

Data Envelopment Analysis to measure relative performance based on key indicators from a supply network with Reverse Logistics

Análisis Envoltante de Datos (DEA) para medir el desempeño relativo basado en indicadores de una red de abastecimiento con Logística Inversa

DOI: <https://doi.org/10.17981/ingecuc.14.2.2018.13>

Artículo de Investigación Científica. Fecha de Recepción: 04/05/2018. Fecha de Aceptación: 17/12/2018.

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Para citar este artículo:

C. Ardila Gamboa y F. Ballesteros Riveros, "Data Envelopment Analysis to measure relative performance based on key indicators from a supply network with reverse logistics" *INGE CUC*, vol. 14, no. 2, pp.137-146, 2018. DOI: <http://doi.org/10.17981/ingecuc.14.2.2018.13>

Abstract

Introduction– Data Envelopment Analysis (DEA) is used to measure the relative performance of a series of distribution centers (DCs), using key indicators based on reverse logistics for a company that produces electric and electronic supplies in Colombia.

Objective– The aim is to measure the relative performance of distribution centers based on Key Performance Indicators (KPI) from a supply network with reverse logistics.

Methodology– A DEA model is applied through 5 steps: KPIs selection; Data collection for all 18 DCs in the network; Build and run the DEA model; Identify the DCs that will be the focus of improvement; Analyze the DCs that restrict or diminish the total performance of the system.

Results– KPIs are defined, data is collected and KPIs for each DCs are presented. The DEA model is run and the relative efficiencies for each DCs are determined. A frontier analysis is made and DCs that limit or reduce the performance of the system are analyzed to find options for improving the system.

Conclusions– Reverse logistics, brings numerous advantages for companies. The analysis of the indicators allows logistics managers involved to make relevant decisions for higher performance. The DEA model identifies which DCs have a relative superior and inferior performance, making it easier to make informed decisions to change, increase or decrease resources, and activities or apply best practices that optimize the performance of the network.

Keywords– Data envelopment analysis; Relative performance; Reverse Logistics; Returnable packages; Warehousing.

Resumen

Introducción– El análisis envoltante de datos (DEA), se usa para medir el desempeño relativo de una serie de centros de distribución (DCs), utilizando indicadores clave basados en logística inversa para una empresa que produce suministros eléctricos y electrónicos en Colombia.

Objetivo– Medir el rendimiento relativo de los centros de distribución en función de indicadores clave (KPI) de una red de abastecimiento con logística inversa.

Metodología– Se aplica un modelo DEA a través de 5 pasos: Selección de KPIs; Recopilación de datos para los 18 DCs en la red de distribución; Se construye y ejecuta el modelo DEA; Identificar los DCs que serán el foco de la mejora; Analizar los DCs que restringen o disminuyen el rendimiento total del sistema.

Resultados– Inicialmente se definen KPI, a partir de los datos recolectados y se presentan los KPI para cada DCs. Se ejecuta el modelo DEA y se determinan las eficiencias relativas para cada DCs. Posteriormente, se realiza un análisis de la frontera y se analizan los DCs que limitan o reducen el rendimiento del sistema en busca de opciones para mejorar el sistema.

Conclusiones– La logística inversa, trae numerosas ventajas para las empresas. El análisis de los indicadores permite a los gerentes de logística tomar decisiones relevantes para mejorar el desempeño del sistema. El modelo DEA identifica a los DCs que presentan rendimientos relativamente superiores e inferiores; lo cual facilita la toma de decisiones informadas para cambiar, aumentar o disminuir los recursos y las actividades, o aplicar las mejores prácticas que optimicen el rendimiento de la red.

Palabras clave– Análisis Envoltante de Datos, Eficiencia relativa, Logística Inversa, Empaques Retornables, Almacenamiento.

I. INTRODUCTION

The case study is focused on a company that produces electric and electronic supplies (which will be identified as EES henceforth), that uses a business model around reverse logistics closely related to sales, wherein their packaging (crates and pallets) are returned to the company and are then re-used, generating valuable savings for the company. EES executives are making efforts on identifying strengths and weaknesses in their distribution network, which is where Data Envelopment Analysis (DEA) models are the perfect tool for this task.

The aim of this article, is to apply a DEA model to assess the relative performance of the logistics network of a company that uses reverse logistics on returnable packaging in order to distribute its products. By comparing each of its DCs and what is observed directly by the authors and the company's experience, a series of conclusions and opportunities are identified that will improve the performance of this reverse logistics-based distribution network in the future.

According to [29], DEA is a linear programming-based tool that can compare (most often complex) multiple outputs and inputs in the form of results against invested resources, in order to identify key focus points for improving the overall system's performance.

For [7] reverse logistics is defined as a series of processes by which products, materials and other resources are retrieved from clients and returned back to the company's hands. It is considered an added-value activity as it recovers the value of the returned goods, reduces costs and improves profitability in companies, also usually associated with an environmental responsibility image, often developed into 'green logistics'. According to [15] explore reverse logistics as post-sale processes for the retrieval of the goods, inspection and sorting of the returned items, which are then directly re-used, re-assembled, recycled, or finally destroyed inside the company which integrates them into their products or services.

The relative performance of the distribution centers in the EES network is measured by applying DEA to a series of performance indicators related to the reverse logistics practices used by this company, such as inventories, cycle times, and production, sales and returns levels. The company will then analyze the results and develop action plans worthy of improving the distribution center activities and the overall system performance.

The rest of this paper goes as follows: In Section II the methodology is exposed. Section III addresses the literature review for 'Reverse Logistics' and 'DEA' applications. Section IV sets the context for applying the DEA model, input and output variables are selected and measured. In Section V the DEA model is run, results are analyzed and a frontier analysis is presented. Last section elaborates the final conclusions.

II. METHODOLOGY

The aim of this article is to apply a DEA model to assess the relative performance of the logistics network of a company that uses reverse logistics on returnable packaging in order to distribute its products. By comparing each of its DC and what is observed directly by the authors and the company's experience, a series of conclusions and opportunities are identified that will improve the performance of this reverse logistics-based distribution network in the future.

A literature review is performed extracting articles from relevant research databases, in order to identify the current state of the knowledge and opportunities regarding the application of DEA models, with particular attention to Reverse Logistics applications.

Thought a case of study, the reader will acquaint with a company that produces electric and electronic supplies, and uses a business model around reverse logistics, wherein their packaging (crates and pallets) are returned to the company and are then re-used. This business model has proven fruitful and grants proper savings in packaging materials to the company.

This company wants to improve the overall performance of its distribution network, and for that, the first step would be to measure the performance of its supply network consisting of 18 distribution centers, by using key indicators based on forward and reverse logistics from the last 12 months. Using DEA this task is simplified and the objective is achieved through 5 steps as follows:

1. Select input and output data that measure performance for each DC of the logistics network. The DEA model proposed will include three inputs and three outputs related to reverse logistics.
2. For each one of the DCs determine the values of the different input and output variables.
3. Build and run the linear programming model that will determine the relative performance of each DC in relation to the others in the system.
4. Organize the DCs from lowest to highest performance, in order to identify the DCs that will be the focus of improvement.
5. Finally, compare the results against the DCs that restrict or diminish the total performance of the system and conclude accordingly.

III. LITERATURE REVIEW

The literature review involves two key topics: 'Reverse logistics' and 'Data envelopment analysis'. To develop this literature review, nine relevant research databases were explored, all of which are based on content indexed around businesses, engineering and logistics (Access Engineering, EBSCO Business Source, Emerald Insight, JSTOR, ProQuest, ScienceDirect, Scopus, SpringerLink and Web of Science);

TABLE 1. EXPLORING THE RELEVANT TERMS IN RESEARCH DATABASES.

Data Base	Returnable Packaging	Reverse Logistics	Data Envelopment Analysis	Relative Performance	Warehousing
Access Eng.	44	259	48,010	86	9,595
JSTOR	232	2,820	15,276	15,863	175,681
ProQuest	5,760	67,059	12,641	317,761	994,227
Scopus	144	5,413	12,612	16,928	82,255
Science-Dir.	825	13,215	9,133	62,713	1,042,112
Springer	740	16,809	7,191	45,036	665,022
Web of K.	24	2,735	6,910	8,269	40,703
EBSCO B.S.	129	1,395	5,746	7,513	2,462
Emerald Ins.	316	4,113	1,884	1,905	42,743
Total	8,214	113,818	119,403	476,074	3,054,850

Source: Authors.

and inputting the terms ‘Data Envelopment Analysis’, ‘DEA’, ‘relative performance’, ‘reverse logistics’, ‘returnable packaging’ and ‘warehousing’. From this first exploration the statistics were built as presented in table 1.

Within the results obtained from this first search in the databases, it is decided to look for relevant sources in JSTOR, ProQuest and ScienceDirect databases. Other databases like Access Engineering and SpringerLink had to be discarded since the terms ‘data analysis’ and ‘warehousing’ gave us a significant number of articles unrelated to the development of this subject. The databases are chosen as they contemplate an important amount of references related to DEA and reverse logistics, which is in the main interest of the authors.

One particularity is that the quantity of related articles falls by combining the related research terms, both in English and Spanish, and then filtering results to the last five years of publications. (Table 2).

TABLE 2. REFINING THE RESEARCH.

Data Base	JSTOR	Science-Direct	ProQuest	Total
DEA + RL	2.542	351	252	3.145
>2012	211	246	150	607

Source: Authors.

By refining the research, a detailed analysis to top relevant articles from the three databases can be done, classifying them by the type of DEA model applied, the industry it was applied to, and the decision the authors look for.

From 50 articles, some statistics can be found in table 3, which highlight China for providing the most authors on the topic, and Iran comes second for compiling the most articles. The most relevant author is Reza Farzipoor Saen (from Iran), present in four (4) different articles.

TABLE 3. AUTHORS AND JOURNALS BY COUNTRY.

Country	Authors	Articles	Ratio
China	23	8	0.35
India	18	7	0.39
Iran	18	10	0.56
USA	14	8	0.57
Italia	9	3	0.33
Brazil	7	2	0.29
Portugal	6	3	0.50
UK	6	4	0.67
Australia	5	3	0.60
Turkey	5	2	0.40
Total	111	50	0.45

Source: Authors.

By exploring and classifying the most relevant topics from the articles found, DEA can be used in several ways, as [26] develops a method for assigning fixed costs by using DEA, and [21] who rationalized the performance inside a distribution network using DEA models.

Other articles focus on measuring efficiency and performance, in some cases to classify multiple decision-making units (DMU) from highest to lowest relative efficiency. This is widely considered as the main benefit of DEA models. Authors [20] apply a DEA model to prioritize and select projects according to their relative efficiency. And others [10] are able to select capable 2PL suppliers from a pool of complex and different options.

Some authors use DEA to analyze the performance from a certain industry or country, like [4], who evaluate the efficiency of postal services by applying DEA models, or [3] that measure relative efficiency in quality management for educational services in Turkish universities. While [14] choose DEA to evaluate and select third-party reverse logistics (3PRL) providers in Brazil.

Others authors move on from classic DEA models, like [24] who identify and classify efficient DMU's by applying a two-stage DEA, and [27] develop a DEA model based around evaluating the effectiveness of PERT/CPM (critic path method) projects, and identifying points of reference between industries. Or [9] apply a DEA model with weight restrictions in their input variables.

Finally, in this part of the literature review on DEA models, some authors are found to apply DEA models to reverse logistics processes; some of them also apply it to green logistics and environmental performance. Develop a network DEA for evaluating environmental management in supply chains [25]. Studies reverse logistics in Czech Republic and their increasing interest in performance measurement and improvement all through DEA [30].

A. Reverse Logistics

According [7] defines reverse logistics as the segment of logistics that focuses on the management and movements of products and resources after sales and delivery to the customer.

Some authors perform an analysis of the history and applications of reverse logistics: Make a literature review of reverse logistics [1]. Study the flow of information in reverse logistics [28]. Presenting a cost-benefit analysis of reverse logistics [32]. By studying the performance of reverse logistics applied to supply chain management (SCM) [31], strategies are proposed for the reverse logistics of products in good condition or non-defective [5].

Some authors explain how the supply chain has evolved to become closed-loop supply chains (CLSC), efficient in the economic and environmental context, integrating flows in reverse to the traditional chain. Develop a multilevel model for the design of a logistics network based on reverse logistics [22].

Several authors identify the value of technology being an enabler for the measurement of efficiency in logistic processes. They identify the impact that

technology has on the performance of reverse logistics [16]. Proposing a mixed integer linear programming model that integrates reverse logistics to the strategic planning of production and distribution of companies [8]. Or the construction a method for the application of reverse logistics based on bilateral integration (producer-client) of technological resources [18].

By [2] applying DEA to identify 16 critical success factors (CSF) for supply chains with reverse logistics. In order of importance as defined by experts, the factors are (1) Control, (2) Quality Management, (3) Process Planning, (4) Capacity, (5) Transportation, (6) Culture, (7) Innovation, (8) Automation, (9) Standardization, (10) Collaboration, (11) Organizational Strategy, (12) Information Technology Management, (13) Human Resources Management, (14) Commitment of Management, (15) Resource Management and finally (16) Logistics Network Design.

B. Data Envelopment Analysis (DEA)

Several authors indicate that the measurement of performance and efficiency have become an important task for managers, since they not only show the achievements of a unit, but also lay the foundations to make future decisions. The idea behind this technique is generally attributed to Farrell in [13], who identified an efficient empirical frontier, based on the best practices observed in a series of real decision-making units. The relative efficiency model proposed by Farrell is expressed in (1) and (2).

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \quad (1)$$

$$\text{Relative_efficiency} = \frac{\text{Weihted_Average_of_Outputs}}{\text{Weihted_Average_of_Inputs}} \quad (2)$$

DEA is a linear programming-based tool used to classify the DMU's of a system (for example: Distribution Centers within a distribution network). It consists of each DMU balancing the resources invested and the results obtained in a different way, and in such a way that the benefit for that DMU is maximized.

DEA model calculates the most favorable weight for each DMU and then compares this weighting against the other DMUs of the system and maximizes the objective function, which finally determines the relative efficiency for that DMU. For [33] state that the linear programming model for an Output Oriented Charnes, Cooper and Rhodes (CCR-O) DEA model is as presented in (3)-(6).

$$\text{Max } h_0 = \sum_r u_r y_{rj_0} \quad (3)$$

Subject to:

$$\sum_i v_i x_{ij_0} \quad (4)$$

$$\sum_i u_r y_{rj} - \sum_i v_i x_{ij} \leq 0 \quad \forall j = 1, 2, \dots \quad (5)$$

$$u_r, v_i \geq \varepsilon \quad (6)$$

Where:

- ur corresponds to the weighted average of each r output,
- vi corresponds to the weighted average of each i input.
- ϵ is a number set by the user of the DEA model, that will be the limit variables ur and vi will take. It is most commonly set to 0 so variables ur and vi are nonnegative.
- yrj are the results or outputs of the system, by DEA subject to be compared to inputs xij . The model is applied for each element or j DMU of the system to determine its relative efficiency.
- $h0$ will then be the relative efficiency of the j DMU, compared to all other DMUs in the system.

This model is the base for several applications that are identified in the literature: analyzes the decomposition and aggregation of efficiencies through the DEA technique applied to networks (network-DEA) [19]. Also analyze a series of applications of the DEA technique using uncertainty in different real-life applications [11]. Apply a sustainable location model using the DEA technique [17], a variation of the DEA technique dependent on contexts [23]. Gather the research of numerous authors on the DEA technique applied to networks (Network Data Envelopment Analysis, NDEA) [6]. Applies the DEA technique for the location of a remanufacturing plant in a network with reverse logistics, thus minimizing costs [34]. And, it uses the DEA technique to identify and capture the key customers of a company, and identify and measure strengths and weaknesses in customer service [12].

The ease of use and understanding of the different DEA models, the simplicity to apply and fast to obtain results and concrete comparisons between similar DMUs, make DEA an excellent tool to apply to the case of study of a company presented in this article.

IV. CASE STUDY

EES has developed its business model based on reverse logistics by using certain returnable packaging for the sale of most of its products (corresponding to around 80% in 2017). The company has a distribution network of national coverage, consisting of 18 Distribution Centers (DC) located at strategic demand points throughout the country, and three production plants (PP). The proximity of the DC to the production plants delimit the three regions in which the distribution network of the company is divided. The location and configuration of the regions are shown in Fig. 1, where the geographical relationship between production plants and DCs can be found:

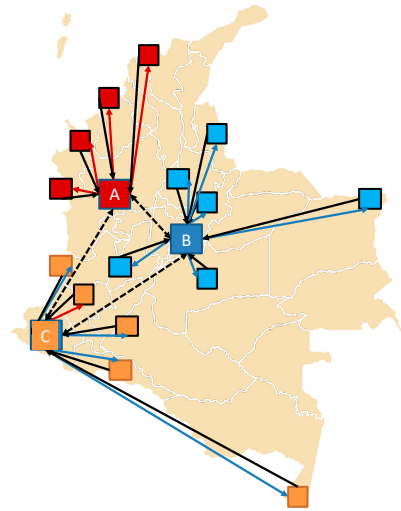


Fig. 1. Location of DCs and regions of the distribution network. Source: Authors.

The products' demand is characterized by their seasonality and a peak of sales marked at a certain time of the year. Its business model based on the Make-to-Stock (MTS) strategy involves the construction of an anticipated inventory of products to support sales, which in turn implies a demanding production program in the plants during the months prior to the mentioned sales peak.

Finished goods are transferred to each DC from the PP located in the same region; along with some products that are sold but not produced in all regions. There is a process to collect the empty packaging, which returns it to the DC and later to the PP.

There is an inventory of empty packaging in each DC, which will be transferred to the respective PP seeking to guarantee production continuity; all additional packaging requirements not covered by returns are satisfied by a local supplier. The new packaging is supplied with the aim of guaranteeing that there are a certain number of production days in each plant during peak sales. To enrich the understanding of the inventory cycles for returnable packaging, they are presented in Fig 2.

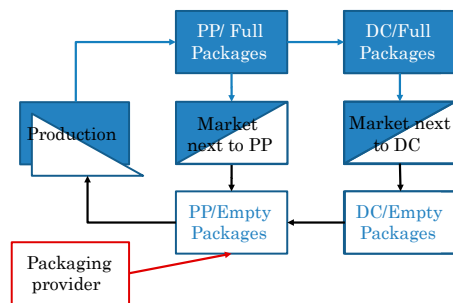


Fig. 2. Inventory cycles for returnable packaging. Source: Authors.

DATA ENVELOPMENT ANALYSIS TO MEASURE RELATIVE PERFORMANCE BASED
ON KEY INDICATORS FROM A SUPPLY NETWORK WITH REVERSE LOGISTICS

The company, like many other companies in the industrial sector, is always in constant improvement of its processes and operations. The executives of the company seek:

- To reduce costs of working capital and investment in new packaging.
- Reduction of inventories of products and empty packaging;
- Improvements in inventory cycle times;
- Improvements in the storage of packaging to prevent deterioration due to exposure to the weather, dust and other hazards.
- To improve the return process, managing that the packaging returns in greater volume and better conditions that allow a higher re-utilization rate.

The production and inventory planning department is always in exploration, development and application of various tools based on mathematical sciences. An effective method to determine the relative efficiency is DEA, applied to the case presented above, which provides the company with an understanding of the interactions between resources (such as costs, inventories, personnel and services) and the results (movements, sales, production and returns) of each element of its distribution network.

From the first step of the methodology explained in Section II, the performance of each DC is identified using the DEA technique, measuring the relative efficiency of the inventories of each DC with regards to its main activities (production in the case of PPs, sales, and returns of empty packaging on all DCs) using the following input data for the previous year 2017, for the 18 DCs:

- Average inventories of finished product, in units.
- Average inventories of empty packaging, in units.
- Cycle times (estimated time that the packaging takes from the last time it was used until it is used again), measured in days. This information is obtained through statistical samples of returned packaging.

And the following results, also from 2017:

- Yearly production (production plants will usually require a higher level of empty packaging), in thousands of packages.
- Yearly sales, in thousands of packages.
- Yearly returns, in thousands of packages.

Data for all the six variables has been provided directly by EES Executives in effort to facilitate the application of the DEA model.

TABLE 4. INPUT AND OUTPUT DATA FOR THE DEA MODEL.

Reg	DC	Ave. Prod. Inv. (Un)	Ave. Pack. Inv. (Un)	Cycle days	YearlyProd. (000 Un)	Yearly Sales (000 Un)	YearlyReturn (000 Un)
A	1	911	722	45.7	34,345	34,345	33,214
A	2	47	19	53.5	-	1,499	1,436
A	3	36	7	42.7	-	1,245	1,240
A	4	33	9	53.8	-	1,264	1,243
A	5	40	7	51.8	-	1,269	1,250
B	6	1,963	1,252	43.1	167,181	53,487	53,589
B	7	1,231	1,352	42.6	-	42,309	41,713
B	8	274	85	50.4	-	12,191	12,112
B	9	330	112	40.7	-	16,351	16,002
B	10	80	22	42.7	-	3,658	3,624
B	11	414	149	42.1	-	28,092	27,756
B	12	127	20	44.6	-	6,200	6,145
C	13	808	1,816	47.4	50,950	19,399	19,205
C	14	119	16	63.3	-	6,595	6,435
C	15	113	15	61.1	-	6,146	6,049
C	16	224	39	64.0	-	11,251	11,198
C	17	48	9	59.7	-	2,720	2,687
C	18	46	17	62.4	-	2,892	2,767
Total		6,844	5,668	46.3	252,476	250,913	247,665

Source: Authors.

For the second step of the methodology exposed in Section II, the following table 4 presents the input data for the 18 DCs to be compared (three of them are the PPs), ordered according to the region to which they belong.

V. RESULTS

On the third step of the methodology explained in Section II, 18 linear programming sub-models are generated (one for each DC in the network) having been structured using MS Excel as a basis, and using the Solver complement, the objective functions associated with each element of the network will be maximized, taking into account each one of the model's restrictions. The resulting relative weights and relative efficiencies for each DEA Sub-model are presented in Table 5 below.

As can be seen in Table 5, there is a strong tendency to obtain lower efficiency in the DCs belonging to region A, partly because it is the regional facility with the lowest level of sales, production and returns, as well as tends to generate a significantly high amount of products inventory and empty packages in its DCs, which in proportion turn out to be almost double of better positioned DCs in the relative efficiency ranking. More specifically, DC # 2 seems

to be limited regarding the results of DC # 11, while DC # 3, 4 and 5 are limited by the results of DCs # 11 and 14.

By the different relative weights obtained, DCs can be classified by the output that best maximize their efficiency (in order), as production-based (DCs 6, 1 and 13), Sales-based (7, 14, 11, 18, 9, 4 and 2) and Returns-based (16, 15, 17, 12, 10, 8, 3 and 5), in order to better understand how the lowest ranked DCs can benefit from the higher ranked DCs.

To carry out the fifth and last step, the four best and worst results are taken to make a comparison of the input data and a series of efficiency indicators, of a single input and a single output, which allows explaining why some DCs obtain the lowest relative efficiency. Against this, four key indicators (KPIs) are defined, which the company actually uses to measure the efficiency of its packaging. For all four indicators, having a higher score represents better efficiency and performance. The comparison is shown in Table 6:

- Percentage of packaging returns over sales (%),
- Sales over the average level of inventories (times per year),
- Returns over the average level of empty packaging inventories (times per year),
- Averaged yearly production cycles (times per year).

TABLE 5. RELATIVE WEIGHTS AND EFFICIENCIES OF EACH CD, ORDERED FROM HIGHEST TO LOWEST RESULT.

R	DC	Ave. Prod. Inv. (Un)	Ave. Pack. Inv. (Un)	Cycle days	Yearly Prod. (000 Un)	Yearly Sales (000 Un)	Yearly Return (000 Un)	Rel. Effic.
B	7	4.0E-2	0	1.18	0	2.4E-3	0	100,0
B	6	5.1E-2	0	0	6.0E-4	0	0	100,0
B	11	2.4E-1	0	0	0	3.6E-3	0	100,0
C	14	7.3E-1	8.3E-1	0	0	1.5E-2	0	100,0
C	16	1.5E-1	1.16	3.4E-1	0	0	8.9E-3	100,0
C	15	7.6E-1	9.2E-1	0	0	0	1.6E-2	98,6
C	17	1.68	2.04	0	0	0	3.6E-2	96,8
B	12	0	3.18	7.8E-1	0	0	1.5E-2	95,5
C	18	2.18	0	0	0	3.2E-2	0	92,7
A	1	4.5E-2	0	1.30	2.4E-5	2.6E-3	0	90,4
C	13	1.2E-1	0	0	8.7E-4	1.8E-3	0	79,7
B	9	0	7.7E-1	3.4E-1	0	4.6E-3	0	75,4
B	10	9.3E-1	1.13	0	0	0	2.0E-2	72,5
B	8	9.5E-2	7.4E-1	2.2E-1	0	0	5.7E-3	69,5
A	3	2.27	2.76	0	0	0	4.9E-2	60,3
A	4	2.28	2.57	0	0	4.7E-2	0	59,7
A	5	2.07	2.52	0	0	0	4.4E-2	55,5
A	2	2,14	0	0	0	3.2E-2	0	47,3

Source: Authors.

DATA ENVELOPMENT ANALYSIS TO MEASURE RELATIVE PERFORMANCE BASED ON KEY INDICATORS FROM A SUPPLY NETWORK WITH REVERSE LOGISTICS

TABLE 6. COMPARISON KPI'S FOR DCS WITH HIGHEST AND LOWEST RELATIVE EFFICIENCY.

Reg	DC	Returns to Sales	Sales to Ave. Product Inventory.	Returns to Ave. Package Inventory	Complete Cycles per Year
B	7	98.6%	34.4	30.8	8.6
B	6	100.2%	27.2	42.8	8.5
B	11	98.8%	67.9	186.1	8.7
C	14	97.6%	55.6	405.0	5.8
A	3	99.6%	34.6	185.8	8.5
A	4	98.4%	37.9	133.8	6.8
A	5	98.5%	31.9	178.2	7.0
A	2	95.8%	32.1	74.7	6.8

Source: Authors.

As observed in table 6, it is clear that DC # 2 does not stand out in any of the measured KPIs versus the DC's with the best relative efficiency result, and is a key candidate to be intervened, in order to enhance the general efficiency of the network.

Analysis of different variables is crucial to determine whether a DC is efficient or not regarding the other DCs. A frontier analysis is then used to identify some opportunities for DC's with lower relative efficiency, such as crossing Sales vs. Cycle Times in a scatter-plot graph as shown in Fig 3.

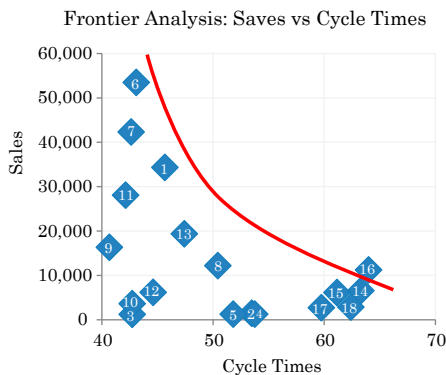


Fig. 3. Frontier Analysis of KPI's for each DC. Source: Authors.

From Fig. 3, it is noticeable that low cycle times are highly related to higher sales levels. DC#6 strongest point in keeping low inventory related to high production, sales and return volumes. Other production-based DCs (like DC#13) can benefit greatly by comparing its procedures to DC#6.

From the previous analysis, the top DCs with the best relative efficiency may be taken as a point of reference, and from there start to build an action plan to support decisions about the design of the chain, such as opening, modifying or eliminating chain links depending on the needs of the company.

VI. CONCLUSIONS

Reverse logistics is a trend that brings numerous advantages for companies such as lower costs, greater profitability and display an image of environmental responsibility to customers. Performance measurement is crucial to identify areas of improvement. Measuring the performance of real logistics systems can be a complex task, and there may be many variables that work as inputs and outputs for each system, making it difficult to make a single decision to improve the overall performance of the distribution network.

Through the design of a methodology composed around five (5) steps, Section II explains how to apply a DEA model successfully, in order to compare the efficiency of DMUs with similar, but complex, inputs and outputs, and identify the strong (or reference) points and weak (or opportunity) points in the overall system.

Section III show that a diverse literature regarding Reverser Logistics and DEA applications is available from many research databases, and the literature review allowed to identify the current state of the knowledge and opportunities for future research. Tools such as DEA models can be used to identify key points of improvement, which allow leading efforts, optimizing invested resources and improving overall results.

From Section IV, the case of study of a company composed of 18 DCs (3 of the being also production plants) is presented, and from the needs of the company, six (6) indicators in terms of forward and reverse logistics are identified. Data for these indicators is consulted and obtained for each of the 18 DCs, first hand from the company managers. Such data served as adequate inputs for the application of a CCR-O DEA model to measure the relative efficiency of this company's distribution network. In the case of EES, some of these indicators enabled an approach to the rotation of the packaging, to identify points (DCs)

with low return/high inventory, and helped analyze some cases of packaging inventory without adequate or slower rotation.

From Section V, through comparison of different KPIs and combination of KPI's, as well as a graphic interpretation, it is concluded that the DEA model measured accurately the relative efficiency of DCs within the supply and reverse network. With the best DCs identified (DCs #7, 6, 11 and 14), they can be taken as a point of reference, and from there, the supply chain manager can build an action plan to support decisions that include opening, modifying or eliminating inferior network links (such as DCs #3, 4, 5 and 2), in order to further enhance the efficiency of the company.

Future opportunities of research include to expand the application DEA models to the sub-processes within the top and bottom DMUs, as making comparisons and identifying and benchmarking best practices can serve greatly to improve the result of certain DMUs and the general relative efficiency within the system,

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