The Digital Transformation Journey: A System Dynamics Approach for Chief Digital Officers

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ABSTRACT

Digital transformation is a complex managerial challenge that almost all organisations have to face. While digital transformation has received increasing scholarly attention, the current extensive and diverse literature on digital transformation lacks a method for Chief Digital Officers to dynamically visualise, analyse, and manage digital transformation. The purpose of this paper is first to analyse the current models for digital transformation. Second, the paper investigates the use of System Dynamics for digital transformation. Next, we present a high-level System Dynamics model of digital transformation. This research is expected to serve as a basis for further research on the use of System Dynamics for digital transformation. Finally, the models presented in the paper allow practitioners to develop their own models and asses their digital transformation efforts.

Keywords

Digital Transformation, System Dynamics, Chief Digital Officer, Digital transformation management, Digital transformation strategy, Digital Transformation model, Dynamic model

1. INTRODUCTION

1.1 Digital Transformation

Digital transformation (DT) is rapidly becoming one of the most mentioned phenomena among academics and practitioners in the field of business [11, 24, 65]. Digital transformation reshapes departments, organisations, and even entire industries [31]. The impact of DT can be seen across nearly all industries. As a result, organisations need to rethink their services, products, processes, business models, and organisational structures. Organisations must adapt or risk losing competitiveness [25, 31]. Furthermore, due to its strategic importance [55], DT is referred to as "the most pervasive managerial challenge for incumbent firms" [39].

Researching and practising DT is complicated by disagreement on terminology and scope in the literature [24]. However, vial [65] proposes a conceptual definition of DT as "*a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies"* (p. 119). As this is the most comprehensive definition at the time of writing, we follow this definition here.

Digital technologies are currently the main drivers of disruptions in society and industries [65]. These disruptions require an agile strategic response from organisations to redefine their value propositions. To realise this, management must implement structural changes and overcome various organisational and technological barriers. In addition, managers must balance various digital capabilities to ensure the appropriate mix between exploring new and exploiting existing technology. DT is an ongoing, never-ending dynamic endeavour that affects all levels of an organisation. It thus requires changes to processes, structure, and culture and the capability to generate new paths for value creation [14, 65]. DT differs from IT-enabled organisation transformation (ITOT). ITOT aims at supporting and strengthening current value propositions, while DT reshapes and redefines current value propositions via which it creates a new organisational identity [68].

1.2 Scope: Chief Digital Officer

Despite increased research and reporting on DT, industrial businesses are failing more than succeeding at DT [60]. The need for proper strategic management is further reflected in the emergence of the new senior executive: Chief Digital Officer (CDO) [19, 29, 55, 56]. CDOs are burdened with the challenge of guiding an organisation through the journey of DT [19]. "Digital transformation differs from the traditional forms of strategic change on the basis that digital technologies have accelerated the speed of change, resulting in much more environmental volatility, complexity, and uncertainty" [67] (p 329). In addition, DT is heavily influenced by external factors such as rapidly altering consumer behaviour and expectations, competitive landscapes, and data availability. As a result, standard methods for business and change management often provide an oversimplified and linear perspective that does not meet the demands of the complex endeavour of DT, where CDOs have to anticipate the effects of numerous dynamic factors to achieve DT successfully.

1.3 Approach: System Dynamics

System Dynamics (SD) is a branch of systems theory that enables the modelling and understanding of the dynamic behaviour of complex systems. It deals with internal feedback loops and time delays that affect the dynamic behaviour of the entire system. Originally, Forrester created System Dynamics in the 1950s as a management method for industrial enterprises, but it has since been applied to many other complex social managerial, economic or ecological systems examples are health care and climate change. [38].

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The key elements of SD are feedback loops, stocks, and flows [16]. With analytical thinking, we often see the world in linear cause-and-effect sequences, but in SD, any activity has an effect back on the element that initiated that activity. Elements are temporarily interconnected in effecting a joint outcome. SD enables the visualisation of these interconnections with Casual Loop Diagrams (CLDs). A CLD is a map of a system with all its constituent variables and their interactions. By capturing interactions and, consequently, the feedback loops, a CLD reveals the complex structure of a system [16].

The other key feature of SD is stock and flow diagrams (SFD) [16]. To perform a more detailed quantitative analysis, a CLD is transformed into a SFD, which helps in studying and analysing the system, typically using computer simulations. A stock is an entity accumulating or depleting over time, such as a bathtub filling with water from a faucet. On the other hand, a flow is an entity that either increases or decreases the level of a stock, for example, the water coming out of the tap. A stock's level can only be changed by flows [38]. A common technique to distinguish a stock and a flow is to consider what would happen if the system were to stop [5]. The stocks, which are accumulations, would still exist. Flows, however, represent activity, so they would stop. Going back to the bathtub example, if you close the faucet, the flow of water stops, but the water level in the bathtub remains. In this sense, the stocks present the state of a system, while flows present the activities affecting that state.

While CLD and SFD are both powerful tools, they are fundamentally distinct. CLDs are helpful for conveying high-level perspectives of a system, particularly to those with minimal prior knowledge of SD or systems thinking [5]. They are simple to comprehend and serve as an effective starting point for systematically investigating a problem. SFD take the analysis to a higher level of rigour [5] and distinguishes between variables that are stocks and those that are flows. Given the fundamental differences between these variables, a SFD produces an enhanced understanding of the system's behaviour [38]. Understanding not only the structure but also the nature of these relations enables us to model and simulate the behaviour over a certain period. SD provide the tools to create a qualitative and/or quantitative representation of how the system will likely develop over time. As no business process can be conducted instantly often, the effects of decisions are delayed. Using simulation, SD allows us to analyse the impact of our decisions in real-time [23].

2. PROBLEM STATEMENT

Although current literature has proven the importance of DT and its management, current literature lacks concrete tools and models for CDOs to support handling the high complexities and dynamics that DT processes may contain [45]. Given the complex situation of DT, CDOs have difficulties overseeing, analysing, managing, and measuring the success of DT. As DT requires extensive change across various levels of the organisation [68], top-level management collaboration is necessary to be successful [70]. Although multiple frameworks [17, 31], strategies [11, 15, 25, 67, 71, 73], and metrics [7, 59] have been presented in the current literature, research on long-term, dynamic modelling of DT is, to our knowledge, absent. This paper will analyse the use, benefits, and potential of System Dynamics for DT. The goals for this paper are:

- **Goal 1:** To critically analyse the current models for digital transformation.
- **Goal 2:** To describe the use of System Dynamics for understanding and modelling the dynamic and complex behaviour of digital transformation.
- **Goal 3:** To develop a System Dynamics model for digital transformation.
- **Goal 4:** To demonstrate the benefits and potential of System Dynamics for CDOs in the context of digital transformation.

To achieve these goals, we search for answers to the following research questions:

- **RQ1:** What is the state of the current models for digital transformation?
- **RQ2:** What are the key aspects, benefits, and downsides of System Dynamics if applied to digital transformation?
- **RQ3:** How can a general System Dynamics model support CDOs in their management of DT?

3. RELATED WORK

To find relevant work for the research topic, Springer, IEEE, Scopus, Google Scholar and other literature databases were used. Searches were conducted using the search term "digital transformation OR digitalisation" in combination with "system dynamics" or in combination with "management" or "chief digital officer" and various combinations of these search terms. After conducting a thorough reading of a selection of the results, based on relevance, we dove deeper by looking at the references and citations of the mentioned papers.

Extensive and diverse research has been conducted on specific areas of DT and how they impact companies. Some of these papers address the lack of common agreement on what DT entails [24, 64, 65]. These papers give valuable insights into what DT encompasses and its scope and provide a conceptual basis for more in-depth research. Furthermore, [68] reveals the differences between IT-enabled organisational transformation and DT.

Research such as [11] focuses on the strategic importance of DT and reveals identifications of themes to guide the thinking on digital business strategy. Chanias and Correani [13, 15] focus on demonstrating the process of formulating and implementing various DT strategies by analysing case studies.

Other papers propose strategies and concepts for guiding management through DT. For example, Konopik et al. [31] propose a dynamic capability conceptual framework for managing DT. Yamamoto [71] presented a Digital Balanced Scorecard as a method to map the main strategic dimensions of DT. Papers such as [19] and [55, 56] investigate CDOs' position and role throughout DT. In addition to this, Barthel [7] and Stich [59] propose various metrics and KPIs to measure the success of DT. Combined, the existing literature gives a solid basis for our research.

4. RESEARCH METHODOLOGY

This section discusses the approach and practical steps needed to answer our research questions and reach our goals. First, we perform an exploratory and descriptive literature review on the current body of knowledge of DT. This describes current models, strategies and methods adopted by academics and practitioners and will reveal what factors are critical to success. Then, the results will be combined to analyse insights and findings related to DT and provide a basis for using System Dynamics for DT.

Second, the literature review will be extended by describing the potential benefits of System Dynamics for DT. Finally, after reviewing DT and the use of System Dynamics throughout the journey of DT, we develop a System Dynamic model for DT. Development and analysis of this model will reveal the benefits of both System Dynamics modelling and theory.

5. LITERATURE REVIEW

5.1 Conceptualisation of Digital Transformation

Extensive and diverse research has been conducted on the different aspects of D, but these papers lack agreement on what DT involves [22, 24, 39, 64, 65, 68]. However, they do provide a basis for what DT entails.

We found different concepts and definitions of DT. Wessel et al. [68] reveal the differences between IT-enabled organisational transformation (ITOT) and DT. Although both have several similarities, they differ in activities and outcomes. ITOT supports and strengthens existing propositions during transformation activities, while DT (re)defines value propositions. As a result, the outcome of DT is a newly defined organisational identity, while ITOT reveals a reinforced corporate identity. DT is a journey that affects all levels and dimensions of a company [22, 24, 39, 64, 65]. As DT triggers operational, organisational [24], and collaboration changes [52], it requires a multi-disciplinary view [64]. The triggers, impacts of these triggers, and responsive changes affect a broad range of processes and people [60]. As a result, DT needs a holistic [24] and comprehensive definition that remains valid if technology adapts. Vial [65] reviews a rich body of information system research on DT. The paper systematically decomposes different conceptualisations presented by various studies to identify the essential properties of DT. These essential properties are combined to create a conceptual definition of DT as "a process that aims to improve an entity by triggering significant changes to its properties through a combination of information, computing, communication, and connectivity technologies." [65] Additionally, Vial presents an inductive framework combining eight "building blocks describing DT as a process where *digital technologies* play a central role in the creation as well as the reinforcement of *disruptions* taking place at the society and industry levels. These disruptions *trigger strategic responses* from the part of organisations, which occupy a central place in DT literature. Organisations use digital technologies to alter *the value creation paths* they have previously relied upon to remain competitive. To that end, they must implement *structural changes* and overcome *barriers* that hinder their transformation effort. These changes lead to *positive impacts* for organisations as well as, in some instances, for individuals and society, although they can also be associated with *undesirable outcomes*." [65] (p. 122)

To summarise, DT is the process of using digital technologies to fundamentally change how an organisation operates and delivers value to its customers. It involves integrating digital technology into all areas of a business, fundamentally changing how the company operates and delivers value to customers. DT can be driven by various disruptions, including the need to leverage data availability, enhance customer experiences, and stay competitive in a rapidly changing market. These disruptions result in the rethinking and redesigning of business processes, organisational structures, and leadership to fully leverage the benefits of these technologies. The goal of digital transformation is to create more agile and efficient organisations that are better equipped to meet customers' needs and adapt to changing market conditions. As a result, it can help organisations improve their operations, drive innovation, and increase competitiveness.

5.2 Current Digital Transformation Models & Phases

The journey of DT through which an organisation can be guided may vary depending on its current digital state and goals [43]. Current literature has formulated various phases [9, 10, 49, 64], maturity levels[21, 69], or roadmaps [36, 43, 53, 69] for DT. As a result, there are many different models for DT, each with its strengths and weaknesses. They provide guidelines and best practices that organisations can use to guide their DT efforts. These models offer a roadmap for implementing changes in a way that is strategic, efficient, and effective. Current literature refers to these 'models' as 'strategies', 'methods', and 'frameworks', sometimes interchangeably without specifying their exact definition in the context. However, most authors and reviewers refer to them as models [9, 10, 12, 20, 21, 24, 33, 44, 47, 50, 64]. Therefore, we also refer to them as models. Table 1 provides an overview of the models thoroughly investigated.

Table 1 Overview of the Models investigated

Reference	Industry	Feedback
Albukhitan [1]	Manufacturing	Single-use
Chanias et al. [13]	Car	Single-use
Sathananthan et al. [50]	General	Continuous
Gökalp et al. [21]	General	Iterative
Schallmo et al. [53]	General	Iterative
Warner & Wäger [67]	General	Iterative

DT requires agile models that allow continuous feedback [34, 53]. Models such as [1, 13] do not allow feedback loops. Even though these models provide insight into the dimensions of DT, the logic of linear DT is oversimplified thinking that could result in wrongful management decisions [47]. While Sathananthan et al.[50] present a method for innovating a business model that highlights the importance of internal and external feedback loops; the narrow focus on designing a digital business model causes it only to be helpful to start DT strategising. Once the DT journey goes through later phases, the model lacks methods of monitoring and revealing new opportunities and innovations.

The Digital Transformation Capability Maturity Model by [21] focuses on improving a DT initiative's maturity level. It is a model that uses the concept of digital maturity from the result of an organisational assessment to evaluate the DT process. This allows for the comparison of DT efforts between different organisations. Within the model, there is a feedback loop that ensures that knowledge gained from gap analysis informs DT strategy changes until the initiative is complete. The model successfully provides an approach for assessing the DT maturity level and achieving a roadmap for improvement. This roadmap is extended with suggestions for maturity level improvement. However, although the model provides feedback mechanisms through iterative organisational learning processes, it only offers high-level descriptive analysis. It thus lacks quantifiable means for managers guiding an organisation through DT.

Digital Maturity Models have extensively been built and researched to support DT [44, 47]. Pham Minh & Pham Thi Thanh [44] provide a comprehensive review of the current

state of DMMs. They highlight the current belief in DMM's effectiveness in helping managers manage their transformations. However, they also emphasise the novelty of research when DMMs are integrated into extensive DT processes. They propose the integration of DMM into a continuous DT process that reflects the rapid changes in customer expectations, dynamics of external conditions [52], and disruptions caused by digital technology [51].

The Integrated Roadmap for a Digital Strategy proposed by [37] provides a model with six phases culminating in the formulation of a digital strategy. The digital strategy options are formed by simultaneously using internal/external and forward/backward approaches. These are then integrated to form the overall strategy. The close alignment of phases two (Strategic Forecast) and four (Strategic Principles) reflect how the model allows for strategy to be formulated through both constructivism and nominalism [20].[1] Although this model provides a comprehensive approach to developing strategy, the model stops after strategy formulation. Feedback after the completion of the strategy formulation process is not integrated, and modification of digital strategy during implementation is a critical feedback loop [24, 25].

Warner & Wäger [67] propose a process model comprising nine micro-foundations that reveal generic contingency factors that enable, trigger, and hinder building dynamic capabilities for DT. Dynamic capabilities can be separated into a firm's ability "(1) to sense and shape opportunities and threats, (2) to seize opportunities, and (3) to maintain competitiveness through enhancing, combining, protecting, and when necessary, reconfiguring the business enterprise's intangible and tangible assets. " [62] (p. 1319). The start of the process of building these dynamic capabilities is triggered by factors including disruptive digital technologies, changing consumer behaviour, and disruptive digital competitors. The proposed model reveals three core factors that enable the development of dynamic capabilities; fast decision-making, cross-functional teams, and executive support. This development is hindered by three core barriers, change resistance, rigid strategic planning, and a high level of hierarchy. Their findings emphasise building strategically agile firms focusing on building digital sensing capabilities and digital maturity in the workforce [67]. However, the process model is limited because it uses qualitative methods to analyse processes rather than quantitative methods to measure the effects of DT on organisations. As a result, they reveal what and not how dynamic capabilities need to be developed by a digitally mature firm [17].

To summarise, we have critically analysed six models for DT. There is much diversity in the approach to modelling DT [20, 44]. Various academia and practitioners have focused on different aspects of DT, such as business model innovation [50], digital maturity [21, 44, 47], dynamic capabilities [17, 67], and the strategic aspect of DT [1, 53]. After a critical analysis of the current state of the modelling of DT, we identified digital maturity and dynamic capabilities to be suitable measures of the progress of DT. Furthermore, we can conclude that although current models provide insight into the complexity of DT, there currently lacks a perspective that integrates these various models focused on different aspects into one model. While also allowing for the necessary continuous modification, integration, quantification and simulation of feedback loops embedded in different components of DT.

5.3 Critical Success Factors

Researchers have analysed DT initiatives to extract common Critical Success Factors (CSF). However, the literature on the success factors of DT differs in scope and detail. Therefore, we have analysed 7 studies [27, 35, 42, 48, 49, 66, 69] on factors that determine DT success. Appendix A provides an overview of each study and its corresponding CSFs. Due to the diversity in results, we have extracted the 17 most essential and overlapping factors and classified them into five dimensions. 1) *Customer experience*, 2) *Governance and Leadership*, 3) *Workforce Capabilities and Culture*, 4) *Organisational Infrastructure and Operations*, and 5) *Business Ecosystem*. These dimensions relate to different DT departments; the CSFs in customer experience, for example, are most appropriate for the sales department. On the other hand, the CSFs in Workforce Capabilities and Culture are more suitable for the human resources department. Furthermore, we combined various success factors into more holistic factors. Additionally, example Key Performance Indicators (KPIs) that can be used to monitor the progress per CSF have been added. Appendix B provides an overview of these dimensions and their corresponding CSFs and KPIs. Both appendixes A and B are available upon request.

The first dimension of *Customer experienc*e reveals the increasingly important and active role customers play in the stakeholder network [65]. The digital business era requires businesses to adapt by employing *a customer-centred approach in designing offerings using analytics to customise and create products & services.* Apart from customizability and personalisation, Digital business strategy builds on *seamlessly integrating offline and online channels* to enhance digital and intangible experiences around the product, which are often of higher importance in comparison to the physical use of the product [27]. To increase available data and enhance customer experience, organisations can use digital customer decision journeys and social media to create a *digitalisation of customer interaction for direct contact to support customer engagement* [30]. As digital markets are disruptive [65] and turbulent by nature [35, 52], firms need to implement *mechanisms for experimentation with new technologies to keep abreast with changing customer needs*. Furthermore, successful digital transformation requires a customer-centric "outside-in" perspective [35]. Therefore, customers need to become the central hub of digital service delivery by internalising the customer viewpoint [27].

The second dimension, *Governance and Leadership*, focuses on the importance of active monitoring and participation by top-level management [56]. DT efforts often fail due to fuzzy goals and unclear strategic vision [30]. Digitally maturing firms must *establish a clear vision supported by guiding policies and embedding Digital Business Strategy & Digital Transformation strategy in general business strategy*. Next to providing management and employees with an improved understanding of the company's goals [15], clear strategic visions also help to *ensure organisational-wide commitment to transformation in strategy and culture* [30]. To further promote employee engagement in DT efforts, it is critical to *establish executive support and digital governance* by, for example, appointing a Chief Digital Officer [55, 56]. *Clearly defined monitoring and evaluation criteria and mechanisms with short feedback loops that support rapid innovation and*

[1] "Under constructivism, a goal is selected, and the strategy is formulated to achieve the goal. Under nominalism, the goal cannot be completely known from the outset and must be determined only in relation to the present state"[20]"

prototyping are essential to ensure initiatives stay on track and deliver the sought-after benefits [43].

Workforce Capabilities and Culture is the third dimension. For successful DT in which joint IT and business initiatives can flourish [42], an organisation must *cultivate a supportive organisational culture that promotes employee engagement*. Furthermore, the digitalisation of companies' business processes requires employees with increasing levels of digital literacy [41]. As a result, DT depends on the firm's ability to *acquire, retain, and attract talent with digital skills, know-how, and a digital mindset.* In addition, due to the complexity of the dynamic nature of DT, individual problem-solving skills and adaptability are crucial to success [3]. Therefore, DT requires organisations to *promote individual creativity and innovation by creating an adaptive culture with evolvable goals*.

Fourth, *Operational Infrastructure and Operations* emphasises the organisational and operational changes crucial to successful DT. The rapid emergence of new technology and competition [63] requires firms to *institutionalise innovation by creating a flexible and agile organisational structure.* Operational and innovation performance can be enhanced by *digitalisation and re-engineering of operational processes towards data-driven digital platforms and bimodal IT infrastructures* [48]. Bimodal IT is defined as "the practice of managing two separate, coherent modes of IT delivery, one focused on stability and the other on agility" [28]. Data-driven processes and decision-making rely on high-quality data [33]. As a result, data managers need to *ensure relevant, reliable, and available real-time data and information from a central source.* Next to the potential benefits of algorithmic decision-making, increased data collection also carries significant security and privacy risks [40]. Mitigating these risks requires extensive *investment in security systems, standards, and practices used to secure data* [46].

Finally, increased partnerships and digital collaboration opportunities have led to the emergence of *Digital Business Ecosystems* [52]. Maintaining competitiveness requires firms to realign their alliances to drive the co-creation of value [65]. To capitalise on the potential benefits of digital value networks, organisations must *promote external collaboration with open systems and partner integration*. The digitalisation of services and products increase the need for specialised knowledge and skills [41]. Besides training and hiring digital talent, firms are encouraged to *leverage external expertise with creative partnerships*.

The five presented dimensions incorporating 17 CSFs support CDOs and other decision-makers during strategy formulation. Additionally, combining the CSFs with KPIs enables setting quantifiable goals and measuring and monitoring progress.

5.4 Systems Thinking

Standard methods and theories related to business and change management incorporate an event-oriented perspective [57]. This perspective leads to a problem-as-event to a solution-as-fix linear thinking style [38]. Linear and event-oriented thinking limit the holistic scope needed to uncover unexpected side-effects, and non-linear behaviour, of DT. Complex business systems have feedback with temporal delays that are difficult to consider intuitively [2] and thus hinder our ability to generate accurate and useful mental models. Mental models are the cognitive organising structures that decision-makers rely upon, representing the collection of routines, assumptions and networks of causal relationships that reveal how a system operates [32]. Consequently, we often have a limited view of the planned change. The quality of decision-making and planning relies on the adequacy of the mental models. Inadequate mental models lead to inaccurate management strategies that do not address the non-linear feedback of these initiatives. Peter Senge [54] argues that to solve this, we need a 'shift of mind', a new way of looking at the social and business world, that eliminates narrow functional perspectives and silo mentalities.

Systems thinking is both a methodology and a philosophy for understanding the behaviour of complex dynamic systems. Systems thinking provides a language for visualising and operationalising the mental models of decision-makers [32]. Systems thinking is distinct in that it emphasises endogenous behavioural explanations [37]. Thus, choosing the system boundary is an important aspect of the analysis. Decision-makers can approach problem-solving in a proactive rather than reactive manner thanks to the endogenous perspective. Feedback systems thinking is an approach that adopts the holistic view needed to examine complex dynamic organisational systems [32]. Interpreting the structure with feedback systems thinking unveils behaviour in the broadest sense, encompassing both material and informational flows. These flows reveal combinations of balancing and reinforcing feedback loops that produce the characteristic behaviours of a system. Repeatedly occurring dynamic phenomena are known as system archetypes [54]. They are a fundamental instrument in the feedback systems approach to help identify the root causes of organisational behaviour. The archetypes outline observed behavioural patterns and link them to possible feedback mechanisms that can generate these behaviours [32]. Consequently, the CLDs of these archetypes do not describe what happens but rather reveal what will happen if the variables were to change [57].

Currently, many [1, 13] employ a linear, event-oriented perspective on managing DT that relies on oversimplification and unrealistic assumptions about how a complex dynamic organisation functions. Due to their fragmented perspectives and out-of-date theories of change, which disregard the dynamic relationship components of organisations, most DTs fail [32]. We need to comprehend the intended effects of the socio-technical shift and recognise any potential unintended consequences to adopt and reap the benefits of DT. To enable both qualitative and quantitative dynamic analysis, CLD and SFD need to be merged into an interconnected diagram [2]. "Modelling is iterative, a continual process of testing and revision, of both formal and mental models." [57] (p.28) This allows organisations to dynamically improve their learning processes while detecting weak signals of change and possible risks from the business environment [2].

6. SYSTEM DYNAMICS APPLIED TO DIGITAL TRANSFORMATION

6.1 Transforming Vial's inductive framework

As mentioned in 5.1, Vial builds an "inductive framework of the current knowledge on DT" [65] (p. 122) by combining eight building blocks; *use of digital technologies, disruptions, strategic responses, changes in value creation paths, structural changes, organisational barriers, positive impacts, and negative impacts*. Although Vial [65] presents a comprehensive conceptualisation of the DT process, the model shown is non-casual and static. As previously argued, DT is a complex change journey with many dynamic interrelations. Therefore, transforming the model proposed by Vial into a stock and flow diagram using System Dynamics will provide CDOs with an enhanced understanding of the

complex behaviour of DT by revealing the cause-and-effect flows, links, and feedback loops between the various building blocks. Additionally, it will allow managers to generate dashboards and run computer simulations. Furthermore, we extend the Vial [64] model by adding two concepts identified as solid progress measures for DT in section 5.2; Digital Maturity and Dynamic & Digital Capabilities.

6.2 Identification of Stock, Flows & Variables

The process of transforming Vial's model [65] into a stock and flow diagram starts with identifying what elements are stocks and potentially identifying any additional stocks needed [4]. The distinction between stocks and flows requires critical thinking as an entity can be either, depending on the context [5]. The stocks we have identified in the model presented by Vial [65] are:

Use of digital technologies - the number of digital technologies currently used.
Strategic responses - the number of active strategic initiatives.
Structural changes – the number of successful changes to the organisation and its infrastructure.
Changes in value creation paths - the amount of successful business model changes.
Positive impacts – the number of positive impacts resulting from the changes in value creation paths.
Negative impacts – the number of negative impacts resulting from the changes in value creation paths.

During the process, we identified the need for two additional stocks. The first stock is Dynamic & Digital Capabilities, which represents the current state of the companies' capabilities, including but not limited to sensing, seizing and transforming capabilities, organisational agility, digital literacy and leadership. The second stock is Digital Maturity, which represents the company's current level of digital maturity. This level can be determined, measured, and tracked using the CSFs and KPIs provided in section 5.3. The additional stocks identified:

Dynamic & Digital capabilities – represents the company's current level of sensing, seizing, and transforming capabilities, agility, and overall digital literacy.
Digital maturity – the current digital maturity level of the company.

The next step is identifying the flows that add or subtract from the stocks [4]. The identified flows are:

Digital adoption – the rate at which new digital technologies are employed.
New strategic initiatives – the rate of deploying new strategic initiatives.
Completed strategic initiatives – the rate of completing strategic initiatives.
Successful organisational change – the rate of successful changes to the organisation.
Business model changes – the rate of successful changes to the value creation paths.
Desirable outcomes – the portion of changes in value creation paths that result in positive impacts.
Undesirable outcomes – the portion of changes in value creation paths that result in negative impacts.
Capabilities development – the rate of developing dynamic and digital capabilities.
Digital maturity improvement – the rate of improving the digital maturity level.

Next, we must identify the remaining variables. These auxiliary variables have two types: constants and variables representing calculations based on stock and flows [4]. The remaining variables are:

Internal pressure – the amount of internal pressure for strategic responses determined by the potential of available data and the level of negative impacts.
External pressure – the amount of external pressure for strategic responses determined by the impact of disruptions.
Organisational barriers – the amount of organisational resistance determined by adding resistance to change and inertia.
Data exploitation – the conversion rate of data into useful information.

Finally, to ensure clarity and a high-level perspective, we have represented three components of DT as sub-models. First, the building block *Disruptions* is a combination of variables measured outside the overall system. In this model, it shows the impact of disruptions on the DT process. Next, we have created the sub-model Digital literacy, which represents the number of digitally literate employees, which is the result of training and hiring employees with digital skills. Furthermore, we have added Organisational change, which is also a sub-model that contains the dynamic interrelations between the need for change, resistance, inertia and the success of change. These models can be accessed online [18].

6.3 High-level model of Digital Transformation

Using the framework provided by Vial [65] as a basis and adding the identified additional stocks, flows, variables and sub-models, we developed a high-level System Dynamic model presented in Figure 2 [26]. To allow for both qualitative and quantitative analysis, we integrated SFD and CLD into one model. Furthermore, we extended the model of Vial [65] by incorporating Digital Maturity, Dynamic & Digital Capabilities, Digital Literacy, and Organisational change. In addition to this, we add to the understanding of the model by revealing the dynamic behaviour of the complex system through cause-and-effect flows, links, and feedback loops between the various building blocks.

The first stock relates to the level of *Use of Digital Technologies;* this typically involves the adoption and implementation of new technologies, such as cloud computing, big data analytics, artificial intelligence, and the Internet of Things (IoT). As companies become more digitally focused and mature, the *Digital adoption* rate increases [47]. As a result, more and more digital technologies will be used by employees and customers. DT is a continuous change caused and affected by episodic bursts [24], or *Disruptions* [65]. The use, emergence [24] and combinations [11] of new digital technologies fuel these disruptions. Furthermore, as stand-alone digital technologies provide little value to an organisation [65], the use and combination of these new technologies within a specific context to add value increases the need for *Organisational change*.

The sub-model *Disruptions* includes various types of disruptions. First, digital technologies profoundly impact consumer behaviour and expectations [24, 65]. Communication technologies, such as social media, cause consumers to actively participate in the dialogue between organisations and stakeholders [72]. As a result, customers' expectations are increasing [24, 65]. Next to this, these digital technologies disrupt the competitive landscape. Digital technologies facilitate opportunities for new digital offerings [24, 52], lower barriers to entry, and threaten the competitive advantage of incumbent firms [8]. These disruptions are

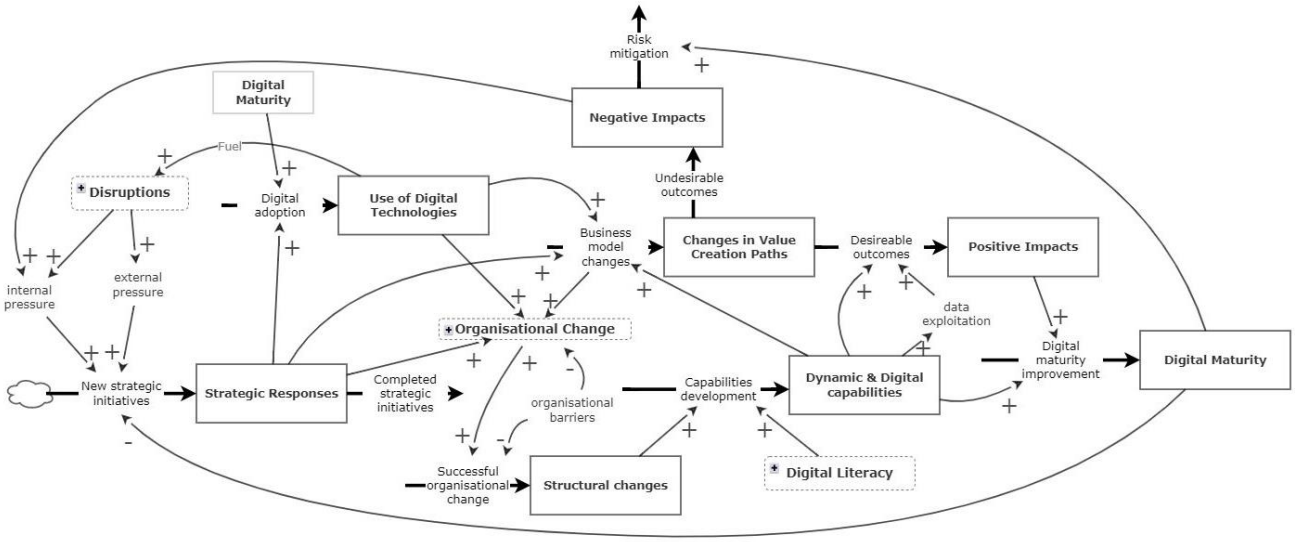

Figure 1 High-level System Dynamic model of Digital Transformation

further amplified by the increased collaboration within digital ecosystems, where platforms have completely redefined existing markets. An excellent example of this is how Apple and Spotify have redefined the music industry. Both of these disruptions increase external pressure to respond strategically. Furthermore, an increase in the availability of data does not only provide opportunities for operational improvement [68]. Digital technologies also allow for the generation of data and the exploitation of this data using analytics to improve services or monetise available data by selling them, thus creating new value opportunities [33]. Data's increased availability results in external and internal pressure to implement strategy accordingly.

The internal and external pressure variables directly influence the *New strategic initiatives* flow that determines the level of the *Strategic Responses* stock. These strategic responses can be split into two concepts in the context of DT: digital business strategy (DBS) [11] and digital transformation strategy (DTS) [1, 25, 34]. DBS refers to the need for the fusion between organisational strategy and information systems strategy rather than their alignment, as this increases the ability to leverage digital technologies to accomplish a firm's vision. As a result, DBS is an "organisational strategy formulated and executed by leveraging digital resources to create differential value" [11] (p. 472). Matt et al. [34] propose the concept of DT strategy as a "focus on the transformation of products, processes and organisational aspects owing to new technologies" [34] (p 339). DTS should provide companies with "a blueprint that supports companies in governing the transformations that arise owing to the integration of digital technologies, as well as in their operations after a transformation." [34] (p. 340). The authors argue that DTS should be separate from other strategies. Both types of strategic responses increase the need for *Organisational change*.

The success rate of *Organisational change* is reflected in the *Successful organisational change* flow, which is hindered by *organisation barriers* and directly impacts the level of *Structural changes*. Organisations are encouraged "to develop agile structures with low levels of hierarchy" [64] that promote individual creativity and innovation by creating an adaptive culture with evolvable goals [27]. Furthermore, Hanelt et al. [24] point out that this organisational change compromises a move towards agile organisational designs that are included and promoted by digital business ecosystems.

The number of *Structural Changes* influences the firm's C*apabilities development*. Next to this, the rate of capability development is affected by the overall level of *Digital Literacy*, which reflects the number of employees with digital skills, know-how and mindset. As capabilities are developed, there will be a rise in the *Dynamic & Digital Capabilities* level. This stock relates to the accumulation of essential skills and abilities. Dynamic capabilities are "the firm's ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments." [61] . On the other hand, the digital capabilities of an organisation refer to how the digital environment allows individuals to express and develop their digital skills [69]. This environment depends on a digital infrastructure that supports and promotes data-driven, digitally automated processes and decision-making [27]. To enable this, the firm must provide relevant, reliable, and available real-time data and information from a central source [66]. A higher level of *Dynamic & Digital Capabilities* directly improves the rate of successful *Business model changes*. Furthermore, it increases the rate of *Desirable outcomes* that result from these transformative initiatives directly as well as indirectly through improved *data exploitation*.

The combination of strategy and the use of digital technologies enables *Business model changes*. The business model changes are reflected in altering value propositions. To illustrate, customer expectations increasingly rely on the provision of services [6], and a shift from the sales of physical products to the sales of digital services requires the need to leverage digitised processes or systems to develop new organisational procedures and business models [10, 64]. A great example here is Netflix. Alongside the altering value propositions, changes in value networks are enabled by digital technologies. The use of digital technologies allows direct exchanges among participants of a value network; these couplings can then be reinforced to enable collaboration [49]. In addition, digital technologies can be used to change distribution and sales channels. These digital channels can be used to create new customer-facing channels through, for example, social media. Next, digital technologies allow organisations to coordinate activities across the organisation by leveraging algorithmic decision-making [33]. These

Business model changes result in *Changes in the value creation paths*. This can result in both *Desirable and Undesirable outcomes* for the organisation.

The *Desirable outcomes* of *Changes in value creation paths* generate *Positive Impacts* that result in a more agile [64] and efficient organisation that is better equipped to meet customers' needs and adapt to changing market conditions [42]. It can help organisations improve operational efficiency, drive innovation, and increase competitiveness [65]. These results can be measured and tracked using a combination of CSFs and KPIs presented in 5.2. These *Positive Impacts* directly result in a higher rate of *Digital maturity improvement*.

However, adapting, digitalising and redefining these value creation paths also generate *Undesirable outcomes* that result in *Negative Impacts*, such as increased security and privacy risks [73]. Furthermore, the reliability risks of digital systems and infrastructure increase as a more significant portion of the operation is automated and digitised [46]. Next to this, radically altering value creation paths can disrupt daily business operations, which could result in customer, employee, or partnership loss [73]. These *Negative Impacts* can be reduced by proactive *Risk mitigation* of the consequences associated with digital changes in business processes [46].

The final stock represents the level of *Digital Maturity*. Digital maturity is more than the technological interpretation reflecting the extent to which a company's IT performs tasks and handles information flows. It also represents a managerial interpretation where it reflects the status of a company's DT, describing what the company has already achieved in terms of performing transformation initiatives [12]. Digital maturity can be assessed by a Digital Maturity Model [12, 44]. In the context of the SD model provided, digital maturity is assessed at the start of the development of the model, after which it is dynamically updated based on the change of *Digital maturity improvement.* An accurate Digital Maturity Model is industry and context-specific [12, 44]. The provided CSFs and their accompanying KPIs in section 5.3 and appendix B serve as a solid basis for developing a dashboard that tracks and measures digital maturity.

As the firm improves its *Digital Maturity*, it will increase the effectiveness of digital *Risk mitigation* [46], serving as a balancing factor against *Negative Impacts*. Alongside this, improved digital maturity also relieves pressure for *New strategic initiatives* because it reduces the impact of disruptions. This is due to an improved competitive position in the market, enhanced data exploitation, and increased consumer satisfaction [73]. On the other hand, a higher level of digital maturity also raises the *Digital adoption rate* as an organisation's focus on digital scouting increases [67]. This reinforcing coupled with balancing behaviour reveals an interesting loop within DT; as an organisation becomes digitally mature, the number of *Disruptions* (and thus the resulting transformation processes) increases while simultaneously the pressure to respond reduces. So while the number of transformation initiatives grows, they become less disruptive and impactful, resulting in less need for *Organisational Change*. This allows organisations to focus efforts on optimising previous initiatives, and improving *Digital Literacy*, resulting in increased *Dynamic & Digital Capabilities* coupled with enhanced *Data exploitation* leading to both higher rates of successful *Business model changes* and *Desirable Outcomes*, ultimately leading to an improvement of *Digital Maturity*.

7. CONCLUSION

To conclude, this paper used a literature review in combination with model development to investigate the potential of a System Dynamics approach to digital transformation. We found that although current models used by academics and practitioners provide critical insights into the complexity of DT, they lack a perspective that allows for the necessary continuous modification, integration, quantification and simulation of feedback loops embedded in different components of DT. This paper demonstrates that a System Dynamics approach provides this necessary perspective. Furthermore, we extracted 17 CSFs that, apart from supporting strategy formulation, enable CDOs to set quantifiable goals allowing them to measure and monitor transformation progress.

Second, we found that System Dynamics provides both theoretical and methodological opportunities for CDOs and alike. Systems thinking provides decision-makers with a language for visualising and operationalising their mental models. Furthermore, moving from a linear, event-oriented perspective to a feedback systems thinking approach is a necessary shift of mind to eliminate silo mentalities and narrow functional perspectives. CDOs need to comprehend the intended effects of the socio-technical change and recognise any potential unintended long-term effects to adopt and reap the benefits of DT.

Third, transforming the model presented by Vial adds to the understanding of DT. Furthermore, it extends the model by adding identified concepts critical to DT measurement and success; Dynamic & Digital Capabilities and Digital Maturity. The developed high-level model supports CDOs in their understanding of the complex dynamic behaviour of DT by incorporating it into a single Stock and Flow Diagram. The SFD provides a basis for CDOs to develop their own models for qualitative and quantitative analysis. Iterative model development allows CDOs and their organisations to dynamically improve their learning processes, which proves vital for successful DT.

Overall, we can conclude that although digital transformation is researched extensively, current literature lacks a methodology that provides Chief Digital Officers with an approach needed to understand and manage the complex dynamic nature of digital transformation. The System Dynamic approach provides Chief Digital Officers with both a methodology and philosophy to improve and share their understanding of digital transformation. Furthermore, we introduced a developed model that managers can use to build their versions, aiding them in their decision-making. In the end, this paper has shown that a System Dynamics approach to digital transformation is beneficial for Chief Digital Officers.

8. LIMITATIONS AND FUTURE WORK

Although this paper provides an application of System Dynamics for digital transformation, the models presented are simplifications of a complex system and thus suffer from limitations [58]. The model has not been tested and validated using real-world cases. Researchers can validate and potentially improve the model by applying it to various case studies. Furthermore, the model contains many intangible assets that can be difficult to quantify. Future research can investigate methodologies for quantifying these assets to enable the creation of dashboards, for example, a digital maturity dashboard showing the progress of the CSFs provided.

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