Physical Internet Towards Sustainable Supply Chain: The Significance Of Digital Interoperability

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Abstract

The purpose of this study is to discover physical internet attributes for satisfying economic, social, and environmental benefits, and frame the hierarchical interrelationships of these attributes. The fuzzy Delphi method is used to define necessary criteria; fuzzy Decision-Making Trial and Evaluation Laboratory is adopted to identify the cause-and-effect relationships based on the experts' viewpoints. Finding - The result also presents the most important criteria having causal effects on others including privacy preservation approaches, system of logistics network interconnectivity, distributed data storage, real-time locating system, and distributed multi-segment intermodal transport, from which recommend practical implications for the decision-making process. This study suggests both theoretical and managerial implications for improving the physical internet towards sustainable supply chain as physical internet has been perceived as a novel logistics model towards sustainability and a key solution for the current paradigms to overcome sustainable issues. This study contributes to the literature by pointing out the causal aspects for physical internet implementation, which are digital interoperability of supply chain, and shared warehouse and transportation networks.

Keywords

digital interoperability; physical internet; shared warehouse and transportation networks; sustainable supply chain

JEL Classification

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Introduction

Industry 4.0 refers to a further advancing stage in the operation and management of the entire value chain process which promotes the storage of products, facilities, and data in the form of cyber-physical systems (Maslarić et al., 2016; Rad et al., 2022). Such cyber-physical networks of devices are considered as a link between the Internet and the physical objects by managing data, inventory of products, and named physical internet (PI) (Babiceanu & Seker, 2016; Li et al., 2022). The traditional logistics networks now are not considered as being sustainable and a feasible answer is a transition to PI, which supports the openness together with interconnection of separate supply chain networks (Sallez et al., 2016; Mangina et al., 2020). The PI encapsulates physical objects into world-standard containers which demand minimum packaging as well as smart tag facilitated with sensors to enable appropriate routing and maintenance (Pan et al., 2019). By which, PI is indicated to help in an increasing merger of multi-transportation when products of various firms are distributed in the same direction (Van der Heide et al., 2018). PI is recognized as a global logistics model towards sustainability and efficiency and a key driver for revolutionizing the contemporary paradigms for overcoming sustainable issues (Pan et al., 2021).

The importance of PI has been highlighted and has become a vital topic for research in both industrial and academic areas since its adoption helps in increasing customer databases, enhancing supply chain performance, and expediting end-to-end processes. Nonetheless, there is a lack of knowledge in effectively utilizing this new technology, and not much attention has been paid to the identification of critical attributes affecting the PI implementation and their interrelationship (Deepu & Ravi, 2021). Consequently, this study is carried out to solve the gap. The fuzzy Delphi method (FDM) and fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL) are used to propose the necessary attributes and define the interrelationship between them. FDM is employed for removing inessential attributes referred to the experts' point of view (Tseng et al., 2022a). Then, FDEMATEL is used for constructing a causal structure of remained attributes and exhibit their interrelationship (Tseng et al., 2022b).

PI is an innovative concept based on physical, digital, and operational hyperconnectivity of logistics activity and supply chain networks. This concept is introduced as one of the novel breakthrough models directed to enhance the worldwide seamless interconnection of logistics systems on multiple layers, anytime and anywhere (Pan et al., 2021). In PI networks, the physical objects are encapsulated in smart containers which are modularly dimensioned, easy-to-interlock and efficient to transport in hyperconnected transportation grids (Sallez et al., 2016), consequently, ensure the integrity and security of these containers (Mangina et al., 2020). By applying PI, firms simply specify a destination for their shipment, and then the system is responsible for arranging the transportation and storage, which eventually creates higher economic benefits (Van der Heide et al., 2018). Although environmental and social sustainability is still not prominent features of PI, its application is visioned to strongly develop and enhance soon to overcome remaining problems (Baydar et al., 2017). Therefore, PI is believed as a critical successful application for future logistics models to deal with issues in sustainability (Pan et al., 2021).

Since the hyperconnectivity network structure of the PI incorporates different participants in the supply chain (Crainic & Montreuil, 2015), fundamental change relating to the operation, infrastructure, data processing, and collaboration practices need to be conducted to make practical applicability of this paradigm and firms' engagement possible (Meyer et al., 2019). Moreover, to overcome challenges of the global logistics operations arising from PI adoption in the industry 4.0 environment, supply chain participants are requested to carry out handling along with storage technologies efficiently, sustainably, and transparently (Yavas & Ozkan-Ozen, 2020). Shared warehouse and transportation networks are indicated as an appropriate solution, in which dynamic shipments are utilized and products are pushed strategically into the network, then timely relocated to where they are most needed, flexibly dealing with inventory imbalances (Van der Heide et al., 2018). Furthermore, digital data interoperability is necessary to coordinate participants in PI because it enables the communication between coordinators and container users in the heterogeneous information systems (Sallez et al., 2016). Digital interoperability is defined as the ability to attain fast, secure, and reliable data transfer between computing equipment, information systems, or other devices, for the aim of enhancing the cooperation of independent participants across supply chains (Pan et al., 2021). To sum up, digital interoperability of supply chain, supply chain operation towards PI, infrastructure for PI, shared warehouse and transportation networks are recommended for researching about PI in supply chain towards sustainability.

There are three objectives of this study:

- To categorize a set of PI attributes towards sustainable supply chain from prior studies;
- To exploit and clarify the interrelationships among attributes and suggest a cause-and-effect framework;
- To present implications for decision-making process in applying PI in the supply chain towards sustainability.

This study's contributions consist of (1) proposing a set of PI enablers founded on associated studies and a qualitative data evaluation; (2) providing an interrelationship framework of PI attributes; and (3) suggesting managerial implications for the PI decision-making process.

Method

The crucial aspects for fostering PI in the sustainable supply chain are suggested founded on prior studies as digital interoperability of supply chain, supply chain operation towards PI, infrastructure for PI, shared warehouse and transportation networks with particularized measurements as follows. The proposed aspects and criteria are displayed in Table 1.

Digital interoperability of supply chain (A1) involves the novel technologies for developing PI in the supply chain. Privacy preservation approaches (C1) are technology-founded methods that assure the secrecy of individual information all along communication among multi-actors (Pan et al., 2021). System of logistics network interconnectivity (C2) demands the embodiment among all business, physical, and digital levels (Pan et al., 2021). As system losses in industrial environments result in high-risk circumstances, industrial internet of things (C3) is an internet-of-things technology in the industrial area, which is more concentrated on enhancing efficiency and bettering safety (Lu et al., 2019). Distributed data storage (C4) refers to a data platform to keep historical data for trackability in a huge supply chain (Pan et al., 2021); whereas blockchain technology (C5) involves a distributed information in the formation of a ledger, which is saved as well as duplicated among all actors in the network (Meyer et al., 2019).

Through the lens of supply chain operation towards PI (A2), the execution of PI is promoted via standardizing cargos, container structures, together with data sharing. Trustful collaboration and data sharing (C6) is the insurance of smoothly continuous collaboration and data revolution (Meyer et al., 2019). Encapsulated merchandise in standard containers (C7) requires that physical objects are managed in PI containers (Montreuil, 2011), which are global standard, green, smart, and modular containers (Sternberg & Norrman, 2017). In company with this is smart network containers (C8) which are adequate for inserting smart objects (Sternberg & Norrman, 2017). Container handling and storage systems (C9) are systems enclosing novel technologies and procedures capitalizing on the features of PI containers (Montreuil, 2011), to facilitate the input, storage, composing, decomposing, supervising, safeguarding, and output (Sternberg & Norrman, 2017).

Infrastructure for PI (A3) centers on the firm's structure from the roles and responsibilities to trustworthy interconnection (Meyer et al., 2019). Benefits through responsibilities and roles (C10) demands firms to equally allocate benefits through designating responsibilities as well as roles of participants. Integrity, robustness, and resilience structure (C11) suggests a structure necessitated for adopting PI infrastructure. Furthermore, a fast, economical, and reliable interconnection (C12) of nodes, containers, and transport assets are also characterized as one essential criteria of this aspect.

Regarding shared warehouse and transportation networks (A4), attributes in connection with warehouse and transportation management are deemed as a motivation for executing PI in the supply chain. Digital information platforms (C13) are places for stakeholders in order to share data, carry out business interactions or communicate with each other (Yavas & Ozkan-Ozen, 2020). Real-time locating system (C14) is necessity concerning handling as well as locating goods, objects, and containers. Logistics center alliances (C15) assists in enhancing all partners' capacity and competitive edges. Digital connectivity (C16) involves the interaction skills, despite machines or humans to show fast reflexes in terms of distribution, payments, or management schemes in the supply chain (Yavas & Ozkan-Ozen, 2020). Distributed multi-segment intermodal transport (C17) refers to a shift, in which variuous carriers along with modes deal with of internode segments (Sternberg & Norrman, 2017).

Table 1. Proposed aspects and criteria

Aspect	Criteria		References
Digital interoperability of supply chain (A1)	C1	Privacy preservation approaches	Pan et al. (2021) Lu et al. (2019) Meyer et al. (2019)
	C2	System of logistics network interconnectivity	
	C3	Industrial Internet of Things	
	C4	Distributed data storage	
	C5	Blockchain technology	
Supply chain operation towards PI (A2)	C6	Trustful collaboration and data sharing	Meyer et al. (2019) Sternberg & Norrman (2017) Montreuil (2011)
	C7	Encapsulated merchandise in standard containers	
	C8	Smart network containers	
	C9	Container handling and storage systems	
Infrastructure for PI (A3)	C10	Benefits through responsibilities and roles	Meyer et al. (2019)
	C11	Integrity, robustness and resilience structure	
	C12	Reliable interconnection	
Shared warehouse and transportation networks (A4)	C13	Digital information platforms	Yavas & Ozkan-Ozen (2020) Sternberg & Norrman (2017)
	C14	Real-time locating system	
	C15	Logistics center alliances	
	C16	Digital connectivity	
	C17	Distributed multi-segment intermodal transport	

Fuzzy set theory and fuzzy linguistic scales are adopted to express the experts' opinions. Yet, these linguistic values are not the actual numbers, which could apply to the computation precisely. Therefore, the min-max method was suggested to transform the linguistic terms into corresponding triangular fuzzy numbers. These numbers then are used to proceed with the next steps of FDM and FDEMATEL. The applied linguistic scale for the transformation is shown in Table 2.

Table 2. Triangular fuzzy numbers linguistic scale

Linguistic terms	Meanings	Corresponding TFN (FDM process)	Corresponding TFN (FDEMATEL process)
VHI	Very high importance	(0.75, 1.0, 1.0)	(0.7, 0.9, 1.0)
HI	High importance	(0.5, 0.75, 1.0)	(0.5, 0.7, 0.9)
S	Strong	(0.25, 0.5, 0.75)	(0.3, 0.5, 0.7)
L	Low importance	(0.0, 0.25, 0.5)	(0.1, 0.3, 0.5)
VL	Very low importance	(0.0, 0.0, 0.25)	(0.0, 0.1, 0.3)

To ensure the reliability of the assessment process, 14 experts were contacted and interviewed for both FDM and FDEMATEL results. The expert panel consists of six professionals from different industries with more than 11 years of experience and have knowledge of the physical internet. The other eight experts are researchers in the academic area with 12 or more years of experience in related fields. The experts' demographic is displayed in the Appendix.

The proposed method includes two main steps:

- Step 1: FDM is suggested to solve the problem of the fuzziness of expert judgments, and indicate essential criteria for further analysis (Tseng et al., 2022a). In FDM process, the threshold σ is calculated to propose essential criteria. The indicator m is accepted if the convex combination value is equal to or more than the threshold.
- Step 2: In the FDEMATEL process, the fuzzy terms are converted using the triangular fuzzy numbers linguistic scale to generate the crisp values which then is placed into the direct relation matrix (Tseng et al., 2022b). Further, FDEMATEL provides the hierarchical framework through categorizing attributes into cause-and-effect groups (Wu et al., 2017). This process is the same for both aspects and criteria analysis. Particularly, these diagrams are presented from the coordinated values [(D + R), (D - R)]. Thereinto, (D + R) is the horizontal axis to illustrate the importance of attribute; the higher values mean that the criteria possess the higher importance. (D - R) is the vertical axis to categorize the criteria into the cause group and the effect group.

Results and Discussion

Results

This section introduces the results from FDM and FDEMATEL processes and emphasized theoretical as well as managerial implications for enhancing PI implementation in the supply chain towards sustainability.

Table 3 illustrates the result of the FDM process. Through this procedure, a final set of 17 accepted criteria are defined from the original set of 35 criteria with values Dm equal to or over the threshold of 0.697.

Table 3. FDM result

Criteria	l_m	r_m	D_m	Decision
C1	.250	.877	.709	Selected
C2	.500	.902	.801	Selected
C3	.500	.781	.760	Selected
C4	.250	.859	.703	Selected
C5	.250	.859	.703	Selected
C6	.500	.848	.783	Selected
C7	.500	.831	.777	Selected
C8	.500	.848	.783	Selected
C9	.500	.848	.783	Selected
C10	.500	.831	.777	Selected
C11	.500	.814	.771	Selected
C12	.500	.831	.777	Selected
C13	.500	.831	.777	Selected
C14	.500	.798	.766	Selected
C15	.500	.798	.766	Selected
C16	.250	.859	.703	Selected
C17	.250	.841	.697	Selected
Threshold			.697	

Table 4 presents the crisp values transferred from triangular fuzzy numbers. The initial qualitative information is converted into these vague values by using the fuzzy linguistics scales from 1 to 5 (no influence to very high influence).

Table 4. Crisp values of aspects

	A1	A2	A3	A4
A1	.697	.497	.538	.429
A2	.455	.709	.386	.429
A3	.413	.357	.699	.400
A4	.457	.510	.454	.701

Referring from Table 5, the aspect's driving power (D) is computed by summing the values in each row, and the dependence power (R) is counted by summing the values in each column applying equations (12)-(16). Aspects with the positive values of (D - R) are categorized into the cause group; otherwise, they are distributed into the effect group.

Table 5. Total interrelationship matrix of aspects

	A1	A2	A3	A4	D
A1	4.229	4.227	4.267	3.947	16.670
A2	3.766	3.993	3.830	3.623	15.212
A3	3.505	3.558	3.757	3.379	14.199
A4	4.047	4.178	4.157	4.036	16.418
R	15.547	15.956	16.011	14.985	Average = 3.906

In Figure 1, the cause-and-effect groups and the interrelationship among aspects are figured out from the dataset (D + R), (D - R). The causal group includes digital interoperability of supply chain (A1), shared warehouse and transportation networks (A4); whereas supply chain operation towards PI (A2) and infrastructure for PI (A3) belong to the effect group. A1 has strong effects on A2 and A3, and A4 has medium effects on the aspects of the effect group. A1 and A4 also have a weak interrelationship, while A2 and A3 have no impact on each other.

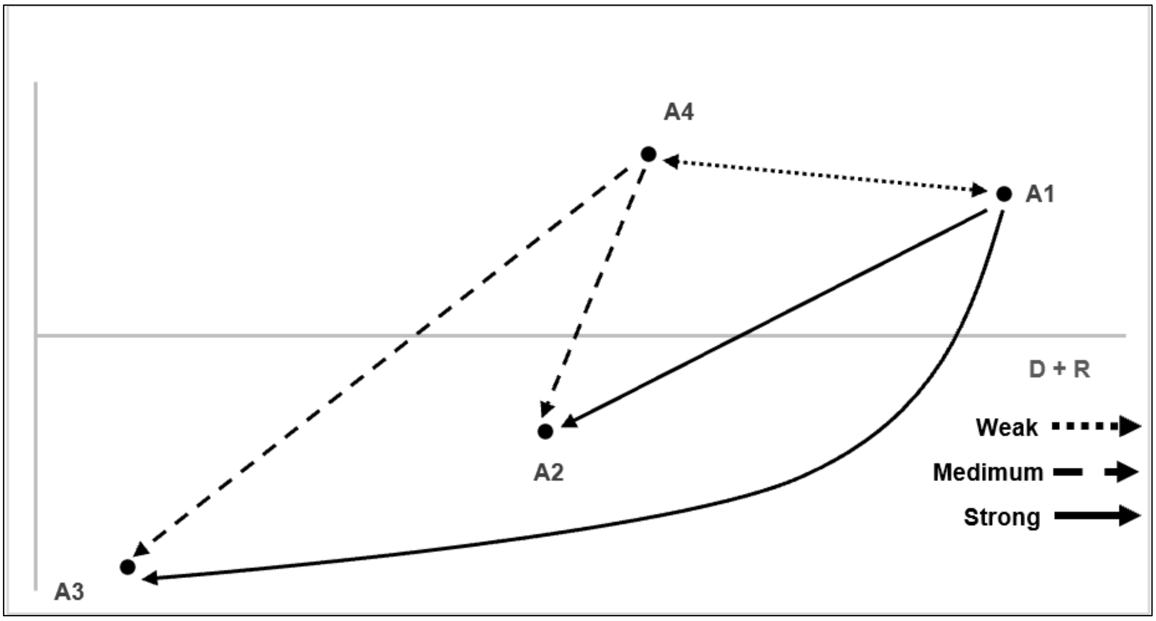

Figure 1. Causal interrelationship diagram among aspects (source: authors)

Table 6 presents the crisp values of criteria while Table 7 illustrates the total interrelations of criteria using the same procedure as aspects. The top five criteria are defined with the highest (D + R) values.

Table 6. Crisp values of criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
C1	.750	.533	.475	.468	.501	.593	.537	.483	.493	.420	.372	.431	.385	.495	.464	.423	.381
C2	.503	.749	.580	.495	.501	.499	.504	.552	.519	.515	.413	.436	.497	.511	.384	.437	.517
C3	.421	.515	.774	.370	.379	.496	.548	.428	.476	.416	.355	.365	.442	.548	.479	.395	.473
C4	.420	.544	.475	.756	.470	.497	.457	.467	.518	.569	.454	.447	.402	.473	.441	.435	.491
C5	.516	.515	.463	.482	.769	.467	.497	.496	.477	.501	.385	.434	.429	.494	.398	.478	.505
C6	.478	.476	.488	.425	.448	.754	.468	.471	.460	.472	.366	.376	.456	.427	.326	.397	.451
C7	.464	.502	.490	.453	.556	.453	.756	.496	.381	.320	.311	.364	.455	.428	.356	.435	.539
C8	.420	.490	.503	.440	.449	.484	.554	.758	.493	.416	.423	.402	.459	.472	.425	.518	.488
C9	.447	.464	.404	.386	.393	.441	.483	.498	.746	.404	.354	.392	.389	.457	.387	.409	.450
C10	.503	.543	.473	.413	.391	.427	.428	.396	.420	.776	.411	.394	.360	.373	.427	.366	.365
C11	.381	.410	.366	.386	.379	.331	.386	.331	.421	.424	.784	.408	.423	.387	.372	.353	.394
C12	.368	.407	.432	.453	.297	.414	.465	.427	.438	.475	.509	.774	.510	.453	.468	.419	.488
C13	.392	.325	.445	.386	.365	.346	.413	.425	.383	.366	.341	.432	1.000	.330	.450	.422	.403
C14	.530	.506	.538	.483	.394	.445	.452	.525	.504	.531	.466	.434	.495	.760	.467	.534	.490
C15	.451	.528	.519	.482	.447	.509	.520	.440	.451	.471	.463	.448	.512	.537	.780	.461	.505
C16	.462	.545	.504	.456	.464	.483	.428	.550	.546	.433	.366	.349	.346	.453	.424	.743	.408
C17	.436	.529	.530	.481	.530	.511	.458	.482	.488	.473	.532	.543	.523	.481	.496	.452	.750

Table 7. Total interrelationship matrix of criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	D
C1	.713	.738	.722	.668	.667	.712	.721	.705	.703	.675	.612	.631	.680	.693	.644	.651	.681	11.616
C2	.714	.797	.768	.701	.696	.732	.750	.745	.738	.717	.645	.660	.725	.726	.664	.683	.729	12.191
C3	.649	.709	.732	.631	.627	.674	.696	.672	.675	.649	.587	.600	.662	.674	.623	.624	.667	11.149
C4	.681	.748	.731	.709	.670	.708	.719	.710	.714	.701	.630	.640	.690	.698	.649	.660	.702	11.762
C5	.693	.745	.730	.678	.707	.705	.725	.715	.710	.693	.621	.639	.693	.701	.644	.666	.705	11.769
C6	.643	.690	.684	.625	.624	.692	.673	.664	.660	.643	.577	.589	.650	.646	.592	.612	.651	10.915
C7	.646	.699	.689	.633	.642	.661	.712	.672	.655	.629	.575	.592	.655	.651	.600	.621	.667	10.999
C8	.672	.731	.724	.662	.659	.696	.721	.735	.702	.672	.617	.626	.687	.688	.638	.661	.692	11.584
C9	.622	.670	.655	.604	.600	.636	.657	.649	.677	.618	.560	.575	.624	.632	.583	.597	.634	10.593
C10	.624	.676	.659	.603	.596	.631	.646	.632	.633	.658	.563	.572	.617	.618	.584	.587	.619	10.517
C11	.566	.612	.599	.557	.551	.574	.594	.579	.588	.572	.569	.533	.580	.575	.536	.544	.578	9.708
C12	.632	.685	.680	.631	.607	.653	.675	.661	.660	.647	.598	.640	.660	.652	.612	.617	.659	10.969
C13	.589	.625	.633	.578	.571	.598	.621	.614	.606	.587	.535	.557	.674	.591	.567	.574	.602	10.122
C14	.713	.763	.758	.695	.679	.720	.738	.736	.732	.714	.648	.656	.720	.751	.670	.690	.721	12.101
C15	.701	.764	.754	.693	.684	.726	.745	.724	.723	.705	.646	.656	.721	.723	.705	.679	.721	12.071
C16	.660	.720	.706	.648	.644	.679	.688	.694	.691	.658	.594	.604	.656	.669	.622	.672	.665	11.270
C17	.711	.777	.768	.705	.705	.738	.750	.742	.740	.718	.666	.679	.734	.728	.683	.690	.762	12.293
R	11.228	12.146	11.991	11.022	10.928	11.532	11.832	11.648	11.609	11.256	10.244	10.448	11.428	11.417	10.617	10.829	11.455	

From Figure 2, the causal criteria consist privacy preservation approaches (C1), system of logistics network interconnectivity (C2), distributed data storage (C4), blockchain technology (C5), reliable interconnection (C12), real-time locating system (C14), logistics center alliances (C15), digital connectivity (C16), distributed multi-segment intermodal transport (C17), and the effect criteria consist of Industrial Internet of Things (C3), trustful collaboration and data sharing (C6), encapsulated merchandise in standard containers (C7), smart network containers (C8), container handling and storage systems (C9), benefits through responsibilities and roles (C10), integrity, robustness and resilience structure (C11), digital information platforms (C13). Privacy preservation approaches (C1), system of logistics network interconnectivity (C2), distributed data storage (C4), real-time locating system (C14), and distributed multi-segment intermodal transport (C17) are the five most important criteria. These criteria significantly impact other attributes in the effect group; hence, improving these criteria has a critical impact on PI implementation.

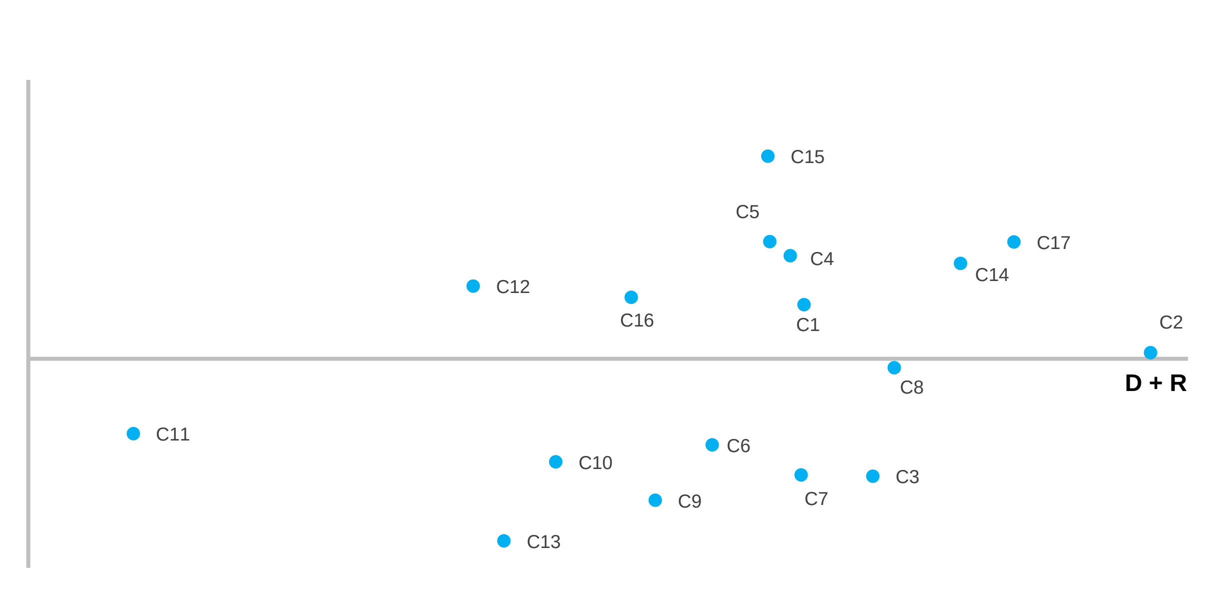

Figure 2. Cause-and-effect diagram of criteria (source: authors)

Theoretical implication

Concerning theoretical implication, four aspects are divided into two groups: digital interoperability of supply chain (A1), shared warehouse and transportation networks (A4) belong to the causal group, while supply chain operation towards PI (A2) and infrastructure for PI (A3) are positioned into the effect group. The finding gives suggestion to enhance the physical internet towards sustainable supply chain, in which digital interoperability has the most important role. This aspect affects strongly supply chain operation and infrastructure, which means that the adoption of innovative technologies like privacy approaches, the internet of thing, blockchain requires deep transformation of the supply chain structure from a connection network to merchandise and container systems. Shared warehouse and transportation networks also pertain to the causal group and mediately impact the effect group. The finding recommends timely changes in the infrastructure and operation of the supply chain to keep up with requirements from developed warehouse and transportation systems. Moreover, among aspects in the causal group, there is a weak relationship which reflects slightly effect of one attribute’s change on the other. Nonetheless, there is no relationship between supply chain operation towards PI and infrastructure for PI, which illustrates equal roles of two aspects in promoting the PI.

Managerial implication

The finding also reveals the top five important attributes for managerial implication, which include privacy preservation approaches (C1), system of logistics network interconnectivity (C2), distributed data storage (C4), real-time locating system (C14), and distributed multi-segment intermodal transport (C17). System of logistics network interconnectivity (C2) possesses the highest dependence and driving power, presenting that improvement of logistics connectivity system among members in the supply chain should be considered as the top concern in the PI implementation. This requires the investment of the participants in the network not only in infrastructure but also in modern technologies.

Multi-segment intermodal transport (C17) ranks at the second position, requesting for fast and seamless operational transformation and communication between the carriers involved in the supply chain transportation. With this function, the attribute directly affects the infrastructure and operation criteria in the effect group. In addition, cooperation agreements between carriers as well as the participating parties need to be concretized to prevent and quickly resolve disputes that may occur during the operation.

The next important criterion is real-time locating systems (C14), which are concerned with standards for controlling and locating containers and goods according to specific timelines. Being able to accurately track the shipment helps the supply chain to operate smoothly, which is also an advantage of the PI application. One of the technologies that support this activity is radio frequency identification, a form of wireless communication to uniquely identify objects. When installing the chip in the containers according to the application of radio frequency identification, the user can conveniently monitor the condition of the goods and determine the specific location.

The criterion, privacy preservation approaches (C1), is the fourth most important attribute that needs to be paid attention to when implementing the PI. This includes the technology-based methods employed to ensure information security during communication between supply chain members. Innovative approaches are recommended to adopt at businesses including mechanism design, data mining, or machine learning.

Distributed data storage (C4) has driving and dependence power at the fifth rank and is considered as a data platform for storing past data. Since data error might be easily circulated throughout the network, trackable and traceable sharing of data is a preferable target, especially in large logistics networks as those backed by PI. Embedded intelligence and edge computing are specific techniques that disclose the potential to overcome this issue.

Conclusion

While PI has become a notable issue recently, the critical attributes for enhancing its implementation towards a sustainable supply chain have not been completely explored. In this study, FDM and FDEMATEL methods are applied to solve the gap and achieve the objectives including pointing out the cause-and-effect group and their interrelationship. The contribution of this study to the theoretical basis is to indicate the role of digital interoperability of supply chain, and shared warehouse and transportation networks as two causal aspects of PI implementation. In addition, the top five important criteria are also presented in the result consisting of privacy preservation approaches, system of logistics network interconnectivity, distributed data storage, real-time locating system, and distributed multi-segment intermodal transport, in consequence, recommend practical implications for the decision-making process.

Although this study has contributed to the PI topic, limitations remain and this allows opportunities for next studies. First, proposed attributes in the framework founded on previous studies and experts' point of view. In the future, there will be new studies related to this topic that can be used to widen the attribute list and increase the applicability of the results. Moreover, although PI is not an arisen issue, the related studies are still insufficient and there are challenges in surveying. The results can be biased because of the limited respondents due to various experiences and opinions of experts, consequently, upcoming studies should enlarge the respondents' number for extra diversification. Finally, the specific industry needed to adopt PI into the supply chain has not been clarified. Accordingly, the following studies should continue researching in a particular area or verify in divergent countries and industries to compare differences and similarities across regions, so that enhancing mutual activities for improving sustainable development in the supply chain.

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