TOWARDS AN EQUILIBRIUM MODEL FOR MEASURING THE IMPACT OF DIGITAL TWIN TECHNOLOGY ON ENTERPRISE AGILITY

Research in Progress

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Abstract

As firms continue to experience changes in their information technology (IT) capabilities owing to the rapid development of IT applications, they are under pressure to use their IT to ensure continuous business adaptability and agility. One of the most promising emerging IT applications is the Digital Twin, a technology in which a digital duplication of a physical object is produced that enables rich analysis and simulation to take place. Firms need to explore the optimum configuration and hybridization of technology to keep enterprise performance on a desirable level. Enterprise agility, defined as the ability of a firm to sense and respond to a changing environment, is seen as playing a vital role in this key challenge, as it satisfies the overall aim of improving a firm's performance while helping to adapt to the changes caused by the emergent IT applications. The authors argue that the equilibrium between agility and the adopted IT application capabilities can be better understood and presented by using the system dynamics model, which aims to quantify predictive scenarios. In this model we categorize the impacts as: (i) Digital Twin applications; (ii) the deployment approach; and (iii) agility contextual enablers. Such impacts cannot easily be measured and understood using cross-sectional methods; rather, an approach that combines description of the current reality and prediction should be adopted to understand the nature and level of the impact on enterprise agility and, ultimately, on enterprise performance.

Keywords: Enterprise Agility, Digital Twins, Systems Approach, System Dynamics Modelling.

1 Introduction

In recent years, enterprises have encountered a challenging paradigm shift from dealing with mass production, traditional market competition, and steady use of information systems (IS) to an environment that is a cyber–physical hybrid, with intensive servitization and the development of complex information systems. It is crucial for the enterprise to adapt to the changing business environment while, as far as possible, increasing productivity and customer satisfaction, and reducing the level of complexity of the technological system. To address these challenges and maintain a successful position in their markets, some enterprises have continued to raise their standards of practice by developing their capacity for exploration and exploitation. This means that firms, to continue their development, must be agile to cope with a rapidly changing sociotechnical environment. That can only happen if they intelligently and dynamically orchestrate their strategic, tactical and operational capabilities. IT will play a significant role in achieving this.

Overby et al. (2006) define enterprise agility as "the ability of a firm to sense environmental change[s] and respond rapidly to it." In the last few decades, researchers have discussed the vital role of IT in enterprise agility, as characterized by various determinants. Earlier, Huang and Nof (1999) discussed the influence of IT on enterprise systems and classified it into three categories. That influence can lead to agility by allowing enterprises to alter their strategy and operations by: (1) speeding up activities, (2) implementing an autonomous and intelligent decision-making process, and (3) enabling distributed, collaborative operations. Wang et al. (2013) described how people are a major concern, and the availability of talent should be considered as firms strive to achieve IT-enabled enterprise agility, as the IT department can be the enabler of both exploration and exploitation activities. Other authors have discussed the notion of "cultivating and advancing," whereby firms can develop and progress their IT capabilities in a way that achieves high performance that dynamically supports their strategic capabilities. Overby et al. (2006) concluded that, depending on how it is deployed and managed, IT can either hinder or improve enterprise agility. Determining the optimum configuration to maximize agility is the focus of this research.

Several studies have identified the importance of IT applications in enabling the agile enterprise. One promising emerging IT concept is the Digital Twin (DT) (Longo et al., 2019), a concept that utilizes several other IT concepts, including the Internet of Things, Data Analytics and Cloud Computing, to offer a unique analytical capability. Since DT is an emerging concept, no studies have yet explored the dynamic relationships among DT, firm agility, and overall performance. Hence, an equilibrium model can be deployed to explore its relationships and their impacts on overall enterprise agility.

Most previous studies exploring the impact of traditional IT applications on agility have adopted static (cross-sectional) studies, using either a qualitative or quantitative approach. However, the focus should be on understanding the dynamic correlations associated with the enterprise as an open system in which sub-systems influence one another in complex interactions. Furthermore, organizations must try to reduce any negative impact of IT on enterprise agility, thereby maintaining or improving performance, and ultimately satisfying customer demand (Ashrafi et al., 2006; Overby et al., 2006; Wang et al., 2013; Avazpour et al., 2014). However, previous studies have fallen short in attempting to explain the actions that firms should take to achieve this.

The intention of this research study is to investigate the DT concept and its deployment methods, and their impact on enterprise agility. This will be done through a mixed-methods (qualitative and quantitative) empirical study that provides input for constructing a simulation model. This will use a system dynamic modelling approach to quantify the correlations between the DT and enterprise aspects in order to measure their dynamic impacts on agility. The results will be used to classify these aspects into a hierarchy based on their impacts. The research questions are developed based on a review of the literature and are presented at the end of section 3.

This study will lead to a quantitative explanatory model of how and why DT capabilities have specific impacts on enterprise agility and, therefore, overall enterprise performance. Executing the simulation model will help to generate predictive analytics relating to different scenarios of how DT can help in strategic, tactical, and operational decision-making. This will enable researchers to understand the circumstances under which the enterprise will have an optimal equilibrium configuration, and for how long agility can be maintained at the highest level before new constraints or DT concepts are introduced. Significantly, the model will also measure how these DT deployments affect enterprise productivity and overall performance. The research-in-progress presented in this paper will, when completed, pave the way for enterprises to understand how to deploy and benefit from DT in changing environments, while avoiding any constraints that DT may introduce to hinder enterprise agility.

2 Literature review

In our literature search, we used the university electronic library and Google scholar to identify relevant articles using the following keywords: Enterprise agility, organization agility, business agility, +/- IT or +/- IS. In an initial scanning phase. The authors focused only on articles that discuss agility in terms of the business strategy, business operations, or information systems domains. In the following sub-sections, we offer a summary of the review results for three different aspects: enterprise agility as a concept, enterprise agility enablers, and the impacts of DT on enterprise agility.

2.1 Enterprise agility

Technology is evolving rapidly and enterprises need to develop significantly and progressively to attain maximum efficiency, productivity, and profitability, while ensuring customer satisfaction in a turbulent environment. “Enterprise Agility” is a common term among academics and practitioners, but its definitions vary. One widely accepted definition can be summarized as “the ability of firms to sense and respond to requirements (Operational or Strategic) of turbulent environments for product delivery and competitive advantages while satisfying customers” (Overby et al., 2006; Karvonen et al., 2018; Nwokeji et al., 2018). In this context, turbulent environments can be caused by either market or technological turbulence (Ashrafi et al., 2019).

The concept of agility became common in information systems in the late 20th century and it seen as being the main competitive factor for firms in an ambiguous environment (Balaji et al., 2014). It is understood to have evolved from direct changes in organizational behavior towards market needs and comprises attributes such as information accessibility, demand variability, and a move towards customer requirements (Abdelilah et al., 2018). Enterprise agility has being used in numerous study areas, including supply chains (Yusuf et al., 2014; Fayezi et al., 2017; Dubey et al., 2018), information technology (Overby et al., 2006; Ravichandran, 2018), and management mechanisms (Fayezi et al., 2019). Adaptability to unforeseen changes has become a necessity for organizations, and agility enables enterprises to redeploy their resources for value creation (Teece et al., 2016).

Previous research has described agility in terms of being highly adaptive and responsive to changes via continuous feedback. Consequently, we can classify enterprise agility according to several attributes. Abdelilah et al. (2018) state that a characteristic of agility is that it “encompasses various aspects of both internal (persons, strategy, product) and external (environment, technology) aspects of an enterprise.” In (2013), Abrantes and Travassos described agility characteristics in terms of distinctive features. The authors identified 16 different characteristics from a wide range of literature, and noted that adaptability was frequently mentioned. In (2014), Avazpour and Ebrahimi further elaborated on the characteristics of agility, building on a previous study by Sherehiy et al. (2007) as a reference. The authors listed flexibility, responsiveness, speed/quickness, integration/low-complexity, sensing, high-quality product, and mobilization of core competency as attributes of agility. Table 1 summarizes the main enterprise agility definitions in the literature. The next section reviews and discusses agility enablers, with a focus on IT systems.

Table 1 Definition of Enterprise Agility

Reference	Sambamurthy et al. (2003)	Overby et al. (2006)	McCoy and Plummer (2006)	Tseng and Lin (2011)
Enterprise Agility Definition	The enterprise can detect opportunities for innovation and seize the competitive market opportunities	The enterprise can respond readily to turbulent environments to achieve success	The enterprise can sense environmental change and respond effectively and efficiently to the change	The enterprise can handle change, uncertainty and unpredictability within the business environment and make an appropriate response
Speed	X	X	X	X
Success	X	X	X	–
Sensing	X	X	X	X
Responsiveness	X	X	X	X
Flexibility	X	X	X	X
Reflection on Customer Needs	X	–	–	–

2.2 Enterprise agility enablers and the role of information technology

Bottani (2010) stated that the first attempt to define agility enablers was that of Gunasekaran (1998). Enterprise agility enablers play a vital role in facilitating the agile features of an enterprise to enhance its performance. Using a fuzzy logic, multiple criteria approach, Avazpour et al. (2014) classified agility enablers into a hierarchy of priority. Bottani (2009; 2010) elaborated on the enablers to include concurrent engineering, technology, hardware tools and equipment, supply chain integration, system integration and database management, information management, knowledge management, and team building. Enablers of agility are often required during changes caused by uncertainty and unpredictability. Bhattacharya and Saha (2015) described enablers as attributes that enterprises can adopt to make them more agile. Moreover, as enablers are bound to evolve, Carvalho et al. (2017) grouped them with respect to capabilities, while Žitkienė and Deksnys (2018) described a framework for enablers based on the qualities that agile enterprises need to have for competitive advantage. Table 2 shows the enablers of enterprise agility ranked in accordance with their agility attributes, thereby identifying team building as the most important agility enabler. Technological enablers can be implemented for the integration of firms with information system capability platforms (Overby et al., 2006; Panda and Rath, 2016; Marcinkowski and Gawin, 2019). Information technology enablers also assist enterprises in achieving agility by coordinating the decision-making process that comprises strategic, tactical, and operational decisions.

Previous studies investigated IT as an enabler of agility. Sambamurthy et al. (2003) used a multi-theoretical approach for understanding the strategic role of IT investment in developing firm performance capabilities. The authors used a three-factor significant organizational approach: agility; digital and entrepreneurial alertness; and strategic process, and classified these as digital options that represent a set of IT-enabled capabilities in the form of digitized enterprise work and knowledge systems. The paper concluded by stating that the "theoretical model and the associated prepositions added granularity towards understanding the important linkage of IT investments and firm's performance." Similarly, Overby et al. (2006) investigated the role of IT in enterprise agility and concluded that "sensing and responding capabilities are needed for agility as IT enhanced these capabilities via knowledge and process capabilities." Furthermore, Sambamurthy et al. (2003) and Chakravarty et al. (2013) proposed two distinctive roles for understanding how IT competency shaped a firm's performance and organizational agility. Using a "latent regression analysis" to test their model and hypothesis based on data samples from 109 "business-to-business electronic marketplaces," their results suggested that "managers are to account for (multiple) contingencies (observed and unobserved) while assessing the effects of IT competencies on organizational agility and therefore the firm performance."

Several studies have investigated IT as an enabler of enterprise agility. Weingarth et al. (2018) describe technology as the most prevalent factor. Other research from authors such as Martínez-Caro et al. (2018), Park et al. (2017), Ravichandran (2018) and, Richardson et al. (2014) finds IT, as an enabler, to have a positive impact on enterprise agility, as it helps organizational performance through enhancing operational efficiency and strategic decision-making for value creation in a competitive environment.

Table 2 Enterprise Agility Enablers

Reference	**Enterprise Agility Enablers**	**Description**
Yusuf et al. (1999); Avazpour et al. (2014)	Team building	Various agile firms require the use of empowering individuals working in teams to decentralize decision-making. This in turn would create way for teamworking.
Avazpour et al. (2014); Ahsan and Ngo-Ye (2005)	Hardware, software tools and equipment	In the agile manufacturing literature, agility needs speedy changeover from the assembly of one product to another, different product. This, in turn, needs rapid hardware and equipment changeover.
Wang et al. (2013); Patel et al. (2017)	Supply Chain Management	Deals with a "dynamic network of organization and linkages in different processes" as it requires "integrating organizational units and coordinating materials, information and financial flows to improve competitiveness" to achieve success in responding to customers' demands.
Avazpour et al. (2014)	Concurrent Engineering	A systematic approach that deals with "handling changes in a manufacturing environment benefits from other systematic approaches of concurrent design of the product and downstream processes for production and support."
Huang and Nof (1999); Overby et al. (2006); Wang et al. (2013)	Information Technology	IT enhances both the sensing and responding capabilities of firms to respond to rapidly changing environmental conditions. It also "enables distributed operation with collaboration." Regarding people, processes, and systems, IT organization capabilities are required in an organization to achieve enterprise agility.
Ashrafi et al. (2006)	Knowledge Management	"Building agility into enterprise through knowledge management systems that acquire, organize and assimilates internal and external storage in a systematic way is suggested key to agility." This approach assists in building a dynamic and absorptive capability to respond quickly and effectively to changes in turbulent environments.
Coronado et al. (2002)	E-commerce	Utilization of e-commerce has enabled the characteristics of agile firms such that there is a response to customers' demands, adaptability and flexibility to changing firms' environments while enabling decentralized operations.
Avazpour et al. (2014)	Systems Integration and database Management	"Systems Integration Architecture (SIA) is based on a new, transformation model of integration and provides sets of elevated level services which allow information system modules, to be rapidly reconfigured."

2.3 Digital Twin technology and enterprise agility

Digital Twin (DT) technology is an emerging concept that consists of three parts: a physical product, a virtual product, and the linkage between the two (Tao et al., 2019). DT shows a comprehensive physical and functional description of a system with available operational data. It is a virtual computerized counterpart of a system that can be used in simulation for real-time exploitation of data from field sensors. It helps in process control and condition-based maintenance, and can be used in agile firms for tactical and strategic decision-making for competitive advantage (Boschert and Rosen, 2016;

Kritzinger et al., 2018). Although mainly associated with manufacturing, it provides an opportunity to simulate and optimize production systems with the objective of increasing productivity, efficiency, and competitiveness (Kritzinger et al., 2018), which are characteristic of enterprise agility. DT technology also allows the realization of new services with reduced effort (Boschert et al., 2018), so that, through modelling and simulation of a firm's replicated system in the virtual environment, predictions can be made and answers found to detailed questions and systems relationships. The virtual models promote understanding the systems and state behavior of physical entities through sensing data to estimate, predict and analyze dynamic changes (Qi and Tao, 2018). This also influences the decision-making process of staff at all enterprise levels (strategic, tactical, and operational) through real-time simulation and two-way mapping between physical objects and their digital representations (Qi and Tao, 2018), thereby contributing toward creating an accumulated impact on agility that positively affects enterprise agility.

3 Critique and research focus

Researchers have acknowledged that IT has a significant impact on enterprise agility, either positively or negatively. IT improves the "entrepreneurial and adaptive" features of organizational agility and the "people factor" also plays a critical role in enterprise agility. Moreover, to reduce negative IT influences, "managers need to recognize the restrictions that emerging IT capabilities pose when environmental dynamism increases"(Chakravarty et al., 2013) and further enable their IT personnel to develop a positive and effective configuration of the IT capabilities of the firm.

This research study will make use of the notion of dynamic capabilities (Teece et al., 2016) as its theoretical grounding. Dynamic capabilities have been extensively researched within the IS field e.g., (Sambamurthy et al., 2003; Pavlou and El Sawy, 2010; Pavlou and El Sawy, 2011; Nan and Tanriverdi, 2017; Patel et al., 2017). Researchers have for many years been focusing on IT and business capabilities to understand the strategic management of IT (Bharadwaj, 2000; Marchand et al., 2000). Bharadwaj (2000) argued that IT competence and the quality of IT capabilities have a substantial and important impact on firm performance. However, Sambamurthy et al. (2003) extended these findings by pointing out that IT competence is a "critical antecedent" for contemporary firms to gain competitive advantage. The authors further argue that IT competence is arbitrated by the relationships among three dynamic capabilities (agility, digital options, and entrepreneurial alertness). These dynamic capabilities are interlinked and influence each other, while the strategic processes (capability building, entrepreneurial action, and co-evolutionary adaptation) help to activate, link, and shape these capabilities for organizations to achieve competitive interventions.

As Sambamurthy et al. (2003) stressed, the notion of dynamic capability links agility, digital option, and entrepreneurial alertness, and the research presented in this paper adopts this perspective to further develop a quantified, predictive equilibrium simulation model. Most researchers' findings are based on either theoretical or empirical views that neglect quantifying a predictive simulation model that shows how equilibrium can be achieved through evaluating the impact of a wide number of relevant factors. A particular focus of this study is how DT capabilities can be accumulated and configured in a way that delivers the required agility for an enterprise to make decisions on differing, short- and long-term timescales (operational, tactical, and strategic). Most previous studies did not significantly discuss the potential of emergent technologies or their impact on enterprise agility; the few that did so did not describe the ways in which enterprises can use dynamic modelling to achieve equilibrium. This study particularly focuses on the DT concept and its impact on enterprise agility. The following research problems are noted based on the discussions in the previous sections:

1. DT capabilities need to be understood so that firms can select an option that will maximize the positive influence on enterprise agility.
2. DT deployment approaches have not previously been studied with a focus on whether they have an impact on enterprise agility, or in what way. Also, enterprises could consider a mixture of technology capabilities if that will benefit to their overall agility.

3. Previous studies were theoretically based, with little empirical (qualitative or quantitative) studies from a static point of view. No previous research has attempted to test the DT concept in a model and simulate its influence on enterprise agility. Therefore, the model should be codified and appropriate simulations run to test the related theories and hypothetical views.

This empirically-based study will focus on answering the following research questions (illustrated by the conceptual model in Figure 1):

RQ1: How, and to what extent, does the use of DT increase enterprise agility?

RQ2: In what ways do the agility enablers, and particularly the DT deployment style, have an impact on enterprise agility?

RQ3: How can we develop a simulation model that quantifies these impacts, with a particular focus on
a) the impact of DT on different level of decision making
b) the influence of agility enablers on DT's accumulated impact on enterprise agility, depending on where and how they are deployed?

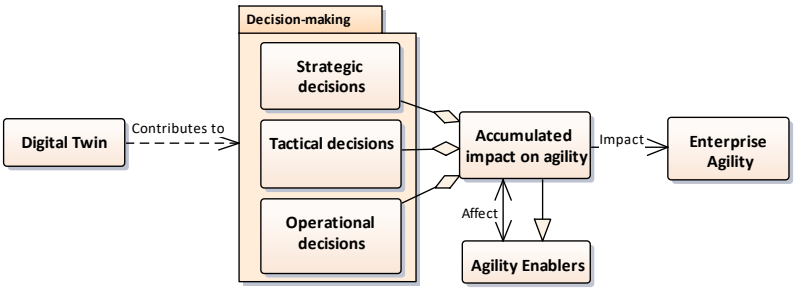

Figure 1. Research concept model

4 Research Approach

This research study uses a hybrid research method within the positivism paradigm (Halfpenny, 1997) that involves both quantitative and qualitative data collection which will finally feed in to the design of a simulation model using system dynamics modelling.

The qualitative study will deal with practitioners' perceptions of how the DT concept might be deployed and enable agility at different decision-making levels. This task is intended to measure perceived agility, which will later be further validated using quantitative operational data to triangulate the research and help to understand whether the perceived agility matches the actual agility. We see agility enablers acting like moderators on the impact of DT on overall enterprise agility, depending on which of the enablers benefit the perceived value of DT and the nature of the deployment. We also remain open to exploring the impact of industry-specific factors that influence DT as agility enablers or hinderers.

The target sample will be IT managers; mid- and high-level managers who have experience with any type of emerging technologies. A tailored version of the protocols will also be used to conduct interviews with strategic and operations managers. The target industry will be six pharmaceutical companies from Europe. Analytical methods, including thematic and causality mapping, will be used to analyze the results and measure the significance of each aspect in terms of its relevance to agility. After the results are streamlined, we will use the results to calibrate our system dynamics (SD) model. This will first be represented on a causal loop (CL) diagram and then quantified on a stock and flow diagram. SD modelling methods are "a set of computer-aided conceptual and modelling tools that assist managers in understanding and analyzing complex problems, to design more effective operating policies" (Sterman, 2002). According to Vallejo et al. (2017), system dynamics is built upon systems thinking, which is capable of "reflecting the world as a complex system where one cannot view the world without thinking that everything is connected to one another." CL is a diagrammatic represen-

tation of a complex system and describes the nature of the relationships between the system's components. A further elaboration is then needed to build a greater level of granularity. This is achieved by using the stock and flow model to model the enablers and constraints, thereby mathematically describing the systems' relationships and their impacts. The results will be shown after running the model simulation and varying the inputs to test different scenarios under different circumstances to explore various "what if?" scenarios.

The authors selected the SD method because of the capabilities it offers for building both contentious and discrete-time simulations; it enables calibration of quantitative variables and traceability from qualitative factors. SD can also help in creating fuzzy variables and differential equations. Using a mixed-methods approach will enable researchers to understand the system in terms of systems thinking and, by gathering stakeholders' perceptions using interviews and operational and strategic data, the study will be able to explore the systems' interdependencies and relationships (Onwuegbuzie and Combs, 2011). Figure 2 illustrates the research model the and process developed for this research study.

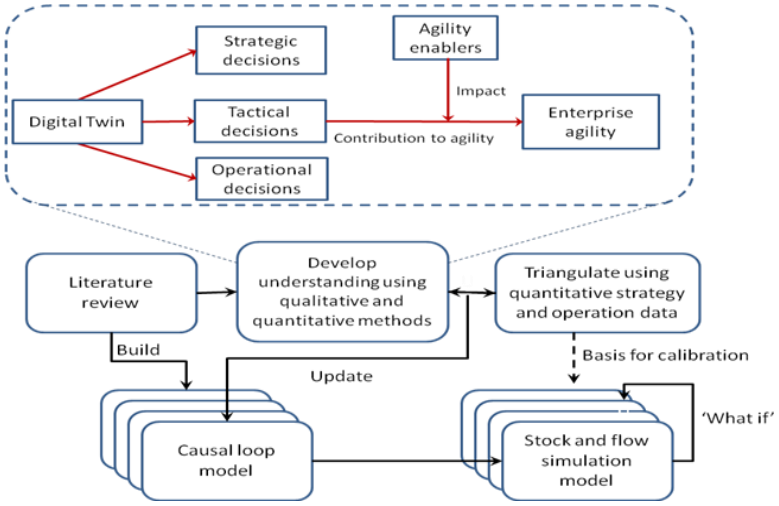

Figure 2. Research Model and Process

5 Conclusion and anticipated contributions

The authors plan to test the dynamic impact of DT capabilities on enterprise agility through a hybrid approach that uses both an empirical study and simulation modelling. To the best of the authors' knowledge, this is the only study to consider measuring the impact of DT capabilities and how they are deployed, along with a simulation model to illustrate how the factors and constraints might influence enterprise agility over time. This study will offer practitioners insights into what impact different methods of deploying DT might have on enterprise agility and will offer further insights into the optimum deployment of DT for short- and long-term decision support for maximizing enterprise agility.

The simulation model will be designed to be flexible, so that organizations can update the impact or manipulate the constraints to test the model under different, emergent circumstances. It is hoped that the suggested two-stage approach will offer a significant advance in understanding the relationship between DT capabilities and enterprise agility.

The next step in the research process is preparation for the empirical investigation, based on both primary and secondary data. The data will include quantitative operational and strategic data, thus enabling results triangulation. The study will progressively construct the causal loop diagram, which will be continuously updated to reflect the results of the empirical study. Both approaches will play key roles in constructing the stock and flow model and translating the impact into a set of mathematical equations that comprise the simulation for testing various scenarios.

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