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# Port Community Systems: Accelerating the Transition of Seaports toward the Physical Internet—The Portuguese Case

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**Abstract:** Supply chains are complex systems that have grown in dimension and spread worldwide. In supply chains, physical and information flows have strict service quality requirements, namely transparency conditions and traceability. Seaports, connecting land and maritime transport, are special components of supply chains where multiple players interact with different perspectives, and conflicting goals may arise. Port community authorities invest in electronic platforms to foster communication and integration with the companies that interact with the seaport, guiding the digitization of the seaport business. In main European and world ports, the Port Community System (PCS) is the platform that supports the creation of a network composed of shipping agents, shippers, freight forwarders, transporters, terminals, logistics platforms, and public entities. PCS focuses on service level, partner networks, maritime services, freight services, logistical services, and advanced port services. These features have an impact on seaport operations, which affects supply chain performance. Digitization within the scope of the PCSs has fostered the development of horizontal collaboration between seaport community partners. The Physical Internet (PI) is an innovative concept that seeks new logistics solutions requiring integration and interoperability between partners in the supply chain, including maritime and land transport. This paper focuses on (i) the evolution guidelines of PCSs and (ii) on the PCS Business Factors that can drive the supply chain into a significant improvement in performance. A survey was sent to a sample of Portuguese supply chain experts regarding the causal relationship between PCS Business Factors and supply chain performance in the next 10 to 20 years. From the data collected, recent services evolving at PCS are promoting a mindset change aligned to the implementation of a Physical Internet. Establishing a Physical Internal in Portuguese seaports could take decades, but it will support the transition to a new phase of PCS, accelerating the transition from Isolated Supply Chains (I-SCs) to Open Supply Chains (O-SCs), thus improving supply chain performance.

**Keywords:** physical internet; port community systems; PCS business factors

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## 1. Introduction

Supply chains are facing an increase in the complexity of physical and information flows. Transparency conditions and goods traceability are now standard service quality requirements. Seaports are special locations in supply chains where various actors interact with different perspectives, and conflicting objectives may arise. The development of supply chains based on information technologies promoted the increase in integration of logistics operations. Investment in information systems is a reality in seaports, leading to paperless interactions between actors of the port community. This is a necessary step toward more competitive seaports. Port Community System (PCS) supports the development of a network connecting the seaport players. In the main European and world seaports, the

PCS is becoming the technological platform that connects shipping agents, shippers, freight forwarders, transport providers, terminals, logistics platforms, and public entities involved in cargo services that cross the seaport.

The Physical Internet is a new concept that looks for new solutions for freight transport, aiming for radical operational improvement and sustainability. The Physical Internet follows the idealistic concept of the digital internet applied to logistics. The Physical Internet involves integration and interoperability between supply chain actors. Seaports are part of worldwide supply chains.

Ref. [1] identifies a PCS as an electronic platform that links multiple systems of distinct companies and organizations in the port community, guiding the seaport toward business digitization. Understanding the influence of PCS Business Factors is very important for seaport authorities and policymakers to guide the next steps of PCS development. There are few studies regarding the impact of PCS Business Factors on supply chain performance. This paper fills that literature gap, through the identification of the main PCS Business Factors that can improve supply chain performance and the respective importance of medication, using the Portuguese case [2,3].

This paper especially focuses on the current development of PCS and the identification of the main PCS Business Factors that can improve supply chain performance toward the development of a Physical Internet in the next 10 to 20 years. A survey was sent to Portuguese supply chain experts with the following PCS Business Factors: Software, Hardware, Physical Structures, Integration, Collaboration, Mindset, and Management and Legal Framework. The authors found that the PCS Business Factors more relevant to the Portuguese supply chain experts were (i) Integration and Collaboration, (ii) Management and Legal Framework, and (iii) Mindset and Physical Structure. The identified PCS Business Factors can promote the future of supply chains toward the Physical Internet. The development of a Physical Internet at Portuguese seaports may require decades, but the change in services provided by PCS is creating a shift in mindset from Isolated Supply Chains (I-SCs) toward Open Supply Chains (O-SCs).

## 2. Literature Review

Supply chain integration implies collaboration at strategic and organizational layers. Sharing data and knowledge among supply chains actors is fundamental for an agile flow of goods in response to the customers' needs. Seaports are important in helping the coordination of supply chain flows (material and data). The alignment of strategies and processes between seaports and logistics communities is vital to ensure service and productivity [4]. Common business factors for seaport communities, in the scope of information systems literature, can be synthesized into three frames: Business, Integration, and Legal [5]. As part of the maritime logistics chain, seaports are important links in supply chains and international transportation [6]. According to [7], seaports are a component of supply chains with an important role in the management of the flow of material and information. The success of a seaport depends on the level of integration with the supply chains crossing the seaport. The seaport community must create synergies with inland actors such as transport operators, shippers, freight forwarders, and other logistics players.

A seaport is composed of a set of organizations in which different transport and logistics operators are interested in creating value for the final customer. Different roles are present at the port community: authorities, members, system operators, supply chain partners, and managers [8]. According to the type of relationships among the seaport partners, four phases of collaboration are established: pre-collaboration, consolidation of partnership, development of PCS, and redesign of the port partnership [8]. Companies are motivated to globalize operations to grow and increase competitiveness and thus take advantage of the development of new technologies available [9]. The concept of integrated logistics management refers to the administration of the various activities as an integrated system. Integration means developing cooperative relationships with the various stakeholders in supply chains, based on trust, technical capacity, and information exchange [9]. Usually, companies do both import and export activities; therefore, a PCS must customize both perspectives, offering a wide range of services [10]. Supply chains with fully integrated seaports have uninterrupted communications, through the just-in-time concept with operations cost reductions. The interconnectivity and interoperability of infrastructure with transport operations increase the provision of added value services and customer satisfaction [11].

Performance of supply chains (with land and maritime transport) has become the crucial source of sustainable and developmental advantage [12]. Ref. [13] underlines the important role that seaports must play within the framework of supply chains, with an emphasis on the creation of value for customers. It is necessary to manage the relationships of the distinct actors that interact with the seaport considering common goals (maritime agents, land transport providers, and cargo owners) [13]. Ref. [14] refers to a port community as an organization that manages the links between maritime and land transport systems. The existing infrastructure and software at a seaport play an important role in the success of a seaport.

The concept of a Physical Internet was first introduced by [15], who defined it as an open logistic system oriented to the sustainable and efficient transport of physical objects worldwide. It is a metaphor from the digital internet to logistics service networks. The Physical Internet is based on highly interconnected systems that enable seamless information and asset sharing, leading to efficient use of available resources through the consolidation of flows within the system. More than a reality, the Physical Internet contains a vision for the near future and the guidelines for a switch of behaviors. The European Technology Platform ALICE (Alliance for Logistics Innovation through Collaboration in Europe) is a platform focusing on the definition of a strategy for the research on innovation regarding supply chain management. The research and statements from this platform may lead to the adoption of a Physical Internet. The implementation of a Physical Internet will use the information made available by the Internet of Things (IoT), using smart tags as a key element to collect data. Collaboration between the actors involved is taken for granted, and trust is critical for success. The vision of a Physical Internet is guiding the transition from independent supply chains to open supply chains [16].

The proposed work focuses on the effect the PCS Business Factors can have on the development of a Physical Internet at Portuguese seaports, leading to an improvement in performance.

## 3. Port Community Systems and Physical Internet of Transportation Hubs

The growing importance of communication between seaport actors has transformed port systems into port community systems. The port community involves various public and private actors, usually operating the port business in a fragmented way [17–19]. The large amount of data exchanged between the members of the port community is a measure of the complexity of operations within the seaport.

### *3.1. PCS Phasing*

PCSs present different levels of evolution. Seaports can be categorized according to the PCS evolution present within them. PCS evolution can be broken down into five phases (Figure 1). Most of the PCSs worldwide are in the first two phases, with some seaports at the beginning of a fourth phase, aiming to enter a fifth phase that involves the integration of PCS with supply chain systems:

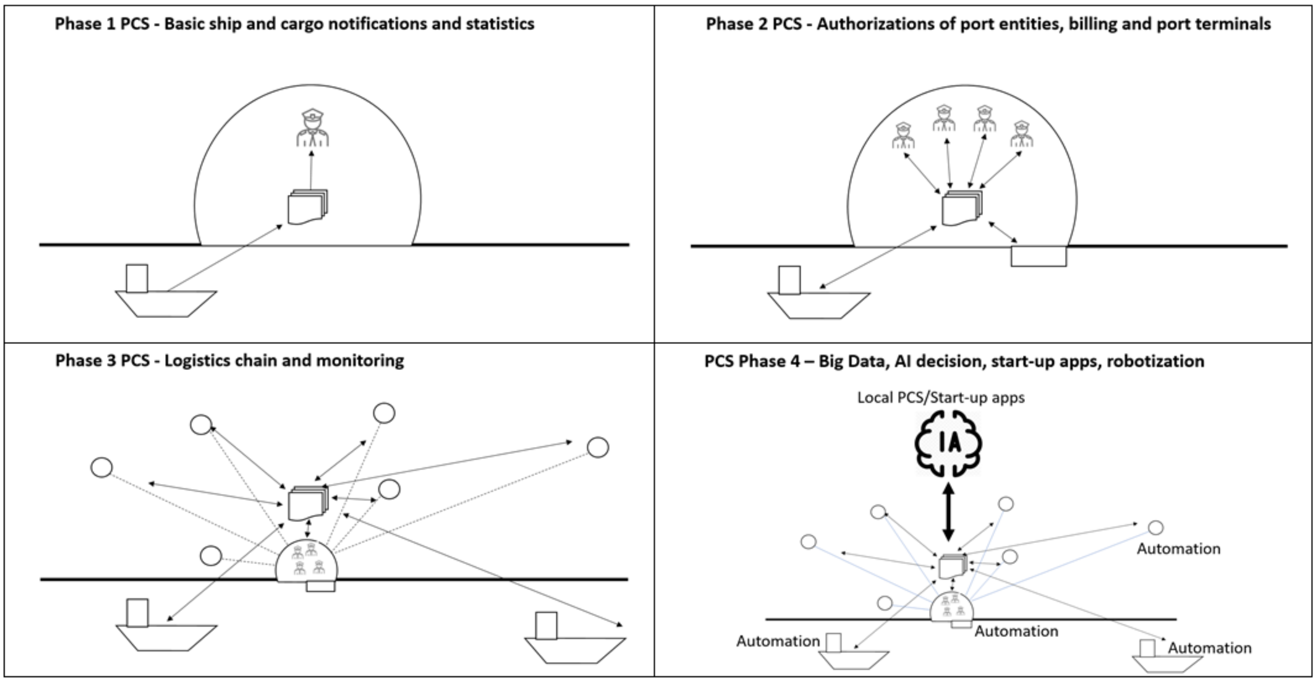


**Figure 1.** PCS evolution phases.

First phase: PCSs include mainly the notifications of ship and goods arrivals, and statistical outputs.

Second phase: PCSs begin to include the port authorities' authorizations, such as those from the port authority, port customs, maritime authority, and health public services. The PCSs begin to include the automatic invoices of authorities and cargo and ship authorizations [11], with no paper in the process.

Third phase: This is known as the expansion phase (regionalization), when the seaports collect information using sensors (following an IoT approach) regarding supply chain information, including road, water, and rail transport modalities, logistic platforms, with full visibility of processes, aiming for the synchronization of operations.

Fourth phase: PCSs have created opportunities that foster the appearance of a nest of new companies and advanced innovation [20]. This is based on new business models, through the development of applications of artificial intelligence [5], robotization, port analysis, Big Data [21], predictive analytics, integrated flows, risk management, and optimization of port operations [22,23]. The fourth phase of PCS corresponds to the settlement of the necessary conditions for the development of a Physical Internet. The use of intelligent tags with cargo (IoT) allows real-time monitoring of cargo locations, which can support the development of synchromodal transport solutions with an impact on land vehicle bookings and transport optimization.

Fifth phase: This phase focuses on the international integration of the PCS with the availability of information. Only in this transnational phase will it be possible to fully integrate supply chains worldwide, with total availability of data and traceability of goods. Management decisions can be updated quickly using the available data, and forecast, in order to coordinate flows. The optimization of decisions taking into account import and export business factors completes the Physical Internet (Figure 2).

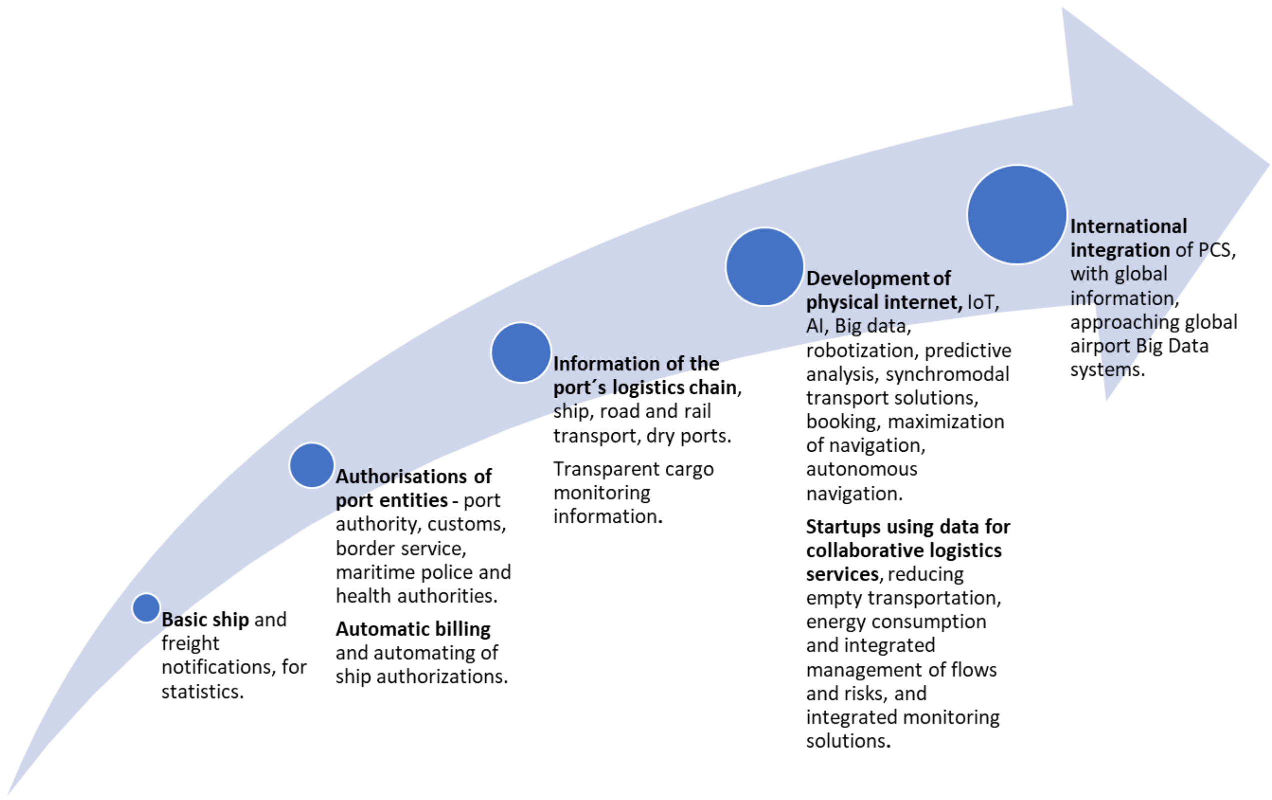


**Figure 2.** PCS evolution phases toward the Physical Internet.

Ref. [24] reports that the PCS and seaport performance are related and involve business factors like the existence of advanced seaport services, vessel-specific services, and partner networks. PCS services are usually limited to the digitization of the cargo and ship processes, without a redefinition of port global processes. Port managers need to focus on creating a network of partners, collaborating toward general and common goals. The PCS is a suitable tool to access data and visibility of cargo and transport modes including supply chain actors [24].

### 3.2. *Physical Internet*

The concept of the Physical Internet has been an intensive research topic since its appearance in 2010 [15] by both the academic and industry communities. The main trends in academic research are divided into (i) conceptual models, (ii) performance assessment, and (iii) decision-making tools based on operations research or simulation tools [25–28]. For the industry, the Physical Internet is a pragmatic concept that aims the adoption of new practices to achieve more sustainable supply chains. The European Platform ALICE has identified five goals: (1) information systems; (2) global supply chain network coordination; (3) sustainable logistics supply chains; (4) corridors, hubs, and synchromodality; and (5) urban logistics. The Physical Internet is unquestionably a mindset changer for both academics and professionals. Port information systems contribute to sustainable development, as is the case with the Antwerp PCS, which seeks to align economic, social and environmental interests in the port community [29].

A Physical Internet at seaports includes intelligent automated decision and forecasting systems. The optimization and forecasting of the best routes in collaboration systems can promote operations efficiency. The availability of data (Big Data) for private platforms offers an opportunity to develop value-added services based on artificial intelligence. Access to data is an essential service to foster the empowerment of innovative start-ups. The PCS evolves from a centralized system to an open system that promotes the integration and innovation of the supply chain.

*3.3. From PCS toward Physical Internet*

Seaport hinterland and foreland are composed of land transporters, shippers, logistics operators, and industries. All these actors collect information at the cargo location with sensors, and information is made available in a transparent manner. It appears that most PCSs are still in the second phase, with a simple operation and connection system between port players, to facilitate operations with ships and cargo. Some, as is the case with Portugal, are already developing the third phase, with its expansion to the hinterland, and the inclusion of the remaining supply chain actors outside the seaports. However, few seaports are advancing to the fourth and fifth phases of their PCS evolution, on the way to achieving the Physical Internet.

The fifth phase involves international collaboration between economic groups of distinct countries and/or continents. At a global level, sharing bottom-up information from the PCS to all supply chain actors creates opportunities for innovation. Applications can be developed offering services with all transport modes integrated. Information regarding schedules, prices, special events, unforeseen delays, and problems can be included in the decision process. An automatic decision of the best routes for each cargo (the best modality choice including transshipment operations and aggregation of cargo) is made to the advantage of all actors, approaching the Physical Internet. For this phase, international collaboration bodies and models are necessary to assure free competition and transparency among actors. The physical internet may not be reached until 2040, and global governance of systems is essential to increase the pace of development and adoption of this concept, especially through ports [30]. Ref. [31] refers to the use of intelligent agents in PCSs and the advantages of sharing data and flow information and optimizing transport in the logistics chain. Many of the innovations involve artificial intelligence (AI) and come from start-ups. Predictive models, artificial intelligence, and machine learning (ML) can establish rules for decisions at seaports and supply chains. Algorithms can have access to thousands of big data logs, can access hundreds of IoT (internet of things) variables, and can use multiple predictive models, to have reliable predictive relationships, to learn and to develop predictive abilities which humans could never be capable of. No human being could devote so much attention to a transaction and make such a complex decision in such a short time. Rapid and exhaustive assessment of the possibilities will make a difference in the supply chain and seaports, and there are new services to be offered by an integrated PCS, at the global level, toward a Physical Internet model.

With Artificial Intelligence, a vehicle booking system at a seaport terminal becomes more than just a way to control the containers. It can be a capacity management system with full quality service. The system can become so sophisticated that reserves can be optimized and allocated autonomously by the algorithm. For example, command actions for truck drivers, the park and dock equipment of the seaport terminal, as well as the slots of ships, and even for the ship, can be given by the algorithm. This reduces time, energy, and costs. By optimizing the planning of equipment and staff, the seaport becomes leaner, more flexible, and develops an increased capacity to respond to environmental and market changes.

Most supply chains lack transparency in critical locations such as seaports and logistics processes. Visibility is needed to better predict and prevent inventory disturbances, changes, and imbalances. One tool available is predictive risk analysis. This helps operators understand, for example, the likelihood of a vessel being delayed. Hundreds of simulation models are generated per shipment to provide the probability of a status change, and the result may be, for example, that 87% of the 130 simulations predict that the shipment will arrive late.

One of the main problems in approaching new projects in this domain is knowing how and when the information must be shared and whether actors would be willing to share information considering the unequal distribution of costs and benefits. The actor's incentive to join a PCS should be high [32,33]. The perception of value and usefulness that should be defined during the implementation of these systems is very important so that they are well accepted and that full collaboration between partners is possible [34]. This issue of collaboration between port terminals, shipping agents, and shipping liners can lead to reductions in bunker consumption but also investment and operating costs and loss of control over information [35].

It is important for organizations and authorities driving the development of seaports to identify which guidelines drive the Port Community Systems from horizontal collaboration toward the Physical Internet. The implementation of a Physical Internet may require decades, but the change in services provided by PCS is setting a shift in mindset from Isolated Supply Chains (I-SCs) toward Open Supply Chains (O-SCs), promoting the Physical Internet.

### 3.4. European Examples

In European seaports, there are cases of private applications under development in ports such as in the Netherlands, Belgium, and Portugal that are offering innovative logistics services [3].

NxtPort: The NxtPort data usage platform was created to facilitate data sharing practices among users in the Port of Antwerp. NxtPort addresses the specific type of data transfer that has not been covered by other community systems. It was created by a private company, and its main objective is to integrate data from terminal operators. It is expected that NxtPort will increase the operational efficiencies of the port's stakeholders, overlaying a new layer of data on the existing information. In addition, the platform aims to create added value for data owners and users, allowing market applications to be built with existing data.

NextLogic: The Port of Rotterdam introduced a parallel initiative–NextLogic–established for and by the market. However, its approach is different from NxtPort, which is an integration platform that, after integrating information from different sources, aims at development opportunities. Instead, NextLogic has a bottom-up approach from the beginning; the platform is aimed at providing solutions to various optimization problems faced by logistics companies operating at the Port of Rotterdam. NextLogic is a data integration platform that addresses the systems of container transport and logistics companies (for example, barge operators, land terminals, port terminals and warehouses, shipowners, and freight forwarders at the port of Rotterdam). NextLogic focuses on dealing more efficiently with inland container shipping, providing a platform on which the entire container transport chain can work together. The benefits for Supply Chain stakeholders that adhere to NextLogic include more reliable planning and predictable response time, optimization of the use of port terminals, cranes, and barges, with connections to the port. The platform is financed by the Port Authority and Rijkswaterstaat, the agency responsible for designing, building, managing, and maintaining the main infrastructure in the Netherlands. The objectives include strengthening the competitiveness of the Port of Rotterdam and stimulating the growth of container transport inland. Private sector companies signed contracts to use NextLogic and provided information for the design and operation of the platform.

CargoStream: CargoStream is a data integration initiative that is based on the participation of all stakeholders in the supply chain, shippers, intermodal terminals, rail and barge operators, and logistics operators. This is another good example of co-innovation. The platform was developed by Nallian, a company focused on improving collaboration in the supply chain. As an open platform, CargoStream offers a "plug and play" architecture, allowing solution providers to offer their algorithms on the platform. Participating shippers contribute to its development, providing information and sharing knowledge. The objective of this independent, neutral, open, and pan-European platform is to help participating shippers reduce their transport kilometres on the highway, combining their transport needs with other shippers so that vehicle usage rates can be improved, route distribution can be optimized, and the use of multimodal transport can be improved. Shippers communicate their regular transportation needs to CargoStream and the platform organizes this information, aggregates the needs of multiple shippers, and applies state-of-the-art optimization algorithms to provide shipping options for the specific cargo. In addition, as it is a neutral platform, ownership of the shippers' data is guaranteed.

Avantida: Avantida is a software developer who started the innovative concept of reuse. The aim is to provide shipowners and other container owners with a way to use their containers more efficiently. Through this platform, empty containers from import operations can be reused for export operations, thus allowing the matching of complete transport orders with the planned trips of empty containers. In other words, this application allows container shipping companies to communicate with land operators and integrate their transport needs and unused transport capacities. By using this platform, minimizing the unproductive transportation of empty space in the containers, benefits are generated for all parties involved. In addition, this innovative initiative results in the reduction in transport costs and $CO_2$ emissions for carriers and can contribute to a reduction in port congestion.

EuroTransCon: Another example of port innovation is the matching mechanism developed by Hakka, a spin-off from the technology company Inuits. This solution is based on an innovative concept called EuroTransCon, introduced by a road transport company, through which container exchanges are carried out to improve collaboration and communication in the road transport industry. In this way, empty containers are not sent back to port depots but are refilled in the vicinity of where they were unloaded. Thus, Hakka brings together road transport operators in the port area to complete their transport tasks more efficiently.

Nexus: Nexus is a recently approved project of the Port Administration of Sines (located in the southwest of Portugal) with the goal to promote high-performance operations for the supply chains crossing the seaport of Sines. The project aims to foster the synchronization of processes between all actors, making use of total visibility over operations and traceability of goods. This project involves 28 companies (national and international organizations). All participants in this network, including the authorities, will gradually share information in real time and align their processes. The alignment of processes will ensure the highest level of integration possible for managing, planning, and executing multimodal services.

## 4. Research Model and Methodology

The research model presented in Figure 3 includes two distinct objectives: (1) understand the experts' perception of the variables and PCS Business Factors influencing the future trends in supply chain performance; (2) quantify the contribution of each identified PCS Business Factor to the future development of supply chain performance. The research hypotheses are as follows:

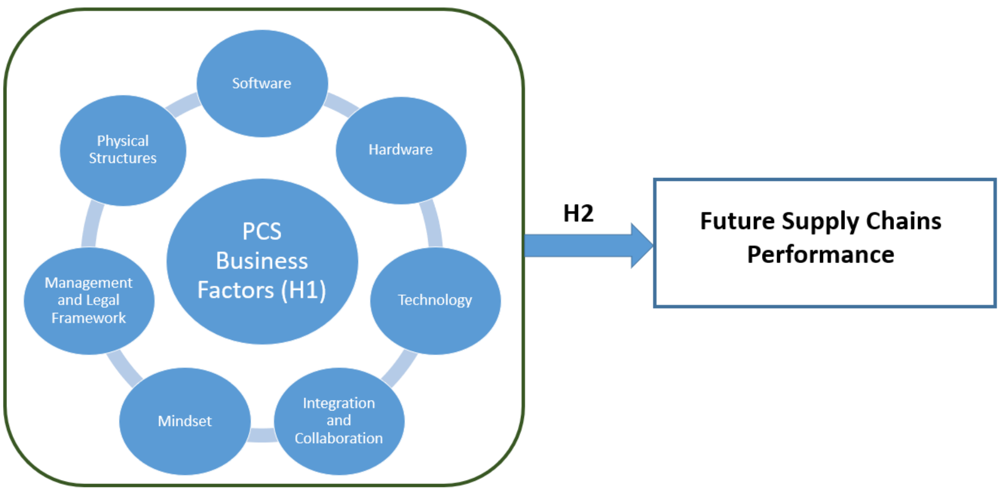


**Figure 3.** Research Model.

**Hypothesis 1 (H1).** *The PCS Business Factors that have an impact on the performance of supply chains in the next 10 to 20 years are Integration and Collaboration, Software, Physical Structures, Mindset, Management and Legal Framework, Hardware, and Technology.*

**Hypothesis 2 (H2).** *The PCS Business Factors identified in H1 have different weight contributions to supply chain performance in the next 10 to 20 years.*

The PCS Business Factors used in this paper were selected according to the literature review:

Integration and Collaboration: focus on the relationships established between the supply chain actors. Includes the following variables: Advancing Planning, Price and Quality, PCS integration, Trust Networks [6], and Intermodal and Synchromodal integration [31];

Software: refers to the evolution of software functionalities allowing monitoring more information and making use of it to support wiser decisions. Includes the following variables: Artificial intelligence [5], Big Data [21], Simulation, Data analytics, Automatic decisions [11], Physical Internet [16], and Internet of Things [16];

Mindset: includes management changes and business model changes toward new paradigms of supply chain management, and consists of the following variables: Mindset changes and Business model changes [34];

Physical Structures: refer to the facilities used to support operations over the supply chain and equipment used to handle cargo, which include the following variables: Intermodal Containers [36], new cranes and new vehicles include Terminals, New Intermodal Containers [37], Traceability [38], and Operational integration and optimization;

Management and Legal Framework: refers to national and international political instruments and environmental changes, and includes the following variables: legal issues, management changes, and supply chain governance and sustainability [15].

Hardware: focuses on the technology necessary to gather or collect data and in the second stage the execution of a decision taken by a decision maker. Includes the variables Robotization and Automation [11];

Technology: changes focus on the advantage of developing new technologies and capabilities [9].

The methodology used was based on a survey sent to 600 Portuguese experts in supply chains, on the importance of the PCS Business Factors influencing the future of supply chain performance in the next 10 to 20 years. The survey used the Likert-7 as a variable scale (from "1–not important" to "7–very important"). The survey was composed of 26 questions with 26 corresponding exogenous variables and one endogenous variable. From the sample, 86 valid answers were collected, representing a 14.3% success rate (37% of responses received were from public organizations experts and 63% from private port and maritime company experts, including the seaports of Sines, Setúbal, Lisbon, Aveiro, and Leixões).

Considering the correlations verified through the correlation matrix (Appendix A Table A1), through which it is possible to conclude that there are several variables observed with a high degree of correlation, indicating the possibility of the existence of superior factors or latent variables, the factor reduction methodology was used through factorial analysis (SPSS). Confirmatory structural equation modeling methodology (SPSS/AMOS) was used to evaluate the contribution of each Business Factor to the endogenous variable of the future supply chain performance.

## 5. Results and Analysis

The average classification of all Business Factors using the Likert-7 scale was higher than 5.00, being in an interval up to 6.15 (Figure 4). The experts considered these factors as important or very important for the referred causal effect.

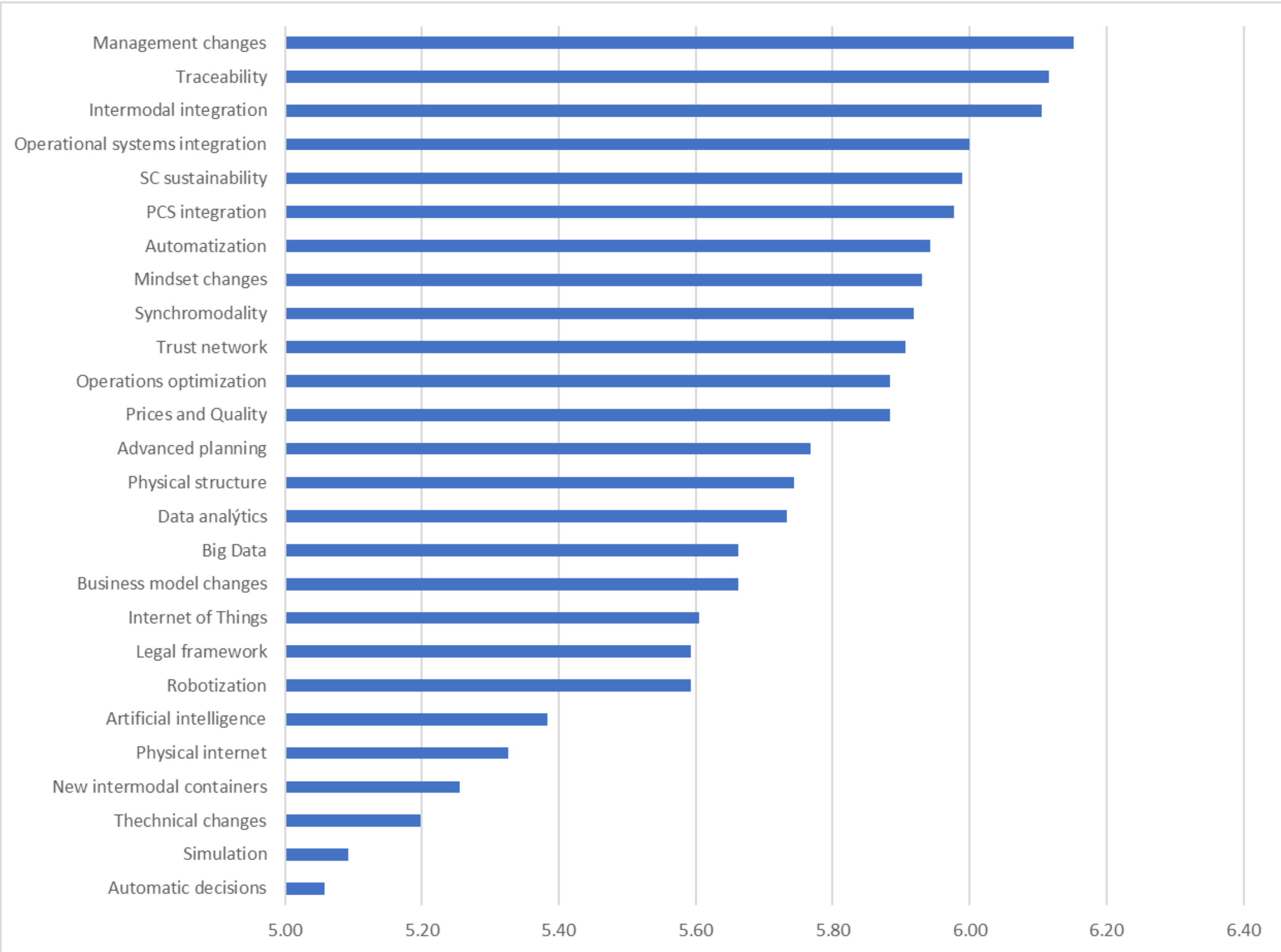


**Figure 4.** Survey results.

### 5.1. Variables

The observed variables with the highest classification were Management Changes, Traceability, and Intermodal integration. This shows the perception of the Portuguese experts regarding the urgent need for higher integration of seaport systems toward the increase in supply chain performance in the next two decades.

The lowest-ranking, yet positive, variables were Automatic Decisions, Simulation, and Technical Changes. They are considered equally important (above 5 in the Likert-7 scale) for future supply chain performance. These variables are oriented to resources and infrastructure needed at seaports, seen as a requirement, and usually taken for granted, and for that reason are less relevant for the managers.

### 5.2. Port Community System Business Factors

A PCS Business Factors analysis using the SPSS (with a varimax rotation of the Business Factors and latent variables) reduced the PCS Business Factors to six. The new Business Factors (or constructs) with a KMO (Kaiser–Meyer–Olkin) test of 0.756 and all variables with a coefficient over 0.4 (Table 1) were obtained, namely:

(a) Integration and Collaboration (variables mean = 5.87)
(b) Software (mean = 5.41)
(c) Mindset and Physical Structures (mean = 5.81)
(d) Management and Legal Framework (mean = 5.9)
(e) Hardware (mean = 5.7)

(f) Technology (mean = 5.2)

**Table 1.** PCS Business Factors and variables results.

| Business Factors and Means | Variable | Factor Score Coefficient |
|---|---|---|
| Integration and Collaboration 5.87 | Trust network | 0.846 |
| | Intermodal integration | 0.716 |
| | Synchromodality | 0.715 |
| | Advanced Planning | 0.673 |
| | Price and Quality | 0.636 |
| | PCS integration | 0.508 |
| Software 5.41 | Big Data | 0.769 |
| | Data Analytics | 0.734 |
| | Artificial Intelligence | 0.723 |
| | Simulation | 0.675 |
| | Physical Internet | 0.556 |
| | Internet of Things | 0.532 |
| | Automatic decisions | 0.498 |
| Mindset and Physical Structures 5.81 | Operation optimization | 0.804 |
| | Operational systems integration | 0.717 |
| | Traceability | 0.705 |
| | New intermodal containers | 0.478 |
| | Business model changes | 0.704 |
| | Mindset changes | 0.653 |
| | Physical infrastructure | 0.408 |
| Management and Legal Framework 5.9 | Legal framework | 0.571 |
| | Management changes | 0.542 |
| | SC sustainability | 0.537 |
| Hardware 5.7 | Robotization | 0.824 |
| | Automation | 0.794 |
| Technology 5.2 | Technical changes | 0.857 |

The Business Factor of Mindset was integrated with the Business Factor of Physical Infrastructures. This effect is very interesting and has not been referred to in the literature. Using the average of the means of the variables that are integrated into each Business Factor, it was possible to measure the importance of each Business Factor from the perspective of Portuguese experts. That is, on one hand, the fact that all factors have an average above 3.50 demonstrates that all are important in the causal relationship that was the target of the survey (confirming H1); on the other hand, the different averages demonstrate that the importance of each factor was ranked differently by experts. Some factors are more important than others for the future performance of maritime supply chains (confirming H2).

Portuguese experts consider that the most important Business Factors for changing the business model of Port Community Systems are the ones related to changes related to (i) Integration and Collaboration, (ii) Management and Legal Framework, and (iii) Mindset and Physical Structures.

This priority change on Business Factors is related to new company internal organization and external relationships. New mindsets and new governance and management models are appearing at seaport players, leading to new business models based on data sharing and integration with partners. The identified Business Factors have an important role in the integration, development, and expansion of PCS, as well as in the process of collaboration and openness of seaport partners to endorse common projects. In a second layer, operational systems integration, PC sustainability, and PCS integration confirm the awareness among Portuguese experts of the need to foster joint work between actors.

Technological changes are also important, but they are not the main issue for the future of ports and maritime transport.

### 5.3. Confirmatory Analysis

To confirm the relationships and understand the weight of each Business Factor to explain the research model endogenous variable, a Structural Equations Modeling methodology (SEM) was used. The authors obtained the model presented in Figure 5, which also proved Hypotheses H1 and H2. The endogenous variable is explained with a coefficient of determination of 0.52. In this perspective, the most important PCS Business Factors for future supply chain performance are the integration and collaboration between the different actors and the management and legal framework issues, followed by the mindset and physical structure.

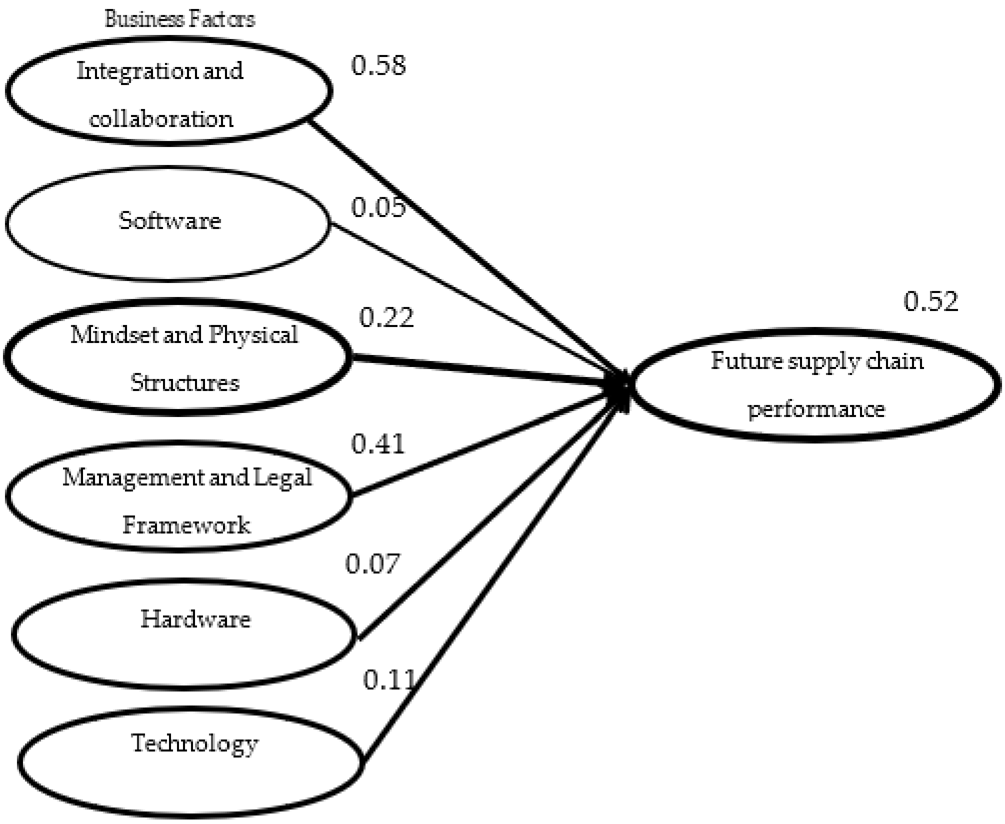


**Figure 5.** Research Model SEM Results.

The Business Factors of software, hardware, and technology, being important, are in the background in the model. These results confirm what was stated by [13] that referred to the importance of port players' collaboration to PCS performance, and by [4,14] about the importance of the integration of seaport actors and the legal framework for the future of PCS. It also confirms the importance of the mindset [39] and infrastructure regarding future PCS changes.

The analysis carried out by the authors shows that the fourth and fifth phases will be driven by the Business Factors of Integration and Collaboration, Management and Legal Framework, Mindset and Physical Structures (as priority factors), and by Software, Hardware, and Technology changes (as second layer factors).

It will be necessary to move toward an international organization model that allows collaboration between countries and seaports to establish rules for the integration of PCS and supply chain systems toward the development of the global Physical Internet.

The survey results show and confirm the respondents' perceptions about the importance of the PCS business change factors found in the literature and their influence on the performance of supply chains in the future between 10 and 20 years.

## 6. Conclusions

Through the analysis carried out in this study, the authors conclude that the PCS Business Factors that will drive the Supply Chain performance in the next decades will include Management and Legal Framework, Integration and Collaboration, Mindset and Physical Structures, Software, Hardware, and Technology. Experts consider that the most important factors are related to changes in the Management and Legal Framework, Integration and Collaboration, and Mindset and Physical Structures, which should be addressed in the first phase.

The main contribution to science and economics consists of a clear vision regarding how to drive the evolution of PCS into the fifth phase toward a Physical Internet. The new PCS will integrate new services like artificial intelligence and Big Data and will be able to improve supply chain performance. This contribution is fundamental for policymakers, seaport managers, and authorities to foster the mindset switch of logistics actors at the national and international levels.

International organizations like the European Union and UNCTAD can have a very important role in the PCS fourth and fifth phases, providing knowledge, common platforms, and experience on innovation and inclusion of IoT, Big Data, and AI. The existence of innovation ecosystems in seaports and including them in PCSs are essential for the creation of a Physical Internet improving supply chain performance.

For the future, new studies on the possible designs of the international cooperation mechanisms should be developed, addressing the integration of the PCS. This study can be enlarged to other ports and countries.

The limitations of this study are essentially the need for further confirmation of the presented vision for the Portuguese case, through a survey of experts in other countries and seaports. The sample is limited to fewer than 200 observations. Factors such as international policy, carbon neutrality, markets, economic environment, culture, transport system technologies and energy can influence the research model and should be analyzed in future studies.

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## Appendix A

**Table A1.** Exogenous variables' correlations.

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Artificial Intelligence | - | 0.52 | 0.17 | 0.28 | 0.32 | 0.40 | 0.18 | 0.45 | 0.19 | 0.37 | 0.36 | 0.33 | 0.09 | 0.22 | 0.32 | 0.33 | 0.26 | 0.41 | 0.19 | 0.14 | 0.21 | 0.24 | 0.25 | 0.11 | 0.12 | 0.09 |
| 2 | Big Data | - | - | 0.39 | 0.20 | 0.51 | 0.45 | 0.33 | 0.65 | 0.43 | 0.37 | 0.35 | 0.34 | 0.12 | 0.27 | 0.34 | 0.33 | 0.31 | 0.26 | 0.10 | 0.16 | 0.16 | 0.17 | 0.22 | 0.29 | 0.31 | 0.16 |
| 3 | Automation | - | - | - | 0.61 | 0.32 | 0.28 | 0.44 | 0.37 | 0.27 | 0.21 | 0.24 | 0.36 | 0.24 | 0.36 | 0.41 | 0.18 | 0.40 | 0.15 | 0.22 | 0.26 | 0.05 | 0.28 | 0.22 | 0.06 | 0.43 | 0.14 |
| 4 | Robotization | - | - | - | - | 0.30 | 0.28 | 0.34 | 0.19 | 0.11 | 0.24 | 0.18 | 0.27 | 0.07 | 0.21 | 0.32 | 0.04 | 0.29 | 0.06 | 0.08 | 0.10 | −0.1 | 0.20 | 0.13 | 0.03 | 0.32 | 0.11 |
| 5 | Internet of Things | - | - | - | - | - | 0.32 | 0.21 | 0.33 | 0.36 | 0.40 | 0.29 | 0.22 | 0.23 | 0.28 | 0.25 | 0.22 | 0.44 | 0.25 | 0.15 | 0.15 | 0.16 | 0.15 | 0.15 | 0.08 | 0.28 | 0.05 |
| 6 | Simulation | - | - | - | - | - | - | 0.29 | 0.51 | 0.34 | 0.43 | 0.26 | 0.33 | 0.18 | 0.23 | 0.20 | 0.23 | 0.17 | 0.14 | 0.19 | 0.01 | 0.12 | 0.17 | 0.04 | 0.11 | 0.23 | 0.01 |
| 7 | Traceability | - | - | - | - | - | - | - | 0.39 | 0.58 | 0.37 | 0.36 | 0.38 | 0.60 | 0.40 | 0.47 | 0.29 | 0.39 | 0.32 | 0.22 | 0.40 | 0.35 | 0.27 | 0.27 | 0.07 | 0.29 | 0.08 |
| 8 | DataAnalytics | - | - | - | - | - | - | - | - | 0.58 | 0.53 | 0.53 | 0.35 | 0.32 | 0.31 | 0.27 | 0.43 | 0.45 | 0.35 | 0.23 | 0.21 | 0.22 | 0.33 | 0.22 | 0.22 | 0.42 | 0.26 |
| 9 | Operational systems integration | - | - | - | - | - | - | - | - | - | 0.43 | 0.42 | 0.43 | 0.54 | 0.58 | 0.33 | 0.30 | 0.31 | 0.34 | 0.23 | 0.32 | 0.29 | 0.27 | 0.31 | 0.15 | 0.29 | 0.06 |
| 10 | Physical Internet | - | - | - | - | - | - | - | - | - | - | 0.57 | 0.30 | 0.38 | 0.28 | 0.33 | 0.26 | 0.32 | 0.21 | 0.19 | 0.31 | 0.23 | 0.18 | 0.35 | 0.16 | 0.25 | 0.11 |
| 11 | New intermodal containers | - | - | - | - | - | - | - | - | - | - | - | 0.38 | 0.41 | 0.36 | 0.35 | 0.23 | 0.39 | 0.34 | 0.19 | 0.41 | 0.28 | 0.24 | 0.39 | 0.12 | 0.19 | 0.16 |
| 12 | Autimatic decisions | - | - | - | - | - | - | - | - | - | - | - | - | 0.33 | 0.40 | 0.34 | 0.12 | 0.45 | 0.47 | 0.26 | 0.07 | 0.11 | 0.19 | 0.24 | 0.12 | 0.27 | 0.02 |
| 13 | Operation optimization | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.39 | 0.42 | 0.13 | 0.43 | 0.34 | 0.27 | 0.40 | 0.27 | 0.16 | 0.33 | 0.09 | 0.21 | 0.08 |
| 14 | PCS integration | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.62 | 0.20 | 0.44 | 0.46 | 0.48 | 0.42 | 0.39 | 0.39 | 0.50 | 0.25 | 0.42 | 0.12 |
| 15 | Intermodal integration | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.44 | 0.60 | 0.58 | 0.47 | 0.47 | 0.40 | 0.51 | 0.64 | 0.13 | 0.39 | 0.08 |
| 16 | SC sustainability | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.46 | 0.51 | 0.37 | 0.49 | 0.52 | 0.55 | 0.42 | 0.13 | 0.24 | 0.30 |
| 17 | Synchromodality | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.73 | 0.55 | 0.48 | 0.36 | 0.50 | 0.50 | 0.14 | 0.39 | 0.20 |
| 18 | Trust network | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.56 | 0.41 | 0.43 | 0.53 | 0.50 | 0.13 | 0.25 | 0.14 |
| 19 | Advanced Planning | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.52 | 0.39 | 0.48 | 0.38 | 0.12 | 0.30 | 0.23 |
| 20 | Physical structure | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.58 | 0.44 | 0.55 | 0.31 | 0.42 | 0.20 |
| 21 | Legal framework | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.60 | 0.44 | 0.12 | 0.40 | 0.24 |
| 22 | Mindset changes | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.45 | 0.19 | 0.51 | 0.46 |
| 23 | Price and Quality | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.34 | 0.27 | 0.18 |
| 24 | Technical changes | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.19 | 0.23 |
| 25 | Management changes | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.33 |
| 26 | Business model changes | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

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