Application of Structural Equation Modeling for evaluation of forklift management model: *an analysis in Brazilian warehouses*

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ABSTRACT

Purpose: This article aimed to propose a model to identify the constructs used in the management of forklift operations in Brazilian distribution centers.

Design/methodology/approach: Through bibliographical research, a model with two dimensions was proposed. Afterward, a survey by convenience sample was sent to 350 logistics operations professionals working in companies associated with ABOL and ABRALOG, of which 99 responded. These responses served as the basis for an Exploratory Factor Analysis in which the dimensions of the model were expanded to 4. Through the model constructs, the results of this EFA were modeled in the SmartPLS 4 software, using the Structural Equation Modeling technique to analyze the validity of the proposed model.

Findings: As a result, the constructs linked to operations management through the correct use of forklifts suitable for lifting materials (R^2: 0.112), through indicators linked to the costs of the equipment used (R^2: 0.484) and the use of other equipment, in addition to forklifts, for moving materials (R^2: 0.328) are statistically significant for the sample developed in the research and the constructs on the use of people productivity indicators (R^2: 0.035) for decision-making are not significant.

Originality: Since the most widely used equipment in material handling operations in logistics distribution centers is the forklift, despite being considered equipment, there are few studies on the efficiency of this asset, which is so crucial to these operations. Therefore, this research aims to contribute to a model for managing the efficiency of this equipment.

Keywords: Warehouse management; Indicators; Survey; Structural Equation Modeling; Brazilian warehouses; Frugal innovation.

1 INTRODUCTION

The continued growth of competitiveness among companies is reflected in supply chains. This competition makes it necessary to operate more efficiently and leanly without affecting the quality of product distribution operations [1]–[3]. Logistics has become essential in supply chain management because it contributes to the movement of products, information, and materials to consumers [4]. Distribution centers (DCs) are connecting

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elements between upstream (manufacturing/transformation/production) and downstream (distribution) components [5]. This increase requires higher efficiency in operations [3].

The performance of operations in these distribution centers affects their productivity and costs. Process-based DC management can play a crucial role in improving operational efficiency and customer service levels, as well as reducing delivery times and operating costs [6], [7]. Efficiency targets are required for DC resources, as well as methods aimed at achieving this performance in real-time [8]. This problem directly affects operations management [9] and the management of the movement of materials, equipment, and assets [10]. Material handling equipment directly determines the efficiency of operations in a DC [11]. Therefore, it is necessary to analyze material movements using forklifts [9], [12]–[17] since forklifts are the most widely used mobile resources for moving materials in distribution centers and warehouses [9], [17]–[21]. The global forklift market surpassed USD 90 billion in 2020 and is expected to grow at over 9% compound annual growth rate (CAGR) between 2021 and 2027. Global industry shipments are projected to exceed 2 million units by 2027 [22].

Due to this complexity and the future scenario of these operations, the need for the evolution of DCs and the challenges of productivity and efficiency increase [23], so new technologies, new methods, new business models, and new customer expectations must be considered as factors to consider in the necessary changes to logistics [24], [25]. Thus, generating faster and better solutions that use minimum resources is critical to meeting operational needs based on the market model and can provide advantages to the economies of Latin America as a whole, especially in Brazil [26], [27]. The measurement of forklift efficiency proposed by Kamali [12] is an example of this, as well as innovation in processes through engineering [28].

Given this context, this research aims to answer the following research question: how are forklift operations managed in distribution centers in Brazil? As a general objective, this article aims to identify the constructs used in the management of forklift operations in Brazilian distribution centers and is divided into six sections: (i) this introduction; (ii) the theoretical review about forklifts [12], [17], [22], [26]–[30]; (iii) the research methodology – a survey and SEM structural equation modeling were applied in conducting this article; (iv) the presentation of the results; (v) the discussion of the results; and (vi) conclusions and suggestions for future research.

2 BACKGROUND

2.1 Forklifts

A forklift is an industrial vehicle that has a toothed device attached, which can be lowered or raised, in which a load can be inserted [22]. These industrial vehicles are used to move and lift different types of loads in loading and unloading and storage operations in factories, warehouses, ports, stores, and distribution centers [31]–[33] and play an essential role in the modern supply chain [34] (Figure *1*).

Figure 1– Example of a Forklift

Source: D'Apolito and Hong (2019).

Forklifts are designed primarily for lifting and transporting goods, involving the stacking of pallets [33], [35], [36]. However, forklifts for use in transporting materials, without lowering and lifting loads, should only move as much as necessary. Otherwise, they become detrimental to material handling operations [35], [37], [38]. There are several types of electric forklifts: internal combustion, order pickers, retractable for narrow aisles, lateral, and trilateral. The use of the appropriate forklift for the operations to be performed is an essential decision in relation to the productivity of this equipment [39]. The short distances to be covered by forklifts and their use in relation to the loads moved must be considered since the less loaded a forklift is, the less efficient it becomes [40].

This equipment is regularly measured by its cost in relation to the workforce (forklift drivers, who are an essential part of a storage system [41], [42], maintenance costs, and their utilization (hours worked)) based on the reading of the hour meters on board the forklifts [42]–[44]. Utilization is defined as putting forklifts into use in a way that achieves maximum productivity with the minimum number of movements or with lower costs [45]. The utilization of the forklift should be considered to avoid excessive investments in the movement of materials [46], considering that in traditional storage systems, the routes taken by the forklifts to store materials in an available location require the return with empty forks [47]–[50]. Based on the utilization estimate, managers can identify the causes of time losses and try to reduce them [51]. Furthermore, in the supply of materials for supplies in manufacturing operations, when based on forklifts, they have a low-level use of equipment, as redundancy is necessary to ensure that a forklift is available when needed [52].

2.2 Warehouse management

Warehouse and inventory management is a frequent issue in many supply chains across industries. Continuous changes in markets directly affect warehouse and inventory management, resulting in surpluses or shortages [53]. The function of storing products is crucial in the manufacturing, distribution, and service industries [54]. The fundamental warehousing activities include (i) receiving, (ii) storing, (iii) picking, and (iv) shipping [55]–[58]. The warehouse performance of a competitive organization is closely related to its competitiveness. Efficient inventory management allows a company to increase profits, reduce delivery times, and provide higher-quality customer service [59]. Improvements in employee performance and efficient logistics will result in more efficient warehouse activities. The efficiency of warehouse performance has a significant impact on a company's finances, especially with regard to the expenses and revenues of an organization or company [60].

To assess warehouse management performance, it is crucial to consider Key Performance Indicators (KPIs) and have the ability to monitor them. Developing a performance monitoring system in an industrial company requires an in-depth understanding of the organization, its needs, and its culture, as well as the ability to collect data and adjust theoretical indicators to the organization's demands [59]. The fundamental components of performance evaluation help in understanding the steps employed by organizations in carrying out performance evaluations. These components include establishing the mission, establishing the organization's objectives and goals, establishing the strategic plan or the company's general and operational policies, and establishing and creating performance indicators that will be quantified and evaluated. Thus, in this study, the fundamental elements are cost, productivity, quality, time, and utilization [29], [60], [61]. Productivity indicators may include receiving productivity, storage productivity, product replenishment productivity, product picking productivity, shipping productivity, delivery productivity, inventory utilization, transportation utilization, warehouse utilization, equipment utilization, and labor utilization [53], [62]. Measures of resource utilization are capacity utilization and labor productivity and labor utilization [61], [63]. Efficiency indicators for logistics operations are scarce [64], [65].

3 METHODOLOGY

This research used the survey methodology, together with data analysis through structural equation modeling, with the primary objective of proposing a model to examine the management of forklift operations in logistics warehouses. A survey is a technique used to collect data or information about the characteristics, behaviors, or points of view of a specific public group. Typically, the instrument used is a questionnaire. Researchers are increasingly using online surveys due to their benefits of reduced costs, speed, and ability to target specific groups. For the interviewee, it is attractive because they can respond in the way that is most convenient for them, at the time and place of their preference [66]–[69].

Structural Equation Modeling (SEM) consists of seven steps: (1) creation of a theoretical model, (2) elaboration of a path diagram of causal relationships, (3) transformation of the path diagram into a set of structural and measurement models, (4) selection of the type of data matrix and determination of the proposed model, (5) analysis of the identification of the structural model, (6) analysis of the quality of fit criteria, (7) interpretation and modification of the proposed model [70]–[73]. Along with SEM, the Partial Least Squares (PLS) methodology was applied to research because it is a broad approach structured with methodological rigor, both theoretical and quantitative. This method seeks to explain the relationships between multiple constructs (dependent and independent variables) of samples from 70 units [68], [74]–[76].

3.1 Working Method

To begin the research, the constructs that served as a basis were defined: forklift and its operations [35], [36], [49], [77], operations management in the use of forklifts in warehouses [20], [64], [77]–[80], and forklift efficiency management [9], [12], [64], [82]. Based on the definition of research constructs, the research hypotheses were developed. Then, the questions were prepared in an online questionnaire to survey Google Forms® [66], [67], [82], [83] (Table I).

Table I – Questions/Indicators for preparing the Survey

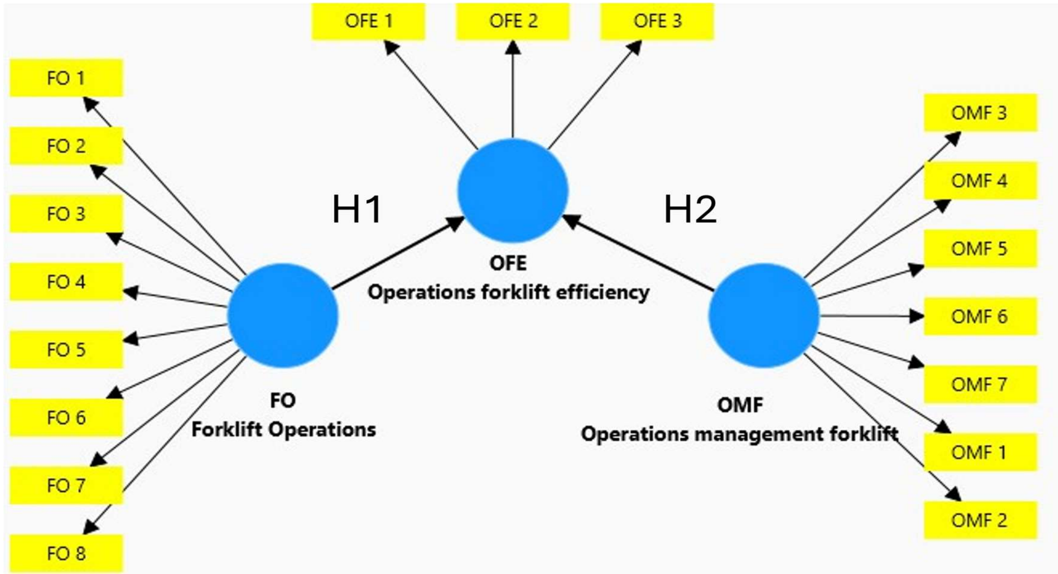
Construct	Indicators	Variables	Acronym	Authors	Hypotheses
Forklift and its operations (FO)	In the operation in which I work, I only use forklifts in load-lifting operations.	Independent	FO 1	Bozer & Eamrungroj (2018); G. H. Park *et al*. (2014); Rushton, A., Croucher, P., and Baker (2014); Wouters & Sportel (2005).	H1: Are forklifts used in warehouse operations effectively for lifting or lowering materials?
	I use a walkie stacker in the operation I work in, only in load-lifting operations.	Independent	FO 2		
	In the operation where I work, I use forklifts to move materials throughout the warehouse in operations without lifting.	Independent	FO 3		
	In the operation I work in, I use turret trucks to move materials throughout the warehouse.	Independent	FO 4		
	In the operation where I work, I use a walkie stacker with elevation to move materials throughout the warehouse.	Independent	FO 5		
	In the operation I work in, I use tow tractors/AGVs to move materials throughout the warehouse.	Independent	FO 6		
	In the operation where I work, I use forklifts and walkie stackers with elevation only for lifting materials and tugs/AGVs, pallet trucks without elevation, and manual pallet trucks for moving materials throughout the warehouse.	Independent	FO 7		
	In the operation I work in, I use hand pallet trucks to move materials throughout the warehouse (including for order separation).	Independent	FO 8		
Operations management in the use of forklifts in warehouses (OMF)	The operation I work in uses specific teams of people for each operational function in the warehouse.	Independent	OMF 1	Costa *et al*. (2022); Frazelle (2016); Kusrini, Novendri, Helia (2018); Putri, Wahyudi (2023); Hirunwat,	H2: Does the use of forklifts in warehouse operations have indicators for
	The operation I work in uses a Warehouse Management System	Independent	OMF 2		

	(WMS) to manage material handling equipment.			Khemavuk, Rungreunganun (2017) Marziali; Rossit, Toncovi (2021); Laosirihongthon *et al*. (2018), Nunes (2023).	managing this equipment and making decisions?
	The operation in which I work has management indicators	Independent	OMF 3		
	The operation in which I work uses these indicators as the basis for decision-making regarding the operation.	Independent	OMF 4		
	The operation in which I work has management indicators related to people's productivity.	Independent	OMF 5		
	The operation in which I work has management indicators related to the maintenance costs of material handling equipment.	Independent	OMF 6		
	The operation in which I work has management indicators related to the costs of material handling equipment.	Independent	OMF 7		
Forklift Efficiency Management (OEF)	The operation in which I work has management indicators related to forklift productivity.	Dependent	OFE 1	Halawa *et al*. (2020); Kamali (2019); Nunes (2023); Tews (2013); Nunes (in press).	
	The operation in which I work has management indicators related to either the availability or the use of forklifts.	Dependent	OFE 2		
	The operation in which I work has management indicators related to the efficiency of forklifts.	Dependent	OFE 3		

Source: The author.

From the constructs and hypotheses, the initial version of the proposed model was generated (Figure 2) using SmartPLS 4 [85].

Figure 2 – Initial proposed model



Source: The author, using SmartPLS 4.

The questioning technique used was the 5-point Likert scale (1 – completely disagree; 2 – disagree; 3 – neither agree nor disagree; 4 – agree; and 5 – completely agree) [67], [68], [86]. A pre-test was carried out to validate the questionnaire. The pre-test was extended to ensure the validity and accuracy of the questionnaire, limited to a group of 10 to 20 participants from the population belonging to the group studied [67], [68], [74]. LinkedIn was initially used to send the pre-test through messages with the survey link to professionals working in logistics operations in warehouses. The survey was carried out between May 17th and June 1st, 2024, with a sample of 18 respondents.

Cronbach's Alpha was calculated using the SPSS® (Statistical Package for Social Science) software to assess the reliability of the pre-test. According to Hubley and Zumbo (1996), reliability is synonymous with consistency, stability, and predictability. Cronbach's Alpha is considered acceptable from 0.60 onwards for exploratory studies [87], [88]. The results of Cronbach's Alpha for this pre-test for the FO construct were: 0.746 (eight questions); for the OMF construct: 0.668 (seven questions); and for the 15 questions, the Alpha was 0.926. Thus, the pre-test was validated.

After validating the reliability of the research instrument, the questionnaires were sent. The survey link was sent via LinkedIn messages to professionals who work in logistics operations in warehouses associated with ABOL and ABRALOG in a non-probabilistic manner for convenience. The Brazilian Association of Logistics Operators (ABOL) is a Brazilian institution that represents the activities of logistics operators (3PL) and has 31 associated companies. The Brazilian Association of Logistics (ABRALOG) is also a Brazilian institution that represents organizations that operate in the areas of logistics, transportation, distribution, and e-commerce and has 144 associated companies. The questionnaire was sent to two employees from each of the 175 companies, and if both were returned, only the first questionnaire answered would be included in the survey. The subsequent ones would be eliminated to avoid creating bias. The period in which the survey was conducted was from August 1st to September 29th, 2024. In total, 350 questionnaires were sent, and the author received 122. Of these, 23 were eliminated because they were from the same company, and thus 99 responses were considered. The return rate in this survey was 56.5%, which is in line with the literature that presents returns between 25% and 46% [67], [89]. In addition to the questions related to the indicators of this survey (Table I), the participants answered five questions regarding their gender, academic background, length of experience in logistics operations with forklifts in distribution centers, their role in the company, and the number of forklifts under their management.

4 RESULTS

Of the 99 respondents, 88 are male and 11 are female. Of these, 92% (91) have higher education (undergraduate), and of these, 78% are studying or have already completed postgraduate studies (81). Regarding their functions, 87% work in management positions (103), 69% have more than 10 years of experience in operations management (69), and 73 (73%) manage a fleet with more than 15 forklifts.

Based on the responses to the questions on the indicators in Table I, an analysis was performed using the IBM SPSS® program to assess the reliability of the questionnaire using Cronbach's Alpha. The results were as follows: FO 0.636; OMF 0.763, and OFE 0.939. That validated the questionnaire and its responses. The sample adequacy was confirmed. This conformity is confirmed by the Kaiser-Meyer-Olkin (KMO) measure, an index used to assess the adequacy of factor analysis. The value obtained for the KMO test was 0.735, lower than that for which factor analysis is adequate since values above 0.60 suggest that the variable analysis factor is adequate [68], [90]. In addition, Bartlett's sphericity test was used, which should have a significance level of $p < 0.05$, also to confirm the adequacy of the data. It tests the null hypothesis that the original brightness matrix is an identity matrix. The result for the significance of the research data was zero. After this analysis, also through IBM SPSS® software, Exploratory Factor Analysis (EFA) was performed to group the variables that presented similar behaviors, and the Varimax rotation was applied, which resulted in four analysis factors, explaining 66.7% of the total variance (Table II).

Table II – EFA factor results

1st acronym	1	2	3	4	New acronym after EFA
FO 1	**.732**	.209	.156	-.020	C1.1
FO 1	**.732**	.209	.156	-.020	C1.2
FO 2	**.825**	.128	.210	.152	C1.3
FO 3	-.419	.165	.186	.497	Deleted
FO 4	.072	.240	.185	**.781**	C4.1
FO 5	.015	.097	-.371	**.741**	C4.2
FO 6	.317	-.150	.389	**.580**	C4.3
FO 7	**.633**	.015	.087	-.058	C1.4
FO 8	.488	-.221	**.609**	.080	C3.1
OMF 1	.173	.173	.549	-.008	Deleted
OMF 2	**.590**	.174	-.140	.087	C1.5
OMF 3	.126	**.823**	.106	.145	C2.1
OMF 4	.099	**.831**	.302	.150	C2.2
OMF 5	.183	**.807**	.156	.047	C2.3
OMF 6	-.041	.338	**.688**	-.023	C3.2
OMF 7	-.075	.319	**.723**	.215	C3.4

Source: The author (2024).

For this analysis, the guidance for identifying significant factor loadings was applied based on the sample size of 99 respondents, which is 0.55 [70]. Thus, the indicators FO 3 and OMF 1 were excluded because they did not reach the necessary factor loadings. From the EFA (Table II), new names were defined for the indicators since the EFA indicated new clusters for the model initially proposed (Figure 2). In addition, a new hypothesis was generated for each of the construct clusters, as shown in Table III.

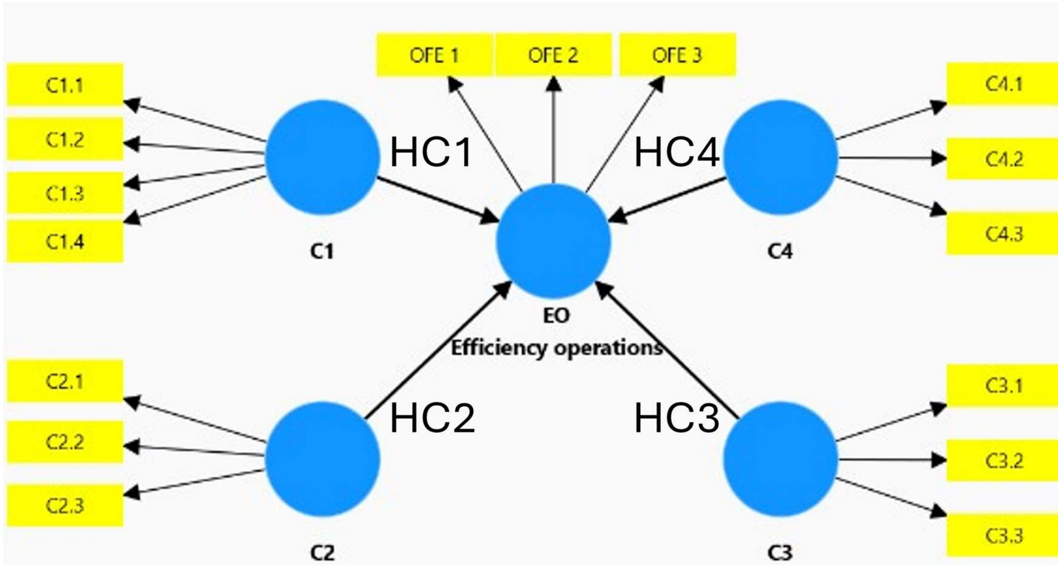
Table III – New constructs and hypotheses after EFA

Constructs	Indicator Acronym	Hypotheses
C1 – Proper use of forklifts.	C1.1, C1.2, C1.3, and C1.4	HC1: Does the proper use of forklifts have a positive impact on the efficiency of this equipment?
C2 – Measurement of people's productivity for decision-making.	C2.1, C2.2, and C2.3	HC2: Does measuring people's productivity have a positive impact on forklift efficiency?
C3 – Measurement of costs and use of forklifts.	C3.1, C3.2, and C3.3	HC3: Does measuring the costs and use of forklifts have a positive impact on the efficiency of this equipment?
C4 – The use of other equipment to move materials.	C4.1, C4.2, and C4.3	HC4: Does the use of other equipment to move materials have a positive impact on the efficiency of forklifts?

Source: The author (2024).

The cluster comprising the initial indicators FO 1, FO 2, FO 3, FO 7, and OMF 2 addresses issues related to the use of appropriate equipment for lifting materials and the use of WMS software to manage these operations. It was renamed construct C1 (Proper use of forklifts). The construct comprising the initial indicators OMF 3, OMF 4, and OMF 5, which address issues related to the use of indicators in operations management, with an emphasis on people's productivity for decision-making, was named C2 (Measurement of people's productivity for decision-making). In relation to the initial indicators FO 8, OMF 6, and OMF 7, a new construct called C3 (Measurement of costs and use of forklifts), which covers issues related to indicators based on operating costs and the use of manual equipment in operations, was formed. The construct that grouped the initial indicators FO 4, FO 5, and FO 6 was called C4 (The use of other equipment to move materials) and addresses the topic of the use of other equipment – not the forklift in the operation of moving materials in the DCs. Having done this, a new model was proposed (Figure 3).

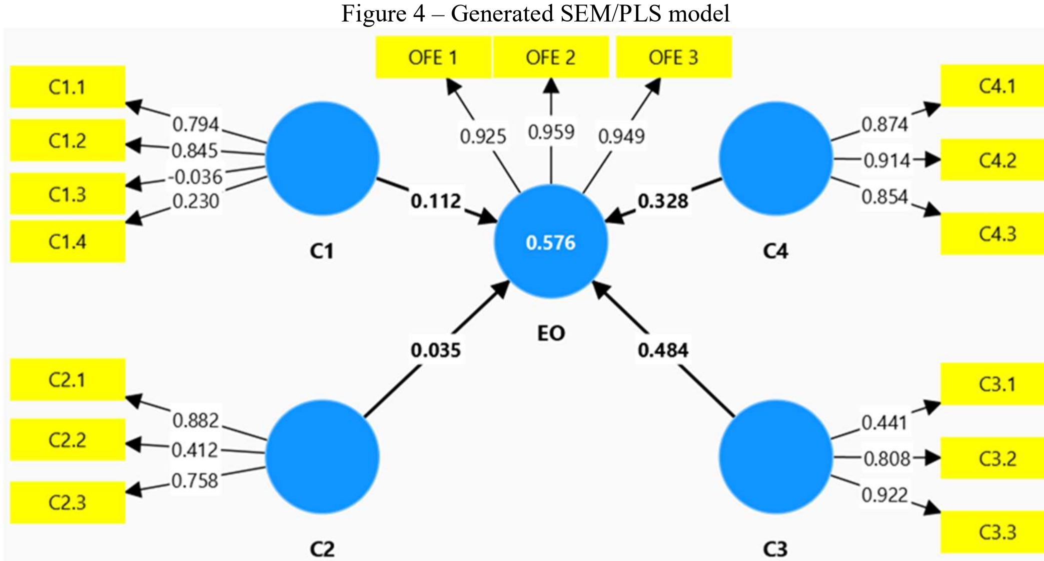
Figure 3 – Model proposed after EFA



Source: The author, using SmartPLS 4.

With the new evaluation model defined, we proceeded to analyze the model using SmartPLS 4 [85]. The evaluation model defines the indicators for each element. This model also verifies the validity of the constructs. Unlike factor analysis, where indicators are defined for each factor, in the measurement model, the researcher defines which variables are indicators of each construct [70], [75], [91], [92]. Figure 4 presents the model, the overall coefficient of determination R^2, and the results generated by SmartPLS 4.

Figure 4 – Generated SEM/PLS model



Source: The author, using SmartPLS 4.

Thus, after being modeled in the SmartPLS 4 software, this research presented a coefficient of determination R^2 for the dependent variable OFE. This variable attempted to identify whether the organizations in which the interviewees work apply efficiency measurements to the management of forklifts. R^2 means that the independent variables moderately explain 0.576 of the variance; that is, the proposed model directly impacts this variable by 57.6 percent. The values of the correlation coefficient between the constructs must be greater than 0.1 to be considered significant [68], [93], [94]. The constructs C1 (0.112), C3 (0.484), and C4 (0.328) in the path relationship, which analyzes the management of operations through the correct use of forklifts suitable for lifting materials, through indicators linked to the costs of the equipment used, and the use of other equipment, in addition to forklifts, for moving materials, are statistically significant, since the path coefficient is greater than 0.1 [67], [68], [94]. As for construct C2, which analyzed people's productivity indicators for decision-making, it is not significant since its path coefficient (0.035) is less than 0.1. From these data, constructs C1, C3, and C4 have a positive impact on the management of forklift operations among those surveyed in the sample presented in this research.

After modeling, we sought to attest to the measures that indicate the predictive capacity of the model to analyze its quality. The evaluation of the PLS-SEM structural model is based on a set of evaluation criteria that must be met: verification of the measurement model involves analyses of composite reliability, convergent validity, Cronbach's Alpha, and discriminant validity [68], [75], [76], [92], [95].

The responses and the sample were evaluated using composite reliability, which refers to indicators associated with the quality of a measure and assesses the quality of the structural model [67], [68], [75], [87]. Values above 0.7 are considered acceptable [96]. In exploratory research, values between 0.60 and 0.70 are considered adequate. For other types of research, values between 0.70 and 0.90 are considered satisfactory [87]. In Smart-PLS 4, the values found for the constructs indicate that the composite reliability is respectively C1: 0.613, C2: 0.740, C3: 0.784, C4: 0.913, and overall: 0.961.

The Average Variance Extracted (AVE) is the portion of the data of the variables that is explained by each respective latent construct; that is, the variables correlate positively with each other with their respective constructs, which is the convergent validity. With AVE values being greater than 0.50, it is assumed that the model converges to a satisfactory result, being sufficient to explain the quantity, on average, of the variables that relate positively with their respective constructs [68], [97], [98]. The AVE results for constructs C1: 0.508, C2: 0.507, C3: 0.566, and C4: 0.777 correlate positively with their respective constructs, assuming that there is evidence that the observable variables have convergent validity.

The reliability coefficients (Cronbach's Alpha) of the constructs were extracted from SmartPLS 4, and their results are C1: 0.713, C2: 0.602, C3: 0.619, C4: 0.856, and overall: 0.939. The results are above 0.6, so they are valid. Discriminant validity is where a construct is empirically differentiated from other similar constructs, as well as verifying what is not conditioned by the constructs. In this way, discriminant validity is perceived when a construct or latent variables are independent of the others through the confrontation of the square roots of the AVE values [67], [87], [99]. Thus, discriminant validity is the extent to which a construct is genuinely distinct from the others by empirical standards. In this way, discriminant validity is understood where the constructs or latent variables are independent of each other. When the confrontation of the square roots of the AVE is greater than the correlation coefficient between the latent variables, the existence of discriminant validity is concluded. Therefore, the discriminant validity of the constructs C1: 0.713, C2: 0.713, C3: 0.752, and C4 0.881 and those in which the values of the correlation coefficients are lower as shown in Figure 3, thus attesting that there is discriminant validity between the respective constructs (HAIR JR. *et al*., 2014).

5 DISCUSSIONS OF RESULTS

Hypothesis HC1, which refers to the construct formed by the initial indicators FO 1, FO 2, FO 3, FO 7, and OMF 2, known after the EFA as C1, and their respective indicators called C1.1, C1.2, C1.3, and C1.4, which discussed the use of appropriate equipment for the transportation of materials and systems for the management of these operations, highlighting forklifts, walkie stackers, and turret trucks in the lifting and lowering tasks, presented an R^2 of 0.112. This indicates that, for the sample examined, this element is relevant but not the main one in the management and execution of operations since, in most material handling activities in distribution centers, forklifts are still the only handling equipment applied. Forklifts are the appropriate equipment for lifting and stacking pallets [35], [36]. For the transportation of materials, without lowering and lifting operations, other equipment, such as tow trucks and AGVs, must be used since forklifts must only move as much as necessary, as they are harmful to material handling operations at warehouse floor levels [35], [37], [38], [100], [101].

Hypothesis HC3, referring to the construct that analyzes issues related to indicators based on operational costs and the use of manual equipment in operations, obtained an R^2 of 0.484. This value represents that this construct is the most representative of the interviewees. Measuring the costs of operating equipment used in DC operations is essential for the management of these operations since cost is one of the fundamental elements in these environments [29], [60], [61]. Third-party suppliers predominantly perform maintenance in this type of business, and this activity impacts the interruption of warehouse operations and causes great financial losses for companies [67]. Moreover, forklifts are machines that require attention in their management due to equipment, labor, and maintenance costs [17].

Hypothesis HC4, related to the construct that grouped the initial indicators FO 4, FO 5, and FO 6 and addresses the topic of the use of other equipment, not the forklift, in the material handling operation in the DCs, presented an R^2: 0.328. This value represents that this construct has a high representation in the sample analyzed since the use of forklifts must be considered to avoid excessive investments in material handling. It is also worth considering that in conventional storage systems, the routes taken by forklifts to store materials in an available location require the return with empty forks. Forklifts used to transport materials without the task of lowering and lifting loads should be moved only as necessary. Otherwise, they may be harmed in material delivery operations [37], [38], [47]–[49].

Regarding Hypothesis HC2 (Measurement of people's productivity for decision-making), which brought together the initial indicators OMF 3, OMF 4, and OMF 5, which addressed the use of indicators in operations management, with emphasis on people's productivity for decision-making, it obtained R^2: 0.035. This value demonstrates that the managers interviewed do not consider this topic important in the management of forklift operations. Considering that the man-machine system of the forklift and operator is vital for the execution of activities since the use of autonomous equipment is not yet a reality in distribution centers in Brazil, it opens a gap to identify the reasons for this non-use by managers. After all, a performance monitoring system uses indicators aligned with the organization's demands [59]. Furthermore, the indicators linked to productivity (receiving productivity, storage productivity, product replenishment productivity, product collection productivity, shipping productivity, and delivery productivity) are fundamental elements in warehouse management [53], [62] since the cost of overtime work of the forklift fleet according to the forklifts available during regular working hours is one of the leading causes of lack of productivity management [39], [40], [42].

6 FINAL REMARKS

This research aimed to identify the constructs that make up the management of forklift efficiency in material handling operations in distribution centers in Brazil. From the analysis of the data, it is possible to state that, in response to HC1 (Hypothesis 1), we can say that, for the respondents, the adequate use of forklifts has a positive impact on the efficiency of forklifts. This variable obtained a load of 0.112. These results corroborate the findings of the literature, which state that forklifts, walkie stackers, and turret trucks should be used in the activities of lifting and lowering materials. HC3 (Hypothesis 3), which examines whether measuring people's productivity has a positive impact on the efficiency of forklifts for the sample researched, has a positive impact since this variable presented a load of 0.484, being the most representative among the interviewees. The authors state that measuring the costs of operating the equipment used in DC operations is crucial for the management of these operations since cost is one of the crucial factors in these contexts. Regarding HC4 (Hypothesis 4), which analyzed the use of other equipment in the movement of materials, it also had a positive impact, with a load factor of 0.328. Although forklifts are used to transport, lift, and lower various types of loads in loading and unloading and storage operations in warehouses, depots, ports, stores, and distribution centers, they should focus only on the tasks of lowering and lifting loads, moving only, when necessary, since the protected equipment for transporting materials at floor level are tow trucks and AGVs.

Another point to be considered, which was not found in the literature, is a model for measuring the efficiency of forklifts. Studies only present the measurement of use by measuring the hours worked and collected by the hour meters installed in this equipment. In this way, a research gap arises. The model proposed in this research can be considered valid because it meets all the required validity criteria [70], [87]and the analysis of the results obtained with the model will contribute to research and to companies that use forklifts as material handling equipment to remain more efficient, productive and therefore more competitive in the distribution market, where one of the focuses is to increase the speed of response to their customers.

For future research, we suggest the application of the model in this manuscript in more warehouses for its refinement and analysis of more samples, as well as the development of a model that contributes to measuring the efficiency of forklifts, aiming to optimize the use of this equipment so widely used worldwide in the movement of materials, as also suggested by Kamali (2019), in addition to using frugal innovation to develop technological solutions to assist in the insertion of digital transformation for data collection and analysis so that this measurement is automated and independent of operator participation, aiming to reduce the variability of this intervention.

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