Logistics Interoperability as a Boost Factor for Industry 4.0: Case Study of a Motorcycle Manufacturer

Alberto Antonio Tuma Neto, Flávio de Barros e Azevedo Ramos, Miriam Maristela Reis Moraes, Sandro Breval Santiago and Armando Araújo de Souza Junior

ABSTRACT

The Manaus Industrial Pole (PIM), located in a tax incentive area, is responsible for relevant economic growth and conservation of the Amazon Rainforest. With the advent of Industry 4.0 (I4.0) bringing new technological approaches, management, and business models and, mainly, insertion in global productive chains, it is necessary to verify the maturity and readiness of the PIM companies regarding this new environment. This article aims to verify the logistical interoperability as a boosting tool of I4.0, through applied and exploratory research, based on the case study of a motorcycle manufacturer, using a logistical interoperability measurement model based on structural equations. As a result, an overall evaluation coefficient value of 4.65 to a maximum of 5.00 was found, and the points for improvement are discussed.

Keywords: Free Zone of Manaus (ZFM), Industry 4.0, Interoperability, Logistics, Manaus Industrial Pole (PIM).

I. INTRODUCTION

Located in the Brazilian Amazon, the Manaus Free Trade Zone (ZFM) is an area of special tax incentives of 10,000 square kilometers created by Decree-Law 288/67, encompassing the municipalities of Manaus, Presidente Figueiredo and Rio Preto da Eva (BRAZIL, 1967). Its purpose was to create conditions for regional economic development due to the distance to the major consumer centers in the country that is managed by the Manaus Free Trade Zone Superintendence (SUFRAMA), an autarchy linked to the Ministry of Economy.

Although three development poles were originally foreseen, namely: industrial, commercial, and agricultural, the first is considered the support base of the ZFM, constituting the so-called Manaus Industrial Pole (PIM), with approximately 500 industries and 500 thousand direct and indirect jobs. In 2020, PIM had a global turnover of R$ 119.68 billion, corresponding to US$ 22.819 billion, registering at the end of that year the mark of 96,934 direct jobs (Suframa, 2021).

Obtaining tax incentives from SUFRAMA occurs upon approval of a technical-economic project, which must comply with the criteria established by Decree-Law 288/1967, along with others included by Law 8387 of December 30, 1991, among which stands out the compliance with the Basic Productive Process (PPB), which is set by an Interministerial Ordinance of the Ministries of Economy and Science, Technology and Innovation, consisting of the "minimum set of operations, in the manufacturing establishment, which characterizes the effective industrialization of a given product" (Brazil, 1991). The establishment of a PPB is regulated by Interministerial Ordinance 32, of July 15, 2019, which in its article 6 establishes the conditions for its approval: search for inter-regional balance, value addition to production, and contribution to the achievement of macro goals contained in government policies, increased employment in the region involved and sustainable use of biodiversity (Brasil, 2019).

The main products manufactured at PIM today are motorcycles, smartphones, air conditioners, microwave ovens, watches, bicycles, audio playback devices and television signal receivers (SUFRAMA, 2020). Holland et al. (2019), using econometric techniques, demonstrated its relevance covering externalities such as the

DOI: http://dx.doi.org/10.24018/ejbmr.2022.7.1.1281

Vol 7 | Issue 1 | February 2022
evolution of per capita income, educational performance, access to services such as water and sanitation and income inequality rates. Through the synthetic control methodology, they pointed out the importance of PIM in generating formal jobs, investment in human capital, improving infrastructure and housing conditions for the population.

In the environmental context, Rivas et al. (2019) state that the PIM is responsible for the conservation of the Amazon Rainforest and the reason for the Brazilian State of Amazonas to maintain 97% of its original forest coverage. They understand that it has a decisive effect on the global climate balance. Based on an analysis of the dynamics of the PIM, they validated this hypothesis based on econometric studies, discussing the effects of its extinction.

Based on the regional development theories of Gunnar Myrdal (Cumulative Circular Causation), Albert Hirschman (Forward and Backward Effects), François Perroux (Growth Poles) and Douglass North (Export Base Theory), Silva et al. (2019), based on the indicators of demographic growth, employability and total product, state that the Free Trade Zone of Manaus model has brought significant progress both for Manaus and for the region, highlighting the contribution of the PIM.

Given the above, we can say that there are enough elements to consider the importance of the PIM as an inducer of socioeconomic development in the Amazon, reducing regional inequalities in the country.

One of the most developed subsectors in PIM is the so-called “Two Wheels”, responsible for 12.37% of its total turnover in 2020 (SUFRAMA, 2021), including bicycles, motorcycles, tricycles, quadricycles, and similar vehicles. In the case of motorcycles, all national production is carried out in Manaus and corresponded to 961,986 units in 2020 (ABRACICLO, 2021).

On the other hand, Industry 4.0 (I4.0) advances rapidly, bringing new technological approaches, management, and business models and, mainly, insertion in global productive chains, leading the most advanced countries to develop specific programs for its implementation. An important aspect of I4.0 is its ability to analyze production data from multiple sources in real time, such as machines, systems, and production processes (XU et al., 2018). However, due to a large number of different manufacturers and the lack of available standardization, the challenge is to establish interoperability between different devices (ALIOTO, 2017).

In Brazil, the National Confederation of Industry (CNI) published the Report “Desafios para Indústria 4.0 no Brasil” (CNI, 2016) with a focus on I4.0, affirming its relevance for industrial production. The document comments on the enabling technologies for the so-called "smart factory", the integration of value chains, production flexibility and mass customization, in addition to the expected impacts of reduced maintenance costs, energy consumption and work efficiency, among others. Applications in production chains and supplier development were identified as one of the seven main dimensions for the development of I4.0 in the country, asserting that the digital integration of companies along the production chains is essential for the expected efficiency gain and should bring about significant changes in the relationships between customers and suppliers.

According to a report by the World Economic Forum (2018), barriers to interoperability must be overcome for the implementation of I4.0. For Di Martino et al. (2017) the wide variety of platforms, architectures, and frameworks, in addition to the new devices continuously launched by different manufacturers, constitute a challenge in establishing interoperability.

In this context, it is essential to verify the maturity and readiness of the PIM companies in relation to I4.0, in order to promote its maintenance as an economic center and enabler of environmental services. Among the main driving factors of I4.0, the interoperability of the logistics chains stands out, in order to meet their requirements for efficiency, flexibility, customization and time to market.

This work is divided into five sections. The first constitutes the Introduction indicating the relevance of the theme, the second deals with the Theoretical Framework, followed by the Methodology used in the case study; the fourth section presents the Results found, and finally, the Conclusions are presented with the suggestion of new research to advance the frontier of knowledge.

II. THEORETICAL FRAMEWORK

A. Supply Chain Management

Globalization has brought many benefits, but also great challenges. Companies serving the local market now have customers from all over the world, while their supply sources and manufacturing bases have spread across the world. It is the flexibility of the purchasing, production and distribution scheme, implemented by market demand (Mangan et al., 2016).

According to Schönleben (2016), Supply Chain Management (SCM) corresponds to the project, planning, execution, and control of activities, with the objective of creating value, building a competitive infrastructure, leveraging global logistics, synchronizing supplying with demand and measuring performance globally.

For the Council of Supply Chain Management Professional (CSCMP), the world's leading association of industry professionals, supply chain management encompasses the planning and management of activities involved in procurement and logistics. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers and customers. In essence, supply chain management integrates supply and demand management within and between companies.

In Supply Chain Management (SCM), the monitoring of operations takes place in real time and computerized systems need to operate in an integrated manner. The increasing use of integrated Enterprise Resource Planning (ERP) management systems has facilitated this integration and favors modern logistical techniques in larger companies. On the other, integrations of data warehouse systems make it possible to modernize logistics operations (Novaes, 2016).

For Mangan et al. (2016) the task of managing and administering this physical network and the flow of information has become a business priority. Consequently, the need to increase the level of capacity in supply chain management is more important than ever, requiring
comprehensive logistics management.

Although, briefly, logistics can be defined as the flow of goods between two points: origin and consumption, still according to Schonsleben (2016), logistics management includes planning, implementation, and control of the flow of raw materials, inventory of semi-finished products, finished products and the respective flow of information, from origin to consumption. Integral logistics management is even more comprehensive, as it involves the integration of operations and supply chain management within and across the company.

In the definition of the CSCMP, Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers’ requirements. Logistics management activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of third party logistics services providers. To varying degrees, the logistics function also includes sourcing and procurement, production planning and scheduling, packaging and assembly, and customer service. It is involved in all levels of planning and execution-strategic, operational, and tactical. Logistics management is an integrating function that coordinates and optimizes all logistics activities, as well as integrates logistics activities with other functions, including marketing, sales, manufacturing, finance, and information technology.

For the Council of Supply Chain Management Professional (CSCMP), Logistics is the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements. This definition includes inbound, outbound, internal, and external movements.

According to Douglas (2016) Inbound Logistics is the supplier’s logistics, which corresponds to the set of operations related to the flow of materials and information from the source of raw materials and components to the factory. According to Dobos et al. (2016), includes the handling of materials responsible for the receipt, identification, and classification, checking, addressing to the stock, storage, removal of stock, accumulation of items, packaging, shipping and registration of operations.

As for Outbound Logistics, it can be defined as downstream logistics, the management of processes related to the output of products so that they are made available on the market and reach the final customer. According to Noveas (2016), for logistics specialists, Outbound is the physical distribution, i.e., the operational and control processes that allow the transfer of products from the point of manufacture to the consumer.

According to Christopher (2016), the change in the business environment has brought heterogeneity, in addition to the latent growth of competition, which are vectors of adaptation of organizations, which seek to reduce costs, improve informational flows and, above all, optimize the use of its assets, requiring the interoperability of systems.

According to Wu et al. (2016) Supply Chain Management (SCM) provides the right product, at the exact volume and time, at the right place and price, in perfect condition for the right customer. For Abdel-Basset et al. (2018) traditional supply chains are becoming more costly, complex, and vulnerable, and to overcome these challenges it is necessary to make them more intelligent. Still according to this author, the Intelligent Supply Chain can be defined as a modern and interconnected system that expands from separate, regional, and single company operations, to more integrated, transparent and based on the use of technological tools.

B. Logistics Interoperability (IOL)

Interoperability can be described as the capacity of systems to share information and use the shared data. Moreover, interoperability is the ability of two or more systems to exchange data and applications despite their heterogeneity (Anand et al., 2012).

In order to build the concept of Logistic Interoperability (IOL), Santiago et al. (2013) analyzed a portfolio of 68 articles selected from bibliometric research, where it is associated with the ability to interact with assets, information, processes and applications of independent organizations maintaining their original characteristics, highlighting the contribution to greater effectiveness, efficiency and responsiveness. Concludes that interoperability contributes to the resolution of anomalies and provides gains in the logistics chain, which can be considered a vector for strategic alignment.

The importance of logistics in 4.0 as an enabler of the production steps and a crucial factor for transportation time, storage costs, supply chain management and, mainly, delivery to the customer on time is emphasized by Forkel (2018). To build an intelligent and interoperable logistics ecosystem, presents a systemic concept on three levels: organizational, systems and physical, supported by an information technology infrastructure. Concludes that systems interoperability is a basic requirement for future advances, especially in the highly automated logistics sector.

According to Pan (2021), in general, interoperability must be considered at the physical, organizational, business and digital levels. He understands that, essentially, the vulnerability observed in the global logistics chains demonstrated by the coronavirus pandemic has to do with interoperability. He also highlights the concept of Physical Internet (PI), a metaphor for digital internet aiming to achieve a perfect global interconnection of logistics networks, claiming that this is the new global paradigm in the direction of efficiency and, therefore, sustainability. From a bibliometric analysis of publications between the years 2010 and 2020, 208 documents were identified upon which he established four challenges for digital interoperability in PI: data sharing format, effective communication, privacy and security, and product / order-oriented data.

Also due to the flexibility and modularity needs of logistic services to adapt to new business processes, extensive information technology systems are increasingly subdivided into smaller software applications (Apps). In this context, in order to avoid costly integration processes, perfect interoperability is a crucial requirement (Böhmer et al.,
In this sense, they present the Business Objects for Logistics (BO4L) communication standard, developed by the Fraunhofer Institute for Material Flow and Logistics IML and the Fraunhofer Institute for Software and Systems Engineering ISST in cooperation with the LogistikRuhr Cluster, which aims to be the first independent standard for the domain of logistics.

C. Models for Measuring Interoperability

For Pedersen (2012), representatives of the industry and the academic community realized the need for a joint initiative to change the interoperability paradigm, to increase the efficiency of logistics and achieve the political objective of reducing the environmental impact of transport. In this sense, he understands as main directions to maintain the exchange of information in an unambiguous way and at the minimum necessary level of complexity, in addition to using open or common use platforms.

The same author, based on the analysis of eight European Union projects on the subject and the GS1 Logistics Forum business initiative, which claims that interoperability is one of the biggest problems in global logistics, proposes a model called Common Framework correlating four domains: Cooperative Systems, Logistics Demands, Logistics and Security Services and Supply Chain Compliance. With the intention of making it a global reference, it was submitted for analysis by OASIS / UBL, a global standardization organization in the logistics area.

Chalmeta and Pazos (2014) clarify that the objective of interoperability is important not only from the point of view of the company individually but also because of the new business structures that are emerging. List as the biggest challenges at the moment the development of frameworks with the necessary holistic vision and the scarcity of practical examples that could serve as drivers.

Based on the analysis of nine existing frameworks, they presented the Interoperability IRIS Framework, composed of six parts, which highlights the methodology as a central axis to guide the company step by step in its project to increase interoperability.

The differential of this model is the fact that it considers the alignment between business and technology, the vision of human resources and economic restrictions. It also accompanies its own maturity model to assess progress, indicating the tools to be used in each phase.

Westerheim and Hauge (2015) state that some of the biggest problems in global logistics chains are still related to limited information regarding the goods themselves as well as their status in the chain. They point out that a prerequisite for a perfect flow of information through the logistics chain and among its stakeholders is interoperability.

Based on aspects of technical and business interoperability, they analyzed four frameworks: IRIS, presented above, Athena, based on conceptual, application and technical integration, SCOR, a reference process model for the logistics chain, and the Common Framework, as presented by Pedersen (2012). They observed that in all of these models there is still a lack of links between technical and business interoperability, concluding that a mapping between the processes at all levels of the SCOR model with the Common Framework functions could be an interesting solution. They conclude by resuming the concept of PI, indicating that the importance of hubs as well as standardization should grow, hence the importance of studying the frameworks to support this new concept.

Santiago et al. (2017) state that a logistic interoperability measurement model can contribute to the improvement of operations, responsiveness, and costs of organizations. In this sense, they developed a conceptual model having strategy, inbound logistics, outbound logistics and internal logistics as latent variables, and the endogenous variable IOL itself, building 76 related observable variables. The measurement model was built using the technique of structural equation modeling using the SmartPLS® software.

III. METHODOLOGY

A. Research Classification

According to Silva (2001), this research is classified, in terms of nature, as applied research, since it is aimed at generating knowledge to solve a specific problem. Being, in relation to the approach, quantitative-qualitative, because the information is classified based on numerical criteria, however, they are analyzed as to the adherence to the proposed theme in a qualitative approach. As for the objectives, it is characterized as exploratory (Gil, 1991).

According to Creswell (2018) the research of mixed methods is an investigation integrating the two forms of information and using different projects that may involve philosophical assumptions and theoretical references. The fundamental assumption of this form of investigation is that the integration of qualitative and quantitative data produces an additional view, in spite of the information provided only by the quantitative or qualitative data in isolation.

As for the research technique, it is a case study, according to Yin (2015) composed of three phases: exploratory, systematization of data collection and delimitation of the study and analysis and interpretation of the findings.

B. Logistics Interoperability Measurement Model

In this study, the Logistic Interoperability Measurement Model (MMIOL) developed by Santiago et al. (2017) was applied, due to its adherence to the objective of this Article and ease of application, as well as the fact that it has been validated with logistics professionals from HIM companies.

Conceptually, this Model is composed of:

a. Structural Module formed by 4 constructs (Latent Variables) that represent the elements of the studied model.
b. Measurement Module formed by 13 indicators and 76 variables, intended for the measurement of constructs (Observable Variables).

Table I shows the structure of MMIOL. The reflective constructs describe latent variables, which are not directly observable in the study environment but are manifested through observable variables (indicators).

The Model was developed based on Structural Equation Modeling (MEE) techniques, a statistical approach to test hypotheses involving relationships. The observable variables are the result of the bibliometric study combined with legitimation by specialists in the field. The model used the PLS Algorithm, generated by the SmartPLS® 3.0 software to...
establish the structural model shown below, validated through statistical tests.

### TABLE I: MMIOL CONCEPTUAL STRUCTURE

| Latent variable   | Indicators                  | Variables |
|-------------------|-----------------------------|-----------|
| Inbound logistics | Spl – supply                | 8         |
|                   | Lu – level of use           | 3         |
|                   | It – internal               | 6         |
| Internal logistics| Sy – systems                | 5         |
|                   | Si – simulation             | 4         |
|                   | St – storage                | 6         |
|                   | Pr – production             | 7         |
| Outbound logistics| Dt – distribution           | 7         |
|                   | Lop – logistic operator     | 5         |
|                   | Tu – type of use            | 4         |
| Strategy          | Cs – client strategy        | 7         |
|                   | Sps – supplier strategy     | 5         |
|                   | Scs – supply chain strategy| 8         |

Source: Santiago et al. (2017).

![Fig. 1. Structural Model of MMIOl. Source: Santiago et al. (2017).](image)

It was applied in the company based on responses to a structured questionnaire, answered jointly by two representatives of the contracted Logistics Operator, one at the managerial level and the other at the supervisory level, on March 25, 2021. Then, a visit was made to part of the production lines and storage locations, aiming to resolve doubts and ratify the answers presented.

### IV. RESULTS

#### A. Company Description

It is a multinational company established in PIM, which produces motorcycles, quadricycles, and stationary engines. The entire purchase and movement of materials are carried out through an associated Logistics Operator, responsible for both inbound and outbound logistics. This Logistics Operator, based on the Contractor’s Production Plan, does all the planning and execution of parts collection at national, local and internal suppliers, through a direct collection or milk-run, performs point-to-point transportation, packaging and distribution, manages warehouses, positioning parts and pieces precisely on the production line and delivering the final product to dealerships or Advanced Distribution Stations (PDAs).

In terms of systems, the SCM uses the IBM AS400 integrated with the Corporate ERPs JDE (generator of the Production Plan) and SAP, the Chronus System developed for product and fleet tracking, and the WMS TOTVS for administrative support. The monitoring and control of international invoices are done by a system called GSM, as shown in Fig. 2.

![Fig. 2. Systems Integration for SCM. Source: Prepared by the Authors (2021).](image)

The Production Plan has daily views for 42 local suppliers, for which the Kanban System is used, monthly views for 170 national suppliers and annual views for imported items. The Logistics Operator uses its own transport equipment tracked in real time, as well as outsourced, serving 1,100 dealerships and 17 PDAs.

#### B. Application of the Logistics Interoperability Measurement Model (MMIOL)

The application of the chosen MMIOL generated a General Evaluation Chart, as shown in Fig. 3, where the Indicators appear with their respective measurements, and 13 specific graphs for each Indicator, where the measurements of each of the 76 Variables appear.

The General Evaluation reached 4.65 at the maximum of 5.00, indicating high interoperability of this Logistics Operator. Of the thirteen Indicators that make up the MMIOL, there was a maximum classification in six, namely Distribution, Supplier Strategy, Interoperability, Logistic Operator, Organization and Simulation. These indicators are detailed in Fig. 4.

The remaining seven indicators presented findings where there is room for improvement, as shown in Table II and detailed in the set of graphs in Fig. 5.

![Fig. 3. General Evaluation Chart for the Logistics Interoperability Measurement Model (MMIOL). Source: Prepared by the Authors (2021).](image)

![Fig. 4. Indicators subject to improvement. Source: Prepared by the Authors (2021).](image)

#### TABLE II: INDICATORS SUBJECT TO IMPROVEMENT

| Indicator          | Grade | Findings                          |
|--------------------|-------|-----------------------------------|
| Systems            | 3.8   | Severely impacted by variable 3.3 |
| Internal           | 4     | 2 variables of negative impact: 2 |
| Transportation     | 4.13  | 5.00 with no improvement point.  |
| Production         | 4.25  | Two variables rated 3.00 which   |
|                    |       | shows room for improvement: 13.3 |
|                    |       | Multihunterprise team creation   |
|                    |       | and 13.4 Client feedback.        |
| SCM strategy       | 4.57  | Impacted by variable 11.3 just   |
| Storage            | 4.83  | All variables highly rated except |
| Supply             | 4.88  | All variables highly rated except |

Source: Research Data (2021).
Fig. 3. General Evaluation Chart. Source: Research data (2021).
From previous results of the application of this same MMIOL, the reference values of Table III were obtained. The value found is close to the reference for the 3PL (Third Part Logistics) Segment, indicated as 4.48, also denoting a strong IOL.

Analyzing the Indicators with possibilities for improvement in Fig. 5, it can be inferred that:

a. As for the systems, the company has an ERP system, but it is not being used to the full, as it depends on other additional systems for its logistics operation.

**Table III: Reference Values for Global IOL Assessment**

| Segment                     | Rating |
|-----------------------------|--------|
| Eletroteletronics           | 3,1    |
| Plastic                     | 2,48   |
| Metal-mechanics             | 3,25   |
| Chemical                    | 4,1    |
| Oil and gas                 | 3,9    |
| 3PL (3rd part logistics)    | 4,48   |
| Retail                      | 2,05   |
| Motorcycles                 | 4,15   |
| Aeroportuary                | 3,75   |

Source: IOL Platform © (2021).

Fig. 4. Maximum Score Indicators. Source: Research data (2021).
b. In relation to internal transport, information flows should be improved, an important point of IOL, seeking greater automation of internal transport (handling). This action results in inventory accuracy, better management of stock positions and reduction of the time of the finished product in the warehouse (aging).

c. Regarding the customers' strategy, there is a certain bias in the response, since the Logistics Operator is between a production “pushed” by the manufacturer, its contractor, and dealers who “pull” the orders, and it is not possible to identify possible recommendations.
Fig. 5. Indicators subject to improvement. Source: Research Data (2021).
V. CONCLUSION

The present paper had as its general objective the verification of IOL as a boosting factor of I4.0 based on the case study of a motorcycle manufacturer in ZFM. We opted to use the MMIOL developed by Santiago et al. (2017), due to its adherence to the proposed theme and because it has already been validated by PIM logistics professionals.

The results of the study indicate high interoperability between the company’s Logistics Operator and the supply network (inbound) and distribution (outbound), with potential aspects for improvement being identified, of which the most comprehensive use of the ERP system and the increase of internal information flows were highlighted.

In the scenario of migration to I4.0, the importance of smart chains within the scope of the SCM was presented, with the concept of IOL being highlighted as fundamental for meeting its requirements for efficiency, flexibility, customization, and time to market.

The chosen MMIOL proved to be objective and easy to apply, suggesting for future research, as a measure to assess the maturity of the PIM in relation to the aspect of the IOL, its application with other companies in different sub-sectors.

The correct application of the Model is able to identify weaknesses and opportunities for improvement in logistical flows, helping in decision making.

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