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Transformação Digital no Cenário Industrial das Pequenas e Médias Empresas: modelo conceitual e abordagens para aplicação prática

Florianópolis
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Orientador: Prof. Enzo Morosini Frazzon, Dr.-Ing.

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O presente trabalho em nível de Mestrado foi avaliado e aprovado, em 09 de Maio de 2023, pela banca examinadora composta pelos seguintes membros:

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Certificamos que esta é a versão original e final do trabalho de conclusão que foi julgado adequado para obtenção do título de mestre em Engenharia de Produção

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Prof. Enzo Morosini Frazzon, Dr.-Ing.
Orientador

Florianópolis, 2023.

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“Cada um de nós compõe a sua história
e cada ser em si carrega o dom de ser capaz,
de ser feliz”
(Almir Sater e Renato Teixeira, 1990)

RESUMO

A transformação digital da indústria vem alterando os modelos de negócio, as formas de interação com o cliente e o desempenho operacional na manufatura. O viés digital e a estratégia organizacional voltada para a digitalização tornaram-se fatores competitivos essenciais no cenário industrial mundial. Para isso, existe a necessidade da inclusão de processos tecnológicos de forma estruturada, principalmente voltados para a tomada de decisão baseada em dados e a integração dos sistemas, pautada nas diretrizes da transformação digital. Porém, apesar de boas práticas identificadas na literatura, muitas empresas não atingem estes objetivos de digitalização de forma consistente e madura, sendo um processo ainda mais desafiador para indústrias de pequeno e médio porte. Portanto, este trabalho visa contribuir para a transformação digital das Pequenas e Médias Empresas (PMEs), realizando uma evidenciação empírica do impacto da digitalização em uma indústria de médio porte, que almeja competir no cenário global. Para atingir este objetivo foram utilizados dados reais em um modelo computacional que simulou três diferentes cenários. O primeiro cenário retratou a realidade da empresa, sem a utilização de tecnologias digitais, o segundo e o terceiro cenários, simularam a digitalização, integração e utilização de tecnologias em uma linha de montagem. Os resultados obtidos foram comparados a partir de quatro Indicadores de Performance operacional: Lead Time, Taxa de Execução da Programação, Produtividade e Impacto no Faturamento. A simulação da utilização das tecnologias em uma linha de produção trouxe resultados positivos para todos os indicadores destacados, evidenciando a melhora da performance operacional diante da digitalização e integração dos dados. Em nível estratégico, os resultados servem como apoio na tomada de decisão por parte de gestores, bem como gera insights sobre a utilização das tecnologias digitais de forma eficiente em seus negócios.

Palavras-Chave: Transformação digital. Digitalização. Integração digital. Pequenas e Médias Empresas.

ABSTRACT

The digital transformation of the industry has been changing business models, customer interaction methods, and operational performance in manufacturing. The digital bias and the organizational strategy focused on digitization have become essential competitive factors in the global industrial scenario. Therefore, there is a need for structured technological processes, mainly focused on data-driven decision-making and system integration, based on digital transformation guidelines. However, despite the good practices identified in the literature, many companies do not consistently and maturely achieve these digitalization goals, which is an even more challenging process for small and medium-sized industries. Therefore, this work aims to contribute to the digital transformation of Small and Medium Enterprises (SMEs), by demonstrating the impact of digitalization on a medium-sized industry that aims to compete in the global scenario. To achieve this goal, real data was used in a computational model that simulated three different scenarios. The first scenario depicted the company's reality without the use of digital technologies, while the second and third scenarios simulated the digitization, integration, and use of technologies in an assembly line. The results obtained were compared based on four operational performance indicators: Lead Time, Planned Execution Rate, Productivity, and Impact on Revenue. The simulation of technology utilization in a production line yielded positive results for all the highlighted indicators, demonstrating improved operational performance due to digitalization and data integration. At a strategic level, these outcomes provide support for decision-making by managers and offer insights into the effective utilization of digital technologies in their businesses.

Keywords: Digital transformation. Digitalization. Digital integration. Small and Medium-sized Enterprises.

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LISTA DE ABREVIATURAS E SIGLAS

CPS - *Cyber Physical System*

ERP - Enterprise Resource Planning

I4.0 - Indústria 4.0

IoT - *Internet of Things*

MES- Manufacturing Execution System

PME- Pequenas e Médias Empresas

SED - Simulação de Eventos Discretos

SMEs – *Small and Medium-sized Enterprises*

TD - Transformação Digital

SUMÁRIO

1 INTRODUÇÃO

1.1 CONTEXTUALIZAÇÃO

Diante da aceleração da Indústria 4.0, a digitalização tornou-se essencial em todos os setores, uma vez que impacta diretamente na manufatura e seus processos. A Transformação Digital (TD) vem sendo o foco da indústria mundial, a qual busca integrar seus processos e organização, a fim de elevar sua competitividade em todos os níveis (BRANCA *et al.*, 2020).

O Conceito de Transformação Digital vem se desenvolvendo ao longo dos anos juntamente com a Indústria 4.0 e sua introdução em inúmeras companhias. Podendo ser compreendido como a utilização das tecnologias digitais associadas à novos processos e modelos de negócio diante da evolução da estratégia empresarial e da cultura organizacional (BOSILJ VUKŠIĆ *et al.*, 2018).

No cenário de concorrência global da indústria, a tecnologia da produção, a manufatura avançada e abordagens da indústria 4.0 são o principal meio de garantir a competitividade, pois proporcionam maior eficiência e resiliência na manufatura (FRAZZON *et al.*, 2020).

Há uma tendência crescente de busca não só pela digitatização (transformação dos dados para informação digital), mas principalmente pela digitalização dos processos organizacionais e de negócio, de forma integrada com as tecnologias da Indústria 4.0 e seus princípios (BOSILJ VUKŠIĆ *et al.*, 2018; BUTT, 2020).

Fang *et al.* (2020) destacam que atualmente o processo de digitalização é considerado meio estratégico para obtenção de um melhor desempenho operacional associado principalmente, à capacidade da análise de um grande banco de dados. Além disso, segundo o Fórum Econômico Mundial (WORLD ECONOMIC FORUM; ACCENTURE, 2018), a digitalização de diversos setores pode beneficiar a sociedade e indústria em mais de 100 trilhões de dólares para até 2025.

Deste modo, a transformação digital pode ser definida nos níveis tecnológico, organizacional e social: a utilização das tecnologias digitais promovem a inteligência e capacidade de análise dos dados, em nível organizacional, a digitalização permite a otimização dos processos e, socialmente, influencia a experiência dos consumidores finais (REIS *et al.*, 2018).

Em relação aos benefícios alcançados por meio da digitalização da manufatura e dos processos de negócio, Ghobakhloo e Fathi (2020) relatam que a transformação digital garante alto desempenho no curto prazo e o progresso futuro das empresas, portanto, é necessário que haja um desenvolvimento e planejamento de um modelo de negócio apto para a implementação das tecnologias e inovações emergentes da Indústria 4.0.

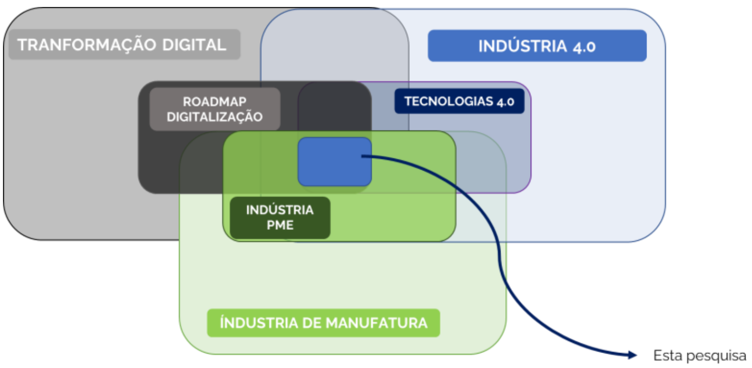
Tratando-se da sua abrangência, a transformação digital engloba toda a cadeia de recursos, informação, objetos e pessoas dentro das redes de valor, trazendo um viés orientado a processos em que o olhar do cliente é o foco. Por meio da digitalização, as empresas podem desenvolver a perspectiva do cliente desde o pedido de compra, processo produtivo, até a entrega e instalação do produto, caracterizando um processo de ponta-a-ponta (end-to-end) (PSCHYBILLA; HOMANN, 2020).

Para que a Transformação digital ocorra de forma eficiente, é necessário que as empresas implementem as tecnologias digitais de modo escalável, entendendo primeiramente sua situação atual e depois construindo seu roadmap de acordo com suas necessidades (DE CAROLIS *et al*., 2018). Ademais, trabalhos na literatura mostram que o processo de transformação digital para indústria de grande porte se difere da realidade das indústrias de menor tamanho (GHOBAKHLOO & CHING, 2019), sendo que as chances de sucesso na jornada de digitalização são maiores para as grandes empresas (FANG *et al*., 2020).

Para o cenário das Pequenas e Médias Empresas (PMEs) a realidade da transformação digital é mais desafiadora, uma vez que, estas possuem menos conhecimento sobre os caminhos e métodos mais efetivos para iniciar sua digitalização (GAMACHE *et al*., 2019). Destaca-se que um dos motivos da baixa adoção está relacionado com a ideia de altos custos e a característica de limitação de recursos financeiros por parte das manufaturas de menor porte (GHOBAKHLOO & CHING, 2019).

Assim sendo, visando contribuir em um cenário de maiores desafios, a Figura 1 demonstra onde esta pesquisa se encaixa no contexto da transformação digital e seus impactos nos processos na indústria de pequeno e médio porte.

Figura 1 - Contextualização da pesquisa.



Fonte: Elaborado pelo autor (2021).

Neste contexto, a presente pesquisa pretende evidenciar de forma conceitual e prática os impactos da transformação digital, trazendo resultados empíricos, com dados reais de uma indústria de médio porte, considerando o cenário de implementação de tecnologias digitais em uma linha de montagem.

1.2 JUSTIFICATIVA DO TEMA

A sobrevivência das empresas no cenário competitivo global requer inovação e melhorias nos modelos de negócio, sendo que a digitalização e as tecnologias 4.0 são essenciais para atingir estes objetivos (BUER *et al*., 2020). De acordo com a literatura, muitas indústrias enfrentam dificuldades na migração completa e direta para a indústria 4.0 (KU *et al*., 2020). Segundo Fang et.al, (2020) o processo de transformação digital possui maior chance de sucesso em empresas de grande porte, enquanto a indústria de pequeno e médio porte necessitam atenção e métodos diferenciados. Para Buer *et al*., (2020) é necessário direcionar atenção e esforços para suportar o desenvolvimento digital em pequenas e médias empresas, visto que o porte das companhias é um fator preditor significativo para o sucesso da digitalização.

No geral, observa-se que a indústria de manufatura como um todo caminha em passos lentos no processo da digitalização, que ocorre muitas vezes de forma fragmentada e sem uma visão holística da mudança necessária, ao mesmo tempo em que é notória a importância da digitalização da indústria, uma vez que este é o setor que determina a liderança da economia digital de muitos países (LOLA; BAKEEV, 2020).

O avanço da transformação digital é considerado desafiador principalmente porque os protocolos de implementação não são padronizados, as tecnologias são aplicadas sem avaliação de impacto e de forma compartimentalizada na empresa, além do que há uma ausência de visão realista sobre o retorno do investimento (BUTT, 2020). Schimitt *et al*., (2019) relatam que há uma oportunidade de orientar as PMEs focando esforços em trabalhos que adaptem os conceitos e protocolos genéricos e customizem os roadmaps para a realidade dos projetos de I4.0 destas companhias.

Para tanto, é preciso acelerar a transformação digital por meio de esforços não apenas na pesquisa aplicada, mas, principalmente, em casos práticos de implementação, a fim de sumarizar o know-how obtido durante o processo (TSCHANDL *et al*., 2020).

Outro fator importante com relação a jornada da Transformação digital na indústria é o nível de sucesso na sua implementação, o qual muitas vezes é prejudicado pela dificuldade na realização da análise de seu custo-benefício uma vez que os investimentos e infraestrutura necessários são considerados altos (PFLAUM; GÖLZER, 2018).

Desse modo, entende-se a necessidade do desenvolvimento de um projeto com foco em apoiar o processo de digitalização e aplicação de tecnologias 4.0 evidenciando seus benefícios quando aplicados à realidade de uma empresa de médio porte.

1.3 OBJETIVOS

Esta pesquisa tem como objetivo geral propor um modelo conceitual para a digitalização de pequenas e médias empresas industriais brasileiras, bem como evidenciar o impacto da transformação digital em uma indústria de manufatura de médio porte. Para atingir este objetivo geral, foram subdivididos os objetivos específicos que estão descritos abaixo.

Dentre os objetivos específicos esta pesquisa busca:

i. Avaliar aspectos da transformação digital presentes na literatura em comparação com o cenário prático brasileiro.
ii. Propor um *guia para digitalização* e um modelo conceitual, visando fomentar a digitalização em indústrias de médio porte.
iii. Comparar e evidenciar, usando simulação computacional, os resultados da aplicação de tecnologias digitais em três diferentes cenários operacionais, utilizando dados de uma empresa real.

No decorrer deste trabalho, um guia abrangente sobre a transformação digital será desenvolvido com base nos conceitos estudados durante a execução do objetivo específico i. Na sequência (objetivo ii), um modelo conceitual específico e prático será estruturado com base em um caso real da indústria de médio porte. Ao final da pesquisa, na etapa do objetivo específico iii, será realizada a aplicação do modelo, de forma computacional, utilizando dados de um use case, a fim de evidenciar os impactos da transformação digital em um caso real em três diferentes cenários, partindo do cenário real, sem a aplicação das tecnologias digitais e aumentando o número de soluções tecnológicas e conceitos para os cenários 2 e 3.

1.4 DELIMITAÇÃO DO ESTUDO

O presente estudo delimita-se ao campo de concentração da Transformação Digital nas médias empresas, tendo como linha de pesquisa a aplicação de tecnologias digitais e a avaliação do impacto destas implementações simuladas com dados reais. Ainda nesta delimitação, o foco desta pesquisa está na aplicação de tecnologias associadas ao chão de fábrica e o impacto operacional gerado pela transformação digital. Utilizando dados de um caso real, o presente trabalho tem como escopo uma empresa de médio porte, brasileira, situada no estado de Santa Catarina, que fabrica equipamentos médicos e odontológicos, atua em modelo *business to customer,* e pretende elevar seus níveis de competitividade tanto no comércio nacional quanto internacional.

1.5 ESTRUTURA DO TRABALHO

Este trabalho apresenta a estrutura de coletânea de artigos, de acordo com a resolução 002/PPGEP/2018, aprovada em 07 de novembro de 2018, desta maneira, está dividido em 5 capítulos, conforme descrito a seguir:

O capítulo 1, apresenta a introdução do tema, subdividido nas seções de Contextualização, Justificativa do tema e Objetivos.

No capítulo 2 está descrito o referencial teórico com os principais tópicos acerca do tema proposto, aprofundando a correlação entre os conceitos de Transformação Digital e Industria 4.0 e as principais Tecnologias envolvidas no processo de digitalização.

O capítulo 3 discorre sobre os métodos de pesquisa adotados, procedimentos, abordagem proposta e o cronograma da pesquisa.

O capítulo 4 apresenta o resultado da primeira fase da pesquisa, em formato de artigo, contemplando os objetivos específicos i e ii apresentados no primeiro capítulo.

No capítulo 5 o último objetivo específico (iii) é abordado com a apresentação do artigo 2. Uma síntese do estudo, apresentando os resultados dos capítulos 4 e 5 estão presentes no capítulo 6, e como finalização o capítulo 7 apresenta as considerações finais do trabalho.

2 REFERENCIAL TEÓRICO

2.1 TRANSFORMAÇÃO DIGITAL E INDÚSTRIA 4.0

A digitalização e a intensa integração dos sistemas, cadeia de valor, produtos e serviços são características centrais da revolução industrial em andamento, conhecida como Indústria 4.0 (MATOS *et al*., 2019). Neste contexto, a transformação digital surge como uma jornada ou progresso contínuo e de ponta-a-ponta de digitalização, por meio da qual é possível desenvolver e otimizar as companhias em seus níveis tecnológicos, organizacionais e sociais (REIS et.al, 2019; PSCHYBILLA; HOMANN, 2020).

Machado *et al*. (2019) define o termo transformação digital como um conjunto de mudanças no modelo de negócio, processos e competências que trazem benefícios à organização por meio da implementação plena de novas tecnologias digitais. Para Gamache *et al*. (2020) a transformação digital pode ser interpretada como um método utilizado por uma organização visando um sistema digitalizado por meio da adoção de práticas voltadas ao desenvolvimento de um melhor desempenho digital.

Segundo Kim e Ha (2023), o conceito de Transformação digital está relacionado com um conjunto de atividades corporativas que visam fortalecer a competitividade do negócio frente as mudanças no ambiente empresarial geradas pela adoção de tecnologias digitais tais como Big Data, Inteligência Artificial, Internet das Coisas, Reconhecimento Facial Automatizado, Sistemas Ciber-Físicos e Plataformas Inteligentes de Operação.

Büyüközkan e Güler (2020) apontam que os principais benefícios da TD estão relacionados à redução da carga de trabalho que não agrega valor ao processo e maior qualidade dos dados que dão suporte à tomada de decisão, tais proveitos resultam em alta eficiência operacional e consequentemente aumentam a satisfação do cliente Frazzon *et al*., (2018) destacam o aspecto da utilização da digitalização para gestão de operações, habilitando o controle da produção e acesso ao estado real do sistema de manufatura.

Os conceitos da Transformação Digital e Industria 4.0 trazem definições e aplicações de tecnologias em toda a cadeia de valor de uma organização, incluindo redes integradas que permitem a comunicação e cooperação entre máquinas, humanos, produtos e logística em tempo real (KALTENBACH *et al*., 2018).

Algumas práticas características da transformação digital são descritas por Gamache *et al*. (2020), sendo estas: visão e estratégia digital, aquisição e desenvolvimento de habilidades digitais, sistemas ágeis e inovadores, cibersegurança, integração, conexão de ferramentas digitais e uso de dados de forma estratégica. Lammers *et al*, (2018) relatam que os padrões adotados em cada organização durante a digitalização diferem em função de sua estratégia, objetivos, contexto industrial e situações de competitividade enfrentadas, tornando-se diferentes entre os diversos países e segmentos da indústria.

No cenário das pequenas e médias empresas, a digitalização, do ponto de vista das fábricas inteligentes, impacta positivamente o desempenho dos negócios em comparação àquelas que utilizam tecnologias de fabricação tradicionais, o efeito de colaboratividade nas cadeias de valor, bem como a priorização da inovação na manufatura e correta alocação de recurso são fatores que influenciam significativamente na jornada para a transformação digital (KIM, JEONG & PARK, 2023).

2.1.1 Aspectos Da Integração Digital

De acordo com Matos *et al.* (2019), o processo de Transformação Digital e suas integrações, ocorrem principalmente em seis dimensões da Indústria 4.0, nomeadamente: (a) vertical, (b) horizontal, (c) end-to-end, (d) aceleração da manufatura, (e) digitalização de produtos e serviços e (f) novos modelos de negócio e envolvimento do consumidor.

O nível vertical conecta os dados da manufatura em tempo real, integrando os sistemas e processos internos (TSCHANDL *et al.*,2020).

a. O nível horizontal, aumenta a eficiência e flexibilidade produtiva por meio da interface entre fornecedores, processos inteligentes e distribuição ao cliente (TSCHANDL *et al.*,2020).
b. A dimensão end-to-end integra toda engenharia desde o desenvolvimento do produto até sua disposição final, bem como a colaboratividade durante seu ciclo de vida (MATOS *et al.*, 2019).
c. A aceleração da manufatura refere-se à utilização das tecnologias digitais de forma exponencial nos processos de fabricação, otimizando a cadeia de valor (MATOS *et al.*, 2019).
d. A digitalização de produtos e serviços está relacionada aos “produtos inteligentes”, por meio da utilização de sensores e sistemas que permitam à interatividade destes durante o ciclo de vida. Além disso, o processo de servitização é considerado neste nível como a capacidade de integrar serviços embarcados aos produtos (MATOS *et al.*,2019).
e. O nível “modelos de negócio e envolvimento do consumidor” determina o foco em processos inovadores que, a partir da digitalização, oferecem uma relação mais próxima ao cliente e suas necessidades (MATOS *et al.*,2019).

Para Buer *et al*. (2020), a digitalização da manufatura pode ser definida em três aspectos: (a) digitalização do chão de fábrica, (b) utilização de tecnologias para integração vertical e horizontal e (c) competências organizacionais em tecnologia da informação.

2.1.2 *Roadmap* para Transformação Digital

Para que a Transformação Digital ocorra de forma consistente, é necessário seguir um modelo estruturado de etapas estratégicas, podendo ser caracterizadas por meio de um *roadmap*, o qual serve como um guia para a inicialização de projetos de digitalização nos processos organizações (SCHMITT *et al*., 2020). Segundo Carolis, De *et al*. (2018), antes de iniciar a jornada, a companhia deve entender seu cenário, por meio da definição de sua maturidade digital, tomando como base os aspectos de organizacionais, de processos, controle e monitoramento, e tecnológicos.

O objetivo geral do modelo de maturidade digital é avaliar o nível em que a empresa se encontra com relação à digitalização e recomendar as ações futuras de forma a orientar para o próximo estágio rumo à TD (COLLI *et al*., 2019).

A maturidade também pode ser descrita seguindo os fatores relatados pelo Índice de Maturidade da Indústria 4.0 da Acatech (SCHUH *et al*., 2020), conforme destaca Stich *et al*., (2020): (i) visibilidade, o quanto a companhia consegue ver o que acontece, (ii) transparência, a empresa entende porque os fatos acontecem, (iii) habilidade de previsão, a organização consegue prever acontecimentos futuros e (iv) adaptabilidade, determinando o quanto a empresa e os processos são otimizados de forma autônoma e adaptativa diante dos fatos.

Após a identificação do estado atual por meio do nível de maturidade, no modelo apresentado por Carolis, De *et al*. (2018), as etapas seguintes contemplam uma análise de forças e fraquezas organizacionais, em sequência, identificação de oportunidades e por fim, a definição de um *roadmap* específico para cada caso.

Buhulaiga e Ramsangar (2019) e Butt (2020) apresentam uma estrutura conceitual para a transformação digital baseada em processos, cujas etapas podem ser definidas de forma ampla como: identificação dos processos organizacionais, análise, transformação dos processos para soluções integradas, análise de custo/viabilidade, implementação dos processos e monitoramento e controle.

Nygaard, Colli e Wæhrens (2020) conceituam um framework da digitalização baseado em uma metodologia de autoavaliação por meio do mapeamento do fluxo de valor em 5 etapas: identificação do escopo, mapeamento de atividades, mapeamento do fluxo de informação, mapeamento tecnológico e por fim, a avaliação do uso real em comparação ao uso potencial das tecnologias para processamento e integração de dados.

Rautenbach *et al*. (2019) descrevem um modelo para a digitalização estruturado em duas fases, visando primeiramente, o entendimento da criação de valor para a organização e em seguida, criando uma proposta de perfil digital para cada área e por fim, unindo estes valores em uma análise de projeção futura, fornecendo não um guia e passo a passo, mas sim, uma estrutura de suporte à decisão diante da criação da estratégia para a transformação digital.

Outro framework desenvolvido por Liu *et al*. (2022), representa dimensões de fluxos de implementação, desenvolvimento de soluções e desenvolvimento do negócio como os guias para a transformação digital, envolvendo também os estágios de interação entre o negócio, tecnologias e inovação. Segundo os autores os *steakholders* podem utilizar as três dimensões como guias para um plano de desenvolvimento tecnológico e empresarial, iniciando pela revolução no modelo de negócio, passando pela definição dos requisitos técnicos de conectividade, computação e inteligência e por fim, inovando nos aspectos de integração entre os negócios e tecnologia.

Contribuindo com uma outra abordagem para a digitalização, o modelo 6B é citado por Elangovan, Seshadri e Seetharaman (2021), propondo-o como um guia que auxilia as organizações de forma sistemática na jornada para se tornarem digitais. Os passos do modelo incluem a avaliação do estado atual, a definição do modelo de negócio digital, a estratégia digital, identificação das alavancas de implementação e a execução a partir de tecnologias inteligentes.

O roteiro descrito por Sufian *et al.* (2021) é representado por uma engrenagem, demonstrando que a jornada de digitalização ocorre de forma gradual e serve como uma visão holística para adotar os conceitos da transformação digital. As seis etapas apresentadas são: estratégia, conectividade, integração, análise e inteligência artificial e, por fim, a fase final de escala, visando a melhoria contínua na jornada da I4.0.

De forma sintética, o Quadro 1 apresenta as principais etapas dos roteiros desenvolvidos pelos autores citados, elucidando alguns pontos em comum nos guias da transformação digital.

Quadro 1 – Síntese de etapas da digitalização

Autores(as)	Etapas para a digitalização						
	Definição do estado atual	Análise da estratégia do modelo de negócio	Mapeamento dos fluxos de informação	Definição de tecnologias	Conectividade e integração	Implementação	Monitoramento e Controle
De Carolis *et al* (2018)	X	X		X		X	
Buhulaiga e Ramsangar (2019) e Butt (2020)	X	X			X	X	X
Nygaard, Colli e Wæhrens (2020)	X		X	X	X		
Rautenbach *et al.* (2019)	X	X					
Liu *et al.* (2021)	X	X	X	X	X	X	
Elangovan, Seshadri e Seetharaman (2021)	X	X		X		X	
Sufian *et al* (2021)		X		X	X		X

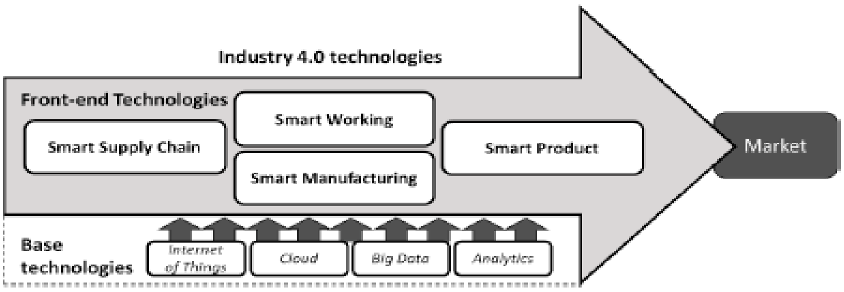
Fonte: Elaborado pelo autor (2023).

2.2 TECNOLOGIAS PARA DIGITALIZAÇÃO

A integração de novas e ferramentas digitais e avançadas tecnologias, de hardware ou software são considerados o ponto de partida para a transformação digital das empresas (DÖRR *et al.*, 2023). Destacam-se os sistemas cyber-físicos, a internet das coisas, computação em nuvem, análise de big data, inteligência artificial e realidade virtual (HAUSBERG *et al.*, 2019; LOLA; BAKEEV, 2020). Conhecidas como tecnologias da Industria 4.0, permitem o acesso em tempo real dos dados e uma visão atualizada e abrangente do sistema de produção (TAKEDA BERGER *et al.*, 2019).

Em outro estudo, Sawangwong e Chaopaisarn (2023), destacam cinco pilares tecnológicos relevantes no contexto da indústria 4.0, sendo eles: Internet das Coisas, Computação em nuvem, Análise de Big data, Manufatura Aditiva e Cibersegurança. Por meio da Figura 2 é possível observar como algumas destas tecnologias estão estruturadas dentro do contexto da digitalização e indústria 4.0.

Figura 2 – Framework das Tecnologias da Indústria 4.0



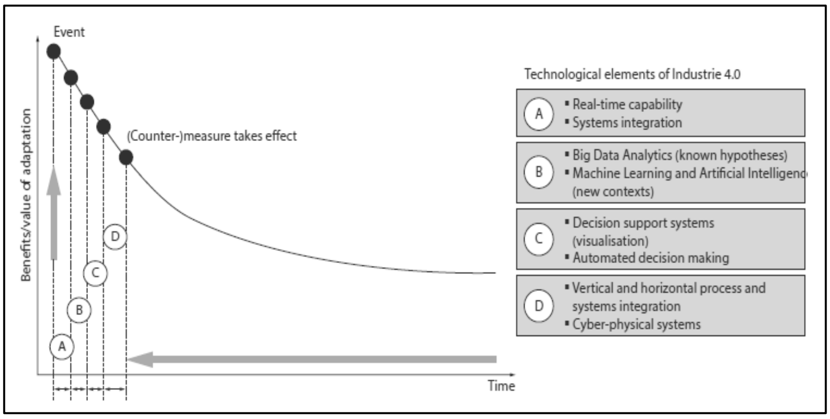
Fonte: (FRANK *et al*., 2019).

Segundo Frank *et al*. (2019) as tecnologias da indústria 4.0 relacionam-se com os conceitos de manufatura, trabalho, logística e produtos inteligentes uma vez que, quando combinadas, permitem a comunicação entre os mundos reais/físicos e virtuais/digitais (ZANGIACOMI *et al*., 2020). A manufatura inteligente é caracterizada pela existência de operações autocontroladas em sistemas compostos por máquinas, sensores e robôs programados de forma automatizada (CHONSAWAT, 2018).

Esta comunicação e interconectividade entre os elementos físicos e a realização da coleta de dados em meio digital são características atribuídas a tecnologia de Internet das Coisas (IoT), a qual permite a conexão entre dispositivos e fornece informação para sistemas internos, externos e possibilita a análise de dados (LEE; LEE, 2015)

Os bancos de dados em nuvem gerados por meio da conectividade dos dispositivos são conhecidos como “Big Data”, a partir dos quais, são realizadas análises (Big Data Analytics) que facilitam a tomada de decisão baseada em dados (IVANOV *et al*., 2019). Consequentemente, estas tecnologias habilitam as empresas a tornarem-se mais ágeis no tempo de resposta a um evento e altamente adaptáveis às mudanças e requisitos dos consumidores (SCHUH *et al*., 2020), conforme exemplifica a Figura 3.

Figura 3 – Relação entre elementos tecnológicos e adaptabilidade à eventos



Fonte: (SCHUH *et al*., 2020).

Destacam-se a integração vertical-horizontal dos processos e as integrações a partir de *cyber physical systems* (CPS), os quais são consideradas como a evolução do design de processos de produção uma vez que visam melhorar o desempenho geral da cadeia produtiva (FRAZZON *et al*., 2013). No âmbito da integração de sistemas, o monitoramento e controle dos processos surge como aspecto importante para as indústrias, para isso, tecnologias como RFID e computação em nuvem contribuem para o desenvolvimento de manufaturas inteligentes na medida em que promovem automatização de dados e rastreabilidade de produtos (PACHECO, JUNG & AZAMBUJA, 2023).

Considerando o cenário das PME's, Mcdermott *et al.* (2023) relatam em seu estudo um destaque para as tecnologias de automação, processos inteligentes, inspeção automatizada e computação em nuvem, bem como a escolha correta de equipamentos e softwares como fatores considerados críticos para o sucesso na digitalização destas organizações.

A tecnologia é fator chave para a transformação digital, por meio do modo como as organizações podem integrar seus processos diante da sua aplicação, porém Mahmood *et al.* (2019) descrevem a importância da análise das tecnologias, dentre todas existentes, para seleção daquelas fundamentais ao processo, respeitando as necessidades de cada organização em particular.

2.3 CENÁRIO GLOBAL DA TRANSFORMAÇÃO DIGITAL

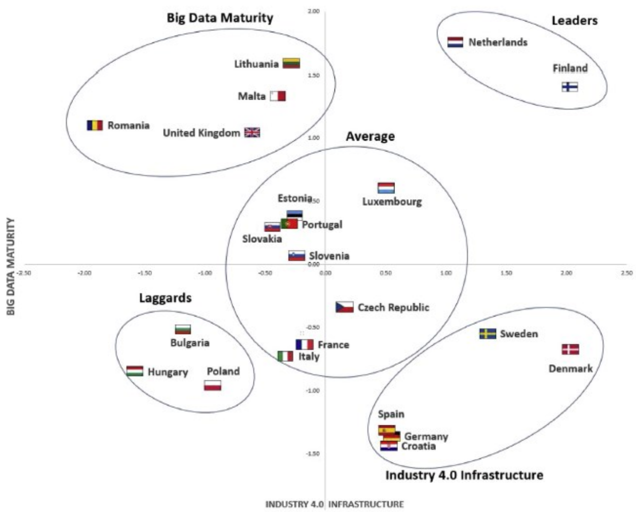
No cenário mundial, alguns estudos destacam o nível e maturidade da transformação digital em diferentes aspectos, tal como Kaltenbach *et al*. (2018), relatando o desenvolvimento de serviços inteligentes por meio de estudos de caso em companhias Alemãs, mostram que há um grande avanço no país em serviços orientados à clientes, mas também elucidam alguns desafios principalmente relacionados à estruturação dos dados e mudança cultural.

Com relação aos aspectos de infraestrutura da indústria 4.0 e maturidade de Big Data, os países da união europeia apresentam grande disparidade evolutiva: países como Finlândia e Holanda são considerados líderes, apresentando níveis elevados na adoção de ambos os fatores, enquanto a Alemanha, país de origem dos conceitos 4.0, necessita ainda de maiores desenvolvimentos na utilização do Big Data Analytics no setor de manufatura (CASTELO-BRANCO *et al*., 2019). A Figura 4 abaixo demonstra o cenário da digitalização entre vários países da Europa, segundo os estudos de Castelo Branco et.al (2019) com base nos aspectos mencionados.

Neste contexto, a Espanha se revela como um destaque entre os países do sul europeu, por apresentar políticas de transformação digital bem definidas e efetivas, visando o desenvolvimento das lacunas de digitalização no país (GRECO *et al*., 2019).

Em paralelo, indústrias da Austrália enxergam o grande potencial da digitalização como fator oportuno de competitividade no mercado global, em vista das desvantagens geográficas do país, Lammers *et al*, (2018) aponta que, é necessário promover e desenvolver tecnologias digitais como sensores, análise de dados, manufatura aditiva e realidade virtual.

Figura 4 – Cenário da Transformação Digital na Europa



Fonte: I. Castelo-Branco *et al* (2019).

Gamache *et al*., (2020) determinou os fatores de maior influência na transformação digital de pequenas e grandes empresas de Quebec no Canadá, revelando que as SMEs (*Small and medium-sized enterprises*) demandam uma transformação digital completa visto que ainda não adotaram muitas das tecnologias 4.0 e que o aspecto mais desenvolvido e implementado em questão tecnológica está relacionado ao monitoramento de processos produtivos e no aumento da flexibilidade.

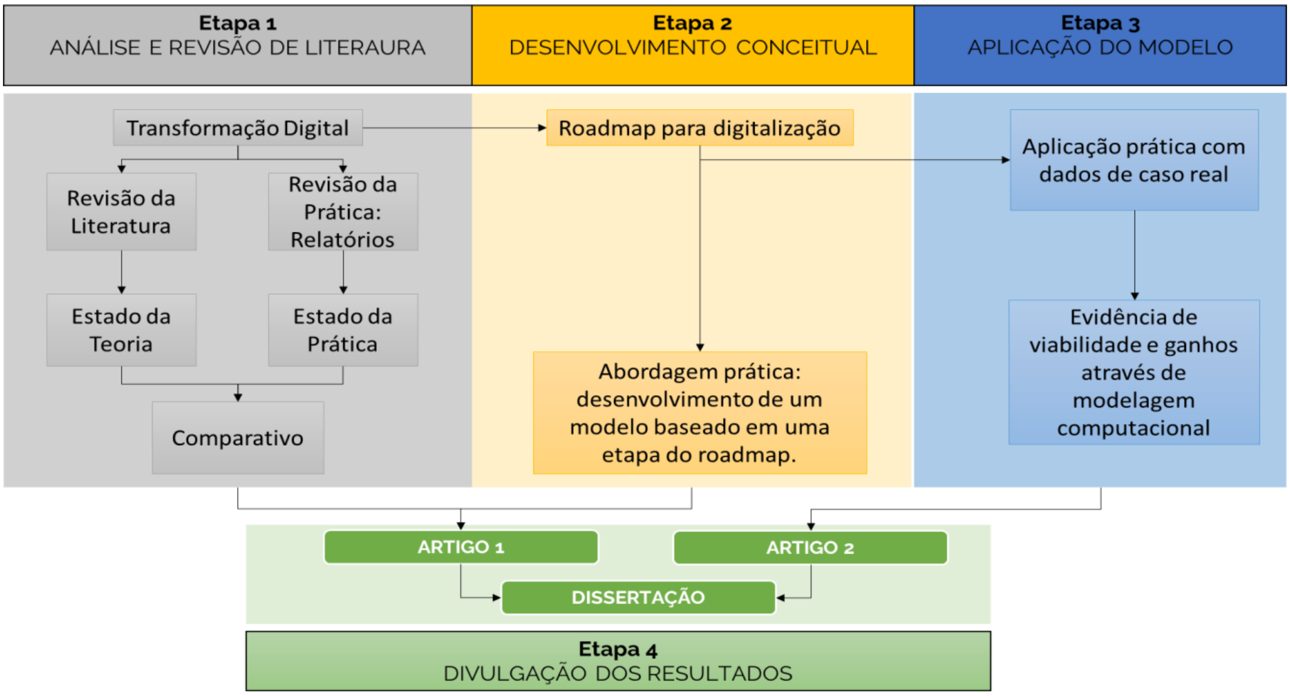
3 MÉTODOS ADOTADOS

Esta seção apresenta a estrutura metodológica e a abordagem proposta da pesquisa em questão.

3.1 PROCEDIMENTOS METODOLÓGICOS

Os procedimentos metodológicos adotados nesta pesquisa visam garantir a execução dos objetivos específicos apresentados anteriormente, para isso, a pesquisa está dividida em quatro macro etapas: (i) Análise e revisão da literatura, (ii) Desenvolvimento do modelo conceitual (iii) Desenvolvimento computacional e aplicação do modelo e (iv) interpretação e divulgação dos resultados. A Figura 5 apresenta de forma detalhada as etapas de desenvolvimento do presente estudo.

Figura 5 – Etapas do desenvolvimento



Fonte: Elaborado pelo autor (2021).

A execução das atividades e condução das etapas estão organizadas de modo a cumprir os objetivos específicos determinados anteriormente. Desta forma, a correspondência com os objetivos está apresentada no Quadro 2 abaixo.

Quadro 2 – Relação entre etapas e objetivos da pesquisa

Etapa	Método	Objetivo Específico	Resultados
1. Análise e Revisão da Literatura	· Revisão Sistemática	· (i) Avaliar aspectos da transformação digital presentes na literatura em comparação com o cenário prático brasileiro.	· Artigo 1
2. Desenvolvimento Conceitual	· Modelagem Conceitual	· (ii) Propor um roadmap e um modelo conceitual, visando auxiliar a implementação de tecnologias digitais em indústrias de pequeno e médio porte.	· Artigo 1
3. Aplicação do Modelo	· Modelagem e Simulação · Caso real	· (iii) Comparar e evidenciar, usando simulação computacional, os resultados da aplicação de tecnologias digitais em três diferentes cenários, utilizando dados de uma empresa real.	· Artigo 2

Fonte: Elaborado pelo autor (2023).

As etapas apresentadas estão descritas a seguir definindo a condução da pesquisa e procedimentos realizados.

a) Análise e Revisão da Literatura: Esta fase tem como propósito revisar a literatura existente de forma sistemática, utilizando a metodologia PRISMA (*Preferred Reporting Items for Systematic Review and Meta-Analysis),* descrita em Moher *et al*. (2010). Nesta etapa será identificado o cenário teórico, apresentado pela literatura, visando definir os principais aspectos da transformação digital e, posteriormente realizar um comparativo destes aspectos os casos práticos da indústria brasileira descritos em relatórios.

b) Desenvolvimento Conceitual: A partir dos resultados obtidos na etapa anterior, um *roadmap* abrangente foi estruturado, visando descrever os principais pilares da transformação digital a serem considerados durante o processo de digitalização das empresas. Derivando dele, ainda nesta fase foi desenvolvido um modelo conceitual específico, com uma abordagem prática baseada em um caso real, objetivando auxiliar empresas de médio porte em sua jornada para transformação digital.

c) Aplicação do Modelo: Nesta etapa do procedimento, foi desenvolvido o modelo computacional, com a utilização da ferramenta de modelagem de simulação Anylogic. Este modelo se baseia na metodologia de simulação de eventos discretos (SED) e foi aplicado utilizando dados reais de uma linha de montagem em uma indústria brasileira de médio porte. O objetivo desta etapa é fornecer dados empíricos que evidenciem os impactos da utilização de tecnologias digitais. A fim de comparar os resultados obtidos, três diferentes cenários foram definidos: um cenário real, sem digitalização, e dois outros cenários com a implementação de tecnologias digitais voltadas à gestão operacional. A comparação foi realizada a partir de quatro indicadores: Lead Time, Taxa de Execução da Programação, Produtividade e Impacto no Faturamento.

d) Divulgação dos Resultados: Esta etapa tem como objetivo disseminar os resultados e contribuir para os avanços da Transformação Digital, principalmente nas pequenas e médias empresas. Para este fim, foram desenvolvidos dois artigos, o primeiro apresenta os aspectos da transformação digital, um *roadmap* abrangente para digitalização e o modelo conceitual específico para um caso real. O segundo artigo contempla o desenvolvimento, a aplicação do modelo computacional e o comparativo entre os resultados obtidos para cada um dos cenários simulados.

3.2 ABORDAGEM PROPOSTA

De acordo com os modelos e métodos de pesquisas existentes, este trabalho apresenta caráter de modelagem quantitativa baseada em simulação, definida por Bertrand e Fransoo (2002) como "construção de modelos objetivos que podem explicar o comportamento de processos operacionais da vida real ou que podem capturar problemas de tomada de decisão enfrentados por gestores em processos operacionais da vida real"

Inicialmente o modelo conceitual foi desenvolvido tendo como base os conceitos definidos durante a revisão de literatura efetuada na etapa 1, e destaca o aspecto de gestão de operações, monitoramento e controle aplicados à linha de montagem principal do caso real. O modelo será descrito com mais detalhes no próximo capítulo.

A segunda etapa inclui a definição do escopo, representado por um sistema de manufatura constituído por uma linha de montagem e suas linhas de abastecimento, que fazem parte do cenário real de uma indústria brasileira de manufatura de médio porte, do segmento metal mecânico, que fornece equipamentos para saúde e trabalha em modelo B2C (Business to Costumer), ou seja, entrega seus produtos diretamente os consumidores finais. Neste caso, a empresa caminha em passos lentos rumo a transformação digital no chão de fábrica, e busca estabelecer mercado em níveis internacionais, além de se manter competitiva no mercado nacional.

Na etapa de modelagem o modelo computacional foi desenvolvido utilizando o Software Anylogic como recurso para simulação. A técnica utilizada foi a de Simulação de Eventos Discretos (SED), amplamente empregada em projetos aplicados a sistemas de manufatura, permitindo a realização de experimentos e simulações que promovem a melhoria dos sistemas reais (KAMPA *et al.*, 2017).

Os dados coletados foram utilizados para realizar a modelagem computacional de três diferentes cenários: (C1) – cenário real - este cenário representa a realidade da empresa em questão, sem a utilização de tecnologias digitais, fluxo de informação em papel e sem integração entre sistemas; o C2 e C3 – cenários 2 e 3 – simulam a implementação de tecnologias digitais na linha de montagem, ou seja, fluxo de informações automatizado e eletrônico, fábrica sem papel e sistemas integrados. A diferenciação entre os cenários 2 e 3 está no tempo de produção, no cenário 2 temos o tempo real de produção, variando com as paradas reais, fora do tempo takt, e no cenário 3, temos o tempo de produção programado pelo Planejamento e Controle de Produção (PCP), ou seja, as linhas trabalhando de forma balanceada, dentro do tempo takt.

A avaliação e comparação dos resultados dos três cenários foi realizada a partir da definição de quatro indicadores:

(a) Lead Time: tempo de atravessamento dos produtos na linha de montagem, desde o momento de entrada da ordem de produção, até a finalização do equipamento;
(b) Taxa de Execução da Programação: percentual de equipamentos produzidos no sequenciamento correto programado pelo PCP, retratando a eficiência do sistema em produzir conforme o planejamento;
(c) Produtividade: número de equipamentos produzidos por colaborador, identificando a eficiência de utilização dos recursos disponíveis;
(d) Impacto no Faturamento: quantidade de receita que a empresa gerou ou deixou de gerar diante das alterações nos cenários.

Neste trabalho estes indicadores serão abordados em nível operacional, devido à disponibilidade de dados do caso real, uma vez obtivemos acesso apenas aos dados da produção. Outro ponto destacado é que a aplicação destes dados no modelo de simulação, visa reproduzir o modelo de operação da indústria em questão, o que viabiliza obter como resultado os indicadores operacionais descritos anteriormente. Os aspectos em níveis táticos e estratégicos serão abordados no tópico de discussão dos resultados.

4 DIGITAL TRANSFORMATION IN BRAZILIAN INDUSTRY: BRIDGING THEORY AND PRACTICE

Este artigo foi publicado na revista Production (2023)

Abstract

Paper aims: This paper aims to evaluate the digitalization scenario of Brazilian industry, as well as to propose a practical approach to its digital transformation.

Originality: No comparison is available that aims to understand the differences and gaps between theoretical research and the reality of digital transformation in Brazilian industries.

Research method: Based on three steps, namely: review and bibliographic analysis to identify the main aspects of digital transformation; content analysis of national reports to define the state of practice; comparison between the results of theory and practice.

Main findings: The results demonstrate an alignment between the aspects found in the scientific literature and the reports analyzed. The pillars of digital transformation are widely discussed in industrial reality. However, implementation gaps (and related opportunities) difficult the digital transformation of the Brazilian industry.

Implications for theory and practice: This paper introduces a proposition that unites theoretical aspects in a model that may be applied to enable digital transformation in the industry.

Keywords: Digital Transformation. Brazilian Industry. Industry 4.0. Digitalization.

4.1 INTRODUCTION

The digitalization of processes has stood out in companies as it promotes a customer-oriented view along with efficiency improvements (VILLALONGA *et al.*, 2020). In the scenario of global industry competition, production technology, advanced manufacturing, and Industry 4.0 approaches are the primary way to ensure competitiveness, as they provide greater efficiency and resilience in manufacturing systems (FRAZZON *et al.*, 2020).

The journey for the use of digital technologies is known as Digital Transformation (DT), through which it is possible to develop highly efficient activities in the corporate value chain (BÜYÜKÖZKAN; GÜLER, 2020). Digitalization is present in most economic sectors and requires companies to quickly adapt to make it the center of their organizational strategy (VILLALONGA *et al.*, 2020). Fang *et al.* (2020) pointed out that the digitalization process is considered a strategic approach to obtaining better operational performance, mainly associated with the ability to analyze a large database that brings new opportunities for traditional companies. Furthermore, according to the World Economic Forum and Accenture (2018), the digitalization of diverse sectors may benefit society and industry by more than 100 trillion dollars by 2025.

Digital transformation may be defined at the technological, organizational, and social levels, given that the use of digital technologies promotes intelligence and data analysis capacity, digitalization allows the optimization of processes at the organizational level, and, socially, it influences the experience of consumers (REIS *et al*., 2018). Regarding the benefits achieved through the digitalization of manufacturing and business processes, Ghobakhloo and Fathi (2020) reported that digital transformation ensures high performance in the short-term and future progress of companies; therefore, it is necessary to develop and plan a business model capable of implementing the emerging technologies and innovations of Industry 4.0. The evolution of information technology and the growth of digitalization makes it possible to connect the physical system and the information flow of the production system. This data-driven approach and the digitalization of production and operations allow possibilities for operational improvements and create value for the organization (AGOSTINO *et al*.,2020).

Nevertheless, many industries face difficulties migrating to Industry 4.0, especially traditional organizations in emerging countries (KU *et al*., 2020). The advancement of digital transformation is considered challenging mainly due to the lack of standardized protocols for its implementation, planning during the application of new integrated technologies, and a realistic vision of the return on investment (BUTT, 2020).

According to Fang *et al*. (2020), the digital transformation process has a greater chance of success in large companies, while small and medium-sized companies need attention and differentiated methods. Still, it is observed that the manufacturing industry moves slowly in the digitalization process, often in a fragmented manner and without a holistic view of the necessary changes, although the importance of digitalization is notorious in the industry as this is the sector that determines the digital economy leadership in many countries (LOLA; BAKEEV, 2020). Therefore, it is necessary to accelerate digital transformation through efforts not only in applied research but mainly in practical implementation cases to summarize the know-how obtained during the process (TSCHANDL *et al*., 2020). From another perspective, the study by Hausberg *et al*. (2019) revealed that the term digital transformation in manufacturing has been a dominant research subject in recent years. Finally, an important factor regarding the journey of Digital Transformation in the industry is the level of success in its implementation, which is frequently hampered by the difficulty in carrying out the cost-benefit analysis since the investment and infrastructure requirements are considered high (PFLAUM; GÖLZER, 2018).

In this context, this research aims to compare the practical and theoretical state of digital transformation in Brazilian industries, proposing a model for the digital transformation. The article is divided as follows: the second section shows the method used in the study, Section 3 discusses the content analysis, and the results are exposed in Section 4, followed by the conclusions and references consulted.

4.2 RESEARCH METHODOLOGY

The research method was structured into three steps, as shown in Figure 1. In the first step, a systematic review was carried out. According to Moher *et al*. (2009), a systematic review is defined as the review of previously formulated questions using systematic methods of collection, analysis, identification, selection, and critical evaluation of relevant research.

According to Snyder (2019), systematic literature review allows investigating the relationship or effect of specific variables on topics, providing a basis for new conceptual models and theories. Xiao and Watson (2019) highlighted that the review offers a deep understanding of existing work and allows the identification of gaps to be explored.

In this first step, the objective of the literature review was to perform a content analysis of the literature on Digital Transformation and determine the state of the theory. The second step was the selection and review of Brazilian reports on the national industry, bringing the state of practice of the manufacturing industries in the digitalization journey. In the last step, a comparative analysis was performed between the theory and practice of the industries regarding the main aspects of digitalization. From the results, a conceptual model with a practical approach to digitization was developed.

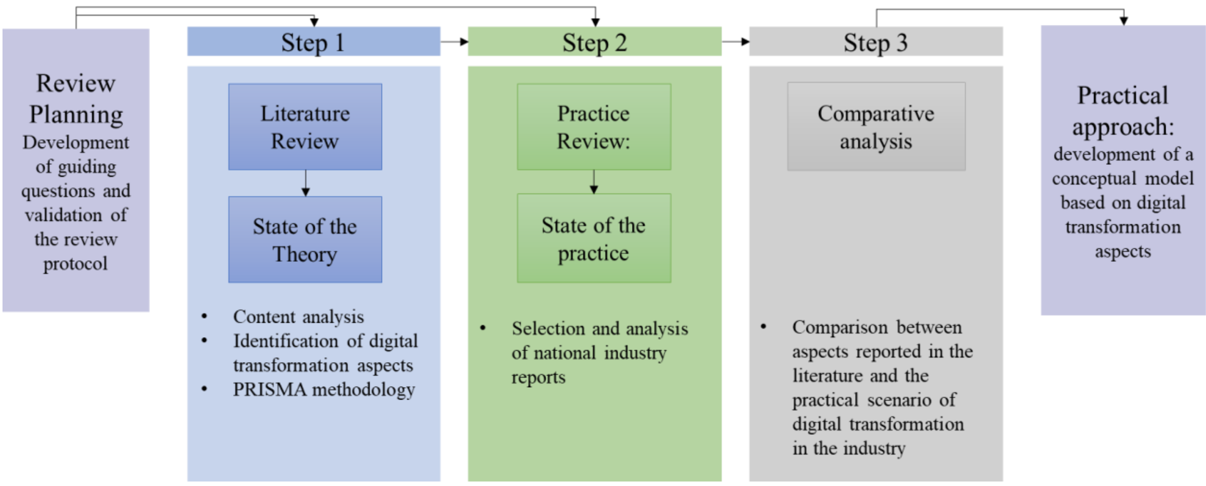


Figure 1. Research steps.

4.2.1. REVIEW PLANNING

During the review planning, the steps of formulating the questions and validating the review protocol are performed. In the context of Digital Transformation, it is considered relevant to consolidate the state of theory in comparison to the reality of manufacturing industries in Brazil, answering the following guiding questions:

a) What are the relevant aspects of Digital Transformation according to the literature?

This question aims to clarify, based on the literature, what are the guidelines most cited by the various authors relative to the application of the concepts of digital transformation in industries, bringing a theoretical basis to compare to Brazilian practices.

b) How is the advancement of digital transformation in the Brazilian industry from a practical point of view?

The second guiding question aims to comparatively analyze the scenario of the practical application of the aspects previously found, classifying the progress of Brazilian industries in view of the guidelines of digital transformation mentioned in the literature.

c) How to promote digitalization in a practical manner in industries?

The third question aims to propose an applicable model of one of the guidelines found when responding to question one that helps promote digital transformation in the practical and real scenario.

The validation of the review protocol describes the elements of the review, essentially containing the inclusion/exclusion criteria and the strategy used during the research, adapted from Uhlmann and Frazzon (2018) and Liao *et al*. (2018). The criteria used for inclusion in the article are described in Figure 2, with the selection of studies in the field of engineering focusing on digital transformation in the manufacturing industry published from 2018 to the dates of the searches, aiming to obtain an updated view of the digital transformation scenario of recent years.

Inclusion	Closely Related (CR)	• The research describes studies about DT in manufacturing Industry; • Time Span: from 2018 to July 2021; • Subject Area: Engineering; • Document Type: Conference pair or article; • Source Type: Conference Proceedings or Journals; • Language: English.
Exclusion	Search engine reason (SER)	• The paper has only its title, abstract, and keywords in English but not its full-text
	Without full-text (WF)	• Paper without full-text available
	Non-related (NR)	• NR-1: A paper is not an academic article. For example, editorial materials, conference reviews, contents, or forewords; • NR-2: The definition about "Digital Transformation" is not related to Industry; • NR-3: The definition about "Digital Transformation" is not related to an application of the principles of industry 4.0
	Loosely related (LR)	• The paper does not focus on the discussion, or problem solving of digital transformation. In which: • LR1: Digital transformation is only used as an example fact • LR2: Digital transformations is used to show an application of technology • LR3: Digital transformation is only used as part of its future research direction, future perspective, or future requirement • LR4: Digital transformation is only used as a cited expression • LR5: Digital transformation is only used in keywords and/or references
	Specific area (SA)	• Digital transformation is only used for a specific application area and the results cannot be generalized.

Figure 2. Inclusion and exclusion criteria.

4.2.2. LITERATURE REVIEW

The systematic review carried out in this research uses the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) methodology, described by Moher *et al*. (2009) and shown in Figure 3.

The review was conducted by searching the existing literature using the Scopus (www.scopus.com) and Web of Science (www.webofknowledge.com) databases. The keywords used were "digital transformation", "digitalization", "manufac*", "4.0", "data", and "roadmap". The strings were formed in three ways, obtaining an initial number of identified papers that went through the screening phase, in which duplicates were excluded and the remaining titles were read systematically to exclude articles according to the SER, WF, and NR1 rules. Thus, 397 selected papers were included in the eligibility phase, in which the LR1, LR2, LR3, LR 4, LR5, and SA rules were applied. Finally, the remaining articles were included in the quantitative synthesis and qualitative analysis. The articles included in the quantitative synthesis m*et al*l inclusion requirements and were read in full, with 38 being selected that brought qualitative value for analysis.

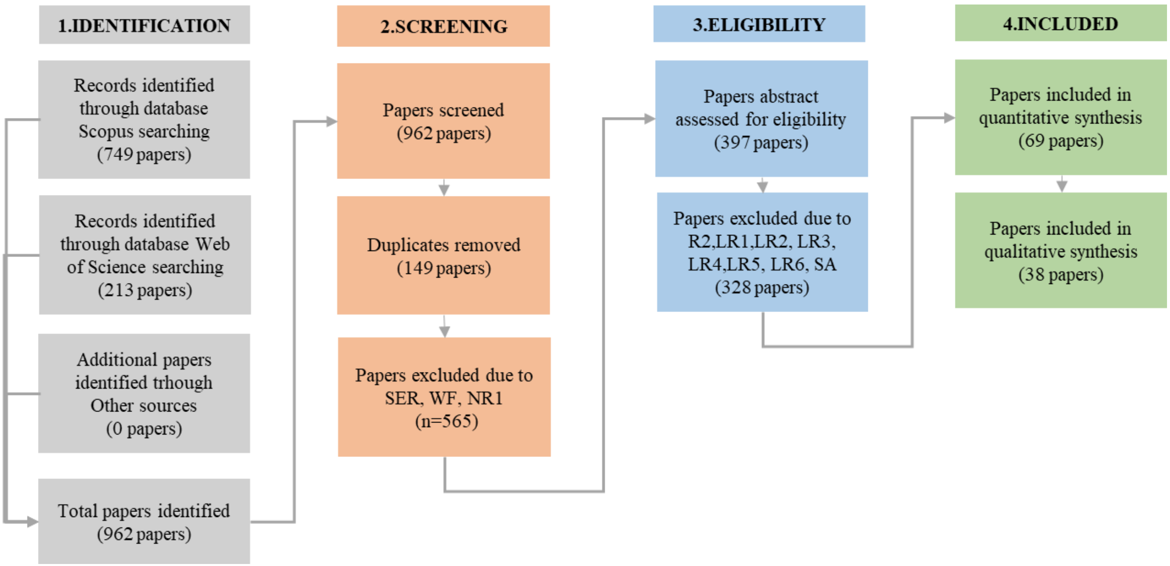


Figure 3. PRISMA steps.

4.2.3 PRACTICE REVIEW

The review of the practice was carried out through a report content analysis with a qualitative approach described by Krippenforff (2018). Searches were performed in Google Scholar databases to identify the state of practice through scenario analysis reports in Brazil, and the primary sources found and used were the Brazilian Government, McKinsey Brazil, ABIMAQ, and the OECD, as shown in Figure 4.

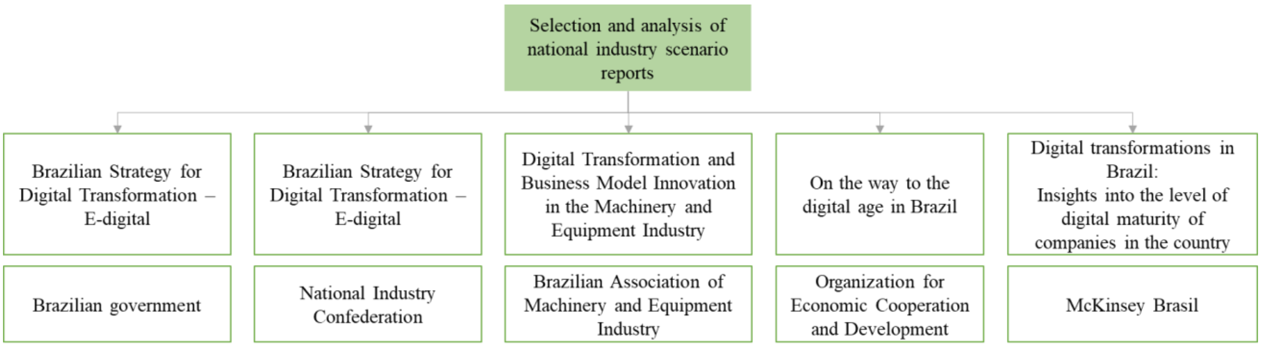


Figure 4. Selected reports

The data were synthesized through a spreadsheet in a structured manner to generate qualitative information based on the literature. The following section discusses the results and presents the content analysis topics, containing an overview of Digital Transformation based on the literature and reports review.

4.3 RESULTS

This section is divided into four parts, demonstrating the results obtained in terms of qualitative analysis (theory and practice), comparative analysis, and a practical approach by developing a digital transformation conceptual model.

4.3.1 THEORY ANALYSIS

This section aims to describe the relevant aspects of Digital Transformation in the industry according to the authors studied in the qualitative analysis. The Organizational pillar refers to aspects that directly influence a company's business models and the organizational strategy for digital transformation. The Process pillar refers to the adaptations of manufacturing and operational processes in accordance with the strategy considering the aspects of data-driven decision-making. Finally, the Technology pillar is intended for the integration of technology into processes and the organizational structure in a systemic way. Each pillar was subdivided, bringing the 12 main aspects pointed out according to 38 authors, as defined in Figure 5.

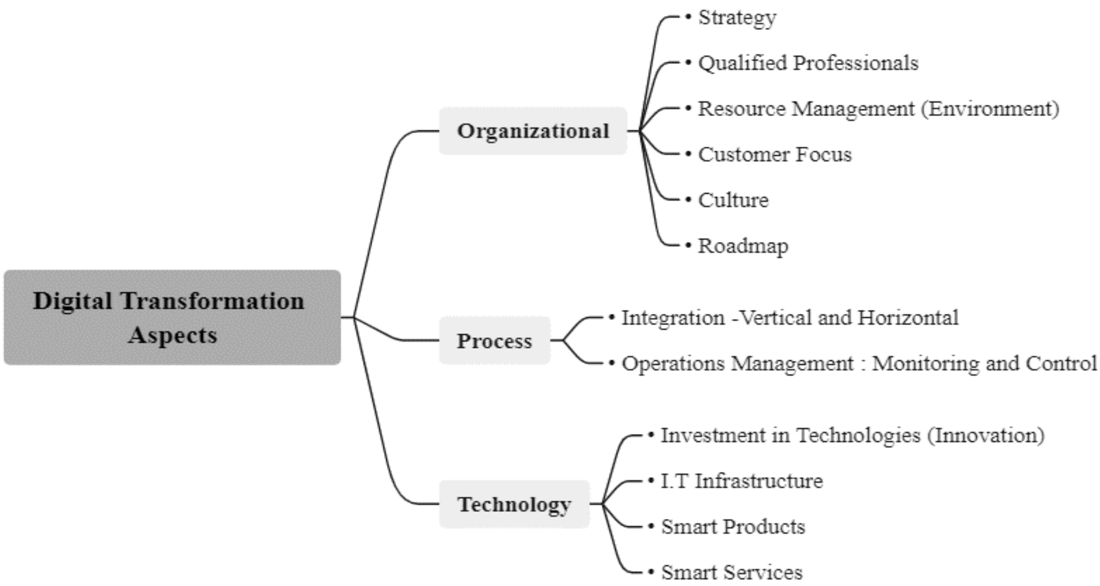


Figure 5. Digital transformation aspects.

Table 1 presents definitions according to some authors, bringing the view of the literature on each of the aspects present in digital transformation.

Table 1. Definitions of digital transformation aspects

Digital Transformation Aspects	Definition	Authors
Strategy	Digital transformation is directly related to creating opportunities through new business models that aim to increase flexibility and improve operational performance. The strategic aspect of the organization must be aligned and planned in a structured manner to achieve the digitalization objectives.	BADER *et al*. (2019) and ZANGIACOMI *et al*. (2018)
Qualified Professionals	It is essential that companies make human competence and employee development one of the main components of the system, strengthening the "digital awareness" of their employees.	HAVLE & UCLER (2018)
Resource Management (Environment)	Refers to using technology aimed at sustainability to reduce the consumption of resources such as energy and materials during the production process.	CALABRESE *et al*. (2020)
Customer Focus	Digitalization of customer contact and integration of product data. Use of digital technologies to intensify customer contact. Use of digital technologies to constantly adapt to customer needs.	RACHINGER *et al*. (2019) and SCHUMACHER *et al*. (2019)
Roadmap	The roadmap helps through planning and visualization over time, following each decision on the way to digital transformation. It is a roadmap of the relevant technologies to be implemented to facilitate the digital transformation journey according to the business model and company needs.	GHOBAKHLOO & CHING (2019) and ZANGIACOMI *et al*. (2018)
Culture	Aspect associated with the company's strategy in the sense of a definition of how the existing culture will be adapted and transformed into a digital culture.	LIPSMEIER *et al*. (2020)
Integration – Vertical and Horizontal	Vertical integration aims to connect processes through ERP and MES systems at all organizational levels, from operations to company management. In turn, horizontal integration aims to ensure the interoperability of the supply chain using technology between suppliers and the organization. This aspect represents the complete integration of the value chain from customer to supplier, covering the entire organizational structure from the shop floor to management.	HAVLE & UCLER (2018) and LIN *et al*. (2020)
Operations Management: Monitoring and Control	Integration between information systems that allow production management, manufacturing execution, and control of manufacturing processes in a connected way for decision-making. This aspect determines the behavior of operations over time and depends on the commitment of top-level process owners to manage the implementation and performance of processes, the management of systems and process requirements, and the quality of metrics used for measuring the success of the operation.	AMBRA CALA *et al*. (2018) and LIN *et al*. (2020)
Investment in Technologies (Innovation)	The organization must invest in internal and external sources for developing new technologies both externally by observing practical examples from other companies and scientific publications and internally by investing in research and development activities.	ZANGIACOMI *et al*. (2020)
Information Technology Infrastructure	The organization must have a clear perception of the value of Information Technology, which includes the development and monitoring of a structure of digital hardware, integration software, data	GHOBAKHLOO & CHING (2019)

	security measures, trained professionals working on technology projects, and, finally, system maintenance.	
Smart Products	Development of products capable of collecting and transmitting information, either for the organization or its own life cycle.	TOROK (2020)
Smart Services	Introduction of new services and solutions added to the product, giving a new value proposition to the business through digitalization.	RACHINGER *et al.* (2019)

The radar chart below in Figure 6 shows the distribution of identified aspects, demonstrating the relevance according to the different authors.

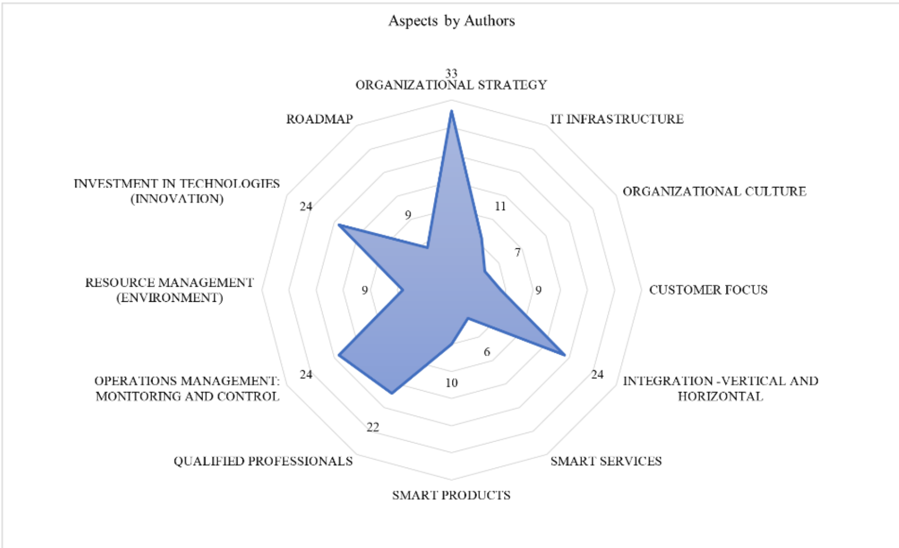


Figure 6. Digital transformation aspects

The results show that, for most authors, the digital transformation journey is directly associated with organizational strategy since both the business model and the operations must align toward implementing and integrating new technologies. In addition, preparation at the strategic level becomes essential as a guideline for the entire organization during the transformation journey. The organizational strategy was cited as the central aspect of digital transformation with 33 citations, representing 87% of presence among the 38 authors.

To Cachada *et al.* (2019), digitalization at a strategic level is how an organization will have integrated information across the entire system, allowing understanding from market movements and customer needs to the manufacturing level and disseminating technologies efficiently and in a structured manner in all sectors.

The second widely highlighted point refers to investment in technology (innovation), mentioned by 24 authors, which may be considered the minimum aspect necessary to support the strategy of digitalization and competitiveness in companies (GHOBAKHLOO; CHING, 2019). Then, operations management and vertical and horizontal integration are identified as relevant digital transformation aspects by the same proportion of authors, with both highlighted by 24 of the 38 authors.

First, the vertical and horizontal integration aspect of the chains within the organization is pointed out as a great enabler of industry 4.0, promoting the necessary connectivity for the joint growth of all internal company departments, as well as creating a flexible and optimized supply chain at the decision level (VEILE *et al*., 2020). The use of systems such as SCADA, MES, and ERP plays an important role in the centralization and management of data in an integrated manner (BAURINA, 2020).

Concerning digitalization at the operational level, operations management or monitoring and control allows the management of plant activities combined with data-based decision-making, enabling improvements in manufacturing performance (AMBRA CALA *et al*., 2018).

The aspect of professional qualification mentioned by 22 authors exposes the need to develop human capital for digital transformation success. Sjödin, Parida, and Leksell (2018) reported that smart factories mature in digitalization have structures that educate people and develop their skills by encouraging the exploration of connected systems and knowledge sharing.

Also, regarding people, according to Sundberg *et al*. (2019), many companies, especially smaller ones, do not have the digital bias so present in the organizational culture. The study by Türkeş *et al*. (2019) also revealed that the lack of knowledge about the importance of industry 4.0 is considered a barrier to digital transformation in small and medium companies.

The aspect of organizational culture was pointed out by seven authors, demonstrating that, despite being relevant since it defines how people within an organization will adapt to new technological processes, it is not highlighted in most works. Figure 7 shows the classification of aspects in order from the most relevant to least highlighted by the authors, as well as the percentage of the total citations.

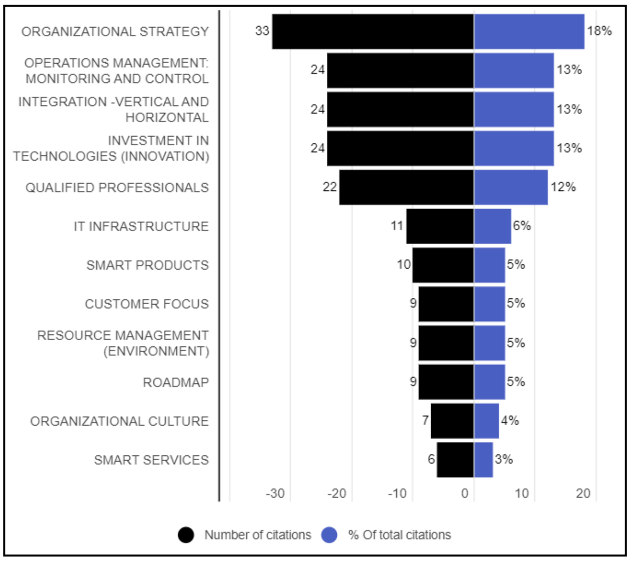


Figure 7. Classification of aspects by number of citations.

4.3.2 PRACTICE ANALYSIS

The following steps were performed to carry out the practical analysis: selection of updated reports with information about the Brazilian industry, full reading for classification, and correlation of each aspect found in the theoretical analysis step with the data provided in the reports. Figure 8 compiles the steps and results obtained in each section up to the current one.

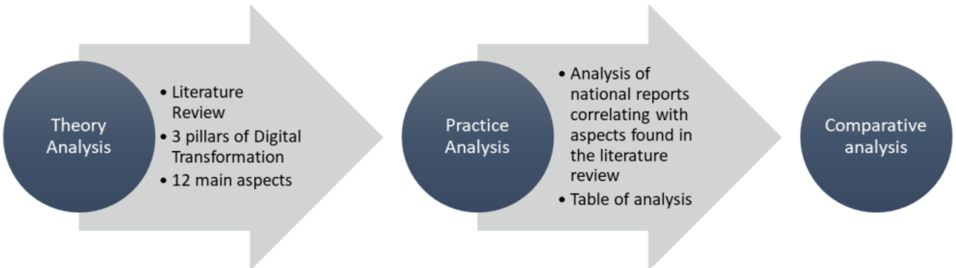


Figure 8. Steps and main results.

Aiming to analyze the Brazilian industry scenario within the described aspects, the evolution of practices adopted by both the government and the manufacturing industry in Brazil was identified. As a result, Table 2 in Appendix A summarizes the state of digitalization practices in the country.

Among the aspects studied, both the government and the companies are clear about the importance of digitalization as the main economic and business strategy to increase the competitiveness of the Brazilian industry (CNI, 2016). According to the Brazilian Strategy for

Digital Transformation report (GOVERNO BRASILEIRO, 2018), defining applicable methodologies and technologies is essential to leverage the productivity and competitiveness of manufacturing and to ensure the generation of value at an international level.

As a feasibility factor for the strategy, roadmaps were highlighted by Mckinsey and Company (2019) as present in large companies, while small and medium-sized companies do not have a specific development that encompasses the entire organization, instead focusing on the pillar of technologies and their implementations (ABIMAQ, 2021).

IT infrastructure is identified as a weak point in the Brazilian case in providing a robust and advanced data network to implement technologies in companies. Also, regarding the adoption of digital technologies in companies, the report by the OECD (2020) highlighted three factors that disadvantage the digital transformation journey in Brazil: insufficient infrastructure, high costs due to the tax system, and financial limitations such as limited access to financing.

In this sense, investments in technology, innovations, and their application still need advances. The CNI highlights that the share of business investment in R&D is 39.9%. In its general report, the ABIMAQ (2021) indicated that 40% of companies associated with it do not use base technologies such as Cloud Computing, IoT, Big Data, and Analytics. Another study classified the diffusion of these technologies and tools in Brazilian companies, demonstrating that the use of cloud computing has an average above that of countries in the OECD (2020), while technologies such as ERP, GRC, and Big Data have low diffusion among Brazilian companies.

These results are linked to aspects of operations management and integration of data generated in the industry and its use in a connected way that enables the digital transformation of its processes. Relative to this aspect, ABIMAQ (2021) described that only 30% of the companies surveyed had connected equipment and processes, and less than 20% developed intelligence or analysis with the data collected. The study by Mckinsey and Company (2019) revealed that many companies still used simple statistical data analysis methods, i.e., they had not adopted more sophisticated models such as machine learning to favor and automate decision-making.

Another important factor present in all studies infers the professional qualification and availability of qualified professionals for digital transformation in Brazil. Through *E-digital*, the government indicates that there is a lack of people trained in basic information technology skills, so it highlights several strategic actions, programs, and policies aimed at training professionals and the population. In the industry, the report by CNI (2016) pointed out that 38% of workers had not completed at least basic education, making clear the need for initiatives in the area of professional qualification as a basis for sustaining digital transformation.

4.3.3 COMPARATIVE ANALYSIS

It is possible to show a comparison between all the aspects described in the literature and the state of the Brazilian industry, as shown in Figure 9, pointing out that there is a similarity between the main factors highlighted by the authors and the points addressed in the reports on the Brazilian scenario, demonstrating a convergence regarding the aspects better known and widespread in both cases.

While the literature identifies aspects as drivers of digital transformation, practical reports present the understanding and rate of implementation of companies towards digital transformation. In this sense, it was determined that the aspects with greater adherence in Brazil are digital transformation as an organizational strategy, operational management through monitoring and control, and vertical and horizontal integration, in line with the most mentioned aspects in the literature.

However, even with the equivalence between the results in relation to aspects, the practical scenario of the Brazilian industry presents less significant advancement in the level of perception of the factors, verified through the superficiality and low rate of technological applications and process integration compared to the deep knowledge present in the literature.

On the other hand, investment in technologies, professional qualification, and IT infrastructure are widely discussed and pointed out at the top of the ranking among the main aspects in the literature. However, they are underdeveloped in most industries in Brazil, showing a disparity between the degree of importance for digital transformation and the level of maturity in the country.

Other points such as resource management, customer focus, intelligent services and products, and the definition of a roadmap are still sparse concepts both in terms of application in the Brazilian industry and the number of citations in research in the context of digital transformation.

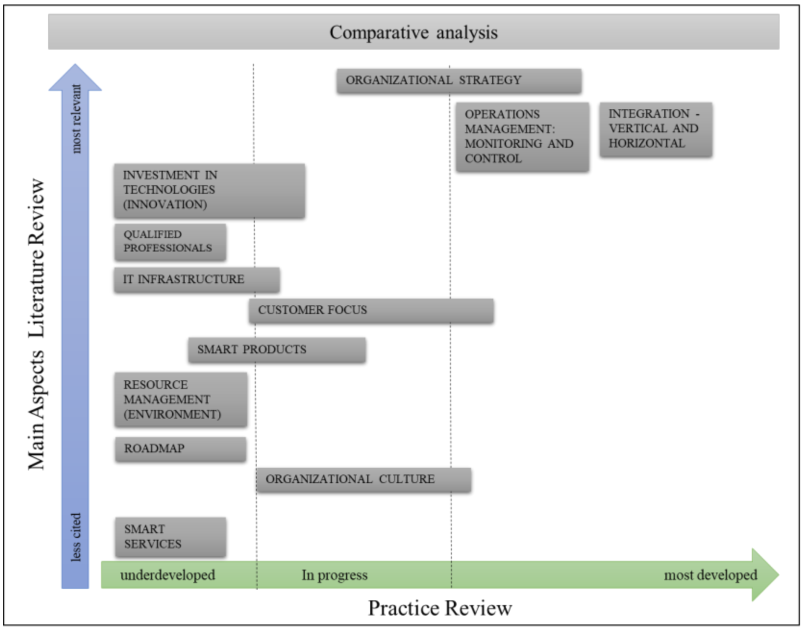


Figure 9. Comparative analysis.

4.3.4 PRACTICAL APPROACH

Based on the definition of the three pillars identified in the literature, namely organizational, process, and technology, a roadmap was developed aiming to create a practical approach to help companies from the beginning of the implementation till the complete digitalization stage. This guide includes the aspects identified during the theory review and then explores one of them, as shown in Figure 10, to promote the advancement of one aspect of digitalization in a real-world case.

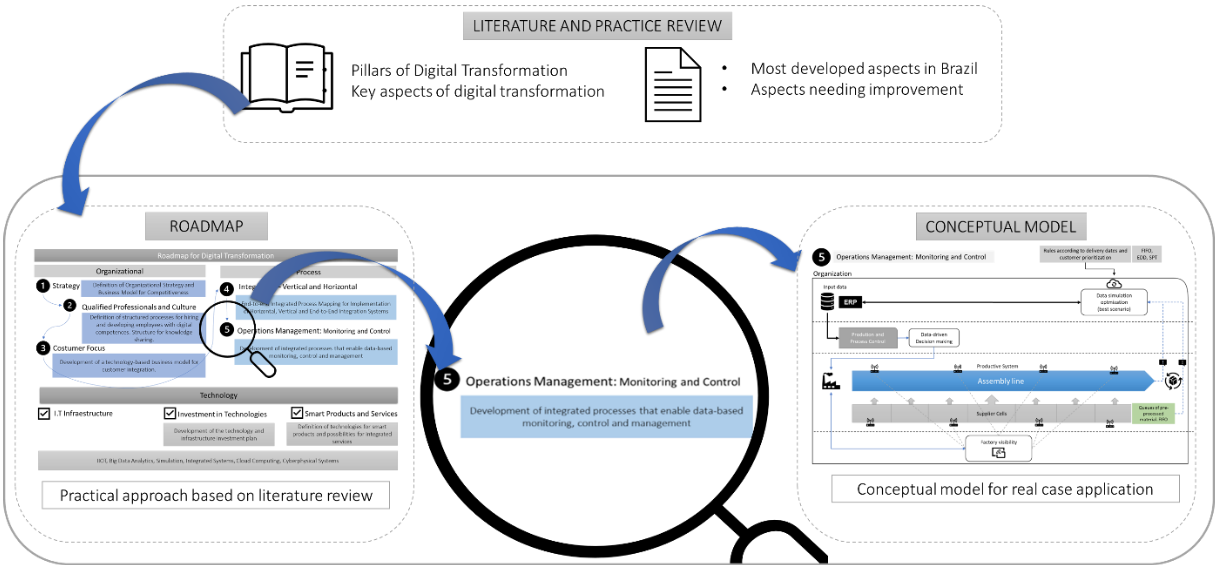


Figure 10. Framework for the practical approach

This section comprises the proposition of a model for the digital transformation of the industry. A roadmap was elaborated with macro-steps that address the key points of digitalization according to the literature. Figure 11 presents the roadmap, adapted according to the Organizational and Process pillars and based on the technological aspects (LIN; WANG; SHENG, 2020). Each pillar includes the dimensions of digital transformation highlighted in Section 3.2. Unlike other roadmaps for digital transformation, such as that in Ghobakhloo (2018), which described a roadmap derived from documented best practices, this roadmap originates from the relevant aspects found in the literature.

For the implementation, companies must first understand their current level at each feature. According to De Carolis *et al*. (2018), the initial flow must contain the steps of maturity assessment, an analysis of the strengths and weaknesses of each aspect, the opportunities identified in each dimension, and the defined roadmap execution.

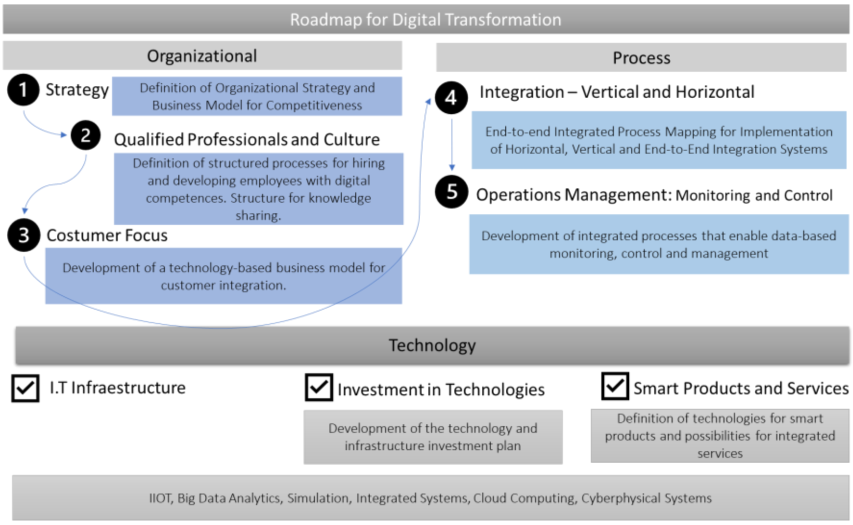


Figure 11. Digital transformation roadmap

Operations management step was chosen because it is one of the most important aspects identified during the qualitative analysis. According to Sjödin, Parida, and Leksell (2018), a company must establish systems to monitor, visualize, and analyze the operating system in real-time, implementing simulation models for testing, prototyping, and plant optimization. As stated by Gamache *et al*. (2020), most of the technologies implemented in the industry are aimed at monitoring and controlling production, mainly seeking to make processes more flexible.

According to Pires *et al*. (2018), the real-time monitoring capability allows decision-making and quick response to conditional changes and, when combined with data optimization models, generates significant improvements in performance, system, and machine efficiency. As a result, a detailed conceptual model is described in Figure 12 to enable a specific aspect of the roadmap and exemplify a structure for its application.

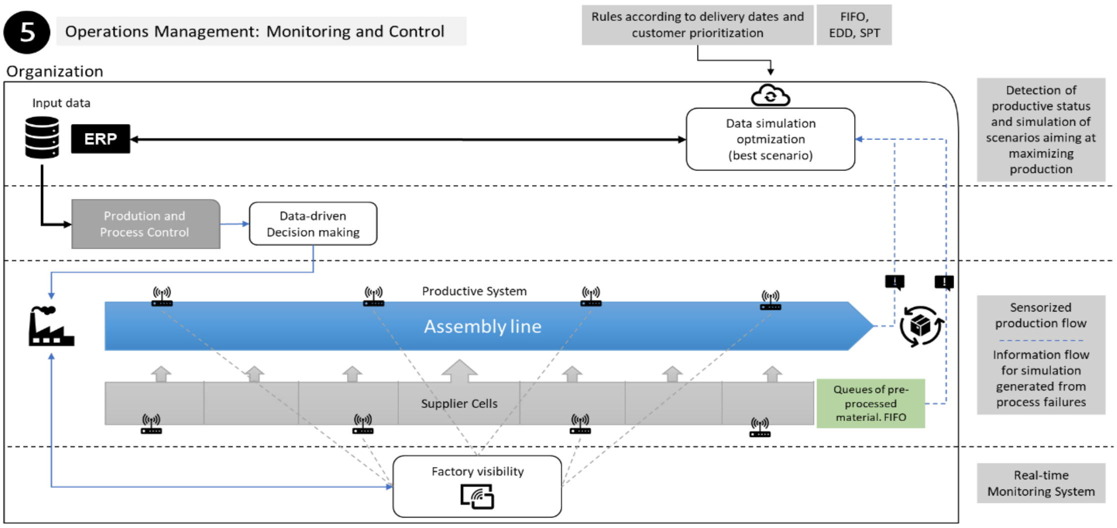


Figure. 12. Conceptual model for a real-world case.

This model proposes the digitization of assembly line data. Initially, the data is available in the Enterprise Resource Planning (ERP) for the production planning and control, including order and priority sequence for to the assembly line. The data is read by barcode readers, RFID sensors in the initial supply cells. This information is transmitted in real time, which promotes the visibility and monitoring of the production. The status of the orders is then transmitted to the cloud, including production stage and interruption reports or line failures, which can be generated by material shortages, equipment breakdowns and other disruptions. This data is used to automatically redefine the queue of products to be produced in the supply cells and, consequently, in the assembly line. For this reordering, regular priority rules are used. This flow allows the production to work in an enhanced way, reducing the number of stops and improving the balance between the supply cells and the assembly line. The digitalization of data promotes fast responses in a synchronized way.

The main objective of this model is to represent the practical aspects of data digitalization applied to a real production system, promoting the concepts of monitoring and control for optimal data-driven decision making. According to Frazzon *et al.* (2020), using analytical optimization models through simulation and analyzing the data generated in the operation improve the performance of manufacturing systems and promote flexibility in the reaction to adverse situations in production systems. These virtual tools and techniques enable support for industrial processes, including system integration and real-time visualization of various scenarios, facilitating user understanding and operator interaction (ESPÍNDOLA *et al.*, 2012). In addition, the collection of this data, characterized by Big Data, and the subsequent processing with business analytics provide information and value to organization, boosting their gains from the management, effective data analysis, and the visibility of processes in real time, promoting the improvement of operational performance (ISASI *et al.*, 2015).

4.4. DISCUSSION

Digital transformation and its aspects are widely discussed both in the literature and in practice, with the main topics concerning the present and future of the global industry. However, many of the major concepts disseminated in depth in the literature still show low adoption in the manufacturing industry in Brazil. On average, the Brazilian industry is in the implementation stage and initial digital development of some technologies compared to other countries in the OECD. The reality of the national industrial scenario demonstrates that, although highlighted as the central aspect, many companies do not have a well-defined digital strategy or do not consistently apply it, corroborating the results that the implementation of technologies such as big data, analytics, and IoT still cannot be considered advanced in the country.

Another correlation factor between the literature and practice concerns the importance of the human element in leading digital transformation. Even though the literature presents several practices and methodologies for digital training, the reality of the Brazilian scenario shows a deficiency in the aspect of professional qualification that may be considered critical in the digitalization journey of Brazilian companies. However, it is evident that there are policies and programs aimed at digital education under development by both the government and the industries, a fact that jointly benefits the aspect of digital culture in organizations.

For companies to be efficient and agile in their digital transformation journeys, a clear integration among the digitalization project, its concepts, and the defined business plan is paramount. An organization's managers must initially develop and communicate questions such as the following: What are the long-term strategic vision and medium-term tactical vision that the company wants to achieve with the project? What is the socio-technical and organizational context of the implementation? What resources are needed, how much, and when? What are the expected returns, how much, and when? What is the implementation schedule, steps, activities, resources, and intermediate and final deliverables? What is the communication plan?

With these definitions, it is possible to understand important aspects for the project to be successful: who are the supporters of the implementation, the decision-makers, if there are needs for employee training, retraining, and/or relocation, which are the teams and profiles needed for implementation, and what is the degree of technological maturity of the company. Intangible returns such as image, mindset, and organizational transformation should also be considered.

Regarding operational management and vertical and horizontal integration, they were indicated in both analyses (theoretical and practical) as key aspects for digitalization, highlighting a bias towards manufacturing and transformation processes as the focus of practice reports and published articles. On the other hand, the actions aimed at using technologies with customer thinking are not so clearly reported by the companies, thus needing further deepening by the industry. Furthermore, sustainable resources management is not mentioned in the industry and government reports as a significant aspect of the digitalization journey.

4.5. CONCLUSION

The purpose of this article was to compare the available theory and the current stage of the digital transformation of Brazilian industry. The literature review showed that the main concepts to be implemented in the industry towards digital transformation are related to the organizational, procedural, and technological pillars. Based on these definitions, a roadmap was developed, which proposes macro steps towards digitalization. The comparison showed that the status of the digital transformation presents implementation gaps in relation to the theoretical aspects, indicating the existence of opportunities for improvements in the industrial scenario by the application of proper digitalization concepts, methods and technologies. A roadmap and application model specifically for the operations management aspect were described in order to illustrate potential benefits in terms of improved flexibility and productivity due to data integration and simulation-based optimization deployment.

Further research and applied projects should focus on bridging the theory-practice gap regarding digital transformation of Brazilian industry, so that, first, scientific knowledge creation is supported by empirical evidence and, second, digital transformation application properly selects and deploys suitable concepts, methods, and technologies.

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Appendix A. Practice analysis.

DT Aspects	Brazilian Machinery Builders´ Association (ABIMAQ) [[Q9: Q9]]	McKinsey	Brazilian National Confederation of Industry (CNI)	Organisation for Economic Co-operation and Development (OECD)	GOVERNMENT (e-digital)
Organizational Strategy	61% of companies are undergoing major changes in their business models, aiming to increase competitiveness relative to the foreign market	Companies are aware of the potential of digital transformation within their organizational strategy. Leading companies in the Brazilian scenario show a clear link between digital and business strategy, while other companies tend to view digital as an additional pillar, generating initiatives that are dispersed within the organization.	The strategic focus on using technologies is highly associated with cost reduction and increased productivity. 58% of companies understand the importance of digitalization for competitiveness; however, less than half of the industries studied use digital technologies in their organizations.	The Brazilian strategy for digital transformation includes a set of practices and incentives of the Brazilian government, following the enabling axes and axes of digital transformation, which unfold strategic actions aimed at the reach and progress of the entire country in the following aspects: data-based economy, connected devices, and new business models, supported by citizenship and government.	
IT Infrastructure	Need to improve infrastructure, especially regarding networks, access, and internet speed, considering these critical factors in the implementation of IoT systems and other technological solutions.	-	The lack of infrastructure is considered the fifth most significant internal barrier to the adoption of technologies, mainly impacted by the high costs of technology implementation, which is regarded as the biggest internal barrier.	The Brazilian scenario reveals that investment in the information and communications technologies (ICT) sector is below the OECD level, which reveals Brazil's backwardness in terms of information technology infrastructure.	The government aims to expand the infrastructure of networks (5G) that support digital applications.
Organizational Culture	Most companies (66%) identify and recognize that their employees are open and engaged in adopting digital transformation in the organization.	Most companies recognize the importance of a culture focused on innovation; however, they still face barriers regarding the long-term financial result mentality generated by digital transformation.	Identified as the third biggest internal barrier to the adoption of digital technologies.	-	-
Customer Focus	Digital transformation actions are developed with a customer focus in 66% of organizations.	Most organizations have widespread concepts regarding focusing on the customer journey and improving the experience.	The industry extensively uses digital technologies for product development with a focus on reducing customer availability.	In Brazil, customer relationship management systems are present in 22% of companies.	-
Integration – Vertical And Horizontal	Integration in the industry is mainly focused on vertical integration, with high levels of Programmable Logic Controller (PLC) implementation (advanced implementation) on the shop floor regarding the digitalization of objects, but ongoing implementation projects and interest in implementing systems such as Manufacturing Execution Systems (MES), Enterprise Resource Planning (ERP), and Supervisory Control and Data Acquisition (SCADA) in an advanced manner. Concerning horizontal integration, they indicate little integration with the supply chain, with a high interest in implementation.	-	Vertical integration is identified as important for competitiveness, but its use is below average among the companies surveyed. There are no results regarding horizontal integration.	The Brazilian average for using vertical integration technologies such as ERP is below the OECD average, representing a gap. However, the significant differential of advancement in integration in small and large companies stands out.	-
Smart Services	Advanced implementation of maintenance, installation, and customer customization services.	-		There are clear initiatives recognized in the National Internet of Things	-

	Growth in the offer of services related to product performance monitoring.			Plan, highlighting "servitized" business models in manufacturing.	
Smart Products	High degree of interest in product digitalization within the scope of performance monitoring and fault detection and maintenance, and low level of implementation of digitized products for autonomous or remote operation.	-	The use of data from customers through Big Data is performed by only 9% of industries, of which only 4% incorporate digital services in their products.	Manufacturing companies in the ICT sector are prone to innovate in their products, while other sectors develop innovations with a focus on the process. Therefore, Brazil is below the OECD average in terms of representation in high-technology manufactured goods.	-
Monitoring and Control	Although most companies have access to data through connected equipment and processes, less than 20% use this data through analytics or digital intelligence. These data are mainly used to develop production indicators and understand patterns.	Companies are still concentrating efforts on structured collection and improving data quality. The data-based mindset is present in specific areas of some industries. However, there is a trend toward increasing the amount of data and the capacity to process it. The opportunities for improvement in the models and analysis techniques used are evident.	Recognized as the most important aspect for industrial competitiveness. Mainly through the implementation of sensors for process control, product identification, and operating conditions. However, its full implementation is still considered low.	The average Brazilian use of cloud computing is above the average of OECD countries, representing 80% of all companies, while big data has a low diffusion in the country, representing 11% among companies.	The government aims to develop actions that promote dynamic and competitive industrial environments through IoT devices, sensors, machines, and equipment.
Operations Management	32% of companies have some type of operation virtualization, which allows them to anticipate problems and make strategic and agile decisions, with this being an aspect that still needs development.	-	-	Still below the average for OECD countries, an increase in the use of M2M (machine-to-machine) cards was identified, indicating an advance in the use of IoT in the industry. In the last three years, only 4.5% of Brazilian manufacturers have been operating with industrial robots. These data reveal a deficit in operations management, monitoring, and control.	The government aims to develop actions that promote dynamic and competitive industrial environments through IoT devices, sensors, machines, and equipment.
Qualified Professionals	Most companies (51%) agree that they have qualified and prepared professionals on their team; however, they recognize that aspects related to digital transformation training need further development.	Many companies report a shortage of skilled talent primarily in analytics, pointing out internal development as an option for professional training.	41% of employers report difficulty in filling vacancies due to the lack of hard skills (digital technical skills)	Companies report the lack of skilled workers as a barrier to adopting and implementing new technologies. In Brazil, the proportion of graduates among the adult population represents 18% compared to 39% in OECD countries.	The Brazilian digital transformation includes actions for professional training aimed at developing skills for use in new technologies, in addition to new educational lines in this area.
Resource Management (Environment)	-	-	-	Until 2017, Brazil registered an increase in the intensity of energy use in manufacturing. The adoption of industry 4.0 technologies is expected to favor the country, boosting energy efficiency, and increasing manufacturing productivity.	-

Investment in Technologies (Innovation)	40% of member companies do not use the base technologies: Cloud computing, IoT, Big Data, Analytics, or AI. Of the companies that own and invest in technology, the most used is Cloud Computing, representing 43%, followed by IoT (30%), Big Data (2%), and Analytics (19%)	-	58% of industries are aware of the importance of technology for industrial competitiveness, but the rate of use is still low.	73% of manufacturing companies use at least one digital technology, such as process automation sensors. However, there is a lack of investments in the technology area due to the high costs in the Brazilian scenario.	The Government is intensifying investment in IoT, in addition to promoting the development of strategic technologies such as collaborative robotics, AI, big data, additive manufacturing, and nanotechnology.
Roadmap	Companies have a well-defined model but with a focus on technology implementation.	Leading companies have clear roadmaps that are being implemented. The other organizations do not have a defined transformation plan.	-	-	Ongoing development of a technological roadmap supporting the information and communication technology sector, not directly the industry.

5 PRACTICAL APPROACH FOR DIGITAL TRANSFORMATION IN SMALL AND MEDIUM-SIZED ENTERPRISES USING SIMULATION MODELING

Abstract

Small and medium-sized enterprises (SMEs) are essential to the global industry value chain, which is why competitiveness among small and medium-sized companies is high to maintain a strong market position. In this sense, digital transformation becomes a crucial and decisive factor for high performance. However, the advancement of process digitization is seen as challenging given the reality of SMEs. The lack of infrastructure, understanding of technology, and intangibility of benefits delayed the Digital Transformation (DT). Another important factor is the lack of studies that address quantitative results using simulation methodologies to support the decision-making process and implementation strategies of DT in SMEs. This article aims to demonstrate the impacts of digital technologies when applied in a manufacturing scenario of a medium-sized company. The results will be compared in three different scenarios based on four indicators: Lead Time, Planned Execution Rate, Productivity, and Impact on Revenue.

5.1 INTRODUCTION

The upward search for the concept of smart factories is broadening the view on manufacturing operations, particularly regarding the availability of high-performance technologies and information (Dassisti *et al*., 2019). In this sense, digital transformation offers opportunities for the manufacturing industry to improve its production processes (Hulla *et al*., 2021; Rahnama *et al*., 2021).

Digital transformation can be defined as a changing process enabled by digital technologies that brings improvements and innovations to an organization, industry, or society, creating value through the leveraging of its key resources and capabilities (Gong & Ribiere, 2021).

Although, digitalization in industry is a growing topic in literature and scientific research. In this context, there are few efforts on seeking the most effective path for a company to make its transition to a digital environment, especially regarding Small and Medium-sized Manufacturing Enterprises (SMME's) (Gamache *et al*., 2019). This issue becomes of high interest since SMEs are recognized for their enormous potential in integrating global supply chains through digital transformation (Baptista & Barata, 2021).

Some factors can be classified as challenges faced by SMEs in adopting Industry 4.0 concepts, including the lack of skilled labor, lack of clarity about Industry 4.0, and the intangibility of its economic benefits (Amaral & Peças, 2021). They tend to underestimate the benefits that digitalization offers and overestimate the complexity of the solutions it provides (Dassisti *et al*., 2019).

It is also noteworthy that the SME's have as outstanding characteristics such as poorly formalized processes, limited information, communication technology infrastructure (ICT) problems, including software and hardware, and limited economic resources compared to large industries (Dassisti *et al*., 2019). These companies often suffer a lack of basic aspects of DT, such as real-time monitoring and control for managing their operations, which results in a low level of digitalization compared to larger companies (Schmitt *et al*., 2020).

According to Gamache *et al*., (2020), there is an opportunity to bring quantitative measures that show the real impact of technology tools on the digital performance of small and medium-sized enterprises. In their research in this same area, Roblek *et al*., (2021) states that quantitative approaches help to illustrate the aspects of the studies.

The approach using real cases promotes greater clarity on how to solve implications that happen in industries, with the use of technologies that seek to digitize and facilitate access to operational data within the production environment (Alexopoulos *et al*., 2022).

Looking at it from the viewpoint of digital transformation and digitalization in the context of small and medium-sized manufacturing enterprises (SMEs), there is a notable amount of effort and work being directed towards the creation of frameworks based on critical success factors. This contributes to the existing literature and enhances our understanding of the topic. However, it is understood that there is a gap in works that combine both approaches (Chavez *et al*., 2022).

Regarding this issue, the article aims to demonstrate the impacts of digital technologies and the benefits they can bring to small and medium-sized industries, based on the previously developed model. To achieve this objective, a computational model was developed and simulated in three different scenarios to represent a real case and the possible improvements with the use of digitization technologies. The simulation can demonstrate possible gains in some indicators such as lead time, productivity, scheduling accuracy, and their respective impact on revenue.

Therefore, to provide a holistic approach, this article builds upon a previously published work that proposes a conceptual model based on a real production system with the aim of representing the practical aspects of digitalization (Stradioto & Frazzon, 2023).

The article is divided into the following composition: the next section presents the contribution to the literature and the gap that this work aims to fill. The third section presents the contextualization of the digital transformation, digital technologies, and operations management themes in the SMEs scenario. The fourth section describes the article's methodology, and subsequently, the fifth section presents the details of the simulation experiments execution, as well as the results and discussion about them. Finally, the conclusion and outlook are presented in the last section (Section 6).

5.2 LITERATURE REVIEW AND CONTRIBUTION

The literature review comprises three topics, initially providing an overview of the scenario of SMEs on the journey towards digital transformation in different countries and the approaches for digitalization of their processes; secondly the topic addresses the most applied and cited technologies by authors in SMEs and how they apply these technologies, mainly in manufacturing, and finally, the topic of operations management is highlighted with the aim of presenting the impact of this aspect on digital transformation in the manufacturing of SMEs.

5.2.1 REVIEW OF APPROACHES FOR DIGITAL TRANSFORMATION IN SMES

Digital transformation is widely discussed due to the many opportunities it generates, even though, in the scenario of small and medium-sized enterprises (SMEs), there is a deficiency in the capabilities for digitization (Fang *et al*., 2020). Some of the main challenges faced, which directly impact SMEs' businesses, could be highlighted as: planning, scheduling and rescheduling challenges, errors, and delays in support for the operator on the shop floor, high costs associated with a lack of monitoring and control, and decision-making not based on data (Alexopoulos *et al*., 2022).

In this sense, it is necessary to seek ways to overcome these difficulties, mainly by taking actions in three main axes: organizational management, operational management, and technology (Saari *et al*., 2021). Dossou *et al*., (2022) define that main fields for digital transformation are based on the Decisional, Physical, Intelligent, and Digital aspects.

Although each SME is unique, Dutta *et al*., (2020) identifies some steps to establish smart manufacturing: starting with the analysis of organizational maturity, followed by the identification of specific needs based on the areas with the greatest impact, then definition of functional interfaces and communication protocols, and finally, establish appropriate metrics during the implementation ofI4.0 aspects.

Another approach defined by Nwaiwu *et al*., (2020) shows that the essential success factors for SMEs' digitization are related to organizational strategy, human resource preparation, use of technology in operations, organizational fit, and market competitiveness with innovative technologies, which directly impact management processes for I4.0.

Brodeur *et al*., (2022) provide a list of success factors that are distributed among three macro stages for the transformation to Industry 4.0 (Identification, Preparation, and Execution), developing a framework directed towards SMEs from specific actions for each of the success factors. The approach suggests that companies identify the success factors and the stages of the process for I4.0, proposing specific actions to assist in the gradual and interactive implementation until the last execution phase (Brodeur *et al*., 2022).

Han and Trimi (2022) provide solutions for SMEs to overcome their challenges related to the implementation of Industry 4.0 technologies, developing three proposals: a roadmap to enhance SMEs' collaboration capabilities, a trust standard among partnerships, and a data science platform. According to the authors, SMEs face challenges mainly in adapting to dynamic changes in the business environment generated by the emergence of Industry 4.0 and the lack of associated standards.

The authors Kumar et al. (2023) highlight ways for SMEs to enhance their digital transformation process using paths of digital resilience and proposing a framework that emphasizes various concepts, among which, the development of management competencies, knowledge management, and monitoring and control are considered the most crucial.

In Nordic countries like Finland, manufacturing SMEs are still evolving towards digitalization, which can be considered as still in the infancy stage of digital transformation. (Saari *et al*., 2020.)suggest that companies follow an approach based on manufacturing digitalization, digitalization of production staff skills, and customer interface improvements.

In the Western scenario, Gamache *et al*., (2020) identified SMEs in the early stages of digital integration but lacking real-time information. Furthermore, the authors highlight that the business process factors, management, IT, production scheduling, services for customers, marketing, and distribution have the most significant impact on companies' digital performance.

Regarding countries like India, in the Asian scenario, Dutta, Kumar, and Sindhwani's (2020) research reveals that digital transformation in small and medium-sized businesses in the country, is seeking to implement 4.0 technologies that directly impact the business values, following the sequence of integration, digitization, and optimization, based on real-time metrics.

This existing literature mainly provides insights into how to support and implement digital transformation in SMEs through different approaches, which are mostly qualitative and do not present the practical aspects of digitization in businesses. In this sense, there is a need to contribute to the literature by developing a work that clarifies, through data and real cases, the implications and results promoted by digital transformation in small and medium-sized enterprises.

5.2.2 DIGITAL TRANSFORMATION TECHNOLOGIES IN SMES

Small and medium enterprises (SMEs) can improve their organizational agility, adaptability, and resilience to stay competitive in today's market by using Industry 4.0 technologies, which have been significantly enhanced through advancements in computing devices, networking, and cloud computing, making data capture, sharing, and analytics become faster and more cost-effective (Han & Trimi, 2022).

Szopa & Cyplik, (2020) describes a digitalization index that brings digital solutions to business models that includes a complete ICT structure, along with hardware, software, big data analysis, and the use of systems such as ERP and CRM.

There are results in the literature that show a certain limitation in the exploration of the various technologies and resources available to SMEs, which end up limiting themselves to the application of Cloud Computing and Internet of Things (IoT) (Alexopoulos *et al*., 2022). According to Gamache *et al* (2020), some of the digital tools identified as most needed in companies include the ERP system, the implementation of MES, real-time dashboards, performance indicator tracking, and a knowledge management system.

However, in their study, Saari *et al*., (2020.) states that, although digitization and the use of technology have already begun in manufacturing SMEs, the process is slower than desired. Control technologies and tools such as Enterprise Resource Planning (ERP) are widely used, but their integration with Manufacturing Execution System (MES) is not widely applied.

Some technologies, including data science, support SMEs by enabling the capture, pre-processing, analysis, and utilization of data, which allows them to create new opportunities and improve their internal processes, as well as better understand the needs of their collaborators (Han & Trimi, 2022).The introduction of cyber-physical systems, consisting of sensors, transmission technologies, IT infrastructure, and data processing, allows product tracking on the production line, while the Internet of Things enables the connection of machines and control and planning systems, with ERP being the basic technology system to enable efficient processes (Stich *et al*., 2020).

In their study, Mcdermott *et al.* (2023) identified that even though SMEs do not include Industry 4.0 in their strategic plans, they understand Industry 4.0 technologies that can assist their businesses, mainly citing automation, smart processes, automated inspection, and cloud computing as the most important ones.

Chonsawat & Sopadang, (2020) suggests some indicators as dimensions of digital technology in SMEs, the first relates to the percentage of implemented big data analytics solutions, which grants real-time decision-making, while others cite information systems based on the percentage of automatic transfer of orders to production, as well as tracking, predictive maintenance, and cybersecurity systems.

5.2.3 DT OF OPERATIONS MANAGEMENT IN SMES

Operations management is the concept that brings together all aspects related to monitoring and controlling production. In the context of digitization and SMEs, it plays an important role along with production technologies that, when incorporated systematically, promote the concept of intelligent manufacturing through production efficiency, cost reduction, and energy consumption in the SME environment (Chonsawat & Sopadang, 2020).

According to Slack *et al*., (2015), operations management encompasses the entire process of planning, controlling, and monitoring the flow of production, starting from the acquisition of inputs to the finished product, with the aim of increasing the efficiency and quality of production processes. According to (Fang *et al*., 2020), the main objective of this concept is planning, organizing, and monitoring the production, manufacturing, or services of a company.

In the context of literature on SMEs and operations management, Braglia *et al*., (2022) highlight in their research that with the implementation of production operations management, physical operations management, and production asset performance management, it is possible to digitize the entire production line, as well as improve its efficiency, quality, and intelligently track all production factors.

Alexopoulos *et al*., (2022) reports that the non-adoption of technologies for digital manufacturing in planning and replanning, floor support, monitoring and control, and uniformed decision-making can have negative impacts on SMEs' businesses, such as increase costs for documentation, delay project delivery, underutilized resources, overtime work, among others. One of the key aspects in operations management is data-driven decision-making. For this, cloud computing technologies and big data analysis help SMEs in data management and its efficient utilization, although relatively few companies are using this factor to improve their competitiveness (Han & Trimi, 2022).

Busto Parra *et al*., (2022) presents that among Austrian companies, only 50% use solutions at an incipient level that facilitate and streamline the transmission of information in their production plants. Another data point shows that 80% of these companies use traditional tracking methods, and 40% benefit from the data (Busto Parra *et al*., 2022). Regarding the aspect of planning and programming of operations, it is evident that the resilience of manufacturing companies depends highly on the collection and conversion of data into relevant information for management (Alexopoulos *et al*., 2022).

In addition, Dinis-Carvalho *et al.* (2023) state that digitalization makes communications between managers and supervisors more efficient, facilitating the management of operations. They also emphasize that management commitment is often defined as the main key factor for the success of digitalization in organizations.

5.3 METHODOLOGY

This section presents the methodological procedures used for the development of this article, as well as the proposed approach to meet the objective of filling the gap in the literature described in section 1. To compose the method of the work, four macro stages were executed: conceptualization, implementing, analysis, and conclusion, adapted from Chwif *et al*., (2013) for discrete event simulation works, which are presented in Figure 1.

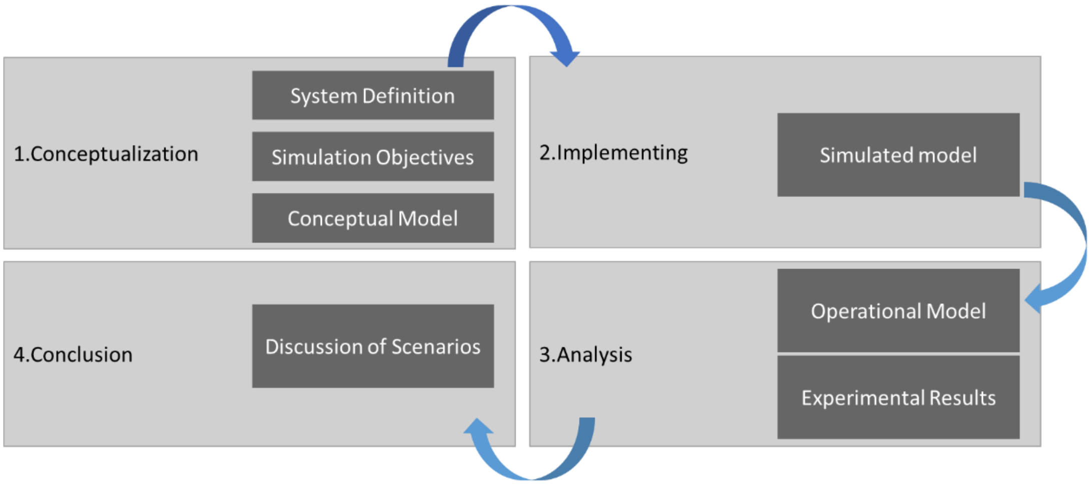


Figure 1 – Stages of the research methodology, adapted from Chwif *et al*. (2013).

This work presents the continuation of ongoing research, consisting of two parts: the theoretical and conceptual (phase 1), and the practical approach (phase 2 - actual article), to be explained further in more detail. Thus, the first step of Conceptualization, which comprises the definition of the system, objective, and the development of the conceptual model, was published in a previous work (Stradioto & Frazzon, 2023). The developed conceptual model is represented in Figure 2 and shows the aspect of operations management integrated with digital technologies, based on a real case.

The stage 2 of Implementing consists of turning the conceptual model into a computational model using a simulation language or a software, to generate the operational model, which corresponds to Stage 3 (Analysis), where the model is ready to provide experimental results and permit practical analysis of the findings. Finally, the Conclusion aims to present a discussion of the simulated scenarios to compare and to obtain relevant data for the case study.

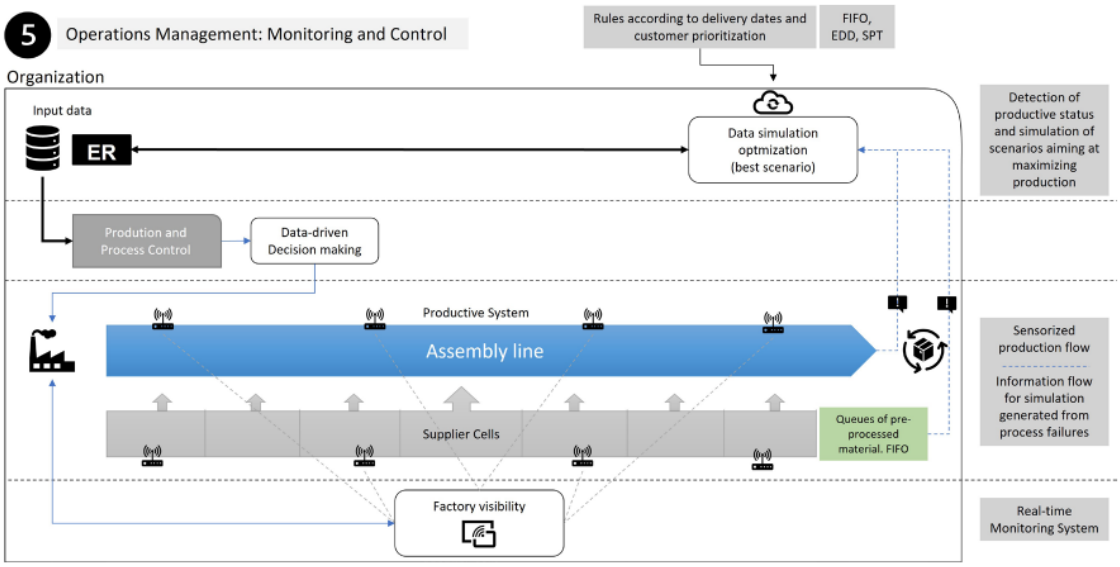


Figure 2 – Conceptual model (Stradioto & Frazzon, 2023)

In the conceptualization stage, the system and objectives of the simulation were defined. The main objective is to provide a representation of a real case of a manufacturing system, as an assembly line of a medium-sized company in the metal-mechanical sector, focusing on healthcare equipment. The aim is to demonstrate the benefits of implementing digital technologies in operations management, contributing to an aspect of digital transformation within the company in question.

The conceptual model was consolidated based on the assembly line described above, which consists of the main assembly system and supply cells. For the correct functioning of the line, it is assumed that there is correct programming through the ERP system. For this purpose, the model considers the application of digitalization technologies and concepts such as automatic production sequencing, paperless factory, barcode reader, big data analysis, automatic transfer of production orders, manufacturing execution system (MES) and traceability system.

Four specific metrics were defined to obtain quantitative results on aspects related to operations management, monitoring, and control, namely (1) Customer lead time, (2) Productivity - equipment per employee, (3) Program accuracy and (4) Impact on Revenue. In this work, these indicators will be addressed at the operational level, due to the availability of real-case data as well as their limitations in the simulation model. Aspects at the tactical and strategic levels will be addressed in the discussion section of the results.

Additionally, the three scenarios defined for the simulation of the model are below.

1. Scenario 1 (C1) - Real - defined by non-digitized programming, without digital sequencing, paper production orders, centralized operation management on the factory floor, and without data analysis and visualization.
2. Scenario 2 (C2) - Improvements - defined by actual tracking times, digitized programming, data analysis for digital sequencing, digital production orders, centralized operations management by administrators, visualization, and action-taking based on data.
3. Scenario 3 (C3) - Optimum - optimized tracking times, digitized programming, data analysis for digital sequencing, digital production orders, centralized operations management by managers.

The implementing phase was carried out using Anylogic software and it included activities such as data collection and adjustment, model design, 3D development, and simulation configuration. These and other stages of analysis and conclusion are detailed in the following section.

5.4 EXPERIMENT DESCRIPTION (USE CASE)

This section aims to describe all the steps taken to perform the simulation experiments, including the description of the use case, a more detailed explanation of the practical case, the simulation development, and the logical description of the scenarios.

5.4.1 REAL CASE DESCRIPTION

The conceptual model is based on an assembly line of a Brazilian medium-sized company (>200 employees) in the metal-mechanic industry, which produces equipment for the healthcare sector. Some peculiarities about the production process should be highlighted, such as the high demand for customized production by the customer, the dominance of the entire production chain, from the receipt of raw materials, processing, and final assembly, with all processes being the responsibility of the company itself.

The assembly and supply lines, which are the focus and object of this study, are highly manual processes executed by operators and without robotics, mainly due to customization that makes automation of these processes difficult and requires high investments.

In addition, it should be noted that the system is defined by a hybrid flow shop where a direct relationship exists between the supply cells and the final assembly. In order for daily production to be carried out correctly, it is necessary to have a synchronization between these workstations, as the stages are interdependent.

The need for synchronization between the stages of the production process is related to the problem of non-digitization of data in the company, since the management of these orders is carried out physically, under the responsibility of the operation itself. In the case in question, there is no integration between the assembly line and the company's ERP, like a MES, which makes monitoring production data and controlling productivity critical.

However, there is a basic system that allows the operation to be recorded to identify which Production Order (PO) was executed at a given moment, so the data used in the simulation was collected with the support of these reports. The period of the collected data corresponds to 26 months of production, between July 2020 and August 2022.

5.4.2 SIMULATION DEVELOPMENT

The simulation was developed using Anylogic software version 8.5.2, where the entire model was built based on the operation of the assembly line and supply cells of the company described in the previous section, therefore, a representation of the real scenario.

To develop the model, the databases provided by the real company were used, dated from July 2020 to August 2022, which contained three main pieces of information: the STRING of the production order, which provides the sequential order of the production order, the scheduled day for its assembly, and the order number; the actual DATE and TIME of production, indicating the moment when a specific equipment or subassembly item was completed, and finally, the QUANTITY of products per production order.

These data were obtained in Excel spreadsheets and imported into AnyLogic, thus generating the database in the system, which was used in the simulation. Figure 3 below shows the database already inputted into the system.

	data	string	quantidade
1	07-07-2020 07:08:00	(OP 1 DIA 07/07) 132032	1
2	07-07-2020 07:37:00	(OP 2 DIA 07/07) 131913	1
3	07-07-2020 07:49:00	(OP 4 DIA 07/07) 132019	1
4	07-07-2020 08:39:00	(OP 5 DIA 07/07) 132030	1
5	07-07-2020 09:23:00	(OP 6 DIA 07/07) 131913	1
6	07-07-2020 10:11:00	(OP 7 DIA 07/07) 132012	1
7	07-07-2020 10:51:00	(OP 8 DIA 07/07) 132017	1
8	07-07-2020 13:02:00	(OP 9 DIA 07/07) 131913	1
9	07-07-2020 13:23:00	(OP 10 DIA 07/07) 131858	1
10	07-07-2020 13:50:00	(OP 11 DIA 07/07) 132011	1
11	07-07-2020 14:20:00	(OP 12 DIA 07/07) 132014	1
12	07-07-2020 15:19:00	(OP 13 DIA 07/07) 131913	1
13	07-07-2020 15:49:00	(OP 14 DIA 07/07) 131979	1
14	07-07-2020 16:22:00	(OP 15 DIA 07/07) 132049	1
15	07-07-2020 16:22:00	(OP 16 DIA 07/07) 132177	1
16	07-07-2020 16:38:00	(OP 17 DIA 07/07) 132191	1
17	08-07-2020 08:40:00	(OP 1 DIA 08/07) 132054	1
18	08-07-2020 09:33:00	(OP 2 DIA 08/07) 131913	1
19	08-07-2020 09:43:00	(OP 3 DIA 08/07) 131953	1
20	08-07-2020 09:58:00	(OP 4 DIA 08/07) 132054	1

The first step in programming was to design the workstations, as well as their connections and production conditions. Figure 4 shows the model ready in computer format, mainly highlighting the use of tools such as "match" and "combine" that define the conditions for production to occur: a production order "OP1" can only be executed on the assembly line when the supply cells complete their work on the same production order "OP1".

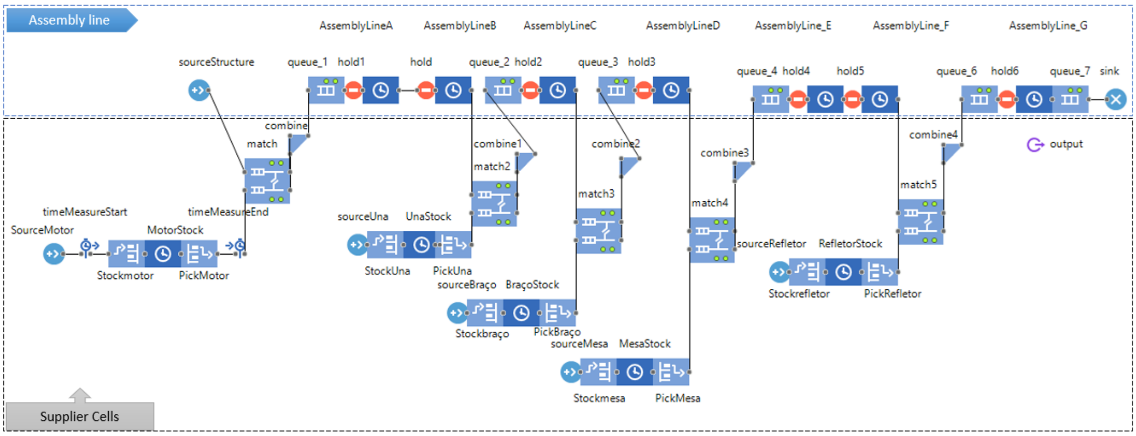


Figure 4 – Simulation Model

Each supply point, named as “Source”, was fed with the collected data, described in operation tracking spreadsheets containing information about each Production Order (PO). These spreadsheets include date and time of manufacture, the order number and scheduled day, in "String" format, and the quantity corresponding to the amount of equipment per PO.

For a better validation of the simulated system, a 3D model was developed, illustrated in Figure 5, bringing the visibility aspect of the productive cells' operation. It is possible to identify the workstations, the operators' movement, the queues, and the production dynamics.

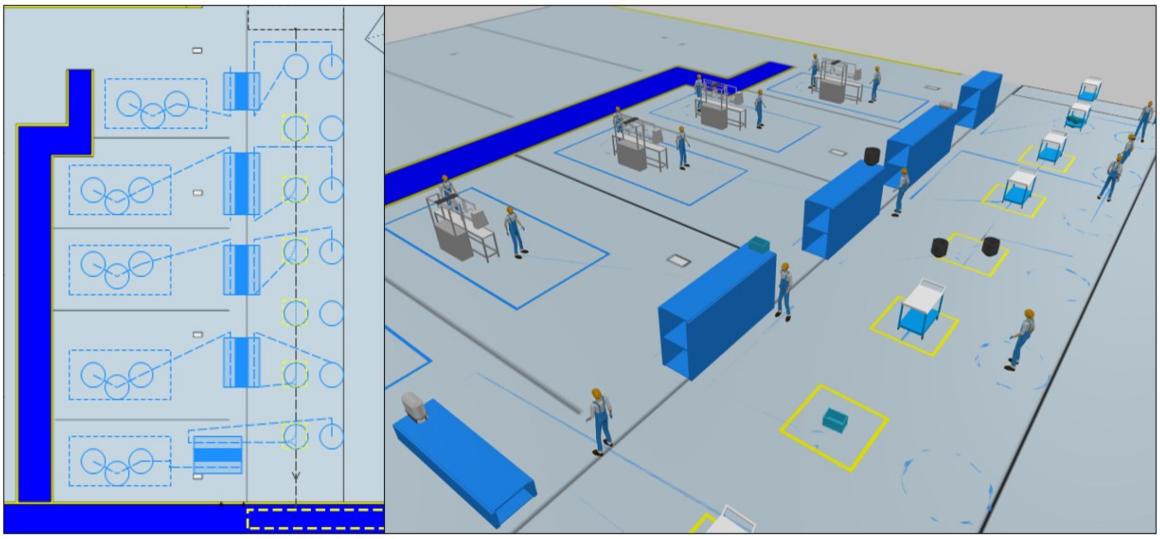


Figure 5 – 3D Simulation Model

5.4.3 SCENARIOS DESCRIPTION

Using the same computational model described in the previous section, the experiment was performed in three different scenarios, for which the main differentiation lies in the simulation of the use of digital technologies that bring improvements to the operation management. Some simulated improvements represent the implementation of a manufacturing execution system, which allows for automated data flow and tracking, digital sequencing of the production order, and visualization panels for management.

In Scenario 1, we are representing the reality of the company, in other words, there is no integration between the ERP system and the assembly and supply lines. The production orders are distributed in a physical way, mainly on paper, for the operation's own management, though production data does not return to the system, and there is no monitoring between the sequences produced.

The manufacturing times in scenario 1 are exactly those reported by the operators, including production stops. Figure 6 shows the logical operation of Scenario 1 (real).

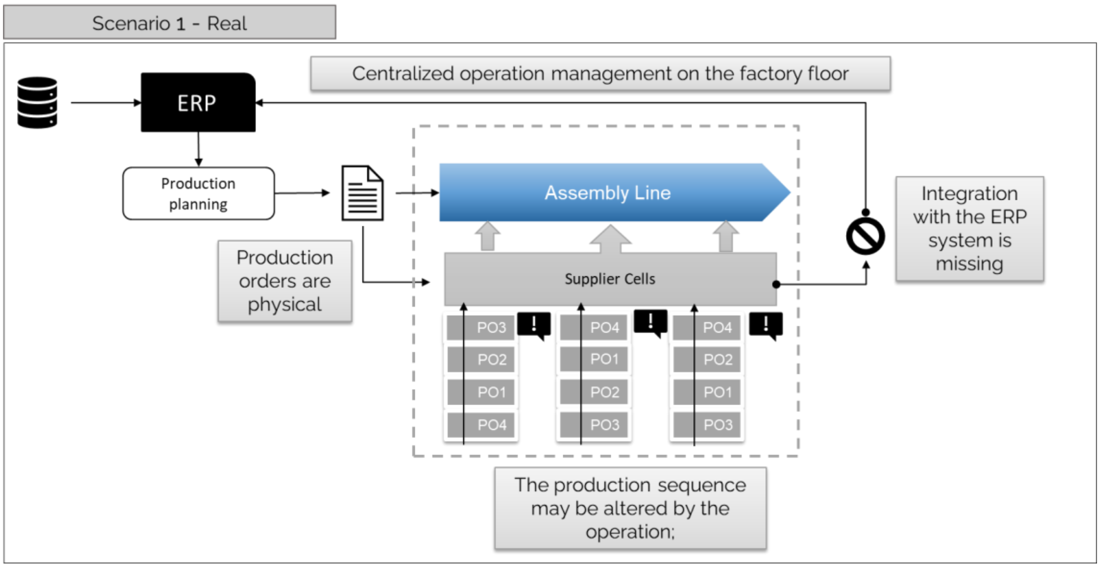


Figure 6 - The operating logic of Scenario 1

Scenarios 2 and 3 are similar by simulating the implementation of technologies aimed at managing operations, such as digitizing production orders, accessing real-time production data, MES integrating with ERP to centralize decision-making by managers, and show greater control over assembly execution. In these scenarios, the factory floor is limited in decision-making, and it is now controlled using technologies.

Thus, in both scenarios, it is considered that systems and digital information flow prevent operator error, sending alerts in case of an out-of-order operation, for example.

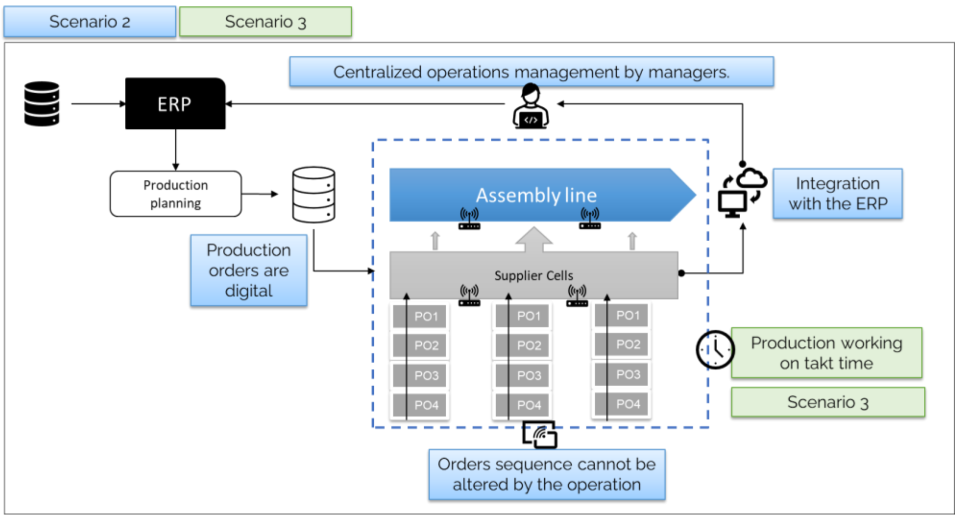


Figure 7 -The operating logic of Scenarios 2 and 3

The main differences between Scenario 1 and Scenarios 2 and 3 can be observed in Figure 7. What sets Scenario 2 apart from Scenario 3 is that, in the last case, the simulation uses the assembly line's takt time as input data, while in the previous scenarios, the time considered is the original recording time, which includes downtimes and delays.

5.5 RESULTS AND DISCUSSION

As highlighted in previous sections, one of the objectives of this article is to provide contributions in quantitative results and data that can elucidate the benefits of digitization in operations management. In this section, the results found for lead time, production, productivity, scheduling execution rate, and impact on revenue indicators are described. Along with the discussion of the findings and their practical implications.

5.5.1 LEAD TIME

To evaluate the behavior of the three different scenarios based on the lead time indicator, the input data of the production orders in the assembly line and the date and time of their exit, this data was considered to obtain a comparative analysis between them.

Figure 8 shows the results for the three scenarios, demonstrating that the real scenario presented an average assembly line lead time of 9.8 hours. Meanwhile, for the same simulated period and the same dataset, but now with the use of technologies on the shop floor, scenarios 2 and 3 have achieved averages of 5.4 and 3.0 hours, respectively.

These results are mainly related to the condition of digitalization and integration of production orders with the system. When the operation management becomes centralized through an ERP system, delays and waiting times due to component shortages are significantly reduced.

On average, there was a 40% reduction in assembly line lead time when comparing scenarios 1 (real) and 2 (with digital technologies), and a 59% reduction between scenarios 1 (real) and 3 (with technologies and production at takt time).

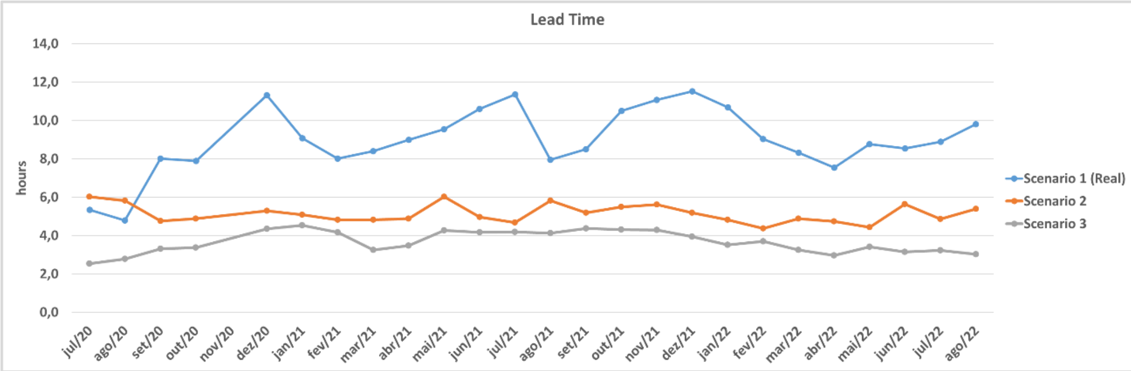


Figure 8 – Results for Lead time in 3 Scenarios

5.5.2 PLANNED EXECUTION RATE

This indicator represents the ability of the scenarios to correctly execute the production sequence programmed by PCP, that is, it shows how much the systems were able to maintain the production order in accordance with the delivery dates to the customers. The results obtained in C2 and C3 were clearly identified as positive, demonstrating an average accuracy rate of 94% and 96%, respectively. The results are presented in Figure 9.

On the other hand, the Real Scenario shows a correct execution rate of only 40% of the programmed orders, a result that corroborates with higher lead times on the assembly line and possible delays in delivery to customers. These data are highly related to physical production orders and the lack of control in executing the programming in C1.

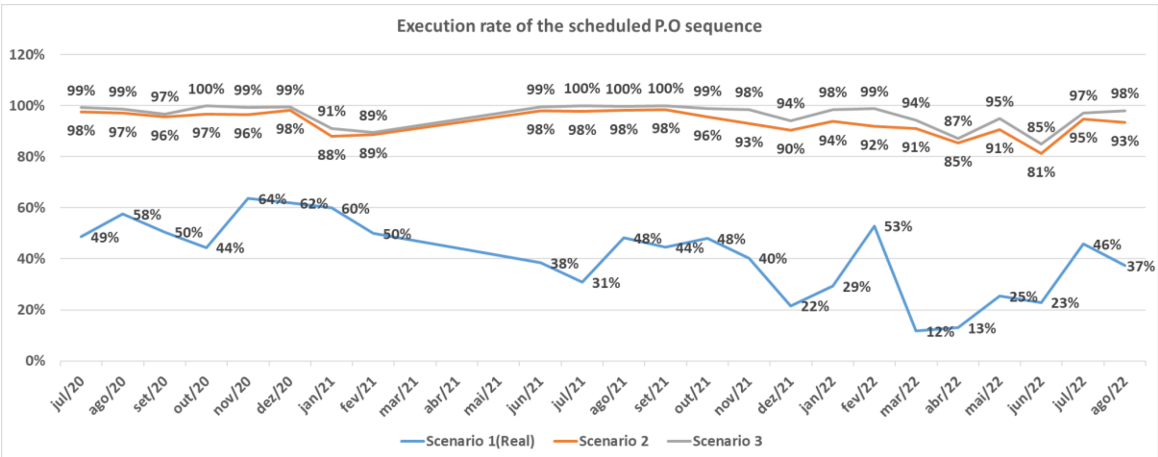


Figure 9 – Results for planned execution rate in 3 scenarios

Positively, in scenarios where technologies such as MES and digital order data distribution, integrated with the ERP system, the assembly line performance increases and the success of the programming can be guaranteed. Analyzing these results, it is possible to affirm that the entire production chain benefits and consequently, the end customer.

The use of technology, in this case, limiting the exchange of production orders by the operation, ensuring greater control and accuracy in the programmed sequence, promotes synchronization between assembly lines and supply lines. This fact contributes to solving situations in the real scenario, such as order delays caused by the lack of coordination between ready components in the supply lines and equipment being assembled on the assembly line.

5.5.3 PRODUCTIVITY

The third indicator highlights the results obtained in productivity, which are presented in the following Figure 10. A similar behavior pattern can be identified among all scenarios since this indicator is directly related to production capacity and the number of equipment scheduled for each month.

Despite that, the analyzed data, and the results from scenario 1 show that production exceeded the plan in some months, producing above what was programmed by the Production Control and Planning (PCP) and using overtime hours to complete the work plan in other periods. This data reveals the lack of control over the scheduling plan, mainly due to the lack of integration between the factory floor and the ERP system.

In comparison, in scenarios 2 and 3, there is no use of extra operating shifts, and productivity remains in line with the monthly plan. In the simulated scenarios with the use of digital orders and integration with the system, there is no waste of overproduction since the equipment's traversal time is shorter, and the assembly line becomes more efficient in executing the program.

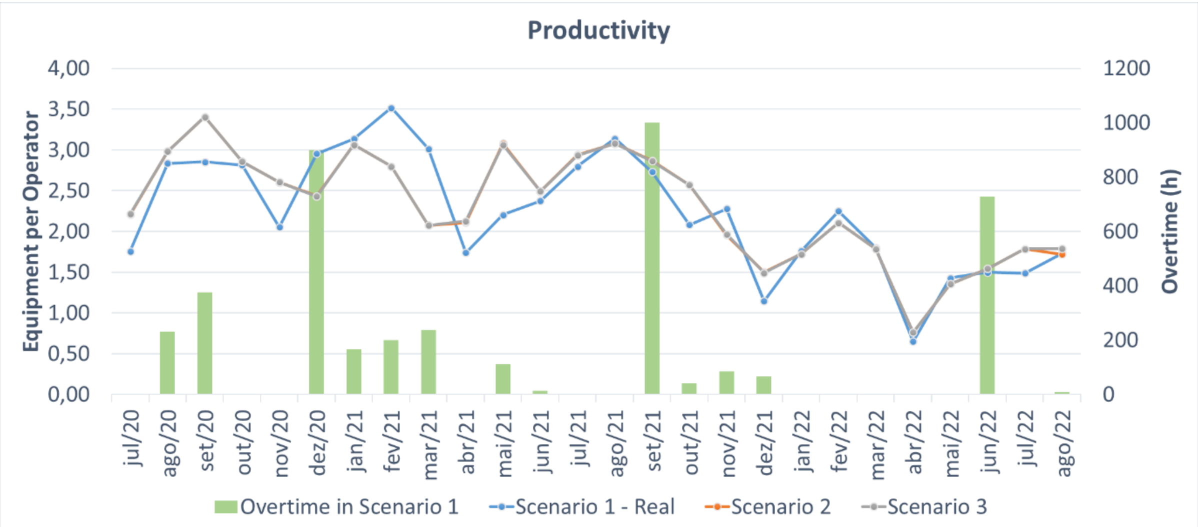
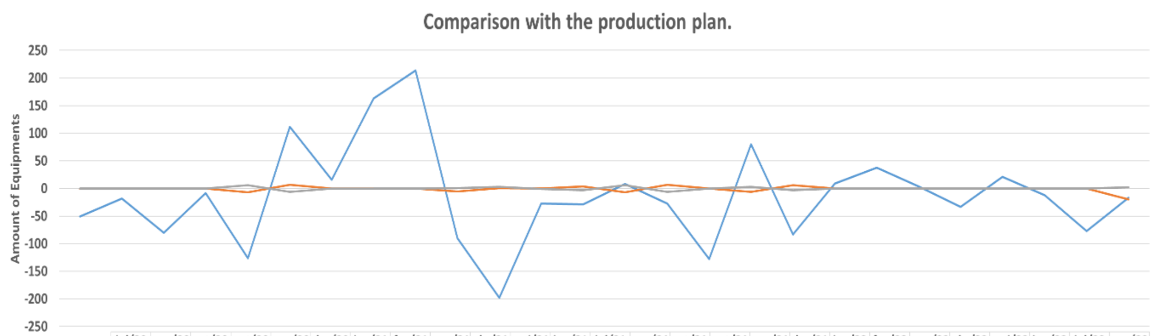


Figure 10 – Results for productivity in 3 scenarios

To provide a more detailed demonstration, Figure 11 shows a monthly comparison between the amount of equipment produced in each scenario and the amount of equipment planned. The zero point, in this case, represents the exact execution of products as per the schedule.



	jul/20	ago/20	set/20	out/20	nov/20	dez/20	jan/21	fev/21	mar/21	abr/21	mai/21	jun/21	jul/21
Scenario 1 - Real	-51	-18	-80	-8	-126	112	16	163	214	-90	-198	-27	-29
Scenario 2	-1	0	0	0	-7	7	0	0	0	-5	1	0	4
Scenario 3	0	0	0	0	6	-6	0	0	0	1	3	-1	-3

	ago/21	set/21	out/21	nov/21	dez/21	jan/22	fev/22	mar/22	abr/22	mai/22	jun/22	jul/22	ago/22
Scenario 1 - Real	8	-27	-128	80	-83	9	38	4	-33	21	-12	-77	-17
Scenario 2	-7	7	0	-6	6	0	0	0	0	0	0	0	-20
Scenario 3	6	-6	0	3	-3	0	0	0	0	0	0	0	2

Figure 11 – Comparison of the production outcome of the scenarios versus the planning.

In scenarios 2 and 3, there is a slight variation between the number of planned and produced equipment, demonstrating a high efficiency in the assembly line. Meanwhile, Scenario 1 shows a higher amplitude, mainly negative, which reflects monthly delivery delays, a fact that can affect both revenue and delivery to the end customer.

When we analyze graphs 3 and 4 together, we can observe a correlation between months of "overproduction" and overtime, such as in Nov/20, Dec/20, Jan/21, Feb/20, and Mar/21, where we had periods of high production coupled with longer working hours.

Upon deeper analysis, we can see how this variation in production impacts the company's monthly revenue. In other words, in Scenario 1, the company would be missing out on “N orders”, which, during months of significant production delays, could represent a loss of revenue of up to 4 million reais, as shown in Figure 12. On the months when revenue exceeds projections, it's also when the company spends more on overtime.

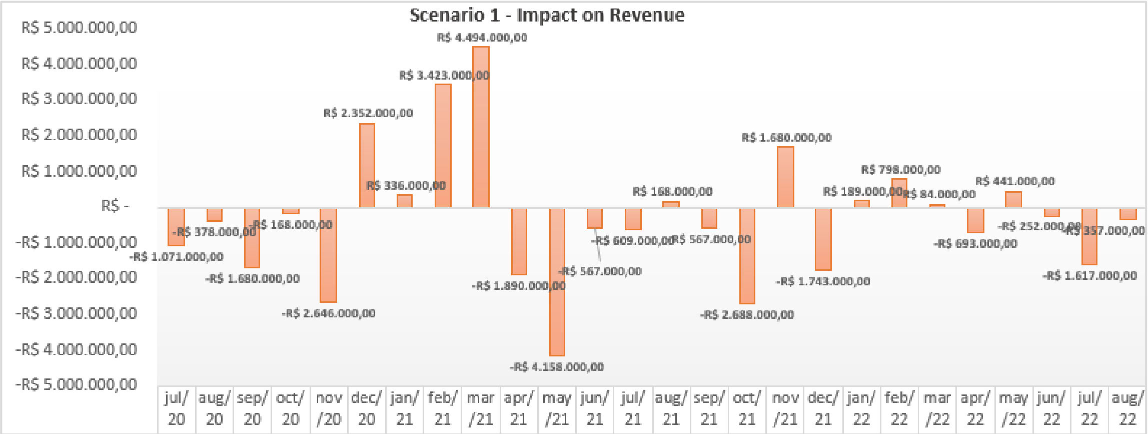


Figure 12 – Impact of scenario 1 on revenue.

5.5.4 RELATED WORK AND PRACTICAL IMPLICATIONS

To define a strategy for adopting digital technologies focused on operational performance and identify KPIs that help measure advancements in digitalization and their impact on the business is crucial for small and medium-sized enterprises (SMEs) seeking to improve the efficiency of their manufacturing processes using accessible technologies that have a good cost-benefit ratio for their context.

Based on the results, it is possible to propose practical implications and insights for the management of SMEs seeking to improve the efficiency of their manufacturing processes using accessible technologies that have a good cost-benefit ratio for their context. The literature, including Busto Parra *et al*. (2022), suggests a consensus regarding the lack of vision of the various dimensions of Industry 4.0-related technologies, which makes it difficult to develop and implement technological solutions and strategies. Thus, their studies support the findings of the present article, highlighting that digital solutions and a well-defined and functional ERP system are fundamental aspects for digital transformation (Stich *et al*., 2020), promoting better management capacity and improvements in production processes.

The results presented by Alexopoulos *et al*. (2022) also demonstrate that the application of technologies in operations management can bring excellent results for SMEs, especially in terms of monitoring the production process. Additionally, they affirm that practical studies are essential for companies to understand how these approaches can help solve real-world problems. The KPIs addressed in this article can be classified as measures for the success of digital transformation in SMEs. According to Stich *et al*. (2020), important metrics are those that impact traceability, paperless production, IT technology integration, ERP implementation, electronic data exchange, production analysis, and monitoring, among others, which are described in this article.

As a contribution to the results, we summarize in Table 1 some actions that fit the reality of these companies. SMEs can have a view of the real return they can obtain from using digital technologies, considering a scenario of uncertainties regarding high investments. Furthermore, these actions can also be incorporated into a research agenda that includes defining the main characteristics in ERP and MES system design for SMEs, developing a framework for adopting and selecting Industry 4.0 technologies in SMEs, proposing indicators to aid in the measurement, monitoring, and management of digitalization, and training and preparing SME employees for the adoption of new technologies.

Table 1. Practical Insights, findings, and actions for Managers

Practical Insights on	***Findings***	***Actions***
Technology	The use of technologies focused on monitoring and control generates significant results in improving operational performance.	Investing in systems such as ERP and MES, focusing on data implementation and integration, is the initial foundation for the success of digitization on the factory floor.
Operations Management	For improving manufacturing processes, operations management is a key point and should always be based on real-time electronic data for visualization and analysis.	Investing in technologies such as Big Data Analytics, IoT, and Business Intelligence can bring significant benefits to a company's digital transformation journey. These technologies can provide valuable insights and data-driven decision-making capabilities that can improve operational efficiency, reduce costs, and increase competitiveness.
SME's Adaptation for Digital Transformation	The success of the journey towards digital transformation in an SME should be based on the business strategy and a focus on implementing technologies that bring returns that ensure the competitiveness of SMEs in the market.	Defining a strategy for adopting digital technologies focused on operational performance and identifying KPIs that help measure progress in digitalization and its impact on the business.
Simulation	The use of simulation helps in the visibility of the benefits generated by investments and can be a useful methodology in decision making.	Developing teams with the skills to perform scenario analysis using simulation.

5.6 CONCLUSION AND OUTLOOK

Given the reality where small and medium-sized enterprises face challenges on the journey towards digital transformation, mainly due to lack of resources, infrastructure, as well as lack of understanding of the tangibility (economic benefit) generated by I4.0 (Amaral & Peças, 2021), this work aimed to contribute to the literature from the perspective of practical applications that assist SMEs in the process of digital transformation. This approach is more realistic and is based on quantitative validations using real data, to support managers' actions in real companies.

As this work is a continuation of a previous conceptual work (Stradioto & Frazzon, 2023), it is important to highlight that there is a set of actions that must be developed beforehand, with a strategic vision in the companies, so that the technologies can be implemented efficiently in their processes. The conceptual works should be used as an initial structuring of the journey towards digital transformation, followed by practical works, such as this article, which promote realistic aspects.

In conclusion, this article presented, through simulation, a practical approach, and results on the impact of technologies applied to a real scenario, with real data. Demonstrating through KPIs such as lead time, planning execution rate, and productivity, the benefits, and significant improvements to the operational performance of manufacturing companies.

Future efforts in research that focus on demonstrating the stages of technology implementation as well as the costs involved in the process would be relevant to complement the practical aspects and increase confidence in the decision-making process by SME managers. Other works demonstrating the functioning and applicability of specific systems and solutions that also serve small and medium-sized enterprises would also assist in this regard.

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6 SÍNTESE DO ESTUDO

Este capítulo apresenta a síntese dos resultados das etapas 1, 2 e 3 do procedimento metodológico, descritos nos capítulos 4 (artigo 1) e 5 (artigo 2) sendo que o primeiro contribui com a base teórica sobre a transformação digital, bem como fornece a base para o desenvolvimento conceitual do roteiro para a TD e do modelo conceitual. O segundo artigo tem como foco a abordagem prática da transformação digital, apresentando a aplicação do modelo conceitual resultante do primeiro artigo. Os artigos foram desenvolvidos visando cumprir os objetivos geral e específicos apresentados na seção 1.3.

Para representar ambos os artigos e trazer uma visão compilada sobre a dissertação, o quadro abaixo relaciona os objetivos específicos, os resultados e as contribuições do trabalho. Na sequência, os capítulos 4 e 5 são descritos de forma mais detalhada.

Quadro 3 - Resumo dos resultados e contribuições dos artigos

	Objetivo	Resultados	Contribuições
Capítulo 4 – Artigo 1	Avaliar os aspectos da transformação digital presentes na literatura em comparação com o cenário prático brasileiro e propor um roadmap e um modelo conceitual, visando auxiliar a implementação de tecnologias digitais em indústrias de pequeno e médio porte.	· 12 aspectos definidos como direcionadores para a jornada da transformação digital; · Tabela de correlação entre os aspectos e o cenário prático brasileiro, a partir de análise qualitativa; · Roadmap definido para auxílio na jornada de transformação digital; · Modelo conceitual estruturado para digitalização com base no aspecto da literatura (gestão de operações), representando um cenário real de indústria de médio porte.	· As principais contribuições neste capítulo podem ser destacadas como um estudo qualitativo que trouxe uma visão da literatura em aspectos importantes para transformação digital e uma visão comparativa, onde pode-se entender de forma ampla o contexto do cenário prático brasileiro. Unindo o viés teórico e prático em um artigo. · Por fim, este capítulo fornece também um roadmap como um guia, contribuindo com a identificação dos passos para uma transformação digital, além de abrir caminhos para uma aplicação prática a partir do desenvolvimento de um modelo conceitual baseado em um caso real.
Capítulo 5 – Artigo 2	Comparar e evidenciar, usando simulação computacional, os resultados da aplicação de tecnologias digitais em três diferentes cenários, utilizando dados de uma empresa real.	· Modelo computacional de uma linha de montagem desenvolvido em Anylogic; · Definição de cenários e análise do impacto da digitalização em KPIs relevantes para o aspecto de gestão de operações; · Análise quantitativa do impacto da digitalização em uma linha de montagem, aumento da performance em cenários com a utilização da tecnologia.	· A simulação dos cenários permitiu identificar a partir de três diferentes indicadores, os impactos das tecnologias digitais na performance de uma linha de montagem. · Neste sentido, contribuindo para o entendimento de como as tecnologias podem impactar positivamente um negócio de médio porte; · Ganhos em lead time, assertividade na sequência de produção e produtividade foram identificados para os cenários com uso de tecnologias

Fonte: Elaborado pelo autor (2023).

O artigo 1, foi dividido em 3 etapas: revisão da literatura, revisão da prática e análise comparativa. A etapa 1 contribuiu com os resultados da revisão de literatura sobre a transformação digital, onde foram definidos os conceitos a serem implementados na indústria com base nos pilares organizacional, de processos e tecnológicos, demonstrando 12 aspectos relevantes. Os 5 principais aspectos da transformação digital foram identificados como:

estratégia organizacional, gestão de operações, integração vertical e horizontal, investimento em tecnologias (inovação) e profissionais qualificados.

Diante dos aspectos, na etapa 2, foi possível definir, a partir de relatórios sobre a indústria brasileira, o cenário da digitalização em empresas do país e na etapa 3, uma análise comparativa foi realizada a partir da correlação com cada um dos aspectos encontrados na literatura durante a etapa 1. Como resultado, uma tabela de panorama geral foi desenvolvida e os principais *gaps* da TD na indústria brasileira foram destacados, concluindo-se que, no país, muitas companhias ainda não possuem uma estratégia bem definida para digitalização de seus processos, bem como faltam profissionais qualificados para a jornada de digitalização. Neste sentido, há oportunidades de contribuição para cada um dos aspectos que ainda estão subdesenvolvidos no país.

Ainda no artigo 1, concluindo seu objetivo, foram propostos um caminho (*roadmap*) para ser utilizado como guia na jornada de digitalização nas empresas e um modelo conceitual específico para aplicação prática, retratando a aplicação de tecnologias digitais com foco na gestão de operações, monitoramento e controle em um caso real da indústria brasileira, visando destacar este aspecto que foi anteriormente identificado como um dos principais para TD.

No quinto capítulo (artigo 2), foram apresentados os resultados relacionados ao desenvolvimento computacional baseado no modelo conceitual descrito no capítulo 4, bem como os experimentos de simulação realizados.

Neste capítulo, foi descrito também sobre o caso real, de onde os dados foram extraídos, tratando-se de uma empresa brasileira de médio porte (>200 funcionários), que produz equipamentos para saúde e que tem como objetivo ser competitiva no cenário global. O escopo do modelo conceitual foi baseado na linha de montagem final e suas células de suprimento, buscando uma abordagem prática para melhorar a performance da operação a partir da utilização das tecnologias digitais. Para evidenciar o impacto da digitalização nesta linha de montagem, foram realizados experimentos de simulação.

O procedimento da simulação passou por quatro macro etapas: conceitualização, onde foram definidos o conceito do sistema para simulação, seguindo da etapa de programação, onde o modelo computacional foi desenhado utilizando a ferramenta de modelagem e simulação Anylogic. Na sequência, os cenários foram simulados com dados reais de apontamento de produção, datados do período de 2 anos, entre 2020 e 2022, em três diferentes cenários, buscando demonstrar os impactos da tecnologia digital em comparação ao cenário real sem digitalização.

Como resultado do artigo 2 foi possível evidenciar que a performance operacional é positivamente impactada pela utilização de tecnologias no chão de fábrica, principalmente relacionadas à gestão de operações. Os resultados foram demonstrados mediante a apresentação de indicadores de desempenho. Destaca-se o indicador de Lead time, onde os cenários 2 e 3 (com tecnologias digitais) apresentaram 40% e 59% de redução em comparação ao cenário 1 (real – sem tecnologias digitais), respectivamente. Estes resultados mostram o impacto da implementação de tecnologias que auxiliam as empresas a se manterem competitivas no mercado, melhorando seus prazos de atendimento com o consumidor final.

Em outro resultado significativo, o indicador de taxa de execução do planejamento mostrou uma taxa de acerto de 94% e 96% para os cenários 2 e 3, respectivamente, enquanto o cenário real, apresentou uma taxa média de acerto da programação de 40%, demonstrando a fragilidade de uma operação que não utiliza a tecnologia a seu favor.

Desta forma, a simulação se mostrou um método eficiente para obter uma visão sobre o impacto da digitalização em uma linha de montagem em uma empresa de médio porte, promovendo visibilidade e consequentemente tornando mais tangíveis os benefícios da aplicação de tecnologias para gestão de operações, tais como: ERP, MES, Big Data Analytics, Inteligência de Dados, Computação em nuvem, entre outras.

7 CONCLUSÕES FINAIS

Esta seção apresenta as considerações finais do trabalho bem como as oportunidades para estudos futuros.

7.1 CONCLUSÕES

Esta dissertação teve como objetivo geral, propor um modelo conceitual para a digitalização de pequenas e médias empresas industriais brasileiras, bem como evidenciar o impacto da transformação digital em uma indústria de manufatura de médio porte, utilizando a metodologia de simulação de eventos discretos para executar experimentos do modelo conceitual desenvolvido. Visando contribuir para a literatura e servir como *know-how* para a prática da digitalização nas empresas de pequeno e médio porte, o trabalho obteve resultados significativos demonstrando dados quantitativos e tangíveis sobre o impacto das tecnologias digitais.

O estudo foi dividido em quatro etapas que compreendem a análise da literatura, o desenvolvimento conceitual, a aplicação do modelo e a divulgação dos resultados. Na primeira etapa uma revisão da literatura foi realizada para compreender e consolidar os principais aspectos a serem considerados no processo de transformação digital. Com base nestes aspectos foi identificado um panorama geral sobre a indústria brasileira em uma análise comparativa de relatórios existentes sobre o cenário nacional e os aspectos definidos pela literatura, demonstrando a posição das empresas do país em relação a cada um dos fatores da TD, concluindo assim o objetivo específico (i).

Para atingir o segundo objetivo específico (ii) um guia para transformação digital foi desenvolvido com base na revisão da literatura, e a partir dele, um modelo conceitual foi proposto visando a aplicação dos conceitos da gestão de operações, monitoramento e controle em um caso real de uma indústria brasileira de manufatura de médio porte. Os objetivos (i) e (ii) fazem parte do artigo 1, descrito no capítulo 4 desta dissertação.

Por fim, na terceira etapa, o modelo computacional foi desenvolvido e simulado com dados reais da indústria, por meio do Software de modelagem Anylogic. Foram realizadas comparações dos resultados para a condição do sistema com relação a implementação de tecnologias em três diferentes cenários, completando assim o objetivo específico (iii). Esta terceira etapa gerou o artigo 2, que juntamente com o artigo da etapa 1, compõem a etapa conclusiva de disseminação dos resultados.

Como consideração final, os resultados empíricos obtidos na simulação mostram os impactos positivos e benefícios no desempenho operacional gerados mediante a aplicação das tecnologias associadas a gestão de operações no chão de fábrica. No aspecto prático, visto que, as empresas de pequeno e médio porte possuem limitações quanto aos recursos disponibilizados e considerando que muitas delas não possuem uma estratégia para transformação digital definida e estruturada, resultados como estes podem auxiliar também no âmbito estratégico, principalmente apoiando a tomada de decisão por parte dos gestores, bem como gerar *insights* na possibilidade de utilização das tecnologias digitais de forma eficiente.

Para literatura, os resultados contribuem trazendo uma combinação de duas abordagens complementares: uma visão conceitual e teórica que auxilia a direcionar as empresas quanto aos aspectos importantes na jornada da transformação digital, e uma visão prática, que traz por meio da simulação, dados quantitativos e indicadores que podem ser utilizados como base comparativa para outros trabalhos. Ainda no âmbito prático, o roadmap da digitalização e a simulação de dados podem ser aplicados e adaptados em pequenas e médias empresas de diferentes áreas.

7.2 OPORTUNIDADES PARA ESTUDOS FUTUROS

A partir das limitações identificadas nesta dissertação, foram observadas oportunidades de trabalhos futuros no campo de estudo da Transformação Digital. Inicialmente, trabalhar na definição do cenário brasileiro de digitalização nas indústrias de pequeno e médio porte, a partir de dados coletados em *surveys*, como oportunidade para estender o entendimento sobre a realidade no país. Ademais, trabalhar aspectos da influência da qualificação profissional no processo de digitalização no Brasil também surge como oportunidade futura.

Visando trazer uma abordagem ainda mais realista, há oportunidade de realizar uma pesquisa com maior interação dos tomadores de decisão das empresas, incluindo opiniões e discussões sobre os impactos da transformação digital no dia a dia da gestão. Ainda, sob este mesmo ponto de vista, trabalhos que apresentem um viés do impacto da transformação digital na gestão estratégica, tática e no modelo de negócio, são importantes para ampliar a discussão no tema.

Outro trabalho relevante pode ser desenvolvido de forma a expandir a aplicação do *roadmap* proposto, ou seja, executando ações de digitalização nos três pilares de uma empresa:

organizacional, processual e tecnológico, realizando um trabalho de ponta a ponta, contribuindo no âmbito de trabalhos com viés de aplicação prática. Ainda, outro campo para ser explorado é a relação custo-benefício entre a aplicação das diferentes tecnologias digitais em diferentes áreas das empresas de pequeno e médio porte e o retorno em desempenho operacional gerado por elas. Visando elucidar este considerado muito relevante para estas companhias.

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