of a task in the process, and task completion timestamps can be collected in the process engine. Different scenarios can be modelled in the ABS and the impact of these changes analysed in the process performance, in order to get a holistic picture.

Hence this area of research is of pivotal importance, as it enables the study of complexity within business processes. Our framework could have applications foreseen not only in science but also within organisations. Understanding whether our proposed method of integrating two engines is feasible to adopt, is essential not only because it could fuel the study of the emergent phenomenon within business processes, which can pave the way to finding patterns and conservation laws that govern business processes, but also because it can be used to extend and enhance decision support systems .

Therefore, our related question RQ is: "*How to implement a simulation interoperability framework, between an agent-based simulator and a BPMN engine using REST protocol?*".

The overall problem is undoubtedly challenging to answer – both in terms of understanding the extent at which such integration is supported by current technology, and in terms of understanding which technology would be best adopted. An identical problem to ours is similarly experienced in (Endert et al., n.d., 2007) and is by no means unique. What distinguishes our approach from the others is the holistic approach we took to implementing our simulation method. Not only we considered the suitability of the method to create reliable simulation results, but also considered other aspects such as difficulties in implementing our framework in organisations, difficulties in finding individuals with appropriate skills to build models in these technologies, implementation costs, and the overall difficulties to gain buy-in from decision-makers to adopt such method. Such a systemic way of looking at socio-technical systems has already been explored in other literature; for instance, Henda et al., 2016 refer to the importance of integrating the social, business, and technical needs of an enterprise.

Some authors (Wu, 2015) also alert to the challenges encountered in modelling socio-technical systems, citing the reason being the complexity of the interactions and interdependencies between the social, technical and contextual elements in and around the system, hence the urgency in finding more reliable methods to study phenomena in them.

For the purpose of our dissertation, we build an experiment, consisting of two types of simulators:

a. An agent-based simulator (ABS) which is dedicated to model and simulate user behaviour and;
b. A BPMN engine to execute and simulate a business process.

During the interaction between agents in the ABS, events are triggered when certain conditions are met, and consequently, REST calls are sent to the BPMN engine representing users initiating and completing tasks.

Finally, to analyse the validity of this method, a real-life inspired business process is modelled and simulated using our approach, and event execution timestamps are compared between the two systems in order to understand how time between events in one system correlates with time between events in the other system. This was particularly an important step of our research as its been highlighted several times in literature (Baker, n.d.; Brodsky, n.d.; Lin & Guo, 2010; Tolk, 2013), that time management is a usual problem to address in distributed simulation engines.

1.2. Hypothesis

The aim of the present dissertation was to study the following hypothesis:

H1: Our interoperability framework does not affect the statistical coherence of simulation results;

1.3. Objectives

This dissertation is set out to explore a new idea on how to simulate complex phenomena within business processes. It relies on reusing already existing simulators and allows them to drive each other, and therefore our objectives can be restated as follows:

O1: Determine the correlation between engine type and task execution interval;
O2: Determine whether the engine type has a significant effect on the task execution interval of different groups of agents;

1.4. Scope of work

The study of complex systems within organisations is not new, and a few examples include Lewis, 1994; *Principles of Complexity and Chaos Theory in Project Execution*, n.d.; Smith & Humphries, 2004; Tsoukas, 1998; Turner, 2006, however, this research is the first step towards a more profound understanding of tooling for studying business processes as complex systems, that takes adoption into consideration.

The focus of our dissertation is oriented towards verifying functional aspects of the framework being proposed. It intends to understand only aspects deemed fundamental for the operation of such way of simulating business processes and ignores the study of specific business processes through it. A detailed analysis of those aspects is outside of the scope of this work, and hence, they are only briefly outlined here.

It is imperative to point out that we are not interpreting complexity as the level of disorder or entropy in business processes, but instead, look at how can we use readily available tools to simulate complex phenomena in business processes.

2 Theoretical Background

2.1 REST

REST stands for Representational State Transfer is a set of constraints that allows for computer systems to communicate with each other over a network in a more straightforward manner(Boyer et al., 2009). Some of these constraints include:

- Client-Server
- Stateless
- Cacheable
- Layered

Systems that implement such standards are denominated RESTful systems and have the particularity of having independent client and server implementations. This means that code on either side can be modified, without compromising the operation on the other side. Such modularity is possible because all the client needs to know is the format of the message(‘Representational State Transfer’, 2020).

2.2 Complexity

The definition of the word complexity according to the Cambridge English dictionary (*COMPLEXITY | Meaning in the Cambridge English Dictionary*, n.d.) is the following: *“The state of having many parts and being difficult to understand or find an answer to”.* Etymologically, the adjective “complex” can be traced back to 1650s, and it has been linked to entities *"composed of interconnected parts, formed by a combination of simple things or elements,"* (*Complex | Search Online Etymology Dictionary*, n.d.). In the context of our dissertation, we share those meanings when referring to the complex, however its essential to delineate the boundaries of our usage of the word as in our case, the word shares some additional features.

A complex system is one characterised by having independent agents interacting with each other in different ways. This sometimes results in a new behaviour to be born, for instance, "spontaneous self-organisation" which occurs without any agent orchestrating it and instead is caused by individual agents adapting to each other. On the other hand, a characteristic of complex systems is that they are adaptive, i.e., they always adjust to the environment. (Warren et al., 1998)

Another relevant concept in complex systems is that there is no master agent in the system. Instead, behavioural patterns originate from the competition and collaboration between agents(Smith & Humphries, 2004). The same author says that these new patterns born from the systematic interaction between agents are denominated “emergent behaviour”. One of the most relevant properties of complex systems is the impossibility to predict the output of changes to the system(Lewis, 1994). He also mentions that because of the so many dependencies and relationships between actors in the system, the number of possible outputs to any given modification is infinite. Small changes can result in an enormous reaction effect because of the chain of events they might incite.

On the other hand, the opposite can also be true, significant variations in input can have an almost insignificant effect on the system as a whole, and this makes controlling a complex system very difficult because there is no absolute governor agent of the system. Because of this, substantial control of any complex system may be impossible. One important note to be made is that complexity in this context, should not be confused with computational complexity theory, which refers to degree of complexity of algorithms.

2.3 Agent-Based Modelling

Agent-based modelling (ABM) is a modelling approach in which actors in a system are modelled as a set of independent, entities called agents (hence its name). These agents can represent system users, physical machines or software systems. Agents can also have predefined behaviours and be set to interact with each other, with the intent of exploring behaviours emerging from these interactions that would otherwise be out of reach of purely mathematical approaches (Bonabeau, 2002).

There is no single conceptualisation of a software agent, although it is very similar to one of the software objects, methods, procedures, and functions. They all encapsulate some sort of logic and attributes; however, an agent operates at a higher level of abstraction. Opposed to defining software in terms of attributes, logic and methods, a software agent is typified in terms of its intended actions and responses instead of identifying classes, methods and properties(Abar et al., 2017). In addition, another distinction according to the same author, between software agents and software programs is that agents are supposed to exist, coexist and collaborate with other agents within an environment, which is not always the case for software programs. This environment can be physical or virtual; it has to have identifiable and quantifiable properties, which therefore create the boundaries of how agents are allowed to behave. Furthermore, agents can also have properties and perform specific actions; however, these are a function of what the environment allows them to do.

During an agent-based simulation(ABS), active elements of the modelled system are represented by software agents, and they are specific in the way they are programmed to follow some behavioural rules and autonomously interact with each other, which replicates the complexity of the system(*Tutorial on Agent-Based Modelling and Simulation*, n.d.). Agents can represent different entities, e.g., organisations, departments, people, and others. Thus, by using ABS, it is possible to simulate complex systems and study its behaviour on either macro or micro-level(*Tutorial on Agent-Based Modelling and Simulation*, n.d.). Achieving the same degree of simulation flexibility by using a different method is sometimes challenging even impossible, especially in areas like, e.g., social sciences.

It has been demonstrated(Abar et al., 2017) that the ABS approach is used across numerous application domains such as climate change, ecology, biology, economics, sociology, social sciences, agriculture and many others.

We illustrate below some examples of ABS systems:

Table 2.1 ABS systems and some properties

Name	License Type	Operating System
AnyLogic	Proprietary; Free Personal Learning Edition available	Cross-platform
Cougaar	Cougaar Open Source License (COSL) is a modified version of the OSI approved BSD License	Linux, macOS, Windows
Framsticks	GPL/LGPL/Propertiary	Cross-platform
JADE	LGPL version 2	Cross-platform
MASON	Academic Free License (Open Source)	Cross-platform
NetLogo	GPL	Cross-platform
Repast	BSD	Cross-platform
SARL	Apache version 2	Cross-platform
Soar	BSD	Cross-platform
StarLogo	Free (closed Source) – Clearthought Software License, Version 1.0	Cross-platform
Swarm	Swarm Development Group	Cross-platform

Source: ‘Comparison of Agent-Based Modeling Software’, 2020

2.3.1 Advantages of ABM

One of ABM's advantages is its ability to model complex systems at both high and low levels of abstraction(TERANO, 2008), which is something that traditional BPM simulation approaches struggle to accomplish. A macro-level analysis is fundamental to support the executive team within organisations in making tactical and strategic decisions, while at the micro-level, ABM can support operational decision making.

Another distinctive advantage is that it enables for simulation of realistic user behaviours, such as communication, cooperation, or coordination, and thus better capture the behaviour of human reSource within the process(Twomey & Cadman, 2002). Some authors(Michal & Roman, 2018) also point out that the modelled user behaviour modelled using ABM can be heterogeneous, i.e., agents can be modelled in groups with different characteristics or behaviour. The importance of modelling behaviour is also highlighted in (Railsback & Grimm, 2012), where the authors refer that ABM allows studying its emergent nature and we can look at it across levels, i.e. not only it is possible to quantitatively study the dynamics of an environment but also study agents within that environment and their interactions between themselves and the environment.

2.3.2 Disadvantages of ABM

It has been pointed out in previous research(Vanhaverbeke & Macharis, 2011) that model validation and verification is a significant challenge in ABM, especially when simulating larger and more complex models. This challenge had been reduced in recent years by using process mining, that generates natural process logs which can be used to compare the simulation results against it.

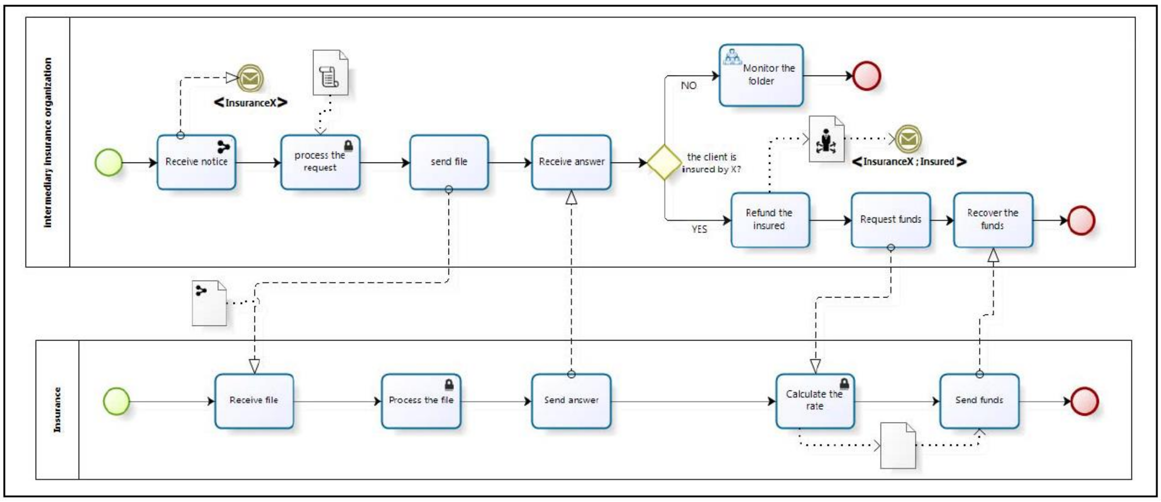
Another problem is the skills needed by the modeller, especially in programming and principles of object-oriented programming(*Tutorial on Agent-Based Modelling and Simulation*, n.d.). This is partially addressed by the use of "no-code" IDE's, which allow for a graphical programming approach; however, there are still scenarios where writing code is necessary(*Tutorial on Agent-Based Modelling and Simulation*, n.d.).

Lack of modelling notation, the fact that ABM is time-consuming and lack of a general framework that both suits academics and practitioners during modelling and simulation time, are also pointed out(Gamoura et al., 2015; Gómez-Cruz et al., 2017; Onggo et al., 2017)

2.4 BPMN

The Business Process Model and Notation is a workflow representation that
can be used both to describe real-world processes and as a high-level modelling language for software applications. (Küster et al., 2016)

Figure 2.1 Example BPMN Diagram



Source: (Amdah & Anwar, 2018)

It is a user-oriented notation, specially designed for easy understandability and representation or real-world constructs. Suited for business analysts, in creating the initial drafts of the business processes, to software developers while writing the software applications that will perform those processes, and finally, to the business users who will manage and monitor them (Guizzardi & Wagner, 2011). BPMN can be used both for making intuitive, non-executable business process models and for making executable models, such as needed for business process simulation.

BPMN emerged publicly in 2004 (White & Miers, 2008) with the intent of consolidating the different vendor-specific modelling languages. Having a standard is essential as the same authors point out, “Without a rigorous way of describing business processes, the interpretation of any given model is always up to the reader” and with each vendor releasing their version of how a process should be modelled, just makes the exercise more subjective.

On the other hand, BPMN, unlike other process modelling languages, is specifically designed to model business processes, with artefacts that are easily converted to real business process constructs and it is also a language that has the end-user in mind, containing much support for straightforward interpretation such as symbols, annotations and artefact taxonomies.

In BPMN, process diagrams are subdivided into pools which represent the concept of "process", and each pool can have lanes, which is an activity classifying mechanism(Team, 2010). Message flows are used to represent communication between pools and other features such as event- and error handling, compensation, transactions and ad-hoc behaviour are also supported.

3 Literature Review

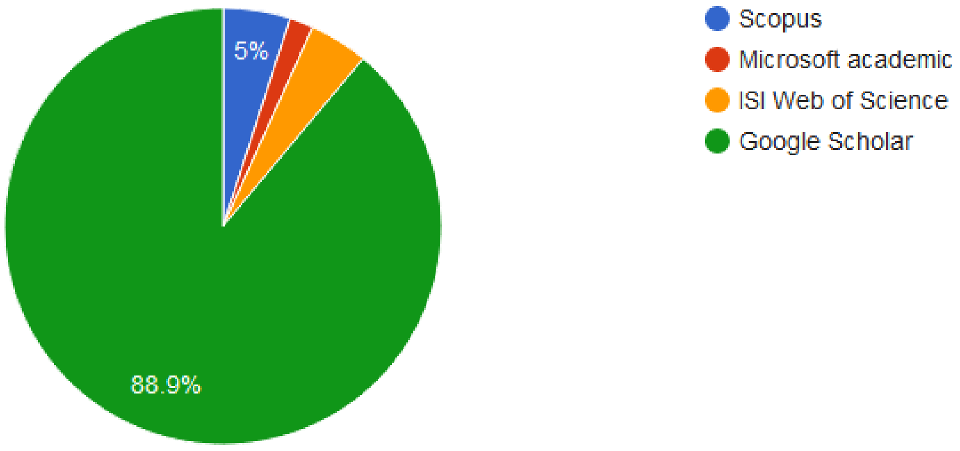
In this section, the author gathered and analysed the current state of research to understand how is BPMN simulation being currently combined with agent-based simulation to enable business process design.

After an initial overview of related work, a total of four repositories were used to collect state-of-the-art research data on the topic, namely, Google Scholar, ISI Web of Science, Microsoft academic and Scopus. From the universe of results, a first, generic filtering strategy was used, with criteria described under section “Selection criteria” in annexe A. The literature is reviewed to examine available methodologies to integrate ABS engines with BPMN engines.

A second more specific wave of filtering was employed on criteria described in the same annexe, under the section “Quality Assessment Checklist”. A bibliographic annotation was created based on the articles that passed both filtering steps and results are compiled below.

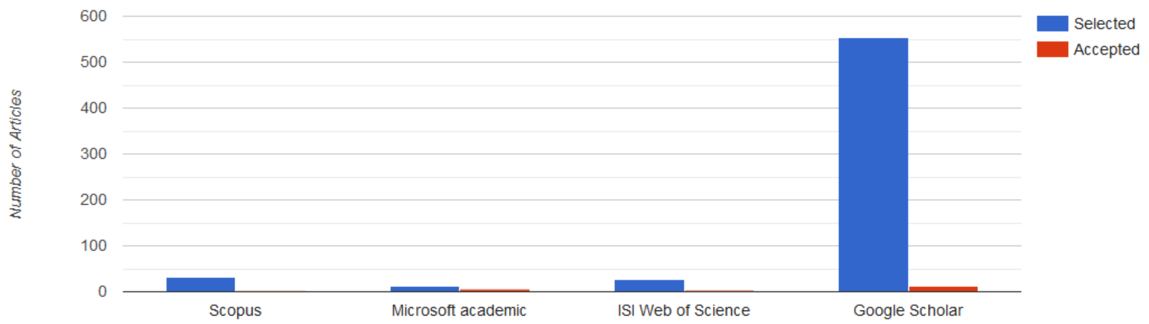
Most of the research found on this topic comes from Google Scholar, with 88.9%. The rest is distributed among other sources as described below:

Figure 3.1 Articles per Source



Source: Author

Figure 3.1 Accepted Articles Per Source.



Source: Author

Breaking those down considering the acceptance criteria, still google scholar came up as the Source with the majority of studies published.

When it comes to integrating simulation methods, namely ABS and BPMN, we find that there is a tendency in current research to understand how agent-based model constructs can be mapped to their BPMN (*BPMN Coordination and Devs Network Architecture for Healthcare Organizations*, n.d.; *Küster et al. - 2015 - A Formal Description of a Mapping from Business Pr.Pdf*, n.d.; *Sbayou et al. - 2017 - AGENT BASED MODELING ARCHITECTURE WITH BPMN AND DE.Pdf*, n.d.; *Zinnikus et al. - A Model-Driven, Agent-Based Approach for the Integ.Pdf*, n.d.; Endert et al., 2007; Küster et al., 2012) equivalent or vice-versa. To our knowledge, some attempts have been made to solve this problem, but there is little to no research around using the two simulation engines to model different aspects of a system and allow the two engines to communicated at runtime. Equally, little research is found about employing both engines and making the two communicate through API calls.

In cases where these are combined, there are very few published results about the implementation of the systems/methods in real scenarios and the extent to which they contribute to enabling the practice of designing business processes.

We will now review the most effective approaches from the literature, examine prior work and go on to propose our own solution and next chapter. We define BPMN and ABS in more details, and it has presented relevant research around the main categories of mappings and flaws of each.

3.1 GO-BPMN

Goal-oriented BPMN focusses on combining process models with goal hierarchy and executed by agents. The individual processes are represented as BPMN processes, but, only a subset of BPMN is used. Notably, each one of the diagrams shows only a single pool, and thus, as in the case of WADE, no communication can be modelled, but just the behaviour of a single agent. Using goals for connecting the individual processes is quite promising; however, the author believes that process diagrams can be used more efficiently, to provide an overview of the system, instead of isolated behaviour of individual agents.

3.2 BPMN & JADL

JADL (Jiac agent description language) is a service-oriented scripting language, very similar to BPEL (Business Process Execution Language). For this very fact, almost direct mapping can be achieved. For instance, as in BPEL, JADL has dedicated language elements for complex actions such as service invocation, or for sending and receiving messages, making the generated code simple to understand.

3.3 BPMN & WADE

WADE (Workflows and Agents Development Environment), is an extension to the JADE multi-agent framework. In WADE, certain aspects of the behaviour of a JADE agent can be modelled using a simple workflow notation (Küster et al., 2016). The workflows consist of only two elements: Activities and Transitions.

However, WADE's simplicity is also a weakness, in that it is limited to a simplistic workflow notation, which only allows for basic workflows to be modelled. Transitions can be annotated with guards (conditions), it seems impossible to model parallel execution and synchronisation, let alone more advanced concepts such as event handling or messaging. Each workflow only covers the behaviour of an individual agent; to our knowledge, interactions between agents cannot be modelled. Later versions of WADE presented extensions(Küster et al., 2012) that solved many of the existing limitations, which included support for long-running business processes, event handling, user-interaction and Web-service integration.

3.4 BPMN & AUML

AUML (Agent UML) extends the UML with several agent-specific types of diagrams, most prominently interaction diagrams.
Although it serves well to describe interactions between agents, interaction focusses on only a single aspect of multi-agent systems. BPMN diagrams, on the other hand, can be seen as a combination of AUML interaction and activity diagrams and thus seem to be better suited for conveying the whole picture of the behaviours and interactions.

4 Methodological Options

The prime objective of this section is to translate the problem under study into a measurable form and define criteria to measure and evaluate our results.

The experimental method was used because our primary goal is to determine whether our proposed solution works at a functional level. This means that in order to determine whether time intervals between events vary between the two engines, we needed to understand how those time intervals change over time between the two engines, and an experiment would give us the control needed to set up those conditions and test our theory. Its been noted in the literature(Dennis & Valacich, 2001) that the objective of experimental research is to enable testing and extending a theory. Also, Williamson & Johanson, 2017 proceed in stating that it is a method that seeks to establish a cause-and-effect relationship between variables, which is the case in our study.

By no means, experimental research, it is the best or worst method, yet it is the most adequate for the following reasons:

1. A cause-effect relationship needed to be understood. Specifically, we wanted to understand whether time intervals between events occurring in an ABS are kept constant upon triggering equivalent events in a BPMN engine.
2. A specific set of conditions are being studied. We only want to verify that REST API requests can be transmitted between the two systems and that the intervals between two events are respected between the two systems.

Nonetheless, one has to also accommodate for the downsides of a method, and weakness of our method as (McGrath, 1981) points out, is that with experiments it is challenging to draw conclusions that can be easily generalised because a small "sample of the real world" is taken just to understand a specific phenomenon. The same author also underlines another weakness which is the fact that for the same reason (a small part of the physical world is studied) conclusions will not automatically be realistic, hence further research is required in the future to complement the aspects above. We understand that this should not be the only method used to prove our theory; hence there are other studies proposed as part of the future work, which would provide complementary points of view about the veracity of our theory.

4.1 The Experiment

4.1.1 Choosing A Real-Life Business Process

It was imperative to inspire our experiment in a real business process to validate our novel approach to simulation. As some authors point out(Guala, 2002) there is higher confidence in an experiment if a real component is used; thus metrics and business process model from a real case study(RCS) had been chosen(Bhat et al., 2014) which is a Lean Six-Sigma(LSS) process improvement study conducted in the Health Information Department (HID) of a Medical College Hospital in India which consisted in using LSS to improve the patient registration process of the hospital.

The RCS concluded that the mother tongue patients and receptionists spoke, had an impact on the process cycle time. This variable was adequate for this experiment because it satisfies the criteria for the case study selection which was that it had to describe the impact of user behaviour in a business process output, in this case, it was communication between patients and receptionists, given that they spoke different languages and how this impacts the number of patients registered per unit of time.

All the staff were proficient in the local languages, namely Kannada and Tulu, in addition to English. The study also observed that out of 16 staff working in the department, only two of them knew Malayalam, five knew Konkani, six knew Hindi, one knew Malayalam and Konkani, and the only one knew all three languages in addition to the local language. Thus, six staff with a different combination of language expertise were selected for the study. The cycle time in handling patients, who were proficient in only local languages, only Malayalam, only Konkani and only Hindi was observed for ten patients in each group(Bhat et al., 2014).

The study concluded that cycle time for registering patients, who only spoke Malayalam, Konkani and Hindi was significantly larger than those who knew local languages and therefore, that is the behaviour we model in our ABS, more specifically, which is difficulty in communication between agents as a function of their fluency in certain idioms.

4.1.2 Purpose

Based on the scenario described above, the agent-based model tries to recreate it, whereby which patients and receptionists interact with each other, in order to get patients registered into the hospital system. Two groups(breeds) of agents are created to represent each group, and they can interact with each other within a rectangular world of finite size (1200 x 480 pixels).

4.1.3 Resources

- Netlogo 6.1
- Camunda Modeler 4.0.0
- Camunda BPM server 7.12.0
- PyNetlogo 0.4.4
- Java settings:
  - CompilerThreadStackSize = 0
  - ErgoHeapSizeLimit = 0
  - HeapSizePerGCThread = 87241520
  - InitialHeapSize = 534773760
  - LargePageHeapSizeThreshold = 134217728
  - MaxHeapSize = 4248829952
  - ThreadStackSize = 0
  - VMThreadStackSize = 0
  - Java version "1.8.0_144"
  - Java(TM) SE Runtime Environment (build 1.8.0_144-b01)
  - Java HotSpot (TM) 64-Bit Server VM (build 25.144-b01, mixed mode)
- Windows Settings:
  - OS Name: Microsoft Windows 10 Home
  - OS Version: 10.0.18362 N/A Build 18362
  - OS Manufacturer: Microsoft Corporation
  - OS Configuration: Standalone Workstation
  - OS Build Type: Multiprocessor Free
  - System Type: x64-based PC
  - Processor(s): Intel64 Family 6 Model 94 Stepping 3 Genuine Intel ~2701 Mhz
  - System Locale: en-gb;English (United Kingdom)
  - Input Locale: en-gb;English (United Kingdom)
  - Time Zone: (UTC+00:00) Dublin, Edinburgh, Lisbon, London

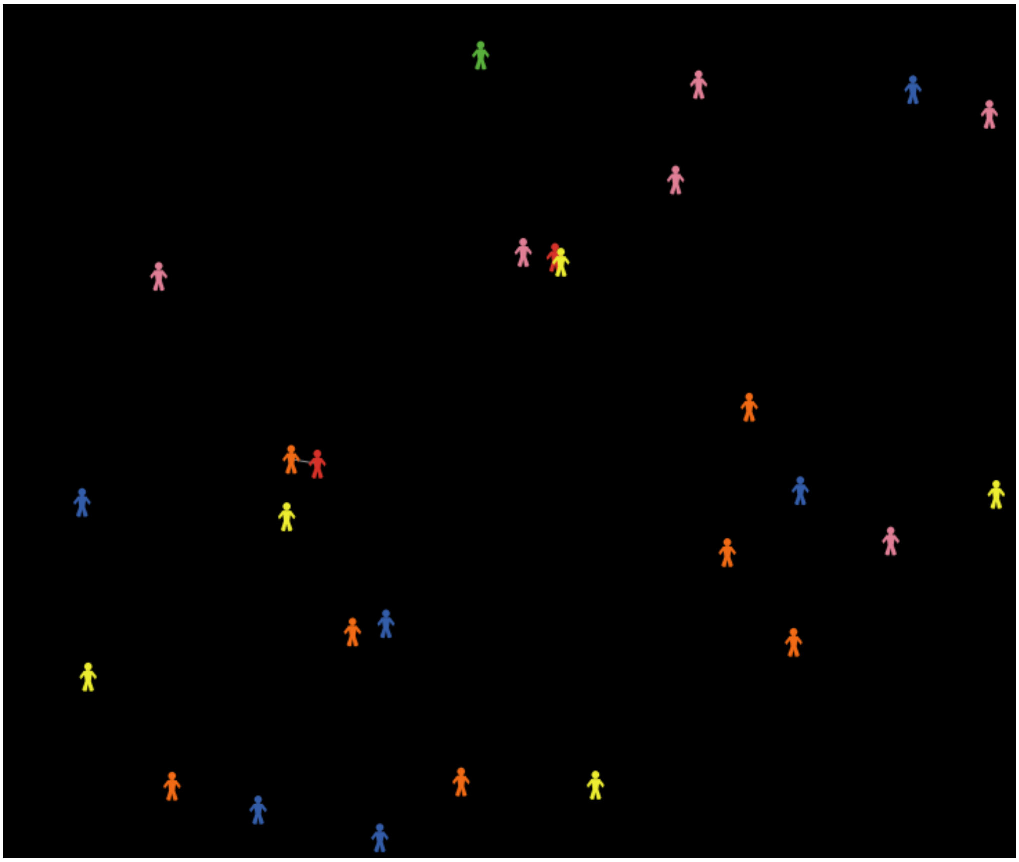
- Total Physical Memory: 32,589 MB
- Available Physical Memory: 17,550 MB
- Virtual Memory: Max Size: 37,453 MB
- Virtual Memory: Available: 19,089 MB
- Virtual Memory: In Use: 18,364 MB
- Page File Location(s): C:\pagefile.sys
- Hyper-V Requirements: VM Monitor Mode Extensions: Yes
- Virtualization Enabled In Firmware: Yes
- Second Level Address Translation: Yes
- Data Execution Prevention Available: Yes

4.1.4 The ABM Model

In our agent-based model[1], at the start of the experiment, both groups are spread randomly across the world, and the simulation starts with a predefined number of agents of each group. The patient agents move randomly until they are in proximity to a receptionist.

[1] Duduka, Jacint. (2020) 00xE8/BPABSIF: Business process & Agent-based Interoperability Framework. Retrieved September 30, 2020, from https://github.com/00xE8/BPABSIF

Figure 4.1 Patient and Staff agents.



Source: Author

Proximity in this context is characterised as the area(pixels) surrounding the agent, and once a patient agent gets within the area surrounding the receptionist, it stops moving. At this moment, the receptionist goes into a “busy” state, to signify that it cannot be connected to any other patient while it is connected to the current one.

The concept of a busy receptionist is used to model the interaction between the receptionist-patient (RP) pair. Such busy-ness occurs for a finite amount of time, after which the patient agent “dies”, meaning that he/she is registered within the hospital system. During this period, the following actions occur:

1. The process in the BPMN engine is started by the Receptionist agent.
2. A predefined delay is observed by the RP pair, to represent the time it takes to fill the registration form.

3. Once this time is elapsed, the patient agent disappears, and the receptionist becomes available again to link with a new patient, from where the cycle repeats.

Patient agents are colour coded by the idiom they speak. The table below describes this relationship

Table 4.1 Language VS Agent Group Color

Idiom	Colour
Hindi	Yellow
Konkani	Blue
Malayalam	Orange
Other	Pink

Source: Author

Receptionist agents can have two different colours depending on whether the agent is busy or not, they are initiated with green colour, and when a patient connects, they turn red. After the patient within the pair dies, the receptionist turns green again.

PR pair remains in a busy state for random delays within a time range. The definition of delay ranges is dependent on how fluently each patient speaks an idiom, and it is assigned randomly to each patient agent from a range defined below:

Table 4.2 Language Vs Agent Group Delay(Ticks)

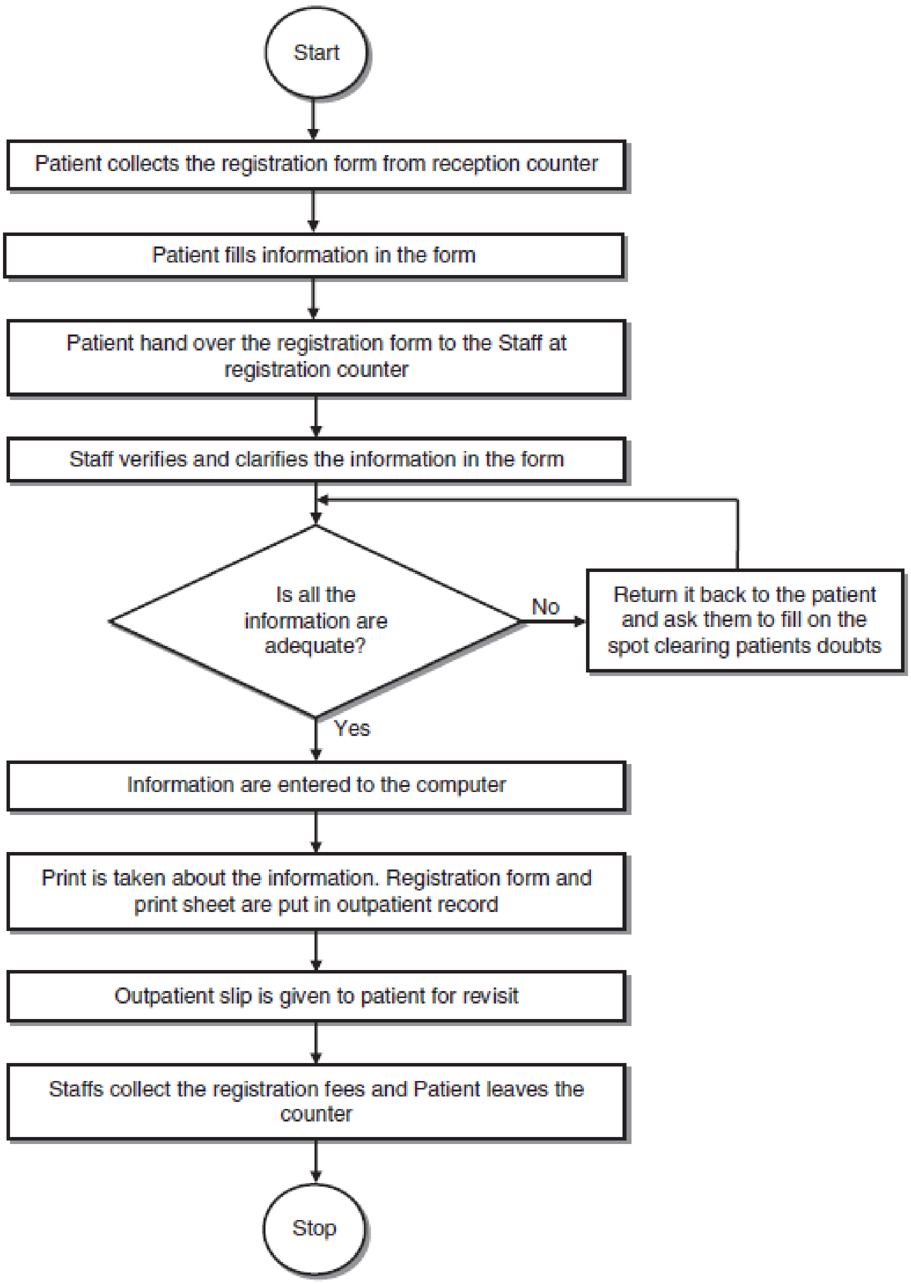
Patient Language	Time Range(ticks)
Hindi	450-550
Konkani	150-250
Malayalam	350-450
Other	0-50

Source: Author

4.1.5 The BPMN Model

Once the behaviour above is configured in the ABS, the business process below is modelled in BPMN:

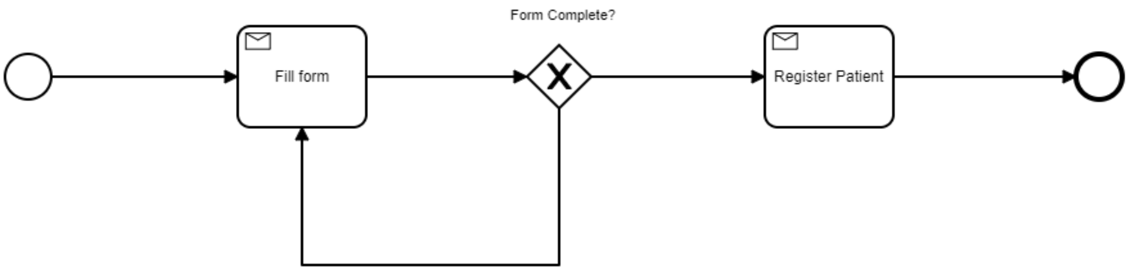
Figure 4.2 Activity diagram of a chosen business process



Source: Bhat et al., 2014

When converting the activity diagram to BPMN, some tasks were omitted as

Figure 4.3 Simplified BPMN Model of the RCS



Source: Author

those played no active part in the experiment because they did not send or receive messages from or to agents.

ABS begins execution, by having agents communicating with each other and invoking the BPMN engine when the PR pair finishes communicating, by sending messages using REST. Timestamps between events are collected and stored in a database for posterior analysis.

4.1.6 Controls

Table 4.3 List Of Controls

Variable Name	Description	Variable Type
DeltaABS	Events interval in ABS (Milliseconds)	Integer
DeltaBPMN	Events interval in BPMN (Milliseconds)	Integer
Konkani	Events interval for Konkani speakers (Milliseconds)	Integer
Other	Events interval for speakers of other languages (Milliseconds)	Integer
Malayalam	Events interval for Malayalam speakers (Milliseconds)	Integer
Hindi	Events interval for Hindi speakers (Milliseconds)	Integer
Source	Source of the event (ABS or BPMN)	String

Source: Author

4.2 Data collection

We collected event timestamps for 453 agents, for each language. Our assumption was that we can compare event intervals between the two systems to understand whether these vary significantly. For each agent, the following fields were extracted:

- Agent ID;
- ABSStart;
- ABSEnd;
- BPMNStart;
- BPMNEnd;
- Language;

The agent-based model inserted the timestamp for ABSStart and ABSEnd into the web request parameters sent to be BPMN engine and the BPMN model logged these into a text file.

Proceeded with importing the text file into a SQL Server database, that facilitated manipulating the data accordingly. Next, we calculated the event intervals for each engine, i.e. ABS event interval (DeltaABS) and BPMN Event Interval (DeltaBPMN). The formulas to calculate the event interval is as follows:

$$\text{DeltaABS} = \textit{ABSEnd} - \textit{ABSStart} \quad (1)$$

$$\text{DeltaBPMN} = \textit{BPMNEnd} - \textit{BPMNStart} \quad (2)$$

This was done by running the query below on our database:

```
SELECT  [AgentId]
   ,DATEDIFF(ms,ABMstart,ABMend) as DeltaABS
   ,DATEDIFF(ms,BPMNstart,BPMNend) as DeltaBPMN
FROM [dbo].[<<DATABASENAME>>]
```

A sample extract from the results can be seen in figure 4.3:

	AgentId	DeltaABS	DeltaBPMN
1	1593	10025	10024
2	1953	10655	10656
3	1816	6943	6942
4	1893	9255	9257
5	1697	10249	10249
6	1625	11231	11229

Figure 4.3: Event intervals per agent per engine type. Source: Author

Values for DeltaABS and DeltaBPMN are collected for each agent instance, and evaluated according to method described in section 4.3.

4.3 Evaluation

The data then is inserted into a statistical analysis tool, denominated “Intellicus Statistics”. There are two main analysis we run, namely Pearson’s Correlation Analysis and Multivariate ANOVA. We broke down the analysis per each objective of the study and can be seen below in more detail.

4.3.1 Evaluating Objective O1

Regarding our objective O1, we define the following experimental question:

EQA: “What is the correlation between DeltaABS and DeltaBPMN variables?”

H0: DeltaABS is not correlated to DeltaBPMN

H1: DeltaABS is correlated to DeltaBPMN

To answer our EQA question, we collect data for the following three sub-analyses, namely: outliers, descriptive statistics and Pearson Correlation.

4.3.1.1 Outliers

Univariate outliers were examined for DeltaABS and DeltaBPMN. An outlier was defined as any value which falls outside of the range of +/- 3.29 standard deviations from the mean (Tabachnick & Fidell, 2019).

4.3.1.2 Descriptive Statistics

Summary statistics were calculated for DeltaABS and DeltaBPMN.

4.3.1.3 Pearson Correlation Analysis

Pearson *r* correlation is a bivariate measure of association (strength) of the relationship between two variables. Pearson correlation analysis assumes that the variables have a linear relationship with each other (Conover & Iman, 1981). The assumption of linearity will be assessed graphically with a scatterplot. Given that the variables are continuous (interval/ratio data), the assumption of linearity is met, and the hypotheses seek to assess the relationships, or how the distribution of the z scores vary, a Pearson *r* correlation is the appropriate bivariate statistic.

Correlation coefficients, *r*, vary from 0 (no relationship) to 1 (perfect linear relationship) or -1 (perfect negative linear relationship). Positive coefficients indicate a direct relationship, indicating that as one variable increases, the other variable also increases. Negative correlation coefficients indicate an indirect relationship, indicating that as one variable increases, the other variable decreases. Cohen's standard will be used to evaluate the correlation coefficient, where 0.10 to .29 represents a weak association between the two variables, 0.30 to 0.49 represents a moderate association, and 0.50 or larger represents a strong association (Cohen, 1988).

A Pearson correlation analysis was conducted between DeltaABS and DeltaBPMN. Cohen's standard was used to evaluate the strength of the relationship, where coefficients between .10 and .29 represent a small effect size, coefficients between .30 and .49 represent a moderate effect size, and coefficients above .50 indicate a large effect size (Cohen, 1988). One of the assumptions made in this work when estimating the Pearson correlation is that a Pearson correlation requires that the relationship between each pair of variables is linear (Conover & Iman, 1981). This assumption is violated if there is curvature among the points on the scatterplot between any pair of variables.

4.3.2 Evaluating Objective O2

It is worth pointing out that the delay defined for each agent, is the mechanism we use to segregate groups of agents. This artificial injection of delays to execute tasks allows us to compare task execution intervals between the two sources, ABS and BPMN, which is the metric we use in our analysis relating to O1 and O2, to understand if there is a discrepancy in the variable between the engines. The assumption is that if there is no discrepancy between agent groups in the two engines, then our framework is going to provide reliable simulation results. Therefore, in relation to objective O2, the following experimental question is defined:

EQB: "What is the correlation between groups of agents with different task execution interval, between different sources (ABS or BPMN), given that the task execution interval is mutually different between groups."

H0: Task execution interval for each agent group is not similar between sources

H1: Task execution interval for each agent group is similar between sources

4.3.2.1 MANOVA

To examine the research question EQB, a multivariate analysis of variance (MANOVA) was conducted to assess if mean differences exist on task execution interval for Hindi, Konkani, Malayalam and Others between the different source engines. The MANOVA is an appropriate statistical analysis when the purpose of the research is to assess if mean differences exist on more than one continuous dependent variable by one or more discrete independent variables(DeCarlo, 1997).

The assumptions of multivariate normality, homogeneity of covariance matrices, multivariate outliers, and absence of multicollinearity was assessed. Multivariate normality assumes that every linear combination of the residuals of the MANOVA follows a univariate normal distribution. Multivariate normality was assessed graphically by plotting the Mahalanobis distances of the residuals against the quantiles of a χ^2-distribution (DeCarlo, 1997; Field, 2017). Homogeneity of covariance matrices assumes that covariance matrices for each within-group are equal. A Box's *M* test did examine the assumption. Multivariate outliers were determined by calculating

Mahalanobis distances on the residuals (Newton & Rudestam, 1999) and comparing the distances to the .999 quantile of a χ^2-distribution with the degrees of freedom being n-1, where n is the number of measurements conducted on the dependent variable. Absence of multicollinearity requires that the dependent variables are not too highly correlated ($|r| > .9$) with each other. Pearson correlations were conducted for each pair of the dependent variables to examine multicollinearity.

MANOVA assesses whether mean differences among groups on a combination of dependent variables are likely to have occurred by chance. The MANOVA analysis creates a linear combination of the dependent variables to create a grand mean and assesses whether there are group differences on the set of dependent variables. The MANOVA will apply the *F*-test to determine if there are any significant differences at a significance level, $\alpha = .05$. If there are significant differences, then an ANOVA will be conducted for each dependent variable. (DeCarlo, 1997)

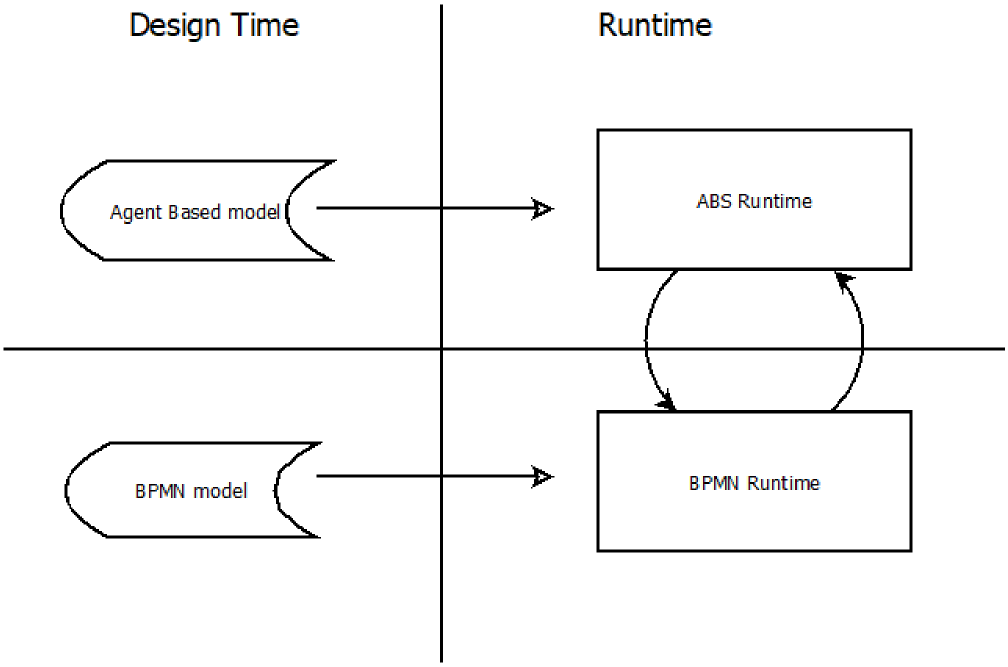
5 Solution Proposal

To address the issue, we frame a solution that approaches the problem from a holistic view. The current state of the art in the topic focusses on two main categories of approaches. In the first category, we can find solutions that try to conceive a concept equivalence framework between ABS to business process modelling notations or vice-versa. Although there is some success in doing this (Aksyonov & Aksyonova, 2013; Dam et al., 2015; Endert et al., n.d.; Ghlala et al., 2017; Laroque et al., n.d.), they agree that there will be concepts that are merely difficult or even impossible to convert.

The second category consists of integrating ABS with process simulation engines that do not take into account the complexities occurring in the enterprise, such as budget limits, training, project deadlines, skillset availability in the workforce, different social pressures in the organization. Between these, we find mainly DES, Petri-nets and some other generic process engines and we deem them inappropriate.

We propose a solution that considers all three dimensions of the Laudon framework namely management, organization and technology. For the technology dimension, it is proposed designing agent-based models and business process models separately and let the software agents drive the business process engine as if they were real users.

Figure 5.1 Concept of proposed ABS/BPMN integration



Source: Author

The same can be said for the software agents and the ABS, which continues working usually and following the rules defined in its model. Agents simply send messages to the BPMN engine when specific preset criteria are met and is not aware of the purpose of those messages.

This approach is different from the current mapping approaches, in that it avoids any sort of concept equivalency problems altogether because models are not converted, they interact with each other during the simulation runtime.

To address the management and organizational dimensions of our solution, it's proposed that we use process engines and notations that are widely adopted. For this, we compared usage trends of business process modelling languages, for the past 16 years worldwide. Although the comparison is not exhaustive of all languages, we focussed on the main ones and collected data using Google Trends[2].

[2] Retrieved September 22, 2020, from https://trends.google.com/trends/explore?date=all&q=%2Fm%2F08kq3d,%2Fm%2F01xc3f,%2Fm%2F01gt82

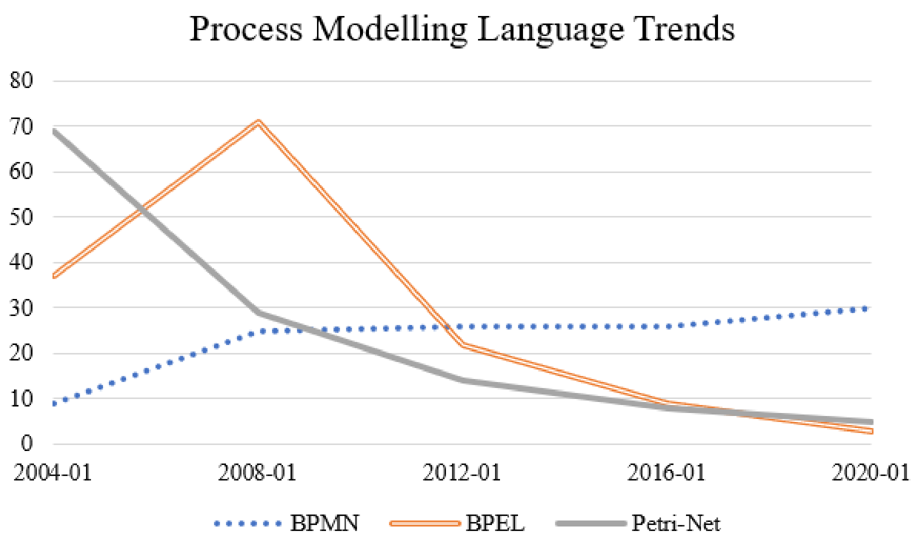


Figure 7 Numbers represent search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular. A score of 0 means there was not enough data for this term. Source: Google Trends. (2020)

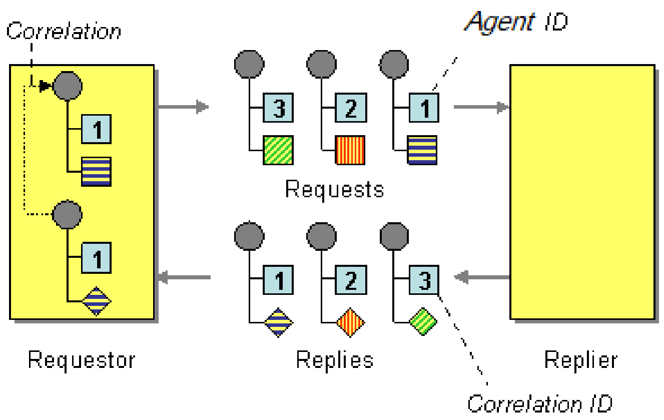
Choosing a highly available modelling language is how we intended to fulfil the management and organizational dimensions of our framework, the assumption being that a highly adopted language requires less investment to implement, less workforce training, less time to convert models, and more skillset reusability encourages collaboration. Given the overall trend of BPMN, we chose it as our business process modelling language.

Our choice for using BPMN as the business process simulation engine in this research is also justified by its ability to serve multiple purposes. First, it is a standard engine adopted in the industry to manage, model and execute processes, with a large community and vendor support (Recker, 2008). The same author mentions that BPMN is also an industry-standard widely adopted, when it comes to business process management, as well as studied from a theoretical point of view. It was essential to find a process engine that not only is reliable to simulate processes but also one that will be simple to implement in the industry as that is where the real business value it, therefore our choice for BPMN.

One of the challenges we encountered in conceiving a distributed simulation framework is that multiple agent instances were being created during the simulation process, as well as multiple process instances in the BPMN engine. The consequence is that messages may be routed to the wrong process instance if no attention is paid to the way messages are transferred between systems. Therefore, the fundamental question to answer related to message correlation is: *"How does a system that has received a message, know which request this is related to?"*

The solution concept we adopted is demonstrated by Hohpe & Woolf, 2012, where it suggested that *"the requestor add a Request ID to the request message, have the replier copy the Request ID to the Correlation ID field of the response message so that the requestor can correlate the reply message to the request message."*

Figure 5.3 Message correlation between requester and replier



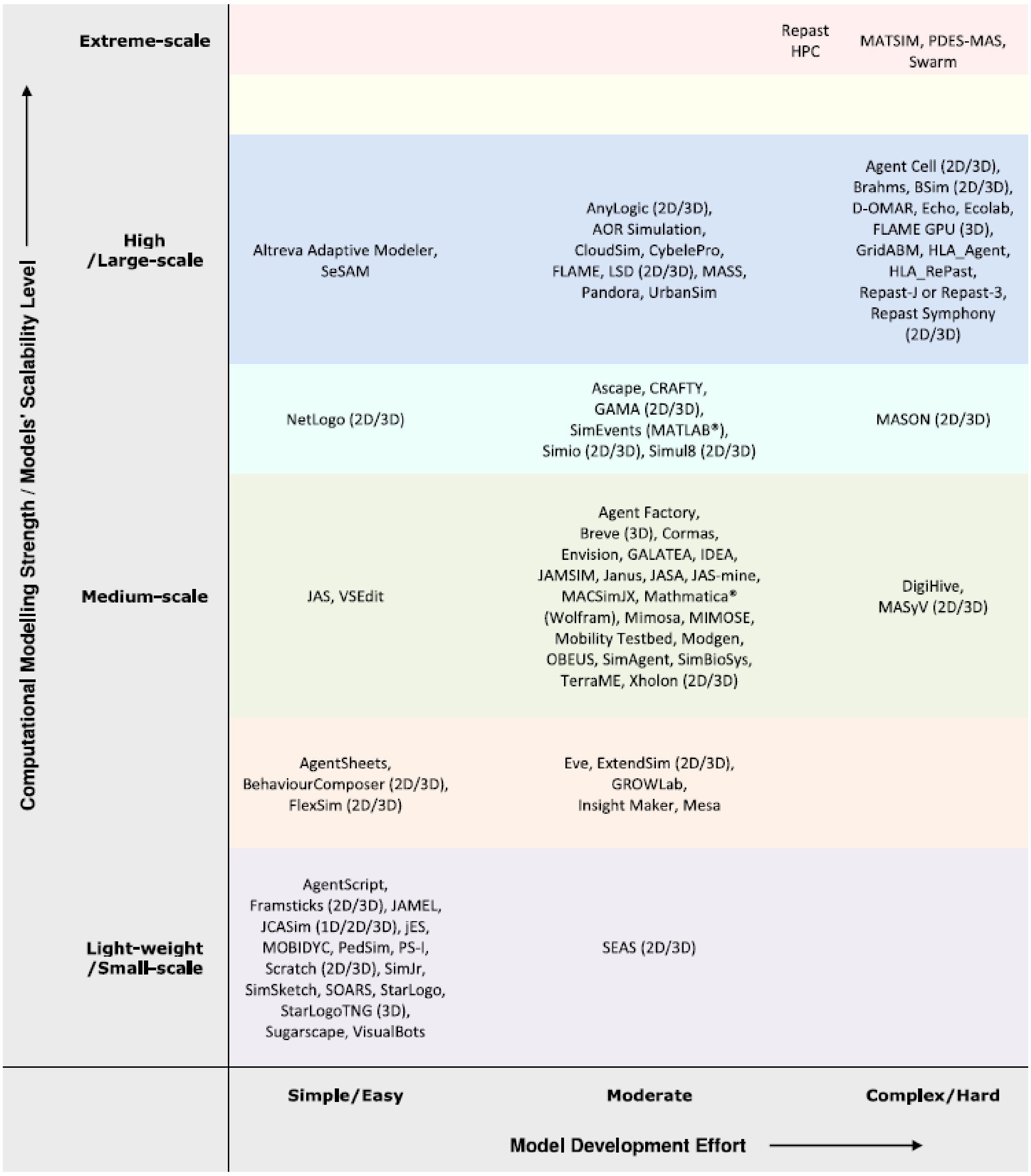
Source: (Hohpe & Woolf, 2012)

In our case, the "Agent ID" is used as the identifier of the message. This separation of concerns also has other advantages, which for instance, opposed to BPMN integration approaches proposed by some authors (Onggo et al., 2017), this one does not suggest any sort of extension artefacts to the BPMN standard. The ability to bypass these difficulties would significantly enhance the process of creating better models because the BPMN standard itself does not need to be modified or extended in any way and no significant investment of time is required to train staff in organisations about features of new extensions, instead, already existing tools are reused.

6 Results

In this section, we present a detailed evaluation of our results.

Figure 6.1 Ease of model development versus ABMS tools' computational modelling capacity or models' scalability level



Source: (Abar et al., 2017)

Netlogo had been highlighted by several authors (Abar et al., 2017; Lytinen & Railsback, n.d.; Railsback et al., 2006) as being versatile enough for small and large experiments, as well as presenting a low learning curve. These characteristics were relevant for our choice as we needed to find an engine that is not only robust but also readily available in the industry to facilitate adoption within organisations, and also in the event that further studies are conducted in the future.

Looking at our objective O1, we were able to gather data about existing ABS systems in relation to the programming languages they use to create their model. Understanding which programming language, they use was fundamental as our assumption was that it would be the primary vector by which the ABS could send web requests, the assumption being that if the underlying modelling language supports web requests, then the engine supports them too.

Table 6.1 Agent-Based Modelling engines vs Programming language they use

Name	Programming Language
AnyLogic	Java
Cougaar	Java
Framsticks	FramScript (similar to JavaScript)
JADE	Java
MASON	Java
NetLogo	NetLogo, Python(PyNetlogo)
Repast	Java, Python (RepastPy); Visual Basic, .Net, C++, J#, C#
SARL	SARL, Java
Soar	Soar 1 to 5 in Lisp; Soar 6 in C; Java, C++, TCL
StarLogo	StarLogo (an extension of Logo)
Swarm	Java; Objective-C

Source: ‘Comparison of Agent-Based Modelling Software’, 2020

From the short review above, key findings emerge: 100% of the ABS engines support programming languages that can submit web requests or support extensions that allow for external scripting engines to be embedded in the agent-based model, which in turn supports sending web requests.

In addition, we specifically studied the documentation of the ABS of choice, Netlogo 6.1 and found that it does not support any capability to perform web requests natively, although there were some attempts (*NetLogo/Web-Extension*, 2012/2020) to introduce similar functionality using extensions, however not for the purpose of sending generic web requests. However, it was also found that one of the extensions supported is the Python scripting engine(Jaxa-Rozen & Kwakkel, 2018) through the PyNetLogo extension. As Python is a generic scripting language, it not only allowed to make web requests via REST protocol but also to establish full integration between the two applications, control message correlation, transformation and logging.

Although the results above confirm that majority of ABS engines support web requests, our method also relies on the BPMN engine supporting a REST API that allows a consumer to start a process. The table below lists BPMN engines and their support for starting processes through REST.

Table 6.2 List of major BPMN engines vs support for process invocation through REST

Engine	Support REST process invocation
ActiveVOS	Y
Activiti	Y
Bizagi BPM Suite	Y
Bonita BPM	Y
Camunda BPM	Y
Flowable	Y
Imixs-Workflow	Y
jBPM	Y
Orchestra	N
Sydle SEED	Undetermined

Source: Author

From this we can understand that the majority of the BPMN engines do provide support for a REST API that allows invocation of processes. From this perspective, these results together demonstrate the adequacy for implementing our method using the majority of ABS and BPMN engines.

6.1 Objective O1 Results

6.1.1 Outliers

There were no outliers present in DeltaABS. There were no outliers present in DeltaBPMN. Table 6.3 presents the number of outliers in each variable, which is zero for both variables.

Table 6.3 Number of outliers detected for DeltaABS and DeltaBPMN

Variable	No. of Outliers
DeltaABS	0
DeltaBPMN	0

Source: Author

6.1.2 Summary Statistics

The observations for DeltaABS had an average of 28477.01 (SD = 16419.91, SEM = 194.36, Min = 492.00, Max = 72758.00, Skewness = 0.00, Kurtosis = -0.88). The observations for DeltaBPMN had an average of 28474.20 (SD = 16420.48, SEM = 194.37, Min = 501.00, Max = 72752.00, Skewness = 0.00, Kurtosis = -0.88). When the skewness is greater than 2 in absolute value, the variable is considered to be asymmetrical about its mean. When the kurtosis is greater than or equal to 3, then the variable's distribution is markedly different from a normal distribution in its tendency to produce outliers (Westfall & Henning, 2013). The summary statistics can be found in Table 6.4.

Table 6.4 Summary Statistics Table for Interval and Ratio Variables

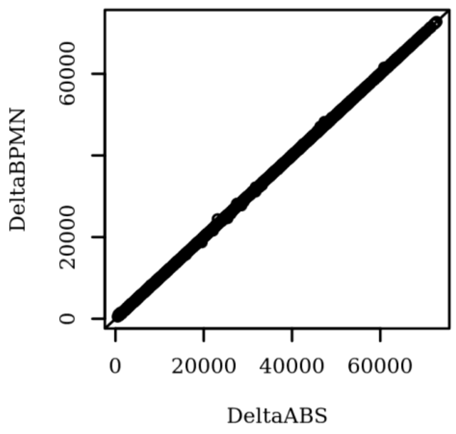
Variable	*M*	*SD*	*n*	SE_M	Min	Max	Skewness	Kurto-sis
DeltaABS	28477.01	16419.91	7137	194.36	492.00	72758.00	0.00	-0.88
Delta-BPMN	28474.20	16420.48	7137	194.37	501.00	72752.00	0.00	-0.88

Source: Author

6.1.3 Pearson Correlation Analysis

Figure 6.2 presents the scatterplot of the correlation. A regression line has been added to assist the interpretation.

Figure 6.2 Scatterplots between each variable with the regression line added



Source: Author

The result of the correlation was examined based on an alpha value of 0.05. A significant positive correlation was observed between DeltaABS and DeltaBPMN (r_p = 1.00, *p* < .001, 95% CI [1.00, 1.00]). The correlation coefficient between DeltaABS and DeltaBPMN was 1.00, indicating a large effect size. This correlation indicates that as DeltaABS increases, DeltaBPMN tends to increase. Table 6.5 presents the results of the correlation. *Note. n* = 7137.

Table 6.5 Pearson Correlation Results Between DeltaABS and DeltaBPMN

Combination	r_p	95% CI	*p*
DeltaABS-DeltaBPMN	1.00	[1.00, 1.00]	< .001

Source: Author

6.2 Objective O2 Results

6.2.1 MANOVA

A multivariate analysis of variance was conducted to assess if there were significant differences in the linear combination of Malayalam, Konkani, Other, and Hindi between the levels of Source. The main effect for Source was not significant, $F(4, 899) = 0.00$, $p = 1.000$, $\eta^2_p = 0.00$, suggesting the linear combination of Malayalam, Konkani, Other, and Hindi was similar for each level of Source. The MANOVA results are presented in Table 6.10.

Table 6.6 MANOVA Results for Malayalam, Konkani, Other, and Hindi by Source

Variable	Pillai	*F*	*df*	Residual df	*p*	η_p^2
Source	0.00	0.00	4	899	1.000	0.00

Source: Author

6.3 Discussion

It has been confirmed that from technology and functional levels, our idea of integrating the two simulation engines is possible. All major agent-based simulation engines do support performing web requests as well as a majority of BPMN engines allows for controlling process execution and messaging via a RESTFul API.

In relation to our objective O1, the results of our experiment suggest the correlation coefficient between DeltaABS and DeltaBPMN was 1.00, indicating a large effect size. This correlation indicates that the task execution interval in the ABS is kept constant in the BPMN engine. It confirms our suspicion that the messages flow between system without significant changes in task execution intervals.

We also investigated whether creating different groups of agents, having different task execution intervals, would be impacted by the communication process between the two systems. The results indicate that the linear combination of Malayalam, Konkani, Other, and Hindi was similar for each level of Source which leads us to conclude that even if the agents were operating in groups and those groups were mutually different in how they behaved in relation to time, those differences would not be affected during message transmission between systems.

7 Conclusions

The main conclusions of this work are drawn together and presented in this section. In the present dissertation, we intended to investigate how could we integrate an ABS system with a BPMN engine, to perform simulations and obtain statistically significant results. The main aim of such integration is to create a mechanism to simulate and study complex phenomena within business processes. Based on the quantitative analysis of event intervals between the two systems and also based on the event intervals of groups of agents between the two engines, it can be concluded that integrating an ABS system with a BPMN engine, produces statistically coherent simulation results.

Despite the success demonstrated, some significant limitations should be highlighted. We could not evaluate how well our findings apply in a real implementation project within an organisation as our experiment has firmly focussed on addressing functional and simulation results significance aspects. It is possible that the practical implementation constrains of our technique outweigh the benefits of using it, so, therefore, it is suggested that further research is undertaken to look into those aspects.

Due to the novelty of the simulation framework proposed, we also encountered difficulties in determining how it compares to other studies in the same field. On one hand, this can be a significant step forward for a holistic business process simulation paradigm, but on the other, for the time being it leaves some gaps in knowledge that can only be filled in by further research.

The main achievements, including contributions, may be summarised as follows. First, we created a new way of simulating business processes. The innovation in our method is that it allows for a holistic simulation to happen, where complex phenomena can be made part of the business process simulation. We did consider no only the technology aspects of the solution but also its organizational and management contexts. This, in turn, opens doors to study more complicated problems, that are difficult to study analytically, such as the effect of emergence, feedback loops and self-organization on process performance and at a broader sense, it enriches our scientific knowledge base in process optimisation methodologies.

It has been shown for the first time that it is possible to use and reuse existing simulation tools to enable this holistic type of simulation. It remains unclear to which degree our framework is related to low implementation costs, for instance, we speculate that our approach requires low investment in purchasing new tools and training staff as tools we propose are readily available in the market. It is suspected that this is an attractive proposition not only for large organisations but also for small to medium businesses that cannot afford expensive software solutions. Finally we contemplate whether our approach is simple and easy to be adopted in academia or for individual researchers, as a tool to study conservation laws in business processes.

The author identified two categories of work to be proposed based on the experiences collected during the dissertation. The first category is related to problems identified during the work undergone, and the second relates to further areas of research that would expand the scope of the work and enrich the features of our method.

Regarding problems encountered during the experiment, we found that although our results point in the direction that our proposed method can be used to simulate complexity in business processes, the author feels that further investigation should be conducted into some aspects that came to light during the current dissertation:

1. Netlogo and many other agent-based simulation engines are synchronous systems. This means that agents perform actions in sequence without true parallelism, and therefore if the business process being simulated require messages to be sent in parallel, this may create challenges. We are proposing further studies to understand the extent to which this can create issues;
2. Impact of errors in simulation results. It is understood that there is a margin of error in every experiment; however, the author suggests a broader study that looks are factors that can cause Netlogo to behave abruptly and understand how these can influence simulation results. These factors could be hardware, software, resource availability;
3. The implementation of functionality within BPMN to handle incoming and outgoing messages. It has been found that custom scripts embedded in to

"receive the message" tasks in BPMN are not invoked when messages arrive but straight after the token arrives in the task. This can influence cycle time results and other problems, and a better way to handle messages in BPMN should be studied;

In terms of improvements to be made to our method, it is proposed that future work consists in exploring other simulation methods that are best suited to simulate different types of factors that influence a business process. More specifically, system dynamics is a method well suited to study how quantitative variables are impacted by the overall dynamics of the process and thus, variables such as costs and budgets, can be included in the simulation to create an even richer understanding of the overall dynamics of the business process.

In order to better comprehend the suitability of this simulation approach in real-world situations, there is a need to employ it in a project from the design phase, so that aspects as the influence of process designer skills and time to create models can be factored into the effectiveness. These are aspects not covered in this dissertation, as we only focus on understanding the feasibility of building a solution that supports such a simulation approach and whether simulation results are reliable enough compared to real ones. Therefore, a case study employing our approach is another suggestion for future work.

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Annexe

Annexe A – Literature Review

Planning

Determine what is state of the art concerning combining BPMN simulation with agent-based during business process modelling

PICOC

Population: business process modelling

Intervention: BPMN simulation

Comparison: an agent-based simulation

Outcome: new insights that enable business process modelling

Context:

Research Questions

How is BPMN simulation being currently combined with agent-based simulation to enable business process design

Keywords and Synonyms

Keyword	Synonyms
Agent-based modelling	Agent-based simulation
BPMN simulation	
Business process modelling	Business process design
New insights that enable business process modelling	New insights that enable business process design

Sources

Google Scholar (https://scholar.google.com)

ISI Web of Science (http://www.isiknowledge.com)

Microsoft academic (https://academic.microsoft.com)

Scopus (http://www.scopus.com)

Selection Criteria.

Inclusion Criteria.

Discuss BPMN simulation in relation to collaboration between users

Discusses BPMN simulation in relation to agent-based modelling

Discusses business process simulation in relation to user behaviour simulation

Exclusion Criteria.

The article cannot be found

Discusses agent-based modelling in isolation

Discusses BPMN simulation in isolation

No plausible evidence to support claims

Not an article

Quality Assessment Checklist

Questions.

Does it discuss the topic in the context of simulation or execution (instead of notation, diagram conversion)?

Does it discuss BPMN simulation with relation to agent-based simulation

Does it discuss business process simulation with relation to any other simulation method

Does it discuss business process simulation with relation to agent-based simulation

Answers.

Yes

No

Data Extraction Form

Reference

Purpose/Objectives

Research questions

Methodology

Main Findings

Relevance

Conducting

Search Strings

"BPMN simulation" AND "agent based simulation"

"BPMN simulation" AND "agent based modeling"

"BPMN simulation" AND "agent based modelling"

”BPMN" AND "agent based simulation"

"BPMN" AND "agent based modeling"

"BPMN" AND "agent based modelling"

Imported Studies

Google Scholar: 554

ISI Web of Science: 27

Microsoft academic: 11

Scopus: 31

Annex B - Github Repository

https://github.com/00xE8/BPABSIF

Annexe C – Resumo em Português

O paradigma atual de um modelo de processo de negócio é que é uma representação de uma sequência de tarefas que atuam sobre alguma entrada de dados, para produzir uma produção, visando a produção de um novo serviço ou produto a ser entregue de um produtor a um cliente. Embora esta seja uma forma válida de pensar, não considera em pormenor a influência de alguns fenómenos nos inputs, por exemplo, comportamento humano, comunicação, interações sociais, a cultura organizacional que pode ter um efeito significativo na produção entregue por um processo de negócio. Como a dinâmica destes fenómenos não é linear, podem ser interpretados como um sistema complexo. Esta forma holística de pensar sobre os processos de negócio abre as portas à possibilidade de combinar diferentes métodos de simulação para modelar diferentes aspetos que influenciam um processo.

Um motor BPMN e um motor de simulação baseado em agente (ABS) são escolhidos para servir a base do nosso trabalho. Na sua conceção, consideramos não só os aspetos técnicos, mas também a exploração das suas dimensões de gestão e organização, com o intuito de facilitar a sua adoção nas empresas, como uma ferramenta de apoio aos sistemas de apoio à decisão. Analisamos a precisão dos resultados da simulação ao utilizar estas duas ferramentas, bem como quais as considerações que devem ser observadas dentro das organizações.