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Doctorado en Logística y Dirección de la Cadena de Suministro

Desarrollo Sustentable y Riesgo Ambiental en la Cadena de Suministro

Presenta

Gladys Bonilla Enríquez

Director / a

Dra. Patricia Cano Olivos

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Universidad Popular Autónoma del Estado de Puebla

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Dra. Patricia Cano Olivos

Directora

Dr. José Luís Martínez Flores

Asesor

Dra. Diana Sánchez Partida

Asesora

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Resumen

La administración de inventarios es una de las herramientas que se debe extender a todos los aspectos sociales, económicos y ambientales que influyen y/o son afectados a lo largo de las cadenas de suministros. Actualmente son de interés los aspectos de Desarrollo Sustentable (DS) y de Riesgo Ambiental (RA).

Estos aspectos son abordados mediante dos investigaciones principales. En la primera investigación se identificaron las variables DS más importantes asociadas con la administración de inventario. Estas variables se integraron como elementos de costo dentro de un modelo de control de inventario no determinista para incluir criterios DS en las estrategias de suministro de inventario. A través de la evaluación del modelo integrado propuesto, se determinó que, aunque las prácticas de DS implican inversiones adicionales, prácticas específicas como la reutilización / reciclaje y los incentivos gubernamentales pueden aumentar los ingresos y las ganancias. Esto es importante para el desarrollo de estrategias gubernamentales y empresariales para realizar prácticas sostenibles.

En la segunda investigación se analizó el impacto de los ftalatos en la salud de las personas en las operaciones de almacenaje, identificando la importancia del control de inventarios para reducir este riesgo. Para este propósito, la generación de ftalato se modeló a través del uso de Redes Neuronales Artificiales (ANN) y su impacto en la estrategia de suministro se evaluó a través de su integración dentro de un modelo de control de inventario estocástico. Como resultado se determinó es posible ajustar la estrategia de suministro para reducir la generación acumulativa de ftalato dentro del almacén y, por lo tanto, reducir su impacto en la salud humana y la sustentabilidad.

Abstract

Inventory management is one of the tools that should be extended to all social, economic and environmental aspects that influence and / or are affected throughout supply chains. Currently, the aspects of Sustainable Development (SD) and Environmental Risk (RA) are of interest.

These aspects are addressed through two main investigations. In the first investigation, the most important SD variables associated with inventory management were identified. These variables were integrated as cost elements within a non-deterministic inventory control model to include SD criteria in inventory supply strategies. Through the evaluation of the proposed integrated model, it was determined that, although SD practices involve additional investments, specific practices such as reuse / recycling and government incentives can increase revenues and profits. This is important for the development of government and business strategies for sustainable practices.

In the second investigation, the impact of phthalates on the health of people in storage operations was analyzed, identifying the importance of inventory control to reduce this risk. For this purpose, the generation of phthalate was modeled through the use of Artificial Neural Networks (ANN) and its impact on the supply strategy was evaluated through its integration into a stochastic inventory control model. As a result, it was possible to adjust the supply strategy to reduce the cumulative generation of phthalate within the warehouse and, therefore, reduce its impact on human health and sustainability.

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INTRODUCCIÓN

El Desarrollo Sustentable (DS) integra la preocupación por la capacidad de recursos de los sistemas naturales con los desafíos sociales, políticos y económicos de la humanidad. La ONU y la OCDE (Organización para la Cooperación y el Desarrollo Económico) han estado trabajando con los países miembros para hacer recomendaciones apropiadas para reducir el impacto de prácticas económicas ineficientes en los aspectos sostenibles del medio ambiente y la sociedad. En este contexto, las industrias de fabricación y servicios son dos de los principales sectores cuyas prácticas impactan en los aspectos económicos, ambientales y sociales.

Si no se atiende, se espera que los impactos en estos aspectos empeoren a medida que más personas requieran productos y servicios, comprometiendo la disponibilidad de recursos ambientales para la producción de materias primas. Por lo tanto, encontrar nuevas soluciones para lograr un consumo y una producción sostenibles es de gran interés para las empresas (sin embargo, esto requiere una comprensión de los efectos ambientales y sociales de los productos y servicios).

Dentro de este contexto, la gestión de inventario es el componente de la cadena de suministros que involucra operaciones que impactan en los aspectos económicos, ambientales y sociales, ya que involucra operaciones de producción y distribución que generan contaminación significativa (por ejemplo, desperdicio de producto, acumulación de partículas contaminantes, etc.) y pérdidas económicas. debido a prácticas de gestión ineficientes.

Por lo tanto, la importancia de este trabajo consiste en el desarrollo de los siguientes modelos de inventarios:

- Modelo de control de inventarios no determinístico con integración de variables de costos asociadas a criterios DS específicos. Para ello se realizó un análisis multi-criterio profundo para identificar las variables DS más importantes asociadas con la administración de inventario. Como resultado se determinó que, aunque las prácticas de DS implican inversiones adicionales, prácticas específicas como la reutilización / reciclaje y los incentivos gubernamentales pueden aumentar los ingresos y las ganancias. Esto es importante para el desarrollo de estrategias gubernamentales y empresariales para realizar prácticas sostenibles.
- Modelo de control de inventarios no determinístico con integración de modelo de generación de ftalatos que son causantes de daños al medio ambiente y a la salud de las personas. Para ello, la generación de ftalatos se modeló a través del uso de Redes Neuronales Artificiales (ANN). Como resultado se determinó que es posible ajustar la estrategia de suministro para reducir la generación acumulativa de ftalato dentro

del almacén y, por lo tanto, reducir su impacto en la salud humana y la sustentabilidad.

Los avances de estos modelos se encuentran reportados en artículos y capítulos de libro que han sido sometidos y aceptados en medios indizados y publicados por editoriales de prestigio. También se realizaron estancias de investigación en universidades en China y Colombia. Evidencias de estos trabajos y estancias se presentan en los Anexos A-F.

Justificación

Los aspectos sustentables no han sido considerados dentro de las operaciones logísticas en la cadena de suministro. Principalmente, la producción, distribución y almacenamiento de inventarios involucran la mayor generación de contaminación asociada a la cadena de suministro.

Tan solo la identificación de los factores asociados a la sustentabilidad e inventarios no se ha realizado, incluyendo una manera de controlarlos dentro de las tareas de reabastecimiento. Para lograr un desarrollo sustentable es necesario resolver estas cuestiones.

Desde el punto de vista de investigación, resolver estas cuestiones implica el desarrollo de políticas y/o estrategias más específicas para optimizar costos en concordancia con el bienestar social y ambiental.

Objetivos Generales y Específicos

Objetivo General

Identificar factores que integren los aspectos de desarrollo sustentable dentro de las estrategias de control de inventarios, y desarrollar modelos acordes considerando incertidumbre en la demanda.

Objetivos Específicos

- Identificar las variables asociadas al desarrollo sustentable más importantes asociadas con la administración de inventario.

- Desarrollo y análisis de modelo de control de inventarios no determinístico con integración de variables de costos asociadas a criterios de desarrollo sustentable específicos.
- Modelación de generación de ftalatos, que son partículas contaminantes emitidas por la mayoría de los materiales plásticos, mediante la aplicación de Redes Neuronales Artificiales (ANNs).
- Desarrollo y análisis de modelo de control de inventarios no determinístico con integración de variables de costos asociadas a la emisión de ftalatos para su reducción.

Hipótesis

- El análisis multi-criterio es una herramienta necesaria para identificar factores de desarrollo sustentable asociados al control de inventarios.
- Existen factores económicos, sociales y ambientales que tienen asociación con las tareas logísticas de abastecimiento y control de inventarios.
- La integración de estos factores dentro de estrategias de control de inventarios se puede realizar mediante variables de costos.
- La presencia de ftalatos dentro de los inventarios representa un riesgo intrínseco en la cadena de suministro.

Preguntas de Investigación

- ¿Es requerido el análisis multi-criterio para identificar factores de desarrollo sustentable asociados al control de inventarios?
- ¿En qué ámbitos se pueden identificar estos factores?
- ¿Es posible la integración de estos factores como variables de costos dentro de estrategias de control de inventarios y obtener beneficios no solo económicos, sino también sociales y ambientales?

Beneficios

Los modelos desarrollados pueden ser utilizados por cualquier empresa que requiera el uso de inventarios y que haya una política de impuestos o incentivos relativos a la preservación del medio ambiente y responsabilidad social. También pueden ser utilizados para evaluar y mejorar la situación de costos asociados a la contaminación generada por el suministro de inventarios.

Limitaciones

Los beneficios de los modelos y análisis desarrollados se realizaron considerando instancias de casos específicos de empresas. Por lo tanto, su viabilidad para otras empresas requerirá de variables adicionales.

Estructura de la Tesis

Los trabajos de investigación realizados se presentan en los siguientes artículos:

- Artículo 1: Se presenta el análisis de factores asociados al desarrollo sustentable.
- Artículo 2: Se presenta la identificación mediante análisis multi-criterio de los factores más asociados al control de inventarios y el desarrollo sustentable. Estos factores se modelan como variables de costo para integrarse en un modelo no determinístico de control de inventarios. Resultados obtenidos con una instancia basada en datos de una empresa nacional se utilizan para evaluar la viabilidad del modelo.
- Artículo 3: Se presenta un modelo de control de inventarios para la reducción de emisiones de ftalatos.
- Artículo 4: Se presenta una estrategia de modelado de emisión de ftalatos usando Redes Neuronales Artificiales (ANNs) para reducir su acumulación en almacén. Este modelo de emisión se integra en un modelo no determinístico de control de inventarios para su aplicación.

ARTICULO 1

Identificación de Variables Asociadas al Desarrollo Sustentable dentro de la Cadena de Suministro

El presente trabajo de investigación fue aceptado para su publicación en el **2nd South American Conference on Industrial Engineering and Operations Management**, **IEOM 2020**, en Sao Paulo, Brasil. La publicación de encuentra indizada en **SCOPUS**. Evidencia de la carta de aceptación e indización se presenta en el Anexo A.

Identifying Variables Associated to Sustainable Development within the Supply Chain

Gladys Bonilla-Enríquez, Patricia Cano-Olivos, José-Luís Martínez-Flores and Diana Sánchez-Partida
Postgraduate Department of Logistics and Supply Chain Management
Universidad Popular Autónoma del Estado de Puebla, UPAEP
Puebla, PUE 72410, México
gladys.bonilla@upaep.edu.mx, patricia.cano@upaep.mx, joseluis.martinez01@upaep.mx, diana.sanchez@upaep.mx

Abstract

Currently, sustainable development (SD) is an important concern within the logistics and supply chain management (SCM) fields. SD emphasizes the balance between economic well-being, natural resources and society without compromising the quality of life of the human population. The present work is aimed to study of SD criteria to determine the economic, environmental and social aspects associated to SD within the supply chain (SC). This is performed through a multi-criterion Analytic Hierarchy Process (AHP) tool. The results led to identify nine variables, factors or aspects which are relevant to SD within SC processes. This contribution is important for specific future development of policies and supply strategies aimed to improve sustainability.

Keywords

Sustainable Development, Analytic Hierarchy Process, Supply Chain, Inventory Management

Introduction

An important aspect for developing sustainable proposals is the growth of the world population, which is expected to be 9 billion people by the year 2050 (Godfray, et al., 2010; Vorst, G.A.J., & Snels, 2014). In this context, sustainable development (SD) emphasizes the balance between economic well-being, natural resources and society without compromising the quality of life of the human population (Kahle & Gurel-Atay, 2014).

As population grows it would require more products and services, compromising the availability of environmental resources for production of raw materials (Godfray, et al., 2010). Thus, finding new solutions to achieve sustainable consumption and production is of main interest for companies, and this requires an understanding of the environmental and social effects of products and services. Within the supply chain (SC), inventory management involves operations which can impact on these aspects (Bouchery, Ghaffari, & Jemai, 2010).

However, what are the specific aspects associated to inventory management which impact on SD? This is important for the development of specific strategies to improve on SD and the integration with the different processes of the SC. Hence, this work is focused on the development of a multi-criteria analysis to identify the most significant factors of the environmental, economic and social aspects, that impact on the SD within the context of inventory supply management.

Literature Review

Studying and identifying the factors which impact on SD is a multidisciplinary task (Linton et al., 2007; Rincón et al., 2015). In this work we reviewed inventory models which have identified some sustainable variables within their formulations. Table 1 presents a general review of these models and their variables associated to sustainability.

As reviewed, the integration of factors associated to SD within inventory models has been explored to consider sustainability with the economic aspects of inventory management. However, these works have considered at most only three variables.

Current markets are changing to increase profits by looking for the economic factor in accordance to environmental and social factors for this goal (Rincón et al., 2015). Thus, more variables or factors must be identified to serve this purpose. Hence, the present work contributes with a multi-criteria analysis to identify more SD associated variables within inventory control.

Multi-criteria Analysis

For the multi-criteria analysis the Analytic Hierarchy Process (AHP) technique was considered. AHP is one of the most useful multivariate analysis techniques to reduce the randomness of subjective evaluations. Its objective is to establish the "trade-off" required in complex decision-making situations, such as the consideration of different objectives based on different criteria (Goodwin and Wright, 2004; Saaty, 2008). Thus, AHP is a MCDM technique that permits subjective and objective factors to be considered where numerical weight or priority is derived for each element of the hierarchy through a series of pairwise comparisons (Balfaqih et al., 2016).

By involving the AHP technique, the management professional can define a decision problem and break it down into a sequence of multiple levels of decision attributes. Then, the decision elements can be compared with each other (comparison of pairs) and with the assigned weights to define which represents the priorities in the decision process (Zahedi, 1986). These weights are obtained by means of the AHP “Scale of Importance” proposed by Thomas Saaty. Table 2 presents an overview of the Saaty’s scale for comparison of pairs of criteria.

Table 2. Inventory models with SD variables

Work	SD Variables
(Bonney and Jaber, 2011)	CO_2 emissions
(Hua et al., 2011)	Water footprint CO_2 emissions Cap-and-trade incentives
(Bouchery et al., 2010)	Water footprint CO_2 emissions Environmental and social criteria
(Benjaafar et al., 2013)	CO_2 emissions and taxes Cap-and-trade incentives
(Tao et al., 2010)	CO_2 emissions and taxes Cap-and-trade incentives
(Battini et al., 2014)	CO_2 emissions
(Arslan and Turkay, 2013)	CO_2 emissions Carbon tax Carbon offsets and social criteria

Table 2.2. AHP Scale of Importance for comparison of pairs

1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong or demonstrated
9	Extreme importance
	Inter medium values 2, 4, 6, 8.

Based on (Wojciech, 2015; Bouchery et al., 2010; Kylili et al., 2016) a review of the main criteria, sub-criteria and alternatives associated to SD factors was developed. These are structured following a hierarchy as presented in Table 3.

Table 3. Review of factors and alternatives associated to SD

Goal	Criteria				Alternatives					Results
	Level 1		Level 2							
	Code	Name	Code	Name						
Definition of criteria SD that impact SC	SD1	Economic	SD11	Quality	Product quality	Supplier performance	On-time delivery	Order fill rate	Customer satisfaction	Customer Satisfaction
			SD12	Efficiency	Information management costs	Loading capacity utilisation	Transport costs	Distribution costs	Inventory costs	Inventory costs
			SD13	Responsiveness	Forecast accuracy	Stock-outs	Lead time	New product time to market	New product time to first sale	Lead time
	SD2	Social	SD21	Health and safety	Number of accidents(non-employees)	Number of accidents that involve company vehicules	Wireless electronics conditions	Number of accidents(employees)	Toxic and hazardous emissions	Toxic and hazardous emissions
			SD22	Waste	Water pollution	Air pollution	solid and garbage			Water pollution
			SD23	Employees	Hours of work covered in time. Energy	Clean workplace	Good use of work tools	separation of garbage in work area	Disposal of work material	Disposal of work material
	SD3	Environment	SD31	Emissions	Level of CO_2 emission	Level of CO2 emission from infractructure	Level of CO2 emission from transport processes	Ordering carbon footprint	Holding carbon footprint	Level of CO2 emission from transport processes
			SD32	Natural resources utilization	Water consumption	Energy use	Energy consumption/revenue	Fossil fuel consumption	Energy efficiency per tonne-kilometre	Energy consumption/revenue
			SD33	Waste and recycling	Level waste	Level of landfill waste	Level of products recycled	Level of products reused	Level of bio-degradable material used	Level of products reused

Then, these criteria and alternatives were evaluated through the Saaty's scale to assess their importance within the SC and SD. For this purpose, we considered a focus group activity with a multidisciplinary team of experts.

Results

As presented in Table 4, nine alternatives or SD variables associated to the SC were identified as result of the AHP analysis. These are the following:

- Economic SD Criteria: Quality, Efficiency and Responsiveness with the SC variables Customer Satisfaction, Inventory Cost and Lead Time.
- Social SD Criteria: Health and safety, Waste, and Employees with the SC variables Toxic and Hazardous Emissions, Air Pollution and Disposal of Work Material.
- Environmental SD Criteria: Emissions, Natural Resources Utilization, and Waste and Recycling with the SC variables CO_2 Emissions associated to Transportation, Energy Consumption Revenue, and Reused Products.

Table 4. Results of the AHP: Identification of SD variables associated to the SC

Goal	Criteria				Results
	Level 1		Level 2		
	Code	Name	Code	Name	
Definition of criteria SD that impact SC	SD1	Economic	SD11	Quality	Customer satisfaction
			SD12	Efficiency	Inventory costs
			SD13	Responsiveness	Lead time
	SD2	Social	SD21	Health and safety	Toxic and hazardous emissions
			SD22	Waste	Water pollution
			SD23	Employees	Disposal of work material
	SD3	Environment	SD31	Emissions	Level of CO2 emission from transport processes
			SD32	Natural resources utilization	Energy consumption/revenue
			SD33	Waste and recycling	Level of products reused

Conclusions and Future Work

In this work nine variables or alternatives were identified as closely related to SD within the SC. In general, the economic aspects are associated to fast inventory replenishment operations (customer satisfaction, inventory costs and lead time). Thus, inventory control is a main logistic area to improve SD efforts.

On the other hand, the social aspects are associated to disposal of hazardous materials. Thus, integral strategies between companies and governmental institutions must be performed to ensure proper disposal of pollutants including recycling.

Finally, the environmental aspects are associated to improvement and reuse of energy consumption. Here, policies and technologies are important to reduce emissions.

Once that these variables have been identified the future work is focused on integrating them within inventory strategies to quantitatively reduce costs and improve SD efforts.

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ARTICULO 2

Modelando los Aspectos de Desarrollo Sustentable dentro de las Estrategias de Suministro de Inventario

El presente trabajo de investigación se encuentra en evaluación para su publicación en la revista **Modelling and Simulation in Engineering** (ISSN: **1687-5591**, **1687-5605**) la cual esta indizada en el **Emerging Sources Citation Index** del **Web-of-Science**. Evidencia del envío y estado se evaluación se presentan en el Anexo B.

Modelling Sustainable Development Aspects within Inventory Supply Strategies

[1]Gladys Bonilla-Enriquez, [2]Patricia Cano, [3]Li-Qun Peng, [4]Weihua Gan, [5]Jose-Luis Martinez-Flores, [6]Diana Sanchez-Partida

[1]gladys.bonilla@upaep.edu.mx, [2]patricia.cano@upaep.mx, [3]lq.peng@ecjtu.jx.cn, 4727595249@qq.com, [5]joseluis.martinez01@upaep.mx, [6]diana.sanchez@upaep.mx

[1,2,5,6]Universidad Popular Autonoma del Estado de Puebla A.C. Mexico, [3,4]East China Jiaotong University, China

Abstract

Nowadays inventory management is a tool that must be extended to cover all aspects of the Supply Chain (SC). One of these aspects is Sustainable Development (SD) which emphasizes the balance between economic well-being, natural resources, and society. As inventory involves the use of natural and economic resources, the integration of SD criteria is important for a more efficient and sustainable SC. In this work, the most important SD variables associated with inventory management were identified. These variables were integrated as cost elements within a non-deterministic inventory control model to include SD criteria within inventory supply strategies. Through the assessment of the proposed integrated model, it was determined that, although SD practices involve additional investments, specific

practices such as reuse/recycling and government incentives can increase revenue and profits. This is important for the development of government and business strategies to perform sustainable practices.

Keywords

Sustainable Development, Analytic Hierarchy Process, Inventory Management

Introduction

Sustainable Development (SD) has its beginnings in the 1980s when the United Nations (UN) requested an investigation about natural resources and their situation in the World in the face of the evident deterioration of the environment and natural resources. This investigation led to the report entitled "Our Common Future" [1] where the term "Sustainable Development" was defined for the first time [2]. SD integrates the concern of the resource capacity of natural systems with the social, political and economic challenges of humanity [3].

The UN and the OECD (Organization for Economic Cooperation and Development) have been working with member countries to make appropriate recommendations to reduce the impact of inefficient economic practices on the sustainable aspects of the environment and society. Within this context, the manufacture and service industries are two of the main sectors whose practices impact on the economic, environmental and social aspects.

If unattended, the impacts on these aspects is expected to worsen as more people would require products and services, compromising the availability of environmental resources for production of raw materials. Thus, finding new solutions to achieve sustainable consumption and production is of main interest for companies (however this requires an understanding of the environmental and social effects of products and services).

The distribution of materials and products throughout the SC is one of the major contributors to emissions of greenhouse compounds with high logistics costs [4]. Within this context, inventory management is the component of the SC which involves operations that impact on economic, environmental and social aspects as it involves production and distribution operations that generate significant pollution (e.g., CO_2 emissions, product waste, etc.) and economic loss due to inefficient management practices [5] [6] [7].

Hence, the importance of this work consists of the development of an inventory model to integrate SD criteria within the SC to reduce economic loss and negative impacts on SD. For the development of the model, the multi-criteria analysis was performed to identify the most significant factors of the environmental, economic and social aspects, that impact on the SD of inventory supply management.

Sustainable Inventory Models

As discussed in [8] the formulation of sustainable tools for SC require a multidisciplinary approach. Thus, the development of an inventory model with SD criteria involves multidisciplinary complexity [2] with different policies or strategies to reduce contaminants and economic loss [6]. In this review, deterministic and non-deterministic inventory models that have addressed sustainable aspects were analyzed. Table 1 presents a detailed analysis regarding the most recent models which have included some sustainable variables within their formulations.

Table 1 Review of works on inventory control with sustainable aspects (own work)

Work	Description	Variable associated to Sustainability
[5]	EOQ model with the vehicle's cost of CO_2 emissions	Economic lot size CO_2 emissions
[9]	EOQ model with the cost of CO_2 emissions associated to logistics and warehousing operations.	Economic lot size Water footprint CO_2 emissions Cap-and-trade incentives
[10]	Multi-objective EOQ model with the cost of CO_2 emissions	Economic lot size Water footprint CO_2 emissions Environmental and social criteria
[11]	EOQ model with facility location that integrates CO_2 restrictions on multiple business units	Economic lot size CO_2 emissions and taxes Cap-and-trade incentives
[12]	EOQ and EPQ models with green costs associated to warehousing and production	Economic lot size CO_2 emissions and taxes Cap-and-trade incentives
[13]	EOQ model with carbon footprint and transportation costs	Economic lot size CO_2 emissions
[14]	EOQ model with sustainability considerations	Economic lot size CO_2 emissions Carbon tax Carbon offsets and social criteria

Bonney & Jaber [5] addressed the importance of analyzing the relation of inventory to the environment and whether if it is possible to create environmentally responsible inventory planning systems. Their results suggested that ordering items in larger quantities (less

frequent orders) in contrast to the traditional economic order quantity (EOQ) model, can lead to reducing transportation costs and consequent CO_2 emissions. Furthermore, their results implied that a cost-benefit analysis can be performed by a joint cost function between the company's benefits and the inventory costs.

Hua, Cheng & Wang [9] addressed the trade in carbon emissions as an effective mechanism to reduce them. This was proposed by investigating how companies manage carbon footprints in inventory management under the carbon emission trading mechanism. They derived the optimal order quantity, and analytically and numerically examined the impacts of carbon trade, carbon price, and carbon cap on order decisions, carbon emissions, and total cost.

Bouchery et al. [10] developed a sustainable EOQ model. Their results were used to provide some insights about the effectiveness of different regulatory policies to control carbon emissions. They also used an interactive procedure which allowed the decision maker to quickly identify the best option among these solutions. The proposed interactive procedure led to a new combination of multi-criteria decision analysis techniques.

Benjaafar, Li & Daskin [11] used the EOQ and News Vendor models to study the extent to which carbon reduction requirements can be addressed by operational adjustments, as an alternative (or a supplement) to costly investments in carbon-reducing technologies. They also used these models to (a) investigate the impact of collaboration among companies within the same SC on their costs and carbon emissions, and (b) to study the incentives that companies might have in seeking such cooperation.

Tao et al. [12] researched the joint optimal decisions on lot size in a coordinated SC between a retailer and a manufacturer under the carbon tax and cap-and-trade mechanisms. The comprehensive cost-based models were proposed to capture the influence of two carbon regulatory schemes on business decisions in a coordinated two-stage SC.

Battini et al. [13] linked sustainability aspects to the raw material lot size, from the beginning of the order purchase to its delivery at the buyer's plant. Thus, the environmental impact of transportation and inventory was incorporated into the EOQ model. The approach was applied to represent data from industrial problems to assess the impact of sustainability considerations on purchasing decisions when compared to traditional approaches.

Arslan & Turkay [14] discussed on sustainable aspects for the standard EOQ model with a single item at a single location with no backlogging, constant lead times, and an unlimited supply. Also, they discussed on relaxations to consider multiple items at multiple locations with planned backorders, variable lead times, finite production rates, quantity discounts, imperfect quality, and resource constraints such as warehouse space.

As discussed, while companies have made efforts to increase profits by looking for the economic factor, research has provided insights regarding the importance of the

environmental and social factors for this goal, and currency markets are moving in that direction [2] [15]. The works reviewed in Table 1 have demonstrated that the integration of these factors within the inventory control techniques can improve on achieving sustainability without conflicting with the economic aspect of inventory management.

In this context, the proposed research contributes with an integrated inventory supply model to address a more comprehensive integration of the economic, environmental and social factors. In contrast to the works reviewed in Table 1, where up to three variables were analyzed, the present work analyzes six variables associated with SD factors. These were identified and modeled as cost elements for their integration within an inventory control technique for uncertain demand, which is a common feature in nowadays markets. The advances of this model are described in the following sections.

Determination of Variables Associated to SD Factors in Inventory Management

The determination of variables associated with the SD factors can be considered a multi-criteria task. This is because each factor is integrated by diverse decisions, costs, and resources, that affect the sustainability of the SC. Also, depending on the context, qualitative and quantitative assessment of the importance of each factor may lead to different conclusions. In the example, in [16] it was mentioned that economic factors should be the dominant ones in inventory management. On the other hand, in [14] It was considered that environmental and social factors should be considered due to the current environmental situation.

For the present work, we extended the analyses reported in [16] and [17] on metrics to measure SC performance and evaluation of sustainable supply chain indicators. The work reported in [16] concluded that the most important SC metrics related to sustainability were those presented in Table 2.

To provide a more general model we performed a focus group discussion with different professionals in the manufacturing and logistics fields for the assessment of these metrics on inventory management. In this way, the metrics presented in Table 2 were extended to those presented in Table 3.

With this information, we proceeded to determine the most important variables or metrics between each other based on a multi-criteria analysis. For the selection of the analysis tool, we studied the work reported in [17] where the AHP technique led to determine that environmental and social factors could contribute more to the sustainability of the Indian automotive industry.

Table 2 Supply chain metrics: performance indicators on sustainability [16].

Social	Economic	Environmental
Health and Safety 1. Number of accidents (employees) 2. Work conditions 3. Number of accidents (non-employees)	*Quality* 1. On-time delivery 2. Customer satisfaction 3. Order fill rate 4. Product/service availability	*Emissions* 1. Level of CO_2 emissions 2. Level of CO_2 emission from transport processes 3. Level of CO_2 emission from infrastructure
Noise 1. Noise volume 2. Time of noise emission 3. Noise emission in urban areas	*Efficiency* 1. Distribution costs 2. Total costs 3. Transport costs 4. Loading capacity utilization	*Natural Resources Utilization* 1. Energy use 2. Water consumption 3. Energy consumption / revenue
Employees 1. Employees skills 2. Employees satisfaction 3. Per cent of labor cost spent on training	*Responsiveness* 1. Stock-outs 2. Product lateness 3. Lead time 4. Forecast accuracy	*Waste and Recycling* 1. Level of waste 2. Level of products recycled 3. Level of products reused

Table 3 Supply chain metrics: performance indicators on sustainability (own work)

Social	Economic	Environmental
Health and Safety 1. Number of accidents (employees) 2. Number of accidents (non-employees) **3. Number of accidents associated to company's vehicles** **4. Wireless electronics conditions** **5. Toxic and hazardous emissions**	*Quality* 1. On-time delivery 2. Customer satisfaction 3. Order fill rate **4. Product quality** **5. Supplier performance**	*Emissions* 1. Level of CO2 emissions 2. Level of CO2 emission from transport processes 3. Level of CO2 emission from infrastructure **4. Carbon footprint – Ordering** **5. Carbon footprint - Holding**
Waste **1. Water pollution** **2. Air pollution** **3. Solid waste**	*Efficiency* **1. Information management costs** 2. Distribution costs **3. Inventory costs** 4. Transport costs 5. Loading capacity utilization	*Natural Resources Utilization* 1. Energy use 2. Water consumption 3. Energy consumption / revenue **4. Fossil fuel consumption** **5. Energy efficiency per ton-kilometer**
Employees **1. Hours efficiently worked (energy optimization)** **2. Clean workplace** **3. Good use of work tools** **4. Classification of waste in work areas** **5. Disposal of work waste**	*Responsiveness* 1. Stock-outs 2. Lead time 3. Forecast accuracy **4. New product – time to market** **5. New product – time to first date**	*Waste and Recycling* 1. Level of waste 2. Level of products recycled 3. Level of products reused **4. Level of landfill waste** **5. Level of biodegradable materials used**

AHP Analysis

For our analysis, the goal of the AHP is defined as the identification of the most important alternatives to be modeled as cost variables within the proposed inventory model. For this,

the SD factors are set as the criteria at Level 1 of the AHP structure. Then, the aspects of each factor are considered as the sub-criteria for Level 2. Finally, the alternatives from which the variables will be identified and modeled are set at Level 3 of the AHP structure. Figure 1 presents the description of the AHP model with the associated abbreviations.

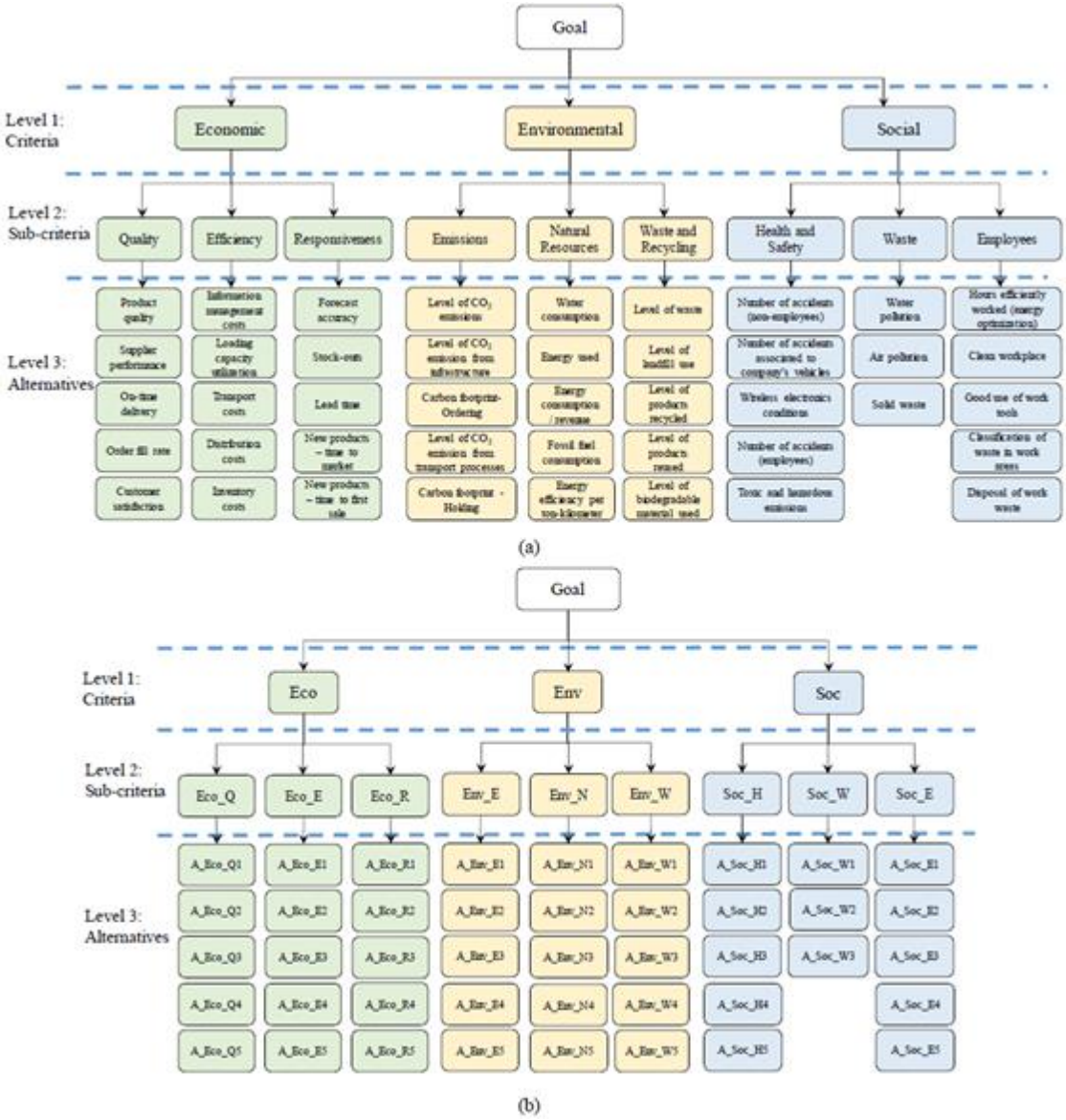

Fig. 1 Hierarchical structure of the information reported in Table 3: (a) descriptive structure, (b) abbreviated structure (own work).

Figure 2 presents the weights (i.e., importance) estimated for the criteria, sub-criteria, and alternatives defined by the AHP structure of Figure 1. These weights were estimated based on the feedback of professionals in the manufacturing and logistics fields, and the results reported in [16]. The details of the professionals' profiles are presented in Table 4.

Table 4 Profiles of eight professionals considered for the AHP analysis: SC = Supply Chain, IM=Inventory Management, SD = Sustainable Development (own work)

Field	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
SC	X	X	X	X	X	X	X	X
IM	X	X	X	X	X	X	X	X
SD	X	X		X				X

With this data, the AHP weights associated with the interactions between all criteria, sub-criteria, and alternatives were computed. These are presented in Table 5.

From Table 5 it is obtained that the Economic criterion (Eco) is the most significant with weight = 0.5936. The Environment criterion (Env) is the second most significant with weight = 0.2493, and the Social criterion (Soc) is the least significant with weight = 0.1571. For each criterion, also the most significant sub-criterion is determined. For example, for Eco, the sub-criterion Responsiveness (Eco_R) is the most significant with weight = 0.2815. Finally, for each sub-criterion, the most significant alternative is obtained (marked in bold and gray). By following the previous example, for Eco_R the most significant alternative is Lead time (A_Eco_R3) with weight = 0.1114 (see abbreviations presented in Figure 1).

Table 6 presents the interpretation of the results of the AHP analysis of Table 5. Note that these results will support the definition of variables that will be modeled as cost elements for the proposed inventory control model with SD criteria.

As presented, there are nine variables (alternatives) associated with the sustainability of inventories through all SD factors (criteria). To equally address the variables through the SD factors, the two most significant variables were selected from each criterion. These are summarized in Table 7.

Consistency: 0.0516; Weightiness to "Goal": 1.0000; λmax: 3.0536

Goal	Eco	Soc	Env	W_i
Eco	1.00	3.00	3.00	0.59
Soc	0.33	1.00	0.50	0.16
Env	0.33	2.00	1.00	0.25

Consistency: 0.0516; Weightiness to "Goal": 0.5936; λmax: 3.0536

Eco	Eco_Q	Eco_E	Eco_R	W_i
Eco_Q	1.00	2.00	1.00	0.38
Eco_E	0.50	1.00	0.25	0.15
Eco_R	1.00	4.00	1.00	0.47

Consistency: 0.0176; Weightiness to "Goal": 0.2493; λmax: 3.0183

Env	Env_E	Env_N	Env_W	W_i
Env_E	1.00	1.00	0.33	0.21
Env_N	1.00	1.00	0.50	0.24
Env_W	3.00	2.00	1.00	0.55

Consistency: 0.0036; Weightiness to "Goal": 0.1571; λmax: 3.0037

Soc	Soc_H	Soc_W	Soc_E	W_i
Soc_H	1.00	0.33	0.20	0.11
Soc_W	3.00	1.00	0.50	0.31
Soc_E	5.00	2.00	1.00	0.58

Consistency: 0.0537; Weightiness to "Goal": 0.2234; λmax: 5.2406

Eco_Q	A_Eco_Q1	A_Eco_Q2	A_Eco_Q3	A_Eco_Q4	A_Eco_Q5	W_i
A_Eco_Q1	1.00	0.14	0.17	0.20	0.11	0.03
A_Eco_Q2	7.00	1.00	0.50	0.33	0.25	0.12
A_Eco_Q3	6.00	2.00	1.00	0.50	0.33	0.17
A_Eco_Q4	5.00	3.00	2.00	1.00	0.50	0.25
A_Eco_Q5	9.00	4.00	3.00	2.00	1.00	0.42

Consistency: 0.0916; Weightiness to "Goal": 0.0523; λmax: 5.4105

Env_E	A_Env_E1	A_Env_E2	A_Env_E3	A_Env_E4	A_Env_E5	W_i
A_Env_E1	1.00	0.33	0.33	0.20	0.17	0.05
A_Env_E2	3.00	1.00	0.33	0.17	0.14	0.07
A_Env_E3	3.00	3.00	1.00	0.33	0.25	0.12
A_Env_E4	5.00	6.00	3.00	1.00	0.25	0.25
A_Env_E5	6.00	7.00	4.00	4.00	1.00	0.51

Consistency: 0.0934; Weightiness to "Goal": 0.0172; λmax: 5.4184

Soc_H	A_Soc_H1	A_Soc_H2	A_Soc_H3	A_Soc_H4	A_Soc_H5	W_i
A_Soc_H1	1.00	2.00	0.11	0.20	0.17	0.06
A_Soc_H2	0.50	1.00	0.14	0.25	0.25	0.05
A_Soc_H3	9.00	7.00	1.00	0.50	0.50	0.26
A_Soc_H4	5.00	4.00	2.00	1.00	0.50	0.27
A_Soc_H5	6.00	4.00	2.00	2.00	1.00	0.36

Consistency: 0.0787; Weightiness to "Goal": 0.0887; λmax: 5.3524

Eco_E	A_Eco_E1	A_Eco_E2	A_Eco_E3	A_Eco_E4	A_Eco_E5	W_i
A_Eco_E1	1.00	0.33	0.13	0.14	0.11	0.03
A_Eco_E2	3.00	1.00	0.20	0.14	0.13	0.05
A_Eco_E3	8.00	5.00	1.00	0.50	0.33	0.18
A_Eco_E4	7.00	7.00	2.00	1.00	0.25	0.24
A_Eco_E5	9.00	8.00	3.00	4.00	1.00	0.50

Consistency: 0.0905; Weightiness to "Goal": 0.0509; λmax: 5.4054

Env_N	A_Env_N1	A_Env_N2	A_Env_N3	A_Env_N4	A_Env_N5	W_i
A_Env_N1	1.00	0.20	0.13	0.17	1.00	0.05
A_Env_N2	5.00	1.00	0.33	0.20	4.00	0.15
A_Env_N3	8.00	3.00	1.00	0.33	3.00	0.26
A_Env_N4	6.00	5.00	3.00	1.00	5.00	0.48
A_Env_N5	1.00	0.25	0.33	0.20	1.00	0.06

Consistency: 0.0707; Weightiness to "Goal": 0.0485; λmax: 3.0735

Soc_W	A_Soc_W1	A_Soc_W2	A_Soc_W3	W_i
A_Soc_W1	1.00	3.00	4.00	0.61
A_Soc_W2	0.33	1.00	3.00	0.27
A_Soc_W3	0.25	0.33	1.00	0.12

Consistency: 0.0853; Weightiness to "Goal": 0.2815; λmax: 5.3821

Eco_R	A_Eco_R1	A_Eco_R2	A_Eco_R3	A_Eco_R4	A_Eco_R5	W_i
A_Eco_R1	1.00	0.25	0.20	2.00	4.00	0.13
A_Eco_R2	4.00	1.00	0.50	5.00	4.00	0.32
A_Eco_R3	5.00	2.00	1.00	3.00	4.00	0.41
A_Eco_R4	0.50	0.20	0.33	1.00	2.00	0.09
A_Eco_R5	0.25	0.25	0.25	0.50	1.00	0.06

Consistency: 0.0934; Weightiness to "Goal": 0.1371; λmax: 5.4184

Env_W	A_Env_W1	A_Env_W2	A_Env_W3	A_Env_W4	A_Env_W5	W_i
A_Env_W1	1.00	2.00	0.11	0.20	0.17	0.06
A_Env_W2	0.50	1.00	0.14	0.25	0.25	0.05
A_Env_W3	9.00	7.00	1.00	0.50	0.50	0.26
A_Env_W4	5.00	4.00	2.00	1.00	0.50	0.27
A_Env_W5	6.00	4.00	2.00	2.00	1.00	0.36

Consistency: 0.0956; Weightiness to "Goal": 0.0913; λmax: 5.4283

Soc_E	A_Soc_E1	A_Soc_E2	A_Soc_E3	A_Soc_E4	A_Soc_E5	W_i
A_Soc_E1	1.00	0.25	0.11	0.17	0.13	0.03
A_Soc_E2	4.00	1.00	0.25	0.20	0.17	0.07
A_Soc_E3	9.00	4.00	1.00	0.50	0.20	0.17
A_Soc_E4	6.00	5.00	2.00	1.00	0.33	0.23
A_Soc_E5	8.00	6.00	5.00	3.00	1.00	0.50

Fig. 2 Weights (importance) of criteria, sub-criteria and alternatives for the AHP analysis (own work).

Table 5 AHP weights obtained for the interactions between all criteria, sub-criteria and alternatives (own work)

Goal	Consistency Ratio	Criteria/Factors		Alternatives				
		L1	L2	L3				
Definition of SD criteria that impact inventory through the SC	0.0516	Eco 0.5936	Eco_Q 0.2234	A_Eco_Q1 0.0075	A_Eco_Q2 0.0269	A_Eco_Q3 0.0375	A_Eco_Q4 0.0568	**A_Eco_Q5 0.0947**
			Eco_E 0.0887	A_Eco_E1 0.0026	A_Eco_E2 0.0045	A_Eco_E3 0.0159	A_Eco_E4 0.0213	**A_Eco_E5 0.0443**
			Eco_R 0.2815	A_Eco_R1 0.0366	A_Eco_R2 0.0895	**A_Eco_R3 0.1114**	A_Eco_R4 0.0245	A_Eco_R5 0.0165
	0.0176	Env 0.2493	Env_E 0.0523	A_Env_E1 0.0024	A_Env_E2 0.0035	A_Env_E3 0.0133	**A_Env_E4 0.0267**	A_Env_E5 0.0065
			Env_N 0.0599	A_Env_N1 0.0028	A_Env_N2 0.0089	**A_Env_N3 0.0288**	A_Env_N4 0.0036	A_Env_N5 0.0158
			Env_W 0.1371	A_Env_W1 0.0076	A_Env_W2 0.0069	A_Env_W3 0.0368	**A_Env_W4 0.0496**	A_Env_W5 0.0362
	0.0036	Soc 0.1571	Soc_H 0.0172	A_Soc_H1 0.0010	A_Soc_H2 0.0046	A_Soc_H3 0.0009	A_Soc_H4 0.0045	**A_Soc_H5 0.0062**
			Soc_W 0.0485	**A_Soc_W1 0.0298**	A_Soc_W2 0.0057	A_Soc_W3 0.0130		
			Soc_E 0.0913	A_Soc_E1 0.0061	A_Soc_E2 0.0028	A_Soc_E3 0.0212	A_Soc_E4 0.0157	**A_Soc_E5 0.0455**

Table 6 Interpretation of results of the AHP analysis presented in Table 5 (own work)

Goal	Criteria/Factors		Final Results (most significant alternative)
	L1	L2	
Definition of SD criteria that impact inventory through the SC	Economic 0.5936	Quality 0.2234	Customer Satisfaction 0.0947
		Efficiency 0.0887	Inventory Costs 0.0443
		Responsiveness 0.2815	Lead time 0.1114
	Environmental 0.2493	Emissions 0.0523	Level of CO2 emission from transport processes 0.0267
		Natural Resources 0.0599	Energy Consumption/Revenue 0.0288
		Waste and Recycling 0.1371	Level of Products Reused 0.0496
	Social 0.1571	Health and Safety 0.0172	Toxic and hazardous emissions 0.0062
		Waste 0.0485	Water pollution 0.0298
		Employees 0.0913	Disposal of Work Waste 0.0455

Table 7 Top six SD cost variables for inventory management (own work)

Economic	Quality Lead Time	C_Q C_{LT}
Environmental	Level of CO_2 emission from transport processes Level of Products Reused	C_E C_{PR}
Social	Water Pollution Disposal of Work Waste	C_{WP} C_{DW}

Development of the SD Inventory Model

From Table 7 the most significant variables associated to SD criteria were identified as cost variables. Then, the applicability of each variable is determined to integrate these variables within the inventory model:

- Quality involves producing products with the minimum defects and the features required by the customer. Within SD criteria, achieving the highest quality supports the reduction of unnecessary waste and re-conditioning processes. As the rejection of a lot is based on the individual detection of defects, the quality cost C_Q is considered as an investment to be associated with units.
- Lead time is associated to prompt delivery of products or raw material. Inefficient delivery is associated with rejection rates of lots, unnecessary additional transportation costs and CO_2 emissions. In this regard, failure to comply with the lead time can be considered as a penalty cost C_{LT} to be associated to lots.
- CO_2 emissions are associated with transportation. If lot sizes are not adequately estimated, unnecessary additional transportation may take place which would produce CO_2 emissions. Thus, the emission cost C_E is considered as a cost associated with the transportation of lots.
- The level of products that are reused is an important sustainability aspect. This can be considered as both, incentive and cost, depending with governmental regulations. In this case, it is considered as an incentive C_{PR} which is dependent of a percentage of a lot.
- Water pollution is an aspect which is commonly omitted in the practice and it can take place in any stage of the production process (i.e., cleaning, maintenance, etc.). The water pollution cost C_{WP} is considered as a shared-cost associated with producing a unit of product.
- Disposal of work waste is also an aspect that is not considered in practice. This requires additional investment for green practices associated with proper disposal of

units which, if the quality is not absolute, is dependent on a percentage of the lot size. Thus, C_{DW} is considered as a cost associated with the lot size.

In inventory management tools there are three main costs: holding costs, ordering costs, and safety stock costs [18]. An inventory control policy must determine a balance between these costs to reduce the impact on the SC.

One of the most widely used models for inventory control under uncertainty is the Continuous Review model or (Q, R) model [19], where Q defines the optimal lot size and R the re-order point which depends on the lead time and average demand [20].

In general terms, the (Q, R) model considers the following constants and variables: Co is the order cost per lot; Ch is the holding cost per unit of product; C is the purchase cost per unit of product; p is the stock-out cost per unit of product; D is the cumulative demand for a planning horizon, and d is the average daily, weekly or monthly demand; LT is the lead time; μ_{LT} and σ_{LT} are the mean and standard deviation of the demand during the lead time; L(z) is the standard loss function; and K is the expected shortage of units of products per cycle. The economic lot quantity Q and the re-order point R then are estimated as presented in Figure 3 [21].

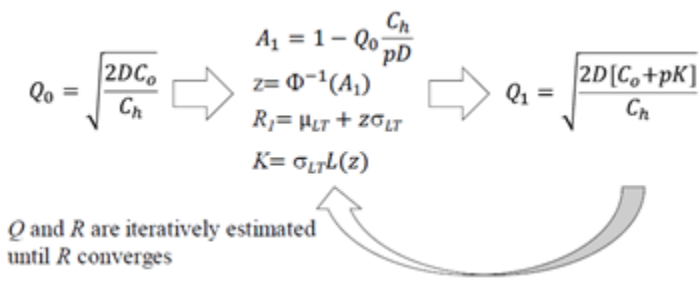

Fig. 3 Estimation process of the inventory control policy under the (Q, R) model [21].

Within the determination of the lot size, pK is equivalent to C_{LT} as it is associated with the units of products not delivered per inventory cycle. Another cost to be performed each time a lot is ordered is the transportation cost. While this can be considered within Co, the CO_2 emission costs are not frequently considered. In [21] a cost metric, based on the transportation distance and CO_2 emissions generated per kilometer, was determined as follows:

$$C_E = E_{CO2} \times dist \times t_{CO2} \quad (1)$$

where E_{CO2} is the average CO_2 emission per kilometer in grams, dist is the total traveled distance between the supplier and the warehouse, and t_{CO2} is a CO_2 emission tax per gram.

About costs associated with units of products, the quality cost C_Q can be added to Ch as an investment to keep products in conforming conditions. Also, the cost of water pollution C_{WP} can be added to the holding cost as a shared cost between the supplier and the retailer. Figure 4 presents the adapted (Q, R) model with these four SD cost variables:

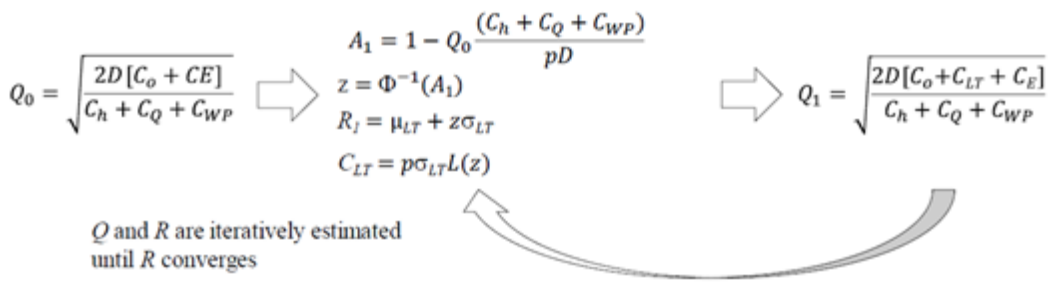

Fig. 4 Estimation process of the inventory control policy under the adapted (Q, R) model with four SD cost variables (own work)

The last two cost variables, C_{PR} and C_{DW} are considered to be dependent on the lot size. Thus, these are integrated into the total cost formulation of the (Q, R) model as described below:

TC = Total Order Cost + Total Holding Cost of Cycle Inventory + Total Holding Cost of Safety Stock + Total Shortage Cost – Total Incentive for Reuse of Products + Total Disposal Cost of Waste (2)

where:

a) Total Order Cost (TCo) = (Co×D)/Q

b) Total Holding Cost of Cycle Inventory (TCh) = (Ch×Q)/2

c) Total Holding Cost of Safety Stock (TCh_SS) = Ch×[R - μ_{LT} +σ_{LT}L(z)]

d) Total Shortage Cost (TC_shortage) = C_{LT}×(D/Q)

e) Total Incentive for Reuse of Products (TCPR) = gQ×(D/Q) = C_{PR}×(D/Q), 0 < g < 1

f) Total Disposal Cost of Waste (TCDW) = rCQ×(D/Q) = C_{DW}×(D/Q), 0 < r < 1

Assessment of the Model

The textile industry is one of the most important manufacturing industries. However, it is also one of the industries that have a more negative impact on the environment and social welfare. In this case, the proposed model can be used to reduce the costs associated with these impacts.

Let us consider the inventory production and distribution of cotton t-shirts of 250 grams. Based on the feedback obtained from two retailers, the annual demand for this product was estimated as D = 40000 units with a delivery cost of 100 USD / lot (Co).

For this product the associated cost elements of the integrated model were estimated as follows (the same methodology can be performed for different products):

- Quality is assured by the implementation of diverse processes and personnel. According to [22] the salary of a quality engineer is approximately 700 USD per month. In practice, approximately 20% of the products are sampled for quality control. This leads to approximately 0.20 × (40000 units /12 months) = 667 units per month. Considering that sampling represents approximately 30% of the activities performed by the quality engineer, the unit cost of quality CQ is estimated as (0.30×700USD)/667 units = 0.32 USD/unit.
- The unit cost C, which considers raw material and production costs, averages 3.0 USD/unit [23].
- Holding cost Ch is minimal as t-shirts do not require specific warehousing conditions. It is estimated as 0.05 USD/unit.
- Nowadays, some countries have a tax policy to regulate the contamination of water caused by textile manufacturing [24]. For this case, a t-shirt requires approximately 2,700 liters of water or 2.7 cubic meters [25]. If the task averages 0.20 USD/m3, CWP is approximated as (0.20 USD/m3) × (2.7 m3/unit) = 0.54 USD / unit.
- It is expected that manufacturers perform the appropriate measures to dispose of waste. Collecting and disposing of a batch of combined waste approximately costs 400 USD/ton [26]. In this case, a cost of 80 USD is considered for C_{DW}.
- Reused products can be considered as refurbished products. In practice, this accounts for approximately 5% of a lot. Thus, C_{PR} = 0.05×(C-refurbished cost)×Q = 0.05×(3.0-2.0) USD × Q = 0.05Q USD.
- For a stock-out unit of product, a cost p = 1.5C is considered due to loss and additional penalties. This leads to define C_{LT} = 1.5×3×K = 4.5K USD.
- To estimate C_E it is important to determine the transportation route from the (supplier) manufacturer to the seller (retailer). Figure 5 presents an example of the route with a length of 375 km. Based on the work reported in [27], for a standard vehicle with a

cargo capacity between 1.305 tons and 1.740 tons, an emission of 225 gCO_2/km is generated if diesel is consumed. This leads to an estimate a total of 85.0 $kgCO_2$ for the trip. In practice, an emission tax is established to try to reduce CO_2 emissions. In this case, a reference of 0.0020 USD per gCO_2/km, this results in C_E = (225 gCO_2/km) × (0.0005 USD per gCO_2/km) × (375 km) = 42.1875 USD.

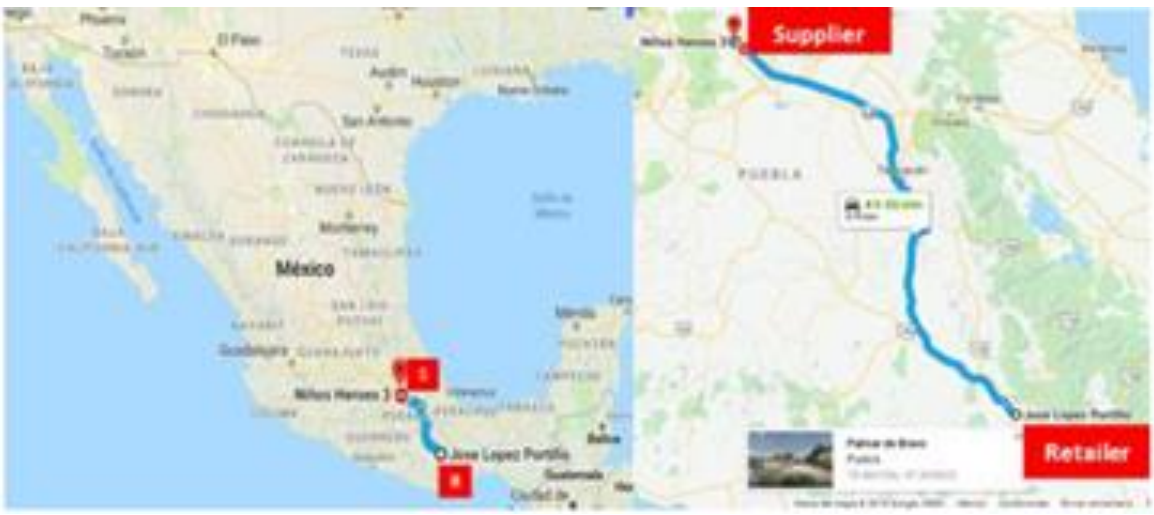

Fig. 5 Route between supplier and retailer for the estimation of C_E.

Table 8 presents the overview of the previously defined cost variables together with the additional variables for the (Q, R) model. As the lead time is defined in days, a reference of daily demand is considered for μ_{LT} and σ_{LT}. Also, as uncertain demand is considered, a coefficient of variability of 25.0% is assumed.

Table 8. Overview of cost variables for the (Q, R) model with SD criteria

D	40000	Units	C_h	0.05	USD per unit
days	360		C_O	100.00	USD per lot
d	112	Units	C_E	42.19	USD per lot
σ	28	Units	C_Q	0.32	USD per unit
LT	10	Days	C_{WP}	0.54	USD per unit
$\mu_{LT} = d \times LT$	1120	Units	C_{DW}	80.00	USD per lot
$\sigma_{LT} = \sigma\sqrt{LT}$	89	Units			
C	3.00	USD per unit			
p	4.50	USD per unit			

On the other hand, Table 9 presents the results of the iterative process for the estimation of Q and R. As presented, convergence is achieved on the 3rd iteration. With this result, where Q = 3568 units and R = 1307 units, CPR=0.05×3568 = 178.40 USD. If no costs associated with SD criteria are considered the following results are obtained: Q = 12677, R=1360. In such cases, R does not change significantly, however Q increases by a factor of 3.55. This is expected because, if SD criteria are to be considered, more care must be taken to establish the economic lot.

Table 9. Results of the (Q, R) model with SD criteria

		A	z			L(z)	$K=\sigma_{LT}L(z)$	C_{LT}
Q_0	3536	0.9821	2.10	R1	1307	0.0065	0.58	2.59
Q_1	3568	0.9820	2.10	R2	1307	0.0065	0.58	2.62
Q_2	3568	0.9820	2.10	R3	1307	0.0065	0.58	2.62
Q_3	3568	0.9820	2.10	R4	1307	0.0065	0.58	2.62
Q_4	3568	0.9820	2.10	R5	1307	0.0065	0.58	2.62
Q_5	3568	0.9820	2.10	R6	1307	0.0065	0.58	2.62
Q_6	3568	0.9820	2.10	R7	1307	0.0065	0.58	2.62

Table 10 presents the total cost analysis for both scenarios. As presented, even though the SD model has more costs due to waste disposal and order costs with CO_2 emissions and quality assurance, one significant income may come from investment in product reuse. This practice can represent a higher incentive which can compensate for the other SD costs. This is an improvement on the standard case where product reuse is not performed.

Table 10. Comparison of total annual costs of the (Q, R) model with SD criteria and the standard (Q, R) model

	(Q, R) SD Model	(Q, R) Model
TC_o=	1121.08	315.53
TC_h=	89.20	316.93
TC_h_SS=	9.38	12.00
TC_shortage =	29.36	1.36
TC_{PR}=	2000.00	
TC_{DW}=	896.86	
Annual Total Inventory Cost =	145.88	645.82

Conclusions and Future Work

An important aspect to perform SD practices is the economic effort needed for their implementation. As discussed, there are specific SD factors associated with inventory control that must be carefully managed in order to maintain economic benefit.

For this purpose, six SD cost variables were identified and modeled within the (Q, R) model for assessment of their impact and outcomes of their implementation. As discussed by other works, implementation of SD practices can increase the costs of the company significantly. This was observed in the analysis presented in Table 10. Particularly, those associated with lots (i.e., emission cost due to transportation and waste management) represent the highest costs. However, the opportunity of product reuse can lead to significant economic benefits which can compensate these costs. This can also lead to important advantages over standard practices where SD criteria are not considered.

Even though these results lead to define specific practices to obtain economic benefits from SD factors, additional work must be performed to extend on the analysis and identification of other SD criteria. In example, stored inventory can lead to emission of contaminants which can affect the workers' health. Thus, this should be considered within the lot ordering process. Also, considering other inventory models can lead to improve the applicability in other industries.

Data Availability Statement

The data used for the present work is described within the manuscript and other resources, when considered, are explicitly referenced.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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ARTICULO 3

Analizando la Presencia de Contaminantes en las Operaciones de Almacenamiento

El presente trabajo de investigación fue aceptado para su publicación en el **2nd South American Conference on Industrial Engineering and Operations Management**, **IEOM 2020**, en Sao Paulo, Brasil. La publicación de encuentra indizada en **SCOPUS**. Evidencia de la carta de aceptación e indización se presenta en el Anexo C.

Analyzing the Presence of Pollutants within Warehousing Operations

Gladys Bonilla-Enríquez, Patricia Cano-Olivos, José-Luís Martínez-Flores and Diana Sánchez-Partida

Postgraduate Department of Logistics and Supply Chain Management

Universidad Popular Autónoma del Estado de Puebla, UPAEP

Puebla, PUE 72410, México

gladys.bonilla@upaep.edu.mx, patricia.cano@upaep.mx, joseluis.martinez01@upaep.mx, diana.sanchez@upaep.mx

Abstract

Warehousing is one of the most important processes within the Supply Chain (SC). While research has been performed to optimize every operational aspect in warehousing, sustainability aspects have not been explored. Particularly, the generation of pollutants within warehousing have negative impacts on the environment and human health. This work is focused on studying the risk of polyethylene particles generated by warehoused products. Inventory control management is considered as the mean to reduce this risk through the SC in accordance to operational cost optimization. The suitability of the economic order quantity model (EOQ) is addressed for this purpose. The results of the present work support the

evidence that warehoused products represent health risks for workers through the SC and that appropriate inventory levels can reduce the associated polyethylene particles.

Keywords

Polyethylene, Warehousing, EOQ, Supply Chain, Sustainable Development

Introduction

Sustainable Development (SD) emphasizes the balance between economic well-being, natural resources and society without compromising the quality of life of the human population (Kahle & Gurel-Atay, 2014). Most of work environments have a high presence of products which contain semi-volatile organic compounds (SVOC) and/or plastic materials.

One of these compounds such as polyethylene releases phthalate particles to air, land and water. There are studies which have found that phthalate released into the air is harmful to human health (García & García, 2013; Weiss et al., 2018; Kashyap & Agarwal, 2018; Suna & Zhang, 2017). Ingestion and inhalation are the main sources of phthalate concentrations in the human body (García & García, 2013).

People can be exposed to this compound in all environments, either at plasticizing processes (García & García, 2013) or at schools, offices, homes, etc., because it is present in many products, commodities, and building materials. Hence, phthalates have been found in residential and occupational environments in high concentrations, both in air and in dust (Wormuth et al., 2008). Also, phthalate levels build up over time in indoor environments where their main sources like children's toys, cosmetics, flexible PVC flooring, and cable insulation among others are found (Kashyap & Agarwal, 2018).

Hence, minimizing the use of plastic products in construction materials and decorations in places which are regularly occupied by people might be critical for exposure reduction. The sources of phthalates which are used in building materials are more permanent in nature and their removal requires regulatory intervention while other sources such as plastic materials and foam mattresses are easier to be replaced or removed (Larsson et al., 2017; Kashyap & Agarwal, 2018).

Phthalates are known to affect the reproductive and developmental systems of humans. Human bio-monitoring studies have indicated that exposure to phthalates can cause adverse

health outcomes like fertility problems, respiratory diseases, childhood obesity and neuropsychological disorders (Katsikantami et al., 2016).

Worldwide, the following phthalates are of specific concern due to their toxic effects: Di-methylphthalate (DMP), Diethylphthalate (DEP), Di-n-butyl phthalate (DBP), Butyl-benzyl phthalate (BBP), Di (2-ethylhexyl) phthalate (DEHP), and Di-n-octylphthalate (DnOP). DEHP, DBP, BBP and DnOP have been limited to ≤0.1% in toys and childcare products by the European Union (Directive 2005/84/EC), the United States of America (Consumer Product Safety Improvement Act of 2008), China (China National Standard GB 6675, 2014), India (BIS, 2011) and Japan (Japan Toy Safety Standard ST-2002 Part 3, 2011). Just in 2015, DEHP, DBP and BBP were classified as reproductive toxins category 1B and completely banned from any application without prior approval from the European Union.

The highest concentrations of phthalates in these products have been found in the range of 300–461 g/kg for DEHP, 283–345 g/kg for DBP, 150 g/kg for DnOP and 20–33 g/kg for BBP in floorings, shower curtains, gloves, plastic sandals, plastic balls, soap packaging among others (Kashyap & Agarwal, 2018).

As this compound is present in many products and environments, warehousing may increase the cumulative concentrations associated to the stored products and the infrastructure itself. In this work, the use of inventory control strategies is proposed to reduce the phthalate concentrations in warehouses caused by the stored goods. This to reduce the health risks and environmental pollution caused by phthalates.

Modeling the Phthalate Concentrations in Warehousing

The economic order quantity (EOQ) inventory control model has been widely used to determine the lot size Q that minimizes two main operational costs associated to inventory supply:

- ordering cost (Co), which is associated to the tasks required for inventory replenishment such as transportation, import taxes, order placement processes, etc.;
- holding cost (Ch), which is associated to the tasks required to handle and maintain in good condition the inventory within the warehouse.

While Co is applied on the supply of each lot of size Q, Ch is applied on each unit of stored product. The appropriate lot size Q must minimize both costs which are associated by the following total cost formulation:

$$TC = (D/Q)C_o + (Q/2)C_h + DC, \quad (1)$$

where D is the cumulative demand through a planning horizon, and C is the products' unitary cost. Then, the appropriate lot size is estimated by the EOQ formulation which is expressed as:

$$Q = \sqrt{\frac{2DC_o}{C_h}}. \quad (2)$$

The phthalate concentrations can be modeled per unit of product. There is evidence that the highest concentrations of phthalates in products have been found in the range of 300–461 g/kg for DEHP, 283–345 g/kg for DBP, 150 g/kg for DnOP and 20–33 g/kg for BBP (Kashyap & Agarwal, 2018). Considering this information, and a standard product unit with weight Y (in kg), the phthalate quantity per stored product unit can be estimated as 0.10Y.

The average lot within the warehouse is estimated as Q/2, thus, the average phthalate concentration would be estimated as (0.10YQ)/2. Finally, phthalate accumulation requires cleaning processes which involve additional costs. A cleaning cost Cp can be associated per average stored unit.

Thus, the EOQ formulation is adapted as:

$$Q = \sqrt{\frac{2DC_o}{C_h + C_p}}. \quad (3)$$

And the total cost formulation is adapted as:

$$TC = (D/Q)C_o + (Q/2)C_h + [(0.10YQ/2)C_p](D/Q) + DC \quad (4)$$

Analysis of Phthalate Concentrations

The data presented in Table 1 was considered to estimate the behavior of the phthalate concentrations within the warehouse through a planning horizon.

Table 1. Test data

$D =$	10000 units	$C_p =$	8 USD
$C_o =$	550 USD	$Y =$	1.5 kg
$C_h =$	10 USD	$C =$	60 USD

The total cost is estimated for different lot sizes as expressed by (4). Each cost element is presented in Figure 1. As presented, the cleaning cost associated to phthalate is constant through the planning horizon. The same is observed for the purchase cost which is defined as DC.

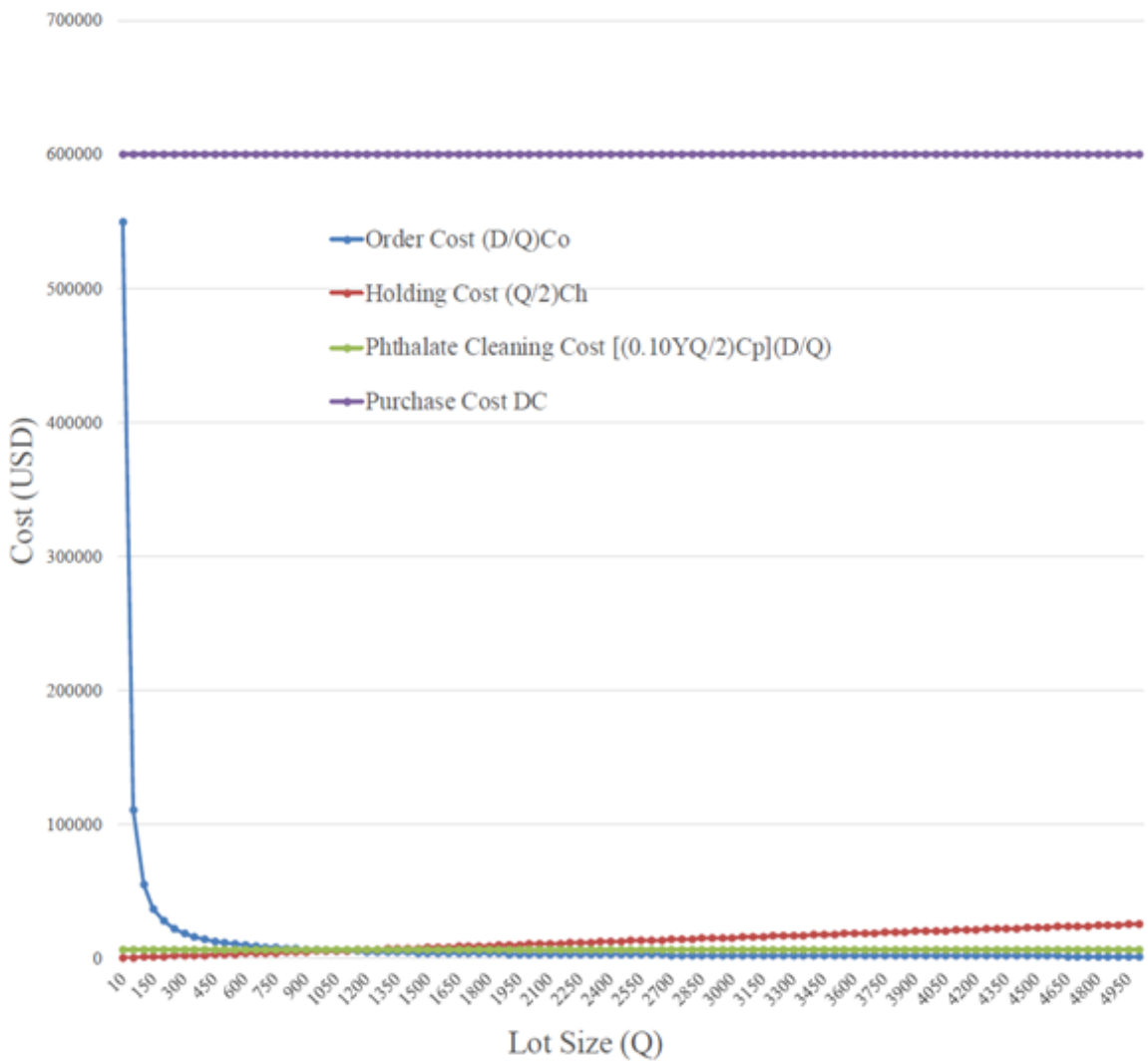

Figure 1. Cost patterns associated to ordering, holding, cleaning and purchasing through a planning horizon.

The optimal lot size estimated with the standard EOQ model (2) is equal to Q = 1,049 units. This lot size leads to a total cost TC = 610,488 USD as defined by (1). This lot size implies a phthalate concentration of:

$$\frac{0.10YQ}{2} = \frac{(0.10\times1.5\times1049)}{2} = 78.66 \text{ g}$$

In comparison, with the adapted EOQ model (3) the optimal lot size is equal to Q = 782. This lot size leads to a total cost TC = 616,944 USD as defined by (4). While this represents a minimal cost increase of (616,944/610,488 – 1)×100% = 1.05%, the associated phthalate concentration is:

$$\frac{0.10YQ}{2} = \frac{(0.10\times1.5\times782)}{2} = 58.63 \text{ g}$$

The reduction in phthalate concentration is more significant and it is approximately equal to (1-58.63/78.66)×100% = 25.46%. Thus, significant phthalate reduction can be achieved with small investment in cleaning processes.

This is very important to establish strategies to balance economic and environmental/health benefits. Particularly within the supply chain, suppliers, manufacturers and distributors are continuously exposed to phthalates which represent health risks in the long term.

Conclusions and Future Work

Minimizing the exposure to phthalate is an important task within all contexts in our society. These compounds are present in office buildings, schools, homes, food packaging, and warehouses, among others. The sources of phthalates which are used in building materials are more permanent in nature and their removal requires regulatory intervention, while other sources such as plastic materials, foam mattresses are easier to be replaced or removed (Larsson et al., 2017; Kashyap & Agarwal, 2018).

In manufacturing, where inventories are the main resource for production, supply and distribution, phthalates are continuously present. However, analyzing the phthalate concentrations associated to stored inventory has not been widely explored.

As presented, the integration of a cleaning cost factor to phthalate concentrations can reduce the size of the ordered lots and thus, the concentrations per supplied lot. Although this may represent an increase in operational costs, this may be minimal (approximately 1.05%) in comparison to the reduction in phthalate concentration (approximately 25.46%).

Thus, the proposed model can be used to support measures to control the presence of phthalate while keeping under control the operational costs. Also, the model can be used as a basis for extended or alternative models.

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ARTICULO 4

Modelando el Riesgo Latente de los Contaminantes de Polietileno dentro de la Cadena de Suministro

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Modelling the Hidden Risk of Polyethylene Contaminants within the Supply Chain

Gladys Bonilla-Enríquez, Patricia Cano-Olivos, José-Luis Martínez-Flores, Diana Sánchez-Partida, Santiago-Omar Caballero-Morales, People's Autonomous University of the State of Puebla (UPAEP), Puebla, México, gladys.bonilla@upaep.mx, gbonillae1973@gmail.com

Abstract

Inventory management is very important to support the supply chain of the manufacturing and service industries. All inventories involve warehousing, however most of the products and packages are associated to plastic which is the main generator of polyethylene (phthalate) pollution in the air and water resources. In fact, phthalate has been identified as the cause of serious health conditions and its impact within the operation of logistic processes has not been studied. In this work we perform research on the generation of phthalate as the control on these emissions is important to adjust the supply strategy to reduce the human risk exposure and contamination of the environment. For this purpose, generation of phthalate is modelled through the use of Artificial Neural Networks (ANNs) and its impact on the supply strategy is assessed through its integration within a stochastic inventory control model. As presented, it is possible to adjust the supply strategy to reduce the cumulative generation of phthalate within the warehouse and thus, reduce its impact on human health and environment sustainability.

Keywords

sustainability, phthalate contamination, inventory control, supply strategy, artificial neural networks

Introduction

An important aspect to consider for sustainable proposals is the growth of the world population, which is projected to increase from 7 to 9 billion people by the year 2050 [1, 2]. This is a challenge for companies to comply with economic, environmental and social needs.

As presented in Figure 1, to address economic, environmental and social issues, companies must address multidisciplinary issues such as:

- sustainable development (SD) which emphasizes the balance between economic well-being, natural resources and society without compromising the quality of life of the human population [3];
- supply chain (SC) management, which is focused on optimizing the flow of goods and services through the supply chain, considering the procurement of raw materials, the distribution from suppliers to manufacturers, the transformation into final products and warehousing operations, and the distribution of final products from manufacturers to retailers. This to actively streamline the company's supply-side activities to maximize customer value and gain a competitive advantage in the marketplace.
- inventory control and management, which is focused on determining the appropriate inventory replenishment strategies to ensure efficient supply and distribution of products when needed at the minimum cost.

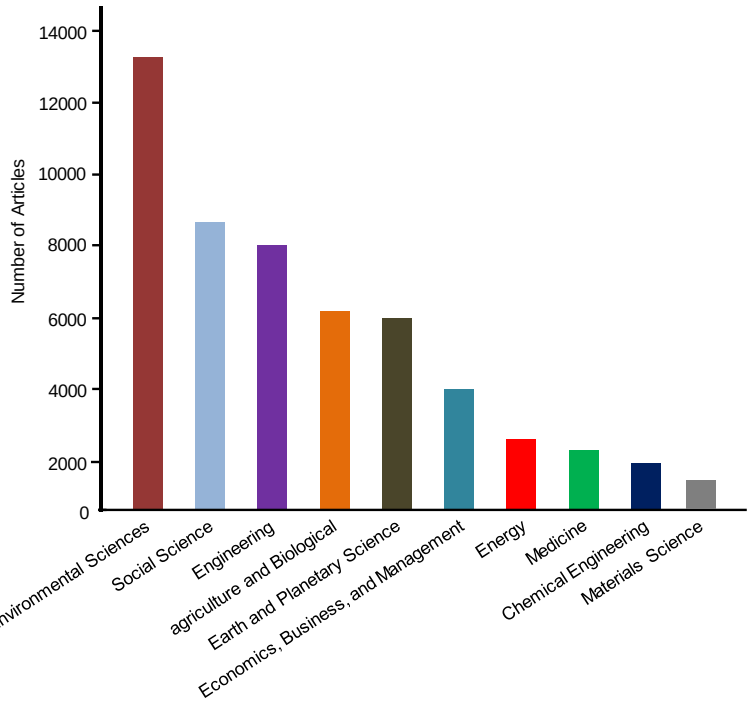

Figure 1. Interdisciplinary studies in Sustainability (adapted and edited from [4]).

Here, it is important to observe that different storage / warehousing is performed through all the SC. Just in the last decade, health risk was identified for people who work at storage facilities due to the presence of semi-volatile organic compound pollutants (SVOC) and plastic contaminants which are generated by the stored inventory [5 – 7]. In this regard, the most abundant SVOCs found among the 58 classified SVOCs are phthalates.

In general, there are six types of phthalate that have been found in outdoor and indoor air and surfaces [6, 8]. Phthalates are distributed worldwide, having a global presence ranging from the most remote regions in the Arctic to isolated rainforests of the Amazon [8, 9]. On March 2019, the United States Environmental Protection Agency (EPA) issued a priority list of 40 chemicals to determine if they are of high or low risk for human health. Phthalates were considered within the “high priority” list [6].

There are studies that have concluded that the pollution of phthalate in the air is harmful to human health [8 - 12]. Also, it has been determined that humans are exposed through ingestion, inhalation, and dermal exposure, even since intrauterine development [13, 14].

Because phthalates, which are organic lipophilic compounds, are mainly used to increase the flexibility of plastic polymers, they are frequently used in printing inks and food packages [14, 15]. Thus, exposure to phthalates mainly occurs via food ingestion [10, 14, 16 - 18].

Inhalation is the second route of exposure as phthalates degrade into particles that diffuse through the air [10]. This can be the main route of exposure for individuals who work in plasticizing processes [10] or in closed places where products with phthalate are stored for long periods of time such as in warehouses. Because phthalates are used as plasticizers in

numerous consumer products, commodities, and building materials, this compound has been found in offices, work places, homes, bathrooms, gardens, and food containers. Table 1 presents an overview of the places where people are more exposed to indoor phthalates.

Table 1. Research works performed on indoor phthalate [8].

Country	Place	Work
Japan	Home	[19]
China	Home/Office	[20]
Sweden	Pre-school	[21]
Canada	Home	[22]
USA (California)	Child care facility	[23]

As presented in Table 1, phthalates are found in human residential and occupational environment in high concentrations, both in air and in dust [24]. Thus, we can consider the facilities of industries such as warehouses, productions areas, and scrap areas, to be frequently contaminated with this compound.

In the case of products which are stored during long periods of time there are economic, environmental and health implications on SD. If the product is not used or moved (e.g., low inventory rotation) it may deteriorate and/or become obsolete, leading to economic losses. Also, a deteriorating product may release other harmful chemicals. Finally, in the social aspect there is the health risk for employees who are exposed to harmful chemicals generated by the stored products. If the management fails to determine the optimal inventory levels and lots, the environmental, social and economic risks can affect all entities through the SC.

To extend on these findings, we perform an updated review of the presence of phthalates and their effect on human health. Also, we extend on the adaptation of supply strategies to reduce these effects through the SC and on the environment. This is performed through the modelling of phthalate generation and integration within a stochastic inventory control strategy.

Pollution related to phthalates

Phthalates are chemicals which are produced in high volumes, accounting for 70% of the world consumption of plasticizers in 2014. In this context, Asia, Western Europe and the U.S.A accounted for 59%, 14% and 16% respectively of the world plasticizer consumption in 2014 [25].

More recently, phthalates accounted for 65% of the world consumption of plasticizers in 2017. Figure 2 presents the main consumers of plasticizers in 2017. However, in 2005 this amount was higher (approximately 88%), and it was forecasted to decrease to 60% by 2022. This decrease was defined to be caused by [25]:

- Rapid consumption growth of non-phthalate plasticizers, mainly terephthalates, epoxy, aliphatics, and benzoates, as replacements for DEHP and other phthalates such as DINP and BBP.
- Continued growth of non-phthalates in different applications and markets.
- Ongoing pressure from retailers and consumers to limit the use of phthalates, especially in developed regions.

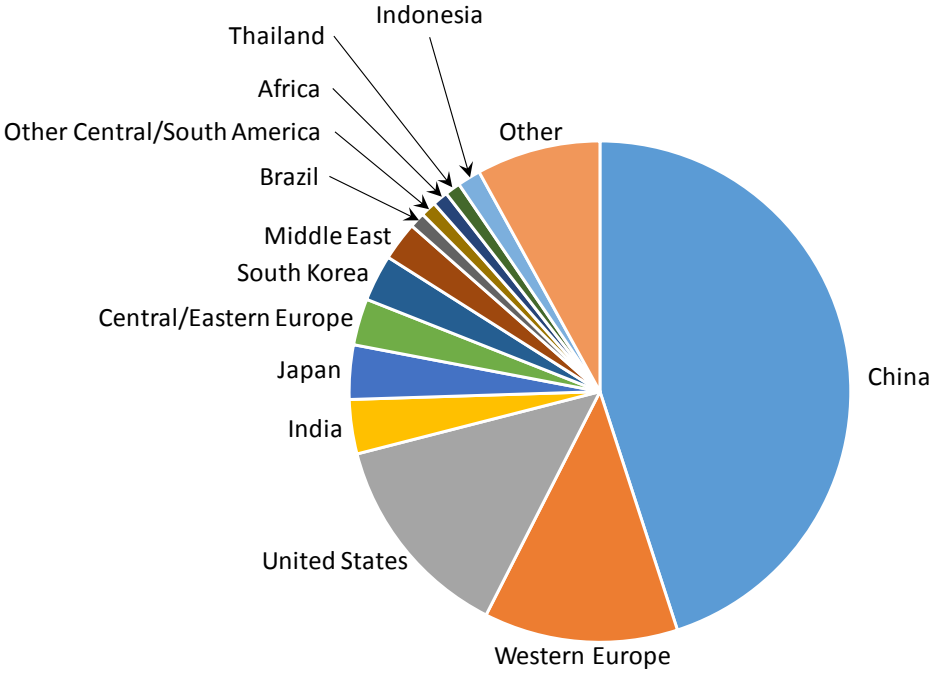

Figure 2. World consumption of plasticizers 2017 (adapted and edited from [25]).

However, consumption of phthalate plasticizers has been also forecasted to grow at an average annual rate of 1.3% during 2017–22. Today, phthalates are known pollutants, which can affect human health. Human bio-monitoring studies from 2000 to 2015 have determined that exposure to phthalates can cause adverse health outcomes like fertility problems, respiratory diseases, childhood obesity and neuropsychological disorders [9, 12, 15, 26]. Other studies found that it may disrupt fetal testicular testosterone production [27, 28].

Although many studies have researched on the impact of outdoor pollution on human health, few studies have investigated the impact of indoor pollution on the human health. Because people spend most of their time indoors, it is crucial to understand how an indoor pollutant, including household dust, affects human health [19, 29].

Indoor pollution is largely influenced by outdoor sources, but indoor activities (e.g., cooking, cleaning, and the use of consumer products and building materials) are also sources of indoor pollution [5, 11, 20, 23, 30, 31]. Phthalate levels build up over time in indoor environments where their main sources like children's toys, cosmetics, flexible PVC flooring, and cable insulation among others are found [8, 31].

Consequently, six phthalates, namely, Di-methylphthalate (DMP), Diethylphthalate (DEP), Di-n-butyl phthalate (DBP), Butyl-benzyl phthalate (BBP), Di (2-ethylhexyl) phthalate (DEHP), and Di-n-octylphthalate (DnOP) have been identified as priority pollutants by the United States Environmental Protection Agency (U.S. EPA) and the European Union (EU). Usage of DEHP, DBP, BBP and DnOP has been limited to ≤ 0.1% in toys and childcare articles by EU (Directive 2005/84/EC), US (CPSIA - Consumer Product Safety Improvement Act of 2008), China (China National Standard GB 6675, 2014), India (BIS, 2011) and Japan (Japan Toy Safety Standard ST-2002 Part 3, 2011). Recently in 2015, DEHP, DBP and BBP were classified as reproductive toxicant category 1B and completely banned from any application without prior approval in the EU.

To compare two exposure pathways, different dust particle sizes were analyzed: a breathable fraction (<5 μm) and an ingested particle fraction in the anticipated size range of skin adherence (<75 μm). Modeling of dust inhalation and ingestion showed that the daily intake of dust-bound phthalate was likely to be 2 times (inhalation) to 12 times (ingestion) higher for 21-month-old children than for adults [11].

However, phthalate exposure (phthalate metabolite levels in urine) among countries indicates the highest exposure for people living in Europe (2.1 × 102 μg/l) closely followed by USA (2.0 × 102 μg/l) and least in Asia (1.3 × 102 μg/l) [26]. In this context, there are reported discrepancies between trends of industrial consumption and human exposure [8, 14, 18].

The highest concentrations of phthalates in different items have been found in the range of 300–461 g/kg for DEHP, 283–345 g/kg for DBP, 150 g/kg for DnOP and 20–33 g/kg for BBP in floorings, shower curtains, gloves, plastic sandals, plastic balls, soap packaging among others [8, 18].

Particularly in Latin America, a phthalate presence study was carried out on beverages, where the results brought that the bottles contained average 2.62 g/kg of Di Ethyl Hexyl (FDEH) [10, 32].

Increased phthalate levels have been found in the presence of temperature changes (i.e., bottled water exposed to higher than 35°C or sunlight) [31, 33-35]. Elevated temperatures considered in various studies do not represent ambient temperature but become important in case of heating of for example food in products containing phthalates. However, the influence of temperature on phthalate emissions in dust requires further investigation.

Also, higher relative humidity has been reported to increase hydrolysis of phthalates which results in a gradual decrease in concentration of phthalates in the source as well as a sink [8]. An increase in temperature increases the emission rates of non-covalently bound phthalates from their polymer matrices resulting in a higher concentration in warmer months [30]. In good agreement, studies have found higher phthalate levels in summer in indoor as well as outdoor surfaces [8, 9].

These studies have been carried out in houses, kinder gardens, and offices in places where cleaning is regular [8, 15]. Hence, in closed places where products with this chemical are

stored, the toxicity risk is even higher. Thus, there is a necessity to reduce the effect of this chemical by storing just the optimal lots.

Where the phthalates are within logistic facilities and what can we do?

Within all industries, management is focused on solving the essential decision-making associated to product design/placement, organization, picking operations, facility layout, and distribution. These operations take place within spaces or logistic facilities such as offices, workshops, and warehouses, where workers spend most of their time (40 - 60 hours per week). In these closed places, airflow distributes many impurities, including phthalates which can be ingested or inhaled [9, 14, 15, 32].

The importance of airflow has been studied when designing the warehouses because phthalates are not chemically bound to the plastics and they can leach into water, indoor dust, and air, resulting in cyclic exposure [14, 36]. In these closed spaces, the stored products can spread out this pollutant which may be increased based on temperature conditions. In this situation, co-workers inhale phthalates during labor time [14, 15] and contamination by phthalates (more than 100 mg/L) has been reported to be common in heavily industrialized areas.

Additional to airflow, inventory movement is another aspect to contribute to phthalate accumulation. As inventory commonly stores packaged products (bottles, bags, paper and boards packaging, etc.) if it remains static it can generate more dust and particles [9-11, 32]. Based on this information, Figure 3 presents the theoretical cycle of emission of phthalate within the facilities present in the SC.

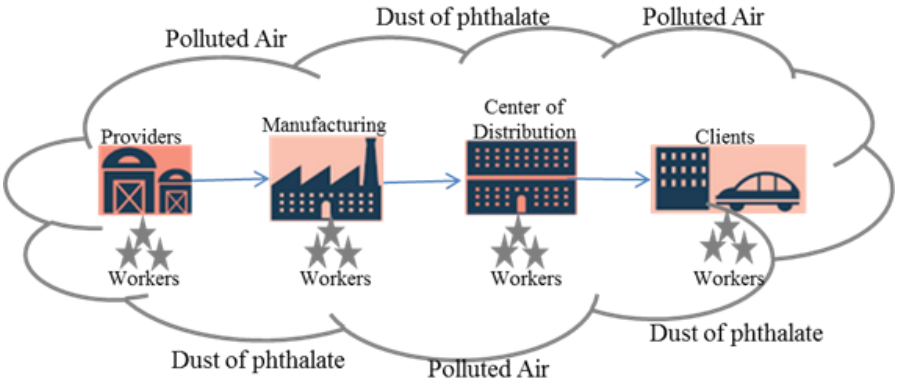

Figure 3. Theoretical exposure of phthalates through the air (own work).

From this cycle of emission, we can identify that inventory movement through the facilities is dependent of the inventory turnover which can be optimized through the use of proper supply strategies. This task requires consideration of real market conditions which are characterized by demand of products with large variability.

Thus, stochastic demand patterns are a main aspect to consider within the strategies to reduce phthalate accumulation / emission and improve inventory turnover.

Modelling the phthalate emission within the supply strategy

Within logistic management of inventories there are strategies to improve inventory turnover and reduce static inventory and inventory levels. As an example, consider the cost equation of the continuous review strategy to determine the optimal lot size Q of inventory to reduce operational costs [37]:

$$E(C) = \frac{DC_o}{Q} + \frac{C_h Q}{2} + C_h[R - \mu_{LT} + \sigma_{LT} L(z)] + \frac{pAD}{Q} \ , \tag{1}$$

where C_o is the order cost per lot, C_h is the holding cost per unit within Q, p is the unit stock-out cost, D is the cumulative demand through a planning horizon, μ_{LT} and σ_{LT} are the mean and standard deviation of the demand during the lead time, $L(z)$ is the standard loss function with $z = \Phi^{-1}(1 - (QC_h)/(pD))$, and A is the expected stock-out units per inventory cycle ($=\sigma_{LT} L(z)$)

As emission of phthalates is associated to the size of the warehoused lot (i.e., Q), this aspect can be integrated into this strategy to determine a more appropriate lot size. For this purpose, consider that $f(t)$ is the general emission function of phthalate through time t per stored unit and H is the maximum safety level of phthalate within a closed space. In this case, the cumulative generation of phthalate through time associated to the average stored lot Q then can be estimated as:

$$\frac{Q}{2}\int_0^t f(t). \tag{2}$$

To determine the optimal lot size considering the minimization of phthalate, the following mathematical formulation can be defined:

$$Minimize\ E(C) = \frac{DC_o}{Q} + \frac{C_h Q}{2} + C_h[R - \mu_{LT} + \sigma_{LT} L(z)] + \frac{pAD}{Q} \tag{3}$$

Subject to:

$$\frac{Q}{2}\int_0^t f(t) \leq H, \tag{4}$$

$$Q \in \Re^+, \tag{5}$$

where (3) is the objective function, (4) is the restriction to ensure that the lot size does not lead to increase the cumulative phthalate over a permissible limit H, and (5) is the restriction over Q to consist of real positive values.

Additionally, periodic surface cleaning and handwashing has been identified as appropriate measures to reduce accumulation and exposure to phthalate [38]. Particularly for co-workers, the use of protective wear within warehouses is highly recommended.

Research performed to model *f(t)* has led to different proposals and values. This is understandable due to the different considered environments and contexts (i.e., home, office, plants, etc.). As we are concerned regarding the applicability of the model in the supply strategy, we propose a general emission model that can be adapted to different contexts by the use of Artificial Neural Networks (ANNs).

The advantage of ANNs to model data when compared to standard regression approaches is that regression only performs well if the regression equation fits very closely the considered data. In contrast, the use of hidden neuron layers provides ANNs with more flexibility to fit any data pattern.

As input data for modelling we considered the estimations presented by [39, 40] regarding phthalate concentrations (μg/m^3) generated by PVC and different materials in indoor spaces. Figure 4 presents a review of the approximate concentration values reported in [39, 40].

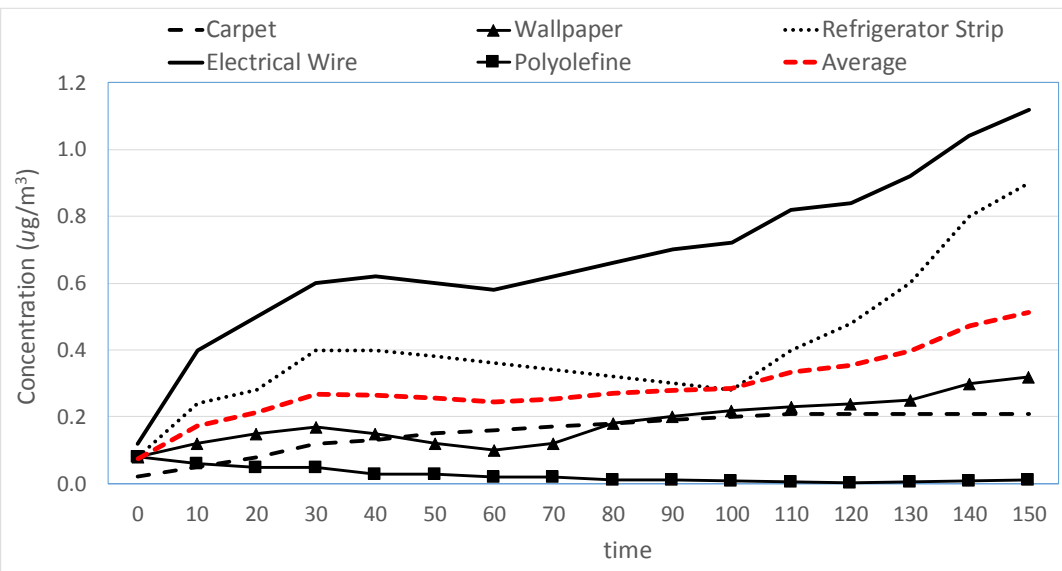

Figure 4. Review of concentration patterns through time on different indoor spaces and materials (own work based on data reported in [39, 40]).

As presented in Figure 5.4, significant differences are found depending on the considered material and environment. For assessment purposes of the proposed model, we consider an average concentration which is also presented in Figure 4.

For modelling through ANNs it was important to match the concentration data based on m^3 to stored units in the warehouse. To accomplish this task the following variables are considered:

V_Q = volume (m^3) associated to each product unit;

E_t = cumulative emission per m^3 associated to a product unit at a time t.

Thus, (4) can be represented as:

$$\frac{Q}{2}\int_0^t f(t) \leq H \;\rightarrow\; \frac{Q}{2} \times V_Q \times E_t \leq H, \tag{6}$$

where Et is obtained through the regression achieved with ANNs.

For this purpose, we considered the Nonlinear Autoregressive with External (Exogeneous) Input (NARX) [41] time series ANN. For time series modelling, the NARX ANN can associate the current value of a time series to (a) past values of the same series; and (b) current and past values of an external series that influences the series of interest [42]. Thus, it can predict a series *y(t)* given *n* past values of *y(t)* and another series *z(t)*. This is leads to more accurate modelling when compared to Nonlinear Input-Output ANNs.

In this case, *z(t)* is the time series (in days) and *y(t)* is the cumulative average concentration (ug/m^3). Implementation of the NARX ANN was performed with the MATLAB R2016a software on a DELL laptop computer with Intel i7 CPU at 2.06 GHz and 8MB RAM. Table 2 and Figure 5 present the details of the ANN and the training algorithm.

Table 2. Training details of the NARX ANN.

Hidden Layers	2
Neurons	10
Training Method	Levenberg-Marquardt

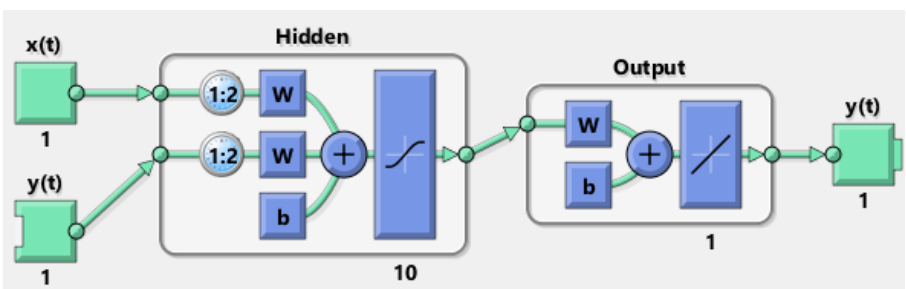

Figure 5. Structure details of the NARX ANN.

Figure 6 presents the comparison of the performance of the ANN for t=0:360 days and the original average data with t=0:150 (as presented in Figure 5.4). It can be observed that the prediction of the ANN closely resembles the available data used for training within the period from t=0:150 days.

With the estimated concentrations we can proceed to assess the model described by (3)-(6) with a supply example. This assessment considers two scenarios: (a) scenario with no control on the phthalate concentrations, and (b) scenario with restriction *H* on the phthalate concentration per inventory cycle. These details of this assessment are presented in the following section.

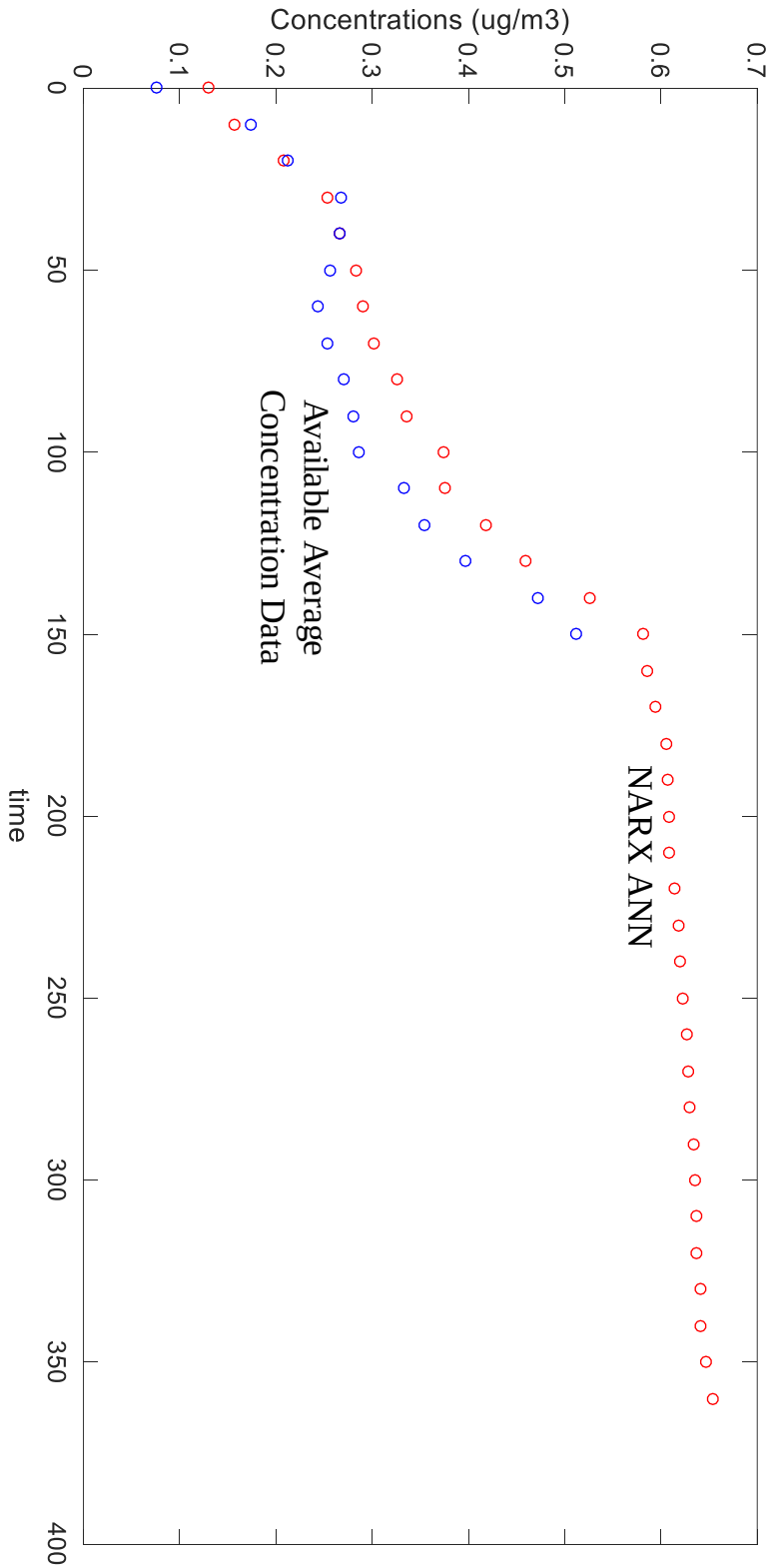

Figure 6. Performance of the NARX ANN for extended time periods.

The economic and environmental impacts of phthalate emission control within the supply strategy

In the previous section we provided the means for phthalate concentration modelling through ANNs and its integration within an inventory supply strategy. To address the impact of this strategy we proceed to quantitatively evaluate the economic and environmental results on an inventory supply case.

Table 3 presents the numerical data of the considered supply case (this is, the set of values for (3) - (6)). This case considers the supply strategy over a 5-years period (1800 days with a cumulative demand of 60000 units). Each unit of product is assumed to have a standard size of 0.50 m× 0.50 m× 0.50m = 0.125 m^3. At t = 250 days the cumulative concentration is expected to be at 0.61 ug/m^3 and an estimate of H = 50.0 ug/m^3 is considered as a safety limit.

Table 3. Assessment data for the integrated model with phthalate emission.

Planning Horizon =	1800 days	D =	60000 units
C_o =	340 USD	Daily Demand =	D/1800 = 60000/1800 = 34 units
C_h =	12 USD	Daily Standard Deviation =	8 units
Lead Time =	180 days	p =	45 USD
V_Q =	0.125 m^3	t =	250 days
H =	50.0 ug/m^3	E250 =	0.61 ug/m^3

With this data, we procced to evaluate two scenarios:

a) Scenario 1: determination of the supply lot size Q is performed based only on the economic aspects of (3) without the phthalate emission factor.
b) Scenario 2: determination of the supply lot size Q is performed based on the economic aspects of (3) and considering the phthalate emission factor defined by (4) and (6).

Both scenarios were solved with the Solver Tool ® of MS Excel. The results which were obtained are presented in Table 4.

Table 4. Results of the integrated model with the assessment data.

Scenario	1	2
Objective Function	$Minimize\ E(C) = \frac{DC_o}{Q} + \frac{C_h Q}{2} + C_h[R - \mu_{LT} + \sigma_{LT} L(z)] + \frac{pAD}{Q}$	
Restrictions	Q>0	Q>0 $\frac{Q}{2} \times V_Q \times E_t \leq H$
Q	1880	1312
R	6257	6271
E(C)	25,646	27,088
$\frac{Q}{2} \times V_Q \times E_t$	71.66 *u*g/m^3	50.00 *u*g/m^3

If no restriction on the concentration of phthalate is considered, then large lots can be ordered (Q= 1880 units). This minimizes the overall operating costs (E(C) = 25,646). Also, these large lots can lead to cumulative phthalate concentration up to 71.66 *u*g/m^3.

If the restriction on the cumulative phthalate is considered, a reduction of 30.22% can be obtained (50.00 *u*g/m^3). However, as this is dependent of the lot size, smaller lot sizes are required (Q=1312 units). As consequence, this can lead to an increase in operational costs up to 5.62% (E(C) = 27,088).

These findings are very important to establish strategies to balance economic and environmental/health benefits. Particularly within the supply chain, suppliers, manufacturers and distributors are continuously exposed to phthalates and thus, represent health risks in the long term.

Conclusions

Minimizing the exposure to phthalate is an important task within all contexts in our society. These chemicals are present in office buildings, schools, homes, vehicles, food packaging, and warehouses, among others. The sources of phthalates which are used in building materials are more permanent in nature and their removal requires regulatory intervention, while other sources such as plastic materials, foam mattresses are easier to be replaced or removed [8].

In manufacturing, where inventories are the main resource for production, supply and distribution, phthalates are continuously present. However, determining the possible risk based on phthalate concentration through time in warehousing facilities is not widely studied.

In this work we explored on this aspect and proposed an integrated inventory control model with phthalate emission factor. Also, we addressed phthalate emission through the use

of ANNs to estimate concentrations for different time periods where are commonly considered during inventory control strategies.

As presented, if phthalate concentrations are not considered, these can be increased in the presence of large lots, which frequently decrease operational costs associated to inventory ordering / re-supply.

If considering the phthalate concentration restriction to a certain permissible level, this can lead to reduce the ordering lots and thus, to increase the operational costs. Nevertheless, the cost increase may be minimal in comparison to the reduction in phthalate concentration.

Thus, the proposed model can be used to support measures to control the presence of phthalate while keeping, also under control, the operational costs. Also, the model can be used as a basis for extended or alternative models considering the costs of cleaning tasks and the risk of specific health complications in certain environments/contexts.

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CONCLUSIONES Y TRABAJO FUTURO

Un aspecto importante para realizar prácticas de DS es el esfuerzo económico necesario para su implementación. Como se discutió, hay factores DS específicos asociados con el control de inventario que deben manejarse cuidadosamente para mantener el beneficio económico.

Para este propósito, inicialmente se identificaron y modelaron seis variables de costo DS dentro del modelo (Q, R) para evaluar su impacto y los resultados de su implementación. Como se discutió en esta etapa de la investigación, la implementación de prácticas de DS puede aumentar significativamente los costos de la empresa. Esto se observó en el análisis presentado en los Artículos 1 y 2. En particular, los asociados con los lotes (es decir, el costo de emisión debido al transporte y la gestión de residuos) representan los costos más altos. Sin embargo, la oportunidad de reutilizar el producto puede generar importantes beneficios económicos que pueden compensar estos costos. Esto también puede conducir a importantes ventajas sobre las prácticas estándar donde no se consideran los criterios DS.

De manera consecuente, otro aspecto relacionado con DS es la generación de contaminantes. Dentro del este aspecto, un contaminante que se está identificado como de potencial peligro para la salud humana y ambiental son los ftalatos. Minimizar la exposición al ftalato es una tarea importante en todos los contextos de nuestra sociedad. Estos productos químicos están presentes en edificios de oficinas, escuelas, hogares, vehículos, envases de alimentos y almacenes, entre otros. En la cadena de suministros, en donde los inventarios son el principal recurso para la producción, el suministro y la distribución, los ftalatos están continuamente presentes. Sin embargo, la determinación del posible riesgo basado en la concentración de ftalato a lo largo del tiempo en las instalaciones de almacenamiento no se estudia ampliamente.

En los Artículos 3 y 4 se exploró este aspecto y se propuso un modelo de control de inventario integrado con factor de emisión de ftalato. Además, se abordó la emisión de ftalatos mediante el uso de ANNs para estimar las concentraciones para diferentes períodos de tiempo que se consideran durante las estrategias de control de inventario.

Tal como se presentó, si no se consideran las concentraciones de ftalato, estas pueden incrementarse en presencia de lotes grandes, que con frecuencia disminuyen los costos operativos asociados con el pedido de inventario / reabastecimiento.

Si se considera la restricción de la concentración de ftalato a un cierto nivel permisible, esto puede conducir a reducir los lotes de pedido y, por lo tanto, a aumentar los costos operativos. Sin embargo, el aumento de costos puede ser mínimo en comparación con la reducción en la concentración de ftalato.

Por lo tanto, el modelo propuesto en los Artículos 3 y 4 se puede utilizar para respaldar medidas para controlar la presencia de ftalato mientras se mantienen, también bajo control, los costos operativos. Además, el modelo puede usarse como base para modelos extendidos o alternativos considerando los costos de las tareas de limpieza y el riesgo de complicaciones de salud específicas en ciertos entornos / contextos.

Aunque estos resultados conducen a la definición de prácticas específicas para obtener beneficios económicos de los factores DS, se debe realizar un trabajo adicional para ampliar el análisis e identificación de otros criterios y contaminantes asociados a DS. Por ejemplo, el inventario almacenado puede generar emisiones de otros contaminantes que pueden afectar la salud de los trabajadores, incluyendo riesgos de explosión. Por lo tanto, esto debe considerarse dentro del proceso de pedido de lotes. Además, considerar otros modelos de inventario puede conducir a mejorar la aplicabilidad en otras industrias.

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ANEXO A

2nd South American Conference on Industrial Engineering & Operations Management
São Paulo, Brazil, April 14-16, 2020
IEOM Society Venue: Maksoud Plaza Hotel, São Paulo

March 09, 2020

Gladys Bonilla-Enríquez, Patricia Cano-Olivos, José-Luis Martínez-Flores and Diana Sánchez-Partida
Postgraduate Department of Logistics and Supply Chain Management
Universidad Popular Autónoma del Estado de Puebla, UPAEP
Puebla, PUE 72410, México

Subject: Acceptance of Paper and Invitation to Attend the 2nd South American Conference 2020

ID 376: Identifying Variables Associated to Sustainable Development within the Supply Chain

Dear Authors:

On behalf of the organizing committee, we are delighted to inform you that your paper has been accepted for oral presentation at the 2nd South American Conference in Sao Paulo, Brazil during April 14-16, 2020. Each paper was subject to peer reviewed by at least two referees. Full papers will be indexed in SCOPUS. Attending the conference and presentation of the paper is required.

IEOM Society has become a premier international platform and forum for academics, researchers, scientists and practitioners to exchange ideas and provide insights into the latest developments and advancements in the fields of Industrial Engineering and Operations Management. IEOM has organized international conferences in Dhaka (2010), Kuala Lumpur (2011), Istanbul (2012), Bali (2014), Dubai (2015), Orlando (2015), Detroit (2016), Kuala Lumpur (2016), Rabat (2017), Bristol, UK (2017), Bogota (2017), Bandung (2018), Paris (2018), Washington, DC (2018), Pretoria (2018), Bangkok (2019) and Pilsen (2019). The IEOM Society International (a 501(c)(3) nonprofit organization) is now organizing the 2nd South American IEOM Conference in Sao Paulo, Brazil.

IEOM is expecting another exciting event in Sao Paulo. Some of the events and activities that are planned include: outstanding keynote speakers, global engineering education track, industry solutions track, technical presentations, women in industry and academia track, undergraduate and graduate student paper competitions, panel sessions, recognition and awards, and exhibition.

You will see the IEOM 2020 Sao Paulo Conference as a great value added event. Your participation is highly appreciated. If you have any question, please contact Dr. Taufiq Islam, Operations Manager at info@ieomsociety.org.

We look forward to seeing you in Sao Paulo.

Regards,

Prof. M.Sc. Vitor Mendes Caldana
Depto. de Eletroeletrônica, IFSP – Instituto Federal de São Paulo – Campus Sorocaba, Santana de Parnaíba, SP, Brazil
Phone: +55 11 983950016
Email: vitor.caldana@ifsp.edu.br

Dr. Ahad Ali - Conference Co-Chair
Associate Professor and Director of Industrial Engineering
Lawrence Technological University, Michigan, USA
Executive Director – IEOM Society International
ahad@ieomsociety.org

Sponsors and Partners

IEOM Society International, 21415 Civic Center Dr., Suite 217, Southfield, Michigan 48076, USA, p.1-248-450-5660, e. info@ieomsociety.org

ANEXO B

5232814: Acknowledging Receipt Recibidos ×

Modelling and Simulation in Engineering <harathi.sivaraman@hindawi.com> vie., 25 de oct. de 2019 14:59
para mí, harathi.sivaraman, patricia.cano, lq.peng, 727595249, joseluis.martinez01, diana.sanchez

inglés > español Traducir mensaje Desactivar para: inglés ×

Dear Dr. Bonilla-Enriquez,

The Research Article titled "Modelling Sustainable Development Aspects within Inventory Supply Strategies," by Gladys Bonilla-Enriquez, Patricia Cano, Li-Qun Peng, Weihua Gan, Jose Luis Martinez-Flores and Diana Sanchez-Partida has been received and assigned the number 5232814.

All authors will receive a copy of all the correspondences regarding this manuscript.

Thank you for submitting your work to Modelling and Simulation in Engineering.

Best regards,

--
****
Harathi Sivaraman
Editorial Office
Hindawi
http://www.hindawi.com
****

Hindawi Manuscript Tracking System

Gladys Bonilla-Enriquez Update Account Logout

Submit a Manuscript Author Activities

This article is temporarily locked as we migrate it to a new review system. The article will be accessible again in the next few days, as soon as we ensure the migration was successful. We apologize for the inconvenience.

5232814.v1 (Research Article)

Title	Modelling Sustainable Development Aspects within Inventory Supply Strategies
Journal	Modelling and Simulation in Engineering
Issue	Regular
Manuscript Number	5232814 (Research Article)
Submitted On	2019-10-25
Author(s)	**Gladys Bonilla-Enriquez**, Patricia Cano, Li-Qun Peng, Weihua Gan, Jose Luis Martinez-Flores, Diana Sanchez-Partida
Editor	Jing-song Hong
Status	Under Review

ANEXO C

IEOM **IEOM Society**

2nd South American Conference on Industrial Engineering & Operations Management

São Paulo, Brazil, April 14-16, 2020

Venue: Maksoud Plaza Hotel, São Paulo

March 09, 2020

Gladys Bonilla-Enriquez, Patricia Cano-Olivos, José-Luis Martínez-Flores and Diana Sánchez-Partida
Postgraduate Department of Logistics and Supply Chain Management
Universidad Popular Autónoma del Estado de Puebla, UPAEP
Puebla, PUE 72410, México

Subject: Acceptance of Paper and Invitation to Attend the 2nd South American Conference 2020

ID 370: Analyzing the Presence of Pollutants within Warehousing Operations

Dear Authors:

On behalf of the organizing committee, we are delighted to inform you that your paper has been accepted for oral presentation at the 2nd South American Conference in Sao Paulo, Brazil during April 14-16, 2020. Each paper was subject to peer reviewed by at least two referees. Full papers will be indexed in SCOPUS. Attending the conference and presentation of the paper is required.

IEOM Society has become a premier international platform and forum for academics, researchers, scientists and practitioners to exchange ideas and provide insights into the latest developments and advancements in the fields of Industrial Engineering and Operations Management. IEOM has organized international conferences in Dhaka (2010), Kuala Lumpur (2011), Istanbul (2012), Bali (2014), Dubai (2015), Orlando (2015), Detroit (2016), Kuala Lumpur (2016), Rabat (2017), Bristol, UK (2017), Bogota (2017), Bandung (2018), Paris (2018), Washington, DC (2018), Pretoria (2018), Bangkok (2019) and Pilsen (2019). The IEOM Society International (a 501(c)(3) nonprofit organization) is now organizing the 2nd South American IEOM Conference in Sao Paulo, Brazil.

IEOM is expecting another exciting event in Sao Paulo. Some of the events and activities that are planned include: outstanding keynote speakers, global engineering education track, industry solutions track, technical presentations, women in industry and academia track, undergraduate and graduate student paper competitions, panel sessions, recognition and awards, and exhibition.

You will see the IEOM 2020 Sao Paulo Conference as a great value added event. Your participation is highly appreciated. If you have any question, please contact Dr. Taufiq Islam, Operations Manager at info@ieomsociety.org.

We look forward to seeing you in Sao Paulo.

Regards,

Prof. M.Sc. Vitor Mendes Caldana
Depto. de Eletroeletrônica, IFSP – Instituto Federal de São Paulo – Campus Sorocaba, Santana de Parnaíba, SP, Brazil
Phone: +55 11 983950016
Email: vitor.caldana@ifsp.edu.br

Dr. Ahad Ali - Conference Co-Chair
Associate Professor and Director of Industrial Engineering
Lawrence Technological University, Michigan, USA
Executive Director – IEOM Society International
ahad@ieomsociety.org

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ANEXO D

IntechOpen

CERTIFICATE OF INVITATION

September 12, 2019, London

To Whom it May Concern,

IntechOpen is one of the pioneers of Open Access book publishing. We published our first open access book, Cutting Edge Robotics, in 2005. At IntechOpen today, we are committed to working with organizations and people who care about scientific discovery, to putting the academic needs of the scientific community first, and to providing an Open Access environment where authors can maximize their contribution to scientific advancement. By opening up access to the world's scientific research articles and book chapters, we aim to facilitate greater opportunity for collaboration, scientific discovery and progress.

When selecting authors to contribute to our publications, we apply a rigorous set of criteria to ensure quality. We invite only experts within a particular subject area based on:

1. A proven, documented record of academic accomplishment
2. Relevance, quality and impact of past publications
3. Knowledge of the subject area

After successfully meeting these criteria, Ph.d. Bonilla-Enriquez has been invited to participate in the book project under the working title "Applications of Artificial Intelligence in Process Industry Automation, Heat and Power Generation and Smart Manufacturing", ISBN 978-1-78985-878-5.

With my best wishes,

Anke Beck,
CEO, IntechOpen

IntechOpen ESTD 2005 LONDON · UNITED KINGDOM

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P: +44 (0) 20 3972 6202 / W: intechopen.com / M: info@intechopen.com

IntechOpen - Thank you for Submitting your Full Chapter - Applications of Artificial Intelligence in Process Industry Automation, Heat and Power Generation and Smart Manufacturing Recibidos ×

Ms. Romina Skomersic <romina.s@intechopen.com> dom., 5 ene. 01:52

para mí, Patricia, José, Diana, Santiago

inglés > español Traducir mensaje Desactivar para: inglés ×

Dear Ph.D. Bonilla-Enriquez,

Thank you very much for submitting your full chapter to our upcoming title, "Applications of Artificial Intelligence in Process Industry Automation, Heat and Power Generation and Smart Manufacturing".

Your chapter is now with the Editor for review.

Expected review results: Within 30 days from the date of your full chapter submission

Upcoming Promotion!

I would also like to take this opportunity to inform you of an upcoming promotion. If your full chapter is accepted for publication, you can pre-order your book and get one print copy for free on the first order you place. All contributing authors can benefit from this exclusive promotion available only through your Author Panel.

If you have any additional questions or concerns, please do not hesitate to contact me.

Cordially,

Ms. Romina Skomersic
Author Service Manager

IntechOpen
10 Lower Thames Street, London, EC3R 6AF, UK
+44 20 8089 5700
www.intechopen.com

ANEXO E

華東交通大學
EAST CHINA JIAOTONG UNIVERSITY

Address: 808#Shuanggangdong Rd., Nanchang, China 330013

Dear Dr. Gladys Bonilla Enríquez:

On behalf of the research group for Logistics and Supply Chain Management in the College of Transportation and Logistics, East China Jiaotong University, I am pleased to invite Dr. Gladys Bonilla Enríquez, from Universidad Popular Autonoma del Estado de Puebla (UPAEP) in Mexico to join our group as a visiting scholar from 1st, September 2017 to 17th, January 2018.

Gladys Bonilla Enríquez research works will be under the supervision by advisor, Professor Cheng Zhang at ECJTU, China. For her research, she can use facilities and resources in our laboratory, which include computers infrastructure.

If you have any questions, please do not hesitate to contact me by email 727595249@qq.com.

Regards

Professor Cheng Zhang
Research Group for Logistics and Supply Chain Management
College of Transportation and Logistics
East China Jiaotong University,

由 扫描全能王 扫描创建

ANEXO F

Universidad Tecnológica de Pereira

CARTA DE ACEPTACIÓN

10 de junio 2019.

Estimada GLADYS BONILLA ENRIQUEZ,

Me complace informarle que, después de haber examinado su solicitud de aplicación, he decidido aceptarla para la estancia, y poder apoyar en su investigación.

La estadía durará 26 días, a partir del 17 de junio de 2019 y concluirá el 12 de julio de 2019, momento en el que terminará su estadía.

Atentamente,

Universidad Tecnológica de Pereira Decano Facultad Fac. Industrial

Wilson Arenas Valencia
Decano Facultad de Ciencias Empresariales
Universidad Tecnológica de Pereira

Jhon Mario Rodríguez Pineda
Docente Programa Ingeniería Industrial
Universidad Tecnológica de Pereira

NIT: 891.480.035 - 9 / Código Postal: 660003 / Conmutador:(57) (6) 313 7300 / Fax: 321 3206 / Dirección: Cra 27 Nº 10 - 02 Los Álamos - Pereira - Risaralda - Colombia / www.utp.edu.co
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