On the Business Models of Cloud-based Modelling and Simulation for Decision Support

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Abstract

Simulation modelling is one of the techniques used for decision support in a wide range of domains and cloud computing is beginning to make some impact on simulation modelling by enabling ubiquitous, convenient and on-demand access to a variety of computing services. The cloud-based modelling and simulation (CBMS) literature has focused on how to develop CBMS tools using existing technologies. While this technical aspect is important, understanding the business aspect of CBMS is instrumental for its adoption by users and for ensuring the sustainability of the broader CBMS service supply chain. This paper presents a review of the business models adopted by vendors that provide Web or mobile applications for simulation modelling. An analysis of the offerings of these vendors provides some insights into how cloud services can be provided and used as part of CBMS business models. The study is conducted by reviewing the websites of simulation vendors. This study fills a gap in the literature on the business aspect of CBMS by providing insights into CBMS business model patterns. It highlights the importance of developing innovative business models that can help generate new market opportunities and revenue streams along the CBMS service supply chain. It also stresses the role of contracting in addressing the reported challenges and risks underpinning the provision and use of CBMS services.

Keywords: cloud-based simulation, model-as-a-service, analytics-as-a-service, business model, contracting.

1. Introduction

One of the grand challenges in *Modelling and Simulation* (M&S) is *Cloud-Based Modelling and Simulation* (CBMS) (Taylor et al. 2012, Taylor et al. 2013). CBMS refers to the use of cloud computing technologies to deliver M&S as services. In this paper, we limit the term M&S to Discrete-Event Simulation (DES), Agent-Based Simulation (ABS) and System Dynamics (SD). The definitions and differences between these simulation paradigms are explained in Heath et al. (2011). As for the term cloud computing, we use the definition in Grance and Mell (2011), i.e. 'a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models.' In this paper, we will refer to the three service models as service types, so that we can use the word 'model' to refer to an analytic model, or else a simulation model.

The five essential characteristics of cloud computing are on-demand self-service (automatic deployment of computing capabilities), broad network access using multiple platforms (such as mobile devices, laptops and desktop computers), resource pooling, rapid elasticity (computing capabilities can be scaled up or down to match fluctuations in demand) and measured service (such as the pay-as-you-use model). Cloud computing offers three service types: *software-as-a-service* (SaaS), *platform-as-a-service* (PaaS) and *infrastructure-as-a-service* (IaaS). In SaaS, users can run applications using cloud infrastructure, while in PaaS users can create applications to be run on cloud infrastructure (hence users have control over their applications). In IaaS, users can have control not only over their applications but also over storage and operating systems. Finally, cloud computing can be deployed in four models: public cloud (infrastructure can be used by the public), private cloud (infrastructure can only be used by an individual organisation), community cloud (infrastructure can be used by a community of users with a shared mission) and hybrid cloud (a combination of the other three deployment models).

The trend of using the Internet and the Web for M&S is not new. Early efforts utilising the Web to support model design, model execution and the analysis of generated simulation results can be traced back to Fishwick's paper on *Web-based simulation* (WBS) in 1996. There are similarities between CBMS and WBS. They aim to bring state-of-the-art Internet and Web technologies to the M&S community. Despite significant advances in WBS research, its commercial applicability and adoption by users did not grow to the desired extent. One possible reason is that the approach taken by the WBS domain failed to take full advantage of the features of the Web, such as common standards, interoperability, ease of navigation and use (Kuljis and Paul 2003). Furthermore, the focus of many WBS studies was on the re-implementation of existing desktop simulation software as reflected in the literature review done by Byrne et al. (2010). WBS should have adequately addressed what simulation users really needed from its usage in practice. Hence, in the context of CBMS, Onggo et al. (2014) identify two lessons that we can learn from WBS research: CBMS must not simply re-implement existing desktop simulation software using cloud computing technologies and successful adoption of CBMS should not be based on a technological push alone, but also on real demand from users. Therefore, it is important to introduce new value propositions (e.g. services and features) that are enabled by the use of cloud computing technologies for M&S and to understand the factors that affect CBMS as a viable business proposition to potential users.

Based on the above two lessons, we believe that research into CBMS should include both technological and business aspects. The technological aspect helps us to understand what can be achieved using existing technology and to identify new technological requirements. The business aspect will help us to understand how to make CBMS a viable business proposition. This includes work to understand the behaviour of the actors involved (potential end users, simulation practitioners, simulation vendors and other related service providers) to find suitable business models for CBMS and to resolve non-technical but important issues through appropriate contracts.

The current literature on CBMS reflects the dominance of research into the technological aspect of CBMS (Kiss et al. 2015). This paper fills a gap in the literature by studying the business aspect of CBMS. Specifically, the objective of this paper is to understand the business models adopted by simulation vendors who make M&S services accessible through Web or mobile applications. These vendors are chosen because they offer insights into how they can leverage cloud services to add value to their products and services. In fact, some of them have already used cloud services as part of their business models. To achieve the objective of the study, we review the websites of simulation vendors listed in a number sources, including the INFORMS biennial simulation software survey (INFORMS 2015). The information on their websites offers insights into their business models, such as what they believe to be the value propositions of their M&S services, how they deliver value propositions to their users, and how they generate revenue from their M&S services.

The remainder of the paper is structured as follows. Section 2 provides an overview of the CBMS literature. It starts with a summary of research into the technical aspect of CBMS that has dominated the literature, followed by existing work on non-technical aspects of CBMS. We explain our research methodology in Section 3. The analytical framework and the findings from the survey of the websites of simulation vendors are presented in Section 4. Section 5 discusses the results highlighting the importance of innovative business models along the CBMS service supply chain, and the role of contracting in addressing challenges underpinning the provision and potential use of CBMS services. Section 6 concludes and presents the study's limitations and some suggestions for future research.

2. Related Work

Given that CBMS has been identified as one of the grand challenges in M&S (Taylor et al. 2012, Taylor et al. 2013), it is not surprising that the literature has been dominated by studies of the technical aspect of CBMS. This body of work has mainly focused on how to make simulation in the cloud a reality by providing functionalities for users to store, share, develop and run simulation models, as well as analyse simulation results. Many scholars have reported how a platform for CBMS can be developed using technologies such as REST architecture (Shekhar et al. 2016, Wang and Wainer 2016), Java-based solutions (e.g. mJADES (Cuomo et al. 2012, Rak et al. 2012) and ClouDES (Padilla et al. 2014)), commercial platforms (e.g. Amazon EC2 (Eriksson et al. 2011, Wang and Wainer 2016), SlapOS/ Python-based solutions (e.g. DREAM architecture (Heavey et al. 2014)), Linux-based container solutions (e.g. SIMaaS (Shekhar et al. 2016)) and others. A number of scholars have specifically focused on creating infrastructure that allows fast simulation execution in the cloud (e.g. Fujimoto et al. 2010, D'Angelo 2011), cloud resource management (e.g. Li et al. 2013, Shekhar et al. 2016), cloud-based model repository (Rak et al. 2012) and the use of mobile applications to interact with a simulation server (e.g. Mancini et al. 2012, Padilla et al. 2014).

Research on the technical aspect of CBMS is essential for the existence and functionality of CBMS. At the same time, as we have learned from WBS, in order for CBMS to be successful, we should not simply re-implement existing desktop simulation tools using cloud computing technologies but should also look into the business and commercial aspects of CBMS (e.g. factors affecting adoption by users). We should also identify M&S services that can take full advantage of the features of cloud computing technologies.

Demirkan and Delen (2013) discuss how service-oriented *decision support systems* (DSS) can be developed in the cloud. They identify three DSS underlying services that can be enabled by cloud computing: *data-as-a-service, information-as-a-service* and *analytics-as-a-servic*e. Data-as-a-service allows organisations to access their data over the cloud. It provides virtualisation of data so that organisations do not need to worry about detailed database management systems. Information-as-a-service facilitates information delivery over the cloud. This service provides a virtualisation layer that integrates various data sources and transforms them into useful information. Analytics-as-a-service enables organisations to use *Operational Research* (OR) models over the cloud. The three services can be seen as variants of the software-as-a-service offering.

Simulation model is one of the key OR models used in DSS. Hence, Demirkan and Delen's idea (Demirkan and Delen 2013) has been extended to simulation modelling. Although the main focus of the work is on how to implement CBMS software, the architecture of the CBMS software developed by Liu et al. (2012) comprises three sub-services under the umbrella of a service type called *simulation-as-a-service*. These three sub-services are *modelling-as-a-service* which includes services like modelling service and model validation service, *execution-as-a-service* which includes services like experimental design service and execution service, and *analysis-as-a-service* which includes scenario design service and data collection service. Hence, Liu et al. (2012) have recognised a number M&S services that can be delivered as software-as-a-service offerings. In his survey of existing technologies that could be used to make CBMS a reality, Cayirci (2013) introduces an M&S service type umbrella called *modelling-and-simulation-as-a-service,* which offers three (sub)services: *simulation-as-a-service*, *model-as-a-service* and *modelling-as-a-service*. However, the two studies above do not discuss the business aspect of CBMS.

Johnson and Tolk (2013) identify five aspects within CBMS research: technical, governance, business, security and conceptual. The above literature is consistent with Kiss et al.'s (2015) observation that there has been significant progress in the study of the technical aspect of CBMS, but there is clearly a paucity of literature addressing the other four aspects. In line with Johnson and Tolk (2013), we submit that all five aspects need addressing to ensure the successful implementation and use of CBMS. The focus of this paper is on the business aspect of CBMS, specifically the business models adopted by vendors of CBMS tools. To the best of our knowledge, the only study on the business aspect of CBMS is one recently conducted by Kiss et al. (2015). They developed a CBMS platform and use it as a test bed to understand how simulation providers, consultants and end users interact in a service supply chain using their platform. They observed five patterns of interaction emerging during their research study which led them to realise that multiple business models are needed to make CBMS financially viable in the real world. In this paper, we complement Kiss et al.'s (2015) study by investigating CBMS business models from the perspective of vendors who already offer M&S services via Web or mobile applications. We employ the notion of business model as our analytical lens, which enables us to compare the components of business models used by CBMS vendors.

3. Methodology

To achieve the research objective, we review the websites of simulation software vendors (or developers) who provide M&S services that can be accessed using a Web or mobile application. This is because they either have already used cloud services or could make use of cloud services more easily in the future, since Web and mobile applications are an important component of cloud computing which is used to access and manage cloud resources. To ensure that we have not omitted any known simulation vendors, we collated a list of simulation vendors from the following sources.

- INFORMS biennial simulation software survey (INFORMS 2015) – INFORMS carries out this survey regularly. The latest survey was done in 2015. The survey focuses more on DES tools.
- List of DES tools (Wikipedia, 2016a)
- Comparison of SD tools (Wikipedia, 2016b)
- Comparison of agent-based modelling tools (Wikipedia, 2016c)
- Reviews of ABS tools by Nikolai and Madey (2009) and Allan (2009)

The above sources collectively list 179 unique simulation tools. Our search and review of tools follows certain inclusion/ exclusion criteria. First, we only review simulation tools that provide online documentation or websites in English. From their online documentation or websites, we exclude simulation tools that do not make at least one of the following services accessible from a Web or mobile application: model repository (i.e. upload, download), model sharing (using a platform, as an applet, or as an HTML5 file), model development, model execution and experimentation (in a server or browser) and collaboration (for non-collocated users, asynchronously or synchronously). The lists of ABS tools in Nikolai and Madey (2009), Allan (2009) and Wikipedia (2016c) include tools for multi-agent systems (MAS) which is different from ABS (i.e. MAS is used for creating software agents). Hence, we exclude MAS tools. The final list comprises 14 tools produced by 13 vendors (see Table 1). It should be noted that this list does not include any vendors who sell their simulation engines (i.e. part of a simulation tool that executes a model) to buyers who can integrate them with other software (which may use cloud-based services). This is because such information is not given in detail on many of the vendors' websites for our analysis and it is not possible to track what the buyers do with simulation engines.

Table 1: Simulation tools and vendors used in the analysis (C: Commercial, F: Free, ABS: Agent-based simulation, DES: Discrete-event simulation, G: General modelling, MC: Monte Carlo, SD: System dynamics)

Tool (vendor name)	**Licence**	**Paradigm**	**Storage**	**Share**	**Development**	**Execution**	**Collaboration**
AgentSheets, AgentCube (AgentSheets Inc.) http://www.agentsheets.com	C	ABS	√	√		√	
AgentCube Online (AgentSheets Inc.) http://www.agentsheets.com	C	ABS	√	√	√	√	
Analytica Cloud Player (Lumina Decision Systems, Inc.) http://www.lumina.com	C	MC	√	√		√	√
Behaviour Composer (Modelling4all) http://modelling4all.org	F	ABS	√	√	√	√	
Forio Epicenter (Forio) http://forio.com/	C	G	√	√	√	√	√
iModeler (Consideo GmbH) http://www.consideo.com	C	SD, MC	√	√	√	√	√
Insight Maker http://www.InsightMaker.com	F	ABS, SD	√	√	√	√	√
MS4 Model Store (MS4 Systems) http://www.ms4systems.com/pages/main.php	C	DES, MC	√				
Run the Model (The AnyLogic Company) http://www.runthemodel.com	C	ABS, DES, SD	√	√		√	
Simio Portal (Simio LLC) http://www.simio.com/products/simio-portal.php	C	DES, ABS	√	√		√	√
Stella, isee Exchange (isee systems) http://www.iseesystems.com	C	SD	√	√	√	√	
Sysdea (Strategy Dynamics Ltd) https://sysdea.com/	C	SD	√	√	√	√	√
Vanguard System (Vanguard Software Corporation) http://www.vanguardsw.com/	C	SD MC	√	√	√	√	√
YouSimul8 (Simul8 Corporation) http://www.yousimul8.com/	C	DES	√	√		√	

Most vendors in Table 1 are commercial ones. All the simulation paradigms that we are interested in (i.e. Agent-Based Simulation (ABS), Discrete-Event Simulation (DES) and System Dynamics (SD)) are represented. It should be noted that Forio supports languages such as Python and Julia, which can be used for general modelling (not restricted to simulation). The remaining columns show the services provided by the tools (which we use in the inclusion criteria). In order to ensure the validity of the secondary data we collected, we triangulated the information provided in Table 1 by testing the simulation tools (when a trial version or free (basic) version was available) or checking the tutorial videos, user guides and reference documents. The summary of the result from the testing is given in appendix B.

4. Results

This section first introduces the notion of business model and the analytical framework of the study, which is based on Osterwalder and Pigneur's (2010) concept of 'business model canvas'. It then applies this framework to provide an analysis of CBMS vendors' business models.

4.1 The notion of business model

The notion of business model was originally associated with internet-based entrepreneurship and gained prominence during the internet boom era (Magretta 2002). Since then, though, it has been extended to other sectors of the economy to describe how any firm conducts business and adds value (Chesbrough and Rosenbloom 2002). There is no agreement in the literature on what a 'business model' is and, thus, there is a plethora of existing definitions (see Zott et al. 2011). Despite this, the existing literature appears to converge on some fundamental characteristics of business models such as an inter-firm network structure (e.g. focal firm, customers, suppliers and business partners) within which value is created and exchanged; a market offering and value proposition to customers; technological capabilities that allow producing and delivering the good or service offered; revenue and cost structures, and payment models and incentives (Mason and Spring 2011; Spring and Araujo 2009; Osterwalder et al. 2005; Chesbrough and Rosenbloom 2002).

For the purposes of our analysis we have adopted the conceptualisation proposed by Osterwalder and colleagues (2005) because it is one of the most popular among practitioners and it has been applied to describe business models from a wide range of organisations. According to this conceptualisation, a business model is "a conceptual tool that contains a set of elements and their relationships and allows expressing the business logic of a specific firm. It is a description of the value a company offers to one or several segments of customers and of the architecture of the firm and its network of partners for creating, marketing, and delivering this value and relationship capital, to generate profitable and sustainable revenue streams." (Osterwalder et al. 2005, p. 14-15)

Osterwalder and Pigneur (2010) have built on the above definition to describe the key components or elements describing a business model at the firm level. Their 'business model canvas' framework consists of nine building blocks: customer segments, value propositions, revenue streams, channels, customer relationships, key resources, key activities, cost structure, and key partnerships. Table 2 presents these nine key components and their definitions (see Osterwalder and Pigneur 2010).

Table 2: The key components of business models (Source: Osterwalder and Pigneur, 2010, p.44)

Business model components	**Definition**
Customer segments	"The various groups of people or organisations that an enterprise aims to reach and serve".
Value proposition	"The collection of products and services that create value for a specific customer segment".
Revenue streams	"The cash a company generates from each customer segment".
Channels	"How a company communicates and reaches its customer segments to deliver a value proposition".
Customer relationships	"The types of relationships that a company establishes with specific customer segments".
Key resources	"The most important assets required to make a business model work".
Key activities	"The most important things a company must do to make its business model work".
Cost structure	"All costs incurred to operate a business model".
Key partnerships	"The network of suppliers and partners that make a business model work".

4.2 Business models of CBMS vendors

In this section, we apply the 'business model canvas' (Osterwalder and Pigneur 2010) framework to describe and analyse the business models adopted by the studied CBMS vendors (see Table 1). Specifically, we draw on the nine components to analyse and compare existing business models for CBMS services. The results are summarised in Tables 3, 4 and 5. In the following we discuss the key components of CBMS business models in turn.

Table 3: CBMS business models (customer segments, value propositions, and revenue streams)

Application	Customer segments	Value propositions	Revenue streams
AgentSheets & AgentCube (AgentSheets Inc.)	Classroom teaching/ education (niche market), agent-based modellers (segmented)	Users can develop an agent-based model more easily and publish the model on the Web (as a Java applet for AgentSheets and HTML5 for AgentCube)	Software licence, free training for teachers
AgentCube Online (AgentSheets Inc.)	Classroom teaching/ education (niche market)	Users can develop 3D agent-based simulation easily using a Web browser and run it on the online platform provided	Subscription fee (monthly, quarterly or annually)
Analytica Cloud Player (Lumina Decision Systems, Inc.)	Analytica users who need to share their models and to develop models concurrently with other people (segmented into modellers and users)	Analytica users can publish their models directly to Analytica Cloud Player (ACP); users can develop Web applications using ACP by wrapping an Analytica model with a customisable user interface; users can review and run models in a browser	ACP group account (individual account is free), extra ACP sessions after the number of free sessions has been exceeded, training (basic training is free), Analytica software licence (the limited Analytica 101 version is free), ACP server licence (if users want to run ACP on their own servers)
Behaviour Composer (Modelling4all)	Agent-based simulation modellers who have little or no programming experience (niche market)	Users can develop an agent-based simulation model using a graphical user interface and the model will be saved in NetLogo format (NetLogo is a free desktop application for agent-based simulation)	Free service (open-source software)
Forio Epicenter (Forio)	Analytics modellers and analytics users; simulation-based training providers and learners/ education institutions (Multi-sided and segmented markets)	Users can create interactive Web and mobile applications for analytics; users can use models created using well-known applications or programming languages and package them as Forio applications	Subscription fee (personal version is free)
iModeler (Consideo GmbH)	System dynamics and Monte Carlo modellers who need to access their models on any device, anywhere (segmented)	Users can develop and run models on iOS devices or any other device as long as it has a compatible browser; users can share their models and to develop models in collaboration with other users; users who are geographically dispersed can collaborate in model development either	Software licence (basic version is free), remote coaching and modelling

		synchronously and asynchronously	
Insight Maker	System dynamics and agent-based simulation modellers (mass market)	It provides all the functionalities needed for a full-model development life cycle as online services accessible via a browser	Free service (open-source software), donation
MS4 Model Store (MS4 Systems)	MS4 Me users (segmented)	Users can share their DEVS models more easily and collaborate with other users across the Web	Free service for MS Me licence holders (users pay for the MS Me licence)
Run the Model (The AnyLogic Company)	AnyLogic users who wants to share their model as a Java applet (segmented)	AnyLogic users can publish their models as Java applets that can be run on a compatible browser; In addition, a portal for sharing the models is provided free	Free service (users pay for the desktop application)
Simio Portal (Simio LLC)	Simio users (segmented)	Simio users can share their simulation results via a browser; Simio users can run set experiments from a browser and run them using cloud services	Information is not available on the Web
Stella (isee systems)	System dynamics modellers (segmented)	Users can publish their models as HTML5 that can be run on any compatible browser. The companion web-based application (isee Exchange) provides functionalities for model development via a web browser.	Software licence
Sysdea (Strategy Dynamics Ltd)	System dynamics modellers (segmented)	It provides all functionalities needed for a full-model development life cycle as online services accessible via a browser	Subscription fee (free for teachers)
Vanguard System (Vanguard Software Corporation)	System dynamics and Monte Carlo modellers (information about market segments is not available)	Users can run their models anywhere using a compatible browser; users can run their models on a Grid Computing infrastructure	Information is not available on the Web
YouSimul8 (Simul8 Corporation)	Simul8 users who wants to share their model (segmented)	Users can publish their Simul8 models using yousimul8 platform for free	Share with the public (free) or via a private channel (for users who have Simul8 (desktop) professional licence only)

4.2.1 Customer segments

'Customer segments' refer to the key organisations or individual customers that a firm intends to reach and serve (Osterwalder and Pigneur 2010). Table 3 shows that all commercial vendors divide their users into several segments. Typically, they divide their users into education (schools or higher education) and commercial sectors. Education-sector users are usually offered a discounted price (in some cases even for free). This is a strategy commonly used by many simulation vendors to increase their user base by targeting students who are studying related subjects. Most commercial vendors in Table 3 further divide their commercial users into multiple segments by providing different software versions or tiered subscription fees. This is a common strategy to reach out to users in a wider market. Some vendors focus on a niche market (e.g. AgentSheets Inc. focuses more on users from the education sector and Modelling4all focuses on users who have little or no programming experience). Non-commercial vendors (Modelling4all and InsightMaker) do not divide their users into segments, i.e. they provide one software edition.

What is clear from Table 3 is that most vendors consider simulation modellers to be their only customers. CBMS provides an opportunity to extend the market to a wider audience more efficiently because cloud services can be construed as a service supply chain in which a provider offers services to a user; subsequently, the user can add value to the services and become a provider to another user (and so on until it reaches an end user) as shown in Figure 1. In a cloud service supply chain, the end user is the one who consumes a cloud service and does not transform it into another cloud service. For example, in the CloudSME project (Kiss et al. 2015), software providers and consultants may consume high performance computing infrastructure as a service, add value by developing simulation applications and offer them as analytic-as-a-service to end users, i.e. SMEs.

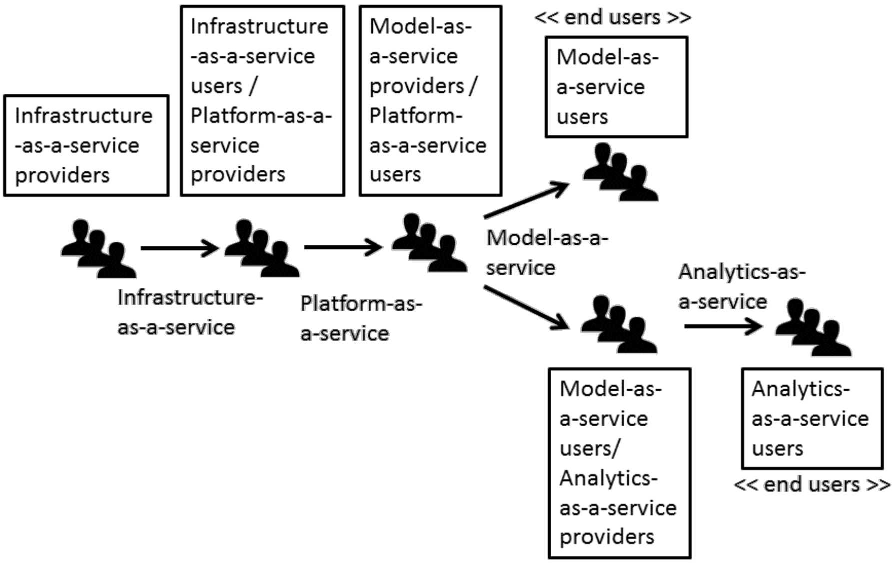

Figure 1: CBMS as a service supply chain

4.2.2 Value propositions

The notion of value proposition refers to value creation potential for specific customer segments through an appealing market offering (Osterwalder and Pigneur 2010). This is important to consider because the successful adoption of CBMS depends on whether potential users can accept the value proposition offered by CBMS services and start using them. As shown in Table 3, the most common value proposition offered by vendors is the ability to run a model anywhere using a browser. Hence, users do not need to install any software, apart from a browser to develop and run a model. Another commonly stated proposition is the ability to store models in cloud storage and share models over the Web. Since all models are accessible by users via a browser, they will always have access to the latest models. Only a few vendors mention support for online collaborative model development as their value proposition. Even fewer vendors explicitly highlight the ability to conduct experiments using scalable and on-demand computing resources enabled by cloud computing (i.e. Forio and Simio LLC) and grid computing as part of their value proposition (i.e. Vanguard Software Corporation).

The value propositions developed by CBMS vendors appear to be consistent with those developed for cloud services in general. More specifically, cloud services allow users to access their data anytime, anywhere, as long as they are connected to the Internet (Armbrust et al. 2009, Rimal et al. 2011, Subashini and Kavitha 2011, Wang et al. 2010, Wyld 2009, Zhang et al 2010, Zissis and Lekkas 2012) and cloud services offer better scalability of computing resources because they can be allocated and de-allocated on demand (Armbrust et al. 2009, Buyya et al. 2009, Katzan 2010, Marston et al. 2010, Rimal et al. 2011, Subashini and Kavitha 2011, Sultan 2011, Wang et al. 2010, Wyld 2009, Zhang et al. 2010, Zissis and Lekkas 2012).

However, CBMS vendors do not emphasise other common value propositions from cloud services which are relevant to CBMS. For example, cloud services reduce IT costs (Armbrust et al. 2009, Katzan 2010, Marston et al. 2010, Benlian and Hess 2011, Rimal et al 2011, Subashini and Kavitha 2011, Sultan 2011, Wyld 2009, Zhang et al. 2010). CBMS vendors and users do not need to purchase IT infrastructure and incur associated capital costs upfront. CBMS vendors can host their M&S services at one of the cloud service providers. A cloud service provider can deliver the service cheaper due to better economy of scale and can therefore pass on the benefits to other CBMS supply chain actors.

Another relevant value proposition is that cloud services can be consumed using a pay-as-you-use (PAYU) model (Armbrust et al. 2009, Katzan 2010, Rimal et al. 2011, Subashini and Kavitha 2011, Sultan 2011, Wyld 2009). PAYU offers flexibility to CBMS providers because the cost for using 1,000 computers for one hour is the same as one computer for 1,000 hours. From an income tax perspective, PAYU may be preferable to some organisations because it converts capital expenses into operating expenses. A CBMS provider can pass on this benefit to their users. In fact, some of the CBMS vendors (e.g. Lumina Decision Systems Inc.) have already offered PAYU to their users but do not emphasise the benefits of PAYU.

The next relevant value proposition is that cloud services transfer the responsibility for hardware, application software and storage facilities to cloud service providers (Armbrust et al. 2009, Katzan 2010, Marston et al. 2010, Sultan 2011, Wang et al. 2010, Wyld 2009). This means that cloud services free users from having to manage the underlying complexity of IT infrastructure. In addition, the risk of over- or underutilising an owned resource is transferred to cloud service providers. This value proposition allows CBMS providers and users to focus on their core business competency. This value proposition is especially enticing for SMEs that may not have enough resources to handle the complexity of IT infrastructure needed for their businesses. Related to this value proposition, resources for cloud services can be deployed faster than in a conventional procurement system (Armbrust et al. 2009, Subashini and Kavitha 2011, Wang et al. 2010, Zissis and Lekkas 2012). This is because users can rapidly access computing resources from cloud services without any human interaction.

The above value propositions are relevant to CBMS but our analysis suggests that they have not been emphasized yet by CBMS vendors. The potential of these value propositions is confirmed by a large-scale survey conducted by IBM Research on 1,090 IT decision-makers around the world shows that cost reduction, scalability, availability, PAYU and rapid deployment of resources are perceived as the key benefits of cloud services (IBM Smart Business 2010). The findings of another IBM survey of 572 business and technology executives of SMEs worldwide show that cost reduction and resource scalability are perceived as the main key benefits by users (Berman et al. 2012).

4.2.3 Revenue streams

Successful commercial adoption of CBMS does not depend only on demand from users, but also on the willingness of providers to supply the services needed. Hence, viable revenue streams for CBMS services are of high importance. According to Osterwalder and Pigneur (2010), revenue streams refer to cash flows generated by each customer segment. The findings in Table 3 offer insights into the early efforts of vendors to generate such monetary flows from their M&S services. We can group these vendors into five, non-mutually exclusive categories.

In the first category, vendors (e.g. AgentSheets Inc.) simply provide the functionality to publish models developed using their desktop applications in formats that can be run on a browser, such as Java applets or HTML5 files. It is up to the users to make their models available online. These vendors generate revenue from their desktop applications. Vendors in the second category provide an online platform to add value to their desktop simulation application. Some of them do not seem to generate revenue directly from their online platform (e.g. The AnyLogic Company, MS4 Systems and Simul8 Corporation). Hence, it is understandable that the functionalities of their online platform tend to be limited to model sharing. Vendors that generate revenue from their online platforms provide more functionalities (e.g. Lumina Decision Systems Inc.). The third category of vendors provides Web applications that support a complete simulation modelling life cycle (e.g. Forio and Strategy Dynamics Ltd). They generate revenue from their online platform through a subscription fee and/or usage fees. Some of them also sell desktop applications that have similar functionalities to their Web applications. Hence, they also generate revenue from their desktop applications (e.g. isee System, Consideo GmbH and Vanguard Software Corporation). Vendors in the fourth category provide a free online platform (Modelling4all and InsightMaker). They generate revenue through research funding.

Vendors classified in the above four categories use a single-sided market model. The fifth category is demonstrated by Forio, which generates revenue from a multi-sided market model via its simulation store (similar to Apple's App Store, Google Play or AppCentre in Kiss et al. (2015)). This type of revenue stream is not new in a broader sense, but it is innovative within the specific CBMS context in its targeting of end users (i.e. those who will use analytic and simulation models to support their decision-making process). Hence, Forio can help its immediate users (i.e. model developers) to generate revenue by selling services (model-as-a-service or analytic-as-a-service) to downstream users. This business model enables CBMS to operate in a service supply chain (see Figure 1). Construed as a service supply chain, CBMS can attract a wider market, from modellers to end users, which in turn has the potential to make the whole CBMS supply chain financially viable and profitable.

Table 4: CBMS business models (channels, customer relationships and key resources)

Application	Channels	Customer relationships	Key resources
AgentSheets & AgentCube (AgentSheets Inc.)	Online store (http://www.agentsheets.com/), platform (http://scalablegamedesign.org/arcade)	Events to engage with education sector and parents, Wiki, social media (Facebook, Twitter, Edmodo)	Curriculum materials, team of mentors, network of trained teachers
AgentCube Online (AgentSheets Inc.)	Online store (http://www.agentsheets.com/), platform (www.agentcubesonline.com)	Events to engage with education sector and parents, Wiki, social media (Facebook, Twitter, Edmodo)	Curriculum materials, team of mentors, platform, network of trained teachers
Analytica Cloud Player (Lumina Decision Systems, Inc.)	Online store (http://www.lumina.com/), resellers, platform (www.analyticacloud.com)	Technical support team, Wiki, webinars, social media (Twitter, LinkedIn, YouTube), online resource	Analytica (desktop), Analytica community, support team, platform
Behaviour Composer (Modelling4all)	Website and platform (http://m.modelling4all.org/)	Online resource, discussion group	Platform, NetLogo, NetLogo community
Forio Epicenter (Forio)	Platform (forio.com)	Online resources, user forum, support team, social media (Twitter, LinkedIn)	Platform, communities related to the supported modelling languages (e.g. Julia, Python, R)
iModeler (Consideo GmbH)	Online store, platform (www.imodeler.info), platform (http://www.know-why.net/)	Online resource, social media (Twitter, YouTube), remote coaching	Platform, KNOW-WHY.NET community
Insight Maker	Platform (insightmaker.com)	Community forum, online resources, webinars	Contributors, Systems Thinking World community (http://www.systemswiki.org/)
MS4 Model Store (MS4 Systems)	Platform (http://www.ms4systems.com/)	Online user guide, DEVS community	MS Me desktop application, DEVS community
Run the Model (The AnyLogic Company)	AnyLogic, platform (www.runthemodel.com)	Online user guide	AnyLogic desktop application, AnyLogic community, platform
Simio Portal (Simio LLC)	Platform (www.simioportal.com)	User forum, online user guide, customer support, social media (Twitter, LinkedIn, Facebook, YouTube)	Platform, Simio community, support team, Simio desktop application
Stella (isee Systems)	Online store, resellers, platform (exchange.iseesystems.com)	Online resources, social media (Twitter, Facebook, YouTube, Google+)	Stella desktop application, Stella community, system dynamics community supporting XMILE standard
Sysdea (Strategy Dynamics Ltd)	Platform (sysdea.com)	Online resources	Platform, Strategy Dynamics Ltd (brand)
Vanguard System (Vanguard Software Corporation)	Website (www.vanguardsw.com)	Support, online resources	Vanguard applications (servers and business analytic suite), Vanguard community
YouSimul8 (Simul8 Corporation)	Platform (www.yousimul8.com)	Online user guide	Simul8 desktop application, Simul8 community, platform

4.2.4 Channels, customer relationships and key resources

The main channels used by vendors to deliver their value propositions (Osterwalder and Pigneur 2010) are their websites, online stores and online platforms, i.e. Web or mobile applications that are used to deliver M&S services (see Table 4). Many of the platforms are hosted by well-known cloud service providers, such as Amazon, Google and Microsoft. Others are hosted by Web hosting companies, some of which support cloud services.

Vendors reach out to their potential customers and maintain their relationships with current users using various channels such as social media (Twitter and YouTube are the most popular among them), Wikis, user forums, webinars, online resources and dedicated support teams (most vendors charge an extra fee for this). Some vendors have organised user conferences so that users can share their experiences with vendors and other users (e.g. AgentSheets Inc., Simio LLC and The AnyLogic Company). Some vendors (e.g. Forio, Simio LLC, The AnyLogic Company, isee Systems, Sysdea and Simul8 Corporation) also have a strong presence at major academic conferences. Forio offers the functionality to import models from well-known applications such as Vensim and convert them into Forio formats. This functionality may appeal to users from the Vensim community who need to use cloud services for their models.

The key resources, defined as important assets that firms require to realise their business models, (Osterwalder and Pirgneur 2010) are also presented in Table 4. For CBMS vendors selling desktop applications the key resources include the desktop application itself (especially when the Web application extends the functionalities of their desktop version) and the user base for the desktop application. This is because users will need to use the desktop version for model development and a large user base is essential to form a community of users for knowledge-sharing and feedback. The key resource for vendors that offer Web/ mobile applications is the online platform. Some vendors have close links to a community (e.g. InsightMaker and System Thinking World community, Consideo GmbH and KNOW-WHY.NET community), or provide functionality that is close to that of a community (e.g. isee Systems and system dynamics community that support the XMILE standard, MS4 Systems and the DEVS community). Another important resource is brands, which can be the product names (e.g. AnyLogic, InsightMaker, Simio and Simul8), vendor names (e.g. Strategy Dynamics Ltd) or brands of key partners (e.g. University of Oxford, University of Colorado and Stanford University). Finally, the support team is a key resource, especially for vendors that provide after-sales services to their users.

Table 5: CBMS business models (key activities, cost structure and key partnerships)

Application	Key activity	Cost structure	Key partnership
AgentSheets & AgentCube (AgentSheets Inc.)	Training/ engagement events, curriculum development, software development, platform development and management	Software development, Platform management and development, training/ engagement events, curriculum development	University of Colorado, Stanford University, schools
AgentCube Online (AgentSheets Inc.)	Training/ engagement events, curriculum development, platform development and management	Platform management and development, training/ engagement events, curriculum development	University of Colorado, Stanford University, schools, cloud service provider (currently, Amazon)
Analytica Cloud Player (Lumina Decision Systems, Inc.)	Software development, platform development and management, support, training	Software development, platform development and management, support team, training	Web hosting company (currently, GoDaddy), resellers, affiliated consultants
Behaviour Composer (Modelling4all)	Platform management	Platform management	Cloud service provider (currently, Google), NetLogo, University of Oxford
Forio Epicenter (Forio)	Platform management, software development, support	Platform management and development, support	Cloud service provider (Amazon)
iModeler (Consideo GmbH)	Platform development and management, software development, remote coaching	Platform development and management, software development, a team of trainers	Internet/ Cloud service provider (CompuNet Systems, Artfiles New Media)
Insight Maker	Platform development and management, newsletter publication	Platform development and management, newsletter	Web hosting company (currently, CloudFare), contributors
MS4 Model Store (MS4 Systems)	Support, platform management	Support, platform management	Web hosting company (currently, GoDaddy)
Run the Model (The AnyLogic Company)	Platform management	Platform management	Cloud service provider (currently, Amazon)
Simio Portal (Simio LLC)	Platform development and management, software development, support	Platform development and management, software development, support	Cloud service provider (currently, Microsoft)
Stella (isee systems)	Software development, platform development and management	Software development, platform development	Information is not available on the Web
Sysdea (Strategy Dynamics Ltd)	Platform management, software development	Platform management, software development	Cloud service provider (currently, Amazon)
Vanguard System (Vanguard Software Corporation)	Software development, support	Software development, support	Information is not available on the Web
YouSimul8 (Simul8 Corporation)	Platform management	Platform management	Cloud service provider (currently, Amazon)

4.2.5 Key activities, cost structure and key partnerships

Key activities that firms engage in to realise their business models and associated operating costs (see Osterwalder and Pigneur 2010) are also analysed. Table 5 presents the key activities and costs related to the delivery of CBMS services. It is noted that activities and costs common to most organisations (e.g. marketing costs) are not in focus here. The key activity and cost structure for CBMS vendors that sell a desktop application is software development. Likewise, the key activity and cost structure for vendors that provide an online platform is platform management and development. Other activities include customer relationship management and customer support. Most vendors do not list their key partners on their website. However, it is clear that those that provide an online platform need to host their platform with a service provider. A further investigation of the IP addresses of platforms revealed that Amazon is the most popular choice. Web hosting companies, Google and Microsoft are also used. Table 5 also offers an overview of key partners of CBMS vendors, which mainly include cloud service providers, web hosting companies and even academic institutions.

5. Discussion

Overall, our study suggests that only a few vendors have started to use cloud services as part of their business models, and that the potential of such CBMS business models is currently under-realised. This may indicate that the demand for CBMS services has not yet reached critical mass. Section 4 analysed the key components of existing business models of CBMS vendors e.g. in terms of customer segments targeted, value propositions, revenue streams, channels and key resources deployed. This analysis also helped to unearth several issues that simulation vendors need to consider to develop truly innovative CBMS business models. These are discussed in Section 5.1 below.

Beyond the need to develop innovative CBMS business models several challenges and risks underpinning the provision and use of CBMS services, which are also reported in the literature, need to be addressed. These issues, which are raised by CBMS customers and especially end users, apply to any type of cloud services and may prevent potential customers from using these service offerings.

More specifically, security is one of the key issues that impedes the adoption of cloud services (Marston et al. 2010, Dillon et al. 2010, Katzan 2010, Benlian and Hess 2011, Rimal et al. 2011, Subashini and Kavitha 2011, Sultan 2011, Wyld 2009, Zhang et al. 2010, Zissis & Lekkas 2012, Ali et al. 2016). This is confirmed by Carrol et al. (2011) who investigated how frequently various security concerns were raised in the literature. The loss of physical control over data is another important factor influencing adoption, especially due to breach of privacy risks (Armbrust et al. 2009, Katzan 2010, Marston et al. 2010, Rimal et al. 2011, Subashini and Kavitha 2011, Sultan 2011, Wyld 2009, Zissis and Lekkas 2012, Xiao and Xiao 2013). This risk is amplified when a vendor is unable to guarantee the physical geographic location of users' data. A simulation model is typically built from first principles instead of a set of mathematical equations. Hence, from a simulation model, people can see the layout of the physical system being modelled (typically in a DES model), the decision-making rules of actors in the physical system (typically in ABS) or a mental map showing how decision-makers view the physical system (typically in SD). In other words, in simulation modelling, both model and data can be highly sensitive and confidential. Hence, concerns surrounding security and privacy are highly relevant to CBMS users.

The ability of vendors to guarantee a Quality of Service (QoS) threshold within the Service Level Agreement (SLA) has also been stressed as a main factor driving the adoption of cloud-based services (Armbrust et al. 2009, Dillon et al. 2010, Marston et al. 2010, Rimal et al. 2011, Zissis and Lekkas 2012). This issue is even more complicated when different providers (in the CBMS supply chain) are involved to provide services to end users, as different users may require different levels of QoS. For example, models used for operational decision-making may need better availability than models used for strategic decision-making. It is suggested that the above challenges and risks can be addressed through well-designed contracts (see Section 5.2).

5.1 Business models of CBMS services

The results of our study indicate that existing CBMS business models present certain deficiencies that would need to be addressed to generate new market opportunities and revenue streams. A key issue is that the majority of simulation vendors included in our study appear to rely on a rather narrow customer basis, mainly consisting of simulation modellers. Construing CBMS as a service supply chain which consists of multiple actors with interdependent requirements (see Figure 1) opens up new opportunities for CBMS vendors to position themselves in the value chain and generate sustainable and profitable market offerings.

Specifically, there are three potential customer segments of CBMS that have not been explicitly targeted by most vendors. The first segment is organisations that use compute-intensive business analytics. Compute-intensive business analytics is suitable for batch processing, which is one of the best candidates to benefit from the cloud. Hence, the increase in awareness of organisations about the benefits of analytics in the era of big data may open up the market for CBMS, especially for the analytics-as-a-service and model-as-a-service. The second segment is existing analytic and simulation users who have been using desktop analytic or simulation tools. There is trend in the software market whereby desktop applications have started to offer seamless extension into online services, including cloud services (e.g. Microsoft Office with Office 365, AutoCAD with AutoDesk 360). There are benefits for existing analytic or simulation users from seamless extension into the cloud, such as the ability to acquire more computing resources quickly when needed. The third segment is those who build simulation models regularly in a team, whose members may not always be based at the same location. Most of the respondents in the survey conducted by Onggo et al. (2014) belong to this category. The survey shows that they appreciate the benefit of having software that has one piece that runs on a thin client (such as a tablet or even a smartphone) and another piece that runs in the cloud. Consequently, they are clearly potential CBMS users.

Beyond the need to target a broader customer basis, simulation vendors also need to extend their value propositions in accordance with the ones identified in the broader field of cloud computing (see Section 4.2.2). A prerequisite for achieving this is to understand in-depth how customers use these simulation models and related services. The focus should particularly be on end users because they are the ones who create the demand for upstream services. Despite our understanding of the perceptions of businesses towards cloud services in general, our knowledge about how simulation (and analytic) customers use their models is rather limited. Hamalainen et al. (2013) called for more research into understanding the behavioural aspect of the use of OR techniques or models in decision support. The term Behavioural OR has been proposed to capture this new and important topic. Wang et al. (2016) in their recent survey also highlighted the need to examine the behaviours of cloud computing users.

In the specific context of CBMS, knowledge about how customers use their analytic or simulation models allows designing CBMS services that can add value to these simulation and analytic users. Value propositions for CBMS that fully cater for the requirements of users are therefore essential for CBMS adoption. The survey conducted by Onggo et al. (2014) helps us to better understand the characteristics of CBMS users (e.g. how they work in a group, exposure to cloud applications and mobile gadgets) and what they require from CBMS (e.g. a fast response time, support for effective communication). However, given that most respondents were modellers (not end users), further work is needed to understand the expectations and needs of end users. Findings from studies on the factors affecting cloud computing adoption (see Low et al. 2011; Morgan and Conboy 2013; Park and Ryoo 2013; Yang and Lin 2015; and Schneider and Sunyaev 2016) may also shed some light on the factors that would help drive CBMS adoption.

Expanding the customer basis and the range of value propositions to different customer segments would work towards developing innovative business models of CBMS services, which would in turn generate new market opportunities and revenue stream for simulation vendors. Our results suggest that the potential for innovative business models in the context of CBMS is currently under-realised, and that it is imperative that more successful examples such as Forio's simulation store and the AppCentre (Kiss et al. 2015) are developed. Vendors need to help their users not only to fulfil their needs and requirements but also to earn revenue by becoming service providers to their downstream users. To achieve this objective, vendors and users need to rethink their value propositions and positioning in the CBMS service supply chain so that they extend business beyond their immediate customers. This view is also echoed by Berman et al. (2012), who argue that there is a lack of innovative business models that harness the true potential of cloud services as enablers for the creation of new market opportunities and revenue streams.

The above essentially suggest that the development of innovative CBMS business models requires going beyond the technical and operational aspects of CBMS service provision to consider how economic value can be created, distributed and captured in the broader value chain (Chesbrough and Rosenbloom 2002). More specifically, innovative business models entail connecting with customers and suppliers in the CBMS service supply chain in creative ways to reconfigure the value network and related service capabilities (Spring and Araujo 2009), to identify new market opportunities, to extend value propositions and to generate sustainable and financially viable market offerings accordingly (Osterwalder and Pigneur 2010).

5.2 Contracting for CBMS services

This section discusses the role of contracting in addressing challenges and risks underpinning the provision and use of CBMS services. As previously outlined, the shifting emphasis on cloud computing has raised certain challenges regarding limited user control over data access, handling and preservation after service termination (Dhar 2012, Weinhardt et al. 2009). The literature on cloud services has stressed the role of contracting for managing some of these risks (e.g. Bradshaw et al. 2011). In what follows we suggest ways to extend this discussion to also address challenges that are specific to CBMS services and relate to privacy and security, ownership of models and analysis outputs, the definition of service levels and performance metrics, incentives and risk-reward sharing, as well as liability allocation.

Similar to other types of cloud computing, simulation services provided over the cloud entail that the geographical location of the servers and data may not be fixed. In fact, data storage locations may well be unknown. This creates concerns regarding country- or region-specific legal systems and jurisdictions underpinning contracts for CBMS services, the enforceability of contracts and the extent to which specific laws can keep up with the rapidity of technological innovation and advanced business models (Pearson and Benameur 2010). Contracts for CBMS services should explicitly address such aspects. For instance, contracts must stipulate the provider's commitments and clearly specify the geographical locations for storing data, models and analytics in order to foster trust on CBMS vendors and facilitate adoption of such services. Contracts should also refer to acceptable legal frameworks and mechanisms for dispute resolution in case any disagreements over data and/or model access and use arise (see Mowbray 2009).

In service outsourcing (including IT outsourcing) formal contracts perform multiple functions, the main one being safeguarding against opportunistic behaviour (Kern and Willcocks 2000, Williamson 1985). Accordingly, contracts for CBMS services should serve as legal and economic safeguards to deal with security and privacy risks, such as the confidentiality of data, models and analysis results, lack of access to data and data-handling after service termination. The reported dispute between LinkUp and Nirvanix (Arburst et al. 2010) regarding the loss of user data is a good example highlighting the crucial role of contracts as safeguarding mechanisms. Of particular importance is the way sensitive data that are used as input for modelling and analysis are handled, as well as whether providers monitor users' use of models and analytic tools. Explicit provisions for handling such issues should be included in service contracts.

In addition, contracting should address issues regarding the ownership status of simulation models and outputs of analysis. Traditional IT outsourcing contracts specify the allocation of intellectual property rights (e.g. Chen and Bharadwaj 2009). Agreements for cloud services tend to include property rights-related clauses that recognise that data and content are (typically) owned by the user (Bradshaw et al. 2011). Likewise, the role of contracts for CBMS services is crucial in this respect, and they should also consider the types of services provided. For example, intellectual property clauses should clearly specify who owns outputs of analysis in an analytics-as-a-service offering. In a similar vein, contractual provisions should address whether vendors can reuse or adapt the developed 'solutions' and 'recommendations' so as to develop templates for other service users.

Furthermore, the contractual SLA plays an important role in terms of defining and incentivizing service performance in outsourcing deals (Selviaridis and Norrman 2014), and CBMS services are no exception. The designed SLAs should clearly specify the performance of CBMS services in terms of key performance indicators (KPIs) and also allocate risks and rewards in a fair way. For instance, the 'performance' of an analytics-as-a-service offering should be clearly defined and it should be set apart from the performance of a model-as-a-service offering. Specific and measurable KPIs must be included in the SLA to enable monitoring of vendor performance. As a guideline, generic cloud computing metrics, such as availability and uptime, can also be used in CBMS service contracts. However, additional aspects that are specific to CBMS (e.g. the quality of modelling and data analytics to support decision-making) should also be considered during contract design.

The design of incentive systems is another issue that also connects to payment schemes and revenue streams for CBMS services. In line with the broader literature on business models, it is important to note that different business models may entail differences in the allocation of risks and rewards (see Spring and Araujo 2009) between CBMS providers and users. Contracts for CBMS services should reflect such differences in business models. At a basic level, they may stipulate penalties for failures to achieve specified service levels. These contractual penalties may manifest themselves in the form of 'service credits' (see Bradshaw et al. 2011) or direct financial compensation to the user. Besides penalties though, a fair contractual incentive system should also extra-reward CBMS vendors for over-performance. These rewards can take many forms including gain-share mechanisms or bonus payments linked to specific service level targets (Selviaridis and Wynstra 2015). For instance, the contractual SLA could stipulate that a customer achieving cost savings by using an analytic tool over the cloud agrees to share part of those savings with the vendor.

A related issue is the role of contracts in allocating liabilities for non-performance of CBMS services. The existing literature on cloud services suggests that vendors attempt to cap their direct liabilities (e.g. failure to access data). They tend to issue disclaimers for warranties and indirect liability to ensure that they do not bear the cost of consequential economic losses arising from service failures (Bradshaw et al. 2011, Mowbray 2009). We suggest that such contracting practices are applicable to

CBMS services and they may help mitigate uncontrollable risks related to service delivery. More specifically, liability for non-performance and financial risks related to SLA penalties are affected by service co-production effects (Sampson and Spring 2012). In essence, the performance of advanced types of simulation-based services (model- and analytics-as-a-service) is the result of joint efforts by the users, providers and even sub-contractors in the service supply chain. For instance, the quality of simulation analysis to support decision-making is determined by the quality of underlying platforms, models and analytic tools, as well as the quality of user data and how users use and interpret the results. Hence, it is imperative that contracts for CBMS services consider the ability to attribute performance in the broader service supply chain (Selviaridis and Norrman 2014). In cases of low performance attribution, contracts should include provisions that limit penalties and liabilities to service failures that can be clearly attributed to factors within the vendor's control (Selviaridis 2016) e.g. the quality of simulation models underlying analytic tools.

6. Conclusion

This study is concerned with the largely neglected business aspect of CBMS and contributes to the scant literature on this topic (see Kiss et al. 2015). More specifically, we extend Kiss et al.'s (2015) work by providing insights into the business models employed by simulation vendors that provide cloud-enabled or Web-enabled simulation modelling services. To the best of our knowledge this is the first study to describe and analyse the key components of existing business models of CBMS vendors based on Osterwalder and Pigneur's (2010) 'business model canvas' framework.

Our analysis has also unearthed several issues that need to be addressed by simulation vendors in order to fully realise the potential of CBMS business models. First, most simulation vendors in the study limit their users to simulation modellers. CBMS can become more sustainable and impactful by being viewed as a service supply chain wherein value is created, distributed and captured among various CBMS actors. To this end, we have identified three additional customer segments that simulation vendors could target. Second, simulation vendors need to extend their value propositions in accordance with those reported in the generic field of cloud computing. Third, the potential of innovative business models of CBMS is currently under-realised. The development of innovative business models entails creative reconfiguration of the value network in the CBMS service supply chain to identify new market opportunities and generate profitable market offerings. These findings contribute to the existing literature by stressing the importance of developing innovative CBMS business models. In addition, we contribute to the scant literature on the business aspect of CBMS by stressing the role of contracting in addressing the challenges and risks underpinning CBMS provision and use e.g. security and privacy risks and allocation of risks and rewards. Finally, CBMS is a subset of cloud-based DSS. Hence, our study also contributes to cloud-based DSS by providing insights into how cloud or Web services have enabled simulation vendors to deliver model-as-service and analytics-as-a-service, as conceptualised in Demirkan and Delen (2013).

The study presents limitations which need to be addressed through further research. Specifically, the review and analysis of simulation vendors is based on secondary data which were collected from the firms' websites and validated by testing the software. This approach provides only a snapshot view of the business models of CBMS service providers. Mason and Spring (2011) have argued that business models are dynamic and affected by changes in the technology and business environment. Future longitudinal studies might be more appropriate to reveal the dynamics of business models in the M&S sector. Also, while data from websites is useful to understand current market segments, value propositions, channels, revenue streams and customer relationships of CBMS vendors, it does not offer equally rich information about key activities, partnerships and, especially, cost structure, which is considered sensitive by many organisations. Hence, future studies on CBMS business models should be based on primary data from CBMS vendors and users through in-depth interviews and /or questionnaires. Such primary data are likely to lead to a more refined understanding of the above components and the business models of CBMS more broadly.

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Appendix A: List of abbreviations

ABS: Agent-Based Simulation

CBMS: Cloud-Based Modelling and Simulation

DES: Discrete-Event Simulation

DSS: Decision Support Systems

IaaS: Infrastructure-as-a-service

MC: Monte Carlo

M&S: Modelling and Simulation

OR: Operational Research

PaaS: Platform-as-a-service

QoS: Quality of Service

SaaS: Software-as-a-service

SD: System Dynamics

SLA: Service Level Agreement

WBS: Web-Based Simulation

Appendix B: Summary of the result from software testing

We have tested all free CBMS tools and commercial CBMS tools that provide the free basic version or free trial version. CBMS tools that do not provide any free version or access are Simio portal and Vanguard. The trial version of MS4 Model Me does not work on our machine. Hence, these three CBMS tools are excluded in our test.

B.1 AgentSheets

AgentSheets provides a desktop application to develop an agent-based model which can be exported into a Java applet. Figure B.1 shows how a predator-and-prey model is submitted to the online platform (Scalable Game Design Arcade). Once it is uploaded to the Arcade, the model can be executed and people can comment on the model as shown in Figure B.2. Hence, AgentSheets provides an online tool for model storage, model sharing and simulation execution.

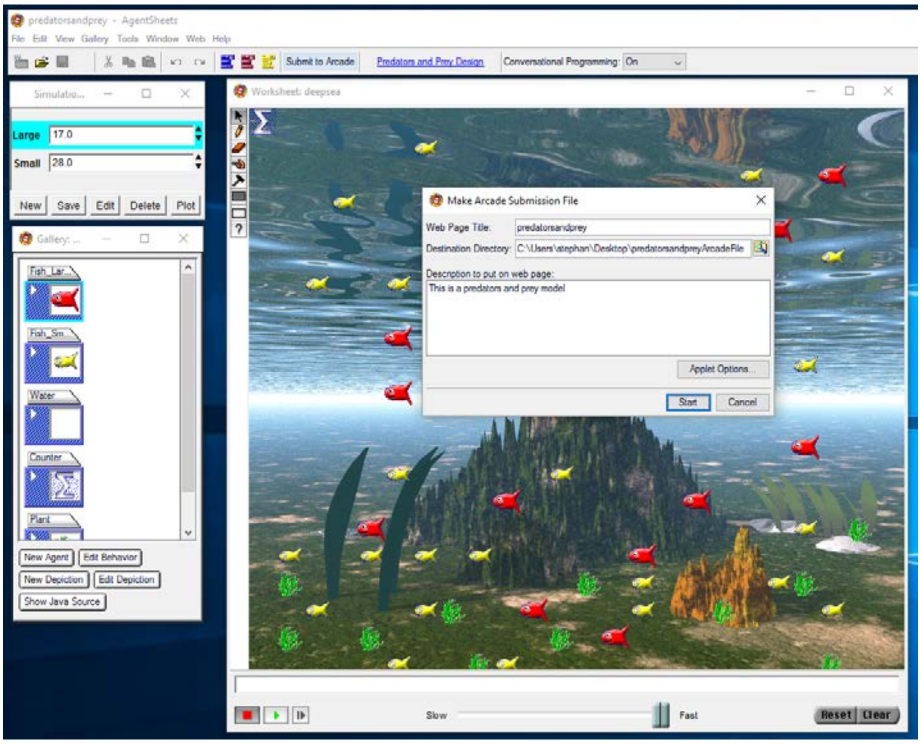

Figure B.1: Submitting a model to its online platform from AgentSheets' desktop application

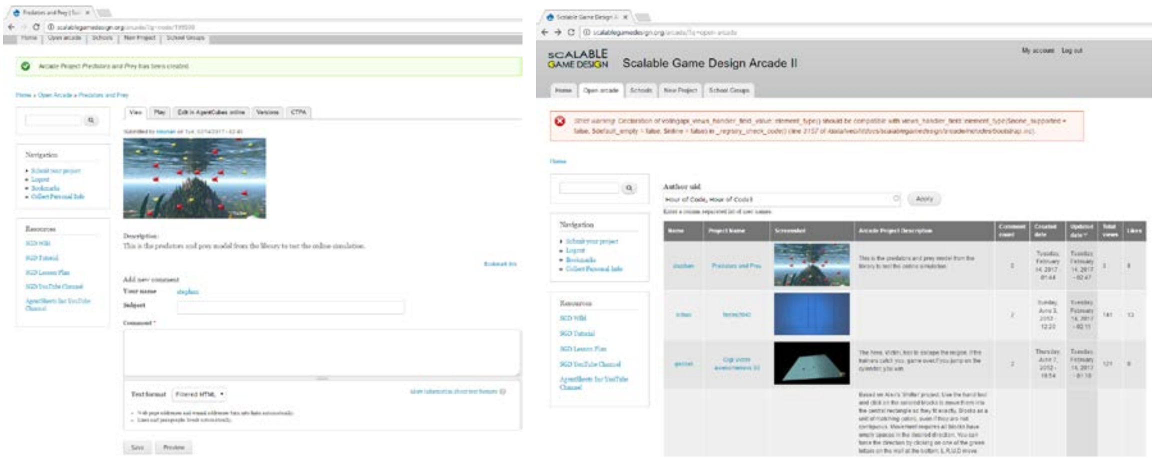

Figure B.2: Model sharing and model execution using AgentSheets' online platform

B.2 AgentCube

AgentCube provides model development facility using both desktop application (Figure B.3) and web-based application (Figure B.4). The desktop application has the facility to upload a model to the online platform (Figure B.3). Once a model is in the online platform, the model can be executed and people can comment on the model. This shows that AgentCube provides an online tool for model storage, model sharing, model development and model execution.

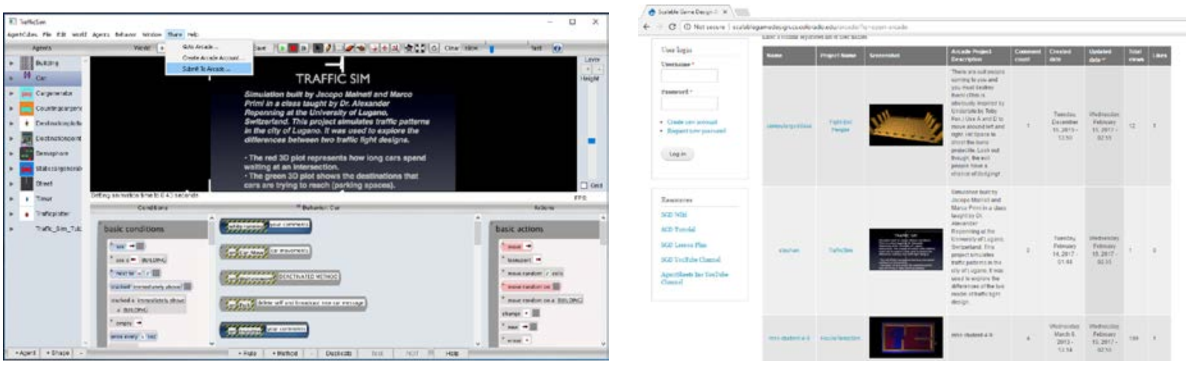

Figure B.3: Functionality in AgentCube's Desktop application to submit a model to its online platform

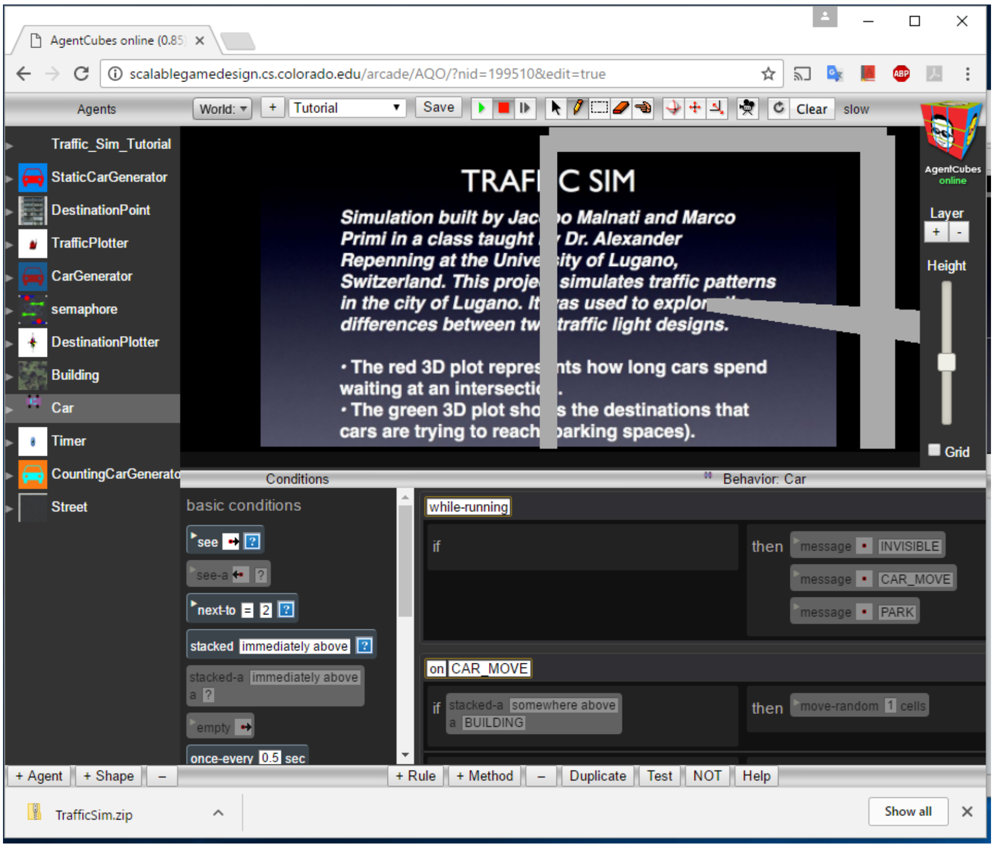

Figure B.4: Model development facility using AgentCube's Web-based application

B.3 Analytica Cloud Player

Analytica provides a desktop application that allows users to develop a model and upload it to Analytica Cloud Player (left figure in Figure B.5). Once uploaded to the cloud, a model can be shared and executed using any compatible web browser (right figure in Figure B.5). Hence, Analytica provides a desktop application for model development and a web-based application for model storage, sharing and execution. Paying customers can also collaborate using the web-based application.

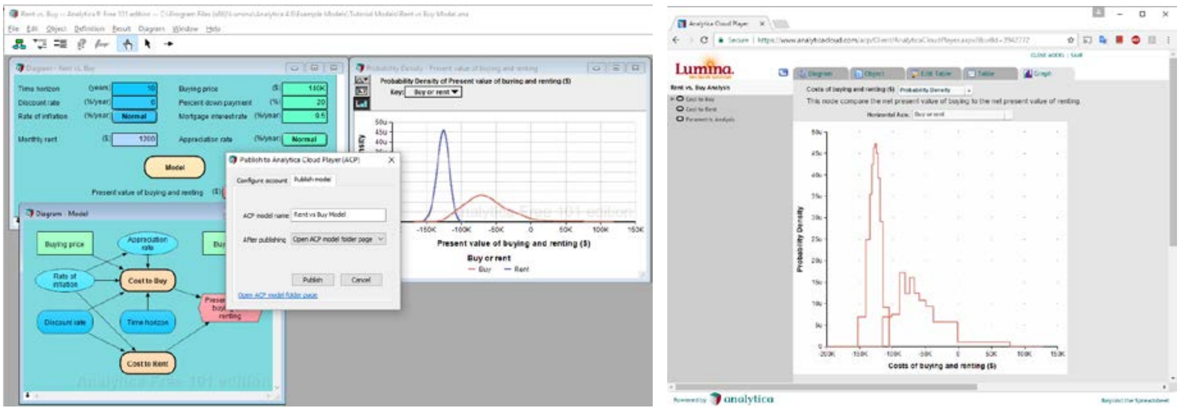

Figure B.5: Model development using Analytica's Desktop application (left) and running a model on Analytica Cloud Player (right)

B.4 Behaviour Composer

Behaviour composer provides a web-based application that can be used to develop an agent-based simulation model as shown in Figure B.6. The application provides a number of generic Net-Logo programming constructs to make it easier for users to piece them together in a model. A model developed in this tool can be shared (Figure B.7 left) and executed (Figure B.7 right) in a web browser. The model can also be exported to a NetLogo file that can be edited and run using NetLogo desktop application. Hence, Behaviour Composer provides a web-based application for model storage, model sharing, model development and model execution.

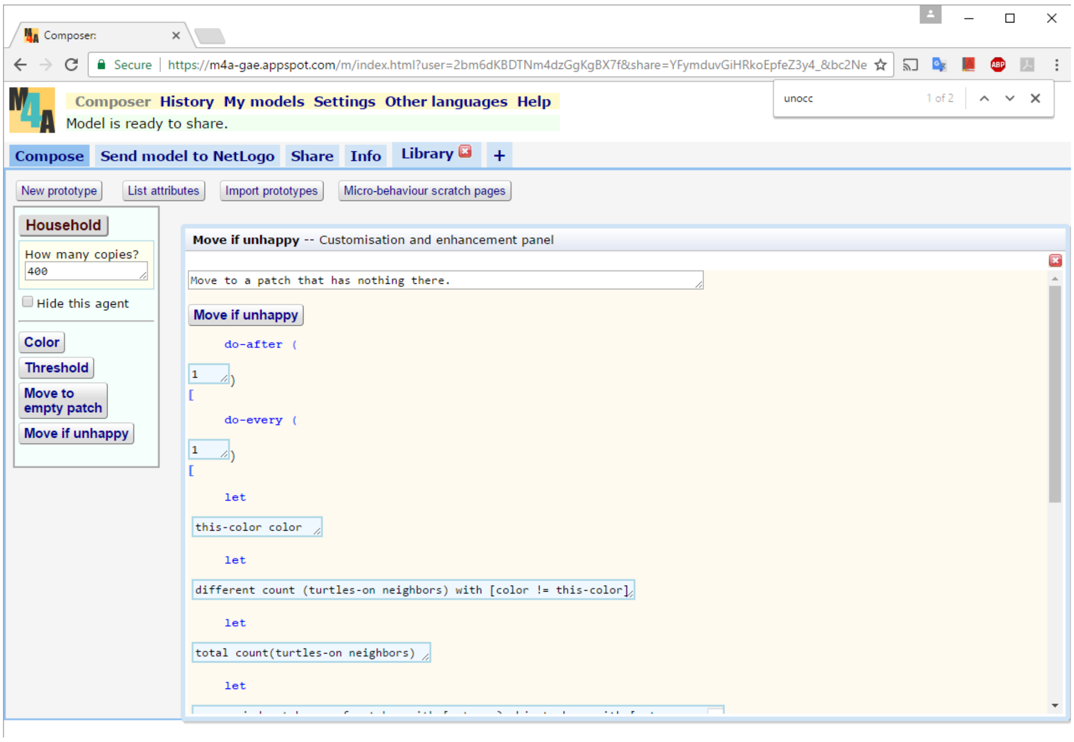

Figure B.6: Developing a model using Behaviour Composer

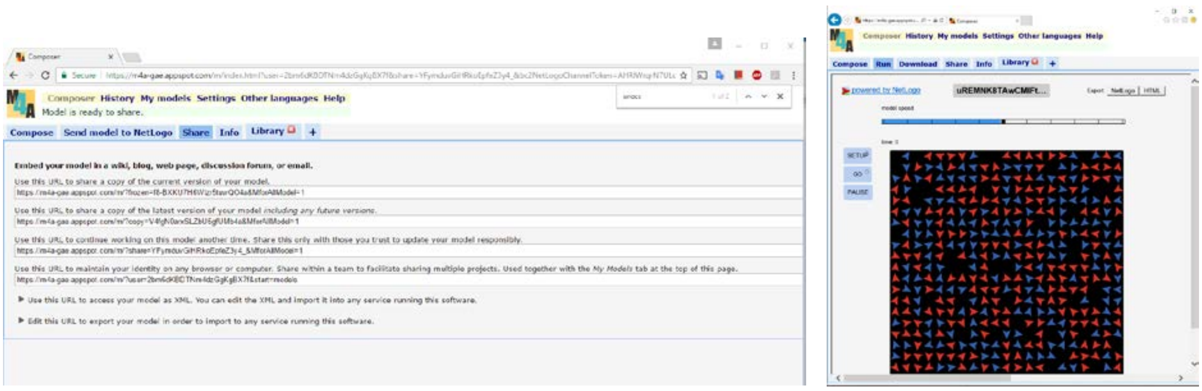

Figure B.7: Behaviour Composer – model sharing (left) and model execution (right)

B.5 Forio Epicenter

Forio provides an online runtime platform called Forio Epicenter (http://forio.com/epicenter/) that can be used to run an analytic application (such as simulation, statistical analysis, and forecasting) using any compatible web browser. The analytic application can be written using various programming or modelling languages including Julia, Phyton, R and Vensim. Julia, Phyton and R enable users to develop almost any kind of analytic models. Vensim (http://vensim.com/) can also be used if the analytic application uses a system dynamics model. Hence, model development can be done using tools that support those programming or modelling languages (e.g. Julia Studio, PhyCharm). Forio provides a facility to upload these models to its online platform (i.e. Forio Epicenter). Users can also use the text editor provided in Forio's online platform to develop their models using their preferred language (Figure B.8 left). Figure B.8 (right) shows how a model is run on Forio Epicenter.

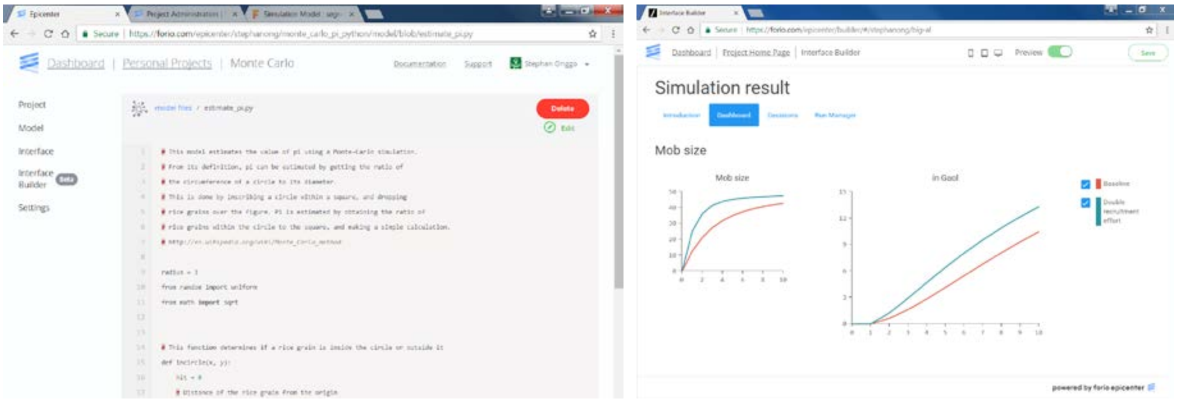

Figure B.8: Forio Epicenter – Model development (left) and model execution (right)

Forio also provides services for its users to manage their development projects (team management, version management, etc.). A paying customer can create a team project that allows team members to collaborate in a model development. In addition, Forio also offers a number of related cloud services such as data store, compute nodes and end-user authentications.

One thing that separates Forio from the rest is that it also provides a store where the public can browse and buy services. Hence, Forio customers can build an analytic application (or an analytic model) and offer it as a service in the store. Forio allows its customers to restrict the access to their services through subscription (see Figure B.9). Hence, it allows its customers to offer analytic-as-a-service and model-as-a-service. The majority of the offered services in the store are analytic-based games (for education and training). In summary, Forio provides both analytic-as-a-service and model-as-a-service.

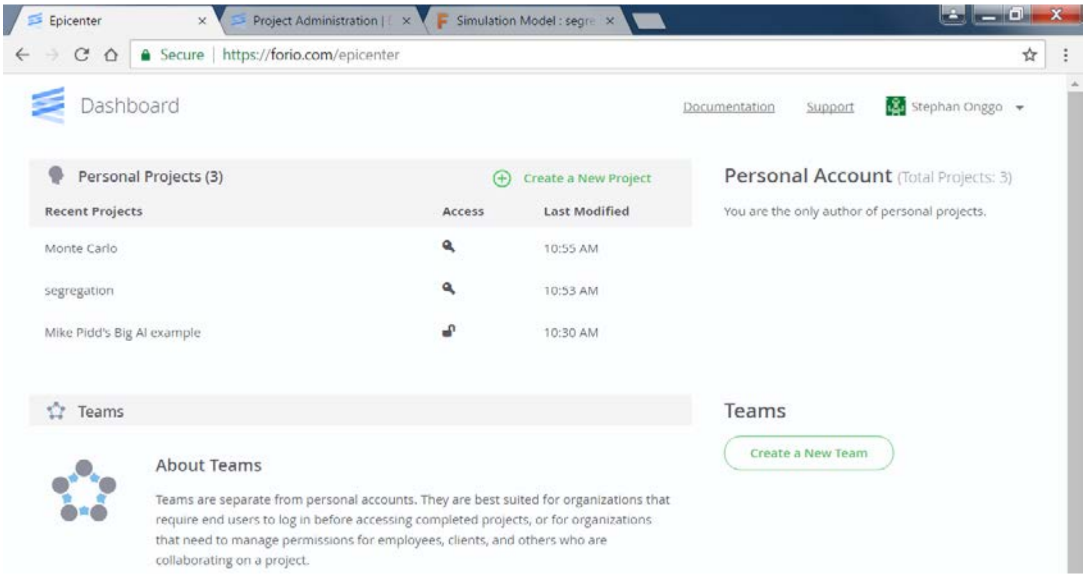

Figure B.9: Forio Epicenter's Dashboard

B.6 iModeler

Consideo provides a web-based application called iModeler where users can store a model (Figure B.10), edit and run the model (Figure B.11). Users can also share their models (via email or twitter) and collaborate with other users (Figure B.12). Hence, iModeler has functionalities for model storage, sharing, development, execution and collaboration.

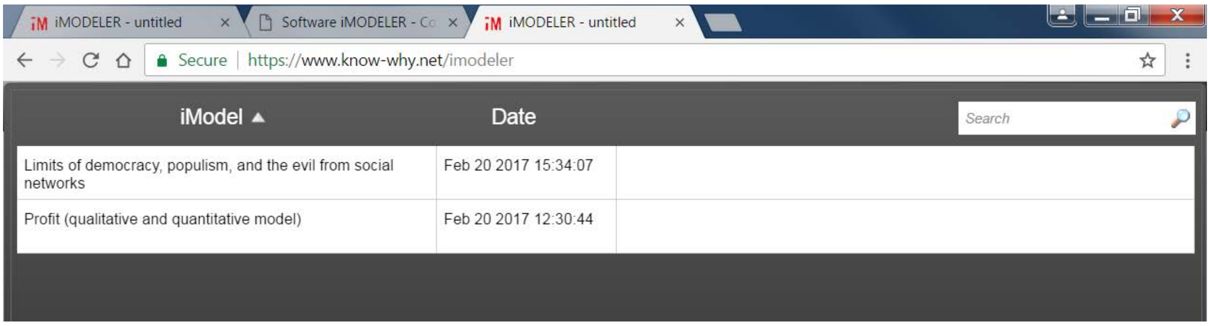

Figure B.10: iModeler – Model storage

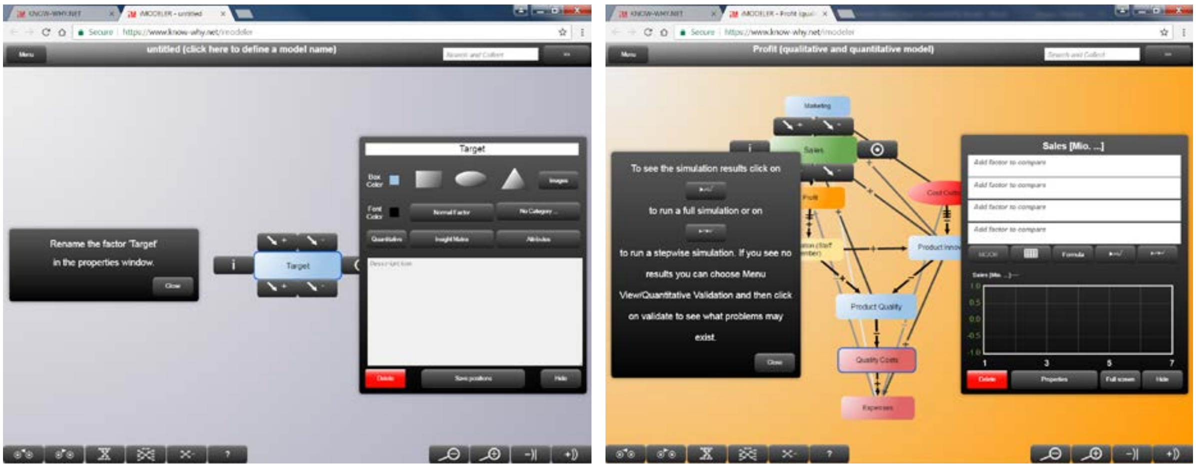

Figure B.11: iModeler – Model development (left) and model execution (right)

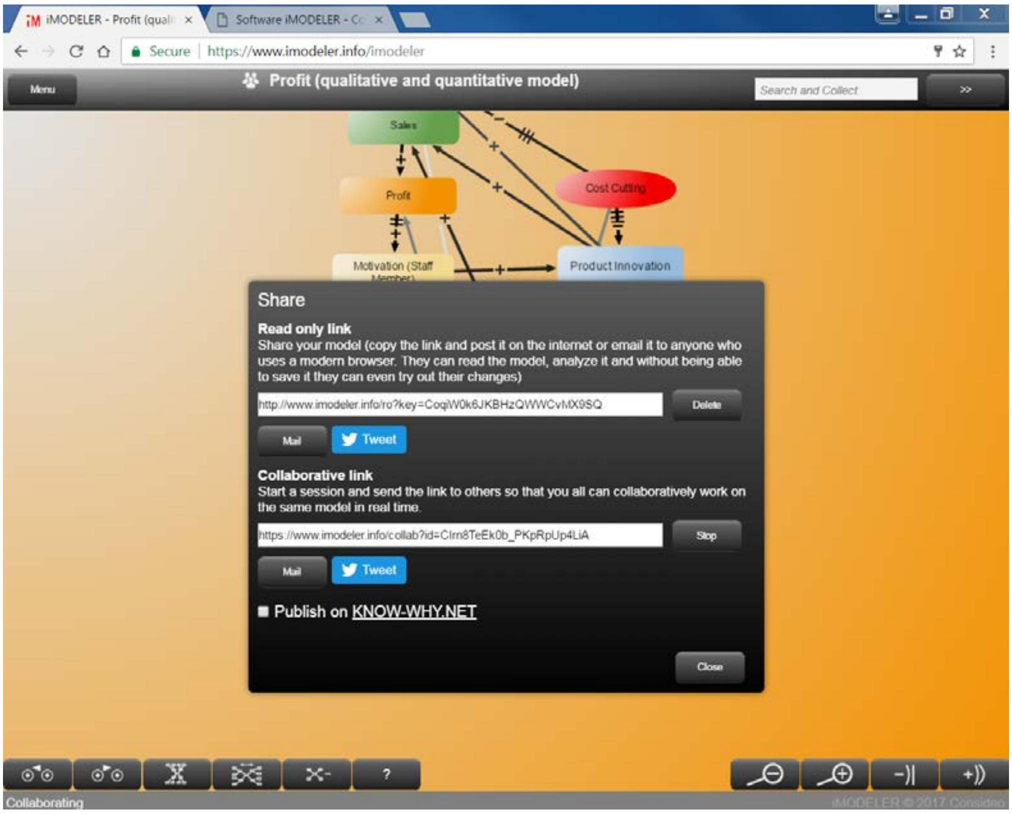

Figure B.12: iModeler – Model sharing and collaboration

B.7 Insight Maker

InsightMaker provides a web-based application to develop and run system dynamics models and agent-based simulation models. Figure B.13 shows the model development facility (left figure) and the execution of a model (right figure). A model created using InsightMaker is stored in the InsightMaker's server (Figure B.14 left). A user can share a model by sending the model URL. The model can be run in a compatible web browser and the output can be exported in a CSV file format for further analysis. InsightMaker allows a customer to collaboratively work on a model by setting an appropriate shared editing option (Figure B.14 right). InsightMaker provides a set of APIs that can be used to control a model using JavaScript. This provides some extra controls over the model (for example, by adding interactive user interface or adding an analytic code that makes use of the simulation output. This shows that InsightMaker provides a web-based application for model storage, sharing, development and execution. It also provides facility for collaboration.

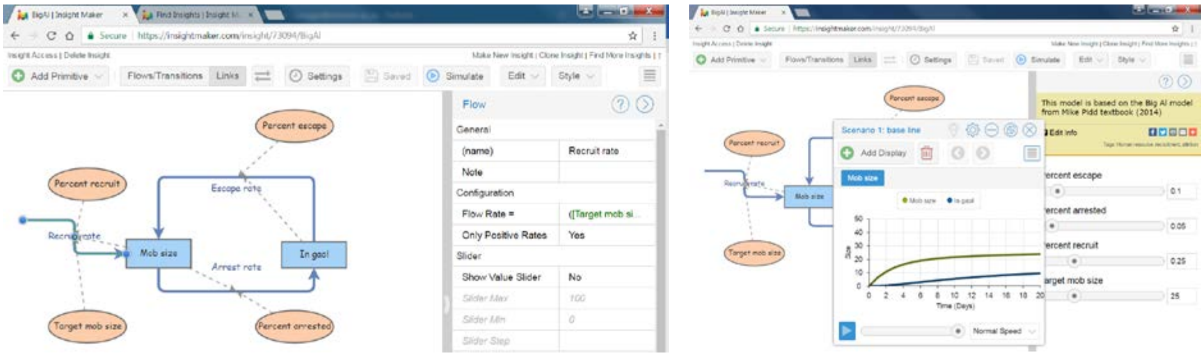

Figure B.13: InsightMaker – Model development (left) and model execution (right)

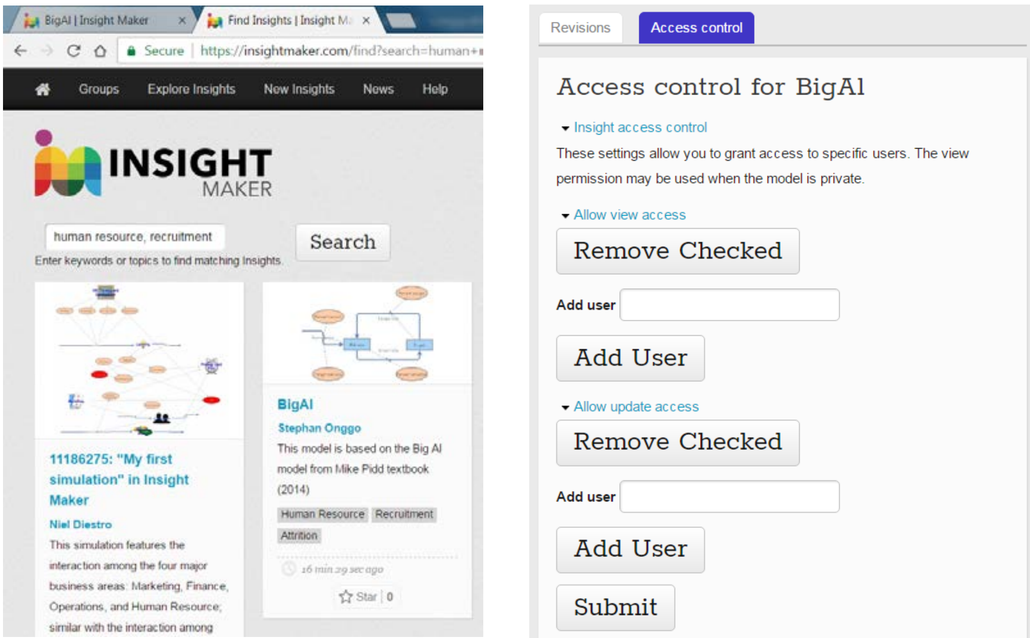

Figure B.14: InsightMaker – Model storage (left) and facility for model sharing and collaboration (right)

B.8 Run the Model

The AnyLogic Company provides a free platform called "Run The Model" for their customers to store and share models via a web browser (Figure B15). Users can provide comments to the publicly shared models. Users with compatible web browsers (i.e. support Java) can run the shared models (Figure B.16).

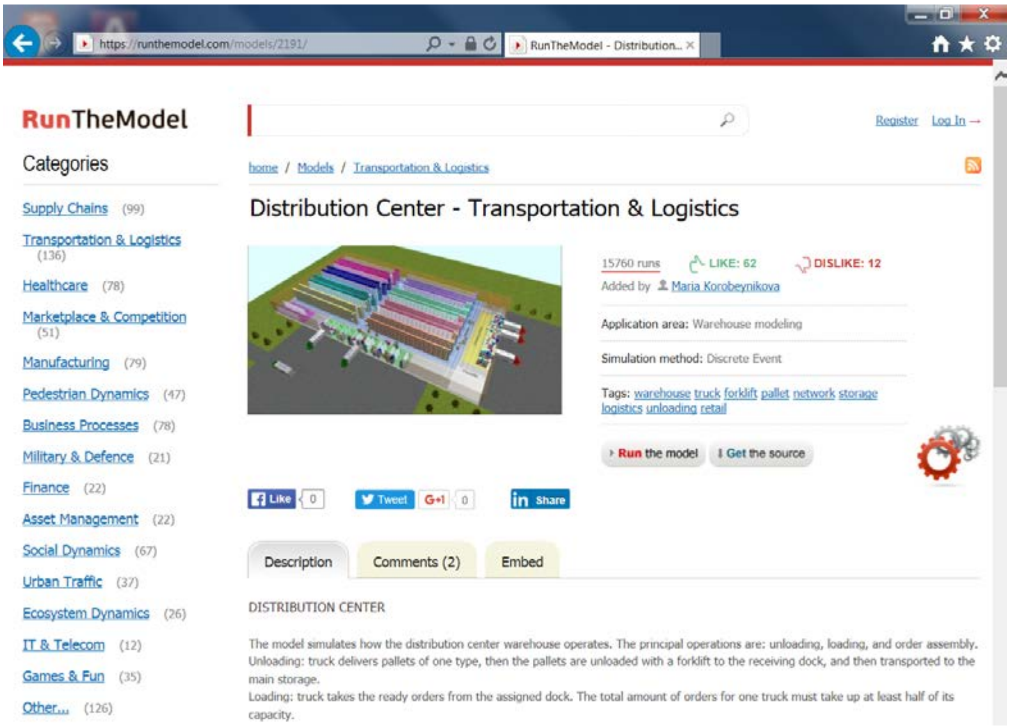

Figure B.15: AnyLogic's RunTheModel – Model storage and sharing

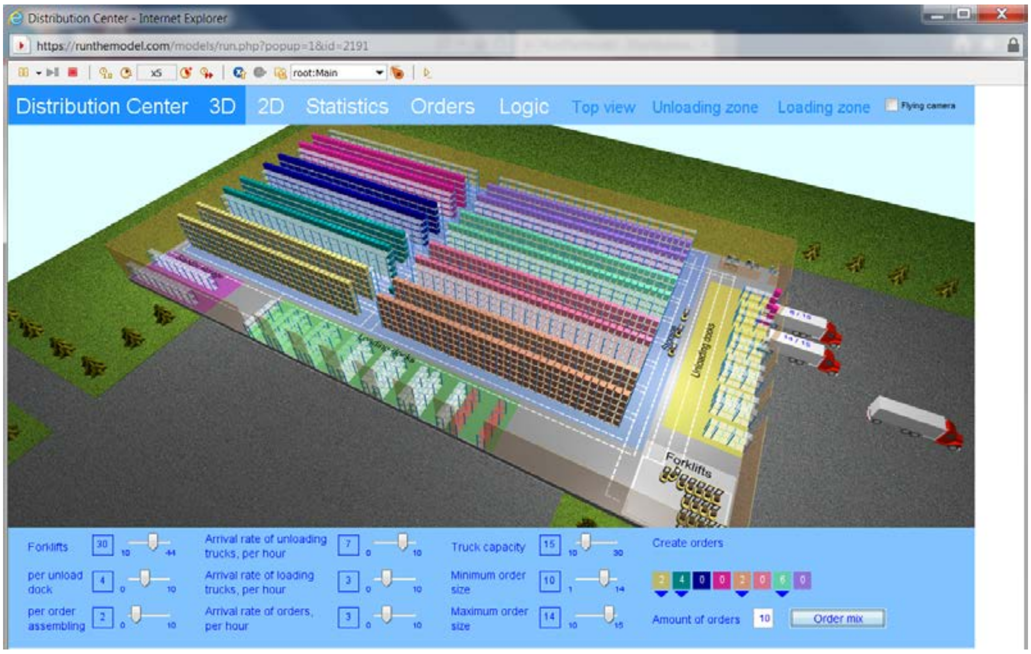

Figure B.16: AnyLogic’s RunTheModel – Model execution

B.9 Stella architect

isee Systems provides both desktop application (Stella) and web-based application (isee Exchange). With isee Exchange, users can develop a model (Figure B.17 left) and run the model (Figure B.17 right) using compatible web browsers. Users can also store and share their models (Figure B.18).

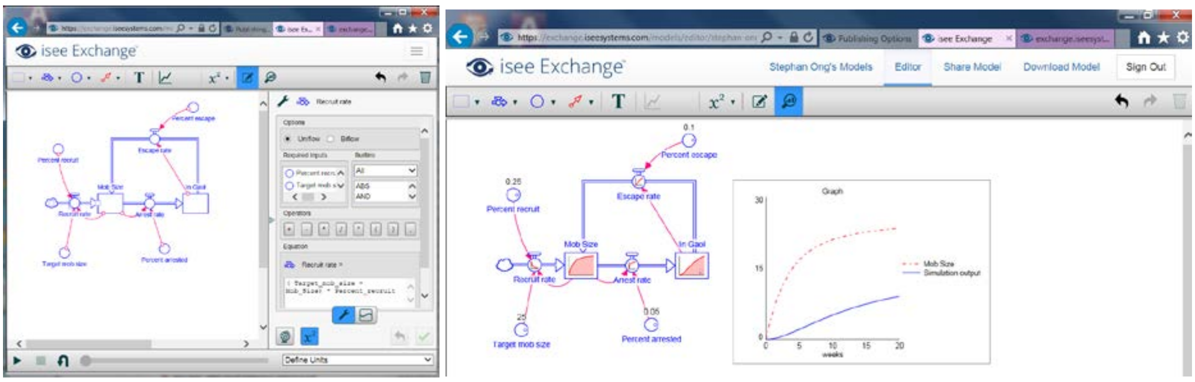

Figure B.17: isee Exchange – Model development (left) and model execution (right)

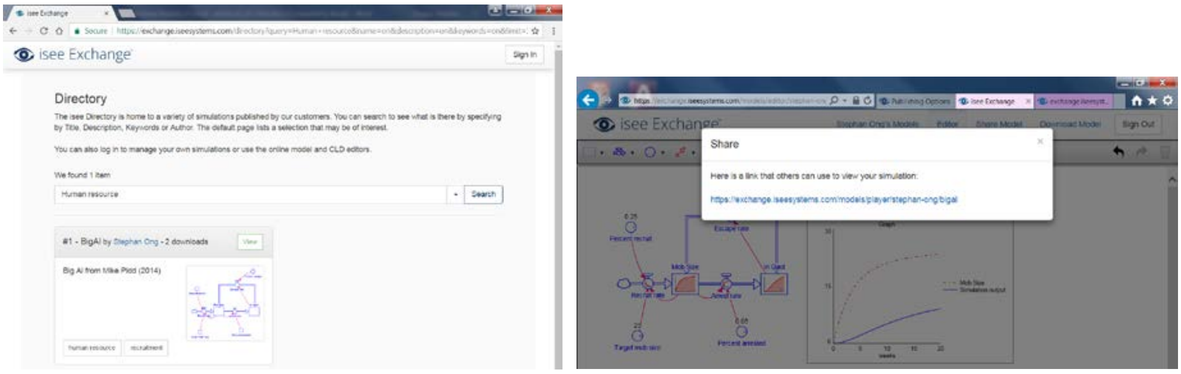

Figure B.18: isee Exchange – Model storage (left) and model sharing (right)

B.10 Sysdea

Strategy Dynamics Ltd provides an online platform called Sysdea (http://sysdea.com) for its customers to build and run their system dynamics models using a compatible web browser (Figure B.19). A model that is developed using Sysdea is stored in Sysdea's server. The users can share their models to the public by sending the model URL. The public does not have to be a Sysdea user. It is possible to display the simulation output in a table which can be copied to other software (for example, spreadsheet) for further analysis. The ability to share the model URL allows a Sysdea user to collaborate with another Sysdea user when building a model.

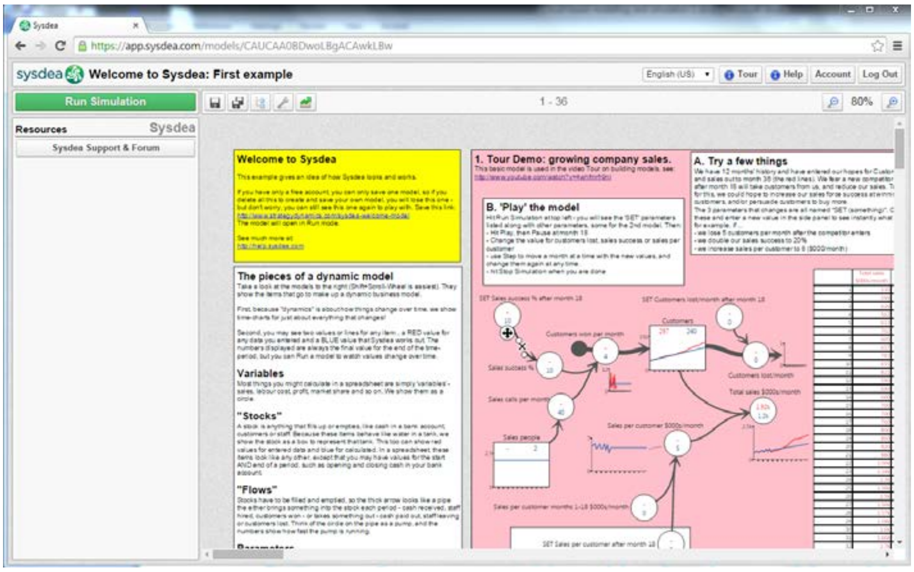

Figure B.19: Sysdea – Web-based integrated model development environment

B.11 YouSimul8

Simul8 Corporation is the vendor of discrete-event simulation software called Simul8 which provides an offline model development and runtime platform. Simul8 Corporation provides an online runtime platform called YouSimul8 for models developed using Simul8. Figure B.20 (left) shows the main page of YouSimul8 which shows that it provides services for users to run, upload and share a Simul8 model. A user can also search for a model using the provided search engine based on the title and description of the publicly shared models. It also provides facilities for a costumer to leave a comment on a shared model and to express whether the costumer likes or dislikes the model (right figure in Figure B.20). All users can upload their models and share the models publicly. However, only users who have a license to Simul8 professional edition can share their models to a number of selected users via private channel (Figure B.21).

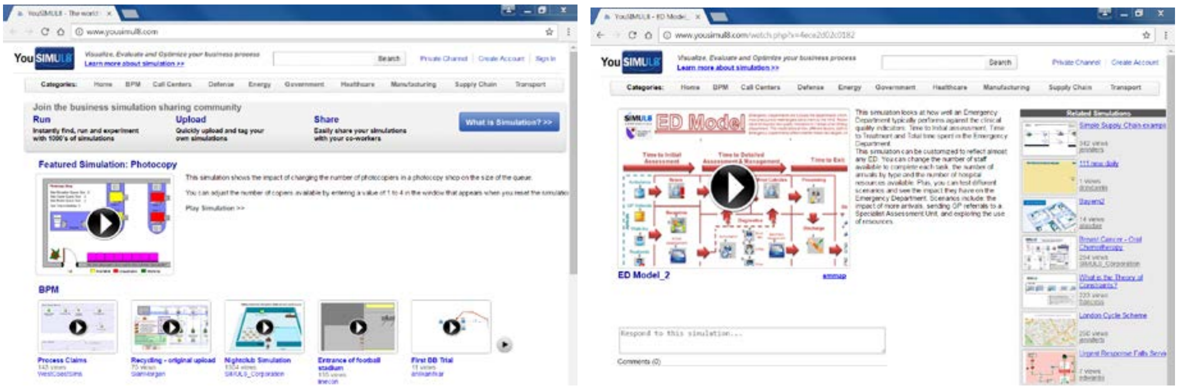

Figure B.20: YouSimul8 – Main page (left) and model storage (right)

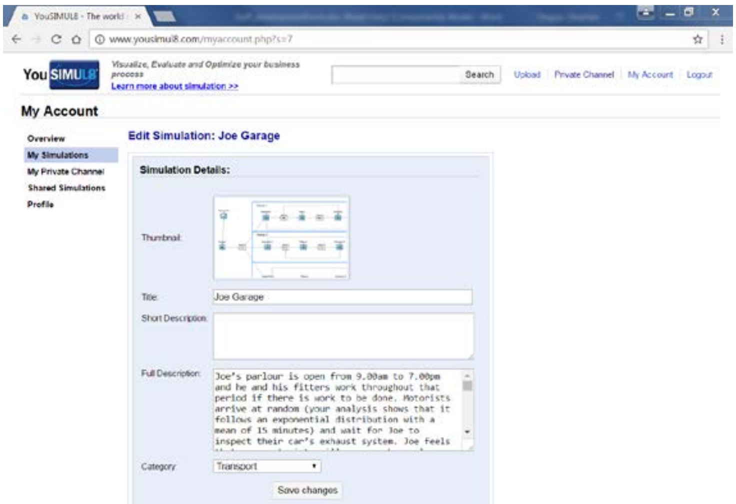

Figure B.21: YouSimul8 – facility for model sharing and collaboration via private channel