Digital Twin of an Organization: Are You Serious?

Markus C. Becker[1](✉) and Brian T. Pentland[2]

[1] University of Southern Denmark, Odense, Denmark
mab@sam.sdu.dk
[2] Michigan State University, East Lansing, MI, USA
pentland@broad.msu.edu

Abstract. Digital twins are becoming established tools for physical devices and systems. Their success has raised the promise and the "grand challenge" of digital twins of organizations. To the extent that organizations include networks of interdependent processes, human agency and conflict, and learning, we argue that building valid, reliable digital twins of organizations involves substantial challenges that might require new methods and new science as compared to current models of business processes. For instance, we need a richer, more complete vocabulary to describe interdependence and regulatory mechanisms that managers can use to design and intervene in networks of interdependent processes. Models from biological sciences might provide fruitful inspiration, given that regulatory networks play important roles in biological systems. If we are serious about digital twins of organizations, we need to push the boundaries of process methods and process science.

Keywords: Digital twins · Routine dynamics · Regulatory networks

1 Introduction

A digital twin is a computational model of a system that is sufficiently valid and reliable that it can be used for design, prediction, maintenance, and other valuable use cases. The Gartner Group [1] defines a digital twin as "a software design pattern that represents a physical object with the objective of understanding the asset's state, responding to changes, improving business operations and adding value." Digital twins have been created for a wide variety of physical systems, such as buildings and automobiles. Generally speaking, artifacts with digital twins are created through a digitalized design process; the digital twin arrives before its physical sibling is born [2].

Recently, the idea of a Digital Twin of an Organization (DTO) has grabbed the imagination of scholars and practitioners in the Business Process Management community (e.g., https://www.my-invenio.com/). In many respects, the basic idea of DTO is not new. Operations management is built on the idea of using mathematical models to design and predict organizational performance (e.g., Little's Law for queueing [3]). The general idea of modeling production processes is an established practice in industrial

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engineering [4, 5] and tools for creating detailed simulations of "virtual factories" are commercially available (e.g., https://www.flexsim.com/factory-simulation/).

So, when Caporuscio et al. [6] refer to DTO as a "grand challenge," they are talking about taking this general idea to a whole new level: "representing all the elements and connections of an organizational system in virtual models, which can be perpetually simulated and analyzed to achieve continuous assessment and optimization of the organization." That is a remarkably broad vision. Our purpose in this paper is to contribute to the debate on DTOs and inform nascent efforts of developing DTOs by contributing clarifications and suggestions from an interdisciplinary perspective that, we hope, might be useful in this endeavor. For this paper, we therefore want to narrow and clarify what we mean by a *digital twin of an organization.* These ideas can be refined in many ways [7], but we focus here on four baseline criteria:

1. ***Organizations include multiple, interdependent processes.*** A single process is not an organization. For example, *order-to-cash* is always linked with *purchase-to-pay,* and each of these major processes typically consists of many specialized, interdependent sub-processes.
2. ***Organizations involve agents with the capacity to make choices, learn from experience, and pursue their own objectives.*** These agents are typically human, but not necessarily. Because agents do not necessarily have the same objectives, conflict is common [8].
3. ***A digital twin is a model that serves a purpose.*** A DTO should help with managing the organization: designing the organization, planning, decision-making on organizational policy in functional domains, etc. If the purpose is simple, the model might be simple. But even simple organizations include multiple, interdependent processes carried out by at least some human agents.
4. ***A digital twin is more than a dashboard.*** Dashboards provide visualization of how tasks are accomplished in an organization. Their contribution is to guide managerial attention to *where* intervention might be required. Dashboards provide visualization, but digital twins provide simulation and prediction [6]. DTOs can contribute not just to "continuous assessment" but also "optimization of the organization" [6] when they enable managers to predict and simulate how the organization might behave when it faces new or different situations.

It should be clear from these criteria that creating a DTO will extend the current state-of-the-art in process mining and modeling. Without question, great strides have been made in making processes visible and providing support for managing and improving processes. A key part of that success has been the ability to "open the black box" to reveal the structures and mechanisms that connect inputs to outputs. Technical innovations, such as neural network models [9, 10], object-centric approaches [11], and mining of simulations [12, 13] are constantly improving the state-of-the-art. Perhaps because of this on-going progress, the DTO idea has entered the conversation.

Our position is that a valid, reliable DTO is not a realistic goal unless we can offer convincing solutions to key issues concerning what are relevant key features of organizations and how to model them. If we are serious about digital twins of organizations, we need to push the boundaries. New methods and new science may be required. Towards this end, we raise four key questions:

1. ***What makes DTO so challenging?*** At a minimum, novel challenges in building digital twins of *organizations* arise from (a) the inclusion of human agents and (b) the inclusion of multiple interdependent processes. To highlight the challenges in creating a DTO, we draw on a recently published example from the literature on routine dynamics [14].
2. ***In light of these challenges, what kinds of models best reflect the true fabric of organization?*** While finite state machines (e.g., Petri nets) are a reasonable way to model deterministic business processes, modelling an "organizational system" is a bigger challenge. It may be useful to take inspiration from biological systems that are modelled as networks of interdependent regulatory processes that give rise to emergent, adaptive behavior.
3. ***How can DTO help managers design effective interventions?*** We envision the main use case for DTO to be helping managers understand *how* to intervene to solve organizational problems, design organizational structures, policies, and incentives. This might involve understanding emergent phenomena.
4. ***How can we evaluate a DTO?*** To the extent that managers need to address problems that extend beyond prior experience (e.g. how to integrate a novel technology?), fitting a model to historical data does not seem adequate. A DTO needs to be built and evaluated with respect to generalizable theory.

2 What Makes DTO so Challenging?

Scaling from simple physical systems to complex social systems involves moving along at least two dimensions: from physical to social and from simple to complex, as shown in Fig. 1. We can define each dimension separately, but in real systems, they interact.

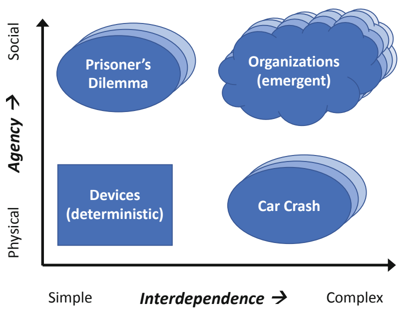

Fig. 1. Scaling from simple physical to complex social systems

The move from physical systems to social systems involves adding *agency*, which we can define simply as the ability to act otherwise [15]. Agency involves the capacity to reflect on the past and anticipate the future [16]. Agency is important even in very simple social systems. For example, in a classic prisoner's dilemma, there are two participants with two choices: to cooperate or defect [17]. This choice is not predetermined or mechanistic. Agents can behave strategically in their own interest so there is always the possibility of conflict [18].

The move from simple to complex involves adding interdependent sub-systems. Interdependence takes many forms, so a succinct definition remains elusive [19]. Basically, interdependence adds complexity. For example, Leonardi [20] studied the use of digital twins to model car crashes. Since modern vehicles are digitally designed to begin with, crash testing virtual cars is much cheaper and faster than crash testing real cars. Each part is relatively simple, but the safety of the vehicle depends on the ensemble of parts and their interconnections and interactions, which are extremely complex.

Now, imagine simulating a car crash where some of the individual parts have agency, learn from experience, and can choose how they will react to sudden deceleration. The analogy to organizations is imperfect, but instructive. The combination of agency, interdependence and learning adds to the challenge of creating valid, reliable models that can help managers to make design and policy decisions. If we take the DTO idea seriously, we see at least four major issues that need to be confronted: discovery, interdependence, agency and learning. The first is methodological, the others substantial.

2.1 Discovering the True Fabric of Organizing

While physical objects may be created through a digitalized design process, organizations generally are not. That means the digital twin has to be *discovered* from observation of an organization that is up-and-running. This has been the core challenge of process mining since its inception. van der Aalst [21] argues that process mining allows us to recognize what he calls the "true fabric of business processes." In that article, he is particularly concerned about modeling concurrency:

> Business processes tend to be highly concurrent and non-monolithic. ... The empirical nature of process mining helps managers, consultants, and process analysts to better understand the "fabric of real business processes" and, thus, also see the limitations of conventional process modeling languages. The challenge is to link elegant succinct formal models like Petri nets to behavior actually observed in reality [21: 690].

It is worth remembering that with the current state of the art in process mining, linking observed data to a specific Petri net can be challenging. Different ways of filtering an event log result in different Petri nets [22]. Applying different mining algorithms to the same event log generally results in different Petri nets [23]. Even for single, mechanistic processes, the "true fabric" remains elusive.

As we move beyond single, mechanistic processes, we expect the problem of discovery to become more difficult. Organizational systems that include humans have latent structures that are difficult to observe (e.g., truces, cultural assumptions and values). A classic problem in social science is that these structures go undetected until they are breached [24]. In other words, there are likely to be unobserved boundary conditions on a DTO that can only be discovered by trial and error, when the model fails.

2.2 Networks of Interdependent Processes

Processes in organizations are often concurrent, but they are also *interdependent* [17, 25]. The fabric of organizing is laced with interdependence. It is like the air: it surrounds everything, but it is hard to see. Within a process, various kinds of task interdependence (pooled, sequential, reciprocal) are common [26]. Across an organization, there is also role, reward, goal, knowledge and epistemic interdependence [17, 27]. For example, the reward (incentive) for one activity may depend on when, where or how another (physically and temporally remote) activity is performed. Like other latent structures, these forms of interdependence may be difficult to observe.

Unfortunately, interdependence between networks of processes is not well understood [28, 29]. Sometimes, there are clusters of interdependent routines with well-defined interfaces [28]. Other times, there are networks of interdependent processes that shape other processes, as described by [30]. The key point is that networks of interdependent processes can generate emergent behavior [31]. By emergent, we mean that the "existence and nature" of the behavior "depend upon entities at a lower level, but the behavior is neither reducible to, nor predictable from, properties of entities found at the lower level" [32: 103].

Interdependence of processes is, therefore, key to modeling the true fabric of organizing. Networks of interdependent processes appear to be important drivers of emergent behavior but modeling them is an area where new method and science seems to be needed [29].

2.3 Modeling Systems with Agency

In their analysis of digital twin technology, Gartner Group [1] refers to "physical object[s]." Yet the phrase *digital twin of an organization* implies aspirations that extend beyond physical objects. Business processes often include human agents. Rather than a digital twin of a car, a DTO would be a digital twin of the car *and its driver*.

We use the term "agent" rather than "actor" to signal that humans have *agency* [16]. Humans have "the ability to remember the past, imagine the future, and respond to present circumstances" [32: 100]. For instance, they can act on their intentions concerning future outcomes, their interpretations of the context, themselves, and others, incentives provided by the context, and their orientation towards past, present or future [16, 33–35]. Each of these mechanisms adds texture to the true fabric of organization.

Agency introduces the need for monitoring and control, which is a central issue in organizational design [7, 36]. The classic "principal-agent" problem in contracting and organizational design stems from the fact that agents can choose their own course of action to serve their own interests. Agency introduces a new challenge to modeling organizations because we cannot assume that all the "parts" are working towards the same goal [37]. There is always the possibility of conflict.

2.4 Modeling Systems with Learning

If a digital twin of an organization was possible today, it would most likely be invalid tomorrow. This is because organizations are open systems that change over time in response to their environment and the particular interests and capabilities of internal and external stakeholders [25, 27, 38]. Organizations undergo an on-going process of emergence [39]. Routines can change through mere repetition [32]. Further, the people in organizations learn from experience and from each other; they change roles; they enter and exit the organization [40–42]. And with learning, there is always forgetting [43]. These learning processes pose an on-going threat to the validity and reliability of a digital twin for purposes of prediction.

Together, these issues (discovery, interdependence, agency and conflict, and learning) underscore the enormous challenge involved in scaling from simple physical objects to complex organizations. In the next section, we describe an example that will help make these issues more concrete.

3 Example: An Agile Software Development Organization

Goh and Pentland [14] use a routine dynamics perspective to describe an organization that develops videogames using SCRUM, an agile development methodology. Goh and Pentland [14] wanted to explain changes in the complexity of the patterns of action enacted by game developers as the project progressed from sprint to sprint. This example could be regarded as an outlier because project work is likely to be less structured and less mechanistic than production work [44]. Nevertheless, it serves to make some useful points.

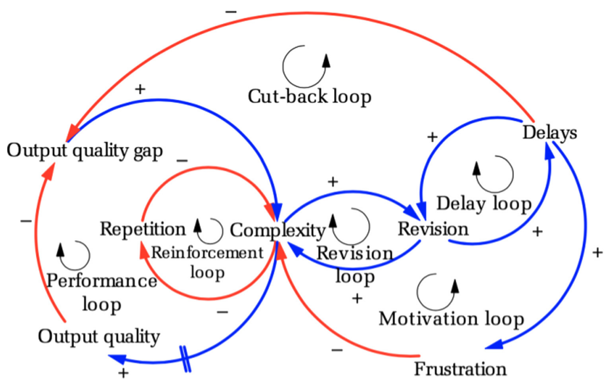

Fig. 2. Interdependent processes in a game development project

Figure 2 shows a causal diagram that includes a set of interdependent processes that influenced patterns of action in game development. This diagram is a qualitative description derived from participant observation and interviews with the game developers. The figure contains the following six causal loops:

- ***Reinforcement.*** Through repetition, the pattern of action becomes simpler and better defined.

- ***Output quality gaps.*** Dealing with quality problems increases the complexity in the pattern of actions.
- ***Revisions.*** Dealing with revisions increases the complexity in the pattern of actions.
- ***Delays.*** Revisions lead to delays, which lead to more revisions and frustration among the developers. Delays also lead to cutbacks.
- ***Motivation.*** When developers get more frustrated, they tend to revert to established work patterns.
- ***Cutbacks.*** Reducing the scope of the project helps reduce quality problems.

There are some key points to glean from this example. First, these processes are highly interdependent and not easily decomposable: delays, revisions, frustration, cutbacks and quality problems form a Gordian Knot that cannot be unraveled. To understand how they generated the behavior of the organization, they need to be considered together. This exemplifies the idea of a 'network of regulatory mechanisms', as described below. Second, these processes are quite generic. Schedule, scope, budget and quality are classic dimensions of any project. It is not surprising that they showed up in this project. Third, it shows that the human element is inextricably bound up in the process network. Frustration and motivation reflect the individual interpretations and emotions of the game developers. Fourth, it shows that exogenous contextual factors (such as scope and schedule) can directly influence the internal dynamics of the process network.

Finally, there is one key point is that not shown directly in Fig. 2 but is essential to its significance: this complex web of interacting processes had a dramatic influence on the execution of the game development work itself. From sprint to sprint, the way the developers worked (as captured in the event log based on their SCRUM sheets) was different. Of course, the extent of contextual influence on a particular process is an empirical question. But in a network of interdependent processes, each process creates context for the others [30]. This dynamic web of interdependence, colored by human agency and learning, is what gives rise to the true fabric of organizing.

4 Models of Organizations: Beyond Organizations as Mechanisms

What kinds of models are best suited to address these challenges and align the focus on the key elements described above (discovery, dynamic web of interdependence, agency and learning) and their implications for valid and reliable DTOs? To address this question, it is useful to consider the overall perspective taken in tackling the challenge of developing DTOs. While we need to avoid overly simplistic metaphors, organizations as *mechanisms* or as *organisms* are two common ways of thinking about organizations [38, 45]. Because the concept of a digital twin emerged from the realm of physical systems, it is natural to think in terms of organizations as mechanisms. This metaphor is consistent with the practice of modeling business processes as finite state machines (e.g., Petri nets). However, as we scale from modeling one or a small number of business processes to modeling larger organizational systems, this way of conceiving of organizations might become less suitable and productive.

Latching onto the challenges identified above, we note that it may be fruitful to take inspiration from how the biological sciences model complex systems. From epigenetics to ecologies, recent theorizing highlights networks of interdependent regulatory processes that give rise to emergent, adaptive systems [46, 47]. These may offer a potentially useful way to think of the dynamic web of interdependence that characterizes complex social organizations.

4.1 Networks of Regulatory Mechanisms

In scaling from simple to complex systems, networks of interdependent processes must play a central role. As mentioned above, process models are often limited to task interdependence (sequential flow). Other kinds of interdependence (e.g., involving rewards and incentives) may be equally consequential in an organizational system. For example, the interdependence between scope, schedule, budget and quality involves the rewards and incentives of various stakeholders, as well as physical constraints. For a valid and reliable digital twin of an organization, it seems important to recognize a more complete range of types of relations and interdependence. We need to understand what drives – and regulates – the dynamics of networks of interdependent processes. If these dynamics are emergent, DTOs need to capture the drivers of those emergent dynamics.

The causal loops in Fig. 2 are reminiscent of the regulatory pathways that are used to model emergent dynamics in the biological sciences, from epigenetics to ecological systems. While the connection is just metaphorical at this time, we expect that it could lead to theoretical and practical insights.

First, by highlighting networks of regulatory pathways as a focus for theory on process interdependence, the connection points to possible means of managerial intervention. In pharmacology, the search for therapeutic drugs is often guided by efforts to reinforce (or disrupt) regulatory pathways [48]. The theory helps guide the practice. Second, it points to a toolbox of analytical and modeling techniques with a track record of application to networks of regulatory pathways and emergent phenomena. We therefore propose regulatory networks as a focus for efforts of developing digital twins that also address social issues and ultimately, digital twins of organizations.

4.2 Discovering Regulatory Networks

As mentioned, one challenge in developing DTO is that the digital twin has to be discovered from observation of an ongoing operation. Given a running organization, it is not clear how accurately the regulatory networks can be recovered through process mining. Process mining for system dynamics [12], for instance, is in its infancy.

Rather than modeling these regulatory mechanisms from a dynamic systems perspective (as systems of differential equations), it may be helpful to think in terms of enabling and constraining relations. Towards that end, declarative mining [49, 50] might be a fruitful way to discover regulatory process networks. In a declarative model, the process is represented as a set of constraints and can be executed in all possible ways as long as these constraints are respected [51: 9238].

The issue is not whether declarative (vs. imperative) notation is better or more expressive. The issue is how to discover dependencies between processes that might not otherwise be apparent (e.g., patterns of behavior that reflect cultural norms). These dependencies may regulate patterns of action in the organization. To design effective interventions, managers may need models that embody a richer, more complete set of relations and regulatory mechanisms.

5 Evaluating a DTO

Fitting a model to observed behavior is a good first step, but the challenge of creating a useful DTO goes beyond linking "succinct formal models like Petri nets to behavior actually observed in reality" [21: 690]. To support managerial intervention, design and policy making, a DTO may need to simulate or predict behavior that has *not yet been observed*. For that reason, the DTO needs to incorporate a theoretical understanding of the underlying phenomena that generalizes beyond a particular set of historical observations.

For physical applications, like automotive crash testing, good theoretical foundations are available. Using finite-element representations for each part of a vehicle, along with knowledge of material properties and physics, engineers can simulate virtual crashes that have never occurred in reality [19].

Unfortunately, for organizational systems, the theoretical foundations are not as well understood and not as deterministic. We can discover models using state-of-the-art techniques, but we can only evaluate them against observed data. That may be sufficient for day-to-day adjustments, but for novel problems, it may not. We need to advance the science, not just the method.

6 Conclusion: A Challenge Worth Pursuing

Without question, a valid, reliable digital twin of a human organization is a challenging goal. Organizations are not deterministic mechanisms; they are woven from interdependence, agency and learning. They contain latent structures that are difficult to observe. While challenging, the goal is worth pursuing for at least two main reasons, one practical and one theoretical.

6.1 A Platform for Designing Interventions for Managers

The practical motivation for DTO is to help managers design effective interventions to solve organizational problems. Given that complex systems are difficult to comprehend for human actors, a DTO would be particularly valuable for managers who are boundedly rational and organizations that are highly complex [52]. Similarly, a DTO would be useful for boundedly rational organization designers [27] in their efforts to create an organization such that it has desired performance features, e.g., provides coordination where needed or handle cooperation problems [53]. For instance, it would enable prototyping and "crash testing" new organizational designs *in silico* [27]. If the costs of trial-and-error experimentation with different organization designs is high, or if the consequences of complex organization designs are difficult to anticipate without a model or simulation, then a DTO would be a particularly attractive tool.

To fulfil these roles, the DTO needs to provide valid, reliable predictions of what would happen if something in the organization were changed. By focusing on business processes, the DTO would already be focused centrally on what generates performance – if nothing happens in the organization, no performance is generated. The ability to model the mechanisms that regulate the system of interdependent processes seems to be central to providing such valid, reliable predictions. If valid and reliable regulatory networks can be discovered, it would thus be a valuable tool for management, offering the possibility to simulate how to tune the organization as a complex system. Thereby, it would help address questions such as how to intervene to increase an organization's performance, but also how to make changes 'stick'. Even intermediate, more limited models than the full digital twin envisioned by Caporuscio et al. [6] would therefore be of great use in practice, such as digital twins that also address social interaction and its consequences.

6.2 A Vehicle for Advancing Science

Research in process management and routine dynamics would benefit greatly from the conversations around DTO as a grand challenge. If our analysis of the challenge is even partly correct, then DTO provides an arena where research on routine dynamics can inform process management and vice versa. Currently, these research communities are quite separate [54]. The endeavor and practice of building DTO would provide a motivation for collaboration. It would provide opportunities to build the science, and may provide an excellent vehicle for discussion, controversy, and learning about questions such as limitations and the appropriate granularity, abstraction, and timescales. We expect that this might be a case of practice leading science, as the necessary data and experimentation would need to be grounded in practical managerial concerns. If we are serious about DTO, engaging in this dialogue seems a fruitful way forward.

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