

Leveraging digital twin technology for industrial transformation: a case study in pharmaceutical technology transfer

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Abstract

Purpose – This study explores the integration of digital twin (DT) technology within technology transfer (TT) processes, focusing on a case study involving a pharmaceutical Contract Development and Manufacturing Organization. It aims to identify barriers to effective TT, propose mitigation strategies and develop a tailored project management methodology.

Design/methodology/approach – The research includes a literature review of TT barriers, interviews with professionals and an analysis of agile project management methodologies (Scrum, Kanban and eXtreme Programming). DT applications were simulated to assess their potential in optimizing the production process of prefilled syringes.

Findings – The proposed methodology effectively mitigates TT barriers, including communication, organizational and knowledge-related challenges. Simulations demonstrated the potential of DT technology in reducing process delays and enhancing decision-making, particularly by improving resource availability rather than setup times.

Research limitations/implications – The methodology relies heavily on inter-organizational collaboration and a “lean” mindset. Further validation is required for broader applications, especially in complex or multi-organizational contexts.

Practical implications – By integrating DT technology and agile management approaches, organizations can accelerate TT processes, enhance quality and reduce completion times, leading to a more efficient resource allocation and faster Return on Investment (ROI).

Originality/value – This study is among the first to combine DT technology with a hybrid agile project management methodology to address barriers in TT processes. Its findings contribute to both academic research and practical applications in industrial settings.

Keywords Technology transfer, Digital twin, Project management, Agile methodology, Pharmaceutical CDMO, Knowledge barriers

Paper type Research article

1. Introduction

The term technology transfer (TT) typically refers to the movement or flow of technical knowledge, data, designs, prototypes, materials, inventions, software, and/or trade secrets from one organization to another, or from one purpose to another (Scarrà and Piccaluga, 2020). These processes are notoriously complex to manage because moving knowledge is much more intricate than any other moving process and is massively affected by people and by the quality of their interactions. Studies, like Fantozzi *et al.* (2022), highlight soft skills and behavioral aspects as pivotal in overcoming organizational and operational barriers, particularly in a collaborative and technology-intensive environment. However, even though the focus on those aspects has grown, inefficiencies in these processes and the absence of project management methodologies specifically tailored to address TT challenges continue to hinder organizations. The authors



verified the need for a new methodology in a real transfer, taking place in a pharmaceutical organization that struggled to efficiently manage a complex transfer process, involving different clients and suppliers, and were unable to find a suitable management solution. In this scenario, the organization had already implemented many traditional TT strategies, the latest of which was Six Sigma. Still, those attempts didn't achieve relevant results due to a lack of reliable data and chronic organizational problems. This inability to find the right solution arose because most papers (Hong *et al.*, 2023; Li and Wei, 2012; Farhadikhah and Hussein, 2015; Simms and Frishammar, 2024), analyze TT processes between research entities and companies, even though a large number of those typically occur between companies, which constitutes a different dynamic, with totally different critical aspects that need to be addressed. Furthermore, in today's rapidly evolving industrial landscape, TT has become crucial for companies seeking to innovate and remain competitive, and managing these transfers efficiently and effectively in complex environments such as multinational firms (Fortwengel *et al.*, 2023), large franchising networks, and highly articulated Supply Chains has increasingly become a strategic priority, making the research of viable solutions much more compelling.

This paper aims to address this gap, presenting a new approach to TT, tailor-made to enhance knowledge and technology exchanges between companies. To develop the proposed methodology, it was extremely important to explore and answer some of the most pressing research questions related to TT practices improvement, specifically in corporate environments:

- RQ1. Which are the most significant barriers impacting technology transfer processes in companies?
- RQ2. How can those barriers be addressed, or at least mitigated?
- RQ3. Is it possible to craft a methodology that incorporates the solutions to all the barriers?
- RQ4. How can Digital Twin technology be leveraged in technology transfer processes?

The first research question will be addressed through a comprehensive analysis of barriers frequently discussed in literature, as well as interviews with individuals involved in the case study, to assess the consistency between literature and companies' experience. The second research question will lead us to propose practical solutions for companies to effectively overcome these barriers. Building on this, answering the third research question, a project management methodology will be introduced, unifying lean project management approaches, such as Scrum, Kanban, and eXtreme Programming, with solutions tailored to mitigate the identified barriers. Finally, the fourth research question examines the potential of digital twin (DT) technology to enhance both the quality and the makespan of TT processes, building on the findings of Fantozzi *et al.* (2024), who show that recent advancements in DT modeling possess a significant capacity to optimize resource allocation and mitigate inefficiencies in industrial operations.

To ease the understanding of what is proposed, this paper is divided into five sections:

- (1) The first section will present the results of a literature review conducted to find the most frequently mentioned TT barriers, to better understand DT, and look for viable lean and agile project management approaches.
- (2) The second section will introduce a new project management methodology specifically designed for TT.
- (3) The third section will focus on applying this methodology to a complex and articulated TT case study conducted within a pharmaceutical Contract Development and Manufacturing Organization (CDMO), which, as the name suggests, develops and manufactures products on behalf of other pharmaceutical companies.
- (4) The fourth section will evaluate the effectiveness of the proposed methodology by analyzing its application in the case study. This chapter will assess how the methodology could have helped avoid the problems that occurred during the TT operations.

- (5) The fifth, and last, section will include some final analysis and considerations concerning what was proposed in the previous sections, and its possible implications.

2. Literature review

2.1 Technology transfer barriers

As said before, technology transfers are crucial for companies and industries; therefore, the great attention they received in literature and the many articles dedicated, like [Hong et al. \(2023\)](#), [Li and Wei \(2012\)](#), [Farhadikhah and Hussein \(2015\)](#), [Simms and Frishammar \(2024\)](#), shouldn't come as a surprise. However, compared to the significant number of articles, the ones investigating barriers and problems in companies' TT process, along with their possible or probable causes, are much fewer. Given the historical relevance of these topics, some of these studies are outdated and discuss barriers and problems that advancements in technology have since addressed; so, to keep this paper as up to date as possible, solely barriers identified and analyzed in more recent articles and papers will be considered, not taking into account publications older than 10 years. The research was conducted in the Scopus database, using the terms "Technology Transfer barriers" and "Knowledge Transfer barriers", and took into consideration the first 100 articles for each term, trying to find the most comprehensive TT barriers clusterization. From the authors' perspective, the article that provided the most accurate and useful analysis of these barriers was [Mazurkiewicz and Poteralska \(2017\)](#), which the authors integrated with a useful guide for TT in small companies, provided by [Kowalik and Anna \(2022\)](#). These papers are particularly relevant for their efforts to categorize the existing barriers into 4 or fewer clusters, simplifying the analysis and making the research for viable solutions much easier. [Mazurkiewicz and Poteralska \(2017\)](#) divided all the TT barriers into three groups: organizational-economic barriers, technical barriers, and system barriers. This division can be improved by introducing a more specific categorization for different aspects: that's exactly what [Kowalik and Anna \(2022\)](#) proposed in their paper, where the division highlights 4 main clusters for organization-caused barriers and 2 clusters for externally caused barriers. The organization-caused barriers clusters are strategic barriers, structural barriers, cultural barriers, and procedural barriers, while the externally caused barriers are divided into relational and environmental barriers. The complete framework, with explicit descriptions of causes and examples, can be found in [Table 1](#).

This clusterization can be extremely useful in the identification of what is causing problems or creating barriers, and help streamlining TT; using it, we can quickly identify feasible and effective solutions. What is proposed in this paper stems directly from these clusters, because having a clear identikit of each group of barriers enabled the authors to study the most effective practices to apply.

2.2 Digital twin applications

In recent times, many significant papers have been published on DT technology and its possible applications in various realms and situations, such as those by [Tao et al. \(2018\)](#), [Lu et al. \(2020\)](#), [Attaran and Celik \(2023\)](#), [Al-Dalati \(2023\)](#), and more. This research focused on those applications that could eventually enhance quality and efficiency in TT. To gain the best understanding possible of this technology's applications, different DT uses in different economic sectors, like energy, healthcare, and manufacturing, and DT combinations with other emerging technologies, such as Generative AI, machine learning (ML), augmented reality, and artificial neural network, were considered. In this exploration, conducted mainly on the database "Scopus", the following research strings were used: "Digital Twin application", "AI and Digital Twin application", "DT and ML", and "DT integrations". Almost 84.000 total publications were found, dramatically reduced to about 300 by filtering by year, excluding all papers older than 5 years, and relevance. In the end, the most useful ones were identified by reading the abstracts and, in the most promising cases, the whole article, finally discovering the 8 most interesting articles, which were reported in [Table 2](#).

Table 1. Main barriers' description and potential examples

Paper	Main barriers	Barriers' cause	Barriers' example
Mazurkiewicz and Poteralska (2017)	Organizational-economic barriers	Lack of organizational and management skills within the organization	Information transmission Different orientations Poor business management
	Technical barriers	Transfer's technical difficulty	Tacit knowledge Too sophisticated technology
	System barriers	Interaction between the organization and the economic system	Lack of developed infrastructure Lobbies or interest groups
Kowalik and Anna (2022)	Strategic barriers	Misalignment regarding objectives and intentions between different parts of the organization	Fragmented view of the process Conflicting goals
	Structural barriers	Excessively rigid hierarchical structure of the organization	Slow communication Slow decision-making process
	Cultural barriers	Lack of an adequate innovation culture within the organization	Punishments for taking risks Unstimulating work environment
	Procedural barriers	Lack of knowledge regarding procedures and expected behaviors from the employees	Unclear procedures Low flexibility Unjustified stalls in process advancements

Table 2. DT applications, with respective realms and enhancing technologies

Realms of application	Enhancing technologies	Application description	Paper
Energy Manufacturing Manufacturing	ML, ANN	<i>Predictive maintenance</i>	Ismail et al. (2024)
	ML, ANN	<i>Production planning</i>	Müller-Zhang et al. (2023)
Manufacturing Energy Healthcare	GAI, AR	<i>Staff training</i>	Piñal and Arguelles (2024)
Healthcare Military	GAI, ML	<i>Operations management and analysis</i>	Han et al. (2023)
Healthcare	GAI, ML	<i>Cure experimentation</i>	Armeni et al. (2022)
Cybersecurity	GAI, ANN	<i>Cybersecurity testing and analysis</i>	Dietz et al. (2020)
Agriculture Manufacturing Healthcare	ML, GAI	<i>Smart Agriculture</i>	Liu et al. (2023)
	ML	<i>Anomaly analysis</i>	Ismail et al. (2024)
Cybersecurity Military Energy Energy Manufacturing	ML	<i>Health indicator analysis</i>	Chen et al. (2023)

2.3 Agile project management approach

Agile project management is considered one of the most practical and flexible approaches to project management, enabling the scope to be moved during the project, following customer needs, maximizing customer satisfaction (Marnada et al., 2022), and enhancing interactions and communications between different companies involved in the same project. This concept contains different methodologies, like Scrum, Kanban, Extreme Programming, and Crystal; most of these are based on an iterative management idea and, even though they were created to enhance software development processes, are nowadays considered consolidated approaches in many different industrial fields. Given the growing popularity of these methodologies, it's common to see, in both literature and organizations, hybrid approaches, taking different

features from different agile (and even non-agile) methodologies, and fusing them to create a new one, tailor-made for the specific project or situation that needs to be managed. The most well-known and accepted hybrid approach is probably the Scrumban, which combines Scrum and Kanban, and can be seen as a simplified version of Scrum, keeping the daily Scrum meeting and the Kanban board. This approach bases all its architecture on six pillars (visualization, limit Work in Progress (WIP) activities, manage flow, create explicit rules, implement feedback throughout the organization, and continuous improvement) (Ellis, 2016) and has been successfully applied to many different fields, such as clinical research (Lei *et al.*, 2020) and construction (Anyosa *et al.*, 2024). Ellis (2016) also considers a possible integration in the realm of software and hardware development, between Scrum and eXtreme Programming, which partially opens the way to the methodology that is being proposed in this paper.

3. Methodology

The methodology being presented is based on the fusion of some of the most promising characteristics of three agile project management practices (Scrum, Kanban and eXtreme Programming), the integration of which, as previously shown, is consolidated in both academia and industry, with a focus on the potential boost that DT technology could provide to the fusion of these approaches, making TT processes faster and more efficient. Before presenting our proposal, the steps that led us to the results we introduce in this paper need to be disclosed. Figure 1 represents each phase of the process in chronological order, and Table 3 provides a precise definition and description of each phase.

In the implemented development strategy, two macro-phases can be identified: one based on detailed observation of the current state and information collection, and another focused on finding fitting solutions to improve the observed state with minimal resource consumption. Once these pieces of information have been provided, it is possible to proceed with the presentation of the innovations introduced in this work, starting with the project management approaches integration part. The ratio that guided this unification was to elevate the strengths of each approach and limit typical and chronic weaknesses. The first key aspect, as it is arguably the most impactful part of the whole methodology, is that the project team needs to be a diverse group in terms of experience, age, background, and competencies, to enable different points of view and limit groupthink. To maximize the chances of success, the percentage of people from the organization that is providing the technology should not exceed 20%, and the number of people involved should vary from process to process; what needs to be kept in mind is that managing more than 15–20 people, all involved in the same TT, can become extremely challenging and time-consuming. Similar to the Kanban methodology, there are no mandatory positions within the team, except for the project manager role; this feature enables organizations to be flexible when constructing the team and create the best-structured team for each TT process. Once the team has been established and the roles of each member are defined, the focus shifts to team management. A key priority is ensuring that at least one member of each organization is involved in every activity; this concept, which is a reinterpretation of Pair Programming (typical eXtreme Programming feature), becomes extremely interesting in these processes, because instead of waiting for each activity to be validated once it's done, the quality levels and the compliance to norms and clients' requests, can be assessed continuously. This strategy also enables the organization to evolve continuously throughout the process, incorporating ideas and solutions from other organizations to improve and accelerate



Figure 1. Methodology research steps representation

Table 3. Methodology creation phase description

Phase	Description
1-Need	Analyzing the type of process that we wanted to accelerate, and the needs of the people involved in these processes.
2-Information collecting	In this phase, we collected information to identify more clearly the needs and the timelines of a technology transfer process.
3-Phenomenon observation	Through a case study, it was possible to observe how these processes were managed in real-life scenarios by certified Project Managers and highlight some relevant problems.
4-Methodologies research	A relevant number of articles and documents was examined in this phase to find viable solutions to our problems, even across different methodologies.
5-Unification phase	Once a viable solution for most of our critical issues was achieved, we unified all solutions into one simple and easy-to-manage methodology. We also checked how these solutions could be enhanced by integrating the use of Digital Twin technology.
6-Utility test	When each solution was integrated into our methodology, we checked if within the methodology our solutions were still as effective as they had been before.
7-Final methodology	Once the utility test was passed, we finally completed the research for our technology transfer methodology.

processes. As an additional measure, the entire TT should be divided into smaller segments, named sprints, with each sprint comprising activities that might last between 2 and 4 weeks; this division is valuable, because, combined with the meeting policy (which will be introduced shortly), minimizes the impact of mistakes made in the initial stages, on the overall process and on the final project outcome. To maintain high-quality standards, the number of activities conducted simultaneously should be reduced as much as possible. Limiting the so-called “WIP activities” will significantly help the team and the project manager keep track of advancements and focus on achieving exceptional quality and efficiency on single tasks, substantially improving the chances of completing each project phase successfully (tools like Kanban boards can be instrumental in these regards). As previously mentioned, effective meeting management is crucial to minimizing the impact of initial mistakes on the entire process. To avoid wasting time on unnecessarily frequent and lengthy meetings, the organization should limit them to a maximum of 2 or 3 per sprint, each lasting no more than 30 min. The exchange of information and ideas needs to be as straightforward as possible, free from reverential awe, fear of consequences, or judgment. If the company wants the meetings to be useful and efficient, it needs to become a free zone, where people can express their thoughts and feelings without restriction. But how do these practices impact each barrier? And how can we guarantee this impact to be positive? In [Table 4](#), a description of how the negative influence of these barriers is reduced and how this methodology can affect a TT process is reported. Once the main obstacles are out of the picture, knowledge can “flow” more organically and naturally from one organization to another, and this flow is usually able to overcome some smaller problems and “frictions”; therefore, everything should fall into place.

In this methodology the authors also see an exciting possibility concerning the use of DT technology, which could be extremely beneficial in tasks such as scheduling, controlling sprints and activities, assigning each activity to a specific team member or group of members, managing processes’ data and documents (which is an important aspect in every TT process, specifically in the pharmaceutical and food industry), and even simulate different strategies to complete the project. These uses of DT models could massively impact project management, giving much easier access to pieces of information and enabling process traceability; therefore, this technology could help overcome Organizational, Procedural, and Structural barriers even more easily. Our pharmaceutical case study, which will be introduced in the next chapter, represents an extremely interesting example of DT applications in companies’ TT, and, more extensively, in companies’ management. In this specific situation, a DT model was used to

Table 4. How each group of barriers is limited by one or more features

Barriers	Impacting features	Impact description
Organizational-economic	Team composition Scrum structure WIP activities management	The team is composed of members from different organizations, who share information and, through Scrum meetings, share information and visions on the project, aligning their efforts. Furthermore, doing this when the number of WIP is limited is much easier.
Technical	Pair Programming Team composition	Correctly assembling the team, in terms of realms of expertise, and making these experts work together and share knowledge while completing tasks reduces obstacles to the flow of knowledge
System Strategic	– Meeting management Team composition Scrum structure	– Involving each organization in the team, we can have a clearer picture of what everyone expects and deal with different views immediately, avoiding possible highly impacting conflicts in the final phases of the project.
Structural	Pair programming WIP activities management	Working together and on fewer activities seems a much simpler way to operate and overcome communication problems. Limiting WIP also enables faster decision-making.
Cultural	Work environment management	Keeping an open work environment helps us with efficient meeting management and enables correct and healthy communication, which is crucial for TT.
Procedural	Scrum structure WIP activities management Pair programming	The Scrum structure and the lower number of WIP give an enormous boost in terms of flexibility and ability to adjust the project scope

help the company rapidly understand how the changes concerning production parameters could affect the ability to respect deadlines and ship the product on time. This knowledge can be crucial during the TT, not only because having that information enables the company to adjust and take countermeasures, but also because mistakes concerning deadlines and/or performance estimates could result in heavy contractual penalties. Shifting the focus to cultural aspects, it is relevant to consider that this methodology requires a specific organizational mindset. What is being proposed in this paper can work only if, throughout the organization, a high level of tolerance for mistakes made in the pursuit of innovation, along with encouragement to propose and implement innovative solutions, prevails. Management and people in charge of Technology Transfers need to recognize that new solutions will likely encounter initial pitfalls and setbacks and that accepting these challenges will be highly beneficial for the organization in the long run. Following this consideration, the importance of this methodology in overcoming smaller uncertainties and frictions shouldn't be underestimated and represents one of the main tools provided to solve possible resistances to change within the company. Every feature of this methodology is designed to create enthusiasm and momentum towards partnerships and interactions between companies, making overcoming resistance much easier. [Table 5](#), reported below, was instrumental in representing this methodology synthetically.

This methodology totally differentiates itself from other integrations between agile project management and DT, because, as previously said, the goal of this integration is to facilitate TT, and each agile approach feature has been selected to reach said goal. From the authors' point of view, it's undeniable that some of the other integrations could achieve good results if used in TT projects; however, a dedicated, tailor-made methodology is far more suitable, as it can deliver superior results without adding unnecessary complexity or excessive organizational challenges.

Table 5. Proposed methodology guidelines

Project management topics	Proposed methodology	Inspired by
Team dimensions	<i>No specific limitations in terms of team dimensions, though managing more than 15–20 members can be challenging</i>	Kanban
Team roles	<i>The only mandatory role is the project manager</i>	Kanban
Team composition	<i>At least 15–20% of members must come from the provider</i>	–
Team management	<i>Each activity should be conducted by a group of people that contains members of every organization involved, and every member of the team should be involved in all kinds of activities</i>	eXtreme programming
Competencies within the team	<i>Needed competencies can vary for each project; therefore, the team needs a motley composition in terms of knowledge and experience</i>	eXtreme Programming
Activities management	<i>The process must be divided, also considering the possible presence of due dates, into smaller parts called “sprints”. Each sprint contains activities that need to be completed in two to four weeks</i>	Scrum, eXtreme Programming, Kanban
WIP activities	<i>The number of activities conducted simultaneously must be as low as possible to maintain high standards</i>	Kanban
Workflow management	<i>Keeping the workflow going is crucial, and keeping track of the advancements is even more important. Therefore, the use of a Kanban board is highly recommended, with a double application, one for each sprint, and one for the entire technology transfer process</i>	Kanban
Periodic meetings	<i>Short periodic meetings are essential for experience sharing, previous sprint analysis, and planning future sprints</i>	Scrum
Emergency management	<i>The inclusion of other organizations involved in the team helps massively when it comes to managing emergency requests from clients or from other organizations</i>	eXtreme Programming
Digital Twin applications	<i>Digital Twin, in this methodology, can be used to schedule and control activities and their state of progress, but also to assign each activity to a specific team member, and to manage processes’ data and documents</i>	–
Main concern areas	<i>The need for collaboration from every other organization involved in the technology transfer process can become problematic if these organizations are not inclined to help The involvement of people from other organizations can create some organizational and communication problems, especially if these organizations are not on good terms</i>	–
Mentality	<i>The absolute focus is on improving the process and exploring possible innovations within the process. Every attempt aimed at facilitating and improving the transfer process, whether successful or unsuccessful, is not only appreciated but also highly encouraged</i>	Kanban, eXtreme Programming

The elephant in the room that needs to be addressed, which will also be extensively considered in the limitations section of this paper, is the topic of areas of concern. The main one being the willingness of other involved organizations to cooperate extensively during these processes; additionally, involving people from outside the company can be extremely challenging in terms of communication and management. From what we discussed, it is

evident that the organizations involved need to have a close working relationship and, ideally, they should have collaborated on smaller projects before taking on more significant challenges, such as a new TT. Another smaller area of concern is the issue of “tacit knowledge”, which is the most challenging to transfer because most barriers are inherent to the process and almost impossible to solve using a project management methodology. Therefore, to achieve better results, the amount of tacit knowledge should be minimized as much as possible before starting the process. Even after taking into consideration the areas of concern, what we are proposing can be considered fascinating, because every organization can, with little to no variations, use it, achieving amazing results in terms of limiting each kind of barrier in the process, in every TT process happening, in every kind of context.

4. Case study

This methodology was applied to a real TT process involving a pharmaceutical CDMO, which introduced, within a working production plant, a new production line dedicated to filling pre-filled syringes. A CDMO organization was selected for this case study due to the exceptionally rapid pace of technological turnover in the pharmaceutical industry, which entails a high frequency of TT and, consequently, a greater risk of resource waste arising from inefficient practices. During this process, which lasted about two years, numerous barriers and problems arose; so, the idea behind this application was to understand how the proposed methodology could have eliminated, or at least limited, the barriers and, in a second instance, how the organization could have benefited from the application of DT technology in this kind of context.

The first approach with this case study involved visiting and studying the newly implemented production process. To briefly present the production line, which is reported in Figure 2, it is sufficient to say that three different types of syringes are produced on this line, each product has different production parameters (availability, setup, batch dimension, etc.), which are reported below, and that the bottleneck is the filling (the second operation) (see Figure 3).

Production parameters, more specifically theoretical production capability, batch dimension, setup time, and overall equipment effectiveness, for each of the three products, can be consulted in Table 6.

To assess whether the set of barriers identified in the literature review could be considered a good approximation of the real set of problems the company faced in the process, and whether these barriers could serve as a basis for developing a new methodology, all 18 team members involved in this specific TT were interviewed, starting with the team manager, and then extending the process to all members; most of them were experts with over 15 years of experience, came from an operations management background, and had already been involved in other TT projects, which made their point of view extremely useful in the methodology development process. In these interviews, which lasted about 30 min each and were conducted in an informal, relaxing setting, the interviewers asked each expert to retrace what happened in each TT process phase, identify the problems they faced, and explain, from their perspective, what caused those problems. To do so, a list of 40 hypothetical problematic situations (like “Clients ask for specifications changes”, “Uncertainty about task ownership”, “Deliverables differing from client expectations”) was submitted, and interviewees were asked to assign a score, ranging from 1 to 5 (5 being the highest frequency), indicating how frequently each

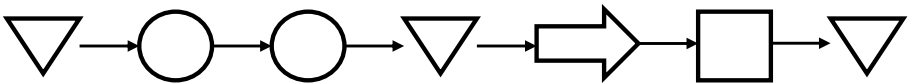


Figure 2. Production process representation

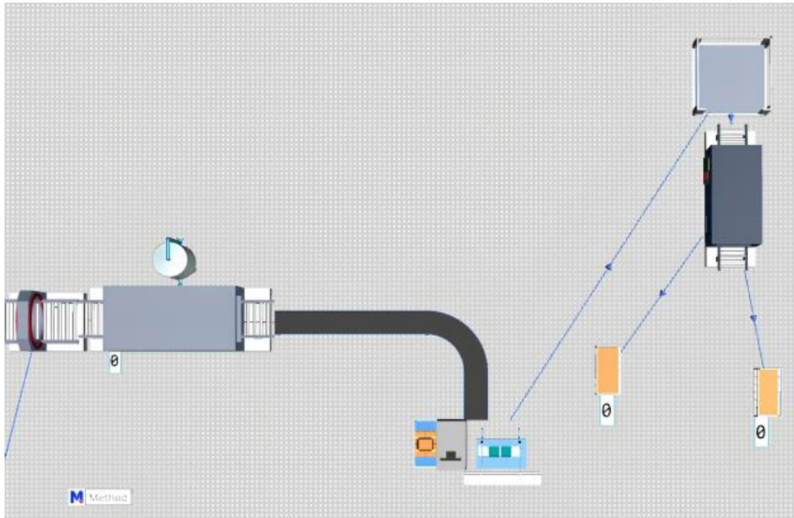


Figure 3. Model representation using Siemens Technomatix Plant Simulation

Table 6. Production parameters for each product

	Product 1	Product 2	Product 3
TPC (or validated)	400 ppm	400 ppm	500 ppm
Batch dimension	500,000 pieces	600,000 pieces	800,000 pieces
Setup time	24 h	24 h	12 h
OEE	32% (50%)	34% (50%)	37% (45%)

situation, or a similar one, presented itself during the process. Once collected, these scores were clustered, revealing four main barrier categories, which were almost identical to the ones identified in the literature review, and on which all participants reached consensus. The methodology proposed in this paper is the result of the authors' efforts to identify viable solutions to the following set of barriers:

- (1) Client-related barriers
- (2) Communication barriers
- (3) Organizational barriers
- (4) Know-how-related barriers

Client-related barriers stem from the inability to manage each client's changing requests and deadlines. Most problems arose from clients being unclear about what they needed and what they wanted to achieve; this ambiguity in the relationship, as one can easily imagine, can become extremely detrimental to the quality and efficiency of TT.

Communication barriers can be divided into two groups: internal and external. The internal ones usually occurred when communicating information such as the time required for each activity or specific aspects of each stage of the process; in these regards, one recurrent situation involved individuals responsible for some crucial activities, deliberately inflating the time required to complete them; such situations usually happen when the fear of the consequence of

being late or making mistakes is deeply ingrained in employees' minds. External barriers, on the other hand, were quite similar to client-related ones; the difference lies in the fact that the relationship causing the barrier wasn't between company and clients, but between the company and other organizations.

Organizational barriers are the most common in this kind of process. In this particular case, the problems were caused by confusion in scheduling and poor management. This confusion was mainly caused by clients' various requests and by some weaknesses in the chain of command; attempting to accommodate all these different requests and to hasten decision-making, the workflow was divided into two different streams, and different work units were created. However, this solution ended up being worse than the problem itself, making the situation even more confused.

Know-how-related barriers identify all those mistakes and wrong decisions caused by the lack of necessary knowledge, especially in the early stages of the process, which can significantly impact tasks' quality and the likelihood of completing the TT on time. This kind of barrier is quite common in TT processes and is always the most difficult to eliminate because the initial lack of know-how is intrinsic in these kinds of processes.

The results of applying this methodology in the case study can be divided into two main groups:

- (1) Reduction of barriers' impact on the TT process
- (2) Use of DT in this specific process

The first group of results demonstrates how the proposed methodology can mitigate the negative effects of the previously identified barriers (client-related, communication, organizational, and know-how-related), accelerating TT. The second group illustrates how the introduction of DT technology can become useful in these processes, and, more specifically, how this technology could have helped the CDMO reduce the time required for this process. Starting with the first group of results, it is crucial to understand how each group of barriers is addressed and hopefully limited by the practices introduced with this methodology; to do so, we synthesized in [Table 7](#) which specific feature of the proposed methodology impacts each barrier.

The second group of results enabled us to understand how DT technology could have been effectively applied to our case study. Given the nature of the line considered (still in test phase) and considering that production data were mainly indicative and not reliable, exploring scheduling applications seemed the most promising idea. More specifically, the goal was to evaluate how potential performance changes could impact the CDMO's ability to meet the deadline agreed upon with clients. To do so, we used the production line's available

Table 7. Table showing how this methodology addresses each group of barriers

Barriers	How does this methodology address each group of barriers
Client-Related	Involving each organization in the same project team allows the information to flow rapidly from the client to the organization receiving the technology transfer. Furthermore, working together and sharing ideas and solutions should reduce any potential lack of clarity regarding shared objectives and needs.
Communication Organizational	The "shared" team composition significantly limits external communication barriers. Limiting simultaneous work-in-progress activities, dividing the process into sprints, and embracing the use of new technologies, such as Digital Twin, to more efficiently schedule and manage activities.
Know-how-related	The main resource in limitation is represented by the division of the process into sprints and the introduction of meetings within each sprint. Periodic review meetings reduce the likelihood of initial mistakes affecting the overall transfer outcome.

information and some data collected during our plant visits to build a DT of the line. Using those data, different simulations were run, varying some parameters, such as setup time and availability (which in this specific case study is considered equal to the product between availability due to failures, performance efficiency, and setup time). In Table 8, we reported the different values used in each of the simulations. Additionally, to show how our model was constructed, we also reported, in Figure 2, the production line model we developed, which shows how every activity of this process was modeled and recreated in the virtual space made available by the Siemens Technomatix Plant Simulation software (see Table 9).

It's possible to affirm that the model we developed was effectively able to simulate the production line's ability to complete the production schedule within a certain time, because through 20 different scenarios in which we compared real performances with what the model simulated, using smaller periods, and using the real-life availability and setup time to correctly compare performance, we calculated a mean absolute percentage error of 4.3% and a PBIAS (Percentage BIAS) of 2.2%. These values tell us that, even though our model tends to slightly overestimate the completion time, it can still be considered reliable and accurate.

These simulations enabled us to understand which time horizons were necessary to be reasonably confident in delivering the product on time and made us realize that availability impacted our chances of meeting clients' requests much more than setup time. This result, which is exclusively relevant to this case study, is particularly interesting because it contradicts what the CDMO was doing to reduce delivery time, showing how a DT model can help making a TT process more efficient; the management indeed believed that the most pressing necessity was to reduce the time required for each setup, and a significant number of resources were being invested in the pursuit of this reduction. However, as our model showed, investing resources in increasing availability values was the fastest way to achieve substantial time reduction.

With these simulations, we demonstrated how valuable a conscious use of DT technology can be in managing TT processes and explored one possible way to leverage this technology to improve and accelerate such processes. As one can easily imagine, there are other fascinating implications regarding this methodology and DT's possible management applications, which extend beyond TT and can involve any area of the organization and, potentially, the entire company.

5. Implications and limitations

The findings of this research hold significant implications for both management practices and the broader social impact of companies. From a managerial perspective, the efficient management of TT projects and the effective use of advanced technologies, such as DT, are critical for organizational success. These advancements could yield considerable benefits for companies, including:

- (1) Enhanced quality in both TT processes and the work environment
- (2) Reduction in project completion times
- (3) Shortened payback periods
- (4) Improving employees' well-being within the organization

Table 8. Data variations used in our simulations

	Product 1	Product 2	Product 3
Availability	55%, 50%, 45%	55%, 50%, 45%	50%, 45%, 40%
Setup time	26, 24, 22 h	26, 24, 22 h	14, 12, 10 h

Table 9. Production simulations completed meeting the due date on different time frames

Completed simulations	45 days	40 days	Calculation time
Availability	16/27 (59.3%)	1/27 (3.7%)	3 min
Setup time	27/27 (100%)	12/27 (44.4%)	4 min
Combined	439/729 (60.2%)	25/729 (3.4%)	79 min

In terms of quality improvements, a well-designed methodology that guides the entire process while remaining adaptable to changing conditions can substantially elevate procedural standards, reducing errors and misunderstandings. Positive effects on quality are closely tied to the reduction of completion times, which is increasingly critical in an industrial landscape driven by rapid technological evolution. By facilitating more agile and effective management of changes, the proposed methodology ensures timely adaptation to new demands. Another compelling outcome of this research is the potential reduction in payback periods. Shortening the duration of TT projects enables organizations to deploy new products or utilize new machinery more rapidly, minimizing idle time and resource wastage. This acceleration allows companies to start recovering their investments sooner, thereby improving financial performance. Implementing these solutions is also likely to promote a more engaging and dynamic workplace. By enabling employees to interact closely with practices adopted in other organizations, this methodology encourages cross-organizational learning and exposure to diverse approaches to work. Such exchanges can support the introduction of innovative practices or improve the existing ones, enhancing overall workplace quality and employee well-being, transitioning from more effective collaboration models to improved decision-making processes and healthier work routines. At the individual level, these influences may contribute to greater motivation, professional growth, and a stronger sense of belonging. At the organizational level, they can promote adaptability, resilience, and long-term success, particularly in contexts where change management and continuous improvement are essential. In this sense, the methodology not only optimizes processes but also supports a broader cultural transition toward more sustainable and people-centered organizational practices. In addition to managerial implications, this methodology can significantly modify companies' social externalities. In these regards, two key positive effects stand out:

- (1) Accelerated development of new technologies
- (2) Reduced workforce stress

A more efficient transfer of technological know-how is essential in reaching higher technological standards in shorter timeframes. This methodology can streamline the ideation, transfer, and realization of new technologies, particularly in industries such as pharmaceuticals, where reduced time-to-market can save lives and address critical issues like high drug prices. Furthermore, by minimizing confusion and inefficiencies, this approach fosters a clearer understanding of roles and responsibilities among employees, particularly in innovation-driven sectors. In turn, this contributes to mitigating the broader social costs typically associated with work-related stress and organizational dysfunctions.

Evaluating how this new methodology aligns with key organizational change theories, it is crucial to understand its potential impact on companies; the proposed approach is fully consistent with established frameworks, providing a practical way to implement many of their guidelines. Removing barriers and resistance to change, while keeping high quality and motivation, is paramount, and approaches like the Kotter 8-step change model, the Awareness, Desire, Knowledge, Ability (ADKAR) model, and Lewin's change model are totally compatible with what is being proposed. For instance, the Kotter model identifies two steps

(Removing barriers and generating short-term wins) that are embedded in this methodology, completely devoted to avoiding or removing barriers, therefore facilitating the information flow, and obtaining small victories through Scrum sprints. Lewin's model is also compatible with this methodology, because what's being proposed can perfectly function as a different approach to the change phase. Finally, the ADKAR model presents many points of alignment with this approach, considering how impactful our proposal can be on the Desire, Knowledge, and Ability components of the model.

Talking about this methodology's relationships with various methodological aspects, it is also important to evaluate how what was proposed differentiates itself from traditional project management approaches and Six Sigma. From the authors' perspective, traditional project management is not completely compliant with what TT processes necessitate and request. Transferring knowledge is complex, and the time required to complete each phase is difficult to estimate precisely, even using Program Evaluation and Review Technique (PERT) or Critical Path Method (CPM), because it depends on an incredible number of variables (culture, people, technology, trust, companies' dimensions, etc.). Another limit of the "waterfall" approach in traditional project management is that, even though the most traceable and desirable way of incorporating knowledge would be through organic growth, these processes are often not organic in their growth; therefore, having a rigid and difficult to modify structure for the entire project, could be less beneficial than having a methodology able to follow this inorganic flow. Instead, when considering Six Sigma methodologies, the most impacting problems are the ones concerning the competences required to apply them, which are costly and time-consuming to develop, and the time required to apply the methodology, which doesn't fit smaller TT processes' needs; furthermore, the need for data is an insurmountable issue, because without those, you can't make Six Sigma work correctly. The development of DTs faces some of the same problems, but our methodology can also work without a complete dataset, using the DT as a simulation tool to improve timelines and resource management, so the methodology's ability to solve companies' problems is marginally limited. These considerations don't mean that traditional project management and Six Sigma cannot be successfully applied to TT processes, but rather that there is a space for new and tailored methodologies to address those mismatches.

Despite its advantages, this methodology has some limitations and criticalities. The first group of constraints concerns collaboration between companies; this strategy can be difficult to apply in the real industrial world, where sharing people and knowledge is still seen by many as a dangerous activity. Therefore, if companies do not completely trust each other, have concerns and uncertainties regarding the collaboration, or do not share the same view on crucial ethical and cultural elements, this methodology will surely fail in its purpose. Another concern in the cooperation we suggest, is the companies' inability to concede some of their human resources to another organization for an extended period, due to their small size or lack of economic resources; as one can imagine, this consideration limits application to technology transfers involving bigger companies and makes it much harder for smaller ones to consider the use of what we are proposing. The second group of limitations concerns the possibility of DT applications in this methodology, and more generally in TT. Using this technology is usually costly and difficult because of the body of knowledge (in terms of data and technical capabilities) needed to develop a DT, and, for a smaller portion, because its use in these situations changes almost completely consolidated dynamics within the company's project management division. The main difficulty is finding the minimum amount of data needed to create a model and ensuring the quality of the dataset used; when the knowledge transfer involves tests and activities on machines, this process is much easier. Instead, when we consider processes that do not involve machines, and are simply characterized by people interacting with each other and exchanging information, integrating a DT (at least until it is possible to create a person's, or a team's, DT), could be labeled as almost impossible and pointless. Anyway, as previously said, if the resources to develop a DT model are not at disposal, this methodology can also be applied without this model, probably with less precise

and effective results, but it would still be one of the most effective. The third and final group of limitations includes all issues related to the accurate documentation and reporting of ongoing activities (when a DT model isn't in place and the methodology is applied partially), a crucial aspect in highly regulated industries such as pharmaceuticals and food processing. To address this, the company could establish a small task force responsible for maintaining comprehensive records and reports throughout the process, making this team report directly to the Project Manager.

6. Conclusions

Considering our case study's results, what is proposed in this paper should be seen as a totally new methodology, which implements many different agile approaches, fuses them with an emerging technology like DT, and has a positive impact on how companies manage TT. As can be expected, this approach is not limited to the pharmaceutical domain and could be applied successfully in many different fields, such as construction, manufacturing, software development, and beyond.

In the coming years, significant advancements in DT technology are anticipated, particularly in its ability to model and simulate increasingly complex systems. These developments could greatly enhance the proposed methodology, amplifying its benefits for organizations. One of the most promising advancements involves the creation of personalized DT for employees, because such models could enable precise analysis and optimization of stress levels, workloads, and productivity, tailored to individual abilities and performance capacities. This level of granularity would not only improve operational efficiency but also foster a healthier, more sustainable work environment, ultimately benefiting both employers and employees.

Looking even further ahead, breakthroughs in neuroscientific research and the simulation of brain functions could revolutionize human resource management. The ability to model cognitive processes and emotional responses may enable companies to evaluate employee engagement, commitment, and well-being in ways previously unimaginable. In these regards, it is also relevant to consider that implementing these technologies in human resource management opens scenarios that are difficult to predict, not only regarding how these DTs will be designed and which data they will rely on, but also in terms of how such models may affect people's careers and lives. Any company considering a workforce DT implementation, if such a scenario were to become feasible, should be fully aware of how problematic this choice could be for employees' morale and motivation, and even more so for their privacy. Moreover, deciding how much work a worker can handle is a deeply complex and personal matter, one that cannot be responsibly delegated to an algorithm. In addition to the concerns already raised, the widespread adoption of these innovations could render many positions within human resources departments redundant, potentially leading to an occupational crisis. Finally, applying to human beings the same methodologies traditionally used to evaluate and optimize machines raises profound ethical and social concerns, particularly due to the heightened risk of alienation.

Combined with these potential advancements, integrating soft skills development within TT processes could be transformative. Skills such as critical thinking, adaptability, and teamwork play a crucial role in overcoming barriers such as miscommunication, resistance to change, and knowledge silos. Organizations that invest in training programs and university-industry challenges can bridge these gaps by fostering interdisciplinary collaboration, enhancing innovation, and preparing a new generation of professionals equipped with both technical expertise and essential soft skills.

In University, TT challenges, such as hackathons, collaborative problem-solving projects, or industry-sponsored competitions, can serve as valuable testbeds for the proposed methodology. These initiatives not only accelerate the adoption of emerging technologies like DT but also cultivate students' ability to work in dynamic, team-based environments. As highlighted by [Di Luozzo et al. \(2023\)](#), University challenges significantly contribute to the

development of essential soft skills, improve the perceived value of educational programs, and enhance job opportunities by aligning academic training with industrial needs.

So, as highlighted earlier, technological progress and skills development alone may not be sufficient for the continued advancement of this methodology. Its effectiveness depends on certain organizational preconditions, such as a collaborative culture, clear communication, and manageable team sizes. Large-scale or multi-organizational projects remain challenging and require further methodology refinement, because managing larger teams and introducing any kind of DT in these projects might change the standard company practices too radically, creating discomfort and confusion. In addition, addressing workforce simulation limitations remains critical; achieving a fully functional “workforce” DT will require overcoming complexities related to the measurement of individual behaviors, stress responses, and soft skills. These limitations align with findings on the growing role of behavioral factors and workforce engagement in enhancing industrial performance.

References

- Al-Dalati, I. (2023), “Chapter 10 - digital twins and cybersecurity in healthcare systems”, in El Saddik, A. (Ed.), *Digital Twin for Healthcare*, Academic Press, pp. 195-221, doi: [10.1016/B978-0-32-399163-6.00015-9](https://doi.org/10.1016/B978-0-32-399163-6.00015-9).
- Anyosa, J., Boza, R. and Barraza, G. (2024), “Application of Scrumban in the execution of single-family homes in Lima, Peru to optimize construction times”, in *2024 Congreso Internacional de Innovación y Tendencias en Ingeniería (CONIITI)*, pp. 1-6, doi: [10.1109/CONIITI64189.2024.10854871](https://doi.org/10.1109/CONIITI64189.2024.10854871).
- Armeni, P., Polat, I., De Rossi, L.M., Diaferia, L., Meregalli, S. and Gatti, A. (2022), “Digital twins in healthcare: is it the beginning of a new era of evidence-based medicine? A critical review”, *Journal of Personalized Medicine*, Vol. 12 No. 8, p. 1255, doi: [10.3390/jpm12081255](https://doi.org/10.3390/jpm12081255).
- Attaran, M. and Celik, B.G. (2023), “Digital Twin: benefits, use cases, challenges, and opportunities”, *Decision Analytics Journal*, Vol. 6, 100165, doi: [10.1016/j.dajour.2023.100165](https://doi.org/10.1016/j.dajour.2023.100165).
- Chen, C., Fu, H., Zheng, Y., Tao, F. and Liu, Y. (2023), “The advance of digital twin for predictive maintenance: the role and function of machine learning”, *Journal of Manufacturing Systems*, Vol. 71, pp. 581-594, doi: [10.1016/j.jmsy.2023.10.010](https://doi.org/10.1016/j.jmsy.2023.10.010).
- Di Luozzo, S., Fantozzi, I.C. and Schiraldi, M.M. (2023), “On the effectiveness of experiential teaching methods: the impact of University Challenges on students’ attitudinal development Proceedings summer”, available at: https://www.summerschoolaidi.it/images/papers/session_4_2023/Camera_ready_ID12.pdf
- Dietz, M., Vielberth, M. and Pernul, G. (2020), “Integrating digital twin security simulations in the security operations center”, *ACM International Conference Proceeding Series*. doi: [10.1145/3407023.3407039](https://doi.org/10.1145/3407023.3407039).
- Ellis, G. (2016), “Chapter 8 - agile project management: scrum, eXtreme programming, and scrumban”, in Ellis, G. (Ed.), *Project Management in Product Development*, Butterworth-Heinemann, Boston, pp. 223-260, doi: [10.1016/B978-0-12-802322-8.00008-5](https://doi.org/10.1016/B978-0-12-802322-8.00008-5).
- Fantozzi, I.C., Di Luozzo, S. and Schiraldi, M.M. (2022), “Soft skills, attitudes and personality traits in operations and supply chain management: systematic review and taxonomy proposal through ProKnow-C methodology”.
- Fantozzi, I.C., Di Luozzo, S. and Schiraldi, M.M. (2024), “The impact of university challenges on students’ attitudes and career paths in industrial engineering: a comparative study”, *Sustainability*, Vol. 16 No. 4, p. 1600, doi: [10.3390/su16041600](https://doi.org/10.3390/su16041600).
- Farhadikhah, Z. and Husseini, S.M.H. (2015), “A review of methods and models of technology transfer”, *International Letters of Social and Humanistic Sciences*, Vol. 62, pp. 173-181, doi: [10.18052/www.scipress.com/ilshs.62.173](https://doi.org/10.18052/www.scipress.com/ilshs.62.173).

- Fortwengel, J., Gutierrez Huerter O, G. and Kostova, T. (2023), "Three decades of research on practice transfer in multinational firms: past contributions and future opportunities", *Journal of World Business*, Vol. 58 No. 3, 101430, doi: [10.1016/j.jwb.2023.101430](https://doi.org/10.1016/j.jwb.2023.101430).
- Han, Y., Li, Y., Li, Y., Yang, B. and Cao, L. (2023), "Digital twinning for smart hospital operations: framework and proof of concept", *Technology in Society*, Vol. 74, 102317, doi: [10.1016/j.techsoc.2023.102317](https://doi.org/10.1016/j.techsoc.2023.102317).
- Hong, J., Cha, J., G., B. and Park, K. (2023), "Evaluation framework for facilitating the technology transfers of universities: focusing on the perspective of technology donors", *PLoS One*, Vol. 18, 12 December, e0293951, doi: [10.1371/journal.pone.0293951](https://doi.org/10.1371/journal.pone.0293951).
- Ismail, F.B., Al-Faiz, H., Hasini, H., Al-Bazi, A. and Kazem, H.A. (2024), "A comprehensive review of the dynamic applications of the digital twin technology across diverse energy sectors", *Energy Strategy Reviews*, Vol. 52, 101334, doi: [10.1016/j.esr.2024.101334](https://doi.org/10.1016/j.esr.2024.101334).
- Kowalik, B. and Anna, S.-J. (2022), "Technology transfer and potential of cooperation with SMEs. A practical guide for corporates", available at: <https://blog.sage.hr/successful-cooperation-between-startups-and-corporation-theory-practice/>
- Lei, H., O'Connell, R., Ehwerhemuepha, L., Taraman, S., Feaster, W. and Chang, A. (2020), "Agile clinical research: a data science approach to scrubman in clinical medicine", *Intelligence-Based Medicine*, Vols 3-4, 100009, doi: [10.1016/j.ibmed.2020.100009](https://doi.org/10.1016/j.ibmed.2020.100009).
- Li, W. and Wei, Y. (2012), "Technology transfer, adaptation and assimilation and indigenous invention patent output: evidence from Chinese high-tech industries", in *Procedia Engineering*, pp. 1392-1398, doi: [10.1016/j.proeng.2012.01.146](https://doi.org/10.1016/j.proeng.2012.01.146).
- Liu, J., et al. (2023), "Exploring the integration of digital twin and generative AI in agriculture", *Proceedings - 2023 15th International Conference on Intelligent Human-Machine Systems and Cybernetics, IHMSC 2023*, Institute of Electrical and Electronics Engineers, pp. 223-228, doi: [10.1109/IHMSC58761.2023.00059](https://doi.org/10.1109/IHMSC58761.2023.00059).
- Lu, Y., Liu, C., Wang, K.I.K., Huang, H. and Xu, X. (2020), "Digital Twin-driven smart manufacturing: connotation, reference model, applications and research issues", *Robotics and Computer-Integrated Manufacturing*, Vol. 61, 101837, doi: [10.1016/j.rcim.2019.101837](https://doi.org/10.1016/j.rcim.2019.101837).
- Marnada, P., Raharjo, T., Hardian, B. and Prasetyo, A. (2022), "Agile project management challenge in handling scope and change: a systematic literature review", *Procedia Computer Science*, Vol. 197, pp. 290-300, doi: [10.1016/j.procs.2021.12.143](https://doi.org/10.1016/j.procs.2021.12.143).
- Mazurkiewicz, A. and Poteralska, B. (2017), "Technology transfer barriers and challenges faced by R&D organisations", in *Procedia Engineering*, Elsevier, pp. 457-465, doi: [10.1016/j.proeng.2017.03.134](https://doi.org/10.1016/j.proeng.2017.03.134).
- Müller-Zhang, Z., Kuhn, T. and Antonino, P.O. (2023), "Towards live decision-making for service-based production: integrated process planning and scheduling with Digital Twins and Deep-Q-Learning", *Computers in Industry*, Vol. 149, 103933, doi: [10.1016/j.compind.2023.103933](https://doi.org/10.1016/j.compind.2023.103933).
- Piñal, O. and Arguelles, A. (2024), "Mixed reality and digital twins for astronaut training", *Acta Astronautica*, Vol. 219, pp. 376-391, doi: [10.1016/j.actaastro.2024.01.034](https://doi.org/10.1016/j.actaastro.2024.01.034).
- Scarrà, D. and Piccaluga, A. (2020), "The impact of technology transfer and knowledge spillover from Big Science: a literature review", *Technovation*, Vol. 116, 102165, doi: [10.1016/j.technovation.2020.102165](https://doi.org/10.1016/j.technovation.2020.102165).
- Simms, C. and Frishammar, J. (2024), "Technology transfer challenges in asymmetric alliances between high-technology and low-technology firms", *Research Policy*, Vol. 53 No. 3, 104937, doi: [10.1016/j.respol.2023.104937](https://doi.org/10.1016/j.respol.2023.104937).
- Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H. and Sui, F. (2018), "Digital twin-driven product design, manufacturing and service with big data", *International Journal of Advanced Manufacturing Technology*, Vol. 94 Nos 9-12, pp. 3563-3576, doi: [10.1007/s00170-017-0233-1](https://doi.org/10.1007/s00170-017-0233-1).

Further reading

- Ahmad, M.O., Dennehy, D., Conboy, K. and Oivo, M. (2018), "Kanban in software engineering: a systematic mapping study", *Journal of Systems and Software*, Vol. 137, pp. 96-113, doi: [10.1016/j.jss.2017.11.045](https://doi.org/10.1016/j.jss.2017.11.045).
- Kadenic, M.D., Koumaditis, K. and Junker-Jensen, L. (2023), "Mastering scrum with a focus on team maturity and key components of scrum", *Information and Software Technology*, Vol. 153, 107079, doi: [10.1016/j.infsof.2022.107079](https://doi.org/10.1016/j.infsof.2022.107079).
- Lawong, D.A. and Akanfe, O. (2024), "Overcoming team challenges in project management: the scrum framework", *Organizational Dynamics*, Vol. 54 No. 1, 101073, doi: [10.1016/j.orgdyn.2024.101073](https://doi.org/10.1016/j.orgdyn.2024.101073).

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