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DANIEL ALEXANDRE MORELLI

PROPOSTA PARA UM MODELO DE APLICAÇÃO DAS TECNOLOGIAS *BLOCKCHAIN* E *CLOUD MANUFACTURING* PARA GESTÃO DE SISTEMAS *LEAN* DE PRODUÇÃO

PROPOSAL FOR AN APPLICATION MODEL OF BLOCKCHAIN AND CLOUD MANUFACTURING TECHNOLOGIES TO MANAGE LEAN PRODUCTION SYSTEMS

LIMEIRA – SP

2024

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Orientador: Prof. Dr. Paulo Sérgio de Arruda Ignácio

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RESUMO

Empresas estão enfrentando novos desafios no atual cenário de crescente globalização, competitividade de mercado e customização em massa. A adoção de tecnologias digitais da Indústria 4.0 (I4.0) ao longo de todo o ciclo de vida de produtos e serviços pode auxiliar essas empresas a alcançarem melhoria de eficiência em seus processos e, consequentemente, vantagens competitivas. A aplicação de tecnologias disruptivas da I4.0 para suporte e desenvolvimento de sistemas *Lean* de produção, caracteriza um modelo chamado *Lean Automation* (LA), integrando tecnologias modernas de alta conectividade a princípios de redução de falhas, custos, tempo e materiais. O objetivo principal desta pesquisa é propor um modelo para aplicação combinada das tecnologias *Cloud Manufacturing* (CMfg) e *Blockchain* a um sistema *Lean* de produção. Assim, são analisados o estado atual das pesquisas aplicadas da tecnologia *Cloud Manufacturing*, e a situação atual de micro, pequenas e médias empresas (MPMEs) brasileiras em relação à implementação de modelos inovadores *Lean Automation*, bem como, é definido e simulado um modelo de integração entre *stakeholders* utilizando a combinação de princípios *Lean* e das tecnologias *Cloud Manufacturing* e *Blockchain*, discutindo de que forma a combinação dessas tecnologias agregam vantagens aos sistemas *Lean* de produção, e suas vulnerabilidades. A intersecção dos temas CMfg, *Blockchain* e Sistemas *Lean* de Produção é abordado com o desenvolvimento de 3 artigos acadêmicos produzidos durante o programa de mestrado e submetidos à publicação em revistas científicas. Esses artigos trazem a relação das áreas de conhecimento propostas na pesquisa através de revisões sistemáticas da literatura disponível nas bases de dados Scopus e Web of Science, estudos exploratórios de levantamento de dados por meio de *survey*, e ainda, simulação computacional na rede Hyperledger Fabric operada por máquina virtual em ambiente de nuvem. Este estudo avalia aspectos identificados como lacunas de pesquisa, incluindo: integração de *stakeholders* na produção colaborativa de produtos customizados, flexibilidade e adaptabilidade a variações de demanda, relacionamento colaborativo de redes envolvendo PMEs, a o comportamento de diversos *players* atuando de forma simultânea e consensual. Os objetivos propostos estão atingidos, obtendo-se um modelo que não apenas combina as tecnologias *Cloud Manufacturing* e *Blockchain* aplicadas a sistemas *Lean* de produção, mas também revela um conceito de compartilhamento de informações

descentralizado e não-linear que promove uma lógica de participação simultânea de todos os *players* envolvidos na cadeia de suprimentos. Esta arquitetura computacional apresenta uma solução diferenciada no planejamento de sistemas de produção integrada e no suporte a processos operacionais, indicando o diferencial deste trabalho e estimulando *insights* a pesquisadores e especialistas na adoção de tecnologias inovadoras, confiáveis e inclusivas em empresas de diferentes tamanhos ou níveis de desenvolvimento tecnológico, com foco em produção enxuta, redução de custos e diminuição do consumo de recursos.

PALAVRAS-CHAVE: Indústria 4.0; *Blockchains* (Base de dados); Computação em nuvem; Cadeia de suprimentos; Pequenas e médias empresas.

ABSTRACT

Enterprises are facing new challenges in the current scenario of increasing globalization, market competitiveness and mass customization. The adoption of Industry 4.0 (I4.0) digital technologies throughout the life cycle of products and services drives these enterprises to achieve efficiency improvement in their processes and, thus, competitive advantages. The application of disruptive I4.0 technologies to support and develop Lean production systems characterizes a model called Lean Automation (LA), integrating modern high-connectivity technologies with waste reduction principles, such as failures, costs, time and materials. The main objective of this research is to propose a model for the application of Cloud Manufacturing (CMfg) and Blockchain technologies to a Lean production system. Therefore, this study analyzes the current state of applied research on Cloud Manufacturing technology, and the current situation of Brazilian micro, small and medium-sized enterprises (MSMEs) in relation to the implementation of innovative Lean Automation models, as well as a model of integration between stakeholders using the combination of Lean principles, Cloud Manufacturing and Blockchain, discussing how the combination of these technologies adds advantages to Lean production systems, and their vulnerabilities. The intersection of CMfg, Blockchain and Lean Production Systems topics is addressed through the development of 3 academic papers elaborated during the master's program and submitted for publication in scientific journals. These papers list the areas of knowledge proposed in the research through systematic reviews of the literature available in the Scopus and Web of Science databases, exploratory data collection studies through surveys, and also, computer simulation on the Hyperledger Fabric network operated via virtual machine in a cloud environment. This study evaluates aspects identified as research gaps, including: stakeholders integration in the collaborative production of customized products, flexibility and adaptability to demand variations, collaborative relationships between networks involving SMEs, and the behavior of several players acting simultaneously and consensually. The proposed objectives have been achieved, obtaining a model that not only combines Cloud Manufacturing and Blockchain technologies applied to Lean production systems, but also reveals a concept of decentralized and non-linear information sharing which promotes a logic of simultaneous participation of all players involved in the supply chain. This computational architecture presents a differentiated solution on the

integrated production systems planning and supporting operational processes, indicating this work differential and stimulating insights for researchers and specialists in the adoption of innovative, reliable and inclusive technologies in enterprises of different sizes or technological development levels, focusing on lean production, reduction of resource consumption and cost reduction.

KEYWORDS: Industry 4.0; Blockchains (Databases); Cloud computing; Supply chain; Small business.

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LISTA DE ABREVIATURAS E SIGLAS

AM: *Additive Manufacturing*, ou Manufatura Aditiva
BTC: Bitcoin
CAAE: Certificado de apresentação de apreciação ética
CAD: *Computer-aided design*, ou Desenho assistido por computador
CAM: *Computer-aided manufacturing*, ou Manufatura assistida por computador
CCPG: Coordenação das Comissões de Pós-Graduação
CEP: Comitê de Ética em Pesquisa
CMfg: *Cloud Manufacturing*, ou Manufatura em Nuvem
CPS: *Cyber-Physical Systems*, ou Sistemas Cyber-Físicos
DOI: *Digital Object Identifier*
ERP: *Enterprise Resource Planning*
I4.0: Indústria 4.0, ou quarta revolução industrial
IaaS: *Infrastructure as a service*, ou Infraestrutura como serviço
IoT: *Internet of Things*, ou Internet das Coisas
ISSN: *Internacional Standard Serial Number*
IT: *Information technology*, ou Tecnologia da informação
JCR: *Journal Citation Reports*, ou Relatório de Citações de Periódicos
JIT: *Just-in-Time*
LA: *Lean Automation*
LM: *Lean Manufacturing*, ou Manufatura Enxuta
LPS: *Lean Production Systems*, ou Sistemas de Produção Enxuta
MCDA: *Multi-Criteria Decision Analysis*, ou Análise de Decisão Multi-Critério
Mfg: *Manufacturing*, ou Manufatura
MPMEs: Micro, pequenas e médias empresas
MSMEs: *Micro, small and medium-sized enterprises*
PaaS: *Platform as a service*, ou Plataforma como serviço
PMEs: Pequenas e médias empresas
PPC: Planejamento e controle da produção
RFID: *Radio frequency identification*, ou identificação por rádio frequência
SaaS: *Software as a service*, ou Software como serviço
SCM: *Supply Chain Management*, ou Gestão da Cadeia de Suprimentos
SCOR: *Supply Chain Operations Reference*
SMEs: *Small and medium-sized enterprises*
USD: Dólar Americano

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1 INTRODUÇÃO

O cenário de crescente globalização, competitividade de mercado e customização em massa revela que empresas tradicionais estão enfrentando novos desafios de negócios em uma economia turbulenta e dinâmica (SIMMERT et al., 2019). O padrão de consumo por produtos personalizados, elevada exigência de qualidade e baixo tempo de entrega tem direcionado empresas a adotar tecnologias digitais modernas de alta conectividade para conseguir vantagens competitivas, esse contexto caracteriza a Indústria 4.0 (I4.0), ou quarta revolução industrial (SHROUF; ORDIERES; MIRAGLIOTTA, 2014; ZHENG et al., 2021).

Diversos estudos acadêmicos vêm avaliando a aplicação das tecnologias inovadoras habilitadas pela Indústria 4.0 e seus impactos nos vários processos que envolvem o ciclo de vida dos produtos. Segundo Zheng et al. (2021) dentre as principais tecnologias inovadoras aplicadas aos processos de gestão da produção e da cadeia de suprimentos, se destacam: Sistemas Cyber-Físicos (CPS), Internet das Coisas (IoT), *Big data and Analytics*, *Cloud Computing*, Inteligência Artificial, *Blockchain*, Modelagem e Simulação, Tecnologia de Visualização, Automação e Robotização Industrial, e Manufatura Aditiva (AM).

Alguns pesquisadores consideram a aplicação de tecnologias emergentes da Indústria 4.0 para suporte e desenvolvimento de sistemas *Lean* de produção, tais modelos que integram tecnologias modernas de alta conectividade a princípios de redução de falhas, custos, tempo e materiais, são caracterizados como modelos *Lean Automation* (KOLBERG; KNOBLOCH; ZÜHLKE, 2017; MA; WANG; ZHAO, 2017).

Dentre os avanços habilitados pela Indústria 4.0 aplicados a sistemas *Lean* de produção, Dombrowski, Richter e Krenkel (2017), e Rybski e Jochem (2020) declaram que empresas alemãs têm adotado a tecnologia *Cloud Computing* como base da transformação digital de seus processos *Lean*, resultando em melhorias de aspectos como agilidade do fluxo de dados, gestão visual e redução de desperdícios.

Husen (2020) e Sordan et al. (2021) estudam a integração da robótica com sistemas de produção *lean* e observam redução da ordem de 28% nos tempos ociosos, bem como ganhos da ordem de 45% na taxa de eficiência operacional.

Rossini et al. (2021) e Tortorella et al. (2020) sugerem que sejam desenvolvidos novos estudos de caso com aplicação prática, ou simulação para

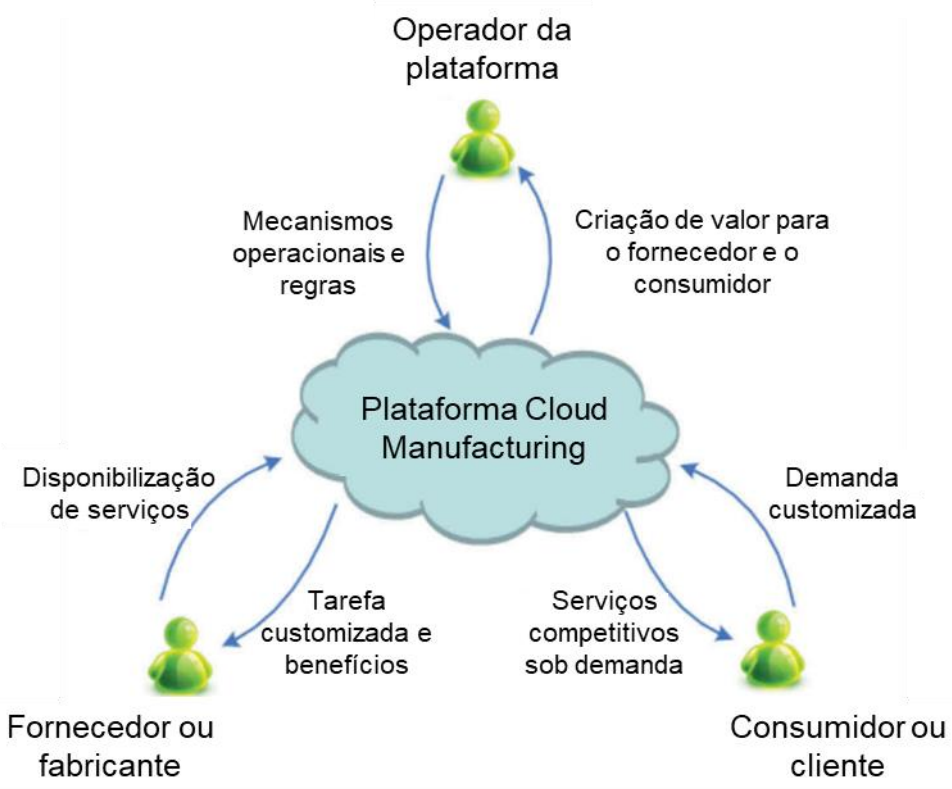
mensurar potenciais ganhos de desempenho operacional dos modelos *Lean Automation* (LA), já os trabalhos de Rybski e Jochem (2020), e Shigematsu et al. (2018) sugerem que sejam avaliadas a aplicação de modelos *Lean Automation* não apenas em países desenvolvidos, como também em países emergentes.

1.1 CONTEXTUALIZAÇÃO DO PROBLEMA DE PESQUISA

Estudos sobre o emprego da tecnologia *Cloud Computing* no ambiente de máquinas e serviços de manufatura caracterizam o conceito do *Cloud Manufacturing* (CMfg), ou Manufatura em Nuvem, em língua portuguesa, que foi introduzida na literatura por Li et al. (2010) como um modelo inovador de plataforma de manufatura.

Esta se baseia em uma rede virtual, que integra diferentes usuários possibilitando acesso remoto a recursos e serviços de manufatura para utilização dos mesmos sob demanda, viabilizando a fabricação de produtos customizados através da internet (JIANG et al., 2016). De acordo com Ren et al. (2017) a rede de manufatura em nuvem, ilustrada na figura 1.1, integra três tipos básicos de usuários.

Figura 1.1 - Usuários no ambiente *Cloud Manufacturing*.



Fonte: Adaptado de Ren et al. (2017).

São três os principais agentes em uma plataforma de CMfg:

- Consumidor ou cliente: é o agente que entra com sua solicitação ou demanda customizada por serviços ou recursos de manufatura, tendo acesso a uma vasta rede de recursos, serviços ou potenciais fornecedores através da plataforma de CMfg, proporcionando serviços competitivos nos aspectos de redução de custos, alta produtividade, agilidade e flexibilidade ao consumidor.
- Fornecedor ou fabricante: é o agente que disponibiliza seus recursos de manufatura, oferecidos como serviços aos consumidores podendo atender às tarefas customizadas de fabricação através da plataforma digital, elevando suas receitas financeiras e a reputação do seu negócio.
- Plataforma de CMfg: é o agente central, que opera e controla a plataforma de manufatura em nuvem, definindo as regras e integrando os processos, bem como gerenciando as transações dos negócios, a entrega dos serviços e a rede de conexão entre consumidores e fornecedores.

Esta tendência de *network* que envolve grande quantidade de indivíduos em diferentes etapas da cadeia de suprimentos deve exigir maior nível de gestão, confiabilidade, agilidade e transparência no fluxo de informações, fatores que podem ser afetados pelo modelo de negócio centralizado, o qual necessita de uma terceira parte para administrar toda a comunicação e os registros das informações entre fornecedores e consumidores (ŠKULJ et al., 2017).

Neste modelo de negócio centralizado os demais agentes envolvidos na operação ficam vulneráveis à confiabilidade do sistema da terceira parte, a qual pode sofrer ataques cibernéticos, perda de privacidade dos dados, ou outros problemas que envolvam a segurança e a integridade da informação (RANGANTHAN et al., 2018).

As pesquisas de Ma, Wang e Zhao (2017), Sony (2018), e Tortorella, Narayanamurthy e Thurer (2021) mencionam que este padrão de *network*, com elevados níveis de integração entre usuários, compartilhamento de recursos e informações, deve empregar tecnologias modernas que eliminem eventuais desperdícios de tempo, materiais ou perda de flexibilidade ao longo da cadeia produtiva, melhorando os aspectos *Lean* de produção.

Nesta linha evolutiva que direciona ao *Lean Automation*, a tecnologia *Cloud* vêm servindo como base da digitalização dos processos em pequenas e médias empresas europeias (DOMBROWSKI; RICHTER; KRENKEL, 2017; RYBSKI; JOCHEM, 2020; WAGNER; HERRMANN; THIEDE, 2017).

De acordo com o estudo bibliométrico de Morelli e Ignacio (2021) os estudos científicos sobre *Cloud Manufacturing* estão agrupados em 4 clusters de enfoque majoritário: (i) “Otimização de processos de manufatura”, (ii) “Redes colaborativas de recursos e serviços de manufatura”, (iii) “Indústria 4.0 e sistemas de computação em nuvem”, e (iv) “Confiabilidade de dados e segurança cibernética”. Nesse artigo identifica-se que o volume de estudos com aplicações práticas relativos à “confiabilidade de dados e segurança cibernética” em redes de manufatura em nuvem é notadamente inferior, sugerindo uma lacuna de pesquisa e, consequentemente, uma oportunidade de estudo a ser verificada, através da aplicação de tecnologias e sistemas que consigam agregar valor aos processos *Lean Automation*.

A tecnologia *Blockchain* se destaca como uma ferramenta inovadora para gestão confiável de dados, e já se encontra consolidada no mercado financeiro de criptomoedas por suas características de descentralização, registro imutável de dados, distribuição de informações entre os membros de uma determinada rede, e transparência na divulgação das transações realizadas (AHAMAD; NAIR; VARGHESE, 2013).

Aplicações da rede *Blockchain* vêm sendo estudadas em diversas etapas da cadeia de suprimentos industrial (JACKSON; SPIEGLER; KOTIADIS, 2023; KSHETRI, 2018; SONG; SUNG; PARK, 2019), apresentando, assim, potencial para auxiliar os processos *Lean* de produção e as plataformas de *Cloud Manufacturing* no enfrentamento dos desafios de confiabilidade de dados e segurança cibernética, identificados como lacuna de pesquisa.

Nesse cenário apresentado, é definida a seguinte questão de pesquisa que guia a investigação deste trabalho.

- Como a combinação das tecnologias *Blockchain* e *Cloud Manufacturing* (CMfg) pode agregar valor aos sistemas *Lean* de produção?

1.2 OBJETIVOS

O objetivo principal desta pesquisa é propor um modelo para aplicação das tecnologias *Cloud Manufacturing* e *Blockchain* para gestão de sistemas *Lean* de produção.

Os objetivos específicos são:

- analisar o estado atual das pesquisas aplicadas da tecnologia *Cloud Manufacturing*, identificando as principais linhas de estudos e potenciais lacunas;
- caracterizar desafios e oportunidades do *Lean Automation* em pequenas e médias empresas de países emergentes;
- definir um modelo de integração entre *stakeholders* utilizando a combinação de princípios *Lean* e das tecnologias *Cloud Manufacturing* e *Blockchain*;
- simular o modelo proposto, analisando o desempenho obtido e discutindo de que forma a combinação dessas tecnologias agregam vantagens aos sistemas *Lean Automation*, bem como as suas vulnerabilidades.

1.3 JUSTIFICATIVA E RELEVÂNCIA

O gerenciamento de dados nas cadeias de suprimentos se trata de um tema amplo e significativo, tanto em pesquisas acadêmicas e tecnológicas quanto na administração do ambiente corporativo (SONG; SUNG; PARK, 2019). Assim diversas ferramentas tecnológicas têm surgido para ampliar as vantagens competitivas das organizações e suas redes de parceiros comerciais, demonstrando a relevância do tema.

De acordo com Alsadi et al. (2023), Langlotz and Aurich (2021), Pereira and Sachidananda (2021), Raji et al. (2021), Vlachos et al. (2021), Ferreira et al. (2022), Mahdavisharif, Cagliano and Rafele (2022) existem lacunas em como implementar e integrar tecnologias da indústria 4.0 em sistemas *lean* de produção. Abideen et al. (2021), Almeida, Albuquerque e Silva (2018), Gunasekaran et al. (2019), Khanna et al. (2021), Nazarov e Klarin (2020), Raji et al. (2021), Udokwu et al. (2022), e Zhao, Bal e Ma (2021) indicam oportunidades de pesquisa na simulação ou estudos de caso aplicados a modelos que integrem múltiplos *stakeholders* em redes globalizadas com foco na visualização e confiabilidade do fluxo de dados, bem como, na agilidade do compartilhamento e análise das variações de mercado.

Alptekin et al. (2021), Aslam et al. (2022), Behl et al. (2022), Jackson, Spiegler e Kotiadis (2023), Kapsoulis et al (2021), Lenarduzzi et al. (2018), Pérez et al. (2020), Prasad, Rao e Lanka (2022), Qureshi et al. (2023), Tortorella, Narayanamurthy e Thurer (2021), e Upadhyay et al. (2021) recomendam o desenvolvimento de estudos relacionados ao uso de plataformas com base na *web*,

computação em nuvem e tecnologia *blockchain* na conectividade de cadeias de manufatura que envolvam grande quantidade de *stakeholders*, cooperação entre os participantes da rede, digitalização de processos e gestão da informação.

Portanto, esta dissertação se justifica na proposta de se aprofundar nos desafios que envolvem redes de manufatura constituídas por grande quantidade de parceiros e elevado volume de informação, exigindo altos níveis de agilidade, transparência, conectividade e confiabilidade.

Especificamente será analisada a gestão de dados em sistemas *Lean* de produção, utilizando plataformas digitais de manufatura em nuvem (CMfg), combinadas a outra tecnologia emergente, o *Blockchain*. O assunto da associação destas duas tecnologias inovadoras, conforme citado anteriormente, compreende uma lacuna e uma oportunidade de estudos para maior aprofundamento neste campo.

Como produto final, esta dissertação apresenta um modelo proposto em relação ao *Lean Automation*, viabilizando o entendimento dos potenciais ganhos de desempenho decorrentes de eventual aplicação integrada das tecnologias *Cloud* e *Blockchain* aos sistemas *Lean* de produção.

Por tanto, este trabalho tem potencial para contribuir com os segmentos acadêmico e industrial como base e motivação para futuras pesquisas e desenvolvimentos sobre o tema inovador, em campos de estudo ainda pouco explorados da cadeia de suprimentos, gerando conhecimento científico aplicado, com capacidade de agregar vantagens competitivas e avanço tecnológico aos seus usuários.

1.4 DELIMITAÇÃO E ESTRUTURA DA PESQUISA

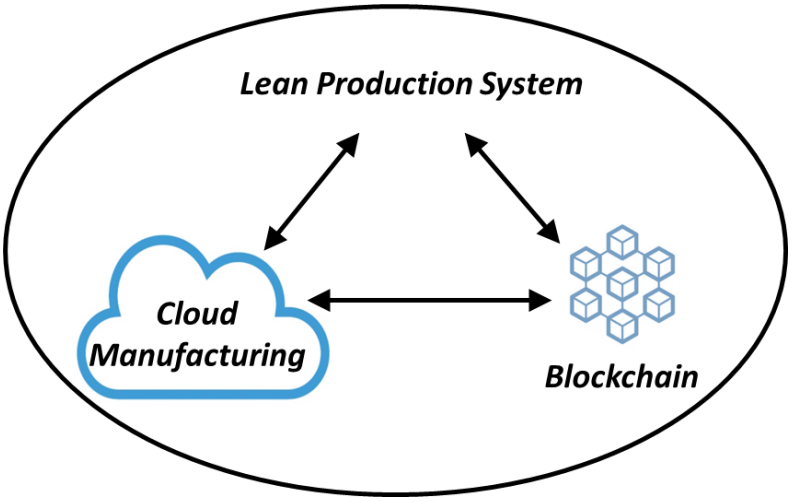
O procedimento metodológico aplicado nesta pesquisa segue o “formato alternativo” proposto pela UNICAMP, conforme a INSTRUÇÃO NORMATIVA CCPG Nº 002/2021.

De acordo com essa instrução normativa, a dissertação no “formato alternativo” deve apresentar os seguintes capítulos no corpo do trabalho: 1) Introdução; 2) Documentos publicados e/ou a publicar, com os dados referentes à publicação e/ou submissão; 3) Discussão; 4) Conclusão; 5) Referências, de todos os materiais bibliográficos citados na introdução, na discussão e na conclusão.

Os documentos publicados, ou a publicar, devem ser em revistas científicas ou anais de congressos sujeitos à arbitragem.

Dessa forma, o resultado desta pesquisa de mestrado, contempla os objetivos de confirmar a integração dos temas *Cloud Manufacturing*, *Blockchain* e Sistemas *Lean* de Produção, abordados através do desenvolvimento de 3 (três) artigos acadêmicos produzidos durante o programa de mestrado e submetidos à publicação em revistas científicas. A integração desses temas se dá na combinação das tecnologias *Cloud Manufacturing* e *Blockchain* como suporte a sistemas *Lean* de produção, conforme ilustrado na figura 1.2.

Figura 1.2 - Delimitação do escopo da pesquisa.



Fonte: Elaborado pelo autor.

As estratégias e técnicas de pesquisa aplicadas estão contempladas e descritas detalhadamente nos 3 (três) artigos, já publicados e submetidos em revistas científicas, exibidos no capítulo 2 deste trabalho. Na sequência é apresentado o conteúdo desses artigos acadêmicos de forma sucinta.

Esta dissertação traz a relação das áreas de conhecimento propostas na pesquisa através de revisões sistemáticas da literatura disponível nas bases de dados Scopus e Web of Science (SCOPUS, 2021; WOS, 2021). Além da revisão sistemática da literatura científica, a dissertação apresenta estudos exploratórios de levantamento de dados por meio de *survey* e simulação computacional.

O primeiro artigo, denominado *'Assessment of researches and case studies on Cloud Manufacturing: A bibliometric analysis'*, contempla o tema *Cloud*

Manufacturing pelo método da análise bibliométrica. Este artigo está publicado na revista *The International Journal of Advanced Manufacturing Technology,* da *Springer,* e seu principal objetivo é mapear a situação atual das pesquisas acadêmicas neste campo, promovendo o conhecimento das tendências, das principais referências, das aplicações práticas em condições da vida real e das lacunas de pesquisa.

São identificadas 4 categorias de pesquisas relativas ao *Cloud Manufacturing*: (I) 'otimização de processos de manufatura', (II) 'redes colaborativas de recursos e serviços de manufatura', (III) 'Indústria 4.0 e sistemas de computação em nuvem', e (IV) 'confiabilidade de dados e segurança cibernética'. As aplicações práticas do conceito *Cloud Manufacturing* se concentram majoritariamente nas categorias (I), (II) e (III) revelando ganhos em planejamento de produção, programação de serviços, redução de custos, minimização do consumo de recursos industriais, sinergia de redes de empresas, integração de operações e escalabilidade. Enquanto, apenas poucos estudos com aplicação prática do *Cloud Manufacturing* estão categorizados no grupo (IV), sugerindo lacunas de pesquisas nos campos da gestão de dados, segurança cibernética, bem como, agilidade e rastreabilidade do fluxo de informações.

O segundo artigo, denominado *'Challenges and opportunities in a Lean Automation model implementation: Characterizing micro, small and medium-sized enterprises of developing countries',* contempla a avaliação do nível de aplicação de tecnologias inovadoras da indústria 4.0 a sistemas *Lean* de produção, em pequenas e médias empresas brasileiras. Este artigo está aceito e divulgado na seção '*Forthcoming and Online First Articles*', em processo para publicação na revista *International Journal of Services and Operations Management*, da *Inderscience*.

São identificadas as principais aplicações de sucesso do *Lean Automation* em micro, pequenas e médias empresas já exploradas na literatura científica, assim é estruturado um modelo conceitual *Just-in-Time Delivery* combinando essas tecnologias da Indústria 4.0 e princípios *Lean* apresentados. O modelo *JIT-Delivery* proposto é utilizado como protótipo para caracterização das forças e fraquezas de MPMEs brasileiras em relação ao *Lean Automation* através de uma *survey*. A pesquisa aborda 54 empresas, majoritariamente do interior do estado de São Paulo. O questionário enviado às empresas e o seu método de aplicação foram aprovados e autorizados pelo Comitê de Ética em Pesquisa (CEP/CONEP) da Universidade Estadual de Campinas (UNICAMP), conforme o certificado de apresentação de

apreciação ética (CAAE) número 47885521.0.0000.5404. O questionário aplicado e o relatório de aceitação do comitê de ética estão apresentados nas seções de APÊNDICES e ANEXOS.

O terceiro artigo, denominado *'Blockchain-based lean supply chain: A simulation approach'*, utiliza os dois primeiros trabalhos como pilares para contemplar a associação da aplicação das tecnologias *Cloud Manufacturing* e *Blockchain* em um ambiente de produção *Lean* através do método de modelagem e simulação, avaliando como a combinação dessas tecnologias promove melhorias de desempenho à cadeia de suprimentos. O artigo está aceito e divulgado na seção '*Accepted Papers*', em processo para publicação no *International Journal of Innovation and Technology Management*, da editora *World Scientific*. Neste artigo, o fluxo de seleção de fornecedores em um modelo *Lean Automation* foi traduzido para a linguagem computacional da rede *Blockchain*, por meio de contratos inteligentes da plataforma Hyperledger Fabric®.

Os resultados deste artigo confirmam um sistema que viabiliza a aplicação e integração dos temas *Cloud Manufacturing* e *Blockchain* em sistemas *Lean* de produção, com acesso aos códigos de execução de seus contratos e análise dos aspectos identificados como lacunas de pesquisa, incluindo: integração de *stakeholders* na produção colaborativa de produtos customizados, condições de flexibilidade e adaptabilidade a variações de demanda, relacionamento de redes de pequenas e médias empresas (PMEs), comportamento de vários *players* atuando de forma simultânea e consensual, bem como os custos das transações na rede *Blockchain* Hyperledger Fabric operada por meio de máquina virtual na nuvem.

Salienta-se que no desenvolvimento dos três artigos apresentados, os dados das empresas envolvidas, tanto na etapa da *survey*, quanto da simulação dos contratos inteligentes, não são relevantes para o desenvolvimento da pesquisa e são compreendidos como caráter sigiloso, logo, não foram divulgados nos artigos publicados em revistas científicas nem na dissertação de mestrado.

A partir dos resultados dos artigos desenvolvidos, esta dissertação analisa as tendências de aplicação de tecnologias como o *Cloud Manufacturing* e o *Blockchain* em sistemas *Lean* de produção; avalia o nível de aderência de MPMEs brasileiras ao *Lean Automation*; identifica desafios e oportunidades da utilização deste modelo; e discute potenciais ganhos de desempenho de sua aplicação prática em condições reais.

Este trabalho está organizado sob os capítulos: Introdução; Documentos Publicados e Submetidos; Discussão; e Conclusão. Cada capítulo tem objetivos específicos conforme descrito na tabela 1.1.

Tabela 1.1 - Estrutura e organização da pesquisa.

CAPÍTULO	OBJETIVO	SEÇÃO
INTRODUÇÃO	Contextualizar sobre os temas *Cloud Manufacturing*, *Blockchain* e Sistemas *Lean* de Produção, e apresentar a questão de pesquisa.	1 e 1.1
	Citar o objetivo principal e os específicos, bem como a justificativa da pesquisa.	1.2 e 1.3
	Exibir a delimitação da pesquisa e a estrutura da dissertação.	1.4
DOCUMENTOS PUBLICADOS E SUBMETIDOS	Apresentar dos artigos produzidos durante o programa de mestrado acadêmico com contribuição para esta dissertação. A sequência dos artigos segue sua ordem cronológica de desenvolvimento.	2
	Assessment of researches and case studies on Cloud Manufacturing: a bibliometric analysis.	2.1
	Challenges and opportunities in a Lean Automation model implementation: characterizing micro, small and medium-sized enterprises of developing countries.	2.2
	Blockchain-based lean supply chain: a simulation approach.	2.3
DISCUSSÃO	Discutir os tópicos dos trabalhos apresentados, promovendo a combinação das tecnologias *Cloud Manufacturing* e *Blockchain*, e explorando as vantagens agregadas por sua aplicação a sistemas *Lean* de produção. Sintetizar os resultados encontrados e identificar as contribuições práticas e teóricas.	3
CONCLUSÃO	Confirmar se o problema de pesquisa foi resolvido, se a justificativa foi validada e se os objetivos foram alcançados, bem como, apresentar as limitações do trabalho e as propostas de trabalhos futuros.	4 e 4.1

Fonte: Elaborado pelo autor.

2 DOCUMENTOS PUBLICADOS E SUBMETIDOS

Este capítulo exibe a compilação dos 3 (três) artigos acadêmicos produzidos durante o programa de mestrado, os quais foram submetidos para publicação em revistas científicas.

Tais artigos contribuíram para o desenvolvimento desta dissertação, que apresenta seu conteúdo conforme o “formato alternativo” da INSTRUÇÃO NORMATIVA CCPG Nº 002/2021 da Universidade Estadual de Campinas - UNICAMP.

As seções 2.1, 2.2 e 2.3 apresentam os artigos na ordem cronológica de seu desenvolvimento durante a pesquisa.

2.1 ASSESSMENT OF RESEARCHES AND CASE STUDIES ON CLOUD MANUFACTURING: A BIBLIOMETRIC ANALYSIS

Título: Assessment of researches and case studies on Cloud Manufacturing: a bibliometric analysis.

Autores: Daniel A. Morelli, Paulo S. A. Ignacio.

Status: Publicado na revista científica *The International Journal of Advanced Manufacturing Technology, Springer Nature,* ISSN Eletrônico 1433-3015, ISSN Impresso 0268-3768, fator de impacto 3,563 (JCR 2021), classificação Qualis A2.

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Referência: MORELLI, D. A.; IGNACIO, P. S. de A. Assessment of researches and case studies on Cloud Manufacturing: a bibliometric analysis. The International Journal of Advanced Manufacturing Technology, v. 117, n. 3, p. 691–705, 2021.

DOI: 10.1007/s00170-021-07782-0

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Resumo: A tecnologia de computação em nuvem tem sido estudada no contexto da I4.0 como uma ferramenta aplicada a serviços e recursos de manufatura. Tal conceito é amplamente conhecido como *Cloud Manufacturing*. Este artigo visa mapear o estado atual das pesquisas acadêmicas nesta área, promovendo o entendimento de tendências, referências e aplicações práticas em condições da vida real. Uma análise bibliométrica foi realizada utilizando as bases Scopus e Web of Sciences, e as ferramentas de mineração de texto do VOSviewer. A partir de uma amostra de 1.420 artigos, este estudo identificou os países que apresentam o maior volume de publicações, os principais periódicos, os artigos mais influentes e quatro agrupamentos por ocorrências de palavras-chave: (i) “Otimização de processos de fabricação”, (ii) “Redes colaborativas de recursos e serviços de fabricação”, (iii) “Indústria 4.0 e sistemas de computação em nuvem” e (iv) “Confiabilidade de dados e segurança cibernética”. Por fim, este trabalho selecionou e analisou os 159 artigos com estudos de caso aplicados, a fim de estratificar e compreender as abordagens mais comuns dentro das quatro categorias pré-estabelecidas. Este artigo pode contribuir para pesquisadores e desenvolvedores que buscam aplicações práticas de sucesso na digitalização de cadeias de manufatura, bem como para aqueles que buscam lacunas nos campos ainda inexplorados do CMfg. Tanto a avaliação quanto a categorização dos estudos de caso sobre CMfg são os diferenciais deste artigo.

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CRITICAL REVIEW

Assessment of researches and case studies on Cloud Manufacturing: a bibliometric analysis

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Abstract

Cloud computing technology has been studied in the context of industry 4.0 as a tool applied to manufacturing services and resources. Such concept is widely known as Cloud Manufacturing. This paper aims at mapping the current state of academic researches on this field, promoting the understanding of trends, references and practical applications in real-life conditions. A bibliometric analysis was conducted using two different databases — Scopus and Web of Sciences — and VOSviewer's text mining tools and techniques. From a sample of 1420 papers, this study identified the countries which had the largest volume of publications, the main journals related to the subject, the most influent articles, and four clusters by keywords occurrences: (i) "Optimization of manufacturing processes", (ii) "Collaborative networks of manufacturing resources and services", (iii) "Industry 4.0 and cloud computing systems", and (iv) "Data reliability and cyber-security". Finally, this work selected and analyzed the 159 articles with applied case studies, in order to stratify and to understand the most common approaches within the four pre-established categories. This article can contribute to researchers and developers searching for successful practical applications in digitalization of manufacturing chains, as well as to those who are looking for gaps in the still unexplored fields of Cloud Manufacturing. Both the assessment and the categorization of the case studies about Cloud Manufacturing are the differentials in this article.

Keywords Cloud manufacturing · Industry 4.0 · Bibliometric analysis · Case studies · Real-life applications

1 Introduction

The manufacturing industry, in the context of the fourth industrial revolution, must be capable of applying advanced technologies and knowledge, integrating the automation of its machines, equipment and sensors. Such integration should include not only the company's processes, systems and/or internal protocols, but also those of other companies that are part of its supply chain [1].

Academic researches and the industry's development departments have initiated to explore a set of innovative tools, among them, a manufacturing model based on the emerging cloud computing technology, integrating different sectors and companies on the network, through the virtualization and sharing of its resources and knowledge, and the communication between machines [2].

Built over web-based architectures, these models can generate value through collaborative processes between stakeholders, cost reduction and scalability [3]. Their proposition intends to promote performance improvement in a supply chain environment over the implementation of a digital and continuous information flow [4].

The application of these standards, which associate cloud computing advantages to manufacturing resources, started to be studied in 2010 and are called Cloud Manufacturing [5]. Since then, many researches have emerged in this field. Some of them are focused on theoretical frameworks, while others propose real-life practical applications through case studies.

A bibliometric analysis about the subject of Cloud Manufacturing was accomplished in this article, in order to assess academic researches and their case studies approaches, published until January 2021.

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This investigation aims at mapping the current state of a wide range of available researches in the field of Cloud Manufacturing, identifying publication trends, countries with the largest volume of papers, most relevant journals and influential articles, as well as the clusters of the keywords co-occurrences. This work then selected and analyzed the researches that included case studies, in order to categorize their approaches.

The contribution of this article is to generate relevant information to expand the knowledge about Cloud Manufacturing, contextualize trends of application tools, make successful practical solutions and relevant references available, as well as, identify gaps or improvement opportunities of studies in unexplored fields of Cloud Manufacturing.

2 Literature review

Cloud computing technology represents a service model that enables users or enterprises to access a whole set of adaptable, configurable and available on-demand IT resources, in an agile way and with a low level of effort [6].

According to Zárate and Mendoza [7], in a cloud computing architecture, all of the computing structures are treated as a service. Figure 1 shows the services delivered through cloud technology.

- IaaS (Infrastructure as a Service), also known as hardware as a service (HaaS), delivers computing infrastructures, such as storage or databases, using virtual machines (e.g., Amazon EC2, GoGrid, Flexiscale or Data Centers);
- PaaS (Platform as a Service) provides a system environment called middleware, driven to software development, as well as, testing and/or hosting of applications (e.g., Microsoft Azure, Google AppEngine or Amazon Simple DB/S3); and
- SaaS (Software as a Service) which offers a set of internet accessible applications to end users (e.g., Google Apps, Facebook, Youtube or Salesforce).

Cloud computing technologies applied specifically to the manufacturing sector is addressed by 3 main terms: Cloud Manufacturing, Cloud-based Manufacturing, or even Cloud-based Design and Manufacturing. By gathering the benefits of cloud computing, such as agility, flexibility, scalability and efficiency, many companies are being able not only to improve their own production processes, but also promote a greater integration and a more collaborative relationship with their business partners [9].

Based on networks, Cloud Manufacturing transforms manufacturing resources and capabilities into services performed through machine virtualization, which can be managed and operated on-demand by users for the whole life cycle of manufacturing [10].

As illustrated in Fig. 2, such process consists of three layers.

- Application Layer — This layer includes interfaces of users that need manufacturing services or resources to meet their customized demands. Those requests can be made by companies or individual users with access though the internet [12].
- Manufacturing Capability Layer — In this layer occurs the connection between the physical manufacturing machines and the cloud servers, by the virtualization of these resources [13]. Countless suppliers offer their specialized services and make their manufacturing machines available worldwide. Generally, these

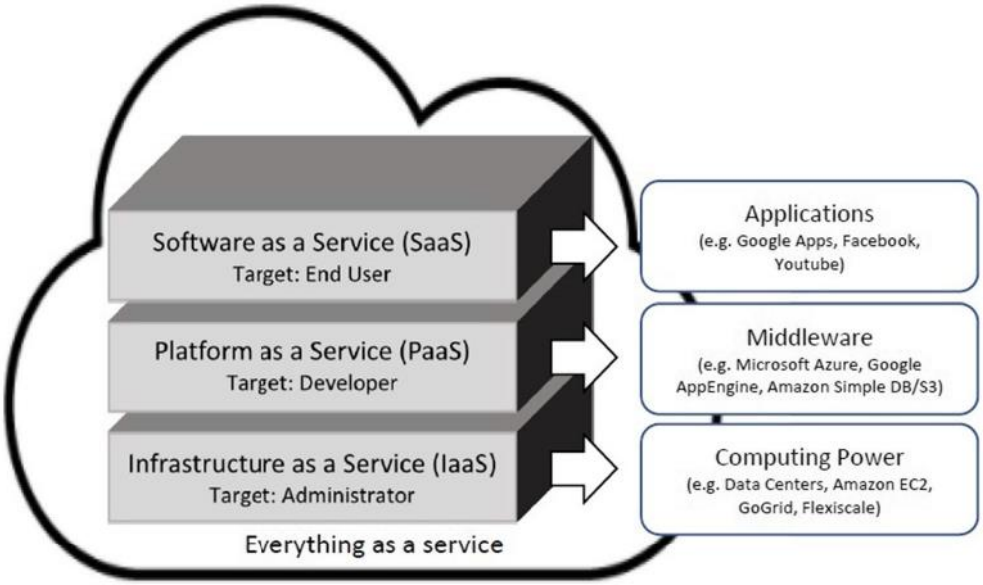


Fig. 1 Resources as a service in cloud computing [8]

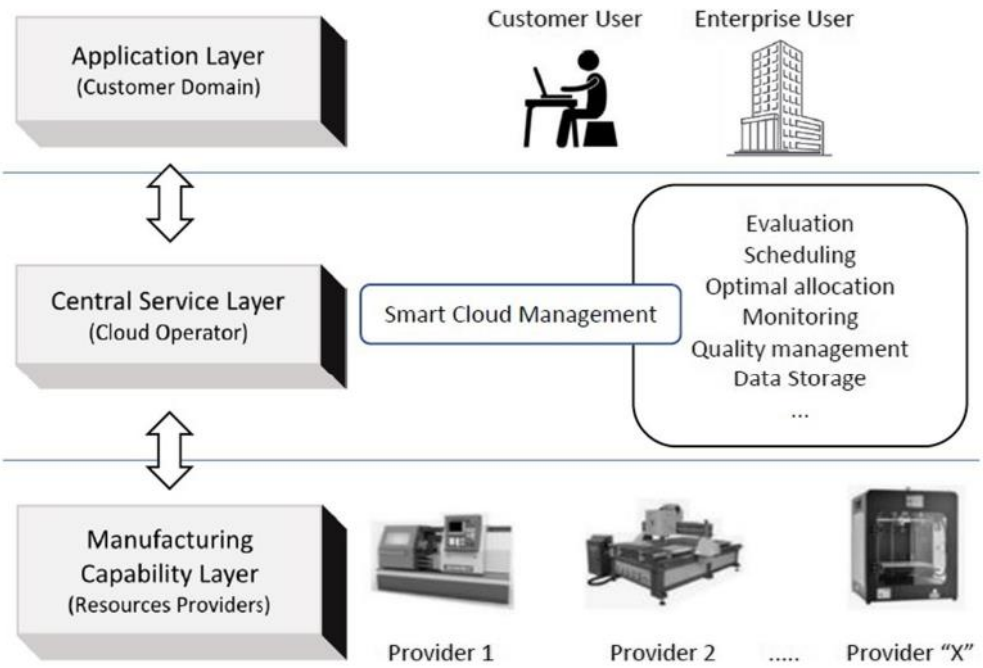


Fig. 2 The Cloud Manufacturing architecture model [11]

facilities are CNC machining centers, foundries industries, 3D printing, plastic injection molding, and other component production processes.

- Central Service Layer — In this layer happens the smart cloud solutions management, as matching between customers' demands and physical resources available. This assessment enables production processes evaluation, scheduling, optimal resources allocation, monitoring, quality management, big data and real time information [11].

Figure 3 describes some of the potential applications enabled by the network connection involving different

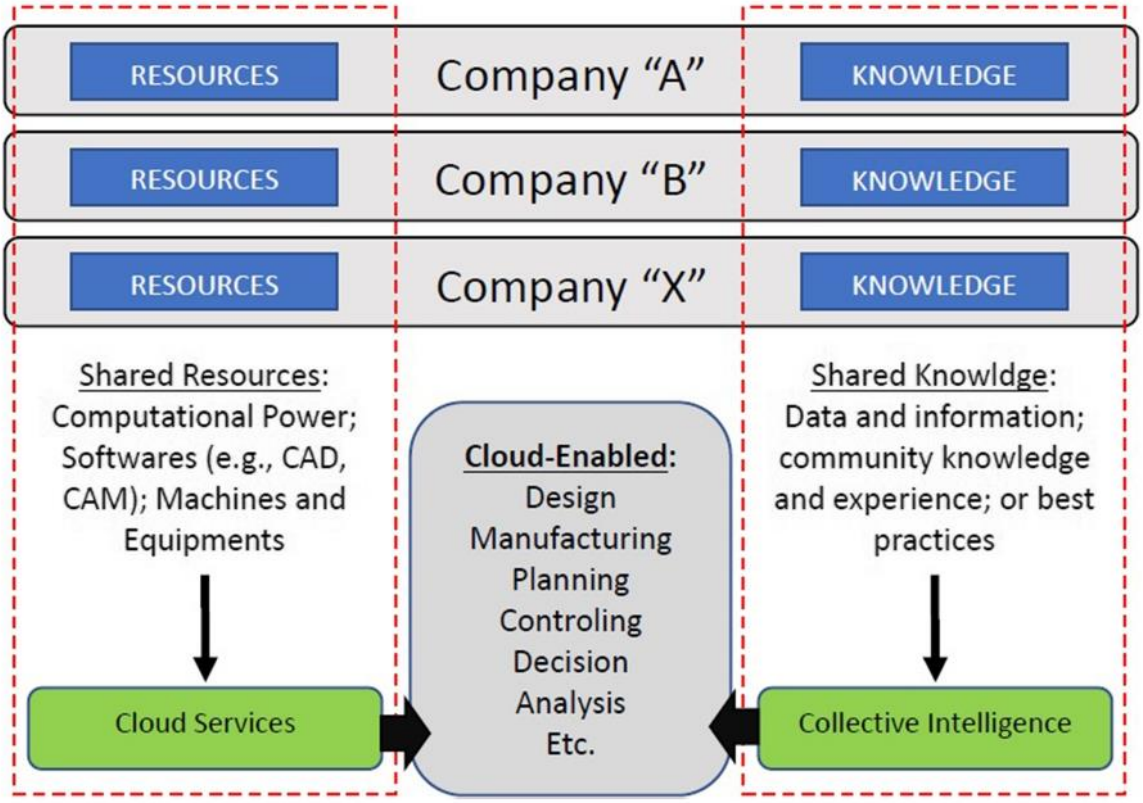


Fig. 3 Potentials of resources and knowledge sharing [14]

Fig. 4 The 5 steps applied in this bibliometric analysis [16]

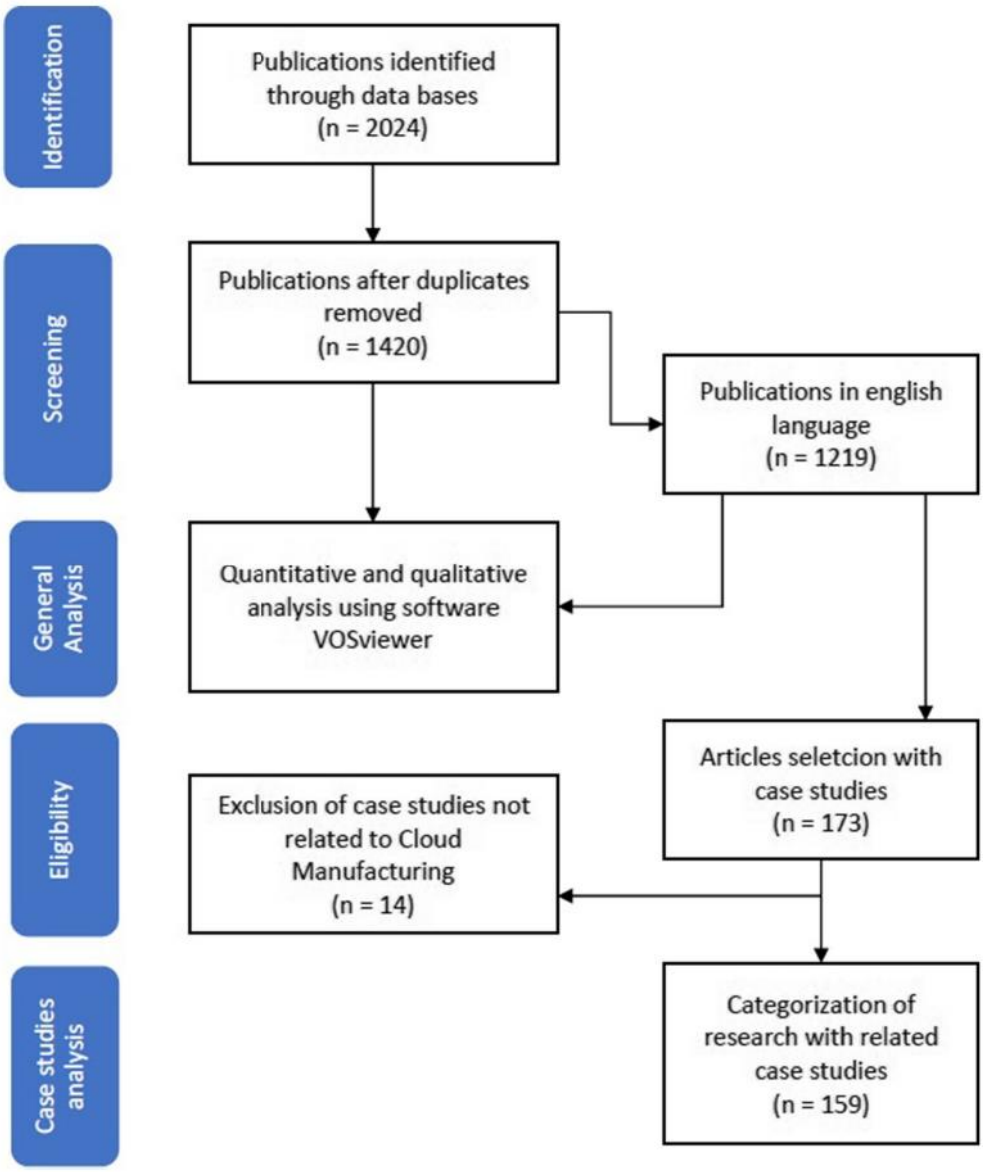
manufacturing companies. Cloud Manufacturing may be used to share resources and knowledge in order to be effective in the support of processes such as design, manufacturing, planning, controling, analysis and decision-making. [14].

3 Methodology

In order to explore the researches on Cloud Manufacturing in a quantitative perspective, this article conducted a bibliometric study based on the appreciation of recorded information in the scientific literature. Subsequently, this analysis used tools and statistical techniques that resulted in indexes which enabled us to recognize correlations among the investigated publications [15]. Figure 4 presents the 5 steps conducted during this study.

The research and analysis methodology is illustrated as a flowchart in Fig. 5, organizing the 5 steps mentioned, with the registration of the quantity of articles detected in each step.

Fig. 5 Detailed flowchart of the research methodology [16]



The 5 steps of the applied methodology are detailed as follows:

1. Identification of the scientifical publications related to Cloud Manufacturing, through researches in both Scopus and Web of Science databases, using the search engine equations described on Table 1. By doing so, this paper identified a total of 907 publications on Web of Science and 1117 publications on Scopus.
2. Screening the publications using Microsoft Excel. By removing duplicates, this work found a total of 1420 publications about Cloud Manufacturing to be analyzed. Still at the screening stage, the English language publications were separate (totalizing 1219) in order to confront with other languages, at both the general and the case studies analysis steps.
3. General analysis over the 1420 publications applying text mining techniques using a software called VOSviewer, developed by the University of Leiden, for construction of bibliometric clusters and maps, providing observation of the relationship of authors, keywords, citations, journals, countries and categorization of the most relevant terms [17].
4. Eligibility of the 159 articles containing applied case studies to quantify practical implementations about the Cloud Manufacturing emerging technology. In order to select the publications with meaningful cases, this paper searched the terms and applied the filters described on Table 1.
5. Case studies analysis from both stratification and clusterization of the researches into the categories determined by VOSviewer, allowing us to identify the most relevant real-life applications of Cloud Manufacturing, as well as to recognize gaps and opportunities for future work.

4 Results

Over the 1420 publications that arose from the screening process, this work built the graph presented in Fig. 6 that shows the overall trend of publications over time about Cloud Manufacturing, since the very first publication in 2010. It is possible to perceive an increase in the number of annual publications, confirming the growing relevance of this subject on both the academic and the industrial fields.

Figure 6 also presents the fitted trend line, generated using the statistical tool from Microsoft Excel, as the following linear equation.

$$y = 16.355x + 29.873;\ R^2 = 0.7616 \quad (1)$$

In order to avoid distortions in the trend equation, this exploration disregarded the 12 publications from January 2021, date when the bibliographic research was conducted.

Table 2 shows the countries with largest volume of publications in English language, indicating China as the leader, with an annual production greater than that of all other 14 countries together. China is also the country that presents the largest number of publications and of citations in any language.

Some countries stand out in the density of publications relative to their population, as New Zealand, Sweden and Finland, with publication rates considerably higher than those of the other countries on the list.

Table 3 ranks the top 10 journals by total number of published papers. Their origin countries are China, the UK, the Netherlands and the USA, with emphasis to the Chinese Computer Integrated Manufacturing Systems, CIMS, which boasts the largest number of publications, the highest number of citations, as well as the highest factor of citations per publication among the members of the list.

Table 1 Summary of the applied search engines [18]

Analysis of publications about Cloud Manufacturing	
Databases	Web of Science and Scopus
Total number of documents	1420 (907 from Web of Science and from 1117 Scopus)
General search engines terms	("cloud manufactur*" OR "cloud?based manufactur*" OR "cloud?based design and manufactur*")
Specific search engine terms (for case studies identification)	(("cloud manufactur*" OR "cloud?based manufactur*" OR "cloud?based design and manufactur*") AND ("case stud*" OR "case analys*" OR "simulat*"))
Specific search filters (for case studies)	Publication Type: Article or Review Language: English
Softwares	VOSviewer and Excel
Types of analysis	Literature review, quantitative and qualitative analysis

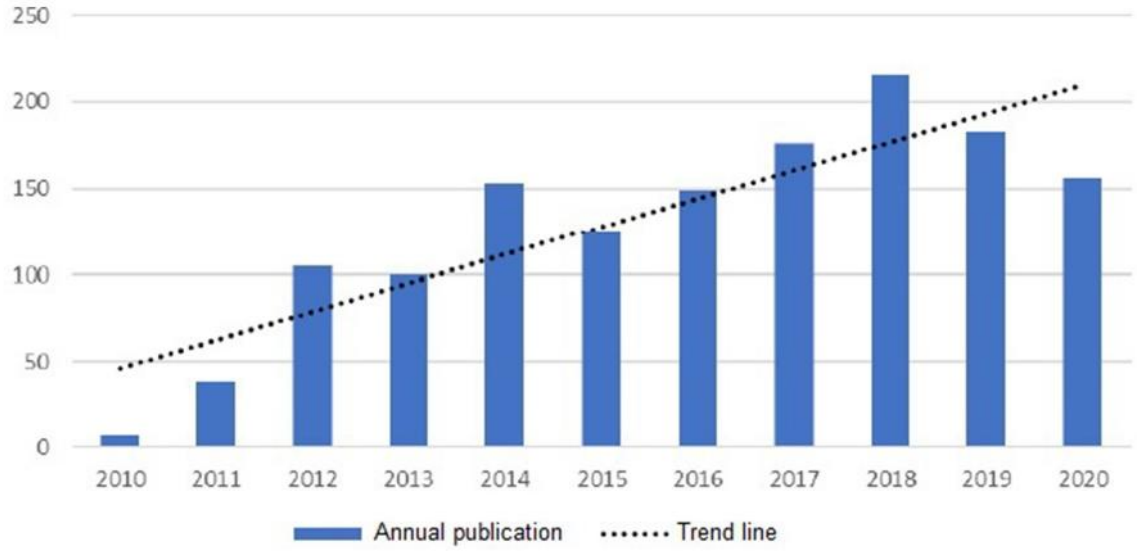


Fig. 6 Annual publications and trend about Cloud Manufacturing

According to the indexed categories in Scimago [20], the most relevant journals are specialized on computer science, mechanical engineering, industrial engineering, mathematics, management science, operations research, manufacturing and artificial intelligence.

Table 4 shows the most influential articles on the subject of Cloud Manufacturing ranked by total citations, presenting keywords targeted for service-oriented business models, advanced manufacturing systems or platforms, internet of things (IoT), cloud computing, services optimization, real-time monitoring, big data, and distributed resources sharing.

4.1 Clustering analysis

Using the software VOSviewer, this study built Fig. 7 that reveals the keywords co-occurrences map, determinated by the documents where they are found together. Both authors keywords, and other relevant words frequently used in titles and abstracts were considered.

Every keyword is represented by a circle, whose size is proportional to its frequency of occurrence. The positions indicate the relationship between two different keywords, and the lines signify connectivity and association of concepts.

Table 2 Top 15 ranked countries with respect to the publications about Cloud Manufacturing

Ranking	Countries	Publications (in English language)	Publications (in any language)	Number of citations	Population as of 2020 [19]	Publications per million inhabitants
1	China	422	618	6669	1,439,323,774	0.43
2	USA	101	101	988	331,002,647	0.31
3	Sweden	42	42	842	10,099,270	4.16
4	UK	41	41	841	67,886,004	0.60
5	New Zealand	40	40	113	4,822,233	8.29
6	Germany	38	40	568	83,783,945	0.48
7	Italy	32	32	181	60,461,828	0.53
8	Iran	25	25	124	83,992,953	0.30
9	India	23	23	54	1,380,004,385	0.02
10	Taiwan	17	17	74	23,568,378	0.72
11	Finland	16	16	225	5,540,718	2.89
12	France	13	13	63	65,273,512	0.20
13	Romania	12	12	60	19,237,682	0.62
14	Brazil	11	11	74	212,559,409	0.05
15	South Korea	9	9	41	51,269,183	0.18

Table 3 Top 10 journals in number of publications

Rank	Journal	Country of origin	Publications	Citations	Indexed Categories [20]
1	*Computer Integrated Manufacturing Systems, CIMS*	China	123	3233	Computer Science; Engineering
2	*International Journal of Advanced Manufacturing Technology*	UK	66	509	Computer Science; Engineering
3	*International Journal of Computer Integrated Manufacturing*	UK	41	472	Computer Science; Engineering
4	*Robotics and Computer-Integrated Manufacturing*	UK	36	645	Computer Science; Engineering; Mathematics
5	*International Journal of Production Research*	UK	29	251	Management Science, Operations Research; Industrial Engineering
6	*China Mechanical Engineering*	China	28	107	Mechanical Engineering
7	*Journal of Intelligent Manufacturing*	Netherlands	21	487	Computer Science; Artificial Intelligence; Industrial Engineering; Manufacturing
8	*Journal of Manufacturing Systems*	Netherlands	20	257	Computer Science; Engineering
9	*IEEE Access*	USA	19	72	Computer Science; Engineering; Materials Science
10	*Journal of Manufacturing Science and Engineering-Transactions of the ASME*	USA	14	98	Computer Science; Engineering

Among the 1420 analyzed papers, this step found a total of 4487 keywords, of which 104 met the requirement of having at least 10 occurrences each, being then applied in the mapping process.

Figure 7 shows the characterization of the four co-occurrences clusters:

- the first cluster (colored red) is defined as "Collaborative networks of manufacturing resources and services", once the most frequent terms refers to manufacture, manufacturing resources and services, distributed systems architecture, and networked manufacturing environments through web-based services;
- the second (green) is defined as "Industry 4.0 and cloud computing systems", once the most frequent keywords are related to computer-aided manufacturing processes in industry 4.0. This cluster encompasses the whole product lifecycle within industry 4.0, including cloud computing technologies, internet of things (IoT) and additive manufacturing;
- the third (blue) is defined as "Big data reliable management in cyber-physical systems, risks and challenges", once the main occurrences are related to big data in cyber-physical systems, processes integration, interoperability, blockchain and implementation challenges; and finally
- the fourth cluster (yellow) is defined as "Optimization of manufacturing processes", once the most frequent keywords are related to optimization algorithms and models of cloud manufacturing, as well as to optimal selection and allocation of resources and services.

The elements of each cluster are shown in Table 5.

4.2 Case studies analysis

The case study approach allows researchers to explore and understand complex problems in real-life applications and, therefore, is recognized by its capacity to generate value to the industrial and academic sectors.

In order to assess practical applications in Cloud Manufacturing, this investigation performed the eligibility step, applying the previously described search filters and terms showed in Table 1, resulting in the selection of 159 academic papers with applied case studies out of 1219 publications in English, as shown in Fig. 8.

Afterwards, all titles, abstracts and keywords of the 159 articles were analyzed, enabling the categorization of their case studies approaches within the four pre-established co-occurrences clusters. Figure 9 presents the final stratification by cluster with the number of related articles.

Table 4 Top ranked 16 most cited articles

Rank	Citations	Title	Authors	Journal	Keywords
1	943	From cloud computing to cloud manufacturing [8]	Xu, X; 2012	*Robot Comput Integr Manuf*	Cloud computing; Cloud manufacturing; Service-oriented business model
2	403	Cloud manufacturing: a new manufacturing paradigm [10]	Zhang, L; et al.; 2014	*Enterprise Information Systems*	cloud manufacturing (CMfg); concept; manufacturing cloud service; manufacturing cloud; cloud manufacturing service platform
3	386	CCIoT-CMfg: Cloud Computing and Internet of Things-Based Cloud Manufacturing Service System [9]	Tao, F; et al.; 2014	*IEEE Transactions on Industrial Informatics*	Advanced manufacturing systems; cloud computing; cloud manufacturin; Internet of services; Internet of things (IoT); Internet of users
4	356	IoT-Based Intelligent Perception and Access of Manufacturing Resource Toward Cloud Manufacturing [12]	Tao, F; et al.; 2014	*IEEE Transactions on Industrial Informatics*	Access; cloud manufacturing; intelligent perception; Internet of Things (IoT); manufacturing resource; manufacturing service
5	337	Cloud manufacturing: a computing and service-oriented manufacturing model [13]	Tao, F.; et al.; 2011	*Proc Inst Mech Eng B J Eng Manuf*	manufacturing system; cloud manufacturing; service-oriented manufacturing; computing-oriented manufacturing; cloud computing
6	332	Current status and advancement of cyber-physical systems in manufacturing [21]	Wang, LH; et al.; 2015	*Journal of Manufacturing Systems*	
7	280	FC-PACO-RM: A Parallel Method for Service Composition Optimal-Selection in Cloud Manufacturing System [22]	Tao, F; et al.; 2012	*IEEE Transactions on Industrial Informatics*	Cloud computing; cloud manufacturing; full connection; parallel adaptive chaos optimization; reflex migration; service composition optimal-selection
8	199	An interoperable solution for Cloud manufacturing [11]	Wang, XV; Xu, XW; 2013	*Robot Comput Integr Manuf*	Cloud; Cloud computing; Cloud manufacturing; Service-oriented architecture; STEP
9	193	Big Data and virtualization for manufacturing cyber-physical systems: A survey of the current status and future outlook [23]	Babiceanu, RF; Seker, R; 2016	*Computers in Industry*	Sensor-based real-time monitoring; Big Data; Internet of things; Cloud computing; Manufacturing cyber-physical systems
10	173	Cloud-enabled prognosis for manufacturing [14]	Gao, R; et al.; 2015	*CIRP Ann Manuf Technol*	Predictive model; Condition monitoring; Cloud manufacturing

Table 4 (continued)

Rank	Citations	Title	Authors	Journal	Keywords
11	164	Advanced manufacturing systems: socialization characteristics and trends [24]	Tao, F; et al.; 2017	*Journal of Intelligent Manufacturing*	Advanced manufacturing system; Socialization; Service; Resource sharing; Value creation; User participation; Cloud manufacturing
12	133	Cloud manufacturing: key characteristics and applications [25]	Ren, L; et al.; 2017	*Int. J. Comput. Integr. Manuf.*	cloud manufacturing; cloud computing; Internet of Things; cloud business model
13	132	A state-of-the-art survey of cloud manufacturing [26]	He, W; Xu, LD; 2015	*Int. J. Comput. Integr. Manuf.*	distributed resources; cloud manufacturing; resource integration; enterprise services; service management; Internet of Things (IoT); cloud computing
14	128	IoT-based real-time production logistics synchronization system under smart cloud manufacturing [27]	Qu, T; et al.; 2016	*Int. J. Adv. Manuf. Technol.*	Cloud manufacturing; Internet of things; Production logistic; Dynamic synchronization
15	125	Cloud manufacturing: from concept to practice [28]	Ren, L; et al.; 2015	*Enterprise Information Systems*	cloud manufacturing; public cloud; cloud computing; service-oriented business model; cloud platform; information systems
16	118	Cloud manufacturing service platform for small- and medium-sized enterprises [29]	Huang, BQ; et al.; 2013	*Int. J. Adv. Manuf. Technol.*	Cloud manufacturing; Small- and medium sized enterprise (SME); Cloud manufacturing service platform

- Optimization of manufacturing processes (69 articles): This cluster contains all case studies which presented platform models or algorithms to generate optimized solutions on the following: (i) production planning [30], (ii) scheduling and selection of manufacturing resources or services [31, 32], (iii) reduction of operational and/or logistic total time [33], (iv) cost reduction, (v) maximization of utilization rates [34], (vi) balancing the allocation levels of machines and tools [35], (vii) minimization of industrial resources consumption by controlling process parameters [36], (viii) energy efficiency improvements [37], (ix) productivity increase, (x) task prioritization [38], as well as other strategies aiming at improving factory performance when compared to traditional approaches.
- Collaborative networks of manufacturing resources and services (52 articles): This cluster contains the models developed as tools to approach the relationship between stakeholders, aiming at assessing the following: (i) synergy of the manufacturing services and enterprises networks [39], (ii) integration of operations, information, knowledge and efforts between players [40, 41], (iii) the sharing of resources capabilities [42], (iv) collaborative troubleshooting process involving multiple companies [43], (v) the dynamic decision-making process made by customers to meet their customized demands in production networks with high levels of flexibility and responsiveness [44], (vi) procedures that increase integration of capabilities in remanufacturing, recycling and recovery [45], as well as other strategies that might increase competitiveness throughout the manufacturing supply chain.
- Industry 4.0 and cloud computing systems (31 articles): This cluster contains studies about experimental prototypes, platforms and/or applications of practical demonstrations that aimed at illustrating the

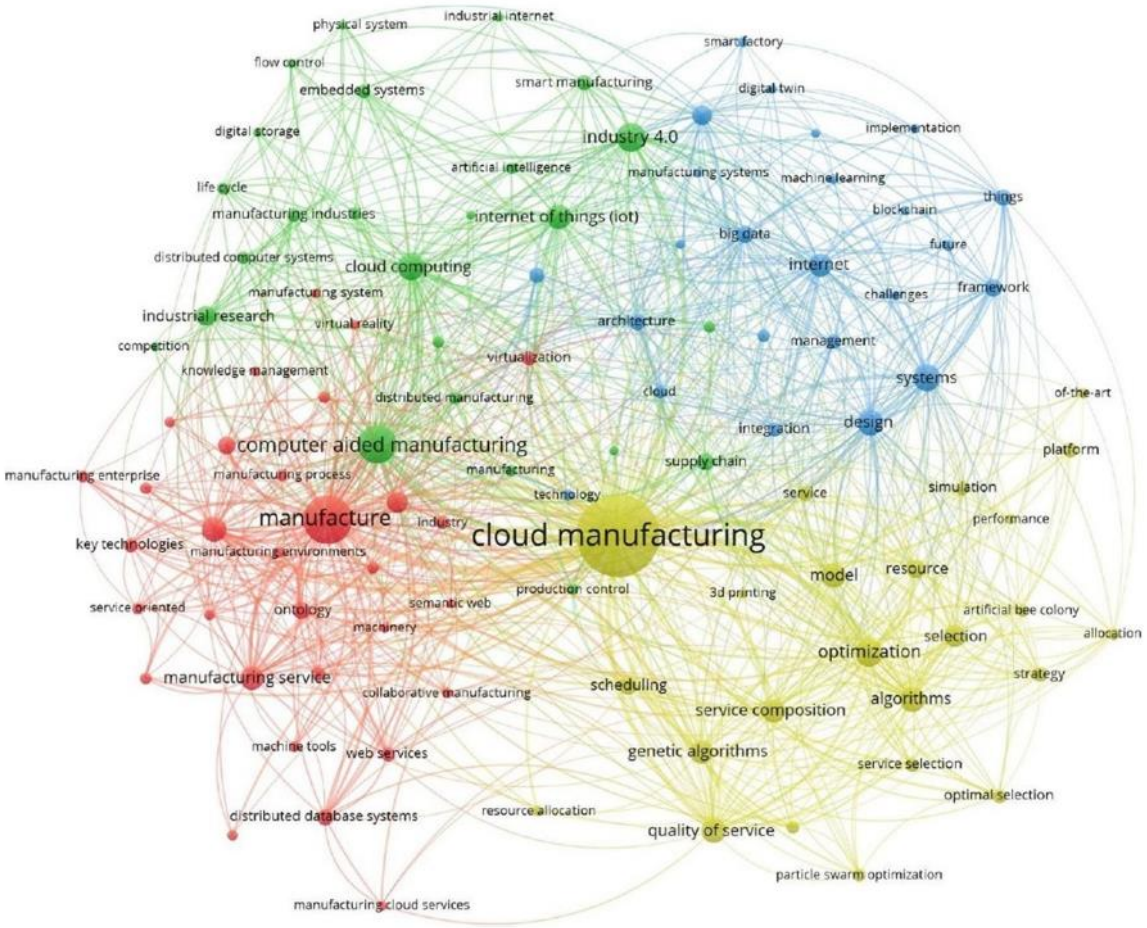


Fig. 7 Keywords co-occurrence map

applicability of Cloud Manufacturing in a generic point of view. Such cases must either (i) present the application of emerging technologies as additive manufacturing (3D printing) [46], internet of things (IoT) [47] and other human-machine interaction approaches in advanced manufacturing of industry 4.0; (ii) test the functionality of prototypes, comparing them to other models in order to validate benefits and disadvantages of adopting Cloud Manufacturing networks and systems [23]; or (iii) highlight implementation challenges and requirements to achieve success in the adoption of virtual manufacturing [11, 29].

- Data reliability, cyber-security, risks and challenges (7 articles): This cluster contains all studies about the following: (i) modeling and simulating architectures that focus both on maximizing transparent data analysis in real-time and on improving cyber-security [48], (ii) using consensus and Proof-of-Authority (PoA) resources to improve the reliability of transaction records between various agents [49], (iii) the application of blockchain technology [50], and (iv) the evaluation of risks or potential failures in transmission of data and/or communication between companies [51].

The great majority of the case studies assessed by this work utilized various computational models, cyber-physical concepts, IT services, and mathematical methods to support decision-making and to create collaborative networks. The most common approaches include Genetic Algorithm [34], Ant Colony [52], Bee Colony [53], Particle Swarm optimization [50], K-Nearest Neighbors (KNN) [49], Chaos Theory [54], Fuzzy logic [55], Game Theory [42], TOPSIS [35], Kano model [56], Artificial Neural Networks [57], Grey Wolf optimizer [37], AHP (Analytic hierarchy process) [52], Blockchain Ethereum [49], and multi-agent systems [58]. Besides, the cases used several simulation softwares, such as Simio [59], FlexSim [60], CloudSim [61], SDMSim [62], MathLab [63], Windows Azure [64], ZigBee [65] and other web-based applications.

Table 5 Characterization and composition of the keywords clusters

Clusters	Items	Keywords (Occurrences)
(1) Collaborative networks of manufacturing resources and services (red)	31	manufacture (267); manufacturing resource (69); manufacturing service (64); cloud services (51); ontology (37); computer architecture (34); distributed database systems (30); web services (25); key technologies (23); virtualization (23); semantics (22); industry (20); manufacturing environments (18); service oriented (18); manufacturing enterprise (17); manufacturing process (17); networked-manufacturing (17); service platforms (17); service-oriented architecture (17); manufacturing capability (16); knowledge based systems (14); collaborative manufacturing (13); information services (13); machine tools (13); mathematical models (13); machinery (12); semantic web (12); knowledge management (11); virtual reality (11); manufacturing cloud services (10); manufacturing system (10).
(2) Industry 4.0 and cloud computing systems (green)	25	computer aided manufacturing (164); industry 4.0 (94); cloud computing (84); internet of things (iot) (70); industrial research (46); supply chain (35); smart manufacturing (27); manufacturing industries (24); embedded systems (23); distributed computer systems (20); product design (19); distributed manufacturing (18); life cycle (18); additive manufacturing (17); decision making (17); manufacturing (17); artificial intelligence (16); production control (14); competition (11); mass customization (11); cyber physical system (10); digital storage (10); flow control (10); industrial internet (10); production planning (10).
(3) Big data reliable management in cyber-physical systems, risks and challenges (blue)	24	systems (80); design (76); internet (63); cyber-physical systems (45); big data (37); framework (36); architecture (33); things (30); management (28); intelligent manufacturing (26); integration (25); interoperability (21); cloud (19); technology (18); future (16); smart factory (13); blockchain (11); machine learning (11); manufacturing systems (11); challenges (10); digital twin (10); implementation (10); industrial internet of things (10); resource virtualization (10).
(4) Optimization of manufacturing processes (yellow)	24	cloud manufacturing (751); optimization (93); algorithms (77); model (69); quality of service (69); genetic algorithms (61); service composition (60); selection (55); scheduling (43); resource (39); service (28); strategy (27); platform (26); optimal selection (23); service selection (23); simulation (22); multi-objective optimization (21); particle swarm optimization (19); artificial bee colony (16); allocation (15); of-the-art (13); performance (13); resource allocation (13); 3d printing (10).

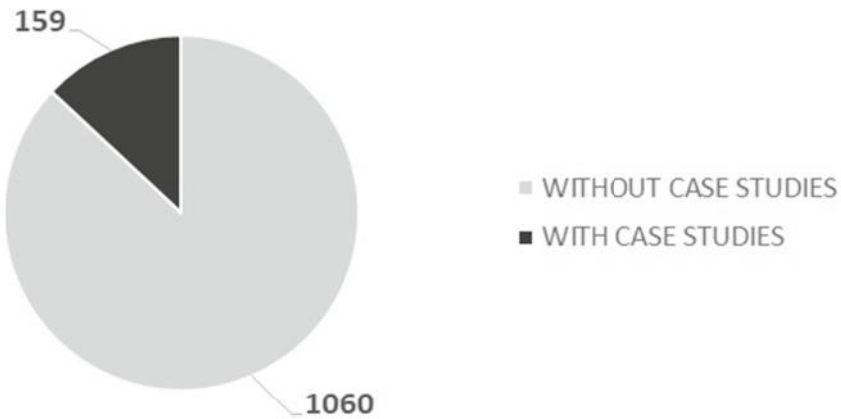


Fig. 8 Publications in English language, with and without case studies

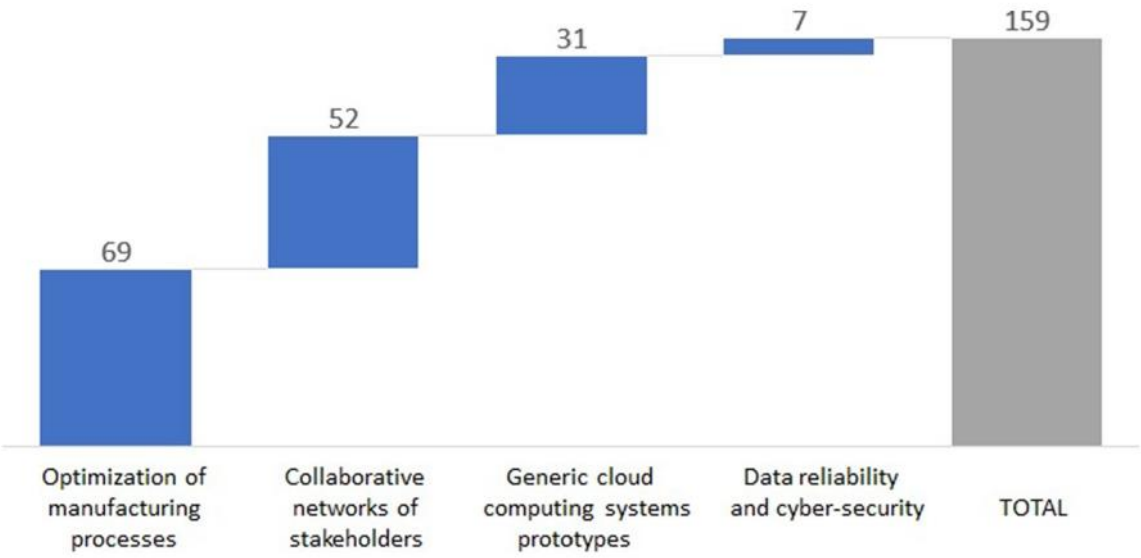


Fig. 9 Case studies classified by their approach

5 Conclusions

From the bibliometric analysis this research conducted on the emerging technology of Cloud Manufacturing, it was possible to map the current literature conditions and to verify that, since 2010, when the first studies appeared, there has been a growing trend in annual publications, suggesting an increasing interest about the subject.

The results obtained reveal that researchers from China are those who generate the highest volume of publications, even when only English language articles are taken into account. Another interesting evidence concerns countries such as New Zealand, Sweden and Finland, which presented considerably high publications rates relative to their populations.

It was not only possible to identify the most relevant journals, with the top editions coming from the USA, the UK, the Netherlands and China, but also a list of the top-ranked articles in terms of influence relative to their number of citations. Those lists can be useful references for researchers interested in the literature about Cloud Manufacturing.

By using the software VOSviewer, this paper elaborated a visualization of bibliometric maps and created four clusters of keywords co-occurrences: "collaborative networks of manufacturing resources and services"; "industry 4.0 and cloud computing systems"; "big data reliability, cyber-security, risks and challenges"; and "optimization of manufacturing processes".

In order to understand the current situation about real-life applications already developed and studied in Cloud Manufacturing, this investigation selected and analyzed all 159 articles written in English that contained case studies. All of them were assessed and categorized according to the four previously cited clusters. It became evident that, while most of the models laid within three of the four clusters — "optimization of manufacturing processes", "collaborative networks of manufacturing resources and services", and "industry 4.0 and cloud computing systems" — only a few of them were related to "big data reliability, cyber-security, risks and challenges".

This cluster analysis of publications containing case studies about Cloud Manufacturing revealed diverse web-based applications that may generate potential gains in production planning, scheduling of services, cost reduction, minimization of industrial resources consumption, synergy of enterprises networks, integration of operations and scalability. However, this analysis also suggests a potential research gap of practical application in the topic of data management and cyber-security, indicating the need of both a reliable data registration, and an agile and traceable information flow, in order to increment the success of this business model.

The great majority of the practical models assessed throughout this study needed a centralized third-party to manage transactions and communication between users. Such practice may reveal weaknesses in data reliability and system cyber-security, resulting in eventual loss, damage, or even manipulation of information and contents. In this context, such centralized digital platforms must apply resources and technologies to increase data management reliability and security against cyber-attacks.

The absence of depth in such an important matter is also an opportunity for development of future works and

researches about the application of technologies for the evolution of cyber-security in cloud manufacturing, improvements of transparency in data traceability, utilization of consensus resources in validation protocols, elimination of the need for a third-party in transactions management, as well as, standardization of systems in order to eliminate communication conflicts between stakeholders of the entire supply chain.

Those key recommendations for further research could potentially reduce breaches or vulnerabilities in cloud manufacturing networks, and contribute to technological advancements in such a new, yet underexplored field.

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Declarations

Conflict of interest The authors declare no competing interests.

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2.2 CHALLENGES AND OPPORTUNITIES IN A LEAN AUTOMATION MODEL IMPLEMENTATION: CHARACTERIZING MSMES OF DEVELOPING COUNTRIES

Título: Challenges and opportunities in a lean automation model implementation: characterizing micro, small and medium-sized enterprises of developing countries.

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Resumo: A abordagem que associa tecnologias inovadoras da Indústria 4.0 com os princípios da Produção Enxuta é chamada de *Lean Automation* (LA). Este artigo visa explorar modelos de LA, investigando desafios e oportunidades para sua aplicação prática em micro, pequenas e médias empresas (MPMEs) no Brasil, contribuindo para o desenvolvimento tecnológico em países emergentes. Assim, este artigo mapeou as principais combinações de Indústria 4.0 e princípios *Lean*, estruturou um modelo conceitual *Just-In-Time* (JIT) *Delivery*, e caracterizou as condições das MPMEs de países emergentes em relação aos padrões do LA. A coleta de dados foi gerada por meio de uma *survey*, e sua análise foi realizada pelo método Promethee-Gaia. Os resultados nos permitiram comparar diferentes setores, revelando suas forças e fraquezas. Este estudo verificou que os segmentos de negócios com as piores adesões ao LA apresentaram baixos desempenhos em conceitos como: '*planning and scheduling*', '*pull-system*', '*lot size reductions*' e '*cyber security*'. Finalmente, organizamos um roteiro viável de 3 etapas para a implementação do LA.

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Challenges and opportunities in a lean automation model implementation: Characterizing micro, small and medium-sized enterprises (MSMES) of developing countries

Author

Address

Abstract: The approach that associates innovative Industry 4.0 technologies with Lean Production principles is called Lean Automation (LA). This paper aims to explore LA models, investigating challenges and opportunities to their practical application in micro, small and medium-sized enterprises (MSMEs) in Brazil, contributing to technological development in emerging countries. As such, this article mapped the main combinations of Industry 4.0 and Lean, structured a conceptual Just-In-Time (JIT) Delivery model, and characterised the conditions of MSMEs of emerging countries in relation to LA standards. The data collection was generated through a survey, and its analysis was performed using the Promethee-Gaia method. The results allowed us to compare different sectors, revealing their strengths and weaknesses. This study verified that business segments with the worst LA adherences presented low rates in concepts such as: 'planning and scheduling', 'pull-system', 'lot size reductions' and 'cyber security'. We organised a feasible 3-steps roadmap for the LA implementation.

Keywords: lean automation; industry 4.0; lean production systems; just-in-time (JIT) delivery; micro small and medium-sized enterprises (MSMEs); developing countries; survey; promethee.

Reference to this paper should be made as follows: Author. (xxxx) 'Title', *Int. J. xxxxxxxxxx xxxxxxxxxx*,

Biographical notes:

1 Introduction

Efforts directed towards cost and waste reductions are such noticeable aspects of the industrial environment to reach satisfactory levels of business competitiveness. Diverse tools and techniques have been established over the last decades for this purpose, among them, a remarkable standard is the Lean Production System (LPS), which appeared in the early 1990s, and whose patterns may be employed to various business enterprise sectors. LPS can provide not only cost and waste reductions, but also process optimisation, productive efficiency, and continuous improvement (Abbadi et al., 2020; Raji et al., 2021; Rybski & Jochem, 2020).

Currently, the manufacturing industry is facing high standards of market demand for intensely customised products, great quality requirements, and low delivery lead-times. These circumstances drive enterprises worldwide to adopt novel digital technologies of

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high connectivity and artificial intelligence to obtain competitive advantage. Such scenery characterises the fourth industrial revolution, known as Industry 4.0 (I4.0) (Dalenogare et al., 2018; Pereira & Sachidananda, 2021).

Modern academic research has emerged considering the integration of both philosophies Lean Production Systems and Industry 4.0, including attributes such as cost reduction and high connectivity (von Haartman et al., 2021). This model combines, simultaneously, Lean principles to innovative I4.0 technologies, and introduces the concept of Lean Automation (LA), which points to boost production flexibility with agile information flow (Kolberg et al., 2017; Ma et al., 2017; Rybski & Jochem, 2020; G. Tortorella et al., 2020).

Taking the detailed background into account, the following research questions arises:

1 What is the situation of micro, small and medium-sized enterprises (MSMEs) in developing countries regarding the implementation of the Lean Automation innovative models?
2 Is it possible to define a feasible roadmap for these enterprises to implement a Lean Automation model?

Thus, this article aims to evaluate an application model of Lean Automation principles and technologies for MSMEs of a developing country. The following steps were performed:

- developing a conceptual model which contemplates both Lean principles and Industry 4.0 technologies suitable to a supply chain stage;
- validating the current affinity status of diverse business segments in relation to the proposed model through a survey;
- identifying and discussing potential barriers to the application of a LA model in MSMEs and, finally;
- organising a roadmap towards a successful implementation of the Lean Automation Just-In-Time (JIT) Delivery model to the MSMEs of emerging countries.

Even though the Lean principles and I4.0 technologies are concepts widely explored individually, their integration is still at a developmental stage. Within the academic scope, both the JIT-Delivery proposed model and the results of the survey analysis should incentivise future analysis in this field, revealing integration opportunities to researchers, as well as, making way for empirical and experimental studies.

While in the practical/professional domain the summarised process not only provides a guide for successful adoption of I4.0 technologies combined to Lean tools, but also contributes to the development of MSMEs in emerging countries, reducing technological inequalities between nations.

In addition to improvements in technological and economic conditions, this research also contributes to social and environmental aspects, fortifying the Lean culture over stakeholder networks, establishing high productivity, standardizing supply chain processes, and optimizing transportation, as well as reducing waste and resource consumption. Such benefits make the integration between partners more transparent, reliable, and responsive, preventing disruption risks of the supply chain.

2 Literature review

2.1. Lean Production System (LPS)

LPS has the ability to eliminate waste and solve problems continuously, and it serves as an alternative model for integrated production that combines highly interrelated elements, including management tools, methods and practices, aiming to generate an efficient system dedicated to continuous improvement (Abbadi et al., 2020).

The concept of Lean Production System, also commonly called as Lean Manufacturing, presents key factors that allow enterprises to have quick reactions to changes, which permit flexibility of market demand through the visualisation of processes and reduction of batch production. Due to this, the Lean philosophy remains widely spread and practiced in the industry, even with the growing technological evolutions in the last decades (Kolberg & Zühlke, 2015; Mokudai et al., 2021).

2.2. Industry 4.0 (I4.0)

The term Industry 4.0 is a concept used to describe the Fourth Industrial Revolution, characterised by technology in automation and data exchange in an intelligent way, with a self-managed network, obtained through the union of production techniques, information technology (IT) and the internet, integrating the physical and the virtual world. This will usher in a new phase of industrialisation and automation, bringing opportunities and challenges (Langlotz et al., 2021; Mrugalska & Wyrwicka, 2017).

According to Karaulova et al. (2019), the new digital industry brings flexibility, cost, efficiency, quality, and competitive advantage, helping enterprises to achieve higher industrial performance.

These improvements are achievable if they follow some technologies trends from the I4.0 idea, such as: Cyber-physical systems, Cloud computing, Internet of Things (IoT), Internet of Services (IoS), Additive manufacturing, Artificial Intelligence, Autonomous robots, Simulation, Horizontal and Vertical system integration, Cyber security, Augmented reality and Big Data analytics (Doh et al., 2016).

2.3. Lean Automation (LA)

Research on this subject shows theoretical and practical concepts about the integration of both philosophies Lean Production Systems and Industry 4.0 (Kolberg et al., 2017; G. L. Tortorella, Saurin, Gaiardelli, et al., 2021; von Haartman et al., 2021).

This LA concept not only introduce models which comprise of information management in cyber-physical environments automated by sensors, controllers and actuators connected to Lean principles digitalizing the production control, avoiding lost and identifying potential improvements (Dombrowski et al., 2017; Pérez et al., 2020; Rossi et al., 2020; Shigematsu et al., 2018), but also examine possible success factors and pathways to implement high performing LA systems in various business sectors (G. L. Tortorella, Narayanamurthy, et al., 2021; Vlachos et al., 2021).

The proposal to apply specific LA models to MSMEs has been addressed by some academic studies in European and Asian countries (Chanarungruengkij & Kaitwanidvilai, 2018; Ma et al., 2017; Pereira & Sachidananda, 2021). However, there is no proposition

of a particular LA model applied to Brazilian MSMEs in the literature. According to (Jamwal et al., 2022) there is a need to develop more LA robust models for micro-small and medium enterprises (MSMEs) as they contribute more to the gross domestic product of developing nations.

2.4. Studies with practical and quantitative applications on LA

This section presents the papers related to the application of LA principles and technologies worldwide. Such studies involve practical implementations, case studies, simulations or surveys.

Dombrowski et al. (2017) and Rybski & Jochem (2020) conducted surveys with German enterprises from different sectors and company sizes. These studies intended to identify the digital elements of I4.0 already implemented on LPS, and to analyse the most relevant interdependencies of I4.0 in relation to LPS.

In other studies that applied cross-sector surveys, Rossini et al. (2021) and Tortorella et al. (2021) identified the relationship between LPS and I4.0 technologies. These results showed the Lean elements which work with a positive association to practically all I4.0 technologies. Afum et al. (2021) investigated the interrelationships between Lean Automation and sustainability.

Ante et al. (2018), Setiawan et al. (2021) and Wagner et al. (2017) studied the integration of elements of LPS and I4.0 technologies – such as sensors, cloud computing, RFID, pull-principle and visualization – in order to develop a specific cyber-physical manufacturing system in the automotive industry. Grube et al. (2019, 2017) describes how small and medium-sized enterprises can reduce wastes and capture benefits of high-level technology tools such as sensors and virtual simulation. Pérez et al. (2020) illustrated a new process automation design methodology through a real-time implementation of a digital twin in the manufacturing operation, allowing for a virtual test environment. These models present real-time collaborative integration between stakeholders that can adjust production layout to meet market demand fluctuations, as well as allow high control in the monitoring and visualization of processes.

Kolla et al. (2019) and Sony (2018) identified that characteristics of small and medium-sized enterprises, such as the ability to produce customised products, lack of advanced manufacturing technologies or deficiency in integrated networks must be assessed to increase competitiveness in global markets.

Malik & Bilberg (2017, 2018, 2019), Pan et al. (2011), Rossi et al. (2020) and Sordan et al. (2021) investigated methods for evaluating and differentiating tasks between humans and machines in flexible automation scenarios. Those case studies assessed advanced manufacturing tasks and variables, resulting in the flexibilization of operations.

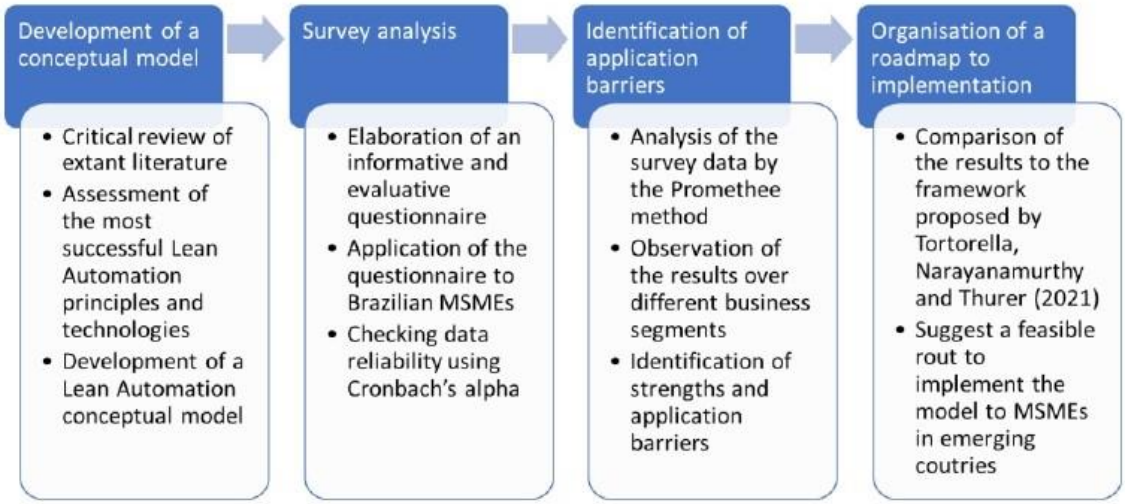
Di Nardo (2020) and Rosin et al. (2020) proposed smart models equipped with sensors and cyber security coupled to an ERP to optimise maintenance and production systems. Osore et al. (2020) evaluated the impact of using Six Sigma automation to improve production efficiency in a case study, which lead to an increase in productivity as a result.

Tortorella, Narayanamurthy, et al. (2021) examine pathways to implement a LA process and indicates a successful implementation sequence in three stages: start-up, in-transition, and advanced practices/technologies.

3 Methodology

This paper investigates the maturity level of MSMEs of a developing country in terms of Lean Automation. Therefore, this research process was structured in four stages: (1) Development of a conceptual model, (2) Survey analysis, (3) Identification of application barriers, and (4) Organisation of a roadmap to implementation. Its flow chart is illustrated in Figure 1 and detailed below:

Figure 1 Research stages flowchart



Source: Adapted from Diaconu et al. (2018) and Ngai et al. (2015)

(1) **Development of a conceptual model** – Regarding the development of a conceptual model of a Lean Automation process, this research conducted a critical review of extant literature on this subject indexed in the Scopus and the Web of Science databases (Diaconu et al., 2018; Ngai et al., 2015; Samanta et al., 2021). This review supported the understanding of Lean Production and Industry 4.0 association, as well as the appreciation of the most successful LA principles and technologies already applied worldwide. Furthermore, this step facilitated the formulation of assumptions which provided the basis for the creation of a LA conceptual model. This model will act as a prototype for the elaboration of a questionnaire which will be applied to MSMEs of an emerging country, in order to characterise their conditions in relation to LA standards.

(2) **Survey analysis** – A survey analysis was designed for this research (Grama, 2007; Lin et al., 2019; Mana, 2018; Storolli, 2020). The questions characterised the participants and their general knowledge on the subject, in addition to allowing for the evaluation of the level of adherence of enterprises regarding the proposed model.

The questionnaire was applied to Brazilian MSMEs, whose sample was defined according to information contained in open access databases and the categorisation of MSMEs given by BNDES (2021), SEBRAE and FGV (2020). All the construct items were measured on a 5-point Likert Scale (ranging from 0 to 4). The questions involved:

- characterisation of the sample: identification of the respondent, professional background, position, role, company segment, and knowledge of the topic;
- technological levelling;
- identification of the use of the main I4.0 techniques and tools related to the model; and
- identification of the use of the main Lean techniques and tools related to the model.

The reliability of the measurement scale was assessed using Cronbach's alpha, giving greater robustness to the study (Gliem & Gliem, 2003; Leontitsis & Pagge, 2007).

The questionnaire and its method of application were approved by the Research Ethics Committee (CEP/CONEP) of the University of Campinas-UNICAMP, according to the certificate of presentation of ethical assessment (CAAE) number 47885521.0.0000.5404.

(3) **Identification of application barriers** – The results were analysed via the Promethee II method, which compares alternatives in the pairwise relation, indicating the performance of each one for multicriteria data (Mareschal & Brans, 2005). In this case, the different sectors of Brazilian MSMEs were correlated with LA technologies.

Thus, the associations that act as drivers of strengths, weaknesses, challenges and opportunities to the application of a LA model to MSMEs in developing countries were found (Storolli, 2020), according to the following aspects:

- comparative between industry, commerce, and services sectors; and
- identification of the technological criteria that act as strengths and weaknesses, stratified by business operating segment.

(4) **Organisation of a roadmap to implementation** – Lastly, the reports created were analysed and compared to the study of Tortorella, Narayanamurthy, et al. (2021), in order to identify and suggest a successful implementation route of the LA technological model for MSMEs in emerging countries.

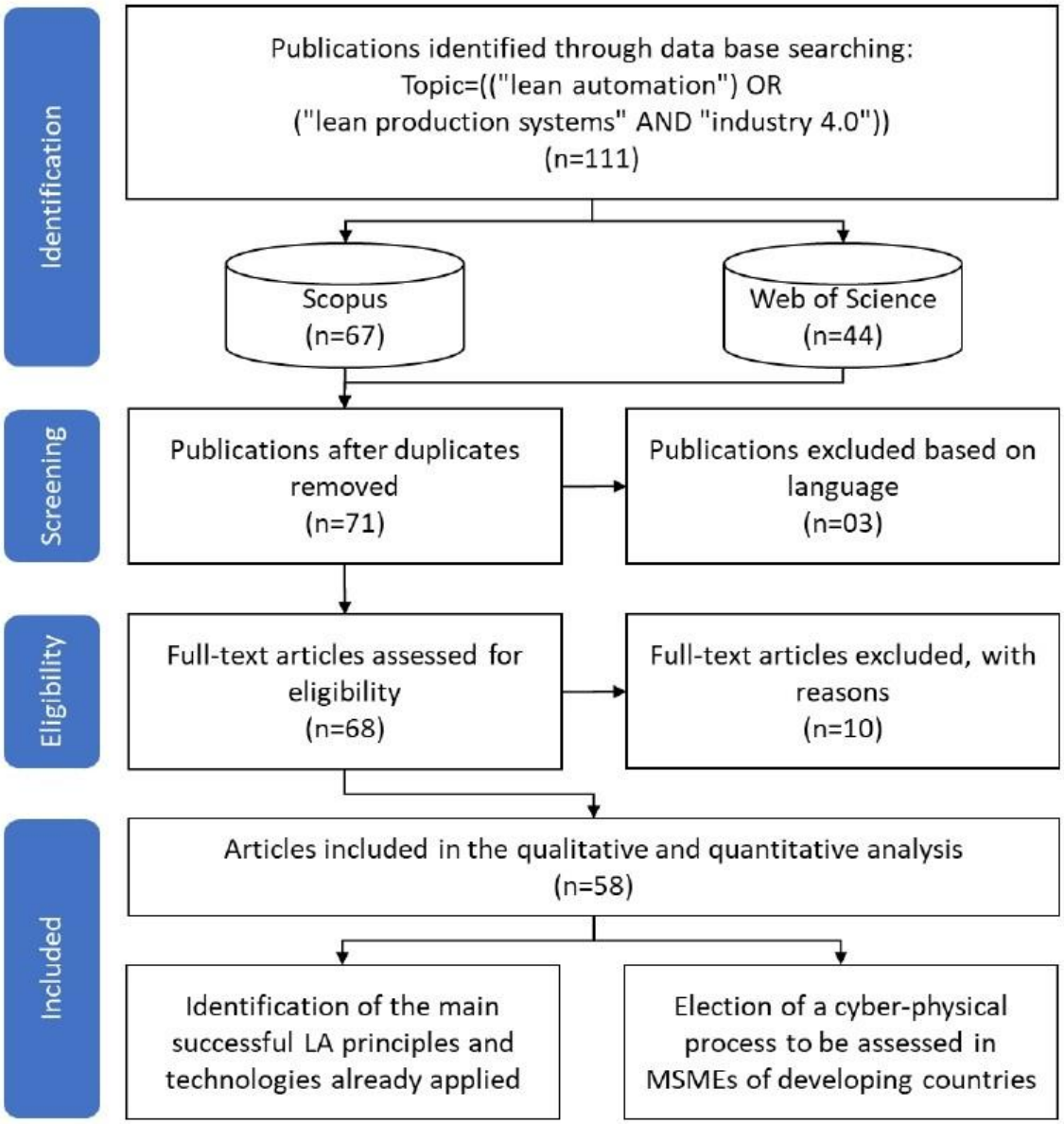
4 Results

4.1. Development of the conceptual model

Firstly, this article conducted a literature review on the field of Lean Automation, selecting articles and conference papers written in English from the Scopus and the Web of Science databases. This initial review demonstrated various worldwide successful applications of innovative I4.0 technologies to lean production environments.

Figure 2 shows the systematic review process, providing details about the search engine and the analysis of the relevant papers in the scope of LA application.

Figure 2 Systematic review process



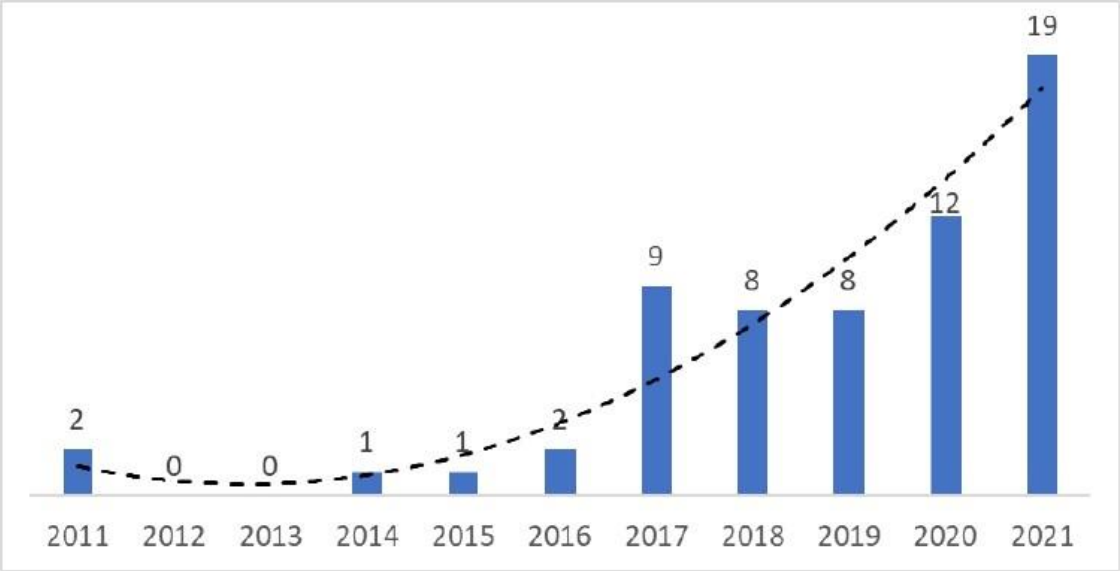
Source: Adapted from Diaconu et al. (2018) and Samanta et al. (2021)

A total of 71 articles or conference papers, published from the year 2011 onwards, were screened. Afterwards, 03 documents were excluded because they were not written in English and 10 documents were excluded because they did not address the relationship between Lean principles and Industry 4.0 technologies.

Finally, a total of 58 publications were selected for qualitative and quantitative analysis. Figure 3 presents the annual publications about Lean Automation, revealing a growing trend in publications on this topic, and suggesting an increase in relevance in the academic and industrial spheres. The polynomial trendline was generated through the Microsoft Excel.

Figure 3 Annual publications trend about Lean Automation

Author



The general content of these articles is presented in the previously sub-section '2. Literature Review'. Through this bibliographic analysis we were able to select the Lean Automation principles and technologies with the most successful application.

Table 1 presents the list of the main principles and technologies addressed in studies involving practical applications, case studies, simulations or surveys. The 'General' column shows the number of publications that evaluate the application of a certain technology in any type of enterprise. The 'MSMEs' column refers to the specific amount of application studies in micro, small and medium-sized enterprises.

Table 1 Most successful technologies/principles already in use

Knowledge	Principle / Technology	General	MSMEs	References
Industry 4.0	Sensors	13	9	(Burggräf et al., 2019; Dombrowski et al., 2017; Grube et al., 2019; Kolla et al., 2019; Langlotz & Aurich, 2021; Ma et al., 2017; Pérez et al., 2020; Rossini et al., 2021; Rybski & Jochem, 2020; Sony, 2018; G. L. Tortorella, Narayanamurthy, et al., 2021; Wagner et al., 2017)
	Cloud Computing	10	6	(Dombrowski et al., 2017; Grube et al., 2017; Husen, 2020; Langlotz & Aurich, 2021; Pereira & Sachidananda, 2021; Rossini et al., 2021; Rybski & Jochem, 2020; Sony, 2018; G. L. Tortorella, Narayanamurthy, et al., 2021; Wagner et al., 2017)
	Big Data	8	8	(Chanarungruengkij & Kaitwanidvilai, 2018; Dombrowski et al., 2017; Kolla et al., 2019; Rossini et al., 2021; Rybski & Jochem, 2020; Sony, 2018; G. L. Tortorella, Narayanamurthy, et al., 2021; Wagner et al., 2017)
	RFID	7	6	(Ante et al., 2018; Dombrowski et al., 2017; Grube et al., 2017; Husen, 2020; Rossini et al., 2021; Rybski & Jochem, 2020; Sony, 2018; G. L. Tortorella, Narayanamurthy, et al., 2021)
	Mobile Devices	4	2	(Kolla et al., 2019; Rybski & Jochem, 2020;

				G. L. Tortorella, Saurin, Filho, et al., 2021; Vlachos et al., 2021)
	Cyber security	4	2	(Di Nardo, 2020; Dombrowski & Richter, 2018; Jamwal et al., 2022; Rybski & Jochem, 2020)
Lean Production Systems	Avoidance of waste	14	8	(Burggräf et al., 2019; Chanarungruengkij & Kaitwanidvilai, 2018; Dombrowski et al., 2017; Grube et al., 2019; Jamwal et al., 2022; Osore et al., 2020; Pereira & Sachidananda, 2021; Rybski & Jochem, 2020; Setiawan et al., 2021; Sony, 2018; Sordan et al., 2021; G. L. Tortorella, Narayanamurthy, et al., 2021; Vlachos et al., 2021; Wagner et al., 2017)
	Pull-principle	9	5	(Burggräf et al., 2019; Davis et al., 2020; Dombrowski et al., 2017; Husen, 2020; Rybski & Jochem, 2020; Setiawan et al., 2021; Sony, 2018; G. L. Tortorella, Narayanamurthy, et al., 2021; Wagner et al., 2017)
	Visualization	9	4	(Ante et al., 2018; Burggräf et al., 2019; Davis et al., 2020; Dombrowski et al., 2017; Grube et al., 2019; Langlotz & Aurich, 2021; Pérez et al., 2020; G. Tortorella et al., 2020; G. L. Tortorella, Narayanamurthy, et al., 2021)
	Integrated Engineering Systems	8	7	(Kolla et al., 2019; Osore et al., 2020; Pan et al., 2011; Rossini et al., 2021; Sony, 2018; G. L. Tortorella, Narayanamurthy, et al., 2021; G. L. Tortorella, Saurin, Filho, et al., 2021; Wagner et al., 2017)
	Standardization	8	6	(Burggräf et al., 2019; Davis et al., 2020; Dombrowski et al., 2017; Kolla et al., 2019; Rossini et al., 2021; Rybski & Jochem, 2020; Sony, 2018; Wagner et al., 2017)
	Communication with key suppliers	6	5	(Davis et al., 2020; Dombrowski et al., 2017; Kolla et al., 2019; Rossini et al., 2021; G. L. Tortorella, Narayanamurthy, et al., 2021; Wagner et al., 2017)

Published papers on this subject reveal higher efficiency in the application of the following novel technologies: mobile devices, cyber security, cloud computing, sensors, RFID and big data; combined to the following lean principles: communication with key suppliers, integrated engineering systems, avoidance of waste, pull-principle, visualisation and standardisation.

Other Industry 4.0 technologies – such as additive manufacturing, digital twins, autonomous vehicles, and augmented reality, among others – were cited in general applications, but appeared at most once as successful LA applications for MSMEs, so they will not be included in the elaboration of the conceptual model nor in the survey analysis.

Similarly, other Lean techniques – such as total productive maintenance (TPM), takt time, SMED, and Poka Yoke, among others – were cited in general applications, but appeared at most three times as successful LA applications for MSMEs, so they will not be included in the elaboration of the conceptual model nor in the survey analysis.

In the process of designing a LA conceptual model, the technologies and principles already successfully studied in academic research were applied, and thus an innovative

conceptual model was developed and proposed to the Just-In-Time Delivery Cyber-physical process, which involves the steps of identifying, selecting, and monitoring suppliers of customised products or services to meet customer needs (Dombrowski et al., 2017; Rybski & Jochem, 2020; G. Tortorella et al., 2020; Wagner et al., 2017).

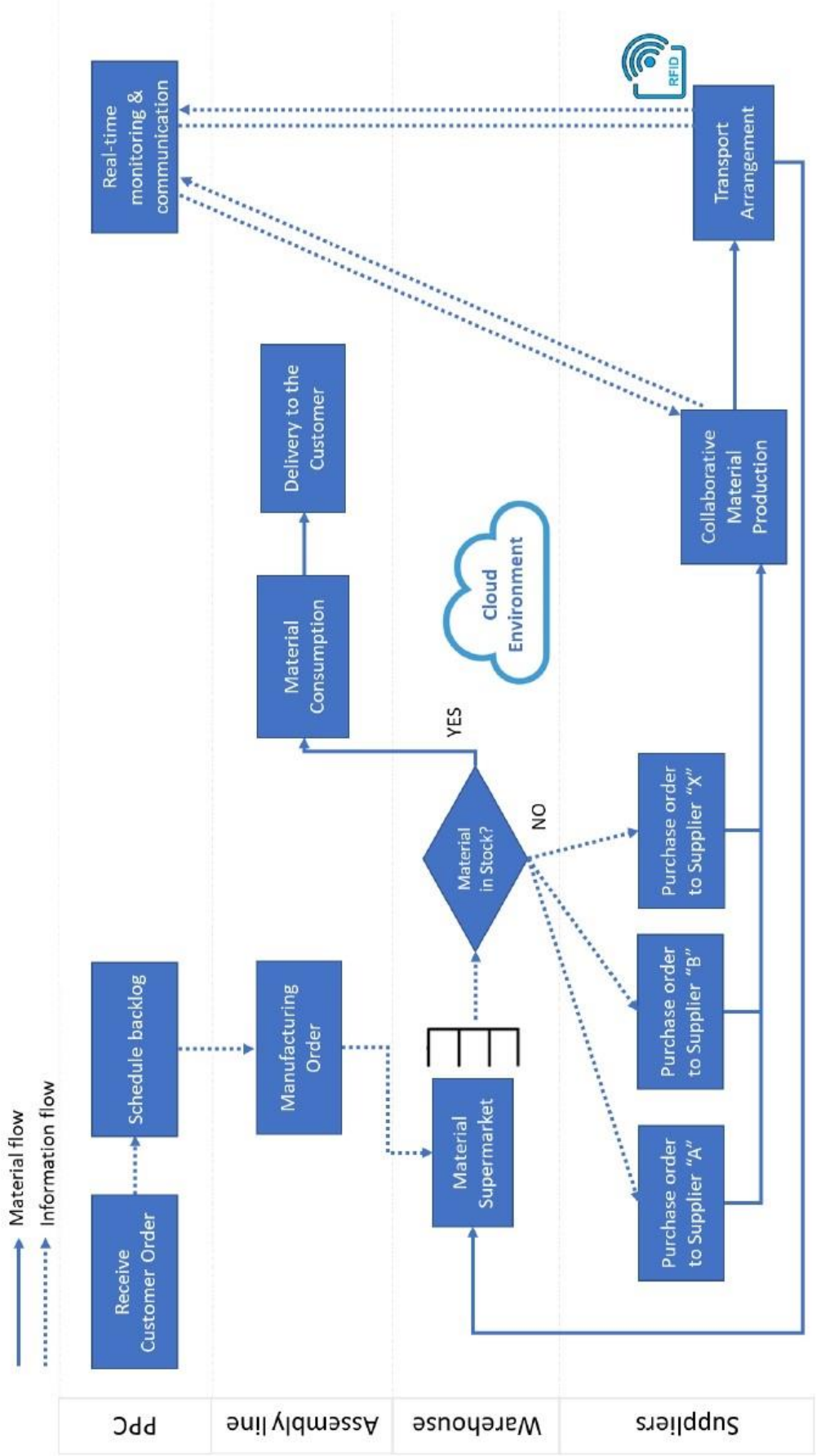
This article elected the JIT-Delivery process, as presented by Wagner et al. (2017), to be studied because, among all of the application models proposed for MSMEs assessed in the literature review, this one is the most suitable for different business segments, assists MSMEs promoting lower levels of inventory and reducing waiting times, as well as, it can involve multiple stakeholders in the network.

The models proposed by Chanarungruengkij & Kaitwanidvilai (2018), Grube et al. (2017) were discarded as they are too specific for industrial production lines. The model presented by Osore et al. (2020) was discarded because it presents specific characteristics to the Sugar production process. The models proposed by Grube et al. (2019) and Pan et al. (2011) were discarded as they study the application of only one specific LA technology, the robotic automation and the digital twins, respectively.

The models presented by Dombrowski & Richter (2018) and Wagner et al. (2017) have applicability for several segments of MSMEs and both could be used for the development of our conceptual model, so we selected the JIT-Delivery model proposed by Wagner et al. (2017), as it presents a more detailed flowchart in his article.

The proposed LA conceptual model applied to the Just-In-Time Delivery process is illustrated in Figure 4. Thereafter a survey analysis was structured in accordance with this model, in order to assess its applicability to MSMEs from Brazil.

Figure 4 The proposed JIT-Delivery conceptual model


Material flow
Information flow
PPC
Assembly line
Warehouse
Suppliers
Receive Customer Order
Schedule backlog
Manufacturing Order
Material Supermarket
Material in Stock?
YES
NO
Material Consumption
Delivery to the Customer
Cloud Environment
Purchase order to Supplier "A"
Purchase order to Supplier "B"
Purchase order to Supplier "X"
Collaborative Material Production
Transport Arrangement
RFID
Real-time monitoring & communication

Author

The given model introduces a Cloud-based solution applied to the manufacturing sector, which is called Cloud Manufacturing (Morelli & Ignacio, 2021; Sony, 2018); this integration mechanism drives a collaborative production environment connecting different enterprises and departments.

The application of this IT solution creates a pull system environment with an agile sharing of information and activities, and allows to eliminate dashboards and other manual operations in the supplier management process (Burggräf et al., 2019; Davis et al., 2020).

Connected to both ERP systems and production planning and control (PPC) departments, this scheme based on the Kanban-principle can identify and eliminate waste, as well as control the progress of work and the feedback of results.

This systems integration must involve key suppliers and promote a collaborative environment capable of delivering products at the right time, right amount and right destination (Kolla et al., 2019). Tortorella et al. (2020) also mentions the importance of the formal supplier certification program as a JIT-Delivery shift.

Such real-time monitoring and communication of the processes can improve the competitiveness of the enterprises beyond sharing forecasting information and gaining speed in the update variations in seasonal demands. These features can increase operational efficiency in manufacturing orders, schedule backlog, material supermarkets, materials in stock and purchase orders to suppliers (Davis et al., 2020; Wagner et al., 2017).

The prototype suggests the application of RFID technology on the monitoring of freight and logistics systems. Such scheme of real-time visualisation includes demand management, traceability and automatic replenishment of out-of-stock goods (Ante et al., 2018; Grube et al., 2017).

The use of mobile devices and cyber security is recommended on the standardisation process, as well as to receive customer orders and mail purchase orders to suppliers. It helps to control the operation, bring IT protection, guarantee a secure connection, and it can also be helpful in real-time monitoring and communication systems (Rybski & Jochem, 2020; Vlachos et al., 2021).

Sensors and Big data platforms not only allow information acquisition, processing and storing, enabling the interaction of products, resources, machines, and equipment with the physical world, but also generate statistical data, which support managers to identify unstable process parameters (Dombrowski et al., 2017; G. L. Tortorella, Narayanamurthy, et al., 2021).

4.2. Survey Analysis

In order to investigate the current situation of enterprises from developing countries regarding the adoption of modern technologies associated with lean production principles, this study conducted a survey analysis involving micro, small and medium-sized Brazilian organisations, as the profiles of these enterprises absorb the majority of formal jobs in emerging countries.

The conceptual model, developed from the JIT-Delivery process and the 12 Lean Automation principles/technologies selected from the literature, was used as a basis for the survey.

In the elaboration of the set of questions which are looking for identifying the adoption of main I4.0 techniques related to the model, the core of Storolli (2020) was

used towards the following tools: Mobile Devices, Cyber Security, RFID, Sensors, Big Data and Cloud Computing.

Furthermore, this article used the study of Mana (2018) as a basis to define the questions that aimed to identify the adoption of the main Lean tools related to the model. This set of questions approached the following principles: production management systems, certification programs, quality management, pull production, inventory management, communication systems, supply chain information sharing, and product design.

Table 2 shows the list of 12 principles and technologies considered in the Lean Automation JIT-Delivery conceptual model. All of those were applied to the survey questionnaire, and subsequently to the results assessment.

Table 2 Principles and technologies applied to the research

Criteria	Principles / Technologies	Related process in the model
C1	Planning and scheduling strategies	Schedule backlog / Manufacturing order / Material supermarket
C2	Formal supplier certification program	Purchase order to suppliers
C3	Mobile devices	Receiving of customer orders / Mailing of purchase orders to suppliers
C4	Cyber security	Receiving of customer orders / Mailing of purchase orders to suppliers
C5	Pull system/Kanban	Receive customer order / Material supermarket / Material consumption / Delivery to the customer
C6	Lot size reduction	Manufacturing order / Material supermarket
C7	Communication on important issues with key suppliers	Purchase order to suppliers / Real-time monitoring / Collaborative material production
C8	RFID tags	Transport arrangement / Real-time monitoring & communication
C9	Sensors	Material supermarket / Material consumption / Collaborative material production
C10	Cloud computing	Production Planning and Control (PPC) / Assembly line / Warehouse / Suppliers
C11	Big data	Production Planning and Control (PPC) / Assembly line / Warehouse / Suppliers
C12	Integrated engineering systems	Collaborative material production / Real-time monitoring & communication

A detailed evaluation of the survey resulted in the validation of 54 responses to be part of the assessment, as presented in Table 3. All of these data were explored using the method Promethee II, correlating different sectors of Brazilian MSMEs to Lean Automation technologies. Then, this study quantified the implementation levels of various innovative technologies in enterprises of an emerging country.

Table 3 Matrix of the survey answers

Author

RESPONDENT	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	Total
1	4	2	2	4	3	2	1	2	4	4	3	2	33
2	2	1	0	2	0	2	0	0	0	1	2	0	10
3	0	4	0	2	0	1	0	0	0	1	2	0	10
4	3	2	0	2	2	2	1	2	0	2	2	3	21
5	0	4	2	4	4	2	2	4	2	4	2	3	33
6	2	1	0	3	0	2	0	0	0	2	0	1	11
7	1	1	0	2	1	2	1	0	0	1	1	0	10
8	4	4	2	4	0	0	0	0	0	4	2	0	20
9	2	2	0	4	3	3	0	0	1	3	3	4	25
10	3	3	2	2	2	3	1	0	2	2	2	0	22
11	4	4	0	4	2	2	2	2	3	3	2	4	32
12	3	0	0	0	0	2	1	0	0	2	0	0	8
13	0	0	0	0	0	2	0	0	0	0	0	1	3
14	0	0	0	3	0	1	0	0	0	4	0	0	8
15	0	0	2	0	1	2	1	0	0	2	2	4	14
16	0	0	2	2	0	0	0	0	0	2	2	0	8
17	2	0	2	0	1	1	0	1	1	1	1	0	10
18	0	0	0	0	1	0	0	0	0	2	0	3	6
19	2	2	2	3	3	3	0	2	2	3	2	3	27
20	3	2	0	2	3	3	0	0	0	2	2	3	20
21	3	0	1	1	3	3	2	0	0	4	1	2	20
22	0	0	2	2	0	2	2	0	0	2	0	0	10
23	3	2	2	4	2	2	3	0	4	4	2	0	28
24	0	1	2	2	0	0	2	0	0	4	3	4	18
25	0	0	0	2	0	0	1	0	0	2	0	0	5
26	0	0	4	4	0	0	0	0	0	2	0	4	14
27	2	2	0	2	2	3	0	2	0	3	0	4	20
28	2	1	2	2	0	2	0	0	2	2	0	0	13
29	0	1	2	2	0	2	0	2	0	2	0	2	13
30	0	0	0	0	0	3	0	0	0	2	0	0	5
31	0	0	4	0	0	0	0	0	0	1	0	0	5
32	0	0	3	0	0	0	0	0	0	1	1	0	5
33	0	0	0	2	0	2	0	0	0	1	2	0	7
34	0	0	0	0	3	3	0	0	0	3	2	0	11
35	2	3	4	0	3	3	3	0	0	2	0	0	20
36	2	0	0	0	1	1	0	0	0	1	0	0	5
37	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	1	0	0	0	0	0	0	2	0	0	3
39	0	1	2	2	0	0	0	0	0	4	0	0	9
40	0	0	1	0	0	3	0	2	0	1	0	0	7
41	0	0	2	2	0	0	2	0	0	2	0	0	8
42	2	4	0	3	1	2	1	0	2	2	2	1	20
43	0	0	1	1	0	0	0	0	0	2	0	0	4
44	0	0	2	2	0	0	0	0	0	2	1	0	7
45	0	0	2	2	0	0	2	0	0	2	2	0	10
46	0	1	2	0	0	4	1	0	0	2	0	0	10
47	0	0	3	2	0	2	3	4	0	2	0	0	16
48	0	0	0	2	0	0	0	0	0	1	0	0	3
49	0	0	0	2	0	0	0	0	0	2	2	0	6
50	0	0	2	3	0	0	0	0	0	2	0	0	7
51	2	1	0	0	3	4	0	0	0	3	2	3	18
52	3	1	1	1	0	4	0	2	1	2	0	0	15
53	0	2	2	3	0	0	0	0	0	2	1	0	10
54	0	0	1	0	0	0	1	0	0	1	0	0	3
Variance	1,848	1,697	1,437	1,880	1,474	1,726	0,846	1,008	1,006	1,058	1,072	2,204	

In the interest of verifying the reliability of the responses obtained by the survey, this study calculated the Cronbach's Alpha coefficient, as presented by Equation (1) (Leontitsis & Pagge, 2007):

$$\propto = \frac{K}{K-1}\left[1-\frac{\sum_i^K Vi}{Vt}\right] \qquad (1)$$

where:

K is the number of items (criteria);

Vi is the variance of each column;

Vt is the variance of the sum of each roll.

$$= \frac{12}{(12-1)}\left[1-\frac{17{,}257}{68{,}552}\right] =$$

$$\propto = 0.816$$

The result 0.816 obtained from Cronbach's Alpha reveals good internal consistency of the data. As presented by Gliem & Gliem (2003), values of Cronbach's Alpha over 0.7 are acceptable.

Thereafter, this analysis established the relations which actuate as drivers to strengths and weakness and identified potential technological associations which indicate the affinity level between the organisations and the proposed model (Storolli, 2020).

4.3. Identification of application barriers in MSMEs

4.3.1. Adherence results to the conceptual model

The matrix was built in Promethee as follows: the enterprises were numbered from 1 to 54 to keep their names confidential and each one received a colour referring to its sector, namely grey for industry, aqua for services, and red for commerce.

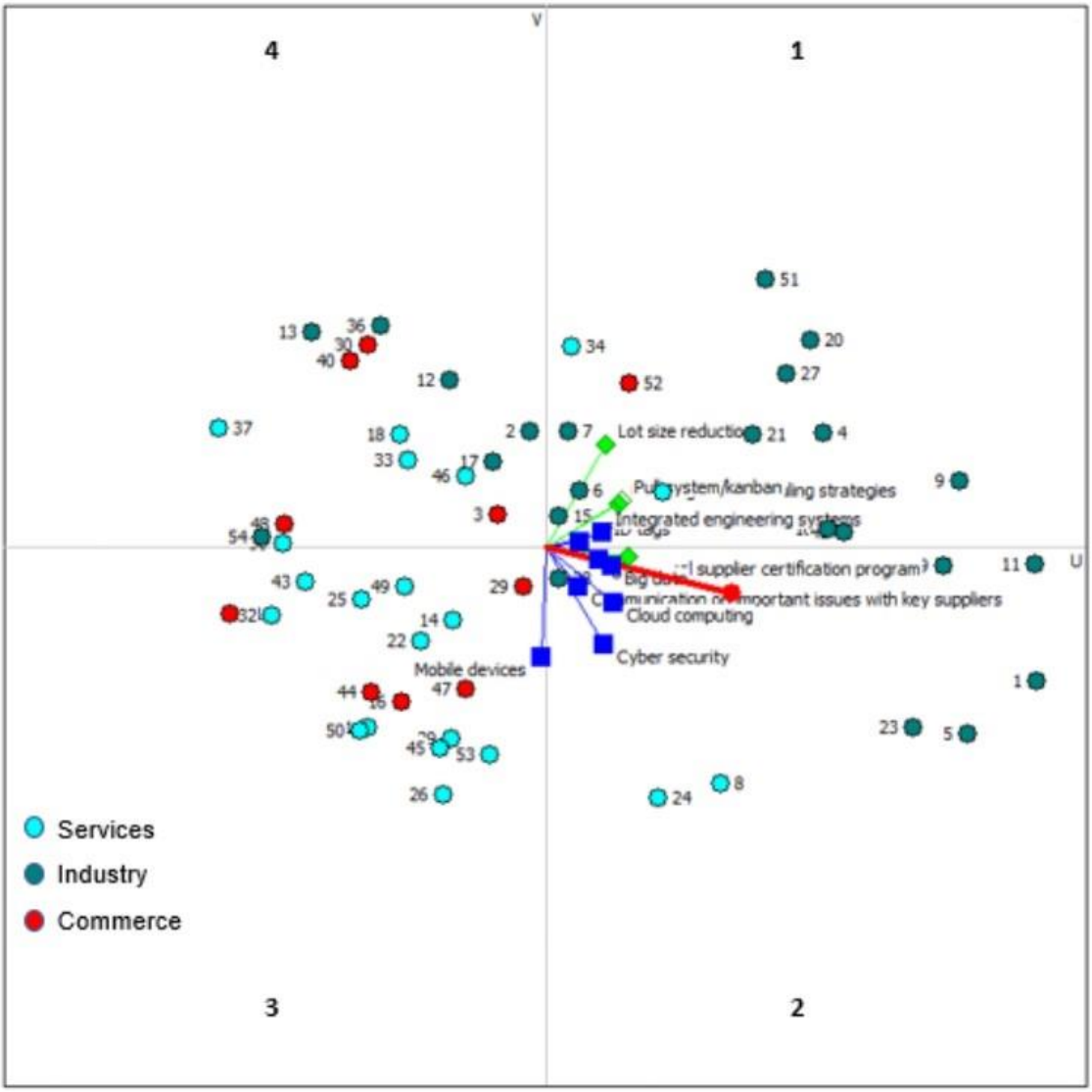
The criteria are the categories that refer to the 12 questions in the questionnaire, and the green ones represent those related to LPS, while the blue ones refer to I4.0.

The weights were defined based on the implementation level exposed by Tortorella, Narayanamurthy, et al. (2021), which refers to the categories defined for the questions. All criteria were settled as maximisation, since the higher their score, the better the performance. In addition, the usual preference function was chosen, since what interests us in this analysis is that if one criterion is higher than another, there is preference.

Figure 5 shows the Gaia Plan of this analysis. We can see that, according to the red axis, the eigenvector of best performance, enterprises 23, 5 and 1, which belong to the industries category, represent the best performances. Since they present a good performance in most of the chosen criteria, it means that they are more adherent and apt to the LA model developed.

Figure 5 Enterprises' performance by sector

Author

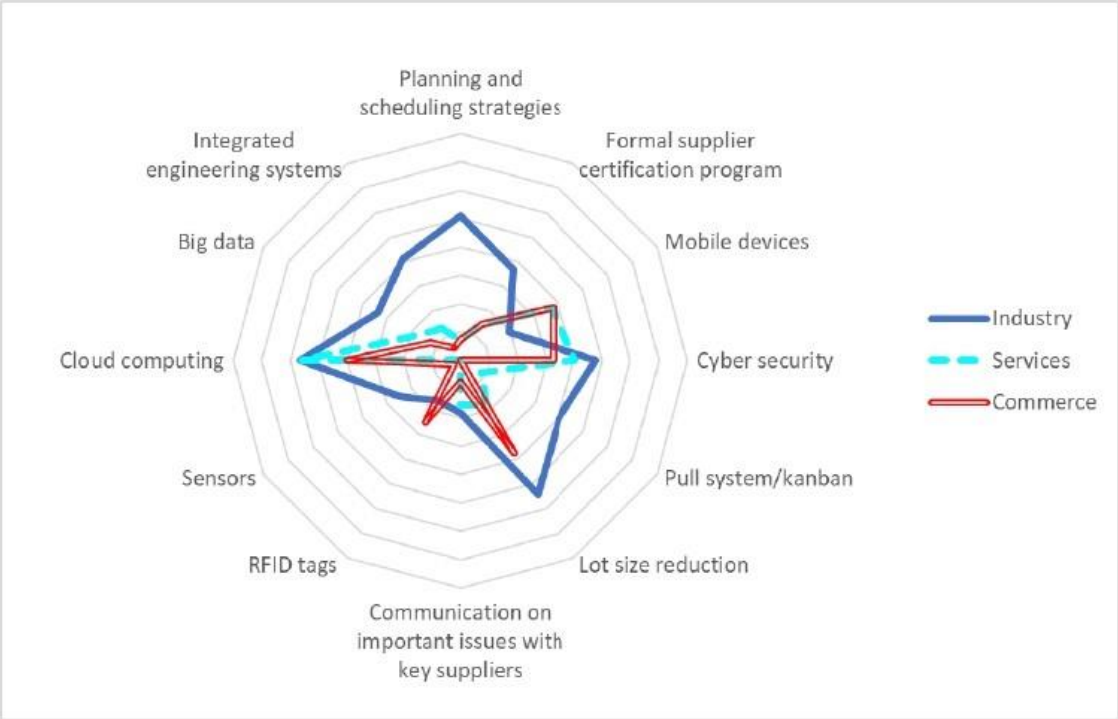


By considering the matter of level of adherence, quadrants 1 and 2 have the most adherent enterprises, with emphasis on the 2nd quadrant. In these, it is important to highlight the industry, which is extremely present, followed by the services sector, with a slightly smaller presence.

Quadrants 3 and 4 have the enterprises with the worst performance, i.e., those that are not yet ready for such an advanced technology model as LA. In these quadrants the services and commerce sectors are more frequent.

Figure 6 shows a set of radar chart analysis that compares each sector's results for each criterion.

Figure 6 Benchmarking by enterprise sector



Starting with the industry analysis, it is possible to observe that the industrial sector examined in this research has the most balanced performance, supporting the results of the Gaia Plan, where the best industry enterprises have a satisfactory performance in I4.0 and Lean.

Despite having close values in cloud computing to the industry sector, and mobile devices and cyber security as other strengths, the services sector does not have a well-balanced result. This can be explained because the services sector offers an intangible product, often linked to information and knowledge transmitted through data, it is valid that it seeks secure storage and protection means, such as those offered by cloud computing. This analysis, as well as the Gaia Plan, shows that it is important that enterprises in this segment seek to use Lean principles and further optimise their processes.

The commerce sector presents good performance only in cloud computing and lot size reduction, while the other criteria are very low. This can be explained by the fact that this sector needs good planning and forecasts throughout its chain, with data to schedule its sales and shipments, since it needs to be prepared to meet the demands at the right time.

4.3.2. Strengths and weaknesses by business segment

The next step of the methodology involves a comparative analysis by business segment. The list of segments is presented in Table 4, this assessment included the 10 segments which obtained at least 3 valid responses in the survey.

Table 4 Promethee Ranking by business segment

Rank	Segment	Phi	Phi+	Phi-
1	Automotive	0.8432	0.904	0.0608

Author

2	Metallurgical/Metal-mechanic	0.3241	0.6567	0.3326
3	Paper and cellulose	0.1997	0.5513	0.3516
4	Finance	0.1996	0.5277	0.3281
5	Graphic	-0.0163	0.428	0.4443
6	Consulting	-0.1994	0.3145	0.5138
7	Textile/Clothing/Apparel	-0.252	0.3686	0.6206
8	Advertising	-0.333	0.2362	0.5692
9	Cleaning	-0.3748	0.2626	0.6375
10	Electronics and IT	-0.3911	0.2001	0.5912

Other segments, such as healthcare, construction, energy, transport and education, also participated in the survey, however they did not enter to this specific ranking analysis, because of their low rates of answers.

The Promethee software generates outcomes presented as Phi, Phi+ and Phi- in order to compare alternatives and criteria. These Phi elements are denominated 'net outranking flow' and they can vary between -1 to 1. Values of Phi+ express how much an alternative is dominant over others, whereas on the opposite hand, Phi- indicates how much an alternative is dominated by others. The 'net outranking flow' value of certain alternative '(a)' is the balance between positive and negative factors, and it is calculated through the following equation:

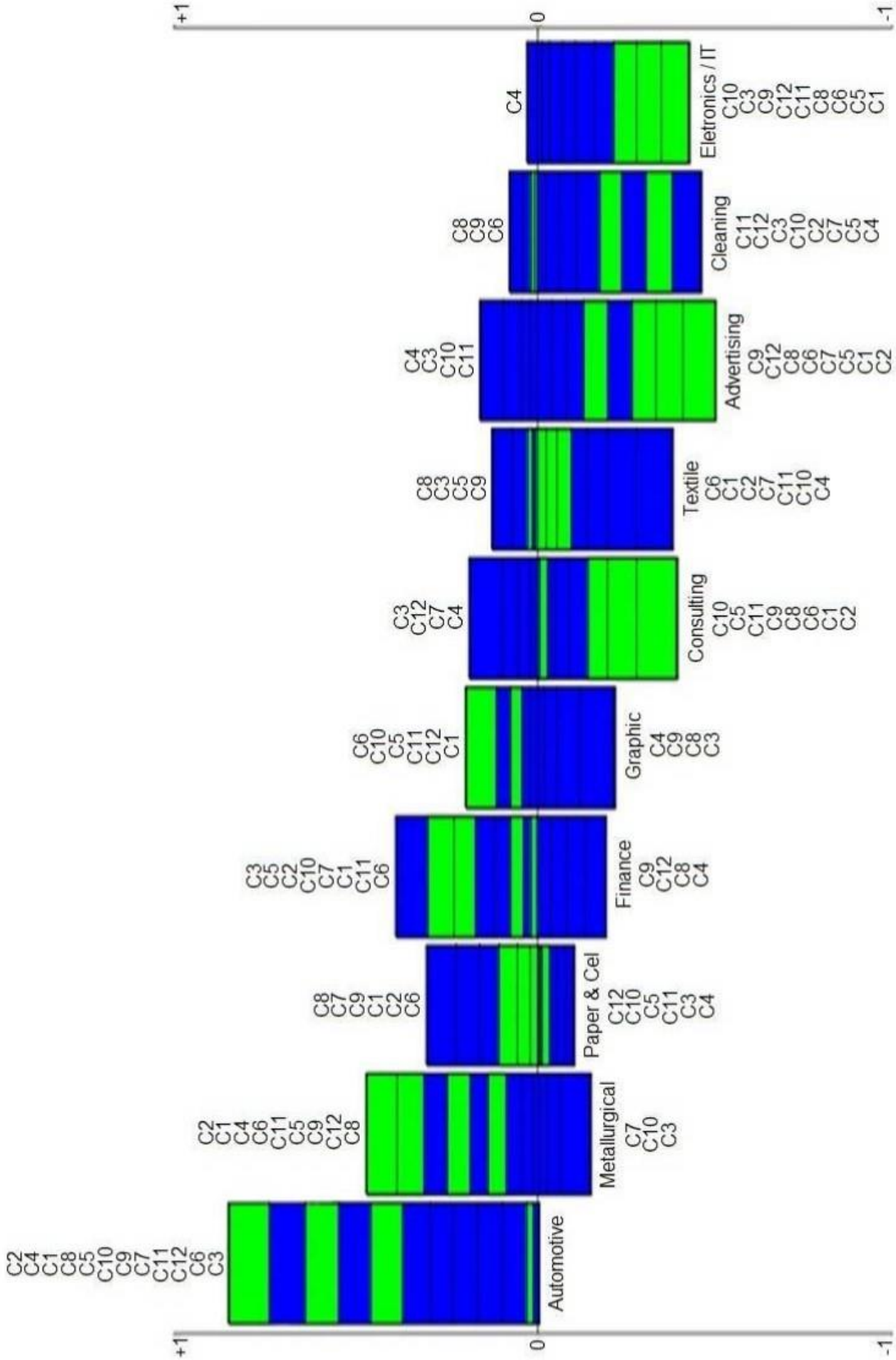
$$P_{hi}(a) = P_h^+(a) - |P_h^-(a)| \qquad (2)$$

The higher the value of Phi(a), the more adherent this alternative is, or even more advanced, with regard to the principles and technologies of the proposed JIT-Delivery model.

The specific technological aspects which comprise the 'net outranking flow' (Phi score) of all segments are presented, in a dissociated way, through the Promethee Rainbow, illustrated by Figure 7. This graphic shows which criteria represent strengths and weaknesses of each segment, where every fraction of the column indicates the contribution of the criteria to the final Phi score.

Fractions located in the positive side (superior) indicate strengths, that is, to the factors with higher levels of adherence to the proposed LA model. On the opposite side, fractions located in the negative side (inferior) of the graphic, indicate weaknesses of each segment, that is, to the less developed factors related to the model. Criteria featured in green represent lean production principles, while blue ones symbolise I4.0 technologies.

Figure 7 Technological aspects detailed through Promethee Rainbow



Promethee Rainbow displays the 10 enterprise segments from the higher ranking (left) to the lower ranking (right) according to the Promethee ranking.

Author

This analysis reveals that factors like 'formal supplier certification program (C2)', 'cyber security (C4)' and 'planning and scheduling strategies (C1)' are the ones that most favour the adherence of the top-ranking segments, indicating strengths of automotive and metal-mechanics enterprises, to the model. While the segments with worst performance, as textile, advertising, cleaning and electronics, demonstrate that the factors which most disfavour their performance, indicating possible weaknesses and opportunities for improvements, are 'planning and scheduling strategies (C1)', 'pull system/Kanban (C5)', 'cyber security (C4)' and 'lot size reductions (C6)'.

Strengths identified as differentials of the top-ranked, characterize 'challenges' for the other MSMEs to develop their service levels and competitiveness incorporating advanced management systems and tools that enable both, higher operational control and real-time communication to stakeholders' networks. Such tools can positively impact organisation flexibility, responsiveness to market changes, as well as assertiveness of decision making.

In addition to these, the implementation of key-suppliers selection and certification processes, developing parameters to elect and categorize them, was identified as a challenge for standardizing processes that can guide enterprises to better relationships, lowering lead-time and reducing inventory levels.

Cyber security conditions were mapped as another relevant aspect, thus, the development of this application might be a crucial challenge, since information technology is determinant in the current business context, in which case the implementation of security resources such as antivirus, firewalls, or consensus networks, like Blockchain, can reduce risks of this nature.

Besides these challenging factors, this research identified weaknesses and opportunities for improvement in basic processes for several segments of MSMEs. Among them, we emphasize the absence of electronic ERP systems, precarious manual controls for inventory management, as well as the absence of a systematic exchange of information and materials between production departments.

An additional finding is about the lean principles (green). The top five ranked segments present, predominantly, lean principles in the positive side of the graphic, indicating that such criteria have good adherence in this group of segments, contributing to their top ranking. In contrast, the five segments with lower global ranking present lean principles mainly in the negative side of the graphic, indicating low levels of adherence to those criteria. Such peculiarity suggests that the lean principles are the base for the implementation of a LA model.

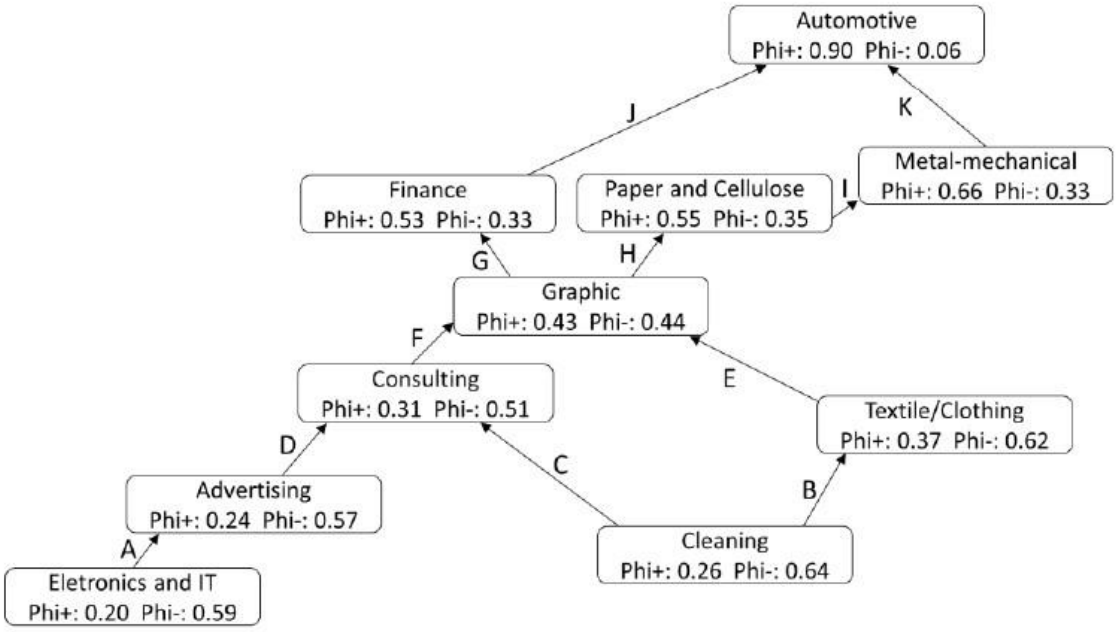
4.4. Organising a roadmap to implementation

In order to identify a feasible route to implement the Lean Automation JIT-Delivery process in MSMEs from developing countries, this study used the Promethee Network tool to analyse the lines of technological evolution of each business segment.

This analysis, based on the conceptual JIT-Delivery model, was compared to the framework proposed by Tortorella, Narayanamurthy, et al. (2021), as this framework provides specific guidance for the implementation of Lean Automation techniques and practices in three stages: Start-up, In-transition and Advanced.

Figure 8 demonstrates the results of Promethee Network, which presents the hierarchy of adherence of the Brazilian MSMEs to the conceptual model, and indicates which segments are related in their stages of technological evolution.

Figure 8 Relationship network of the technological evolution



Results clearly show that enterprises from the Automotive segment boast the most significant levels of adherence related to the proposed model. On the opposite side, it is possible to verify that the Cleaning, Advertising and Electronics segments present the lowest levels of adherence.

The connecting arrows indicate which segments adopt similar courses of technological evolution. The network analysis exposes 11 evolutionary lines (connector arrows), labelled by the characters: A, B, C, D, E, F, G, H, I, J and K.

For instance, the connecting arrow 'B' shows a similar evolution line between Cleaning and Textile companies, in addition to this, and based on the survey results, we can verify the technological gaps for Cleaning enterprises to evolve to the level of Textile, in this case they need develop in the use of 'Mobile Devices' and 'Pull System'.

Regarding the evolutionary line 'E', enterprises in the Textile segment presents a technological gap in the use of 'Big Data' and 'Cloud Computing' to evolve to the levels of the Graphic segment.

These 'technological gaps' of each connecting arrow can be considered as improvement opportunities for enterprises to advance in the implementation of the Lean Automation model.

Following this logic, Table 5 shows the technological gaps in each evolutionary line. The sequence of the analysis starts with the lowest connecting arrows (start-up stage) to the highest ones (advanced stage). This table also presents the LA implementation sequence proposed by the framework of (G. L. Tortorella, Narayanamurthy, et al., 2021).

Table 5 Technological gaps in each evolutionary line

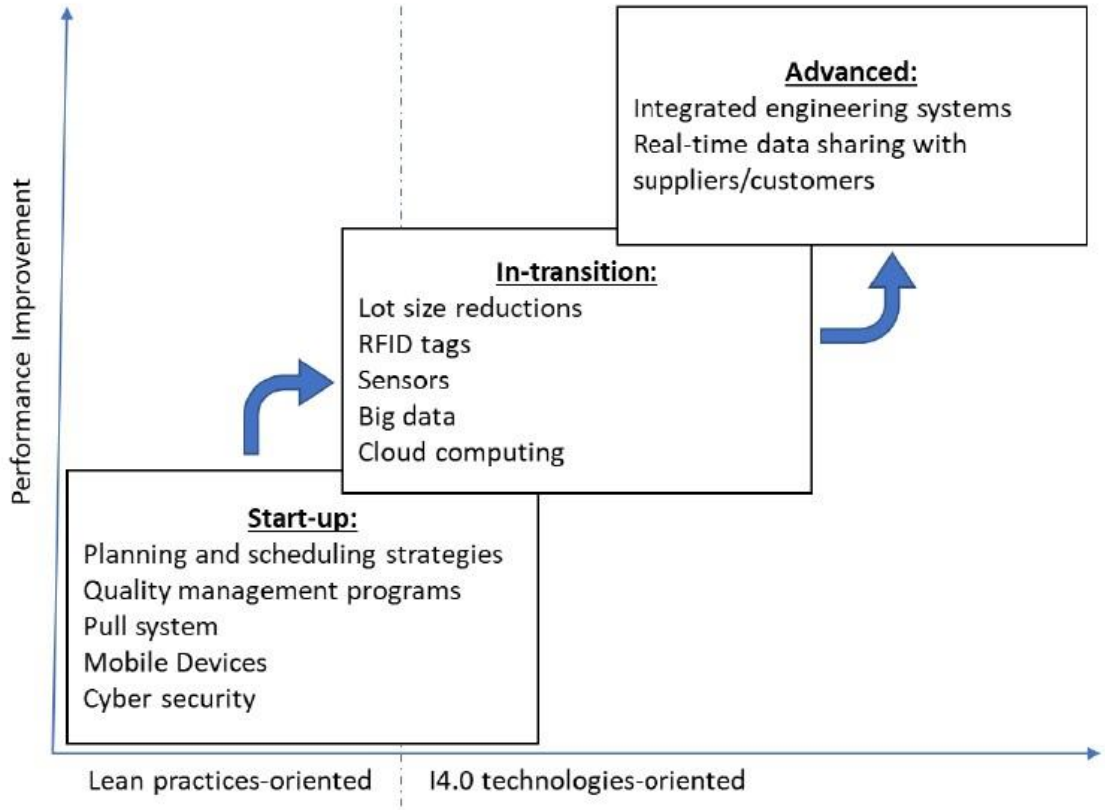
Stage	Technological gaps (Based on the conceptual model of this research)		Implementation sequence (Based on Tortorella, Narayanamurthy, et al. (2021))
	Evolutionary line	Principle/Technology Gap	Principle/Technology
Start-up	A	Big data	Planning and scheduling

Author

	B	Mobile Devices Pull System	strategies Quality management programs New process equipment/technologies (Mobile Devices, Cyber security)
	C	Cyber security Quality management programs	
	D	Quality management programs	
In-trasition	E	Big data Cloud Computing	Pull system Lot size reductions Real-time data sharing with suppliers/customers RFID tags at products Sensors for monitoring the production process
	F	Lot size reductions	
	G	Mobile Devices	
	H	RFID Tags Sensors	
	I	Big data Cyber security	
Advanced	J	RFID Tags Cyber security	Big Data Cloud computing system Integrated engineering systems
	K	Cloud Computing Real-time communication with key suppliers	

Finally, the framework proposed by Tortorella, Narayanamurthy, et al. (2021) was adapted, to MSMEs from emerging countries, considering the results presented by the conceptual model of this research. Figure 9 shows an organised sequence for adoption of the Lean Automation JIT-Delivery model in MSMEs from emerging countries.

Figure 9 Implementation roadmap to the Lean Automation JIT-Delivery model



Source: Adapted from Tortorella, Narayanamurthy, et al. (2021)

The Start-up stage indicates practices to be first adopted in a LA Just-In-Time Delivery implementation. Those fundamental criteria are defined by: 'Planning and schedule strategies', 'Quality management programs (Formal supplier certification program)', 'New process equipment/technologies (Cyber security and Mobile Devices)' and 'Pull system/Kanban'. This first stage should impact mainly in the internal processes' development, improving the inventory management, operational control and the information flow between different departments, such as PPC, Assembly line and Warehouse.

The next stage of the model implementation, named as In-Transition, proposes the use of the following higher technological criteria: 'Lot size reduction', 'RFID tags', 'Sensors', 'Cloud computing' and 'Big data'. Such implementation should provide not only a cyber-physical environment supporting all departments involved in the model, but also a real-time visualisation of materials in transport.

The final stage, labelled as Advanced, comprises the criteria for greater network integration, such as: 'Integrated engineering systems' and 'Real-time data sharing with suppliers/customers'. This implementation should provide a progressive integration with customers and suppliers' processes, resulting in the improvement of performance, transparency, and communication.

5 Discussion

In the competitive scenario faced by enterprises, the integration of consolidated manufacturing principles and innovative technologies can be a business efficiency differentiator. Thus, the goals of this study were to: explore research trends in the field of Lean Automation, identify the combinations of technological tools from Industry 4.0 and lean principles which have already been successfully implemented, evaluate the level of adherence of MSMEs from a developing country to LA, and organise a feasible roadmap to implement a LA model.

The association of LPS with I4.0 technologies is an evolving theme. The review of papers on this subject added to the survey analysis provide theoretical and practical contributions.

Firstly, this study revealed as the main successful applications of Lean Automation in MSMEs the following I4.0 technologies: mobile devices, cyber security, sensors, cloud computing, RFID and big data; in addition to the following lean principles: pull-principle, communication with key suppliers, integrated engineering systems, avoidance of waste, visualisation and standardisation.

Secondly, this study structured a conceptual model of the JIT-Delivery process, contributing to current and future researchers as a LA framework, which not only promotes an integration mechanism that connects different enterprises and departments, driving the supply chain to a collaborative production environment, but also supports agile sharing of information and activities, eliminating wastes, and promoting the automatic restocking of products in the correct time, quantity and destination.

Thirdly, this study used the proposed JIT-Delivery framework as a prototype to characterize the condition of MSMEs from emerging countries in relation to LA. This analysis was conducted through a survey involving 54 Brazilian enterprises from the industry, commerce and services sectors, and concluded that the industry sector is the

most likely to adopt the LA framework, as it had the best levels of adherence to the prototype, compared to the commerce and the services sectors.

This investigation covered 10 business segments to identify challenges and opportunities for improvement. It was found that segments with worst performance had low rates in concepts such as 'planning and scheduling', 'pull-system', 'lot size reductions' and 'cyber security'. It exposed a recurrent lack of organisational management structures, deficiencies in mapping and defining processes, low access to basic management and planning tools, unfamiliarity with methods and technologies, and scarcity of financial resources to carry out certification programs.

In addition to its theoretical contribution, our research provides managerial implications that may support MSMEs from emerging countries to improve efficiency and market competitiveness through the adoption of innovative technologies associated with lean production principles.

This study organised a 3 stages implementation roadmap for the JIT-Delivery model (Start-up, In-transition and Advanced), such results adds to the studies by Tortorella, Narayanamurthy, et al. (2021), as we focused exclusively on applying the most successful technologies to MSMEs in emerging countries, presenting the main differences in the last stage, 'Advanced', since in our roadmap this stage is specifically composed by the development in the integration and sharing of information along the supply chain.

The recommended pathway can be replicated for the implementation of other Lean Automation models in MSMEs from developing countries, following the logic of starting with the adoption of lean practices-oriented, then going through the adoption of I4.0 technologies-oriented, and later adopting the advanced integration with the stakeholders network.

This research found that if MSMEs from emerging countries implement the sequence initially suggested by the start-up stage, they can achieve reduced variability in their processes, better predictability of their supply chain, data protection and increased agility of responses to stakeholders, in addition to potential gains in assertiveness in decision-making, increased rate of action execution and increased operational control. As shown in the results, after establishing the initial phase implementations, such enterprises could progress to in-transition and advanced stages, until reaching the full implementation of the LA model.

6 Conclusions

It has been concluded that this study explored the research questions, supporting enterprises, managers and researchers to improve their understanding about the situation of MSMEs in developing countries regarding the combination of LPS factors with innovative information and communication technologies in resource management, waste reduction and transport optimisation.

The results demonstrated the main challenges and opportunities faced by MSMEs from emerging countries, and presented a feasible roadmap for the adoption of LA practices. This implementation guide focused on improving processes and knowledge, directing enterprises networks to reduce the technological deficit and improve their conditions of competitiveness against enterprises from markets with greater technological development.

In order to assess the applicability of the innovative LA concept in MSMEs from emerging countries, this study was limited to analysing the application of a specific JIT-Delivery model in Brazilian enterprises, mostly in countryside municipalities of the state of São Paulo.

We recommend that studies be conducted on the application of other LA models not only in different emerging markets, but also in the development of research involving additional innovative technologies such as 5G telecommunication, Blockchain, or even in the improvement of sustainable systems. Additionally, we recommend the development of applied research through case studies or simulation with similar models in order to quantify their effects.

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2.3 BLOCKCHAIN-BASED LEAN SUPPLY CHAIN: A SIMULATION APPROACH

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Resumo: Este artigo visa propor um modelo baseado nas tecnologias *Blockchain* e *cloud computing* como suporte a técnicas *lean* de produção para gestão da cadeia de suprimentos industrial, avaliando como a combinação dessas tecnologias proporciona melhorias de desempenho na cadeia. A revisão da literatura contextualiza o estado da arte em estudos relacionados à aplicação da tecnologia *Blockchain* à processos de produção *lean*, bem como, identifica lacunas de pesquisa neste campo. Este estudo simula uma arquitetura baseado na rede Hyperledger Fabric e em uma máquina virtual na nuvem, avaliando sua aplicabilidade e desempenho. A análise aborda aspectos *lean* identificados como lacunas de pesquisa, incluindo: integração de *stakeholders* na produção colaborativa de produtos customizados, condições de flexibilidade e adaptabilidade a variações de demanda, relacionamento coordenado de redes envolvendo PMEs, e comportamento de diversos *players* atuando de forma simultânea e consensual. O modelo proposto revela um conceito de compartilhamento de dados descentralizado e não-linear que demonstra a lógica de participação simultânea de todos os *players* envolvidos na cadeia de suprimentos. Esta arquitetura oferece uma solução de integração entre *stakeholders* para suporte a processos operacionais, promovendo *insights* a pesquisadores e especialistas na adoção de tecnologias da informação inovadoras, confiáveis e inclusivas para empresas de diferentes tamanhos e níveis de desenvolvimento tecnológico, com foco em produção enxuta, redução de custos e minimização de consumo de recursos. O modelo desenvolvido, que combina as tecnologias *Blockchain* e *cloud computing* aplicados a sistemas *lean* de produção, apresenta uma solução diferenciada no planejamento de sistemas de produção integrada, indicando o diferencial deste trabalho.

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BLOCKCHAIN-BASED LEAN SUPPLY CHAIN: A SIMULATION APPROACH

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This paper aims to propose a model based on blockchain and cloud computing technologies to support lean production techniques for industrial supply chain management, evaluating how the combination of these technologies provides improvement in the chain performance. The literature review contextualises the state of the art in studies related to the application of blockchain technology to lean manufacturing processes, as well as identifies research gaps in this field. Besides, this study models and simulates an architecture based on both the Hyperledger Fabric network and a virtual machine in the cloud environment, assessing its applicability and performance in the industrial supply chain. The analysis addresses lean aspects identified as research gaps, including: integration of stakeholders in the collaborative production of customised products, conditions of flexibility and adaptability to demand variations, coordinated relationship of networks involving SMEs, and behaviour of various players acting simultaneously and consensually. The proposed model reveals a decentralized and non-linear information sharing concept that demonstrates a logic of simultaneous participation of all players involved in the supply chain. The low costs and processing times identified in the simulation indicate the robustness of the system even in transactions involving a large number of companies and a large amount of data. This architecture offers an integration solution between stakeholders to support operational processes, providing insights for researchers and specialists in the adoption of innovative, reliable and inclusive information technologies for companies of different sizes or levels of development, with a focus on lean manufacturing, reduction in resource consumption and cost reduction. The developed model, which combines blockchain and cloud computing technologies applied to stages of lean production systems, presents a differentiated solution on the planning of integrated production systems, indicating the differential in this work.

Keywords: Blockchain; Cloud Computing; Supply Chain Management; Lean Production Systems; Lean Automation; Just-in-Time (JIT) Delivery.

1. Introduction

Over the last four decades, lean production systems have been researched and incorporated in different segments of the global economy, ranging from agribusiness, manufacturing, transport, construction, services and public organizations to finance, healthcare and education, among others (Bhamu and Sangwan, 2014; de Oliveira, Sousa and de Campos, 2019).

In general, such studies present or develop models that are able to optimise profits, reduce waste, reduce resource consumption, increase flexibility, increase streamlining, monitor production indicators, standardise company processes or offer innovative solutions that support sustainability, innovation and competitiveness (Novais, Maqueira Marín and Moyano-Fuentes, 2020; Piotrowicz, Ryciuk and Szymczak, 2021).

The modernization of production processes with the implementation of disruptive digital technologies has been studied in different settings and has been transforming industry, guiding the management and operation of activities in cyber-physical environments with high connectivity that integrate products, people and processes, typical of the fourth industrial revolution, also called Industry 4.0 (I4.0) (Dalenogare *et al.*, 2018; Morelli and Ignacio, 2021; Sordan *et al.*, 2021).

However, according to Langlotz and Aurich (2021), Pereira and Sachidananda (2021), Raji *et al.* (2021), Vlachos *et al.* (2021), Ferreira *et al.* (2022), Mahdavisharif, Cagliano and Rafele (2022) there are gaps on how to implement and integrate Industry 4.0 technologies into existing lean production systems. This perspective of innovative technologies with high connectivity associated with the principles of lean production is also addressed under the name of 'lean automation' (Kolberg, Knobloch and Zühlke, 2017; Tortorella *et al.*, 2020; Rossini *et al.*, 2021; Morelli *et al.*, 2022; Xiao *et al.*, 2022).

Researches on lean automation show the application of several modern technologies such as cloud computing, IoT, big data analytics, cyber security and blockchain as essential technology trends in both contributing to supply chain management (Sun *et al.*, 2019; Nazarov and Klarin, 2020; Pytel, Hofmann and Winkelmann, 2020; Alptekin *et al.*, 2021) and supporting lean principles such as lead time reduction, inventory minimization and just-in-time delivery, as well as cooperative planning and the use of information technologies (IT) in the integration of manufacturing activities (Gunasekaran *et al.*, 2019; Raji *et al.*, 2021; Upadhyay *et al.*, 2021; Zhao, Bal and Ma, 2021).

Barriers are still observed in the application of lean principles integrated with I4.0 technologies, indicating research opportunities in some areas of this field, such as simulation or applied research with multi-stakeholder integration models in globalised networks that improve reliability in information flow, and agility in sharing and analysing market demands, making it possible to trace and visualise data and materials in real time along the supply chain (Almeida, Albuquerque and Silva, 2018; Gunasekaran *et al.*, 2019; Nazarov and Klarin, 2020; Abideen *et al.*, 2021; Khanna *et al.*, 2021; Morelli and Ignacio, 2021; Raji *et al.*, 2021; Zhao, Bal and Ma, 2021; Udokwu *et al.*, 2022).

Studies related to the use of web-based platforms, cloud computing and blockchain technology are seen as research opportunities in the fields of network connectivity involving multiple stakeholders, cooperation between agents, process digitization and information management (Lenarduzzi *et al.*, 2018; Grube, Malik and Bilberg, 2019; Pytel, Hofmann and Winkelmann, 2020; Pérez *et al.*, 2020; Alptekin *et al.*, 2021; Tortorella,

Narayanamurthy and Thurer, 2021; Upadhyay *et al.*, 2021; Kapsoulis *et al.*, 2021; Aslam *et al.*, 2022; Behl *et al.*, 2022; Mahdavisharif, Cagliano and Rafele, 2022; Morelli *et al.*, 2022; Prasad, Rao and Lanka, 2022).

Given the above, this paper aims to evaluate how the application of blockchain and cloud computing technologies provides improved performance in the relationships between supply chain agents that involve production systems characterised by lean automation.

This main goal is complemented by the following specific objectives:

- to evaluate studies on the application of blockchain in lean production systems;
- to identify the most applied metrics to these models;
- to point out gaps or research opportunities for the use of such technology resources in these processes;
- to study the applicability and performance of the architecture in processes still few studied in the industrial supply chain, considering aspects of data reliability, transparency, process decentralization and scalability; and
- to simulate an architecture based on the blockchain network to support lean production techniques.

This system will be specifically applied to the innovative Just-in-Time (JIT) Delivery process, previously studied by Wagner, Herrmann and Thiede (2017) and Morelli *et al.*, (2022).

The integration of the blockchain network with lean production systems is still under development, so the model proposed in this work will serve as a basis and motivation for future research and developments on the subject in both academia and the practical/professional field.

Besides technological application, the study also contributes to the economic, social and environmental areas by disseminating innovative scientific knowledge that can be applied in countries with different levels of technology evolution and networks of companies of different sizes, including SMEs. This provides not only the development of responsible production and consumption models, and waste reduction, but also the standardization of practices and intelligence across the network of stakeholders, making the process more transparent, inclusive, reliable, and responsive.

The remainder of this paper is organised as follows: Section 2 describes the theoretical frameworks of the concepts of lean automation, blockchain and cloud computing and presents previous research on the combination of those concepts, describing approaches, results and research gaps. Section 3 describes the methodological approach used in this paper for both the systematic review on the subject and the mapping and development of a model applicable to the process through simulation. Section 4 presents the mapping of the stages, events and agents of the process of integration and information exchange between multiple stakeholders in the manufacturing industry, identified as a research gap, as well as the development and results of the simulation of this process in the Hyperledger Fabric blockchain network. Lastly, the results obtained will be analysed and discussed and conclusions and suggestions for future studies will be presented.

2. Theoretical Framework

Considering both the 'Lean Production Systems' and the 'Industry 4.0' philosophies, with their attributes of cost reduction and high connectivity, respectively, academic studies about the integration of these two models emerge, combining Lean principles with innovative technologies of Industry 4.0, originating the term Lean Automation (LA) which aims to increase production flexibility with agile information flows (Kolberg, Knobloch and Zühlke, 2017; Xiao *et al.*, 2022).

Piotrowicz, Ryciuk and Szymczak (2021) suggest a set of 08 aspects focusing on metrics of cost, productivity, inventory, quality, agility, lead time, service level, customer satisfaction, responsiveness, flexibility, information sharing, relationship, collaboration, and integration, as being the most relevant for measuring, monitoring, and evaluating the behaviour of Lean systems, as shown in table 1.

Table 1 - List of lean performance aspects and metrics. Source: Adapted from (Piotrowicz, Ryciuk and Szymczak, 2021).

Aspects	Metrics' detailing
Cost	Cost of goods, manufacturing cost, overhead cost, total logistic cost, price, profitability
Productivity	Organizational productivity, effectiveness of master production
Inventory management	Stock level, availability, inventory turnover rate
Quality / Service level	Product quality, high information and value-added contents, accuracy of forecasting techniques, customer satisfaction, customer effectiveness
Time / Responsiveness	Order cycle time, delivery lead time, total cycle time, velocity, quick response
Flexibility / Adaptability	Adaptiveness, customer/market sensitivity, customization, innovativeness/new product introduction, proactiveness
Information sharing	Communication, information integration, information accuracy, data accessibility.
Cooperation and integration	Buyer–suppliers relationship level, collaborative relationship coordination, process integration, network integration

Based on the theoretical studies of Gunasekaran *et al.* (2019), Nazarov and Klarin, (2020), Abideen *et al.* (2021), Khanna *et al.* (2021), Upadhyay *et al.* (2021), Mahdavisharif, Cagliano and Rafele (2022) and Sharma *et al.* (2022), as well as on the practical approaches of Lenarduzzi *et al.* (2018), Perboli, Musso and Rosano (2018), Barge *et al.* (2020); Kapsoulis *et al.* (2021) and Aslam *et al.* (2022), there are research opportunities in the field of lean production models simulation using innovative digital web-based platforms, cloud computing and Blockchain, in order to evaluate impacts and contributions of its aspects of high connectivity, integration and reliability on the performance of Lean chains.

Studies on the use of Cloud Computing technology in the environment of manufacturing machines and services characterise the concept of Cloud Manufacturing (CMfg), which was introduced in the literature by Li *et al.* (2010) as an innovative manufacturing platform model. This is based on a virtual network, which integrates different users, allowing remote access to manufacturing resources and services in order to

use them on demand, enabling the manufacture of customised products over the internet (Jiang *et al.*, 2016; Charro and Schaefer, 2018).

However, there are opportunities for improvement regarding the need for a reliable third party to record and distribute transactions among users, as well as the generation of contracts that define costs, terms and conditions of the business, since these are fully managed by buyers and suppliers, not relying on any cloud manufacturing platform capability to support participants (Barenji *et al.*, 2018; Kumar *et al.*, 2020; Morelli and Ignacio, 2021; Zhang *et al.*, 2021).

In the centralized concept of Cloud Manufacturing, the data flow and the relationship between users is generally linear, directly involving adjacent stakeholders, such as buyer and supplier, not allowing information distribution for visualisation or participation by other players further away from the chain (Hasan and Starly, 2020; Kaynak, Kaynak and Uygun, 2020; Amiri Ara, Paardenkooper and van Duin, 2022; Asante *et al.*, 2023).

Blockchain is a digital technology that allows data management involving a network of users, combining information security mechanisms through cryptography, checking, validation, recording and distribution of transactions. This technology emerged from the publication of Nakamoto (2008), who presented the logic of applying Blockchain technology to an electronic payment system, allowing the transfer of financial resources from one person to another, without the need for a financial institution as an intermediary.

Blockchain mechanism has at its essence the technology of distributed ledger, which enables a network of users to access, verify and approve transactions and information contained in such records. Transactions are recorded chronologically in interconnected blocks, generating a chain which is permanently stored on the Blockchain network (Queiroz, Telles and Bonilla, 2019; Zhang *et al.*, 2021; Lai *et al.*, 2023).

In addition to the financial field of cryptocurrencies, the immutable characteristics of recording and sharing data of Blockchain technology, have been applied to other economy sectors, which involve the negotiation or exchange of information between partners, eliminating the need for a third party to guarantee transactions reliability (Kshetri, 2018; Queiroz, Telles and Bonilla, 2019; Hasan and Starly, 2020). Following this trend, researchers have studied applications of blockchain technology to support Lean production systems.

Among several lean automation application models, some academic studies explore the use of blockchain technology to support lean production principles, evaluating the benefits and challenges of using it, whether through case studies, simulations, surveys or systematic reviews. Such studies present performance impacts at strategic, tactical and operational levels, evaluating aspects related to innovation, product development, value chain, manufacturing systems, inventory control, material flow, information flow, resource allocation, supply network integration and chain disruption risks.

Regarding the application of the blockchain approach to lean process management, service sectors such as construction (Dakhli, Lafhaj and Mossman, 2019; Pattini, Di Giuda and Tagliabue, 2020; Perera *et al.*, 2021), finance (Soleymani and Paquet, 2020; Cai *et al.*, 2021; Sarwar *et al.*, 2021), transport (Li, Zhu and Lin, 2019) and education (Sivakumar and Chawla, 2022) evaluate aspects of cost reduction, reduction of events that do not generate customer value and failure reduction, in addition to integration with ERP systems,

increased cooperation between players, process management and automation of payment systems.

The sectors of food (Perboli, Musso and Rosano, 2018; Barge *et al.*, 2020; Sharma *et al.*, 2022), agriculture (Nayal *et al.*, 2021), energy (Sun *et al.*, 2019), oil and gas (Aslam *et al.*, 2022; Zhao *et al.*, 2022), and healthcare (Narendra Kumar Rao, Bhaskar Kumar Rao and Vellingiri, 2019; Faruk *et al.*, 2021; Wasim Ahmad *et al.*, 2022) assess how blockchain technology can improve quality management and agility, mitigating disruption risks of essential chains, improving sustainable aspects and combining its application with other technologies enabled by Industry 4.0, such as cloud computing, RFID and IoT.

High technology development industries such as aerospace (Raju, Ravichandran and Khadri, 2018), automotive (electric and traditional) (Alptekin *et al.*, 2021; Upadhyay *et al.*, 2021), advanced manufacturing (Gambhire, Gujar and Pathak, 2018) and software development (Almeida, Albuquerque and Silva, 2018; Lenarduzzi *et al.*, 2018; Nayaka and Lal, 2022) have been studying blockchain technology opportunities in the development of their lean processes to support flexible meeting of demand for customised products, cooperative relationship between stakeholders and the search for greater streamlining in these emerging business models.

Research by Behl *et al.* (2022), Mahdavisharif, Cagliano and Rafele (2022), Prasad, Rao and Lanka (2022) and Chen (2023) addresses the retail and manufacturing sectors in heterogeneous supply chains that involve a large number of stakeholders in different markets, with countries at different levels of technology development and companies of different sizes, such as large, small and medium-sized companies. Potential for improving performance and barriers to the use of blockchain technology is highlighted in aspects related to sustainability, process digitization, lead time, inventory management, productivity and information sharing.

Other academic studies that investigate complex supply chains compare the performance of lean aspects in systems with and without the use of blockchain, cloud computing and machine learning technologies, characterizing smart manufacturing and generating more value for chain participants (Sturm *et al.*, 2018; Pytel, Hofmann and Winkelmann, 2020; Abideen *et al.*, 2021; Kapsoulis *et al.*, 2021; Xiong *et al.*, 2021; Zhao, Bal and Ma, 2021; Udokwu *et al.*, 2022).

Some of those articles report quantitative gains related to lean metrics. According to Dakhli, Lafhaj and Mossman (2019) this technology can generate reductions of 8.3% in total operating costs. The study by Perera *et al.* (2021) compared several blockchain platforms and highlighted Hyperledger Fabric as having the lowest cost in system implementation and maintenance. In the model studied by Perboli, Musso and Rosano, (2018), smart contracts contribute to supply chain productivity, processing data that involve the daily tracking of 1,000,000 food products, while the model presented by (Sarwar *et al.*, 2021) is able to process over 400 records per second in ERP systems. Zhao, Bal and Ma (2021) shows inventory reductions of 30% and improvement in meeting customer demand, from 94% to 99%, following the implementation of the blockchain-based network. In the prototype for shared transport of people and/or products presented by Li, Zhu and Lin (2019),the system based on blockchain technology improves responsiveness to service consumers, as this specific innovative system takes only 32ms to generate transport availability replies.

In addition to the aforementioned gains, several studies on the use of blockchain associated with lean production systems also point to barriers in the application of Blockchain technology and possible research gaps.

Potential barriers are identified in the studies by Perboli, Musso and Rosano (2018), Zhao, Bal and Ma (2021), Mahdavisharif, Cagliano and Rafele (2022), which reported challenges in communication and information sharing in a multi-stakeholder network, since companies may have different requirements and goals. The studies by Pattini, Di Giuda and Tagliabue (2020), Behl *et al.* (2022) and Sharma *et al.* (2022) stress that there are study gaps and opportunities regarding the cooperative relationship between multiple suppliers of products or services. Alptekin *et al.* (2021), Prasad, Rao and Lanka (2022) address blockchain technology applied to the management of cooperative networks of SMEs characterised by an integrated network or microfactories, suggesting that feasibility studies be carried out on the implementation and use of blockchain in these cooperative company networks to determine how to break down technology barriers to system integration (Pytel, Hofmann and Winkelmann, 2020; Abideen *et al.*, 2021; Alptekin *et al.*, 2021; Upadhyay *et al.*, 2021; Prasad, Rao and Lanka, 2022).

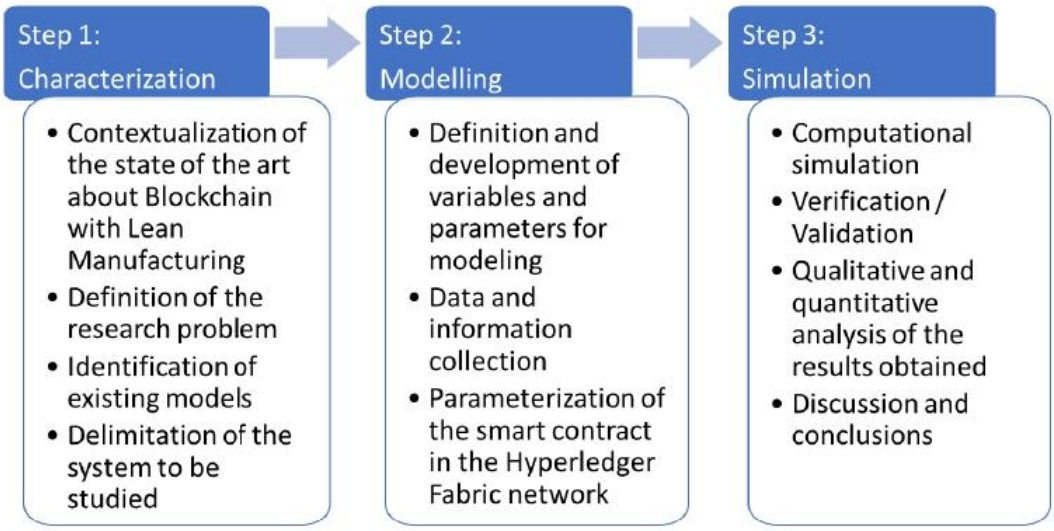
3. Material and method

According to the academic articles on innovative systems involving lean automation and blockchain, presented in section '2. Theoretical Framework', there are research opportunities on the development of lean manufacturing models using modern technologies enabled by Industry 4.0, such as cloud computing and blockchain, in the integration of multi-stakeholder chains (Lenarduzzi *et al.*, 2018; Perboli, Musso and Rosano, 2018; Núñez-Merino *et al.*, 2020; Pérez *et al.*, 2020; Tortorella, Narayanamurthy and Thurer, 2021; Upadhyay *et al.*, 2021; Zheng *et al.*, 2021; Kapsoulis *et al.*, 2021; Raji *et al.*, 2021; Behl *et al.*, 2022; Mahdavisharif, Cagliano and Rafele, 2022; Morelli *et al.*, 2022; Chen, 2023).

Therefore, this research paper explores the application of these technologies to support lean production techniques, evaluating how the combination of cloud computing and blockchain provide improvement in the performance of events and relationships between agents in a just-in-time (JIT) delivery process, previously studied by Wagner, Herrmann and Thiede (2017) and Morelli *et al.* (2022). The research methodology involves three steps: (i) Characterization, (ii) Modelling and (iii) Simulation. Its flowchart is illustrated in Figure 1 and detailed below:

(1) **Characterization** – This paper undertakes a literature search in the Scopus and Web of Science databases following the PRISMA protocol for systematic reviews (Núñez-Merino *et al.*, 2020; Castro and Ferreira, 2023). The search criteria are analysed for the terms '((blockchain) AND (lean))' present in the titles, abstracts and keywords of

Figure 1 - Research design flowchart. Source: Adapted from (Beiler *et al.*, 2020; Perera *et al.*, 2021; Piotrowicz, Ryciuk and Szymczak, 2021; Gao *et al.*, 2022).



articles published in scientific journals and conference papers. Such a search provides key material for contextualization of the state of the art of scientific productions that simultaneously address the topics of blockchain and lean.

Next, this study analyses and stratifies the selected sample of articles, not only identifying the papers that present applied simulation models or case studies, and the lean production performance metrics addressed by each of those existing models, but also determining the metrics to be considered in the JIT delivery model to be studied. The determination of lean performance indicators and metrics verified in the systematic review follows the framework proposed by Piotrowicz, Ryciuk and Szymczak (2021).

(2) **Modelling** – Modelling is developed based on the delimitation of the performance metrics and indicators selected in the previous step and also in the stages and events of the supply chain addressed in the JIT delivery process. These steps are detailed and adapted from previously developed related academic models to identify the decision variables and modelling parameters, thus making it possible to develop and propose the application of blockchain technology and its smart contracts to the indicated process.

This model is translated into the computational language of the blockchain network through smart contracts on the Hyperledger Fabric® platform, which enable the simulation of processes and, consequently, the analysis of aspects related to transactions, demand for computational resources, processing responsiveness and access to the execution codes of the contracts (Bharathan *et al.*, 2018; Perera *et al.*, 2021; Nodehi *et al.*, 2022).

(3) **Simulation** – Lastly, simulation of the process on the blockchain Hyperledger Fabric network provides results that represent the prediction of the application of the model in a real environment, generating information for the qualitative and quantitative analysis of the results obtained and identifying potential gains of and risks to the project (Gao *et al.*, 2022).

For interaction with the smart contract and execution of the transaction routine, this model uses the Postman application, an API Client that makes it possible to send and receive data on the Hyperledger Fabric network, such as inputting function parameters and creating and forwarding orders. The transaction costs of the model are evaluated in this study by considering the use of a virtual machine on the Google Cloud platform (Posey *et al.*, 2019).

Stakeholder information for application in the software in a simulation environment is based on the web interface and databases of USINPAGE (www.usinpage.com), a Brazilian startup that implements technology solutions for the manufacturing supply chain. These data are partially presented, complying with confidentiality standards.

This study explores and discusses the application of a smart contract in the blockchain network to support lean production techniques, regarding the following aspects: transaction registration standard, ledger distribution model, information accessibility, data transparency, traceability and transcription operating costs.

4. Development and results

4.1. *Contextualizing the state of the art*

To contextualise the state of the art in studies related to the application of blockchain technology to lean production processes, as well as identify the performance metrics applied to the models and possible research gaps in this field, the literature review carried out in the Web of Science and Scopus databases selects articles and review papers in English published in scientific journals or conferences.

Figure 2 shows the systematic review process, providing details on the search tools and analyses of the papers related to the combination of the topics of lean and blockchain.

The search string used is '((blockchain) AND (lean))' restricted to titles, abstracts and keywords, in order to evaluate the different practical and theoretical approaches involving the combination of the topics of lean and blockchain previously published in scientific journals and conferences.

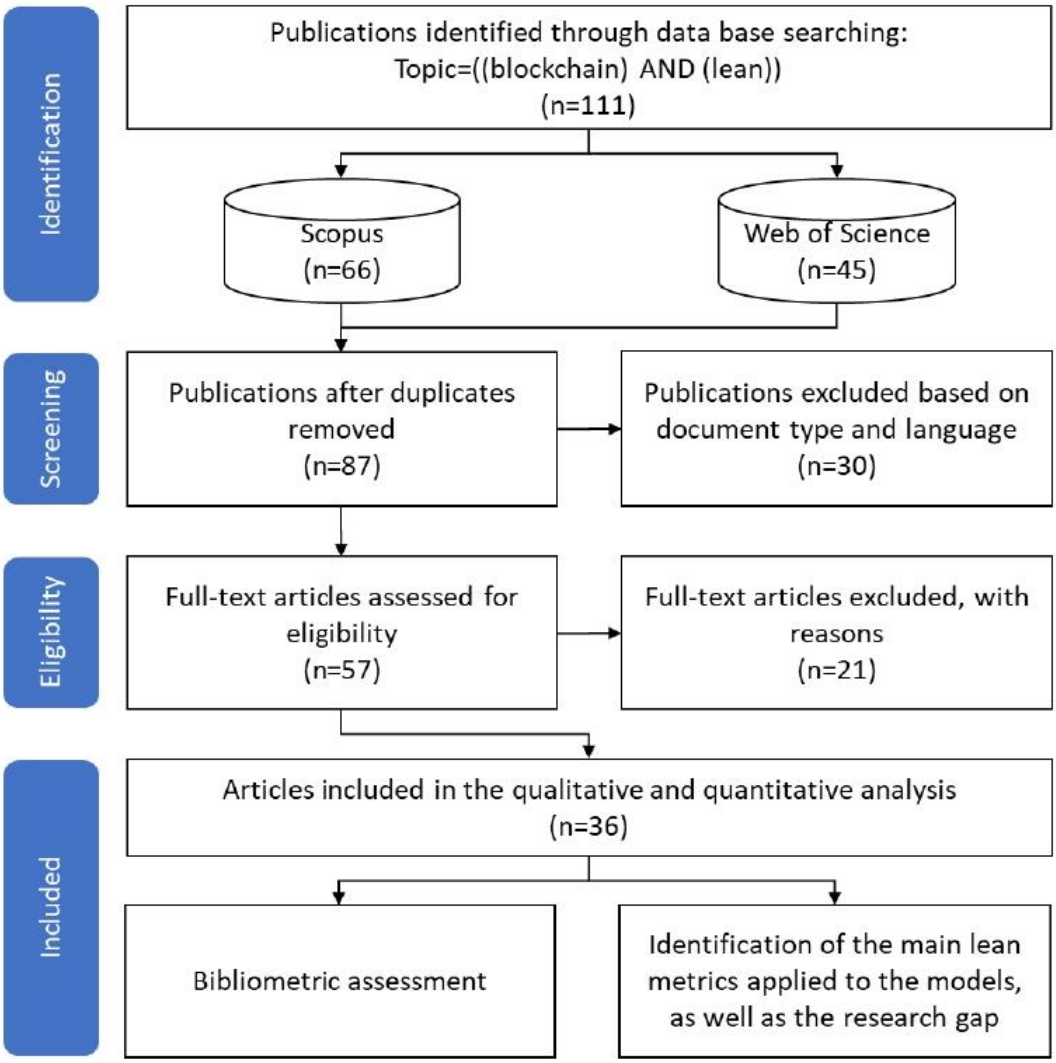
This study initially identifies 111 publications in the databases, 66 in Scopus and 45 in Web of Science. Duplicates are eliminated in the screening stage, resulting in a set of 87 publications from both databases.

Next, publications classified as book chapters and reports and publications in languages other than English are eliminated, resulting in a set of 57 articles and conference papers to be evaluated in full. Finally, 21 articles are excluded for not presenting studies related to the relationship between blockchain and lean production principles.

Thus, 36 articles related to the combination of the topics of blockchain and lean are selected for analysis, in which various approaches are identified, from systematic reviews, meta-analyses and proposals for theoretical frameworks to practical studies drawing on

case studies and system simulations. The content of these articles is summarised in sub-section '2.4. Related studies'.

Figure 2 - Systematic review process. Source: Adapted from (Castro and Ferreira, 2023).



4.1.1. Bibliometric analysis

A bibliometric evaluation of the sample of 36 articles is undertaken to identify the annual trend of these publications, the most influential articles and authors and the economic sectors or fields of research addressed in the studies. Lastly, this review proposes to identify the main lean performance metrics applied to models previously studied in the literature, indicating the research gaps to be considered in the modelling and simulation of an innovative lean automation process.

Figure 3 presents the annual publications related to the intersection of the topics of blockchain and lean, revealing a growing trend of publications on this subject and suggesting an increase in its relevance in both academia and industry. The exponential trend line is generated using Microsoft Excel.

Figure 3 - Annual publications related to the intersection of blockchain and lean.

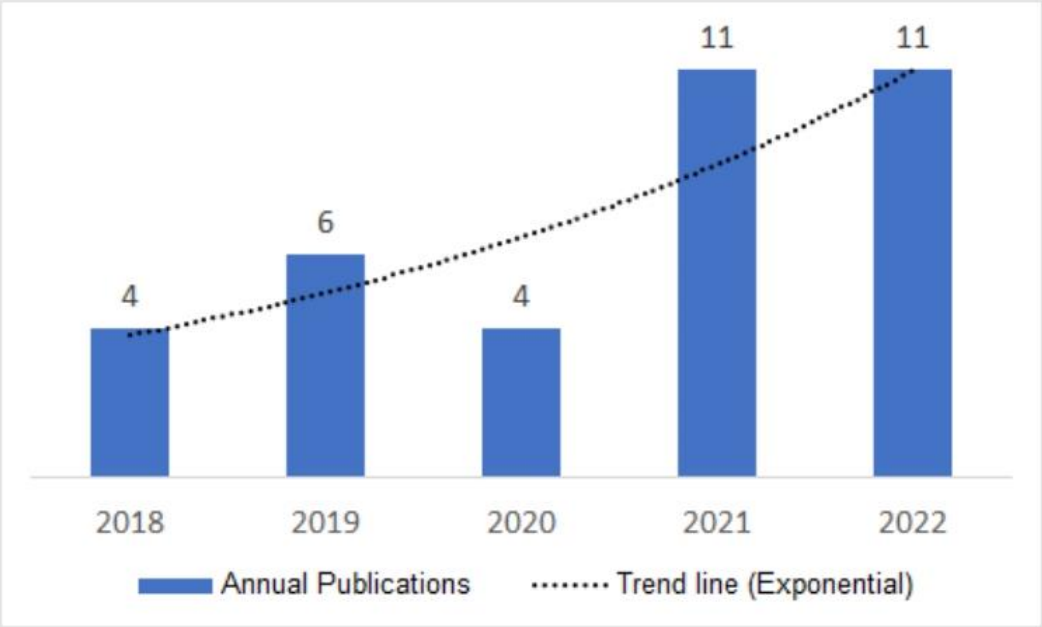


Table 2 features the top 10 most influential articles and authors in this field ranked by number of citations, indicating their respective journals and keywords.

Figure 4 shows the economic sectors or research fields addressed in all 36 articles of this systematic review, indicating that several of them such as manufacturing, healthcare, food, construction, finance, software development, oil and gas and automotive, among others, express interest in the development and research of the use of blockchain technology to support the lean production system.

Table 2 - Top ranked 10 most cited articles.

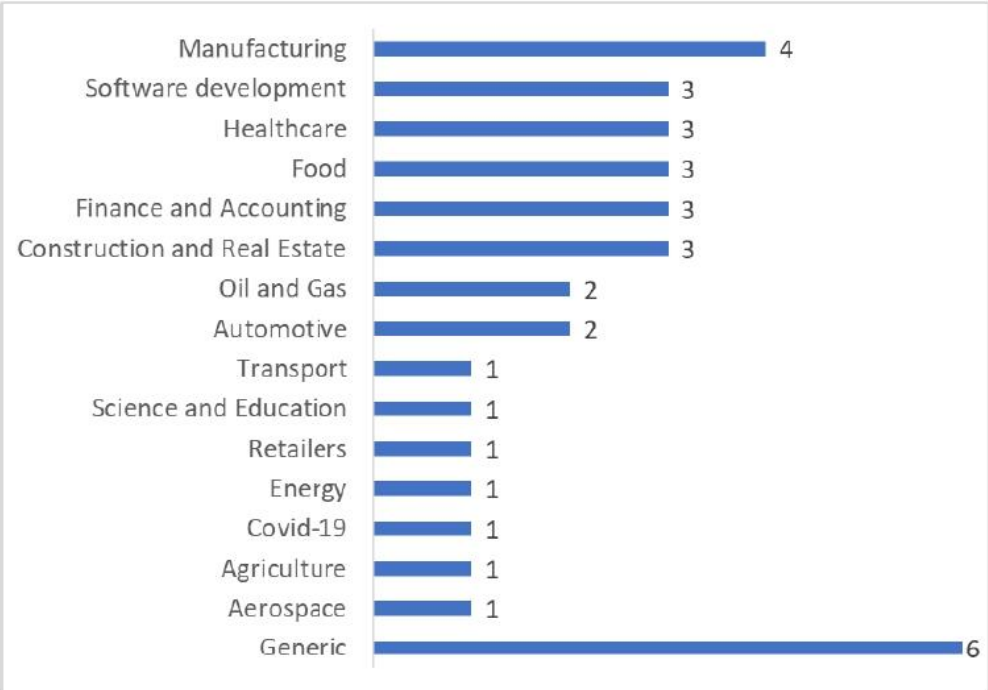
Rank	Citations	Authors	Article Title	Source Title	Author Keywords
1	290	Perboli, G; Musso, S; Rosano, M (2018)	Blockchain in Logistics and Supply Chain: A Lean Approach for Designing Real-World Use Cases	IEEE ACCESS	Blockchain; hyperledger; supply chain
2	126	Li, M; Zhu, LH; Lin, XD (2019)	Efficient and Privacy-Preserving Carpooling Using Blockchain-Assisted Vehicular Fog Computing	IEEE INTERNET OF THINGS JOURNAL	Blockchain; carpooling; fog computing; security and privacy; user matching
3	54	Dakhli, Z; Lafhaj, Z; Mossman, A (2019)	The Potential of Blockchain in Building Construction	BUILDINGS	blockchain; construction; BIM; transactional costs; lean construction
4	37	Soleymani, F; Paquet, E (2020)	Financial portfolio optimization with online deep reinforcement learning and restricted stacked autoencoder-DeepBreath	EXPERT SYSTEMS WITH APPLICATIONS	Portfolio management; Deep reinforcement learning; Restricted stacked autoencoder; Online leaning Settlement risk; Blockchain
5	29	Xiong, YC; Lam, HKS; Kumar, A;	The mitigating role of blockchain-enabled supply	INTERNATIONAL JOURNAL OF	Blockchain; Supply chain management; COVID-19;

		Ngai, EWT; Xiu, CY; Wang, XY (2021)	chains during the COVID-19 pandemic	OPERATIONS & PRODUCTION MANAGEMENT	Event study; Abnormal stocl returns; Contingency theory
6	28	Upadhyay, A; Ayodele, JO; Kumar, A; Garza-Reyes, JÁ (2021)	A review of challenges and opportunities of blockchain adoption for operational excellence in the UK automotive industry	JOURNAL OF GLOBAL OPERATIONS AND STRATEGIC SOURCING	Qualitative; Opportunities; Blockchain; Operational excellence; Management challenges; Technological; Opportunities of blockchain adoption
7	26	Sharma, M; Joshi, S; Luthra, S; Kumar, A (2022)	Managing disruptions and risks amidst COVID-19 outbreaks: role of blockchain technology in developing resilient food supply chains	OPERATIONS MANAGEMENT RESEARCH	Blockchain Technology (BC T); Disruption; Food Supply chains (FSCs); Resilient strategies; FAHP; WASPAS
8	25	Sturm, C; Szalanczi, J; Schönig, S; Jablonski, S (2019	A Lean Architecture for Blockchain Based Decentralized Process Execution	Lecture Notes in Business Information Processing	Blockchain; Business process management; Choreography processes; Collaborative process management; Process execution
9	21	Nayal, K; Raut, RD; Narkhede, BE Priyadarshinee, P; Panchal, GB; Gedam, VV (2021)	Antecedents for blockchain technology-enabled sustainable agriculture supply chain	ANNALS OF OPERATIONS RESEARCH	Blockchain technology (BLCT); Sustainable supply chain performance (SSCP); Agricultural-food supply chain (ASC); Structural equation modeling (SEM)
10	17	Abideen, AZ; Sundram, VPK; Pyeman, J; Othman AK; Sorooshian, S (2021)	Digital Twin Integrated Reinforced Learning in Supply Chain and Logistics	LOGISTICS-BASEI	digital twin; data-driven technology; lean manufacturing; supply chain 4; 0; reinforced learning; simulation modelling; prescriptive analysis; systematic review

4.1.2. Lean performance metrics used in blockchain models

Next, this paper classifies the articles that feature applied simulation models, case studies or theoretical frameworks, and then analyses and stratifies this sample, identifying the lean

Figure 4 - Economic sectors or research fields addressed.



production performance metrics addressed by each of those existing models. It also determines the metrics to be considered in the JIT delivery model to be studied.

Table 3 lists the 29 articles from the sample classified by the systematic review that address lean metrics in their studies.

Table 3 - Lean metrics addressed by the studies.

	Cost	Productivity	Inventory management	Quality / Service level	Time / Responsiveness	Flexibility / Adaptability	Information sharing	Cooperation and integration
(Sturm *et al.*, 2018)	X							X
(Prasad, Rao and Lanka, 2022)	X	X	X					
(Behl *et al.*, 2022)							X	X
(Narendra Kumar Rao, Bhaskar Kumar Rao and Vellingiri, 2019)		X		X			X	
(Pattini, Di Giuda and Tagliabue, 2020)								X
(Lenarduzzi *et al.*, 2018)	X							
(Perboli, Musso and Rosano, 2018)	X	X	X				X	
(Aslam *et al.*, 2022)			X		X			
(Perera *et al.*, 2021)	X							
(Zhao, Bal and Ma, 2021)			X	X	X	X	X	
(Sarwar *et al.*, 2021)	X	X		X			X	
(Sivakumar and Chawla, 2022)		X		X				
(Chen, 2023)		X			X			X
(Li, Zhu and Lin, 2019	X				X			
(Soleymani and Paquet, 2020)					X			
(Wasim Ahmad *et al.*, 2022)				X				
(Mahdavisharif, Cagliano and Rafele, 2022)			X				X	
(Sun *et al.*, 2019)		X			X			
(Sharma *et al.*, 2022)	X		X		X	X	X	X
(Udokwu *et al.*, 2022)	X					X		
(Barge *et al.*, 2020)				X	X			

(Kapsoulis *et al.*, 2021)				X				
(Zhao *et al.*, 2022)		X		X				
(Nayaka and Lal, 2022)	X							
(Alptekin *et al.*, 2021)								X
(Xiong *et al.*, 2021)			X			X		
(Dakhli, Lafhaj and Mossman, 2019)	X			X				
(Faruk *et al.*, 2021)								
(Pytel, Hofmann and Winkelmann, 2020)				X				
TOTAL	11	8	7	10	8	4	7	6

Metrics related to costs are addressed in 11 articles on the list, considering system development, implementation and maintenance costs (Perboli, Musso and Rosano, 2018; Perera *et al.*, 2021; Prasad, Rao and Lanka, 2022), reduced production, operation and logistics costs (Dakhli, Lafhaj and Mossman, 2019; Sarwar *et al.*, 2021; Zhao, Bal and Ma, 2021; Nayaka and Lal, 2022; Sharma *et al.*, 2022; Udokwu *et al.*, 2022), and computational costs of transactions in the blockchain network (Sturm *et al.*, 2018; Li, Zhu and Lin, 2019), which are expressed by the authors in units of 'seconds (s)' or Ether. It is shown that blockchain characteristics contribute to reducing costs by eliminating operational redundancies in the auditing and checking of data and records (Perboli, Musso and Rosano, 2018; Li, Zhu and Lin, 2019; Nayaka and Lal, 2022; Sharma *et al.*, 2022), as well as by improving operational visibility (Zhao, Bal and Ma, 2021).

Productivity indicators are addressed by eight of the articles, which identify gains in production control (Narendra Kumar Rao, Bhaskar Kumar Rao and Vellingiri, 2019; Sun *et al.*, 2019; Sarwar *et al.*, 2021; Zhao *et al.*, 2022), supply chain management (Perboli, Musso and Rosano, 2018; Sivakumar and Chawla, 2022), reduced consumption focused on sustainability (Prasad, Rao and Lanka, 2022; Chen, 2023), and effectiveness of electronic payments methods in business (Sarwar *et al.*, 2021).

Inventory management is addressed by seven articles, considering gains in inventory control by viewing real-time data and increased availability by facilitating negotiation with alternative suppliers, assisting in the decision-making process (Perboli, Musso and Rosano, 2018; Aslam *et al.*, 2022; Sharma *et al.*, 2022) and improving operational visibility among supply chain stakeholders thanks to blockchain ledger distribution capabilities (Xiong *et al.*, 2021; Zhao, Bal and Ma, 2021; Mahdavisharif, Cagliano and Rafele, 2022; Prasad, Rao and Lanka, 2022).

Metrics related to quality and level of service are addressed in 10 articles on the list, considering quality gains in terms of data and information recording (Narendra Kumar Rao, Bhaskar Kumar Rao and Vellingiri, 2019; Pytel, Hofmann and Winkelmann, 2020; Kapsoulis *et al.*, 2021; Sarwar *et al.*, 2021; Zhao *et al.*, 2022), as well as improved service levels by increasing operational visibility among stakeholders (Zhao, Bal and Ma, 2021; Sivakumar and Chawla, 2022), visibility in the transport of products (Barge *et al.*, 2020)

and reduction of efforts that do not generate customer value (Dakhli, Lafhaj and Mossman, 2019; Wasim Ahmad *et al.*, 2022).

Time and responsiveness criteria are addressed in eight articles, with reduced time in various stages of the supply chain such as transportation (Li, Zhu and Lin, 2019; Barge *et al.*, 2020), logistics network (Sun *et al.*, 2019; Zhao, Bal and Ma, 2021; Aslam *et al.*, 2022; Sharma *et al.*, 2022; Chen, 2023) or digitization of financial transactions (Soleymani and Paquet, 2020).

Aspects related to flexibility and adaptability are addressed in only four articles on the list. Zhao, Bal and Ma (2021) and Udokwu *et al.* (2022) determined that gains in operational visibility and information along the chain, thanks to the blockchain network and RFID sensors, provide agility and adaptability in response to unforeseen changes in market demand or the development of new customised products. Xiong *et al.* (2021) and Sharma *et al.* (2022) report that, in general, supply chains are at risk of disruption and considerable financial loss due to the lack of stakeholder network structures that provide high adaptability to meet market changes or personalised requirements.

Information sharing metrics are addressed by seven articles, which evaluate potential contributions of blockchain technology to lean systems from the viewpoint of information security, transparency and reliability of records (Narendra Kumar Rao, Bhaskar Kumar Rao and Vellingiri, 2019; Sarwar *et al.*, 2021; Mahdavisharif, Cagliano and Rafele, 2022), as well as from the perspective of potential communication barriers involving a complex network with multiple stakeholders (Perboli, Musso and Rosano, 2018; Zhao, Bal and Ma, 2021; Behl *et al.*, 2022).

Cooperation and integration patterns are addressed by six articles on the list, considering supply chains integrated by the blockchain network, favouring both the sharing of knowledge between users (Behl *et al.*, 2022; Chen, 2023), and the sharing of resources and infrastructure (Sturm *et al.*, 2018; Pattini, Di Giuda and Tagliabue, 2020; Alptekin *et al.*, 2021; Sharma *et al.*, 2022). These studies consider the integration of two links in the chain, usually buyer and supplier. Therefore, an opportunity for future research relates to the inclusion of a third link acting simultaneously in a supply chain with multiple actors, for example, integrating the supplier's supplier or the customer's customer in the blockchain network. One notes in this context the scarcity of discussion involving SME networks.

Noticing that the least addressed metrics in the selected studies are related to cooperation/integration and flexibility/adaptability. Therefore, the research gaps identified concern practical studies involving flexibility to respond to market variations, adaptability of customised cooperative production, coordinated relationship between SME networks as well as integration of various players acting simultaneously and consensually.

Cost metrics are frequently addressed in the selected articles, highlighting their relevance in this subject. Therefore, costs are also analysed in this study from a transactional and structural perspective to evaluate the execution of the system that combines cloud computing and blockchain technologies.

4.2. *Defining modelling parameters*

The identified gaps will be evaluated and discussed according to the lean automation conceptual model proposed by Wagner, Herrmann and Thiede (2017) and Morelli *et al.*

(2022). This model, based on lean just-in-time (JIT) delivery principles and the application of several modern Industry 4.0 technologies, includes steps that involve different companies and departments, as shown in figure 5.

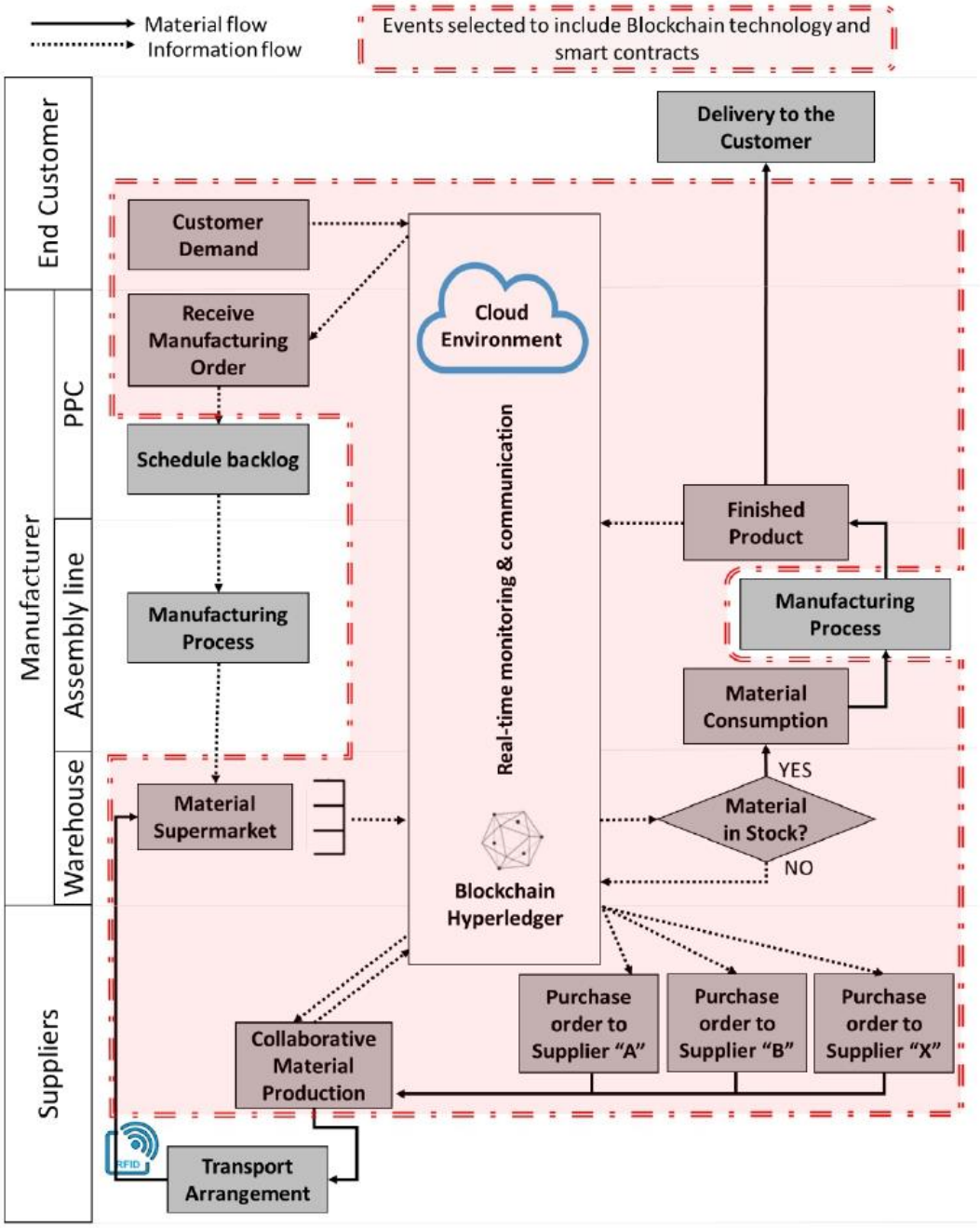
The cyber-physical system presented supports material sourcing processes, based on manufacturing order, materials in stock, supplier selection and real-time monitoring (Dombrowski, Richter and Krenkel, 2017; Wagner, Herrmann and Thiede, 2017; Tortorella *et al.*, 2020).

This concept, which works in a cloud computing environment, not only creates a gapless information flow between manufacturing order, material delivery, material stock, material consumption and automatic purchase order to suppliers, but also increases the level of management and traceability of physical products along the supply chain using RFID and sensors (Wagner, Herrmann and Thiede, 2017; Morelli *et al.*, 2022).

This study selects the steps involved in information or material flows between different players in the chain, namely: end customer, intermediate manufacturer and suppliers. Then, blockchain technology is included to support data management and reliability, and real-time monitoring and communication. The events selected for inclusion in the development of the model's smart contracts are identified in Figure 5.

That is how the simulation in the blockchain network is structured, since these selected flows and steps make it possible to explore research gaps, analysing and discussing the following aspects: collaborative relationship between stakeholders, integration of

Figure 5 - Lean automation JIT-delivery conceptual model. Source: Adapted from (Wagner, Herrmann and Thiede, 2017; Morelli *et al.*, 2022).



processes and information in the chain, flexibility towards market variations and adaptability to customised orders, and transaction costs, in addition to the participation of

the various players (end customer, intermediate manufacturer and suppliers) in both monitoring and consensual decision-making.

4.2.1. Detailing modelling steps

According to the JIT delivery flowchart previously shown in Figure 5, the practices and steps involved in this study begin with a customer demand through a manufacturing order in a system based on cloud computing and blockchain technologies. This flow of information and materials also passes through several of the manufacturer's departments and involves other service providers, from the generation of contract terms to the validation of all production traceability in the finished product.

These steps are adjusted in the blockchain and smart contracts routine, providing direct and simultaneous integration of all agents in the chain (end customer, intermediate manufacturer and suppliers). All links in the chain are able to visualise, monitor and communicate in real time with the other players, enabling, for example, consensual decision-making regarding supplier selection.

The explanation of the stages involved in this study's system are described according to the definition of Apics (2017):

- **Customer Demand** - The need to purchase a customised product (sS3) is the process of generating orders for customised products or specialised services that are developed based on the requirements or specifications of a customised demand.
- **Receive Manufacturing Order** – Receipt of drawings, specifications and other details related to the end customer's demand in order to manufacture a customised product (BP.111).
- **Material Supermarket/ Material in Stock** – Management of material in stock (HS.0058) based on demand and consumption forecasts.
- **Purchase order to Supplier** - Identifying suitable suppliers (sS3.1) means identifying and qualifying potential suppliers capable of developing and delivering customised products that meet all specifications (BP.132, HS.0134 and HS.0022).
- **Collaborative Material Production** – Relationship between stakeholders for the use of resources, services or even stock shared with key suppliers, in order to collaborate on production planning and maximise added value in meeting end customer demand (BP.156 and BP.034).
- **Material Consumption** – Selection, transport and consumption of materials in manufacturing activities (sM3.3 and sM3.4).
- **Finished Product** – This is the fulfilment of the end customer's demand and expectations regarding a customised product or specialised service (sM2.3, sM3.6 and RL.1.1). Production is concluded and the product is matched to the original customer demand.

4.2.2. Building a cloud computing embedded with blockchain system

This section describes the technical analysis of opportunities and potential for improving a lean automation system that involves implementing blockchain technology and its smart

contracts at the process stages of collaborative production in a digital cloud manufacturing platform.

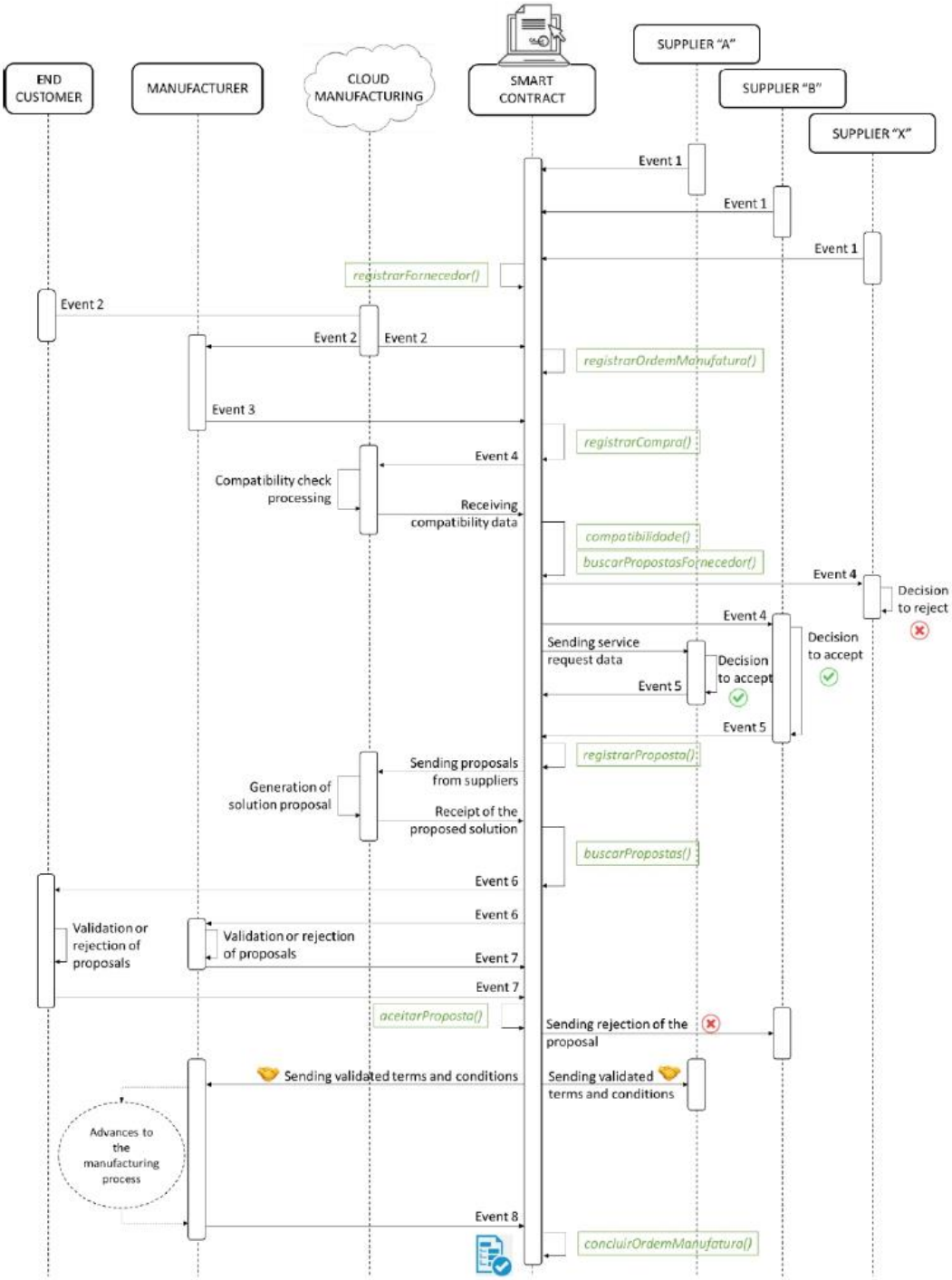
Implementation of the smart contract makes it interact with all process participants (producer, suppliers, end customer and the cloud manufacturing platform), recording, storing, checking and processing relevant transactions for the entire flow.

The combined implementation of blockchain and cloud computing not only provides characteristics of data reliability, information immutability, participant network synergy, real-time information availability and operational integration, but also the possibility of triggering participants in a non-linear manner in cases of anomalies or disapprovals in the information flow of the collaborative production.

For the specific JIT-delivery process presented in the previous section, the object of this study, the flow is defined in eight events. The diagram in Figure 6 details the model with the series of interaction events between the smart contract and the participants.

Each of these interactions involving intermediate manufacturer, end customer, suppliers of manufacturing resources and the cloud manufacturing digital platform are processed through smart contracts transcribed in the Hyperledger Fabric blockchain network. This transaction flow, which is subdivided into eight events and comprises nine computational functions, is detailed below:

Figure 6 - Transaction diagram of the proposed smart contract.



- Event 1 – Suppliers register their manufacturing resources and services in the Blockchain network. This information is stored in the system's database, so that these potential suppliers may be contacted in the future through the digital platform to supply their resources or services.

- Event 2 – The end customer accesses a producer's digital platform through a cloud-based interface, the cloud manufacturing platform. Then that end customer places a direct order to the producer for the production or delivery of material according to project specifications. The system immediately records the data of this order in the Blockchain network and triggers the material manufacturing process for the intermediate producer.
- Event 3 – During the manufacturing process of the ordered material, the intermediate manufacturer identifies the need for a customised item or service to meet the end customer's order, then opens a collaborative production order for the customised supply of this specific item or service.
- Event 4 – The smart contract interacts with the cloud manufacturing platform, carrying out compatibility check processes and prospecting for potential suppliers that are able to meet the need for collaborative production. The result of the compatibility check is recorded in the smart contract, which issues a service order, forwarding all the details and specifications of the order to potential pre-selected suppliers.
- Event 5 – Potential suppliers evaluate the order and decide on their interest to accept or reject its terms. If the decision is 'reject', the process is terminated for that supplier, while suppliers who are willing to 'accept' the terms of service provision submit their technical and business proposals to the smart contract. The system checks whether the order is still available to then register the proposals from interested suppliers and transmit them to the cloud manufacturing platform.
- Event 6 – The digital platform generates a solution proposal with details of potential suppliers capable of taking part in the collaborative production process. This solution proposal is registered in the smart contract and transmitted simultaneously to the intermediate producer and the end customer, enabling a decentralised evaluation by both players so that it can be consensually validated or rejected by at least one of the parties. This decentralised model gives the end customer the opportunity to participate in the decision regarding the supplier of the intermediate manufacturer (supplier's supplier). This type of relationship involving supplier's supplier or customer's customer does not usually occur in linear chains.
- Event 7 – The intermediate producer and the end customer may consensually accept the proposal from a given supplier, and thus the collaborative production contract is concluded. Otherwise, the intermediate producer and/or end customer reject the proposal, turning down a given supplier. In the smart contract programming of this study, the decentralised decision by consensus is mandatorily validated by unanimity of the decision-making parties. Once the proposal has been consensually validated by the intermediate producer and the end customer, with all the terms referring to deadlines, prices, obligations, among other pre-established criteria and conditions, the smart contract informs the rejected supplier that its proposal was not accepted, forwarding at the same time the final validation to the supplier selected in the process, initiating the collaborative production process involving the intermediate manufacturer and the selected suppliers.
- Event 8 – Once the collaborative production process is concluded, the intermediate producer validates the finished product, confirming that it complies with the end customer's order, and awaits the delivery process. Lastly, the manufacturing order is

concluded in the system, recording the entire production history and enabling the traceability of components and service providers.

To execute the automated routine in the presented model, computational functions were programmed. The codes and computational algorithms of those functions are available in the Unicamp-Redu data repository (https://doi.org/10.25824/redu/RLA4FC). As an example, this paper shows the code of the '*registrarFornecedor()*' function, which registers and stores manufacturing resources and services in the Hyperledger blockchain network for use on demand through the cloud manufacturing platform.

Computational code: Registration of manufacturing resources '*registrarFornecedor()*'

```
'use strict';
const { Contract } = require('fabric-contract-api');
class Chaincode extends Contract {
  async initLedger(ctx) {
    console.info('Initialized Ledger');
  }
  async queryBlockchain(ctx, key) {
    const dataAsBytes = await ctx.stub.getState(key);
    if (!dataAsBytes || dataAsBytes.length === 0) {
      throw new Error(`${key} does not exist`);
    }
    console.info(dataAsBytes.toString());
    return dataAsBytes.toString();
  }
  async registrarFornecedor(ctx, id, jsonPayload) {
    await ctx.stub.putState(id, jsonPayload);
    return 'Fornecedor registrado com sucesso';
  }
}

Input: {
        "name": "registrarFornecedor",
        "request": {
                "method": "POST",
                "header": [],
                "body": {
                        "mode": "raw",
                        "raw":  "{\n  \"nome\": ,
                                 \n  \"idFornecedor\": ,
                                 \n  \"tecnologiaManufatura\": ,
                                 \n  \"materialBase\": ,
                                 \n  \"estado\": ,
                                 \n  \"municipio\": ,
                                 \n  \"regiao\": ,
                                 \n  \"telefone\": }",
                        "options": {
                                "raw": {
                                        "language": "json"
                                }
                        }
                },
        },
}
```

Table 4 describes the nine functions of the smart contract involved in the event routine of registering, storing and distributing the transaction data among the agents.

Table 4 - Description of functions used in smart contracts.

Process Event	Function	Input	Output	Permission	Description
(1) Registration of manufacturing resources	***registrarFornecedor()***	name, idSupplier, tecnologyManufactur, materialBase, region, contact	'Successfully registered supplier'	Supplier	Resource registration and manufacturing services for on-demand use through the Cloud Manufacturing platform.
(2) End customer order for material production	***registrarOrdemManufatura()***	idEndCustomer, requirements, projec		End Customer and Producer	End Customer request enters the Producer's system for production or delivery of material according to project specifications.
(3) Customised service order	***registrarCompra()***	code, idProducer, region, description, tecnologyManufactur, materialBase, attachments	'Successfully registered purchase'	Producer	Intermediate producer needs a customized item or service to meet the End Customer request, so it enters a demand for customized supply.
(4) Prospection of suppliers (Compatibility check)	***compatibilidade()***	tecnologyManufactur, materialBase, region	Identification of suppliers compatible with the request	Cloud Mfg Platform	Processing and registration of the compatibility check of potential suppliers of resources and services previously registered on the Cloud Manufacturing platform.
	buscarPropostasFornecedor()	idSupplier	Identification of proposals compatible with suppliers	Supplier	Suppliers receive access to manufacturing service request data that matches their capabilities and expertise.
(5) Availability to meet order	***registrarProposta()***	code, supplier, price, term, propostaTecnicaComercial, attachments	'Proposal registered successfully'	Supplier	Potential suppliers can reject or accept the request, transmitting their technical and commercial proposals to the smart contract.
(6) and (7) Solution proposal	***buscarPropostas()***	code	Registered technical proposals	Cloud Mfg Platform, Producer, Supplier and End Customer	Cloud Platform generates a proposal for a solution to be evaluated in a decentralized way, in consensus between intermediate Producer and End Customer. Transactions registered by consensus on the Blockchain network generate greater reliability for the chain.
	aceitarProposta()	idSupplier, acceptEndCustomer, acceptProucer	Supplier validated in the process	Producer, End Customer and Supplier	End customer and intermediary Producer validate the pre-established terms, criteria and conditions approving the selected supplier in the process.

(8) Finished product	***concluirOrdemManufatura()***	IdManufacturing, productDetails	Finished product as per customer reque	Producer, End Customer and Supplier	System validates the finishe product as requested by the End Customer, recording the entire production history and enabling the traceability of components and service providers.

The model configures non-linearity in the information flow, since the system allows simultaneous information inputs and outputs from multiple agents (customer's customer and/or supplier's supplier) in the various stages of the system. Such non-linearity is verified in the decision-making of the supply chain, which now occurs in a decentralised manner, introducing a concept of consensus and cooperation between stakeholders, as can be seen in events 6 and 7, which enable consensual choice in decision-making of supplier selection. This concept of management and relationship between stakeholders provides the construction of transparency, collaboration, security and reliability in transactions and operations.

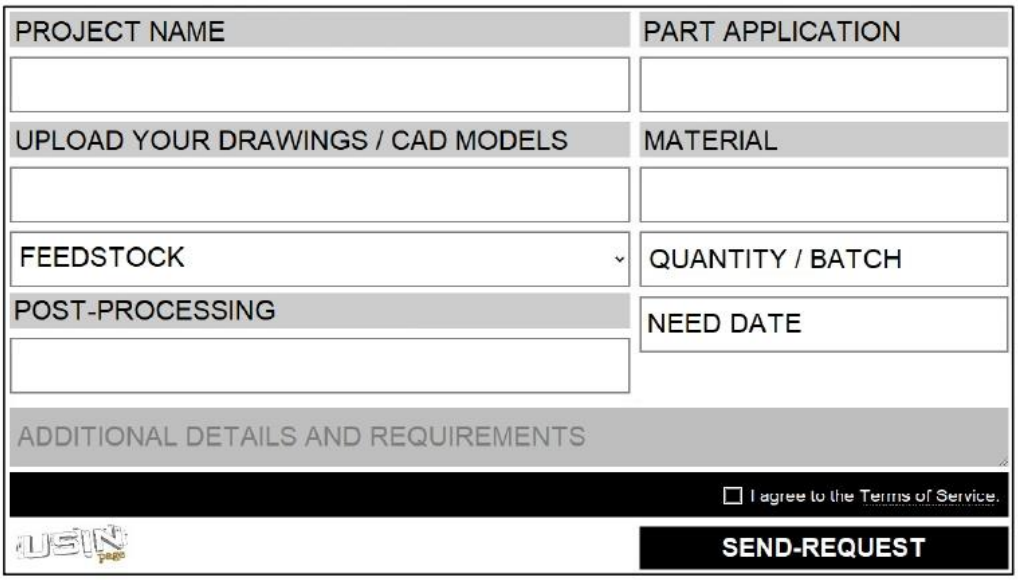
4.3. *Simulating lean automation model using blockchain technology*

This section features the simulation results and performance of the proposed lean automation system, which combines cloud manufacturing and blockchain technologies.
The studied model covers from a customer order for the production of a customised industrial component, and the collaborative production of this customised material involving an intermediate producer and its suppliers of materials or services, to the validation of the finished product with the registration of the entire history of production and traceability of materials.

This setting, which enables real-time data visualization and monitoring, occurs in a cloud manufacturing environment, with web interface and database on the Hyperledger blockchain network. From this front-end, users direct the execution of functions and routines established in smart contracts. Figure 7 shows the web interface for customised product or service orders.

The smart contracts are translated into the computational language of the Hyperledger Fabric® platform, since, according to Perera *et al.* (2021), this blockchain network has the lowest cost in terms of system implementation and maintenance. The project's codes and

Figure 7 - Web interface for customised demand. Source: Adapted from (Usinpage, 2023).



computational algorithms are available (open source) in the Unicamp-Redu data repository (https://doi.org/10.25824/redu/RLA4FC).

Table 5 features the computational configuration of hardware, software and cloud environment used to simulate the project.

Table 5 - Configuration of hardware, software and cloud environment.

Hardware	
CPU	Intel Core I5 11th Gen
Hard Disk	120 Gb SSD
Memory	RAM: 8 Gb
Software	
Op. Sys.	Ubuntu Linux
Docker	Version 1.19
Hyperledger Fabric	Version 2.5
Cloud environment	
Google Cloud Platform	
Instance type	e2-standard-2
vCPUs	2
RAM	8Gb
Datacentre location	Sao Paulo (southamerica-east1)

4.3.1. Event protocols

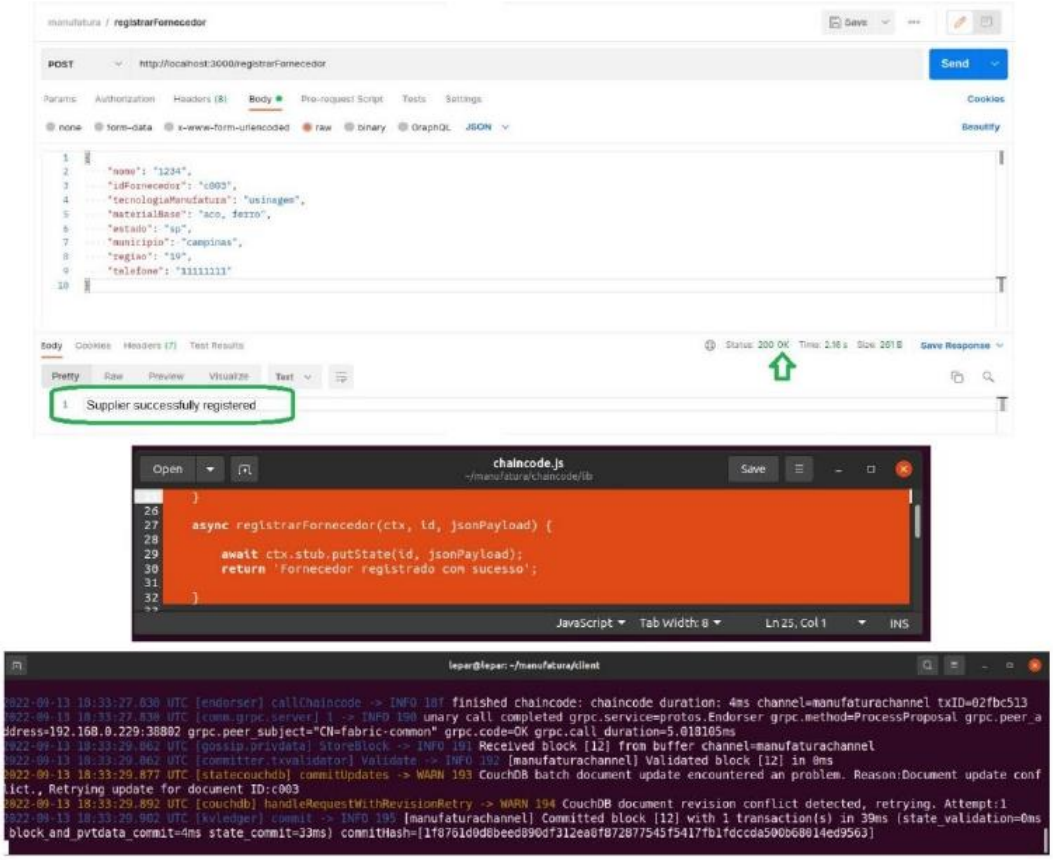
Several scenarios are simulated for the different events that make up the JIT delivery model under study, addressing all the routines and functions of the smart contracts developed in this research.

The transaction routine execution uses the Postman application and the Hyperledger Fabric network. The records, executions and responses processed in Postman for each event are presented below.

In the 'Registration of manufacturing resources' event, where several suppliers register in detail their resources and services in the cloud manufacturing platform, Figure 8 shows that the registrarFornecedor() function was successfully executed, indicating an 'OK' status and returning the 'Supplier successfully registered' output message. This figure also shows the computer code and the function's invoking result, with the details of the block generation in the Hyperledger Fabric network, the transaction time and the generated hash.

On the cloud manufacturing platform, the end customer enters a direct order for the manufacture of a product according to its specifications. This event, called 'End customer order for material production', executes the registrarOrdemManufatura() function. Figure

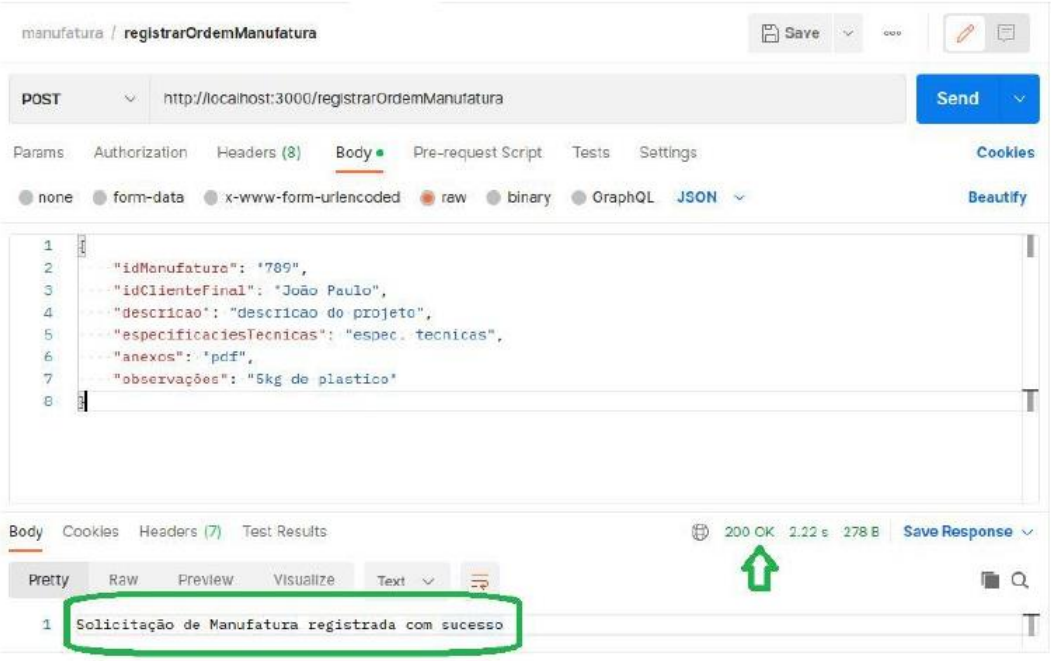
Figure 8 – Execution of the *registrarFornecedor()* function.



9 shows that a manufacturing order was successfully generated directly in the intermediate manufacturer's system.

If, during its manufacturing process, the intermediate manufacturer identifies the need for a customised item it does not have in stock or the need to provide a customised service, the registrarCompra(), compatibilidade() and buscarPropostasFornecedor() functions are

Figure 9 - Execution of the *registrarOrdemManufatura()* function.



executed by the smart contract, and the 'Customised service order' and 'Prospection of suppliers (Compatibility check)' steps are triggered.

Figure 10 - Execution of the *registrarCompra()* function.

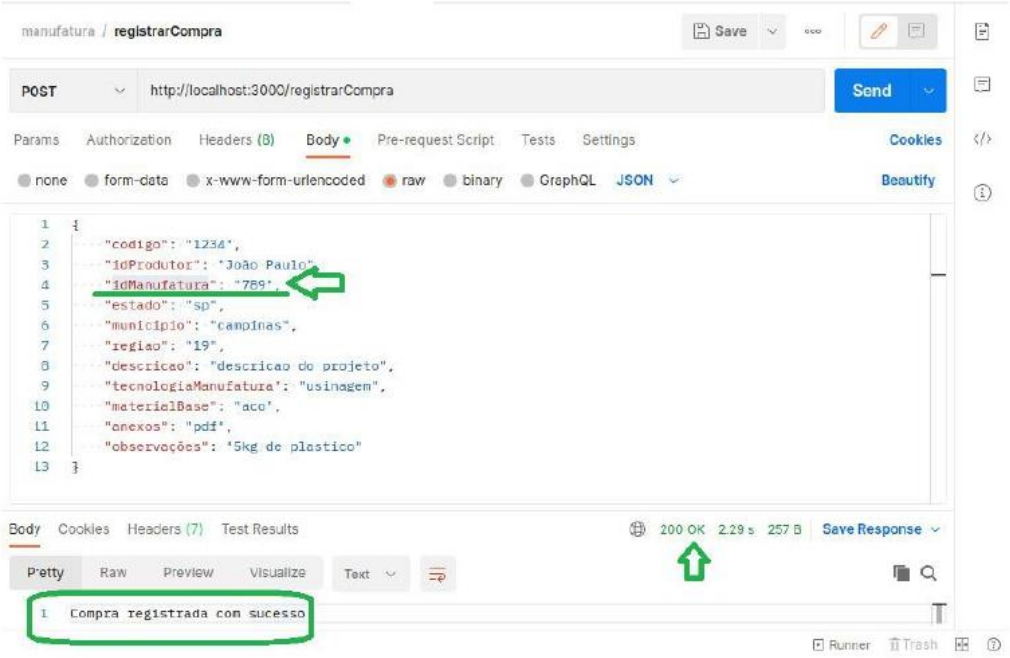
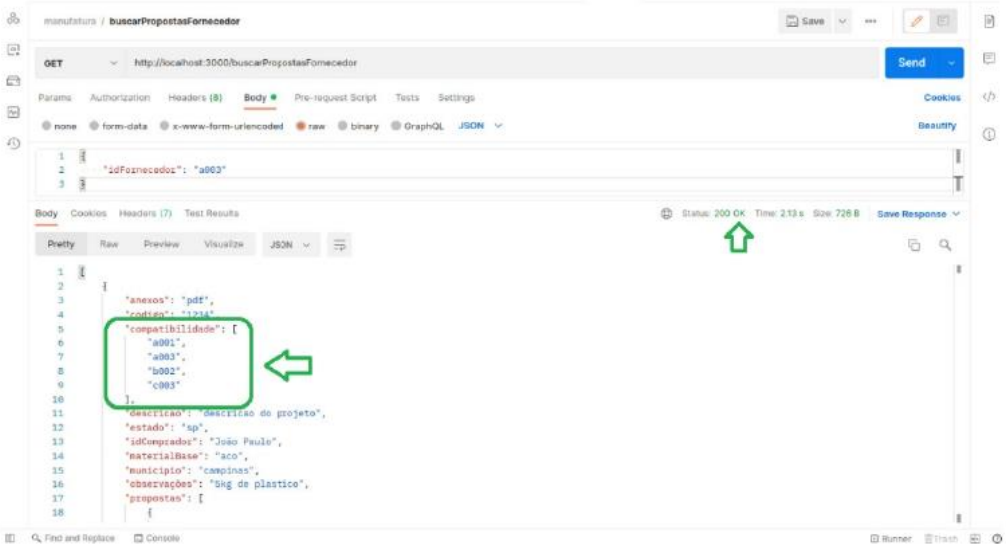


Figure 10 shows the successful execution of the registrarCompra() function. One notes that the identification of the original manufacturing order of the end customer, 'idManufatura', is registered in the history of this order, ensuring traceability of the process.

The compatibilidade() function carries out automatic prospecting of suppliers, checking the compatibility of their resources with the registered order. Figure 11 shows the result of this check, which identified four potential suppliers to join the collaborative production process, forwarding to them the customised order by means of the buscarPropostasFornecedor() function.

The potential suppliers can reject or accept the order, submitting their technical and business proposals to the smart contract. This event that stores the suppliers' proposals is called 'Availability to meet order' and is executed by the registrarProposta() function. Figure 12 shows an organised solution proposal with the participation of several suppliers,

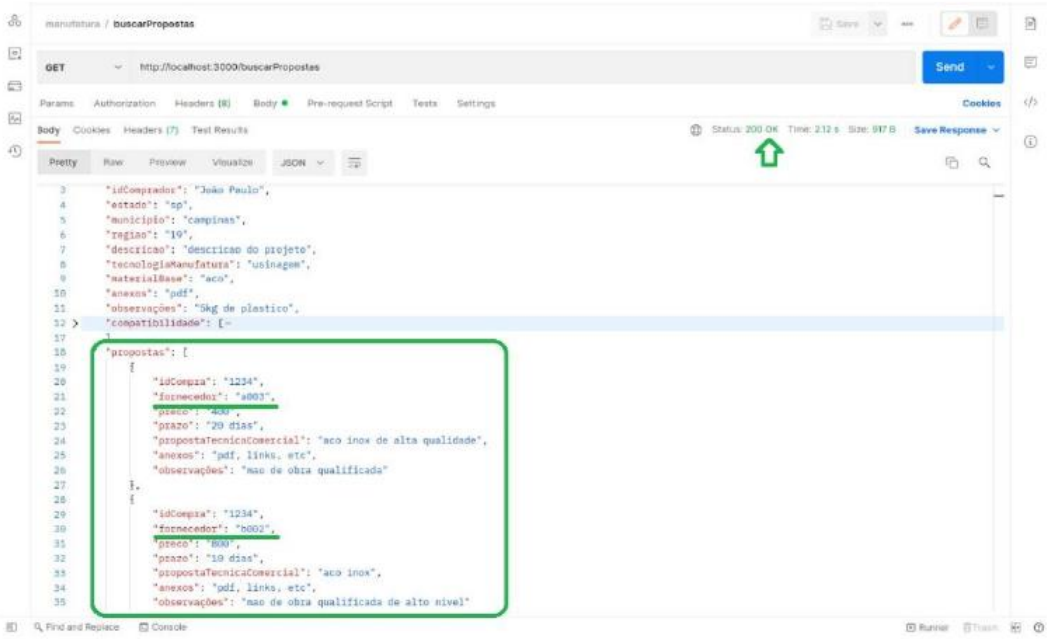
Figure 11 - Execution of the *buscarPropostasFornecedor()* function.



executed by the buscarPropostas() function and forwarded for consensual evaluation by the end customer and intermediate producer.

The decentralised evaluation of the collaborative production proposal is characterised by the consensual approval of the end customer and intermediate producer. This type of consensual registration affords greater transparency and reliability to the chain. In this study, this event is called 'Solution proposal' and executes the aceitarProposta() function.

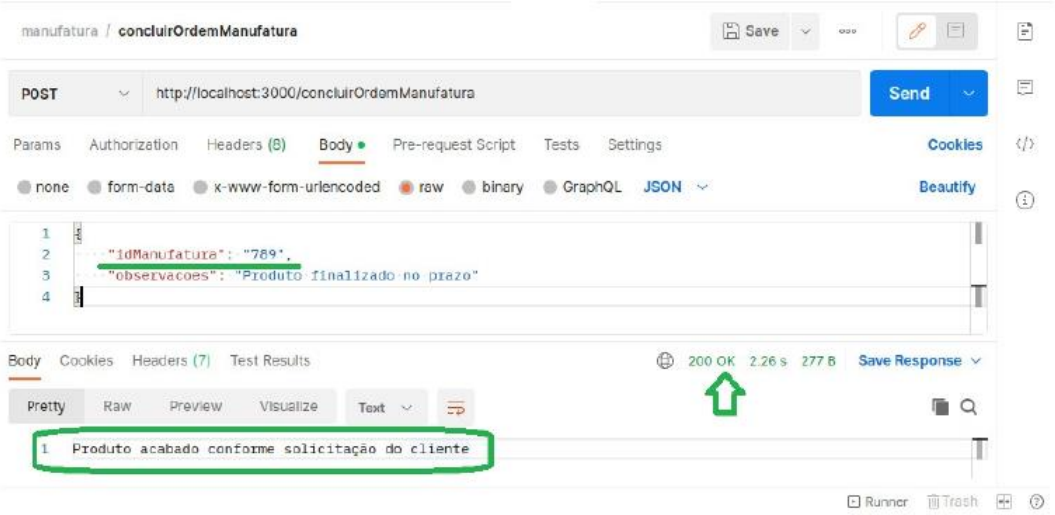
Figure 12 - Execution of the *buscarPropostas()* function.



The proposal can only be validated by unanimous approval (approved by both the end customer and the intermediate manufacturer). There are five possible statuses for each proposal in the system: 'Rejected', 'Accepted by the manufacturer (awaiting consensus from the end customer)', 'Accepted by the end customer (awaiting consensus from the manufacturer)', 'Pending approval' or 'Accepted by consensus'. That is how the collaborative manufacturing process begins.

Lastly, after the conclusion of the entire manufacturing process of the product, involving the suppliers and intermediate manufacturer steps according to the order of the end customer, the concluirOrdemManufatura() function is executed by the smart contract in the step named 'Finished product', and, as shown in Figure 13, information of the entire

Figure 13 - Execution of the *concluirOrdemManufatura()* function.



history of the manufacturing order is recorded in the block, enabling traceability and transparency from the production process to the end product.

4.3.2. Transaction times and costs

The mean processing time for each of the model's functions is shown in Table 6, as well as the standard deviation, maximum and minimum time. The data were identified by means of a set of 20 simulations performed on the Hyperledger Fabric network.

Table 6 - Transaction processing times (in milliseconds).

Function	Time Stats (in msec)			
	Mean	Std. Dev	Max	Min
registrarFornecedor()	32.6	8.2	47	21
registrarOrdemManufatura()	23.0	5.8	34	12
buscarOrdemManufatura()	17.1	4.9	29	12
registrarCompra()	31.2	6.3	43	19
compatibilidade()	processed automatically within the *registrarCompra()* function			
buscarPropostasFornecedor()	18.0	5.0	29	12
registrarProposta()	42.2	10.2	61	26
buscarPropostas()	15.4	4.3	24	9
aceitarProposta()	24.4	6.6	38	13
concluirOrdemManufatura()	20.4	6.4	31	11

The transaction costs of the model are evaluated in this study by considering the use of a virtual machine on the Google Cloud platform. These results serve as an order of

magnitude benchmark for the transaction costs of the proposed model and may vary if services from other platforms with cloud databases are used to run the system.

The Google Cloud platform has execution costs related to the resources and operating times of the virtual machine which are charged per seconds of use. The estimated costs for the configuration used in the simulation of this model are around US$ 0.11 (eleven US cents) per hour of use.

The estimate of slight transaction times and costs involved in executing the smart contracts of this model by means of a virtual machine in the cloud environment shows potential for scalability gains in projects that comprise a large amount of data.

4.3.3. Security and permission

The model is developed on a permissioned blockchain network, in which each user has a digital identity with controlled access. As shown in Figure 14, the functions 'ca.enroll' and 'ca.register' are used in the model's chaincode to register users on the network.

These functions are part of the Hyperledger Fabric infrastructure as a certificate authority (CA), guaranteeing the relationship between the parties, communication, permissions and digital signatures.

The Hyperledger Fabric system uses the Raft consensus algorithm to ensure

Figure 14 - Certificate authority code.

```
const secret = await ca.register(
  { affiliation: 'org1.department1', enrollmentID: user, role: 'client' },
  adminUser
);

const enrollment = await ca.enroll({
  enrollmentID: `${user}`,
  enrollmentSecret: secret
});
```

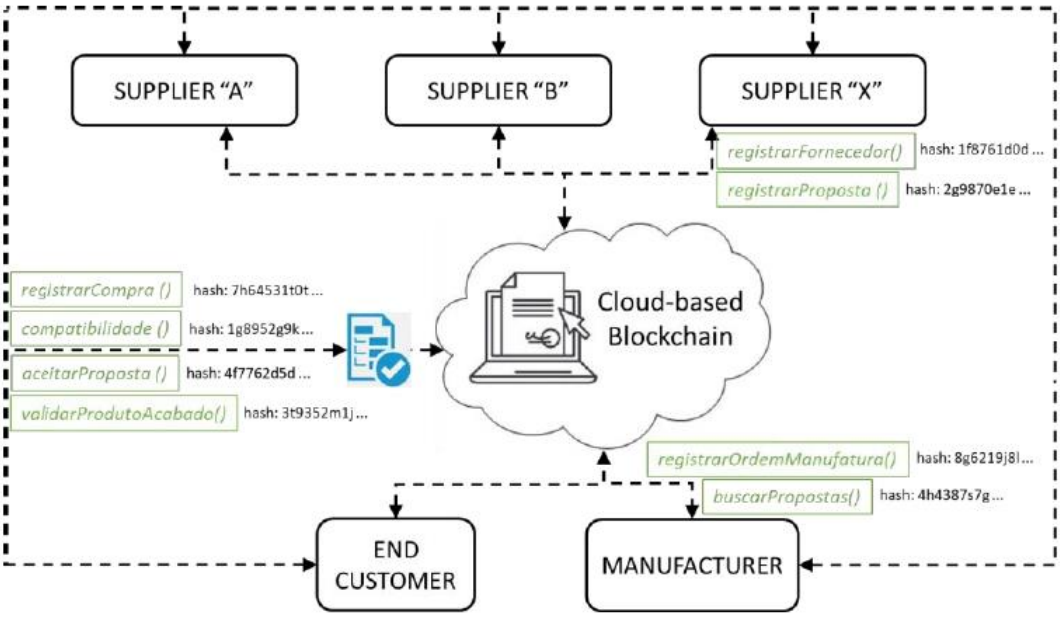
transactions, execute the chaincode, and validate and confirm the block (Androulaki *et al.*, 2018).

4.4. *Analysis of the proposed model*

The final result of the study shows the transition from a traditional supply chain following a linear information flow to a chain that manages and distributes information in a non-linear way. Figure 15 exemplifies this non-linearity of the chain as a result of including blockchain technology and its smart contracts in the model.

Figure 15 displays the transaction execution points, computational functions, smart contract routine and hashes that confirm the events in the blockchain network, evidencing the logic of simultaneous sharing of information with all players and showing that, rather

Figure 15 - Non-linear chain with the cloud-based blockchain platform.



than being necessarily sequential, event management may occur in a more integrated way for all, enabling information to flow circularly with a focus on the registration and distribution of data by the cloud-based blockchain platform.

The system allows all stakeholders to access manufacturing information updated in real time via the encrypted data-sharing platform, streamlining decision-making, process checking, product tracking and anomaly handling. Moreover, the information history and reputation related to all parties involved in the chain can also be checked on this database.

The simulation results make it possible to compare the proposed model with other lean automation models that do not use the blockchain network. Table 7 shows the comparison of this blockchain-supported just-in-time delivery prototype with two other JIT delivery systems without blockchain technology previously studied in the literature, the models of Wagner, Herrmann and Thiede (2017) and Morelli *et al.* (2022). Such studies serve as a benchmark for the development of this blockchain prototype and therefore were selected for this comparison section.

Table 7 - Comparison of the proposed model with other models without Blockchain.

Characteristic		Model with Blockchain	Models without Blockchain
Cooperation /	Decentralisation	Decentralised	Centralised in the producer's manufacturing system
	Linearity	Non-linear chain	Linear chain
	Traceability	Records on the Blockchain network	Records on the manufacturing and production planning system

	Immutability	Immutable data in the Blockchain network	Data susceptible to producer system management
	Privacy Protection	Blockchain Hyperledger Fabric certificate authority	Data susceptible to producer system management
	Transparency	Real-time visualization of all information on the Blockchain network	Real-time visualization of only the information provided by the producer's system
Flexibility / Adaptability	Scalability	Open network available for use by numerous customers, producers and suppliers	Network restricted to the specific producer's customers and suppliers
	Productivity	Information flow with low latency	Information flow with low latency
	Quality of service	Quality control determined and judged in consensus by several players	Quality control centralised in the intermediary producer
	Applicability to SMEs	Low costs for processing transactions on the Blockchain Hyperledger network	Considerable costs for developing computational adequacy to the producer's system

Each of the features of the blockchain model listed in Table 7 were previously described in the modelling and simulation results.

5. Discussion and Conclusion

The digitization of production processes has been transforming industry in terms of management, communication, integration and operation. The use of disruptive digital technologies to improve lean production systems is addressed in the literature under the name of lean automation, a subject still in development and which presents opportunities for research on the evaluation of its gains and application barriers.

Therefore, the goal of this study is to evaluate how the use of blockchain and cloud computing technologies can improve performance in production systems characterised by lean automation. The review of articles in this field, added to the modelling and simulation of a computational system developed on the Hyperledger Fabric blockchain network, provides theoretical and practical contributions.

This study reveals a consistent annual increase in the number of published articles or conference papers related to the subject of blockchain applied to lean production systems. The bibliometric analysis also indicates that the most in-depth aspects of these papers are: system development and implementation costs, reduced production costs, improvement in service levels due to greater visibility and reliability of real-time events, and streamlined response time of supply chains and financial transactions.

In this study, a lean automation JIT delivery model is structured, built on a computational system based on cloud computing and blockchain technologies, presenting the events, flows and relationships in a decentralised and non-linear chain, in addition to the routines and computer codes of smart contracts developed on the Hyperledger Fabric network.

The analysis and simulation of this prototype addresses lean aspects identified as research gaps, including: integration of stakeholders in the collaborative production of customised products, conditions of flexibility and adaptability to demand variations, coordinated relationship of networks involving small and medium-sized enterprises (SMEs), behaviour of various players acting simultaneously and consensually, and

transaction costs of the Hyperledger Fabric blockchain network operating by means of a virtual machine in the cloud.

Aiming to evaluate such aspects, the study compares the characteristics of this JIT delivery prototype based on blockchain technology with those of JIT delivery models previously studied by Wagner, Herrmann and Thiede (2017) and Morelli *et al.* (2022), which do not use blockchain.

It is noted that in the proposed model, the integration of stakeholders is based on a decentralised platform that favours sharing and comprehensive visualization of data by all players, with no possibility of manipulation by intermediaries. The chain structure is non-linear, with data distributed and transacted not only with adjacent stakeholders, but also with distant nodes in the chain, avoiding inefficiencies, distortions or loss of information as they advance along the entire network.

Considering that records are not entered in the system of a given intermediate producer, thus not being susceptible to management by only one chain member, the network integration model of this research provides a level of collaborative relationship among stakeholders, with knowledge exchange and updated information on processes, improving the quality of communication, transactions and use of resources, reducing waste such as overproduction or excess stock in meeting orders.

The system proves to be robust even in transactions involving several subcontractors in the production chain, since the traceability of records on the network, the immutability of such data, the transparency of information in real time and the authority certificates of the permissioned blockchain network prevent delays in communication or extra costs, such as the need for human intervention to exchange or share information. The distributed ledger feature of blockchain technology automates data collection and reduces possible human errors.

In this non-linear model, decision-making is also shared among the various agents, not being the sole responsibility of the intermediate producer, giving all players the opportunity to participate in the decision-making processes, avoiding rework and improving both the quality of the service and the finished product, since quality control is determined and judged consensually by multiple players and departments. Although in this model in particular consensual decision-making is strictly unanimous, alternative models can be tried out. With adjustments to the algorithm, decision-making can happen, for example, by a majority, with evaluation of whether possible gains in the streamlined flow impact the quality of decision-making and, consequently, the finished product.

The results obtained by simulating the model show potential for scalability in practical applications that involve a large amount of data exchange, not only for revealing streamlined processing times, low latency times and slight transaction costs, but also for offering an open network, available for use by a large number of customers, producers and suppliers.

Added to its theoretical contributions, this research provides managerial implications to support networks of companies of different sizes in the adoption of innovative technologies to improve their internal processes and the relationship with their stakeholders, resulting in potential competitive advantages.

The simulation confirms the connection pattern between the different companies, offering a homogeneous communication environment that facilitates the integration of

several companies participating in the chain, including SMEs, which can benefit from lower technology development costs, since access to the blockchain network by means of a virtual machine in the cloud through a web interface eliminates the need to invest in their own structures for the development and implementation of advanced computing systems, establishing a more inclusive and transparent ecosystem.

The possibility of bringing SMEs closer together, including in the international context, such as emerging and developed countries, to take part in manufacturing networks on a global scale, helps these companies advance in aspects such as organizational productivity, information integration, response time, market sensitivity and collaborative relationship, besides increased business visibility and competitiveness in supply chains. Gains with cybersecurity can also be mentioned, since the operating platform provides the security and cryptography features of the blockchain network.

Thus, despite the identified opportunities for improvement, the adoption of digital platforms poses a few challenges. Cultural barriers are potential obstacles to application, especially in emerging countries, since there are still paradigms related to the use of cloud computing and blockchain. Poor familiarity with these technologies is another barrier, as despite the automated resources of smart contracts, some events require human intervention, thus becoming susceptible to eventual failures in entering or interpreting information, especially in manufacturing processes that involve intangible services or products.

Poor access to basic management and planning tools may also be a challenge for SMEs, as the system does not guarantee that resource or service providers will deliver what was agreed in the production plan.

Therefore, decision-making in the selection of stakeholders must evaluate the historical records of each player involved, as well as monitor the process in real time. It is also worth mentioning scarce financial resources as a possible barrier, for despite the low transaction processing costs of the model, financial difficulties may persist as a major challenge.

5.1. *Limitations and avenues for further research*

This research evaluates a new approach to the application and integration of blockchain and cloud manufacturing into lean production systems. The results presented reveal not only the performance improvements achieved in several lean metrics, but also present an architecture that integrates multiple stakeholders in globalized networks and contribute to the dissemination of inclusive scientific knowledge which can be applied in countries with different levels of technology evolution and networks of companies of different sizes, including SMEs.

In order to analyse the viability of a system based on cloud computing and blockchain technologies applied to lean automation processes, this study is limited to developing and simulating a routine of functions and smart contracts in specific stages of supplier prospecting for the collaborative production of customised materials.

We identify opportunities for further studies, not only simulation or case studies involving other lean automation process steps, such as Make to Order, transportation or circular economy, but also in the development of research involving other Industry 4.0 enabling technologies, such as 5G telecommunication, artificial intelligence, machine learning, RFID, IoT and metaverse, among others. Additionally, we recommend

structuring schemes that help business managers evaluate the levels of technology development of their processes, enabling the understanding of potential performance gains resulting from the application of Industry 4.0 technologies.

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3 DISCUSSÃO

Esta dissertação é o resultado de uma pesquisa organizada em 3 etapas. Na primeira etapa desenvolve-se um estudo que avalia a aplicação da tecnologia *cloud computing* ao ambiente de manufatura, que caracteriza o conceito do *Cloud Manufacturing.* Na segunda etapa desenvolve-se um estudo relativo à aplicação de tecnologias inovadoras da Indústria 4.0 em sistemas de produção enxuta, que caracteriza o *Lean Automation*, em MPMEs brasileiras. E, finalmente, a terceira etapa utiliza os outros dois estudos como pilares para desenvolver a pesquisa que propõe um modelo baseado nas tecnologias *Blockchain* e *Cloud Manufacturing* como suporte a técnicas *Lean* de produção para gestão da cadeia de suprimentos industrial.

O produto de cada etapa da pesquisa é o desenvolvimento de um artigo acadêmico, totalizando a elaboração de 3 artigos ao final deste projeto de mestrado, e possibilitando a discussão da combinação dos 3 tópicos – *Cloud Manufacturing*, *Blockchain* e *Lean Production* – tanto no gerenciamento de dados em redes empresariais, quanto nos potenciais tecnológicos e barreiras de aplicação.

O mapeamento de estudos acadêmicos sobre o tema *Cloud Manufacturing* revela que as aplicações práticas deste conceito promovem ganhos em planejamento de produção, otimização de processos de manufatura, programação de serviços, redução de custos, minimização do consumo de recursos industriais, sinergia de redes de empresas, colaboração de recursos, integração de operações e escalabilidade. Este mapeamento identifica, ainda, lacunas de pesquisa nos campos da gestão de dados, segurança cibernética, bem como, agilidade e rastreabilidade do fluxo de informações.

A revisão da literatura confirma que a grande maioria dos modelos de redes de empresas que contemplam o conceito do *Cloud Manufacturing* necessitam de uma terceira parte que centraliza e gerencia as transações e a comunicação entre os usuários. Tal prática pode apresentar fraqueza na confiabilidade dos dados e nos sistemas de segurança cibernética, resultando em eventuais perdas, danos, ou mesmo, manipulação das informações e do seu conteúdo. Esta revisão conclui, também, que as plataformas digitais *Cloud Manufacturing* devem aplicar recursos e tecnologias para melhoria da transparência na rastreabilidade de dados, utilização de recursos de consenso nos protocolos de validação, eliminação da necessidade da

terceira parte na gestão das transações, bem como, padronização de sistemas para eliminar conflitos de comunicação entre *stakeholders* na cadeia de suprimentos.

Em paralelo esta pesquisa estuda as principais aplicações de sucesso do *Lean Automation* em MPMEs de diversos mercados globais. As tecnologias da Indústria 4.0 mais relevantes identificadas nessas aplicações são: equipamentos *mobile*, segurança cibernética, sensores, computação em nuvem, RFID e *big data*; associados aos seguintes princípios *Lean*: *pull-principle*, comunicação com fornecedores-chave, eliminação de desperdícios, integração de sistemas de engenharia, visualização e padronização. Com base na combinação dessas tecnologias da Indústria 4.0 e princípios *Lean*, estrutura-se um modelo conceitual *Just-in-Time (JIT) Delivery* que conta com mecanismos de integração e conexão entre diferentes empresas e departamentos, direcionando a cadeia de suprimentos a um ambiente de produção colaborativo, agilizando o compartilhamento de informações e atividades, e ainda eliminando desperdícios de tempos e recursos.

O modelo *JIT-Delivery* proposto é utilizado como protótipo para caracterização das forças e fraquezas de MPMEs brasileiras em relação ao *Lean Automation* através de uma *survey*, analisada no artigo 2. O estudo identifica que o setor industrial apresenta maior aderência e melhores condições para implementação dos padrões *Lean Automation*, quando comparado aos setores de comércio e serviços. Verifica-se também que dentre os 10 segmentos de negócio avaliados, os que apresentam pior desempenho na aderência ao *Lean Automation* apontam baixos níveis em aspectos como ‘planejamento e programação’, ‘sistema puxado’, ‘redução de tamanho de lote’, e ‘segurança cibernética’, expondo deficiências em suas estruturas organizacionais, no mapeamento de processos, e no acesso a ferramentas e tecnologias básicas de gestão e planejamento, bem como, escassez de recursos financeiros para desenvolvimento de programas de certificação.

Promovendo uma definição de rota viável para aplicação dos padrões *Lean Automation* a pequenas e médias empresas de países em desenvolvimento é organizado um *roadmap* com três estágios de implementação. As etapas da sequência recomendada para implementação são caracterizadas como: *start-up*, *in-trasition* e *advanced*. Estas iniciam com a adoção de práticas orientadas para o *Lean*, então avançando para aplicação de tecnologias da Indústria 4.0, e finalmente adotando redes avançadas de integração com os *stakeholders*. A implementação completa dos três estágios visa a melhoria de processos e conhecimento,

direcionando essas redes de empresas a reduzir o déficit tecnológico e melhorar suas condições de competitividade frente a mercados de empresas com maior desenvolvimento tecnológico.

Posteriormente esta pesquisa propõe e simula a aplicabilidade de um sistema que combina aspectos do *Lean Automation* com as tecnologias *Cloud Manufacturing* e *Blockchain*, utilizando como base as barreiras e oportunidades identificadas nos estudos sobre as tecnologias *Cloud Manufacturing* e *Lean Automation*, como: fraqueza na confiabilidade dos dados e nos sistemas de segurança cibernética, deficiência no acesso a ferramentas e tecnologias de gestão e planejamento, possibilidade de eliminação da terceira parte na gestão das transações entre *stakeholders*, padronização de sistemas para eliminar conflitos de comunicação na cadeia de suprimentos, bem como, a oportunidade de avançar para adoção de tecnologias da Indústria 4.0 proporcionando redes avançadas de integração com os *stakeholders*.

O modelo simulado contempla um sistema *Lean Just-in-time Delivery*, construído sobre uma base *cloud computing* na rede *Blockchain* Hyperledger Fabric. Os resultados da simulação permitem a avaliação dos aspectos deste sistema, bem como, a comparação de suas características com outros modelos *Just-in-Time Delivery* previamente estudados por Morelli et al. (2022), Wagner, Herrmann e Thiede (2017), os quais não usam a tecnologia *Blockchain*.

Nota-se que o modelo proposto se baseia em uma plataforma descentralizada, favorecendo o compartilhamento e visualização das informações por todos os *players*, sem a possibilidade de manipulação por intermediários. A estrutura da cadeia é não-linear, possibilitando transações e distribuição de dados não apenas com *stakeholders* adjacentes, mas também com outros elos distantes na cadeia, evitando ineficiências, distorções ou perda de informação conforme elas avançam ao longo de toda a rede.

O sistema apresenta robustez mesmo em transações envolvendo diversos *players* na cadeia, já que a rastreabilidade dos registros, a imutabilidade dos dados, a transparência da informação em tempo real, a automação da distribuição do banco de dados e os certificados de autoridade da rede *Blockchain* permissionada previnem atrasos na comunicação ou custos extras, como a necessidade de intervenção humana no compartilhamento de informações, ou mesmo reduzindo a possibilidade de falha humana. Os resultados da simulação também mostram potencial de

escalabilidade para aplicações práticas que envolvam grandes volumes de dados, já que este apresenta baixos tempos de latência e custos transacionais irrisórios, além de oferecer uma rede aberta, disponível para utilização de grande quantidade de produtores, clientes e fornecedores.

Neste modelo não-linear, o processo de tomada de decisão também é compartilhado por diversos agentes, não sendo apenas responsabilidade do produtor intermediário, dando a todos os integrantes a oportunidade de participar da tomada de decisão, evitando retrabalho e melhorando tanto a qualidade do serviço quanto do produto final, já que o controle de qualidade é determinado e julgado consensualmente por diversos *players* e departamentos.

A simulação do sistema que combina tecnologias *Blockchain* e *Cloud Manufacturing* com aspectos *Lean* de produção, confirma o padrão de conexão entre diferentes empresas, oferecendo um ambiente de comunicação homogêneo que facilita a integração de empresas participantes à cadeia, incluindo MPMEs, que podem se beneficiar dos baixos custos para desenvolvimento de tecnologia da informação, já que o acesso à rede *Blockchain* por meio de máquina virtual na nuvem através de interface *web* reduz a necessidade de altos investimentos no desenvolvimento e implementação de sistemas computacionais avançados, estabelecendo um ecossistema mais transparente e inclusivo.

A possibilidade de aproximar MPMEs, num contexto internacional, envolvendo países desenvolvidos e em desenvolvimento, participando de redes de manufatura globalizadas, ajuda essas empresas a avançarem em aspectos como produtividade organizacional, integração da informação, tempo de resposta, sensibilidade de mercado, e relacionamento colaborativo, além de aumentar a visibilidade do negócio e a competitividade na cadeia de suprimentos.

Adicionalmente, os resultados da simulação identificam benefícios práticos para empresas em outros aspectos *Lean*, como: redução de custos, qualidade e lucratividade. Nota-se que a digitalização do fluxo de informações elimina registros físicos em papel ou transporte de documentos, além de possibilitar a detecção e a rastreabilidade de produtos defeituosos, identificando a origem do problema e possibilitando a remoção do produto defeituoso evitando o *recall* de toda a cadeia produtiva.

O compartilhamento de dados e indicadores de desempenho através de toda a rede pode ser utilizado para controlar as especificações e processos desde a

matéria-prima até o produto acabado. Constata-se aumento da velocidade do processo com a característica de distribuição de informações automáticas, reduzindo intermediários e, consequentemente, diminuindo o tempo de ciclo produtivo. A distribuição da informação em tempo real também possibilita o monitoramento do desempenho e da produtividade de toda a cadeia de suprimentos, identificando *gaps* mesmo em fornecedores ou clientes distantes na rede.

Os ganhos com segurança cibernética também podem ser mencionados, já que a plataforma operacional conta com as características de criptografia da rede *Blockchain*.

Os resultados obtidos neste trabalho consolidam os objetivos propostos e respectivas evidências de soluções para as lacunas identificadas durante o desenvolvimento teórico e aplicado da pesquisa.

Na tabela 3.1 é apresentado um ‘quadro-síntese’ que contempla os objetivos, resultados e lacunas identificados nos 3 artigos desenvolvidos durante esta pesquisa, destacando, em negrito, os objetivos correspondentes aos declarados para esta dissertação.

O ‘quadro-síntese salienta, ainda, a correlação do terceiro artigo com os outros dois que serviram como pilares para o seu desenvolvimento, já que os resultados do terceiro artigo contemplam as lacunas identificadas nos dois primeiros artigos desenvolvidos.

Tabela 3.1 - Quadro-síntese dos artigos desenvolvidos durante o mestrado acadêmico.

	Objetivos gerais e específicos	Resultados	Lacunas identificadas / sugestões de trabalhos futuros:
Artigo 1 (*Cloud Manufacturing*)	• **mapear pesquisas acadêmicas sobre CMfg**; • identificar as tendências de aplicação; • categorizar os estudos com aplicação prática; • **identificar lacunas de pesquisa**.	• identificação de 4 clusters de linhas de pesquisa; • aplicações práticas focam majoritariamente nos clusters de 'otimização de processos', 'redes colaborativas de recursos e serviços', e 'indústria 4.0 e computação em nuvem'.	• lacuna de estudos no cluster 'confiabilidade de dados e segurança cibernética'; • sugestão de estudos com plataformas CMfg que eliminem a necessidade de uma terceira parte centralizadora.
Artigo 2 (*Lean Automation*)	• **avaliar aplicação do LA em MPMEs brasileiras**; • desenvolvimento de modelo conceitual LA; • validar aplicabilidade através de uma *survey*; • **identificar barreiras de aplicação do LA em MPMEs**; • organizar um *roadmap* para implementação do LA.	• identificadas aplicações do LA em MPMEs; • estruturado um modelo conceitual LA; • caracterização das condições das MPMEs brasileiras em relação ao LA; • identificados os desafios e oportunidades de aplicação; • organizado um *roadmap* para implementação do LA em três estágios.	• Sugestão de trabalhos com aplicação prática ou simulação que suportem os princípios *Lean* aplicando tecnologias inovadoras para mitigação das dificuldades mapeadas nos processos organizacionais, gestão, implementação tecnológica e integração com os *stakeholders*.
Artigo 3 (*Cloud*, *Lean* e *Blockchain*)	• mapear estudos de aplicação do *blockchain* em sistemas *lean* de produção; • **simular modelo integrado das tecnologias *cloud*, *blockchain* e sistemas *lean*;** • **avaliar como a aplicação melhora o desempenho e o relacionamento entre parceiros em uma cadeia de suprimentos**.	Contempla as lacunas dos artigos 1 e 2: • estudo prático de sistema CMfg com foco na confiabilidade de dados e segurança cibernética; • eliminação da necessidade de terceira parte centralizadora; • simulação de tecnologias inovadoras suportando sistemas *Lean* para MPMEs;	• sugestão de estudos em outras etapas e processos do *lean automation*; • agregar outras tecnologias da indústria 4.0 nos estudos sobre LA; • estruturar métodos que auxiliem gestores de empresas na avaliação dos níveis de desenvolvimento tecnológico de seus processos.

4 CONCLUSÃO

Esta dissertação tem como objetivo principal propor um modelo para aplicação combinada das tecnologias *Cloud Manufacturing* e *Blockchain* a um processo *Lean Automation*, visando investigar como a combinação dessas tecnologias pode agregar valor aos sistemas produtivos que contemplam um *network* que envolve grande quantidade de indivíduos em diferentes etapas da cadeia de suprimentos, exigindo elevado nível de gestão, confiabilidade, agilidade e transparência no fluxo de informações.

Com este fim, estão estruturadas três etapas com objetivos específicos bem definidos. Inicialmente são analisados o estado atual das pesquisas aplicadas da tecnologia *Cloud Manufacturing*, identificando as principais linhas de estudos e potenciais lacunas. Em paralelo são caracterizados os desafios e oportunidades da aplicação dos conceitos e tecnologias *Lean Automation* em micro, pequenas e médias empresas brasileiras, através de uma *survey*, mapeando as forças e fraquezas em diversos segmentos da indústria, comércio e serviços. Por fim, é definido um modelo de integração entre *stakeholders* utilizando a combinação de princípios *Lean* e das tecnologias *Cloud Manufacturing* e *Blockchain*.

A proposta se cumpre com a análise e simulação do sistema computacional com uma nova abordagem de aplicação e integração tecnológica em relação aos aspectos identificados como lacunas de pesquisa, incluindo: integração de *stakeholders* na produção colaborativa de produtos customizados, condições de flexibilidade e adaptabilidade à variações de demanda, relacionamento coordenado de cadeias envolvendo pequenas e médias empresas, comportamento de diversos participantes atuando de forma simultânea e consensual, bem como, custos e tempos transacionais da rede *Blockchain* Hyperledger Fabric operando por meio de uma máquina virtual na nuvem.

De acordo com os resultados apresentados, constata-se que o objetivo principal desta pesquisa está atingido. É possível concluir que o modelo específico estudado que combina a aplicação das tecnologias *Cloud Manufacturing* e *Blockchain* com processos *Lean* se mostrou viável, e conforme a simulação, esta proposta apresenta os seguintes potenciais:

- favorece o compartilhamento e visualização das informações por todos os *players* evitando ineficiências, distorções ou perda de informação ao longo da cadeia;
- mostra-se robusta em transações envolvendo *network* com grande quantidade de participantes, prevenindo atrasos na comunicação ou custos extras através da automação da distribuição do banco de dados;
- apresenta capacidade de escalabilidade para aplicações que envolvam grandes volumes de dados, evidenciando baixos tempos de latência, custos transacionais irrisórios e oferecendo uma rede aberta, disponível para utilização via *web*;
- promove a todos os integrantes a oportunidade de participar das tomadas de decisão, evitando retrabalho e melhorando os padrões de qualidade, através da decisão simultânea e consensual;
- oferece um ambiente de comunicação homogêneo que facilita a integração de empresas participantes à cadeia, incluindo MPMEs, por meio de máquina virtual na nuvem através de interface *web*;
- proporciona ganhos em segurança cibernética com os recursos de criptografia da rede *Blockchain*;
- reduz a necessidade de altos investimentos no desenvolvimento e implementação de sistemas computacionais avançados, estabelecendo um ecossistema mais transparente e inclusivo.

4.1 OPORTUNIDADES FUTURAS

O desenvolvimento desta dissertação limita-se a estudos envolvendo uma amostra de MPMEs do interior do estado de São Paulo e a simular, na rede *Blockchain* Hyperledger Fabric, uma rotina de funções e contratos inteligentes em etapas específicas da produção colaborativa de materiais customizados, em um modelo conceitual *Just-in-Time Delivery* baseado na literatura acessada sobre *Lean Automation*.

Considerando as limitações deste modelo conceitual, são sugeridos estudos futuros que apliquem seus conceitos em uma condição real através de estudos de caso, ou expandindo sua abrangência a redes de empresas de diferentes localidades, envolvendo outros países emergentes e outros segmentos de negócio.

A recomendação de avanço com estudos futuros na linha de pesquisa pode promover a exploração de alguns desafios e oportunidades de melhorias mapeados nesta pesquisa, como barreiras culturais e paradigmas relativos ao emprego das tecnologias *Blockchain* e *Cloud Computing*, baixa familiaridade na utilização de contratos inteligentes podendo resultar em falhas na interpretação ou aproveitamento dos dados, falhas na gestão ou na execução dos processos produtivos que andam em paralelo à automação dos contratos inteligentes, ou ainda, escassez de recursos financeiros para adequação tecnológica.

Adicionalmente, como oportunidades futuras, identifica-se a necessidade de novos estudos com simulação ou estudos de caso envolvendo outras etapas do ciclo produtivo de processos *Lean Automation*, como *Make to Order* e transporte, práticas *Six Sigma,* princípios da sustentabilidade, ou economia circular, bem como o desenvolvimento de pesquisas envolvendo outras plataformas *Blockchain* descentralizadas, como Ethereum e IBMBlockchain, outros ambientes da computação em nuvem, ou ainda, explorando outras tecnologias habilitadoras da Indústria 4.0, como telecomunicação 5G, inteligência artificial, aprendizado de máquina, RFID, manufatura aditiva, CAD/CAM, IoT ou metaverso, entre outras.

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APÊNDICES E ANEXOS

Os documentos apresentados nas seções de Apêndices e Anexos, complementam a argumentação desta dissertação. Alguns dados associados a esta produção científica também estão armazenados e disponíveis no Repositório de Dados de Pesquisa (REDU) da Unicamp, sob os seguintes identificadores DOI (*Digital Object Identifier*):

https://doi.org/10.25824/redu/JCPFUA

https://doi.org/10.25824/redu/RLA4FC

APÊNDICE A – Questionário *online*: adaptado de Grama (2007), Mana (2018) e Storolli (2020), padrão Google Forms (https://forms.gle/b9VLhrZjhRHvMyuQ7). Utilizado na *survey* do artigo 2.

Pesquisa: Caracterização de oportunidades e desafios na implementação de um modelo Lean Automation em PMEs brasileiras

1. Você está sendo convidado a responder a uma pesquisa acadêmica da UNICAMP (Universidade Estadual de Campinas), com foco em apoiar o desenvolvimento tecnológico de pequenas e médias empresas brasileiras.
2. Essa pesquisa será realizada através da aplicação de um questionário online para caracterização do perfil da empresa e das tecnologias utilizadas.
3. Informamos que todas as perguntas do questionário deverão ser respondidas obrigatoriamente pelo participante da pesquisa, para que esta seja considerada válida.
4. O preenchimento do questionário se dá através da marcação de uma opção para cada pergunta.

A seguir, apresenta-se o documento intitulado Termo de Consentimento Livre e Esclarecido, aprovado pelo comitê de ética da UNICAMP, o qual visa assegurar seus direitos como participante da pesquisa e é elaborado em duas vias que serão validadas eletronicamente pelo pesquisador e pelo participante. Ressalta-se a importância de o participante guardar em seus arquivos o e-mail que receberá com a cópia do questionário de pesquisa.

Ressalta-se a importância de o participante guardar em seus arquivos o e-mail que receberá com a cópia do questionário de pesquisa.

Em relação ao convite de sua cooperação como participante, destaca-se que você somente será abordado uma única vez para contribuir com a pesquisa. Caso não tenha interesse de colaborar com a pesquisa, você não será convidado a participar novamente.

Por favor, leia com atenção e calma e aproveite para esclarecer suas dúvidas. Se houver perguntas você poderá esclarecê-las com o pesquisador. Não haverá nenhum tipo de penalização ou prejuízo se você não aceitar participar ou retirar sua autorização em qualquer momento.

*Obrigatório

E-mail *

Seu e-mail

Termo de Consentimento Livre e Esclarecido

Justificativa e objetivos:
A aplicação de tecnologias inovadoras vem sendo estudada em diversos cenários da indústria de manufatura. A abordagem que combina tais tecnologias digitais de automação com os conceitos de sistema de produção enxuta é também chamada de Lean Automation. Este projeto visa investigar o nível de aplicação dessas tecnologias inovadoras, seus benefícios e barreiras, auxiliando assim as pequenas e médias empresas brasileiras no seu desenvolvimento tecnológico.

Procedimentos:
Participando do estudo você está sendo convidado a responder o questionário que será enviado através de um link por e-mail, utilizando a ferramenta "Google Forms", com duração média de 15 minutos.

Desconfortos e riscos:
A pesquisa não apresenta riscos previsíveis ao participante. Por se tratar de um ambiente virtual os pesquisadores ficam limitados na garantia da total confidencialidade dos dados, pois existem riscos potenciais inerentes de atuação de hackers no acesso indevido das informações. Fora desse contexto os pesquisadores se comprometem em manter sigilo dos dados pessoais dos participantes durante e após a realização da pesquisa. Você não deve participar deste estudo se for contra a política de sua empresa ou se sentir qualquer desconforto em fornecer as informações solicitadas.

Benefícios:
Ao participar, você irá contribuir com a difusão do conhecimento de tecnologias inovadoras e métodos Lean em seu ramo de atuação.

Acompanhamento e assistência:
Os responsáveis pela pesquisa estarão disponíveis por meio eletrônico (e-mail e telefone) ou pessoalmente (se possível) para auxílio, tirar dúvidas e acompanhamento. Você tem o direito à assistência integral e gratuita devido a danos diretos e indiretos, imediatos e tardios, pelo tempo que for necessário.

Sigilo e privacidade:
Você tem a garantia de que sua identidade será mantida em sigilo e nenhuma informação será dada a outras pessoas que não façam parte da equipe de pesquisadores. Na divulgação dos resultados desse estudo, seu nome não será citado.

Ressarcimento e Indenização:
Esta pesquisa não apresenta nenhuma despesa e remuneração referente à participação. Você terá a garantia ao direito à indenização diante de eventuais danos decorrentes da pesquisa, conforme determina a lei vigente.

Contato:
Em caso de dúvidas sobre a pesquisa, você poderá entrar em contato com os pesquisadores:

1) Daniel Morelli: email d023433@dac.unicamp.br e telefone (11) 9 6145-5684.
2) Gabriella Colombo: email g265747@dac.unicamp.br e telefone (11) 9 6134 7131.
3) Giovana Catussi Paschoalotto: email g161560@dac.unicamp.br e telefone (18) 99795-2901.
4) Pedro Henrique Ribeiro Botene: email p265751@dac.unicamp.br e telefone (19) 98102-6117.

Faculdade de Ciências Aplicadas (FCA) – Universidade Estadual de Campinas (UNICAMP), Rua Pedro Zaccaria, 1300, Limeira.

Em caso de denúncias ou reclamações sobre sua participação e sobre questões éticas do estudo, você poderá entrar em contato com a secretaria do Comitê de Ética em Pesquisa (CEP) da UNICAMP das 08:00hs às 11:30hs e das 13:00hs as 17:30hs na Rua: Tessália Vieira de Camargo, 126; CEP 13083-887 Campinas – SP; telefone (19) 3521-8936 ou (19) 3521-7187; e-mail: cep@fcm.unicamp.br.

O Comitê de Ética em Pesquisa (CEP).
O papel do CEP é avaliar e acompanhar os aspectos éticos de todas as pesquisas envolvendo seres humanos. A Comissão Nacional de Ética em Pesquisa (CONEP), tem por objetivo desenvolver a regulamentação sobre proteção dos seres humanos envolvidos nas pesquisas. Desempenha um papel coordenador da rede de Comitês de Ética em Pesquisa (CEPs) das instituições, além de assumir a função de órgão consultor na área de ética em pesquisas.

Consentimento livre e esclarecido: Após ter recebido esclarecimentos sobre a natureza da pesquisa, seus objetivos, métodos, benefícios previstos, potenciais riscos e o incômodo que esta possa acarretar, aceito participar: *

☐ Sim. Aceito participar.

Nome do (a) participante da pesquisa: *

Data *

Data

/ /

Responsabilidade do Pesquisador:

Asseguro ter cumprido as exigências da resolução 466/2012 CNS/MS e complementares na elaboração do protocolo e na obtenção deste Termo de Consentimento Livre e Esclarecido. Asseguro, também, ter explicado e fornecido uma via deste documento ao participante da pesquisa. Informo que o estudo foi aprovado pelo CEP perante o qual o projeto foi apresentado e pela CONEP, quando pertinente. Comprometo-me a utilizar o material e os dados obtidos nesta pesquisa exclusivamente para as finalidades previstas neste documento ou conforme o consentimento dado pelo participante da pesquisa.

Limeira, 4 de junho de 2021.

Daniel Alexandre Morelli
Gabriella Carlucci Tavares Colombo
Giovana Catussi Paschoalotto
Pedro Henrique Ribeiro Botene

Próxima

Parte 1 - Caracterização da amostra

Idade do participante *

Sua resposta

Gênero

- ◯ Feminino
- ◯ Masculino
- ◯ Prefiro não dizer

Posição/Cargo/Função *

Tempo na função *

- ◯ Menos de 6 meses
- ◯ De 6 meses a 1 ano
- ◯ De 1 ano a 2 anos
- ◯ Mais de 2 anos

Qual o seu nível de escolaridade? *

- ◯ EM: Ensino Médio
- ◯ GR: Graduação
- ◯ PG: Pós-Graduação/MBA
- ◯ MS: Mestrado
- ◯ DR: Doutorado
- ◯ Outro:

Nome da Empresa *

Município/Estado de Localização da Empresa *

Setor Empresarial *

- ◯ Comércio
- ◯ Serviços
- ◯ Indústria
- ◯ Construção Civil
- ◯ Agropecuária
- ◯ Outro: _____

Segmento Empresarial *

- ◯ Textil / Vestuário / Confecção
- ◯ Química
- ◯ Metalúrgica / Metal Mecânico
- ◯ Eletrônico / Tecnológico
- ◯ Papel e celulose
- ◯ Agroindustrial
- ◯ Alimentos
- ◯ Automotivo
- ◯ Cerâmico
- ◯ Outro: _____

Porte da Empresa *

- ◯ MEI - Microempreendedor Individual
- ◯ ME - Microempresa
- ◯ EPP - Empresa de Pequeno Porte
- ◯ Empresa de Médio Porte
- ◯ Grande Empresa
- ◯ Outro: _____

Quantidade de funcionários *

_____

01) Como você julga o seu nível de conhecimento ou familiaridade com os conceitos do Lean Manufacturing? *

- ◯ 0 = nenhum 0%
- ◯ 1 = parcial 25%
- ◯ 2 = parcial 50%
- ◯ 3 = parcial 75%
- ◯ 4 = total 100%

02) Como você julga o seu nível de conhecimento ou familiaridade com os conceitos da Indústria 4.0? *

- ◯ 0 = nenhum 0%
- ◯ 1 = parcial 25%
- ◯ 2 = parcial 50%
- ◯ 3 = parcial 75%
- ◯ 4 = total 100%

Voltar Próxima

Parte 2 - Práticas e métodos utilizados pela empresa

03) Sua empresa utiliza ferramentas ou sistemas de gestão da produção, do tipo MRP (Materials Requirements Planning), MRP II (Manufacturing Resource Planning), MPS (Master Production Schedule), ou outros, integrando diferentes departamentos e parceiros comerciais? *

- ◯ 0= "não existente" ou "não sei"
- ◯ 1= Sistema de gestão de produção, em fase de implementação
- ◯ 2= Sistema de gestão de produção, já implementado em alguns departamentos da minha empresa
- ◯ 3= Sistema de gestão de produção, já implementado em todos os departamentos da minha empresa
- ◯ 4= Sistema de gestão de produção, já implementado em minha empresa e integrado com meus clientes e fornecedores.

04) Sua empresa utiliza o sistema puxado de produção, Kanban, ou outras ferramentas, baseado no sistema Toyota, para redução de desperdícios? *

- ◯ 0= "não existente" ou "não sei"
- ◯ 1= Sistema puxado de produção com controle manual dos estoques de materiais, em fase de implementação
- ◯ 2= Sistema puxado de produção com controle manual dos estoques de materiais, já implementados
- ◯ 3= Sistema puxado de produção com controle automático dos estoques de materiais, já implementado
- ◯ 4= Sistema puxado de produção com controle automático dos estoques de materiais, já implementado e integrado com fornecedores e clientes.

05) Sua empresa possui um sistema de gestão de estoque para controle de volume mínimo e máximo de material? *

- ◯ 0= "não existente" ou "não sei"
- ◯ 1= Sistema de controle de estoque em fase de implementação
- ◯ 2= Sistema de controle de estoque manual já implementado
- ◯ 3= Sistema de controle de estoque de forma automática já implementado
- ◯ 4= Sistema de controle de materiais de forma automática já implementado e as informações são integradas com a produção, cliente e fornecedores.

06) Sua empresa promove programas de certificação e/ou incentivo de implementação de práticas de gestão da qualidade em seus processos internos e em seus fornecedores? *

- ◯ 0= "não existente" ou "não sei"
- ◯ 1= Programas de certificação e/ou incentivo de implementação de práticas de gestão da qualidade em fase de implementação
- ◯ 2= Programas de certificação e/ou incentivo de implementação de práticas de gestão da qualidade já implementados em seus processos internos
- ◯ 3= Programas de certificação e/ou incentivo de implementação de práticas de gestão da qualidade já implementados em seus processos internos e em seus fornecedores
- ◯ 4= Programas de certificação e/ou incentivo de implementação de práticas de gestão da qualidade já implementados em seus processos internos, em seus fornecedores e na homologação de novos fornecedores.

07) Sua empresa utiliza ferramentas ou sistemas de compartilhamento de informações na cadeia de fornecimento, integrando máquinas e equipamentos a fornecedores e clientes? *

- ◯ 0= "não existente" ou "não sei"
- ◯ 1= Minha empresa utiliza compartilhamento de informações por e-mail com clientes e fornecedores
- ◯ 2= Minha empresa utiliza plataformas profissionais para compartilhamento de informações com clientes e fornecedores
- ◯ 3= Minha empresa utiliza plataformas profissionais para compartilhamento de informações em tempo real com clientes e fornecedores.
- ◯ 4= Minha empresa utiliza tecnologia de comunicação entre máquinas (IoT) para compartilhamento de informações em tempo real com clientes e fornecedores

08) Sua empresa utiliza ferramentas de sistemas digitais portáteis, do tipo celulares, tablets, ou similares, nos controles dos processos? *

- ◯ 0= "não existente" ou "não sei"
- ◯ 1= Sistemas digitais portáteis em fase de implementação
- ◯ 2= Sistemas digitais portáteis já implementados em alguns processos da minha empresa
- ◯ 3= Sistemas digitais portáteis já implementados em todos os processos da minha empresa
- ◯ 4= Sistemas digitais portáteis já implementados em todos os processos da minha empresa e integrados com meus clientes e fornecedores

09) Sua empresa utiliza técnicas de segurança dos dados de informática, do tipo antivírus, gateway, sistemas avançados Cyber Security ou similares? *

- ◯ 0= "não existente" ou "não sei"
- ◯ 1= Sistemas de segurança de dados de informática em fase de implementação
- ◯ 2= Sistemas antivírus já implementados em todos os computadores da rede da minha empresa
- ◯ 3= Sistemas antivírus e gateways já implementados em todos os computadores da minha empresa
- ◯ 4= Sistemas de criptografia avançada e Cyber Security implementados em todos os computadores da minha empresa.

10) Sua empresa utiliza sistema informatizado para monitoramento e rastreamento de produtos ou materiais em tempo real? Através do uso de ferramentas do tipo código de barras, RFID ou similares? *

- ◯ 0= "não existente" ou "não sei"
- ◯ 1= Sistema de gestão por código de barras, ou similar, em fase de implementação
- ◯ 2= Sistema de gestão por código de barras, ou similar, já implementado
- ◯ 3= Sistema com tags e sensores RFID, em fase de implementação
- ◯ 4= Sistema com tags e sensores RFID, já implementado.

11) Sua empresa faz o uso de sensores para monitoramento do processo produtivo, como sensores de temperatura, umidade, presença, movimento, atuadores ou similares? *

- ◯ 0= "não existente" ou "não sei"
- ◯ 1= Sensores para monitoramento do processo produtivo em fase de implementação
- ◯ 2= Sensores para monitoramento do processo produtivo já implementados
- ◯ 3- Sensores para monitoramento em tempo real do processo produtivo implementado
- ◯ 4= Sensores para monitoramento em tempo real do processo produtivo implementado e integrado com toda a cadeia de produção

12) Sua empresa acessa serviços ou recursos computacionais através da internet? *

- ◯ 0= "não existente" ou "não sei"
- ◯ 1= Os computadores da minha empresa têm acesso à internet
- ◯ 2= Os computadores da minha empresa têm acesso à internet e já utiliza alguns aplicativos de armazenamento de dados em nuvem como Google Drive, Dropbox, Amazon Cloud, ou similar
- ◯ 3= Os computadores da minha empresa têm acesso à internet e tem seus principais datacenters ou servidores em nuvem
- ◯ 4= Os computadores da minha empresa têm acesso à internet, utiliza datacenters ou servidores em nuvem e integra suas bases de dados com fornecedores e clientes.

13) Sua empresa utiliza um sistema de análise de dados internos da corporação e externos (fornecedores e clientes) para gestão da cadeia de suprimentos? *

- ◯ 0= "não existente" ou "não sei"
- ◯ 1= Sistemas de análise de dados em implementação
- ◯ 2= Sistemas de análise de dados através de planilhas de preenchimento manual, como MS Excel
- ◯ 3= Sistemas de análise de dados através de softwares específicos, como Minitab, Matlab ou similares
- ◯ 4= Sistemas de análise de dados com tecnologia autônoma de tomada de decisão em tempo real.

14) Sua empresa e seus fornecedores utilizam sistemas integrados de engenharia para visualização, modelagem e simulação no desenvolvimento de produtos? Através do uso de ferramentas do tipo CAD, CAM ou similares? *

- ◯ 0= "não existente" ou "não sei"
- ◯ 1= A minha empresa contrata serviços para modelagem e desenvolvimento de produtos
- ◯ 2= Tecnologias de modelagem de produtos, em fase de implementação na minha empresa
- ◯ 3= Tecnologias de modelagem de produtos, já implementados na minha empresa para desenvolvimento de produtos
- ◯ 4= Tecnologias de modelagem de produtos, já implementados na minha empresa para desenvolvimento de produtos e/ou gestão da produção.

Uma cópia das suas respostas será enviada para o endereço de e-mail fornecido

Voltar | Enviar

Nunca envie senhas pelo Formulários Google.

APÊNDICE B – Código computacional: com a rotina programada para o contrato inteligente na rede *Blockchain* Hyperledger Fabric, desenvolvido nesta pesquisa, para o artigo 3. Outros dados da programação computacional estão disponíveis no repositório da Unicamp e podem ser acessados pelo link: https://doi.org/10.25824/redu/RLA4FC

```
'use strict';

const { Contract } = require('fabric-contract-api');

class Chaincode extends Contract {

    async initLedger(ctx) {
        console.info('Initialized Ledger');
    }

    async queryBlockchain(ctx, key) {
        const dataAsBytes = await ctx.stub.getState(key);
        if (!dataAsBytes || dataAsBytes.length === 0) {
            throw new Error(`${key} does not exist`);

        }
        console.info(dataAsBytes.toString());
        return dataAsBytes.toString();
    }

    async invokeTransaction(ctx, id, jsonPayload) {

        await ctx.stub.putState(id, JSON.stringify(jsonPayload));

    }

    async registrarFornecedor(ctx, id, jsonPayload) {
        await ctx.stub.putState(id, jsonPayload);
        return 'Fornecedor registrado com sucesso';
    }

    async registrarCompra(ctx, codigoCompra, jsonPayload) {

        const jsonItems = JSON.parse(jsonPayload);

        const fornecedoresCompativel = await this.compatibilidade(ctx,
jsonItems.tecnologiaManufatura, jsonItems.materialBase, jsonItems.regiao);

        jsonItems.compatibilidade = fornecedoresCompativel;
        await ctx.stub.putState(codigoCompra, JSON.stringify(jsonItems));


        const ordManfAsBytes = await ctx.stub.getState(jsonItems.idManufatura);
        let ordManJson = JSON.parse(ordManfAsBytes.toString());

        ordManJson['codigoCompra'] = codigoCompra;
        console.log("   ordManJson['codigoCompra'] ",
ordManJson['codigoCompra']);

        await ctx.stub.putState(jsonItems.idManufatura,
JSON.stringify(ordManJson));

        return 'Compra registrada com sucesso';
    }

    async registrarProposta(ctx, codigoCompra, proposta) {
        const dataAsBytes = await ctx.stub.getState(codigoCompra);
        let compraJson = JSON.parse(dataAsBytes.toString());
        const propostaJson = JSON.parse(proposta)

        if (compraJson.propostas == undefined) {
            compraJson.propostas = [propostaJson];
        } else {
            compraJson.propostas.push(propostaJson);
```

```
        }
        compraJson.compatibilidade

        await ctx.stub.putState(codigoCompra, JSON.stringify(compraJson));
        return 'Proposta registrada com sucesso';

    }

    async aceitarProposta(ctx, codigoCompra, idFornecedorAceita,
statusClienteFinal, statusProdutor) {
        let statusFinal = "";

        const dataAsBytes = await ctx.stub.getState(codigoCompra);
        let compraJson = JSON.parse(dataAsBytes.toString());
        compraJson.propostas.forEach(item => {
            if (item.fornecedor == idFornecedorAceita) {
                if (item.status == "Aceito pelo produtor(aguardando consenso do
cliente final)") {
                    item.status = "Aceito por consenso";
                    statusFinal = "Aceito por consenso";
                } else if (item.status == "Aceito pelo cliente final(aguardando
consenso do produtor)") {
                    item.status = "Aceito por consenso";
                    statusFinal = "Aceito por consenso";
                } else {
                    if (statusClienteFinal == "Aceito") {
                        item.status = "Aceito pelo cliente final(aguardando
consenso do produtor)";
                        statusFinal = "Aceito pelo cliente final(aguardando
consenso do produtor)";
                    }

                    if (statusProdutor == "Aceito") {
                        item.status = "Aceito pelo produtor(aguardando consenso
do cliente final)";
                        statusFinal = "Aceito pelo produtor(aguardando consenso
do cliente final)";
                    }
                }

                if (statusClienteFinal == "Rejeita" || statusProdutor ==
"Rejeita") {
                    item.status = "Rejeitado";
                    statusFinal = "Rejeitado";
                }
            }
        });

        await ctx.stub.putState(codigoCompra, JSON.stringify(compraJson));
        return statusFinal;

    }

    async registrarOrdemManufatura(ctx, idManufatura, jsonPayload) {
        const jsonItems = JSON.parse(jsonPayload);
        await ctx.stub.putState(idManufatura, JSON.stringify(jsonItems));
        return 'Solicitação de Manufatura registrada com sucesso';
    }


    async concluirOrdemManufatura(ctx, idManufatura, observacoesFinais) {

        const ordManfAsBytes = await ctx.stub.getState(idManufatura);
        let ordManJson = JSON.parse(ordManfAsBytes.toString());
```

```
        ordManJson.observacoesFinais = observacoesFinais;
        ordManJson.status = "Produto acabado conforme solicitação do cliente";

        await ctx.stub.putState(idManufatura, JSON.stringify(ordManJson));

        return "Produto acabado conforme solicitação do cliente";
    }

    async buscarPropostas(ctx, chaveProposta) {
        const proposta = await ctx.stub.getState(chaveProposta);
        return proposta.toString();
    }

    async buscarPropostasFornecedor(ctx, idFornecedor) {
        // const queryString = `{"selector":{"propostas":{"$regex":"$
{idFornecedor}"}}}`;
        const queryString = `{"selector":{"propostas":{"$elemMatch":
{"fornecedor": "${idFornecedor}"}}}}`;
        console.log(queryString);
        const allResults = [];
        const iterator = await ctx.stub.getQueryResult(queryString);
        console.log(iterator);

        if (iterator.length == 0) {
            return 'Nenhuma proposta encontrada para o fornecedor';
        }

        while (true) {
            const res = await iterator.next();
            if (res.value) {

                const fornecedorJson =
JSON.parse(res.value.value.toString('utf8'))

                allResults.push(fornecedorJson);

            }
            console.log(allResults);
            if (res.done) {
                await iterator.close();
                return allResults;
            }
        }

    }

    async compatibilidade(ctx, tecnologia, material, regiao) {
        const queryString = `{"selector":{"tecnologiaManufatura":{"$regex":"$
{tecnologia}"},"materialBase":{"$regex":"${material}"},"regiao":{"$regex":"$
{regiao}"}}}`;
        console.log(queryString);
        const allResults = [];
        const iterator = await ctx.stub.getQueryResult(queryString);
        console.log(iterator);
        if (iterator == undefined) {
            return 'Nenhuma compatibilidade encontrada';
        }

        while (true) {
            const res = await iterator.next();
            if (res.value) {

                const fornecedorJson =
JSON.parse(res.value.value.toString('utf8'))
```

```
                const id = fornecedorJson.idFornecedor;
                if (id !== undefined) {
                    allResults.push(id);
                }
            }
            console.log(allResults);
            if (res.done) {
                await iterator.close();
                return allResults;
            }
        }
    }
}

module.exports = Chaincode;
```

ANEXO A – Parecer consubstanciado do CEP/CONEP – UNICAMP: relatório de aceitação e aprovação da pesquisa, conforme o certificado de apresentação de apreciação ética (CAAE) número 47885521.0.0000.5404.

UNICAMP - CAMPUS CAMPINAS

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: CARACTERIZAÇÃO DE OPORTUNIDADES E DESAFIOS NA IMPLEMENTAÇÃO DE UM MODELO LEAN AUTOMATION EM PMEs BRASILEIRAS

Pesquisador: DANIEL ALEXANDRE MORELLI

Área Temática:

Versão: 2

CAAE: 47885521.0.0000.5404

Instituição Proponente: Faculdade de Ciências Aplicadas - FCA

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 4.860.664

Apresentação do Projeto:

Introdução: O esforço por redução de custos e desperdícios é um aspecto bastante evidente na indústria para se atingir níveis satisfatórios de competitividade de mercado. Diversas são as técnicas e ferramentas desenvolvidas nas últimas décadas com este fim, dentre elas, destacamos os Sistemas de Produção Enxuta, ou Lean Production Systems (LPS), que surgiram no início dos anos 1990, cujos procedimentos podem ser aplicados nos mais diversos setores da manufatura para otimização de tempo de processos, melhoria contínua, eficiência produtiva e redução de desperdícios (MANA; MAKYIA; CESAR, 2016).SISTEMAS LEAN DE PRODUÇÃO (LPS)A filosofia Lean teve seu início no Japão pós guerra. Referenciada na época como Sistema Toyota de Produção, só passou a ser conhecida como Lean Manufacturing em 1990 quando Womack, Jones e Roos (2007) publicaram a primeira edição do livro "A máquina que mudou o mundo", evidenciando os benefícios proporcionados por esta filosofia de produção, como produzir mais com menos defeitos, ao mesmo tempo que recursos como funcionários, tempo e espaço são reduzidos e a qualidade é melhorada (BHAMU; SANGWAN, 2014; KIM; SPAHLINGER; BILLI, 2009; WOMACK; JONES; ROOS, 2007).O Lean tem em sua essência a capacidade de eliminar desperdícios e resolver problemas de forma contínua (LEAN INSTITUTE BRASIL, 2021). Ela pode ser definida como um modelo alternativo de produção integrada que combina elementos altamente interrelacionados, como ferramentas, métodos e práticas de gerenciamento que objetiva gerar um sistema eficiente dedicado à melhoria contínua (BHAMU; SANGWAN, 2014; SHAH; WARD, 2007; SIMPSON; POWER,

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UF: SP **Município:** CAMPINAS
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2005).O conceito de Sistema de Produção Enxuta, também amplamente chamado de Manufatura Enxuta ou Lean Manufacturing (LM), apresenta fatores chave que contribuem para reações rápidas das empresas permitindo adaptabilidade às mudanças de demanda do mercado, através da visualização dos processos e redução dos lotes de produção (VOLPE et al., 2016). Por essas características, a filosofia Lean se mantém amplamente difundida e praticada na indústria, mesmo com as evoluções tecnológicas crescentes nas últimas décadas. INDÚSTRIA 4.0 (I4.0)O contexto atual da indústria de manufatura enfrenta padrões de consumo por produtos altamente personalizados, com elevada exigência por qualidade e baixo tempo de entrega. Esses requisitos tem direcionado empresas a adotar tecnologias digitais modernas de alta conectividade e inteligência artificial para conseguir vantagens competitivas, caracterizando a Indústria 4.0 (I4.0), ou quarta revolução industrial (SHROUF; ORDIERES; MIRAGLIOTTA, 2014).O termo Indústria 4.0 é um conceito usado para descrever a Quarta Revolução Industrial, caracterizada pela tecnologia na automação e a troca de dados de uma forma inteligente, com uma rede auto gerenciada, obtida através da união das técnicas de produção, tecnologia da informação (TI) e Internet, com o objetivo de integrar o mundo físico e virtual. Isso dará início a uma nova fase na industrialização e automação, trazendo assim grandes oportunidades e desafios (AICHHOLZER et al., 2015). Segundo (FREITAS; FRAGA; SOUZA, 2016), a nova indústria digital promete aumentar a
flexibilidade na produção, a customização em massa, a velocidade no processo na cadeia de valor, a melhorar a qualidade do produto e produtividade. Essas melhorias são atingíveis se seguirem alguns conceitos pré-estabelecidos pela ideia da Indústria 4.0, tais como: sistemas Ciberfísicos, Big Data, Computação em nuvem, Internet das Coisas (IoT), Internet dos Serviços (IoS), Manufatura aditiva, Inteligência Artificial, entre outras. LEAN AUTOMATION: Considerando ambas as filosofias Lean Production Systems e Indústria 4.0, com seus atributos de redução de custo e alta conectividade, respectivamente, surgem estudos acadêmicos de integração destes dois modelos, combinando os princípios Lean às tecnologias inovadoras da Indústria 4.0, originando o termo Lean Automation (KOLBERG; ZÜHLKE, 2015) que visa elevar a flexibilidade produtiva com fluxos ágeis de informação. Dentre as pesquisas sobre Lean Automation (LA), são abordados conceitos teóricos e práticos que identificam potenciais fatores de sucesso de aplicação em diversos segmentos industriais. Por meio de questionários envolvendo empresas de setores variados, alguns trabalhos já identificaram quais combinações genéricas de tecnologias da Indústria 4.0 com princípios Lean podem proporcionar maiores ganhos e integração aos sistemas (DOMBROWSKI; RICHTER; KRENKEL, 2017; RYBSKI; JOCHEM, 2020; TORTORELLA et al., 2020), outros apontam caminhos de implementação para alta performance desta filosofia (TORTORELLA;

NARAYANAMURTHY; THURER, 2021).A proposta de aplicação de modelos específicos de Lean Automation que envolvem a gestão da informação enxuta em ambientes cyber-físicos automatizados por sensores, controladores e atuadores, integrados à princípios Lean, também já tem sido abordada em alguns estudos acadêmicos em países europeus e asiáticos (CHANARUNGRUENGKIJ; KAITWANIDVILAI, 2018; MA; WANG; ZHAO, 2017; WAGNER; HERRMANN; THIEDE, 2017), no entanto, nota-se a ausência da avaliação de aplicabilidade de um modelo característico de Lean Automation a um determinado processo da cadeia de suprimentos de PMEs brasileiras.

Hipótese: Dentro do contexto da pesquisa proposta, vem o questionamento sobre a resposta esperada, onde a hipótese se consolida na seguinte questão de pesquisa: "Qual é a situação atual das pequenas e médias empresas (PMEs) brasileiras em relação à implementação dos modelos inovadores Lean Automation (LA)?"

Metodologia Proposta: O processo de pesquisa foi estruturado em quatro etapas: (i) Identificação, (ii) Elegibilidade, (iii) Modelagem, e (iv) Análise da Survey.A etapa de identificação será desenvolvida através da revisão bibliográfica, sendo desenvolvida com base em material já elaborado, construído principalmente de artigos científicos e livros (GIL, 2002), com a finalidade de identificar conceitos, métodos e ferramentas Lean e da Indústria 4.0, bem como a associação de ambas as filosofias, que origina o conceito do Lean Automation.Na etapa de elegibilidade foram selecionados os artigos com estudo de casos aplicados e destacadas as tecnologias mais adequadas às práticas das PMEs em diversos mercados. Além disso, esta etapa facilita a formulação de hipóteses, limitações de pesquisa e serve de base para a criação do modelo de Lean Automation.No caso da modelagem de um processo tecnológico Lean Automation, foram aplicadas as tecnologias e princípios já estudados com sucesso em pesquisas acadêmicas, e assim foi desenvolvido e proposto um modelo inovador ao processo Just-in-Time (JIT) Delivery, que envolve as etapas de identificação, seleção e monitoramento de fornecedores de produtos personalizados (DOMBROWSKI; RICHTER; KRENKEL, 2017; RYBSKI; JOCHEM, 2020; TORTORELLA et al., 2020; WAGNER; HERRMANN; THIEDE, 2017).Para avaliação da aplicabilidade do modelo proposto foi realizada a aplicação e análise de uma survey, as amostras serão definidas de acordo com informações contidas em bases de dados de acesso aberto e com a categorização de pequenas e médias empresas (BNDES, 2021; SEBRAE; FGV, 2020). O método utilizado para envio dos questionários será via e-mail e Google Forms.O questionário conterá 14 perguntas do tipo de

múltipla escolha com resposta única. Considerando que o levantamento busca obter uma percepção preliminar a respeito da adoção da tecnologia em estudo nas PMEs e descrever a distribuição do fenômeno em uma população (TURRIONI; MELLO, 2012). As perguntas do questionário serão divididas em dois grupos: (i) informativas, variáveis que dizem respeito aos conhecimentos gerais do respondente quanto ao tema e, (ii) avaliativas, que são referentes ao nível de adesão das empresas quanto ao modelo proposto. Para a forma de resposta disponível, será utilizada a Escala Likert de 5 pontos. Nos questionários com Escala Likert os entrevistados especificam seu nível de concordância com um item do questionário, por meio de um critério subjetivo ou objetivo (GRAMA, 2007; MANA, 2018; STOROLLI, 2020).As questões devem envolver: i. Caracterização da amostragem: Identificação do respondente, formação profissional, cargo, função, segmento da empresa e conhecimento do tema; ii. Nivelamento tecnológico; iii. Identificar o uso das principais técnicas e ferramentas da I4.0 relacionadas ao modelo; iv. Identificar o uso das principais técnicas e ferramentas do Lean relacionadas ao modelo. Na construção do questionário desta pesquisa, optou-se pela caracterização da amostra baseada nos elementos propostos por Mana (2018) e Storolli (2020), os quais propõem o levantamento das informações de nome, localização, setor, segmento, quantidade de funcionários e porte da empresa e nível de escolaridade, posição ocupacional e conhecimento acerca dos temas Lean Manufacturing e Indústria 4.0 do respondente. Em relação ao conjunto de perguntas que buscam identificar o uso das principais técnicas da I4.0 relacionadas ao modelo, utilizou-se como substrato o questionário de Storolli (2020), o qual foi adaptado para questionamento acerca das ferramentas Mobile devices, Cyber Security, RFID, sensores, Big Data e Cloud Computing. Além disso, a partir do trabalho de Mana (2018), determinou-se as perguntas para identificação do uso das principais técnicas e ferramentas do Lean relacionadas ao modelo.

Critério de Inclusão: A pesquisa utilizará as informações coletadas de empresas de pequeno porte situadas no estado de São Paulo e que atuam nos setores de serviços e indústria. Além disso, serão considerados os participantes que sejam maiores de 18 anos de idade e que atuam nas posições de proprietários, diretores, gerentes ou coordenadores nas empresas pesquisadas.

Critério de Exclusão: Serão excluídos da pesquisa todos os participantes que não atendam aos critérios de inclusão.

Objetivo da Pesquisa:

Objetivo Primário:

O objetivo principal deste artigo é propor um modelo de aplicação das tecnologias e princípios do Lean Automation a PMEs brasileiras.

Objetivo Secundário:
Os objetivos secundários são: (i) desenvolver um modelo que contemple as tecnologias da indústria 4.0 e princípios Lean a uma etapa da cadeia de suprimentos industrial; (ii) propor uma sequência de implementação do modelo de Lean Automation - JIT-Delivery nas PMEs brasileiras; (iii) avaliar a percepção do nível de aderência atual dos diferentes setores industriais em relação ao modelo proposto; (iv) identificar as barreiras de implementação do modelo Lean Automation nas PMEs brasileiras.

Avaliação dos Riscos e Benefícios:
Riscos: A pesquisa não apresenta riscos previsíveis. Você não deve participar deste estudo se for contra a política de sua empresa ou se sentir qualquer desconforto em fornecer as informações solicitadas.

Benefícios: O participante da pesquisa não terá benefício direto sobre os resultados, ao participar, irá contribuir com a difusão do conhecimento do conceito de Lean Automation em seu ramo de atuação. Além disso, este estudo pode também contribuir na identificação das forças e fraquezas das empresas em relação à adoção das tecnologias inovadoras, identificando oportunidades para tomadas de decisões envolvendo investimentos para melhoria de produtividade, para que estas sejam equilibradas e sustentáveis.

Comentários e Considerações sobre a Pesquisa:
Este protocolo se refere ao Projeto de Pesquisa intitulado "CARACTERIZAÇÃO DE OPORTUNIDADES E DESAFIOS NA IMPLEMENTAÇÃO DE UM MODELO LEAN AUTOMATION EM PMEs BRASILEIRAS", cujo Pesquisador responsável é DANIEL ALEXANDRE MORELLI (Aluno de Pós-Graduação), com a colaboração de GABRIELLA CARLUCCI TAVARES COLOMBO (Aluna de Pós-Graduação), GIOVANA CATUSSI PASCHOALOTTO (Aluna de Pós-Graduação), PEDRO HENRIQUE RIBEIRO BOTENE (Aluno de Pós-Graduação), PAULO SERGIO DE ARRUDA IGNACIO (Professor Doutor), ANIBAL TAVARES DE AZEVEDO (Professor Doutor), ANTONIO CARLOS PACAGNELLA JÚNIOR e ALESSANDRO LUCAS DA SILVA. A Instituição Proponente é a Faculdade de Ciências Aplicadas da Unicamp. Segundo as Informações Básicas do Projeto, a pesquisa tem orçamento estimado em R$ 100,000 (cem reais) e o cronograma apresentado contempla início da Coleta de dados no dia 01/09/2021, com finalização da Submissão para publicação no dia 31/12/2021. Serão abordados ao todo 150

pessoas.

Considerações sobre os Termos de apresentação obrigatória:

Foram analisados os seguintes documentos de apresentação obrigatória:

1 - Folha de Rosto Para Pesquisa Envolvendo Seres Humanos: Foi apresentado o documento "Folha_de_Rosto_Pesquisa_Lean_Automation.pdf". Adequado.

2 - Projeto de Pesquisa: Foram analisados os documentos "Projeto_de_Pesquisa_CEP_Lean_Automation_ALTERACOES_REALCADAS.pdf" e "PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1771463.pdf". Adequado.

3 - Orçamento financeiro e fontes de financiamento: Informações sobre orçamento financeiro incluídas nos documentos "Projeto_de_Pesquisa_CEP_Lean_Automation_ALTERACOES_REALCADAS.pdf" e "PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1771463.pdf". Adequado.

4 - Cronograma: Informações sobre o cronograma incluídas nos documentos "Projeto_de_Pesquisa_CEP_Lean_Automation_ALTERACOES_REALCADAS.pdf", "PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1771463.pdf" e "Cronograma_do_projeto_de_pesquisa.pdf". Adequado.

5 - Termo de Consentimento Livre e Esclarecido e Termo de Assentimento Livre e Esclarecido: Foi apresentado o documento "TCLE_Lean_Automation_ALTERACOES_REALCADAS.pdf". Adequado.

6 – Atestado de matrícula do Pesquisador responsável: "Atestado_Matricula_2021_01sem.pdf ". Adequado

7 – Questionário google form: "Questionario_gerado_pelo_google_forms.pdf ". Adequado

8 – Carta de resposta às pendências "Carta_Resposta_CEP_Lean_Automation.pdf ". Adequado

Conclusões ou Pendências e Lista de Inadequações:

As pendências foram sanadas.

Considerações Finais a critério do CEP:

- O participante da pesquisa deve receber uma via do Termo de Consentimento Livre e Esclarecido, na íntegra, por ele assinado (quando aplicável).
- O participante da pesquisa tem a liberdade de recusar-se a participar ou de retirar seu consentimento em qualquer fase da pesquisa, sem penalização alguma e sem prejuízo ao seu cuidado (quando aplicável).
- O pesquisador deve desenvolver a pesquisa conforme delineada no protocolo aprovado. Se o pesquisador considerar a descontinuação do estudo, esta deve ser justificada e somente ser realizada após análise das razões da descontinuidade pelo CEP que o aprovou. O pesquisador deve aguardar o parecer do CEP quanto à descontinuação, exceto quando perceber risco ou dano não previsto ao participante ou quando constatar a superioridade de uma estratégia diagnóstica ou terapêutica oferecida a um dos grupos da pesquisa, isto é, somente em caso de necessidade de ação imediata com intuito de proteger os participantes.
- O CEP deve ser informado de todos os efeitos adversos ou fatos relevantes que alterem o curso normal do estudo. É papel do pesquisador assegurar medidas imediatas adequadas frente a evento adverso grave ocorrido (mesmo que tenha sido em outro centro) e enviar notificação ao CEP e à Agência Nacional de Vigilância Sanitária – ANVISA – junto com seu posicionamento.
- Eventuais modificações ou emendas ao protocolo devem ser apresentadas ao CEP de forma clara e sucinta, identificando a parte do protocolo a ser modificada e suas justificativas e aguardando a aprovação do CEP para continuidade da pesquisa. Em caso de projetos do Grupo I ou II apresentados anteriormente à ANVISA, o pesquisador ou patrocinador deve enviá-las também à mesma, junto com o parecer aprovatório do CEP, para serem juntadas ao protocolo inicial.
- Relatórios parciais e final devem ser apresentados ao CEP, inicialmente seis meses após a data deste parecer de aprovação e ao término do estudo.
-Lembramos que segundo a Resolução 466/2012 , item XI.2 letra e, “cabe ao pesquisador apresentar dados solicitados pelo CEP ou pela CONEP a qualquer momento”.
-O pesquisador deve manter os dados da pesquisa em arquivo, físico ou digital, sob sua guarda e responsabilidade, por um período de 5 anos após o término da pesquisa.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações	PB_INFORMAÇÕES_BÁSICAS_DO_P	08/07/2021		Aceito

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Continuação do Parecer: 4.860.664

Básicas do Projeto	ETO_1771463.pdf	17:13:56		Aceito
Outros	Carta_Resposta_CEP_Lean_Automation.pdf	08/07/2021 17:10:50	DANIEL ALEXANDRE	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_Lean_Automation.pdf	08/07/2021 17:08:43	DANIEL ALEXANDRE MORELLI	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_Lean_Automation_ALTERACOES_REALCADAS.pdf	08/07/2021 17:08:30	DANIEL ALEXANDRE MORELLI	Aceito
Projeto Detalhado / Brochura Investigador	Projeto_de_Pesquisa_CEP_Lean_Automation.pdf	08/07/2021 17:07:09	DANIEL ALEXANDRE MORELLI	Aceito
Projeto Detalhado / Brochura Investigador	Projeto_de_Pesquisa_CEP_Lean_Automation_ALTERACOES_REALCADAS.pdf	08/07/2021 17:05:59	DANIEL ALEXANDRE MORELLI	Aceito
Outros	Questionario_gerado_pelo_google_forms.pdf	08/07/2021 17:01:52	DANIEL ALEXANDRE	Aceito
Cronograma	Cronograma_do_projeto_de_pesquisa.pdf	09/06/2021 15:38:52	DANIEL ALEXANDRE	Aceito
Outros	Atestado_Matricula_2021_01sem.pdf	09/06/2021 14:28:03	DANIEL ALEXANDRE	Aceito
Folha de Rosto	Folha_de_Rosto_Pesquisa_Lean_Automation.pdf	09/06/2021 13:22:19	DANIEL ALEXANDRE	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

CAMPINAS, 21 de Julho de 2021

Assinado por:
jacks jorge junior
(Coordenador(a))

Endereço: Rua Tessália Vieira de Camargo, 126
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ANEXO B – Autorização da editora SPRINGER NATURE: para a inclusão do artigo *'Assessment of researches and case studies on Cloud Manufacturing: a bibliometric analysis'* na dissertação.

Licence to Publish

SPRINGER NATURE

Journal Name:	The International Journal of Advanced Manufacturing Technology	(the 'Journal')
Manuscript Number:	JAMT-D-21-01662R1	
Proposed Title of Article:	Assessment of researches and case studies on Cloud Manufacturing: a bibliometric analysis	
Author(s) [Please list all named Authors]:	DANIEL MORELLI, Paulo Sergio de Arruda Ignacio	(the 'Author')
Corresponding Author Name:	DANIEL MORELLI	

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