

A Method to Measure Logistic Interoperability using Structural Equation Modelling

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Abstract

This article seeks to build the method to measure the Logistics Interoperability (LI) using the structural equation model. It was built from the functional link of logistics and interoperability. Partly, the result identified some determinants of LI (constructs) as external logistics, internal logistics, inbound logistics, and strategy.

This work was characterized as exploratory, descriptive, qualitative, and quantitative approaches with bibliometric research, and a survey, consisting of a questionnaire, was applied in an industrial company in the Industrial Park of Manaus. The data were analyzed using Smart PLS® 3.0 to test measurement and structural model.

The outputs show the validity (convergent and discriminant), confiability and reliability of the proposed conceptual model, through the analysis of reliability (Cronbach's alpha) and strong correlations between variables with relevant factor loadings. A major limitation of this study is the use of data from a single city (Industrial Pole of Manaus), despite the high degree of internationalization of each company studied.

The definition of the Logistic Interoperability can facilitate decision-making and the importance of each in the logistics process and provides a guide to managers and organizations.

Keywords

Interoperability, Structural Equations Model, Measurement, Logistic.

1. Introduction

In today's business environment, organizations are looking for a better responsiveness to customer demands, a more consistent relationship with their suppliers in order to reduce inventories, costs and, above all, consistency in their decisions. The main connection of these relationships happens with the exchange of information and assets, thus necessitating an improvement of the logistics (Zampou et al. 2015).

At the same time, logistics also enables better relationship between suppliers and customers, by coordinating the material flow and related information. Thus, logistics acts as a synchronizing element between supply and demand. (Ballou 2006; Wilding et al. 2012).

In the context of inter-relationships, the management philosophy of the supply chain (SCM) insists on the need to move away from interactions with long arms to sort of partnership arrangements between companies to create highly competitive supply chains. (Stank et al. 1994).

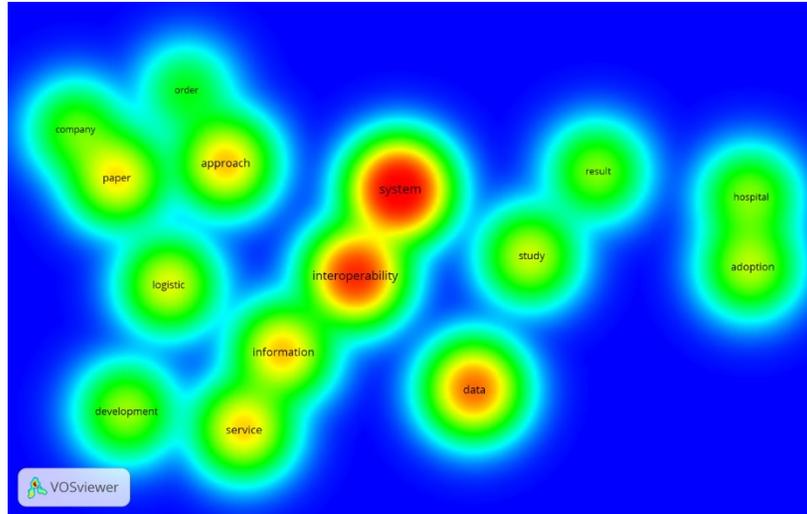
The literature, in general, considers interoperability as the capability of an organization to act in an interoperable way, both internally and externally, with significant competitive advantage, as it can cut costs, improve response time and allow for a greater scope of their operations, it's usually desired in the area of information systems, and it was observed that its principles could also be applied to logistics. (Arsenyan et al. 2015; Bruzzone et al. 2011; Cabral et al. 2014), allows for effective inter-company connections enabling the sharing, interaction, collaboration, and compatibility of inventory, transportation, production and other information.

Interoperability enables the interaction between processes, information flows, equipment, and systems from different organizations. (S. Carson 2009; Ma 2009; Ming-yong 2009; Panetto and Molina 2008) and it's deemed to have been achieved if efficient collaboration is carried out at least in the layers of business technologies, knowledge, information, communication technologies, and taking into account the semantic aspects that complement the previous three. (D. Chen et al. 2008). The advance of the need for interoperability comes from the 90's, with the development and evolution of information systems and increased data flow at all levels of organization (Manola 1995) and between these organizations to obtain higher profits in the production chain.

It can be observed, therefore, that the inclusion of elements of interoperability in logistics studies may be relevant to the development of this area. On one hand, companies use the interoperability to share information, stocks and structures with their customers and suppliers. The other aspects of logistics are an important link between the companies in relation to materials and information, so it can be concluded that interoperability and logistics, together, provide important elements for effective organization of trade relationships.

The perception obtained in the literature, combined with the classification of the works, is the use of interoperability in an indirect way to the logistics, as support of performance, demonstrating the existing conceptual gap. The Figure 1 shows the knowledge cluster on interoperability. A broader view is given by Wang and Wang (2009) that treats interoperability as the ability to work together with other companies, acting in the exchange of information and equipment, with the minimum of final impact on them. It is observed that in addition to the information, the author also treats the equipment, perpetuating the application of the concept that originally was restricted to the area of information systems (Figay et al, 2008).

The main objective of this article is to develop a method of measuring logistic interoperability through the use of structural equations and their application in industrial company.



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Figure 1. The knowledge cluster on interoperability

2. Methodology

This section discusses the methodology, covering the classification, methods, bibliometric study, and script development research. For purposes of research, the nature of this work is Exploratory-Descriptive-Conclusive. Exploratory, considering to build knowledge on the subject through the article selection process and bibliometric analysis. Descriptive, because it describes the characteristics of the works that make up the portfolio literature in journals and periodicals published on the subject, representative articles and authors and most used keywords (Ensslin et al. 2010; Gil 1999); and it was developed through an electronic survey with logistics professionals from Brazilian organizations.

Portal journals of Portal CAPES Collection were used, as well as the following databases: OneFile, Emerald, Web of Science, Science Direct, Oxford Journals, Springer Link, Wiley, DOAJ, Sage, JSTOR, SCOPUS, among others. After the literature review, possible components of logistic interoperability were identified and a questionnaire was developed. This questionnaire was validated by experts in the logistics area, and after the experts' analysis, it was applied in PIM companies to measure logistics interoperability.

The data analysis, which, at first, was due to the application of a factor analysis and, later, by using the structural equation using the PLS (Partial Least Squares). Data were analyzed through SmartPLS ® 3.0 software to determine the model of causality. Researchers prefer this SEM software because they can use a variety of approaches and, besides, because data could be distributed in a not normal way. Another important aspect is the possibility to use small samples. It can be used to analyze established constructions of reflective indicators.

3. The Concept of Logistics Interoperability

The initial results of the bibliometric review initially demonstrate for the interoperability of systems, for military purposes or exchange of information between businesses and companies. An interoperable business network, interconnected business processes of independent organizational units, using a uniform infrastructure in which all stakeholders (partners) interact with each other on the network, where adjustments and changes occur quickly and transparently, where capacity of interaction between business applications, and its effectiveness is given for the execution of three levels: data, resources and processes (Ducq et al. 2004).

According to de Castro and Santos (2014), and Phoha (2001), interoperability is the ability of two or more systems to exchange their data from the codification of rules and description schemes used by the cataloguer in standardized and methodological preparation of metadata and conceptual structuring of the information environment provided by ontologies. Interoperability of systems refers to the ability of two or more systems or components to exchange information and use the information that exchanged. Organizational interoperability is related to the ability of two or

more units to provide services and accepting the service from other units and to use medium services exchanged so that they can operate together in efficiency (Legner 2006).

Interoperability allows multiple organizations to provide data without interfering in their technology choices, production processes or internal culture. Interoperability is the capability of a system or its components to share information and applications regardless of their heterogeneity. (Anand et al. 2012; Bishr 1998; Blatter et al. 2012). In (Pagell 2004), integration is defined as the process of interaction and collaboration between parts of a company (manufacturing, purchasing, and logistics) for work together with the purpose of achieving acceptable results. Today, this range adds integration of the relationship with suppliers and customers.

The perception obtained in the literature, combined with the classification of work is the use interoperability indirectly in the logistics, as performance support, demonstrating the existing conceptual gap, like the study (Blatter et al. 2012; de la Fuente et al. 2008; Helo and Szekely 2005; Lendermann et al., 2003; Weichhart et al. 2010). In the literature some aspects of logistics, however indirectly, such information systems that support the operation, transport and supply chain, Helo and Szekely (2005), Fenies et al. (2006), Wang and Wang (2009), Weichhart et al. (2010), Pan et al. (2010), and Azevedo and Carvalho (2012). Park et al. (2006) and de la Fuente et al. (2008) address the issue of interoperability as a semantic model of manufacturing systems and SCM sharing data and information, and, on the other hand, simulation models (Brambert 2006; Helo and Szekely, 2005; Pan et al. 2010) that provide collaborative aspects in services to customer.

In this way, the question of compatibility is displayed in the logistics approach, especially as regards to assets and operations, as in transport. In this context, it is essential to exchange information - although there is heterogeneity. (Anand et al. 2012; Cavalieri et al. 2000; M. C. Chen et al. 2010; Fried 2006; Khalifa et al. 2011; Leviakangas et al. 2007). According to S. Carson (2009), interoperability in the logistics field to reach its maximum level should work in four key areas, namely: command and control, information management, transport system, equipment, and logistical support services. An interoperable system can generate more efficiency, since it provides a centralized command structure, reducing logistics costs with unnecessary operations including multi-modal solutions. (Brim 2005; Fried 2006; Leviakangas et al. 2007; Schilk and Seemann 2012)

4. Structural equation model – Partial Least Square

Structural Equation Modeling is a multivariate technique that combines aspects of multiple regression (examining dependency ratios) and factorial analysis (representing unmeasured concepts - factors - with multiple variables) to estimate a series of interrelated dependency relationships simultaneously (Hair jr et al. 2005). SEM requires the definition of two models, the measurement model and the structural model, which represent two sets of linear equations (HENSELER et al. 2009). The structural model (or internal model) comprises the relations between latent variables (LV), which have to be obtained from theoretical considerations. Independent LVs are also referred to as exogenous variables and dependent LVs as endogenous variables.

In general, there are two possible applications of PLS (Chin 1998): It can be used for theoretical confirmation or development of a new theory. In the latter case, PLS is used to develop proposals, exploring the relationships between variables. The measurement model demonstrates the relationship between the latent variable and its observable or manifest variables, and the structural model specifies the relationship between the unobserved constructs or latent variables (Henseler and Sinkovic 2009).

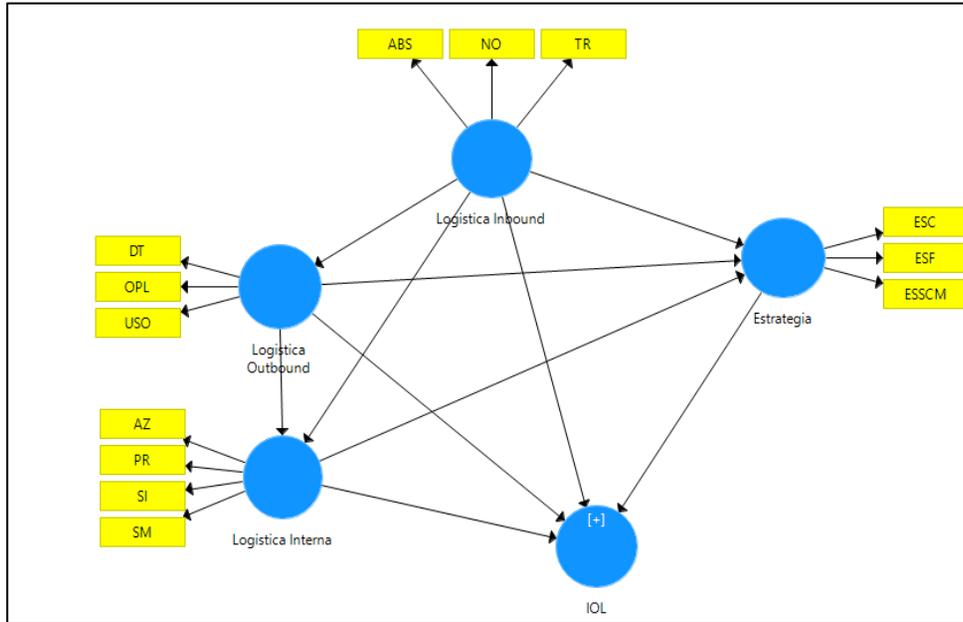
The structural model defines the relationship between exogenous and endogenous latent variables. Therefore, this model specifies which latent (exogenous) variables influence right or indirect changes in the values of the other latent variable (endogenous or dependent) (Hair et al. 2000). From this moment it is possible to carry out the analyzes, and in the case of this model the measurement of logistic interoperability. The model was elaborated, with the latent variables linked to the variables that were developed, based on the bibliometric study. The confirmatory analysis was carried out with the purpose of evaluating the validity of the constructs of the model.

5. Conceptual model to measure logistics interoperability

5.1 Research Constructs

The conceptual model will be analyzed in this section. This section provides four constructive model assumptions linking internal logistics, external logistics, inbound logistics, and strategy (figure 2). Each construct was developed based on the results of the literature.

The indicators were chosen based on the content analysis of the portfolio, in which it presented among the possible observable variables: Supply (ABS), Distribution (DT), Transport (TR), Storage (AZ), Logistic Operator (OPL), Production (PR), Information System (SI), Simulation (SM), Use Type (USO), Organizational Level (NO), Suppliers Strategy (ESF), Customers Strategy (ESC) and Supply Chain Strategy (ESSCM).



Source: Prepared by the authors based on the research using Software SmartPLS® 3.0

Figure 2. Conceptual Model

5.2 Measurement Model

For evaluation of the measurement model, a confirmatory factor analysis was made with all the latent variables connected to each other, and the model estimated it with the weighting scheme weighting factor (each arrow is estimated as a correlation between the latent variables).

The evaluation of the discriminant validity of the SEM is an indicator that the latent constructs or variables are independent of each other. (HAIR et al., 2014). There are two ways of observation: 1) Cross Load analysis - indicators with higher factor loads in their respective VL (or constructs) than in others (Chin 1998), the Fornell and Larcker (1981) criterion that compares the square roots of the AVE values of each construct with the (Pearson) correlations between the constructs (or latent variables). The square roots of the AVEs should be larger than the correlations between the constructs. Table 1 shows the values of loads encountered.

Table 1. Discriminant Validity

Indicator	Strategy	Logistics Interoperability	Inbound Logistics	Internal Logistics	Outbound Logistics
ABS	0.555	0.695	0.818	0.710	0.559
AZ	0.555	0.695	0.818	0.710	0.559

DT	0.653	0.775	0.664	0.676	0.841
ESC	0.805	0.732	0.669	0.635	0.585
ESF	0.870	0.839	0.631	0.730	0.877
ESSCM	0.732	0.629	0.513	0.495	0.503
NO	0.920	0.608	0.722	0.469	0.505
OPL	0.520	0.839	0.631	0.730	0.877
PR	0.870	0.708	0.543	0.806	0.623
SI	0.606	0.673	0.476	0.761	0.620
SM	0.585	0.658	0.489	0.708	0.594
TR	0.688	0.764	0.816	0.660	0.665
USO	0.506	0.650	0.528	0.567	0.754

The SmartPLS® 3.0 software was used in this study to test the convergence and discriminant validity of the constructs. All variables in this study have an Average Variance Extracted (AVE) greater than 0.5, indicating that the variables have a convergent validity. (Fornell and Larcker 1981) Property measurement scales are presented in Table 2.

Table 2. Convergent Validity – Average Variance Extracted (AVE)

Item	Strategy	Inbound Logistics	External Logistics	Internal logistics
AVE	0.647	0.619	0.682	0.558

The reliability for each construct indicates the level of internal consistency and all scales have a Cronbach's alpha above 0.7, indicating that the scales are reliable. Indicator reliability describes the extent to which a variable or set of variables is consistent regarding what it intends to measure. The reliability of one construct is independent of and calculated separately from that of other constructs. The researcher can monitor reflective indicators' loadings to assess indicator reliability. Generally, it is postulated that an LV should explain at least 50 percent of each indicator's variance. Property measurement scales are show in Table 3.

Table 3. Composite Confiability and Reliability

Item	Strategy	Inbound Logistics	Outbound Logistics	Internal logistics
Composite Re-ability	0.846	0.829	0.865	0.835
Cronbach's Alpha	0.728	0.692	0.767	0.735

Cross-loadings are obtained by correlating the component scores of each latent variable with all other items. If the loading of each indicator is higher for its designated construct than for any of the other constructs, and each of the construct loads is highest with its own items, it can be inferred that the models' constructs differ sufficiently from one another. (Chin 1998b). The discriminant validity between the latent variables shows that most of the diagonal values are greater than the correlation between the latent variables. The values are shown in Table 4.

Table 4. Correlations between Latent Variables

Latent Variable	Strategy	Inbound Logistics	Internal Logistics	Outbound Logistics
Strategy	0.804			
Inbound Logistics	0.753	0.786		

Internal Logistics	0.782	0.788	0.746	
Outbound Logistics	0.836	0.738	0.802	0.825

Note: Values on the diagonal of the correlation matrix refer to the square root of the average variance extracted.

5.3 Assessment of the structural model

The next step of the structural model's assessment comprises the evaluation of the path coefficients between the model's LVs. Therefore, the researcher should check the path coefficient's algebraic sign, magnitude, and significance. The relations are confirmed because all path coefficients were statistically significant ($p < 0.05$). Table 5 shows the results of the "bootstrapping" procedure with 500 sub-examples (outer loadings).

Table 5. Correlations between Latent Variables

Relations	Factor Loadings	Standard Error	Value- <i>t</i>	Value- <i>p</i>
ABS - Inbound Logistics	0.819	0.037	21.879	0.000
AZ - Internal Logistics	0.710	0.058	12.291	0.000
DT - Outbound Logistics	0.841	0.035	24.151	0.000
ESC - Strategy	0.809	0.036	22.717	0.000
ESSCM - Strategy	0.730	0.020	43.817	0.000
NO - Inbound Logistics	0.729	0.060	11.969	0.000
OPL - Outbound Logistics	0.877	0.021	41.900	0.000
PR - Internal Logistics	0.806	0.050	16.102	0.000
SI - Internal Logistics	0.761	0.048	15.701	0.000
SM - Internal Logistics	0.708	0.067	10.540	0.000
TR - Inbound Logistics	0.816	0.030	26.820	0.000
USO - Outbound Logistics	0.754	0.057	13.170	0.000

The importance of paths included in the proposed model was tested using a bootstrap resampling procedure with 1,000 repetitions or replicas. When evaluating the PLS model, the multiple square correlation (R^2) of all endogenous latent variables was initially examined and significance of structural paths was evaluated. The results of the bootstrapping test is the importance of all factor loadings and structural factor are highly significant ($p < 10^{-60}$). All coefficients are in a standardized manner and are highly significant ($p < 0.01$). The Predictive validity assesses how much the model approaches what was predicted for it (or the prediction quality of the model or accuracy of the adjusted model). From the resampling, the total effects on the LI variable and other VL's were estimated, based on the structural coefficients.

The values related to the total effects on the LI were considered, according to table 6 below, where such effects suggest the behavior of the organization and its possible actions in improving the degree of interoperability. According to the proposed model the LI grade is calculated from the mean logistic effects and the strategy effect, in which it totaled 0.493 (see expression 1 below).

$$LI = [\Sigma(\text{Log Inb} + \text{Log Int} + \text{Log Out} + \text{Est}) / 4] \quad (1)$$

Table 6. Total Effects

Relationships	Effect
Strategy -> LI	0.288
Inbound Logistics -> LI	0.753
Internal Logistics-> LI	0.337

Outbound Logistics -> LI	0.592

6. Discuss and Findings

These constructs were composed from the pertinent information of the literature review and legitimation with specialists, according to section 2 of this work, propitiating the assembly of the conceptual model base, as well as the definition of the 13 indicators and 76 manifest variables.

The Partial Least Square Path Modeling (PLS-PM) technique was used to estimate the parameters of the structural equations using the SmartPLS® software. From the tests performed on the measurement model (convergent validity, discriminant validity, internal consistency and composite reliability) and the structural model (Pearson determination coefficient, Bootstrapping, Relevance or Predictive Validity, Effect size, Model adequacy index) , It is possible to observe the impact of the constructs and their respective factor loads in the IOL measurement.

The structural model with its respective loads of the latent variables and their respective indicators, which demonstrates the validities and above all the evaluation of the Pearson coefficient of determination (R^2), where the R^2 evaluates the portion of the variance of the endogenous variables, which is explained by the structural model, and in this research it was 98% (0.989). Both for the criteria of Cohen (1998), Henseler et al. (2009) or Chin (1998) the loads presented are classified as substantial or moderate.

The results indicate a higher structural coefficient of the Outbound Logistics (0.329), which in a certain way records scientifically what has been developed - through literature and legitimation with the experts - regarding the external border of the organization and its respective internal operations, i.e logistic interoperability is Impacted by the distribution, Logistic Operator and Usability of interoperability.

It is important to highlight the variable (DT - Distribution) that dealt with the questions related to the form of order reception, forecasting, company use of EDI, RFID and ECR technologies, collaborative planning and integrated refueling, Monitoring routines to customer service, as well as the way to integrate with the supply chain. As for usability, the model refers to the sharing, interaction, compatibility and collaboration between assets and information flow. It is noteworthy that the Pearson coefficient (R^2) relative to the Outbound Logistics is 0.710. In addition, the structural coefficient between Inbound Logistics and Internal Logistics is high (0.798), which clearly shows the relationships mainly between Production, Supply and Internal Transport, taking into account the validations previously described in their respective constructs.

This relationship also shows that the IOL is also impacted internally, including relations at all levels (Strategic, Managerial and Operational), observing the factorial load of 0.718. In the same way, we can cite the "Strategy" construct with its respective relationships with other constructs, where a high degree of impact is seen in all other variables, where its manifest variables (ESC - Customer Relationship Strategy, ESF - Strategy with suppliers, ESSCM - Supply Chain Relationship Strategy) have extremely satisfactory factor loads (0.807, 0.872 and 0.728 respectively). In the specific case of ESF, the importance of aspects related to: the use of JIT by the supplier, improvement in the delivery rate, its location, rapid responses to operational contingencies, tax differences and rapid communication regarding losses are perceived.

The results point to the importance of the IOL to the need for managerial perception for the construction of the Strategy and its impacts on the IOL measurement model, directly or indirectly. A relevant fact regarding this construct is that the indicator ESSCM - Strategy of relationship with the supply chain - was the one with the lowest load (0.728) of the construct, that is, the relationship with customers and suppliers has the greatest impact on the IOL.

The analysis of the measurement model should precede the analysis of relations between constructs or VL, and for this purpose, the convergent validity, the composite reliability, and discriminant validity were analyzed. The results showed convergent validity (average variance extracted over 0.5) and adequate reliability (above 0.7). Chin (1998) recommends that in studies designed by structural equations, an evaluation of the reliability of the construct was made for reliability composed and is above 0.7.

The evaluation of the proposed SEM where the standardized coefficients of the trajectory representing the direct effects of buildings, their statistical significance, and the proportion of the variance explained by endogenous of each construct are given. The relations are confirmed because all path coefficients were statistic significant ($p < 0.05$). The results of the factor loadings indicate the model validation applying SmartPLS® noted that R^2 (multiple correlation square) is relevant to all latent variables.

The relevance of R^2 and reliability (Cronbach's alpha above 0.7) reinforces the viability of the proposed model for conceptualizing Logistics Interoperability components. The measurement model observes the predominance of low cross-loads, validating (convergent and discriminant) existing relationships.

7. Final Considerations

The purpose of this study was to contribute to theoretical and methodological results in Logistics Interoperability by analyzing relationships among latent variables. All scales of measurement of constructs were developed and tested according to their validity and reliability. The structural model was tested by analyzing the regression coefficients and the total explained variance of each endogenous construct.

The concept of Logistics Interoperability (LI) can contribute to the reduction of operational work, greater agility and service, logistics cost reduction, improving management and data integrity in order to promote greater coherence between the physical flow and information flow, and increased efficiency of the whole system permeating all levels of the organization.

Finally, the structure of the research methods proves to be a logical potential for application in other researches on interoperability and logistics, as well as in other areas of knowledge. This is based on the process of a solid literature and results consistent with the proposed objective, expanding the field of knowledge.

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