IMT Mines Albi-Carmaux
École Mines-Télécom

Physical Internet Enabled Hyperconnected Circular Supply Chains

Ziqing Wu[1], Raphaël Oger[1], Matthieu Lauras[1], Benoit Montreuil[2], and Louis Faugère[2]
[1]Centre Génie Industriel, IMT Mines Albi, Université de Toulouse, Albi, France
[2]Physical Internet Center, ISyE School, Georgia Institute of Technology, Atlanta, U.S.A.
Corresponding author: ziqing.wu@mines-albi.fr

Abstract: *Physical Internet (PI) and Circular Supply Chains (CSC) are both promising supply chain paradigms aiming toward the significant improvement of sustainability. PI potentially provides a set of solutions for implementing CSC as both emphasize interconnectivity. This paper presents the Hyperconnected Circular Supply Chain (HCSC) framework, which aims to combine the strengths of both CSC and PI to create a comprehensive set of guidelines for supply chain stakeholders. The proposed HCSC framework encompasses nine core characteristics, addressing aspects such as product design for circularity, on-demand materialization in PI open production fabs, local material and energy recovery, hyperconnected logistics systems for materials and products, sharing economy enablement with PI, circular functionalities exploitation for existing facilities, open and hyperconnected sustainability performance monitoring, and technological and business model innovation.*

Keywords: *Circular Supply Chain Management, Physical Internet, Hyperconnected Circular Supply Chain, Circular Economy, Sustainability, Conceptual Framework*

Conference Topic(s): *logistics and supply networks; PI fundamentals and constituents; PI impacts; PI implementation.*

Physical Internet Roadmap *(Link): Select the most relevant area for your paper: ☒ PI Nodes, ☒ PI Networks, ☒ System of Logistics Networks, ☒ Access and Adoption, ☐ Governance.*

1 Introduction

According to the Footprint Data Foundation, humanity's consumption level has exceeded the planet's ability to sustain it by 1.8 times (Global Footprint Network, 2022). The Circular Economy (CE) offers a potential solution to address unsustainability challenges by transitioning from the traditional linear "take-make-dispose" model to a restorative and regenerative framework, with a zero-waste vision (Ellen MacArthur Foundation, 2013; Geissdoerfer et al., 2017). End-of-life objects are not perceived as simply disposable items, but as valuable inputs that can be reintroduced into production processes or repurposed for alternative uses. Within a CE, material and energy loops are decelerated, constricted, and sealed, accomplished through durable design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling (Geissdoerfer et al., 2017).

Supply Chain Management has historically focused on adding value, maximizing profitability through operational efficiencies, and ensuring customer satisfaction (Stock & Boyer, 2009). However, the growing importance of sustainability-related concerns has prompted the development of new frameworks, such as Circular Supply Chain Management (CSCM), which integrates circular thinking into the traditional supply chain paradigm (Batista et al., 2018; Farooque et al., 2019; Montag, 2022).

While conventional supply chains aim to maximize the supply chain's added value, Circular Supply Chains (CSC) seek to reconcile sustainability and circularity goals (Chopra & Meindl, 2016; Vegter et al., 2020; Montag & Pettau, 2022). CSCM serves as a vital mechanism for implementing CE principles within supply chain processes and practices. CSC research is currently in its nascent phase, offering numerous research opportunities for the practical adoption of its principles (Montag, 2022).

Interconnectivity among various stakeholders is an inherent requirement for CSC. To effectively and efficiently valorize secondary materials and resources, it is essential to facilitate the seamless material, information, and financial exchange among independent companies (Saavedra et al., 2018). The Physical Internet (PI), an alternative supply chain paradigm, is distinguished by its hyperconnectivity (Montreuil, 2011; Montreuil et al., 2012). This feature implies a high degree of interconnection among components and actors across multiple layers, facilitating real-time interactions at any time and place (Montreuil, 2020).

Physical Internet (PI) potentially provides a set of solutions for implementing CSC principles, through hyperconnectivity, horizontal collaboration, and optimal use of supply chain assets (Ballot et al., 2021). Despite its potential, no existing study has explored the possible synergy between PI and CSC to the best of our knowledge. The research question of this paper is thus: How can PI inspire and contribute to the implementation of CSC? In response, we introduce a conceptual framework for Hyperconnected Circular Supply Chains (HCSC) to contribute toward bridging the gap.

The remainder of this paper is structured as follows: Section 2 provides an overview and key elements of CSC and PI. In Section 3, we introduce the concept of Hyperconnected Circular Supply Chains (HCSC) and elaborate on its major characteristics. Section 4 concludes and suggests future research directions.

2 Circular Supply Chains and Physical Internet

As the aim of this paper is to investigate the potential synergy between CSC and PI, it is necessary to provide a concise introduction to these two concepts and their key characteristics. Therefore, the first part of this section is dedicated to outlining the definition of CSC and its archetypal characteristics, as described by Montag (2022); the second part describes the major characteristics of PI.

2.1 Circular Supply Chains

Considering the early stage of CSC and CSCM conceptualization, there is currently no consensus on their definitions. Batista et al. (2018) characterize CSC as the coordination of forward and reverse supply chains, while Geissdoerfer et al. (2018) defined CSCM as the configuration and coordination of various organizational functions to achieve CE objectives. Jia et al. (2020) regard CSCM as a notion that complements Closed-Loop Supply Chains.

Among the various definitions of CSCM, the one proposed by Farooque et al. (2019) is considered to provide a comprehensive and integrated perspective on the subject (Montag, 2022). Their definition is as follows: "Circular supply chain management is the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically restores technical materials and regenerates biological materials toward a zero-waste vision through system-wide innovation in business models and supply chain functions from product/service design to end-of-life and waste management, involving all stakeholders in a product/service lifecycle including parts/product manufacturers, service providers, consumers, and users".

Montag (2022) has synthesized six archetypal characteristics of CSCM, which include: R-imperatives, restorative and regenerative cycles, sustainability framework, value focus, holistic system thinking, and paradigm shift. R-imperatives encompass a variety of product recovery strategies, such as repair, remanufacturing, refurbishing, and recycling (MahmoumGonbadi et al., 2021). These strategies involve reintegrating end-of-life products into new or alternative usage cycles, retaining their original form, or transforming them to serve different purposes, ultimately extending their life span and reducing waste. Restorative and regenerative cycles entail the circulation of both technological and biological nutrient-based products and materials throughout the economic system (Ellen MacArthur Foundation, 2013). Sustainability framework necessitates the holistic integration of the Triple Bottom Line into CSCM. This implies the simultaneous consideration of environmental, social, and economic aspects.

Value focus emphasizes the importance of leveraging various strategies to maximize resource efficiency. These strategies encompass the power of inner cycles, in which tighter loops yield greater benefits by replacing virgin materials; the power of cycling longer, where products' useful lives are prolonged by undergoing numerous consecutive cycles and remaining within each cycle for an extended period; the power of cascaded use and inbound material/product substitution, which advocates for circulating materials across a variety of product categories; and the power of purer input, necessitating a certain degree of material purity and product/component quality to maximize the value generated through the circular supply chain processes (Ellen MacArthur Foundation, 2013). Holistic system thinking highlights the significance of addressing each stage of the supply chain and comprehending the intricate interconnections among organizations. The paradigm shift entails a considerable transformation in both supply and demand sides to fully embrace CE principles.

2.2 Physical Internet

PI, as described by Montreuil (2020), is a “hyperconnected global logistics system enabling seamless open asset sharing and flow consolidation through standardized encapsulation, modularization, protocols and interfaces, to improve the capability, efficiency and sustainability of serving humanity’s demand for physical objects”. This vision, proposed to tackle the challenges of unsustainable global logistics, is conceptualized through a set of thirteen characteristics, which cover a wide range of logistics and supply chain issues, from product design and realization to transportation services (Montreuil, 2011). The following paragraphs in this section present these thirteen characteristics of PI, along with related recent research updates.

Encapsulate merchandises in world-standard smart green modular containers. One of the key pillars of PI is to use standard and modular PI-containers instead of current heterogeneous good packages, cardboard cases, and pallets (Landschützer et al., 2015). PI-containers shall be designed with several generic characteristics such as easy to handle, store and transport, connected, and environmentally responsible (Montreuil et al., 2015).

Aiming toward universal interconnectivity. The primary goal is to significantly reduce the time and cost associated with load breaking by fostering seamless connections across the supply chain. Achieving this level of interconnectivity necessitates the standardization of loading units, processes, and services, as well as digital interoperability among diverse stakeholders (Ballot et al., 2020; Pan et al., 2021).

Evolve from material to PI-container handling and storage systems. Logistics nodes in PI embrace automated standardization and interconnected processes (Ballot et al., 2020). In particular, Chargui et al. (2022) explore the PI’s impact on cross-docking platforms, emphasizing their open, automated nature compared to traditional setups.

Exploit smart networked containers embedding smart objects. PI-containers need unique identification, tracing, tracking, and monitoring capabilities, while adhering to data compatibility, interoperability, and confidentiality standards. As active products, they should conduct scheduled reporting, event initiation, goal adjustment and communication, peer interaction, negotiation with equipment, and learning from experiences (Sallez et al., 2016).

Evolve from point-to-point hub-and-spoke transport to distributed multi-segment intermodal transport. With this feature, PI contributes to reduce driving distances and durations, greenhouse gas emissions and social impact of truck driving (Fazili et al., 2017).

Embrace a unified multi-tier conceptual framework. In urban environments, this characteristic can be manifested as appropriate urban pixelization and an interconnected multi-layer logistics web linking meshed networks (Montreuil et al., 2018).

Activate and exploit an open global supply web. Supply network nodes should be accessible to most actors, enabling on-demand service capacity usage and effective handling of stochastic client demand (Ballot et al., 2020). Nodes can be classified into four categories: production fabs, deployment centers, logistics hubs and customer interfaces (Montreuil, 2020). Production fabs, conceived under the hyperconnected mobile production framework, incorporate distributed, outsourced, on-demand, modular, additive, mobile, containerized, and hyperconnected production strategies (Fergani et al., 2020). Deployment centers facilitate the prepositioning of objects to efficiently fulfill demand, while logistics hubs streamline processes such as consolidation, cross-docking, sorting, swapping, and transshipping. Customer interfaces encompass smart lockers, retail stores, and other points of customer interaction.

Design products fitting containers with minimal space waste. Product design should consider logistics, ensuring compatibility with specific container sizes and easy completion near the point of use. This entails creating modular products for quick assembly, disassembly, and adaptation to local conditions. This idea can be considered as an integration of design tools, including design for assembly, disassembly, and logistics (Chiu & Okudan, 2010).

Minimize physical moves and storages by digitally transmitting knowledge and materializing objects as locally as possible. This can be achieved by standardized dematerialization specifications, readily accessible hyperconnected mobile production facilities, and robust legal safeguards to protect intellectual property and ensure product authenticity. 3D printing is a promising technology for the implementation of this feature (Ryan et al., 2017).

Deploy open performance monitoring and capability certifications. PI emphasizes the need for live, globally accessible performance tracking, which promotes informed decision-making and continuous improvement. Transparency is essential for building trust and collaboration among logistics stakeholders. Encouraging improvement through benchmarking based on publicly available performance records fosters continuous innovation within the industry.

Prioritize webbed reliability and resilience of networks. In PI, the network utilization adapts to reduce adverse effects by effectively combining transport and storage resources, altering modes and routes as needed. This ensures consistently high network performance and a guaranteed service level (Ballot et al., 2020; Kulkarni et al., 2022).

Stimulate business model innovation. PI requires a paradigm shift in the logistics industry, prompting stakeholders to adapt and seize opportunities. By promoting diverse business models and collaboration among manufacturers, distributors, and retailers, PI fosters innovation, efficiency, and sustainability in the logistics ecosystem.

Enable open infrastructural innovation. PI encourages the enhancement of infrastructure capacity by leveraging standardizations, rationalizations and automations (Montreuil, 2011). Such advancements are expected in vehicles, carriers, facilities and their interconnections.

3 Hyperconnected Circular Supply Chains

In this section, we present the Hyperconnected Circular Supply Chain (HCSC) framework, depicted in Figure 1. The framework is composed of nine key characteristics that contribute to the improvement of product design, manufacturing, logistics operations, ultimately promoting circularity and interconnectivity within supply chains. These characteristics are derived from merging CSC and PI features discussed in Section 2. The connections between HCSC and PI features, as well as HCSC and CSC features, are visually illustrated in Figure 2 through a qualitative Sankey diagram. HCSC features are displayed in the center, and the flows connecting CSC and PI features represent their relative contributions to the development of HCSC features. The nine characteristics of HCSC will be elaborated upon in the subsequent parts of this section.

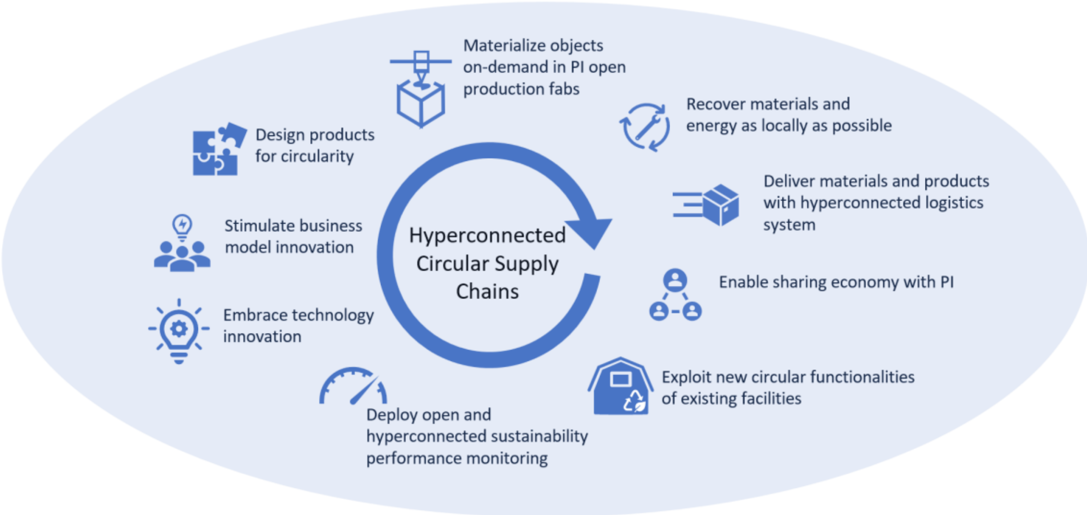

Figure 1: Core characteristics of Hyperconnected Circular Supply Chains

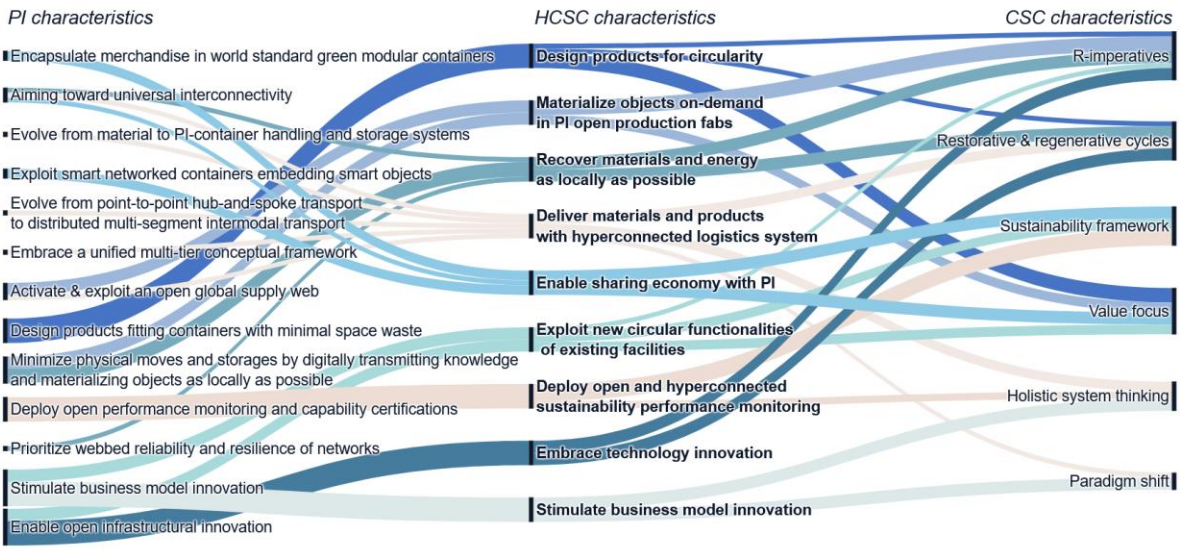

Figure 2: Interrelationships between HCSC, PI, and CSC features

3.1 Design products for circularity

In the HCSC framework, products are specifically designed to ensure they can be easily disassembled, repaired, ungraded and recycled. Emphasis is placed on modular design, where products are composed of self-contained units or modules (Nowak et al., 2018). Product subassemblies and modules should be tailored to specific PI-container sizes to fully capitalize on the efficient logistics operations enabled by PI.

Repairing and upgrading of products are significantly simplified for end-users due to the ease of exchanging modules with new, refurbished, or upgraded ones. The rapid delivery of these modules, facilitated by the efficient logistics operations of PI, further contributes to the accessibility of repairing and upgrading processes, thus retain values. Moreover, the cost of repairing or upgrading an existing product is expected to be considerably lower than purchasing a new one, making it a more sustainable and economically viable option for consumers. Additionally, recovery processes for products are smoother as a result of their easy disassembly. This allows for the seamless reintegration of modules and units into another usage cycle following appropriate treatment.

3.2 Materialize objects on-demand in PI open production fabs

Products are occasionally discarded due to the unavailability of spare parts or the prohibitive cost of sourcing or producing the necessary components. PI open production fabs can address this issue by manufacturing spare parts on demand and close to the point of use. By digitally transmitting drawings and production specifications for required spare parts to PI open production fabs, localized production can be achieved, enabling rapid delivery to users. Additive manufacturing is one of the key technologies that empowers localized on-demand manufacturing (Foshammer et al., 2022).

Materializing objects on demand can also help address the complexity arising from product differentiation strategies employed by manufacturers. These strategies are intended to attract customers but can create significant additional workload for product recovery processes. Customized refurbishment or upgrading solutions often need to be developed for each model within a product category. The HCSC framework offers a potential solution by proposing a single standard core for refurbishment or upgrading, with model compatibility addressed by the customized production capabilities of open production fabs, operating on demand.

This HCSC feature helps extend product lifetimes and preserve value by simplifying repairs, refurbishments, and upgrades. It is enabled by the PI's open global supply web and guided by the principle of minimizing physical moves and storages.

3.3 Recover materials and energy as locally as possible

The zero-waste vision of CSC highlights the potential for outputs from one actor to serve as inputs for others. "Waste" can be converted into valuable resources through recycling (materials recovery) and thermal processing (energy recovery) (Themelis & Bourtsalas, 2019). Building recycling centers and waste-to-energy power plants within or near urban areas can contribute to localized resource utilization and minimizing transportation needs.

This feature exemplifies the PI principle of minimizing physical moves and storages while simultaneously leveraging and promoting universal interconnectivity and network resilience. As actors interconnect through resources and energy, their dependence on remote suppliers diminishes, leading to a more efficient supply chain with increased resilience. Moreover, it supports the implementation of R-imperatives and fosters restorative and regenerative cycles.

3.4 Deliver materials and products with hyperconnected logistics system

The enhanced logistics efficiency provided by PI can significantly transform the way that objects are realized, used, and recovered. In HCSC, multiple options are provided for users to return end-of-life products, such as home pick-up, retail store, recycling bins, or smart lockers (Bukhari et al., 2018). The hyperconnected logistics system ensures a smooth circulation of materials and products.

This feature is empowered by several characteristics of PI, including universal interconnectivity, PI-container handling and storage systems, distributed multi-segment intermodal transport, a unified multi-tier conceptual framework and an open global supply web. It can facilitate the cycling of materials and potentially drive a paradigm shift.

3.5 Enable sharing economy with PI

The sharing economy is characterized by consumers providing temporary access to their under-utilized physical assets ("idle capacity") to one another, often in exchange for financial compensation (Böcker & Meelen, 2017). This concept can also be found in the Service Web of PI, which aims to enhance the accessibility and usage of assets and goods through interconnected open pooling (Darvish et al., 2014). For instance, it is conceivable that infrequently used tools, such as hand tools, gardening tools, or power tools, can be easily transported via hyperconnected logistics network. Customers can access these tools without incurring high ownership costs, using them as needed. The production of fewer tools overall leads to reduced energy and resource consumption.

This feature aligns with the value focus and sustainability aspects of CSC. By using objects more efficiently, value is retained. Economic, environmental and social benefits are expected, as both providers and users can receive monetary rewards, efficient use of goods can conserve resources otherwise needed for production, and beneficial human interactions can be fostered.

3.6 Exploit new circular functionalities of existing facilities

Both CSC and PI recognize the presence of untapped value in existing assets, and exploring alternative uses for these assets can contribute to enhanced efficiency and sustainability. CSC emphasizes the importance of R-imperatives, wherein repurposing materials or components is a common practice. PI seeks to optimize production, logistics and transportation assets utilization. For example, public transportation vehicles and infrastructure are employed for parcel delivery (Crainic & Montreuil, 2016), thereby reducing the need for additional trucks in urban areas.

In HCSC framework, the potential of existing customer interfaces and other infrastructure will be maximally exploited to smoothly interconnect circular processes and make CE practices more accessible to end users. For instance, retail stores can integrate repair, refurbishment, and recycling functions for certain products.

This feature necessitates innovation in both business models and infrastructure to unlock additional value for existing facilities. By generating revenue, reducing environmental impact through the avoidance of new constructions, and creating job opportunities, it contributes to the triple bottom line of sustainability.

3.7 Deploy open and hyperconnected sustainability performance monitoring

In the HCSC framework, the implementation of performance assessment and capability certification systems necessitates the inclusion of sustainability and CE metrics, in addition to traditional measures such as speed, service level, and reliability. These new metrics can be categorized into four dimensions: circularity, economy, environment, and society (Vegter et al., 2020; Montag & Pettau, 2022). By employing an open and hyperconnected performance tracking system and incorporating holistic system thinking, continuous improvement and innovation are encouraged across all stakeholders within a supply chain ecosystem.

3.8 Embrace technology innovation

Transitioning to a CSC requires an innovation-rich process that includes restructuring and adjustment, with both technical and non-technical aspects needing consideration. Technological innovation can enhance the eco-design of products, services, and promote sustainable consumption (Kasmi et al., 2022).

This feature capitalizes on the PI's ability to facilitate open infrastructural innovation, contributing to a greater variety of material and energy recovery options and improving the circulation of materials and energy.

3.9 Stimulate business model innovation

Similar to PI, HCSC fosters the evolution of business models. As CSC hinges on cooperative efforts among multiple actors and system-wide integration, innovative organizational and commercial approaches are needed to enable stakeholder cooperation and potentially trigger a paradigm shift. The ReSOLVE framework, featuring regenerate, share, optimize, loop, virtualize, and exchange as key business actions, was introduced by the Ellen MacArthur Foundation (2015) as a tool to generate circular initiatives.

4 Conclusion and Perspectives

The Hyperconnected Circular Supply Chain (HCSC) framework proposed in this paper aims to offer a comprehensive set of guidelines for implementing Circular Supply Chains (CSC) by harnessing the synergy between CSC and Physical Internet (PI). This framework comprises nine core characteristics that encompass product design, manufacturing, waste management, logistics, performance monitoring, and innovation. It is designed to be serving as a blueprint for various supply chain stakeholders to follow in order to optimize resource utilization, reduce waste, and minimize the environmental impact of their operations while maintaining high levels of customer satisfaction. Transitioning towards HCSC necessitates embracing change, proactively adapting products and processes, fostering collaboration, and promoting open communication on best practices.

Future research avenues include further refining and expanding of the HCSC framework to incorporate additional characteristics; exploring the framework's full potential through case studies across various industries; investigating its implementation potentiality at different scales through simulations, digital twins, field pilots, and living labs; quantifying, analyzing and learning from a multi-criteria and holistic perspective.

References

- Ballot, E., Barbarino, S., van Bree, Bas, Liesa, F., Franklin, J. R., Hooft, D., Nettsträter, A., Paganelli, P., & Tavasszy, L. A. (2020). *Roadmap to the physical internet*. ALICE-ETP.
- Ballot, E., Montreuil, B., & Zacharia, Z. G. (2021). Physical Internet: First results and next challenges. *Journal of Business Logistics*, *42*(1), 101–107. https://doi.org/10.1111/jbl.12268
- Batista, L., Bourlakis, M., Smart, P., & Maull, R. (2018). In search of a circular supply chain archetype – a content-analysis-based literature review. *Production Planning & Control*, *29*(6), 438–451. https://doi.org/10.1080/09537287.2017.1343502

- Böcker, L., & Meelen, T. (2017). Sharing for people, planet or profit? Analysing motivations for intended sharing economy participation. *Environmental Innovation and Societal Transitions*, *23*, 28–39. https://doi.org/10.1016/j.eist.2016.09.004
- Bukhari, M. A., Carrasco-Gallego, R., & Ponce-Cueto, E. (2018). Developing a national programme for textiles and clothing recovery. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *36*(4), 321–331. https://doi.org/10.1177/0734242X18759190
- Chargui, T., Ladier, A.-L., Bekrar, A., Pan, S., & Trentesaux, D. (2022). Towards designing and operating physical internet cross-docks: Problem specifications and research perspectives. *Omega (United Kingdom)*, *111*. https://doi.org/10.1016/j.omega.2022.102641
- Chiu, M.-C., & Okudan, G. E. (2010). Evolution of Design for X Tools Applicable to Design Stages: A Literature Review. *Volume 6: 15th Design for Manufacturing and the Lifecycle Conference; 7th Symposium on International Design and Design Education*, 171–182. https://doi.org/10.1115/DETC2010-29091
- Chopra, S., & Meindl, P. (2016). *Supply chain management: Strategy, planning, and operation* (Sixth Edition). Pearson.
- Crainic, T. G., & Montreuil, B. (2016). Physical Internet Enabled Hyperconnected City Logistics. *Transportation Research Procedia*, *12*, 383–398. https://doi.org/10.1016/j.trpro.2016.02.074
- Darvish, M., Boukili, M. E., Kérékou, S., & Montreuil, B. (2014). *Using Cloud computing as a Model to Design the Service Web*. 1st International Physical Internet Conference, Québec City, Canada.
- Ellen MacArthur Foundation. (2013). *Towards the Circular Economy 1: Economic and business rationale for an accelerated transition*. https://ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an
- Ellen MacArthur Foundation. (2015). *Growth Within: A Circular Economy Vision for A Competitive Europe*. https://ellenmacarthurfoundation.org/growth-within-a-circular-economy-vision-for-a-competitive-europe
- Farooque, M., Zhang, A., Thürer, M., Qu, T., & Huisingh, D. (2019). Circular supply chain management: A definition and structured literature review. *Journal of Cleaner Production*, *228*, 882–900. https://doi.org/10.1016/j.jclepro.2019.04.303
- Fazili, M., Venkatadri, U., Cyrus, P., & Tajbakhsh, M. (2017). Physical Internet, conventional and hybrid logistic systems: A routing optimisation-based comparison using the Eastern Canada road network case study. *International Journal of Production Research*, *55*(9), 2703–2730. Scopus. https://doi.org/10.1080/00207543.2017.1285075
- Fergani, C., El Bouzekri El Idrissi, A., Marcotte, S., & Hajjaji, A. (2020). Optimization of hyperconnected mobile modular production toward environmental and economic sustainability. *Environmental Science and Pollution Research*, *27*(31), 39241–39252. https://doi.org/10.1007/s11356-020-09966-9
- Foshammer, J., Søberg, P. V., Helo, P., & Ituarte, I. F. (2022). Identification of aftermarket and legacy parts suitable for additive manufacturing: A knowledge management-based approach. *International Journal of Production Economics*, *253*, 108573. https://doi.org/10.1016/j.ijpe.2022.108573
- Geissdoerfer, M., Morioka, S. N., de Carvalho, M. M., & Evans, S. (2018). Business models and supply chains for the circular economy. *Journal of Cleaner Production*, *190*, 712–721. https://doi.org/10.1016/j.jclepro.2018.04.159
- Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048
- Global Footprint Network. (2022). *National Footprint and Biocapacity Accounts 2022 Public Data Package*. https://www.footprintnetwork.org/licenses/public-data-package-free/
- Jia, F., Yin, S., Chen, L., & Chen, X. (2020). The circular economy in the textile and apparel industry: A systematic literature review. *Journal of Cleaner Production*, *259*, 120728. https://doi.org/10.1016/j.jclepro.2020.120728
- Kasmi, F., Osorio, F., Dupont, L., Marche, B., & Camargo, M. (2022). Innovation Spaces as Drivers of Eco-innovations Supporting the Circular Economy: A Systematic Literature Review: *Journal of Innovation Economics & Management*, *N° 39*(3), 173–214. https://doi.org/10.3917/jie.pr1.0113

- Kulkarni, O., Dahan, M., & Montreuil, B. (2022). Resilient Hyperconnected Parcel Delivery Network Design Under Disruption Risks. *International Journal of Production Economics*, *251*. Scopus. https://doi.org/10.1016/j.ijpe.2022.108499
- Landschützer, C., Ehrentraut, F., & Jodin, D. (2015). Containers for the Physical Internet: Requirements and engineering design related to FMCG logistics. *Logistics Research*, *8*(1). https://doi.org/10.1007/s12159-015-0126-3
- MahmoumGonbadi, A., Genovese, A., & Sgalambro, A. (2021). Closed-loop supply chain design for the transition towards a circular economy: A systematic literature review of methods, applications and current gaps. *Journal of Cleaner Production*, *323*, 129101. https://doi.org/10.1016/j.jclepro.2021.129101
- Montag, L. (2022). Circular Economy and Supply Chains: Definitions, Conceptualizations, and Research Agenda of the Circular Supply Chain Framework. *Circular Economy and Sustainability*. https://doi.org/10.1007/s43615-022-00172-y
- Montag, L., & Pettau, T. (2022). Process performance measurement framework for circular supply chain: An updated SCOR perspective. *Circular Economy*. https://doi.org/10.55845/KAIZ3670
- Montreuil, B. (2011). Toward a Physical Internet: Meeting the global logistics sustainability grand challenge. *Logistics Research*, *3*(2–3), 71–87. https://doi.org/10.1007/s12159-011-0045-x
- Montreuil, B. (2020). *The Physical Internet: Shaping a Global Hyperconnected Logistics Infrastructure*. International Physical Internet Conference, Shenzhen, China. https://www.picenter.gatech.edu/sites/default/files/ipic2020-keynotehyperconnectedlogisticsinfrastructure_20201116_web.pdf
- Montreuil, B., Ballot, E., & Tremblay, W. (2015). Modular Design of Physical Internet Transport, Handling and Packaging Containers. In *Progress in Material Handling Research: 2014*.
- Montreuil, B., Buckley, S., Faugere, L., Khir, R., & Derhami, S. (2018). *Urban Parcel Logistics Hub and Network Design: The Impact of Modularity and Hyperconnectivity*. 15th IMHRC Proceedings, Savannah, Georgia, USA.
- Montreuil, B., Meller, R. D., & Ballot, E. (2012). Physical Internet Foundations. *IFAC Proceedings*, *45*, 26–30. https://linkinghub.elsevier.com/retrieve/pii/S1474667016331214
- Nowak, T., Toyasaki, F., & Wakolbinger, T. (2018). The Road Toward a Circular Economy: The Role of Modular Product Designs in Supply Chains. In H. Qudrat-Ullah (Ed.), *Innovative Solutions for Sustainable Supply Chains* (pp. 111–133). Springer International Publishing. https://doi.org/10.1007/978-3-319-94322-0_5
- Pan, S., Trentesaux, D., McFarlane, D., Montreuil, B., Ballot, E., & Huang, G. Q. (2021). Digital interoperability in logistics and supply chain management: State-of-the-art and research avenues towards Physical Internet. *Computers in Industry*, *128*. https://doi.org/10.1016/j.compind.2021.103435
- Ryan, M. J., Eyers, D. R., Potter, A. T., Purvis, L., & Gosling, J. (2017). 3D printing the future: Scenarios for supply chains reviewed. *International Journal of Physical Distribution & Logistics Management*, *47*(10), 992–1014. https://doi.org/10.1108/IJPDLM-12-2016-0359
- Saavedra, Y. M. B., Iritani, D. R., Pavan, A. L. R., & Ometto, A. R. (2018). Theoretical contribution of industrial ecology to circular economy. *Journal of Cleaner Production*, *170*, 1514–1522. https://doi.org/10.1016/j.jclepro.2017.09.260
- Sallez, Y., Pan, S., Montreuil, B., Berger, T., & Ballot, E. (2016). On the activeness of intelligent Physical Internet containers. *Computers in Industry*, *81*, 96–104. https://doi.org/10.1016/j.compind.2015.12.006
- Stock, J. R., & Boyer, S. L. (2009). Developing a consensus definition of supply chain management: A qualitative study. *International Journal of Physical Distribution & Logistics Management*, *39*(8), 690–711. https://doi.org/10.1108/09600030910996323
- Themelis, N. J., & Bourtsalas, A. C. (Eds.). (2019). *Recovery of Materials and Energy from Urban Wastes: A Volume in the Encyclopedia of Sustainability Science and Technology, Second Edition*. Springer New York. https://doi.org/10.1007/978-1-4939-7850-2
- Vegter, D., van Hillegersberg, J., & Olthaar, M. (2020). Supply chains in circular business models: Processes and performance objectives. *Resources, Conservation and Recycling*, *162*, 105046. https://doi.org/10.1016/j.resconrec.2020.105046