The unified perspective of digital transformation and continuous software engineering

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ABSTRACT

Software is a key component of most products, services, industrial processes, and back-office functions. Thus, companies may gain an advantage by establishing fast feedback cycles to improve their software.

Continuous software engineering (CI/CD) is being primarily studied as an engineering topic. However, the rest of the organization needs to align and be prepared to utilize the benefits of CI/CD.

In this paper, we explore the overlap between CI/CD and digital transformation (DT). We study literature in both areas to develop a map of conditions, mechanisms, and outcomes. As a result, we present a unified perspective of CI/CD and DT.

We found that CI/CD can be seen as an implementation of DT in a software organization. DT perspective can help to guide the adoption of CI/CD from an organizational perspective.

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1 INTRODUCTION

Software is a key component of most products, services, industrial processes, and back-office functions. The capability to rapidly and continuously improve software is essential to respond to changing customer needs and market conditions. Rapid and incremental adjustments in software allow fine-tuning the product and using data-driven approaches to steer further product decisions. Such an approach is known as continuous software engineering (CI/CD) [15, 28].

Our earlier work identifies that the adoption of CI/CD starts within the engineering part of the organization and expands from there. However, the adoption of CI/CD is often treated and limited to an "engineering problem". Organizations hesitate to consider broader changes to their ways of working to fully benefit from CI/CD [32].

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The hesitation to change can be explained by a lack of understanding of the potential benefits of CI/CD beyond engineering and interdependency to digital transformation (DT). To implement and maximize benefits from frequent delivery of incremental features, the organization needs to adjust their value proposition, relationships with customers, and the overall technology strategy. Although, these activities are mainly outside the realm of engineering, they are critical to realize benefits of the CI/CD. For instance, investments in faster release cycles are worthwile only if the the rest of the organzation is aligned and can support the increased pace [28, 32].

Digital transformation aims to leverage technology to improve the overall organizational performance, CI/CD focus on improving software delivery. However, as shown in our earlier research, the scale of improvements in software delivery often depends on the organizational ability to realize them [32].

Software is as major differentiator and value carrier in nearly every industry. Thus, it is prudent to treat software engineering (SE) as the central activity and tweak other organizational functions to maximize the value from software, its application, and delivery process [20].

In this paper we use the term CI/CD to refer to all continuous software engineering activities, including but not limited, to development, integration, verification, delivery, use, collection of feedback, data analysis, and planning [15, 32].

State-of-the-art primarily focus on *how* to implement CI/CD. The literature discusses adoption steps and practices, such as pipeline tooling and automation. The benefits of automating development tasks are well documented and accepted within the industry [47]. A few papers explore the adoption challenges. Authors point out that the organizational change is the most significant challenge. Yet, the discussion of why an organization as a whole should change is limited [6, 15].

Management and organizational studies discusses the potential of digital transformation, leveraging technology, such as software, data analytics, artificial intelligence (AI), to increase the flexibility and performance of an organization and its offerings. Some authors compare the impact and potential of DT to the industrial revolution in the late nineteen century [20, 23, 52].

Looking at both organizational and SE literature, the overlap between CI/CD and DT becomes evident. Adoption of CI/CD can be seen an implementation of DT in a software organization. Such an overlap presents an opportunity to use DT literature to justify the organizational change required to fully realize benefits of CI/CD, and use engineering literature to guide the implementation of CI/CD.

In this paper, we explore the mapping between CI/CD and DT. This mapping aims to support the adoption of CI/CD in industry by connecting organizational and SE perspectives. We highlight conditions leading to a decision to invest in adopting CI/CD, and the business impact from the adoption.

The rest of this paper is structured as follows, Section 2 presents background and related work, Section 3 states research questions and outlines the research approach, Section 4 presents the results, Section 5 discusses the findings and answers the research questions, Section 5 concludes the paper and formulates avenues for further work.

2 BACKGROUND AND RELATED WORK

2.1 Agile, Lean and Continuous Software Engineering

Agile SE emphasizes delivering working software over extensive upfront planning and documentation [17]. Agile principles have inspired a large number of agile SE practices [29, 35, 48]. Most importantly, agile practices aim to deliver value in small increments, facilitate collaboration and anticipate changes in customer needs and the environment [3, 26].

Lean SE is an adaptation of lean principles in the software domain [40]. Lean and agile principles are often applied in connection [2, 43]. Both lean and agile emphasize rapidly delivering customer value while minimizing activities that do not provide value, i.e. waste.

CI/CD is a paradigm to deliver new software features to end-users in small increments and as rapidly as possible. The speed is achieved by combining lean and agile principles with extensive automation, removal of organizational silos, and streamlining the software delivery pipeline [6].

In CI/CD, software travels through a series of interconnected and largely automated steps to develop, build test, integrate, and deliver the latest software changes to end-users with minimal delay. After delivery, end-users use the software and generate telemetry that is relayed back to the software vendor to steer further product development. Automation is used extensively to ensure speed and scalability of the software delivery pipeline [28].

2.2 Digital transformation

Digital transformation is a process of adopting technology to radically improve organizational performance [52]. The technology can be leveraged to support manufacturing, sales, logistics, and after sales of pure physical products without software components [30]. The technology can also be embedded into the product itself, enhancing its value [22]. DT increases the flexibility of the organization to better respond to dynamic market trends and changing customer needs [23, 52].

In the literature, DT is discussed in a variety of contexts [7, 21, 24, 33, 53]. Giebhart et al. [18] discusses the challenges and approaches to DT in software organizations. Many scholars and businesses deem DT to be one of today's most relevant technological phenomena. DT involves the use of technologies to redefine an organization's value proposition, as well as a transformation of the organization's identity. In contrast, SE enabled organizational transformation activities are designed to enhance an existing organizational identity while supporting the value proposition [55].

The software embedded in products and tied to organizational processes can collect data along the way informing further organizational and product decisions [49]. Importantly, the data can be used to a) improve the offering, i.e. what to features and qualities to add or remove, b) to improve the engineering process, i.e. how to build, and c) to tweak the delivery process, i.e. how to deliver to maximize value of the offering.

3 RESEARCH APPROACH

In this paper we explore the mapping between CI/CD and DT. We aim to identify overlaps and gaps between the two to create a joint road-map for further studies in the area.

We set forth the following research questions:
RQ1: What are the building blocks of CI/CD?
RQ2: What are the building blocks of DT?
RQ3: What is the overlap between DT and CI/CD?

3.1 Research methodology

In our research methodology we follow a number of steps: a) identification of sources, b) extraction of building blocks, c) analysis and identification of the overlap. We continue by detailing each step.

Identification of sources. To answer the research questions we analyze state-of-the-art of both CI/CD and DT. To cover engineering perspective, we start with a recent literature review [47], research roadmap [15], and our recent work analyzing two industrial cases [32]. To cover DT perspective, we look at two systematic reviews [23, 52], and an industrial case study [8]. The initial source were selected by both authors jointly.

Extraction of building blocks. We analyze the sources to extract the building blocks for both CI/CD and DT. We start by extracting heading-level information, then look for references in the secondary sources and perform additional searches using Google Scholar to describe each block.

Analysis and identification of the overlap. Both authors analyze and compare descriptions of the building blocks to identify both CI/CD and the DT perspectives. With the analysis we determine if the block is primarily DT or CI/CD concept, or is equally well represented from both perspectives. The overlap analysis was performed jointly by both authors, i.e. by looking for additional supporting literature, and considering different viewpoints.

4 RESULTS

We structure our results following the model proposed by Hanelt et al. [23] and differentiate between *conditions* leading to DT and adoption of continuous engineering practices, *mechanisms* and practices implementing the transformation, and *outcomes* from the transformation and adoption of continuous engineering practices.

We summarize the results in Fig. 1. In the figure, we differentiate between conditions, mechanisms, and outcomes. We separate concerns that are caused by or affect only the organization itself (internal), and concerns that primarily originate or have effects externally (external). We further separate strategic and operational

concerns. Strategic concerns pertain identification and planning of long-term aims. Operational concerns realize said aims.

4.1 The Conditions

The DT literature points out that external market pressures such as growing customer expectations, availability of technology, and competitor moves push organizations to develop and follow an DT strategy [23, 52].

From an engineering perspective, the growing product size and complexity in combination with demands for faster time-to-market pushes engineers to adopt efficient approaches to engineering. For instance, to automate repetitive tasks and streamline software delivery [32, 47].

Table 1 summarizes the conditions from CI/CD and DT perspectives. Evidently, the CI/CD perspective takes an engineering and problem solving approach. That is, how to solve a problem. However, the DT attempts to maximize benefits from new market opportunities.

4.2 The Mechanisms

State-of-the-art in CI/CD identifies tearing down organizational boundaries, implementing automation, and streamlining software delivery pipelines as the tools to achieve higher efficiency. Removing silos, changing organizational culture and structure are identified as the most challenging obstacles to adopting CI/CD [6, 28]. Similar terms are used in management and organizational studies to refer to required organizational changes, albeit in more general way.

Hanelt et al. [23] discusses creating digital innovation, exploring digital capabilities, increasing technological flexibility and unlocking the organizations as means to implement DT. Vial [52] discuss organizational, structural and cultural changes happening to overcome organizational resistance to change.

An important link between engineering and organizational perspectives is resources planning. Traditionally, organizations create yearly or quarterly resources plans, e.g. budgets, staffing plan, infrastructure development roadmap. Such plans then guide engineering and product development work. However, such long planning periods may also limit the organizational flexibility to exploit a new and short-lived market opportunities [15].

We have moved some items, such as 2.3 Technology-driven management and 2.7. Automated, data-driven processes, from *Outcomes* to *Mechanisms*. Our rationale is that process automation and management focus deliver little value on its own. They are tools enabling the organization to attain more relevant outcomes.

Process automation is discussed as one of the key elements in DT. Process automation is aimed to remove the need for operator intervention for menial and repetitive tasks, see Block 2.7. However, the discussion is general and does not provide further details. Literature on CI/CD points out that automating repetitive engineering tasks can improve efficiency and quality of the software development. Furthermore, automating the software delivery pipeline is critical for continuous value delivery, see Block 2.13. It appears that both process automation from DT perspective and CI/CD aim to achieve the same objectives. Nevertheless, we discuss them separately to differentiate between general process automation and specifically automating the software delivery pipeline.

4.3 The Outcomes

Both organizational and engineering literature list somewhat similar outcomes from DT and adoption of CI/CD, see Fig. 1. However, the highlights are different.

Engineering literature highlights the increased internal efficiency, access to data for decision support, and fast feedback loops contributing to fine-tuning of current offerings.

Management literature identifies the potential of new value propositions and business models. The new value propositions are enabled by organizational speed and flexibility stemming from technology adoption and putting digital technology in the center.

Both engineering and management literature emphasizes the shift from transactional business models to more service and experience based models.

Interestingly, management and organizational literature identifies several adverse outcomes from digital adoption. Namely, the collection and use of data raises security, privacy, and ethical issues. Specifically, data from one stakeholder can be used to create value for another. Such practices requires transparency and buy-in from all stakeholders, especially less-protected groups, e.g. ill-informed end-users [38].

5 DISCUSSION

Looking at the results in Fig. 1, the overlap between DT and CI/CD is evident. Organizational literature emphasizes aspects such as market, strategy development, and opportunities enabled by the DT. Engineering literature emphasizes specific practices of implementing digital strategies and focuses on improved efficiency.

The unified perspective is important. It shows that *the adoption of CI/CD is the implementation of DT in a software organization.*

The unified perspective informs organizational stakeholders about the potential of CI/CD using familiar terms. It also highlights the role of engineering in realizing this potential. For engineering stakeholders, the unified perspective connects engineering concerns to higher organizational objectives helping to communicate the benefits of CI/CD to stakeholders from other domains.

For researchers, the unified perspective connects business and engineering research areas enabling cross-disciplinary studies. Such studies are important to better align software business and engineering to realize the full potential of software intensive products and services.

5.1 RQ1: What are the building blocks of continuous software engineering?

The need for CI/CD is motivated by internal considerations to become faster and more efficient in delivering software. The speed and efficiency is required to keep up with requirements of faster time-to-market for new features, see Block 1.5 in Fig. 1. The increase in efficiency is also needed to minimize adverse effects of manually synchronizing and coordinating many engineering teams working on a complex product, see Block 1.1.

The implementation of CI/CD practices start with automating tedious and repetitive engineering tasks, such as regression tests,

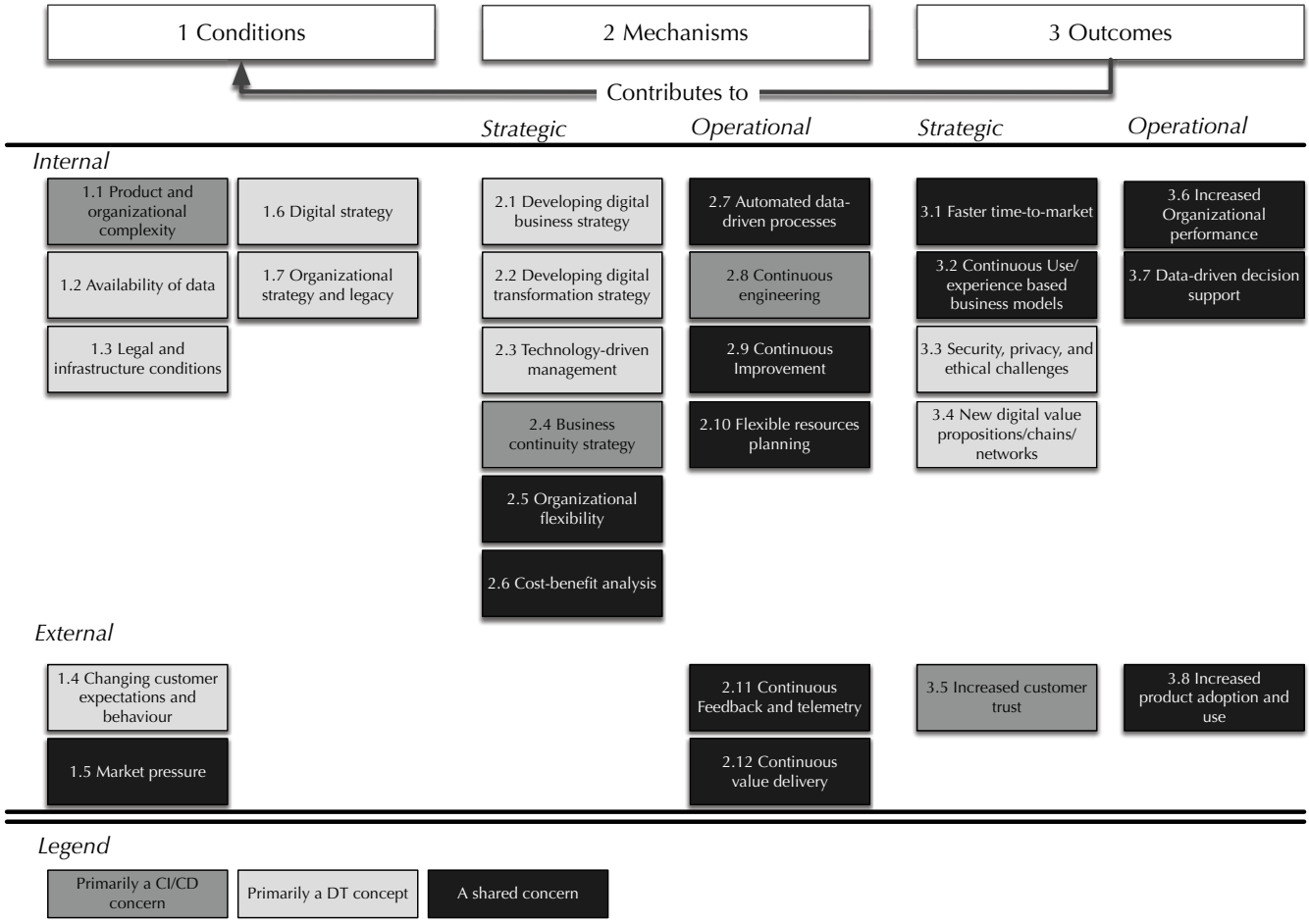

Figure 1: The unified view of digital transformation and continuous software engineering concerns.

setting up staging environments, and building software. The automation can be extended to customer environments by automatically delivering the latest changes to end users once developers have completed them. In an idealized scenario, the software development is largely automated and requires few manual steps, see Blocks 2.7-2.12. Such a scenario requires the use of adaptive technologies to achieve advanced automation (the automation of non-trivial, less repetitive tasks).

Product engineering use generates data, customer feedback and telemetry that is automatically relayed back to the vendor for analysis and decision support. Importantly, this data can be used both to support product decisions (*What to build?*) and to improve the software delivery process (*How to build?*), see Block 2.8.

The use of automation in SE leads to increased performance and flexibility, see Blocks 2.5 and 3.6. These qualities allow the organization to be among the first to respond to new market opportunities. Importantly, the speed and flexibility increase the organization's risk tolerance. When it easy to launch a new experimental feature to the end-users, it is equally easy to recover from an unsuccessful update. Frequent deliveries of value and fast feedback cycles help to establish collaborative relationships with customers and involve them in product development, see Block 3.5. In combination, these factors provide software organizations more freedom to experiment and discover new opportunities, see Block 3.4.

When retrofitting an organization with CI/CD, it is important to ensure continuity of services, see Block 2.4. Adoption of CI/CD can be disruptive, e.g. old software delivery mechanisms are replaced with new and more efficient mechanisms. However, not all customers may be ready to accept it. Existing service agreements may be difficult to renegotiate limiting the options for change. Supporting customers, business models, and implementations throughout the change until all customers are upgraded is an important concern.

5.2 RQ2: What are the building blocks of digital transformation?

DT is primarily driven by external market pressures and customer expectations pushing organizations to become better at delivering cutting-edge products and services, see Blocks 1.4-1.5. The pressure stems from the overall digitization of modern world, availability of data, see Block 1.2, and prevalence of digital products and services.

Table 1: The mapping of conditions leading to adoption of CI/CD and digital transformation

#	Condition	DT perspective	CI/CD perspective
1.1	Increasing product and organizational complexity	Physical and digital blend together creating opportunities for smart products and services [11, 57]	Software products grow in size and complexity requiring new methods of engineering and more complex development organizations [15, 28]
1.2	Availability of data	Digital products leave traces of data at every step of their life-cycle. Such data can be monetized and used to create business value [52].	Data-driven approaches can support product engineering to develop more relevant products and services [42]
1.3	Legal and infrastructure conditions	New infrastructure and regulatory frameworks enable new forms of value creation [9]	Certain regulated domains are less suited for end-to-end CI/CD [32]
1.4	Customer behavior and expectations	With the widespread adoption of media technologies, customers are becoming more vocal stakeholders [56]	Customers expect frequent deliveries of new cutting-edge features and qualities tailored to their needs [28].
1.5	Market pressure	DT disrupts whole markets and forces other players to step up or perish [36]	To remain relevant in the market software companies need a rapid pace of innovation [15, 28]
1.6	Digital strategy	Organizations wish to increase the value of their offerings by leveraging software [31, 34]	Continuous software value delivery as the business strategy [28]
1.7	Organizational strategy and legacy	DT offers game changing opportunities and existential threats to organizations [46]	Organizational inertia is a major challenge in adopting CI/CD [6, 32]

Customers expect frequent deliveries of exciting features tailored to their needs. Improving infrastructure and new regulations enable organizations to revise their strategy and search for new forms of value, see Block 1.3.

Literature highlights strategic activities to plan the implementation of DT, see Blocks 2.1-2.2 in Fig. 1. Importantly, these strategic initiatives are enabled and supported by technology-driven management (Block 2.3) with a vision to leverage technology. On the operational level, DT implements process harmonization and automation, see Blocks 2.7-2.12.

The adoption of DT leads to new strategic advantages, see Blocks 3.1-3.4 in Fig. 1. Efficiency, flexibility and fast feedback-cycles allow organizations to implement experience based business models and rapidly capture new market opportunities. Digitization of an organization enables new value chains and forms of value propositions.

The literature identifies a number of concerns stemming from digitization, such as ethics, data privacy and security. New digital business models are often asymmetrical and involve leveraging data from one stakeholder to deliver value to another. In these scenarios, concerns fair use of data become central (Block 3.3).

5.3 RQ3: What is the overlap between digital transformation and continuous software engineering?

DT and CI/CD are triggered by similar conditions, uses similar mechanisms, and aim to achieve similar outcomes. The main difference is that DT is presented from the organizational perspective and is agnostic to a specific domain or industry. However, CI/CD is presented from an engineering perspective specific to the software industry.

A common driver to CI/CD and DT is the market pressure forcing organizations to evolve, see Block 1.5 in Fig. 1. We observe that there could be relationships between building blocks presented in the Fig. 1. For example, changing customer behavior (Block 1.4) can be seen as a specific market pressure (Block 1.5). Similarly, organizations may revise their strategy (Block 1.7) as a response to increasing product size and complexity (Block 1.1). Such relationships hint to an even broader overlap between the DT and CI/CD.

The essence of CI/CD are to remove bottlenecks and achieve uninterrupted flow of value supported by automation. DT aims to achieve process automation. However, engineering details out specific processes, see Blocks 2.7-2.12, that are relevant to organizations developing software-intensive products and services.

Both DT and CI/CD list increased internal efficiency and market performance as the key outcomes. We argue that here as well, some relationships between the concepts are likely. For instance, data-driven decision support (Block 3.7) is not a goal in its own. Rather it is an essential factor to achieve increased performance (Block 3.6). Similarly, experience based business models (Block 3.2) are enabled by faster feedback cycles (Block 3.1).

We observe that the combined outcomes of DT and CI/CD contributes to the conditions driving the transformation creating a self-feeding loop, see the top part of Fig 1. The increased speed of delivering cutting-edge products and services contributes to market pressures and shift customer expectations towards even more advanced products. Similarly, the ability to deliver even larger and more complex products contributes to increasing the product complexity, thus pushing organizations to find even more efficient approaches to engineering.

We believe that future research should also focus on AI transformation (AIT). In our view, AIT should be treated differently than DT or CI/CD. We can see that recent developments in AI as well as specialized hardware have enabled implementation of AI software solutions across a wide variety of domains and applications. In contrast to other technologies studied within DT, AI will

Table 2: Mapping of mechanisms of adopting of CI/CD and performing digital transformation

#	Mechanism	DT perspective	CI/CD perspective
2.1	Development of digital business strategy	Software, its development and capabilities become central to the business model [4]	Software enables new business models [10]
2.2	Development of digital transformation strategy	Identification the links between digital technologies, business strategy and the organizational capabilities [37]	Cost-benefit analysis guide the adoption of specific practices [32]
2.3	Technology driven management	General Business Management: applying various technologies to develop new business models through software systems, which can lead to return of investment [45].	Management support is required for successful adoption of CI/CD throughout the organization [6, 28]
2.4	Business continuity strategy	Operational Management: Organization or a network of organizations that can transform within various context such as cultural, technological, governance strategy [27].	Implementing new models of delivering software should not disrupt ongoing operations and current service contracts [32]
2.5	Organizational flexibility	Using technologies and distribution of responsibilities to use new opportunities more efficiently [33, 44].	Organizational and offering flexibility to quickly capitalize new opportunities [15, 28]
2.6	Cost-benefit analysis	Cost-benefit analysis aid understanding of trade-offs associated with the DT [58].	The investments to adopt specific CI/CD practices need to be justified with tangible benefits [32].
2.7	Automated, data-driven processes	Repetitive and menial tasks are optimized and automated with software tools [11]	See 2.8
2.8	Continuous SE	See 2.7	Processes start and complete without operator intervention [39]. Automation helps to deliver software changes from developers to end-users without delay, thus improving the flow of value delivery [15, 28, 32]
2.9	Continuous improvement	A systematic and ongoing process of implementing micro-adjustments in an organization [51]	An ongoing process to streamline and remove bottlenecks to software delivery pipeline [15]
2.10	Continuous product and resources planning	Datafication of the relationship with customers [14]	Traditional yearly or quarterly planning activities need to replaced with more flexible approaches to capture opportunities as they arrive [15]
2.11	Continuous feedback & telemetry	Collection and utilization of data is one of the cornerstones of the DT [25]	Collection of customer feedback, and product telemetry to inform product decisions in real-time [28, 42]
2.12	Continuous value delivery	Services based business models allow more flexibility in customizing the offering to the exact customer needs [54]	Value for the customers and the organization is created by an ongoing series of software micro-deliveries (in contrast to transferring all the value at the moment of sales) [12]

enable the shifting of cognitive work from humans to computers. Consequently, AIT will have a more significant impact on the organization than most other technologies. The shifting of the cognitive load reduces human labor but, perhaps more importantly, also leads to the changing of traditional job descriptions and roles and the introduction of new roles.

We observe that more and more organizations are adopting AI. There is a lot of computer science research about AI, but very little about its impact on organizations and business models. Moreover, the SE of AI systems is understudied.

6 CONCLUSIONS

Organizations with a flexible enough learning environment to unify the view on DT and CI/CD will likely manage DT more effectively. The changes occurring in the business environment due to DT requires a clear strategy with priorities and objectives supported by capital resources, leadership, and employees' involvements.

With a multidisciplinary perspective, this study puts forward the adoption of CI/CD as a fundamental aspect for the future of digital transformation. To answer the research questions on the building blocks of CI/CD and DT, we started with a discussion on the state-of-the-art of both concepts. Next, we discuss the differences between

Table 3: Mapping of outcomes of adopting of CI/CD and performing digital transformation

#	Outcome	DT perspective	CI/CD perspective
3.1	Faster time-to-market	Being first in the market with new services provides a competitive edge [13]	Streamlined software delivery pipeline allow delivering new features to market faster [15]
3.2	Continuous use, experience based business models	Customer experience is another value delivery channel [52]	Continuous value delivery strengthens trust and enables a more collaborative business models [19, 50]
3.3	Security, privacy and ethical concerns	DT raises new issues of data ownership, management, and fair use of data [16].	Customers may see opening up and sharing data as a risk and not an opportunity to contribute to product development [32]
3.4	New digital products, value propositions, chains, and networks	Digitization enable new products and services [23, 52]	Implied (e.g Humble et al. [28]) but not explicitly discussed
3.5	Increased customer trust	DT and the use of digital communication are likely to create d loyalty and trust among it customers and wider community [46]	Frequent deliveries of value and longitudinal relationships contribute to trust enabling more closer business models [15, 19, 50]
3.6	Increased efficiency and organizational performance	Improved performance in terms of better service quality or lower cost [1, 5]	More effective (building the right product) and optimal (building it the right way) product development [28, 32]
3.7	Data-driven decision support	Generation and use of data is one of the cornerstones of DT [23, 52]	Product decisions can be supported and evaluated based on customer data not managers opinions [28, 42]
3.8	Increased product adoption and use	Digital offerings enable more closer collaboration between stakeholders leading to new forms of value, especially in domains where traditional product development is challenging [1, 41].	Tailored offerings and continuous value delivery contribute to increased product use [15, 28]

the conditions that are leading to DT and adoption of continuous engineering practices, mechanisms, and practices implementing the transformation, and outcomes from the transformation and adoption of continuous engineering practices.

In our view, a critical question for organizations is to establish an ongoing process for adopting and assimilating novel digital technologies. Essentially, CI/CD will intertwine with DT and AI. Initially, this study supports the adoption of CI/CD in industry by connecting organizational, management and SE perspectives. We highlight conditions leading to a decision to invest in adopting CI/CD, and the business impact from the adoption. We hope researchers will explore in greater depth the way DT and CI/CD intertwine and how this will affect the way decisions are made in organizations, as well as how processes are executed.

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