OmniaScience

Journal of Industrial Engineering and Management
JIEM, 2025 – 18(1): 130-144 – Online ISSN: 2013-0953 – Print ISSN: 2013-8423
https://doi.org/10.3926/jiem.8573

A Framework for Facility Layout Problem Characterization in A Bi-Directional Logistics Context

Paola Vintimilla-Alvarez[1*], Faustino Alarcón-Valero[2]

[1]*Dept. of Applied Chemistry and Production Systems. Universidad de Cuenca (Ecuador)*
[2]*Research Centre on Production Management and Engineering (CIGIP). Universitat Politècnica de València (Spain)*

[*]*Corresponding author: paola.vintimilla@ucuenca.edu.ec*
faualva@omp.upv.es

Received: October 2024
Accepted: January 2025

Abstract:

Purpose: This paper aims to propose a framework to define the facility layout problem in a bi-directional logistics context, specifically highlighting the main factors that enterprises must consider when reverse flow is introduced in forward logistics.

Design/methodology/approach: A characterization of the problem is proposed based on outstanding works that define similar problems in the literature and main characteristics in the facility layout problem have been identified through a bibliographic review. Aspects to consider for bi-directional logistics are distinguished, classified, and synthesized using the proposed framework, which is exemplified through an application case on a jewelry factory.

Findings: Nine factors have been identified as relevant for enterprises when considering the introduction of reverse flow in a facility layout. Furthermore, these factors have been thoroughly analyzed within the study case. Moreover, Research findings indicate that bi-directional logistics is an unexplored term. There are no articles that connect this concept with facility layout problem, there is an unaddressed gap.

Research limitations/implications: Founded articles refer to reverse logistics characteristics the ones about bi-directional logistics.

Practical implications: Academic and practical implications of this article include understanding the importance of facility layout problem in the bi-directional logistics context, identifying the impact of factors such as material, machinery, labour, among others.

Originality/value: This article proposes an opening to study the impact of bi-directional logistics in the facility layout problem for enterprises.

Keywords: facility layout problem, characterization, bidirectional logistics, reverse logistics, forward logistics

To cite this article:

Vintimilla-Alvarez, P., & Alarcón-Valero, F. (2025). A framework for facility layout problem characterization in a bi-directional logistics context. *Journal of Industrial Engineering and Management*, 18(1), 130-144. https://doi.org/10.3926/jiem.8573

1. Introduction

Recently, reverse logistics (RL) has garnered significant attention. Its implementation is steadily increasing across enterprises due to its growing influence on supply chains. Key drivers of this trend include environmental regulations, corporate social responsibility, legislation, circular economy sustainable competitiveness and opportunities (Suzanne, Absi & Borodin, 2020; Cortés-Pellicer & Alarcón-Valero, 2018; Agrawal, Singh & Murtaza, 2015; Rubio & Jiménez-Parra, 2014). These aspects compel companies to integrate reverse flows into their traditional forward processes to recover products or components.

As Wardani, Handayani and Wibowo (2022) highlight, RL practices are increasingly viewed as a strategic decision for enterprises. However, integrating RL into supply chains and businesses originally designed for forward flows can be complex. Relying only on forward logistics (FL) systems, RL can lead to inefficiencies and high costs (Dey, LaGuardia & Srinivasan, 2011; Alarcón, Cortés-Pellicer, Pérez-Perales & Mengual-Recuerda, 2021). Münch, von der Gracht & Hartmann (2021) point out that RL presents challenges, often linked to uncertainties, such as the unpredictable quantity and quality of returned goods and the work to be performed (Omatseye & Urbanic, 2022; Zamani, Abolghasemi, Seyed-Hosseini & Saman-Pishvaee, 2020; Topcu, Benneyan & Cullinane, 2013).

Although the term RL has been used to describe the incorporation of reverse processes —such as remanufacturing, re-assembly and refurbishing— within forward flows on the supply chain, the more accurate term that integrates both RL and FL to close the loop in circular economy is bi-directional logistics (BL) (Ding, Wang & Chan, 2023).

BL involves more than merely incorporating reverse flows into forward processes. It requires careful attention to the original flow along with specific processes such as collection, inspection and separation, reprocessing and disassembly, redistribution, and disposal (Zhao, Liu & Wang, 2008). For example, facilities must be equipped with the appropriate workspace and specialized machinery, along with adequate space for storage and sorting. Introducing reverse flows into forward systems necessitates infrastructure that can handle the increased volume of used and recovered products (Choudhary, Sarkar, Settur & Tiwari, 2015). Otsuki (2024) underscores the importance of processes for managing end-of-life items, including disassembly, recovery of valuable materials, removal of toxic substances, and disposal. Despite this, little attention has been given to the design of remanufacturing facilities, which are often more dynamic and complex (Topcu et al., 2013).

BL significantly impacts plant layout, making facility layout problem (FLP) a more critical component of business operations and strategic planning (Pérez-Gosende, Mula & Díaz-Madroñero, 2021) than it has been perceived. The integration of reverse flows into established forward processes can have substantial repercussions on overall operational efficiency, underscoring the importance of thoughtfully designed layouts to accommodate these changes. Therefore, facilities must be designed with flexibility to address challenges such as uncertain demand, emerging technologies, new processes, and the variety and volume of products (Pérez-Gosende et al., 2021; Hosseini-Nasab, Fereidouni, Fatemi-Ghomi & Bagher-Fakhrzad, 2018). Moreover, the facility layout must address specific requirements, such as sufficient space for storage and classification, along with designated areas for the recovery of products, parts, and components.

However, despite the importance that BL seems to have in FLP, there is limited literature connecting these concepts. As Omatseye and Urbanic (2022) note, there is limited research addressing the challenges of RL in manufacturing and remanufacturing processes. Also, the term BL hasn´t been defined or characterized. In order to cover these gaps, this paper proposes a framework to characterize the FLP in a BL context based on defining characterization on similar articles in the bibliography and a literature review to define and connect BL with facility layout.

The paper is organized in six sections. After this introduction, section 2 presents the methodology. Results are presented in section 3 which includes: problem characterization in operations management, factors affecting FLP, FL, RL, and BL main characteristics affecting FLP, the characterization for a FLP in a BL context through a framework, and an example of an application case in a jewelry factory. Section 4 details the discussion. Finally, conclusions are developed in section 5.

2. Methodology

The development of the methodology for a characterization of the Facility Layout Problem in a bidirectional logistics context has been carried over the course of 2024. It is composed of three steps: a) Defining characterization, b) Main Characteristics Identification in facility layout problems, and c) Framework development for the FLP characterization in a BL context.

a) Since this paper aims to characterize the facility layout problem in a bidirectional logistics context, a literature review has been carried out for outstanding works that characterize similar problems in the bibliography. Articles regarding the identification/definition of problems in facility layout, operations management and supply chain have been reviewed from Scopus and Google Scholar databases, covering the last 20 years. Field labels, keywords, and boolean operators are detailed in Table 1. As a result, seven papers have been identified to define the way to characterize the facility layout problem in a bidirectional logistics context. Detailed results are presented in section 3.1.

Facility layout problems search	(TI= ('characteriz* AND facility AND layout') OR TI= ('characteriz* AND facility AND layout AND problem') OR TI= ('definition AND facility AND layout AND problem') OR TI= ('defining AND facility AND layout AND problem'))
Operations management search	(TI= ('characteriz* AND operation* AND management') OR TI= ('characteriz* AND operations AND management AND problem') OR TI= ('definition AND operations AND management AND problem') OR TI= ('defining AND operations AND management AND problem'))
Supply chain search	(TI= ('characteriz* AND supply AND chain') OR TI= ('characteriz* AND supply AND chain AND problem') OR TI= ('definition AND supply AND chain AND problem') OR TI= ('defining AND supply AND chain AND problem'))

Table 1. Field labels, keywords, and boolean operators for problems characterization

b) Given that identifying the main factors that affect FLP in a BL context is an input for the problem characterization, a search on Scopus and Google Scholar databases using "facility layout problem" and "bidirectional logistics" has been carried out without success. Few founded articles didn´t connect these terms. Due to the results, a state of the art has been conducted in two phases. The first one has been focused on identifying the main factors of the FLP. The second one has tried to identify how BL influences those elements.

For the first phase, an exploration of the databases has focused on FLP and its factors within a 20-year timeframe. One relevant article has been selected, leading the review of Muther's book (Muther, 1955) with similar content that emphasizes the factors affecting plant layout. Field labels, keywords, and boolean operators are detailed in Table 2. Detailed information is presented in section 3.2.

Facility layout problem and bi-directional logistics search	(TI= ('facilit* layout problem') AND ('bidirectional* AND logistic* OR ('bi*directional'))
Facility layout problem factors	(TI= ('facilit* layout problem') OR ('facilit* layout') AND ('factor*'))

Table 2. Field labels, keywords, and boolean operators for factors that affect FLP in a BL context

Cause the bibliography doesn´t connect the terms BL and FLP, the second phase has tried to identify the main characteristics of BL through a literature review of FL and RL. There is complexity in BL that must be explained through forward and reverse flows. Also, RL has been selected cause most bibliography refers to reverse the two-way flow of BL. Field labels, keywords, and boolean operators are detailed in Table 3. As a result, sixteen relevant papers have been identified for the characterization, while irrelevant and duplicate articles were excluded based on predefined criteria. Detailed results are presented in section 3.3.

Field labels, keywords, and boolean operators	(TI= ('facilit* layout AND forward logistic*') AND ('facilit* layout AND reverse logistic*')) (TI= ('reverse logistic* AND forward logistic* AND definition OR characterization OR characteristic*'))
Database	Scopus
Document Type	Research articles
Time window	No (due to the limited number of founded articles)
Initial Number of articles	134
Removed and duplicates	122
Snowball articles	4
Final Number of articles	16

Table 3. Field labels, keywords, and boolean operators for main characteristics of forward, reverse and bidirectional logistics for a Facility Layout

c) Identified specific characteristics for FLP in a BL context have been classified and categorized according to the factors proposed by Muther (1955) and Monga and Khurana (2015) through a theorical framework and analyzed using a study case of a jewelry factory. Results are presented in section 3.4. and 3.5.

3. Results

3.1. Problem Characterization in Operations Management Research

Results found in the literature, after reviewing articles regarding the definition of problems in facility layout, operations management and supply chain, show different ways of characterization. Pérez-Gosende et al. (2021) derive a classification from the bibliography and enhance it with additional criteria to address facility layout problems. Drira, Pierreval and Hajri-Gabouj (2007) propose a rough tree representation of different factors to characterize layout problems. Chen and Paulraj (2004a) build a conceptual framework for problems and opportunities associated with supply chain management. Mentzer, DeWitt, Keebler, Min, Nix, Smith et al. (2001) detail definitions of supply chain management by source, define in one concept the main ideas, and illustrate a graphic model to represent a supply chain and its flows. Somapa, Cools and Dullaert (2018) summarize the supply chain visibility characterization in a table that provides samples of the relevant text of the literature review and tabulates them under specific characteristics from existing studies. Heckmann, Comes and Nickel (2015) detail the core characteristics of supply chain risk and summarize them in a scheme of categories and subcategories. Also, Zsidisin (2003) remarks notable studies that define risks and build a table of classification of supply risk definitions to finally propose his own definition or the term. Finally, Chen and Paulraj (2004b) identify relevant findings of Supply Chain Management and integrate them in a Theoretical framework; each element is described as well.

Characterizing a problem means pointing out the main characteristics of a subject that defines it and makes it unique. From reviewed articles, it can be deduced that a problem characterization in Operations Management Research can be done by a detailed definition of the subject; also, schemes, conceptual frameworks, and tables of detailed characteristics and classification support the characterization.

3.2. Factors affecting Facility Layout Problem

Monga and Khurana (2015) have grouped the characteristics and considerations affecting plant layout in eight categories: materials, machinery, labour, material handling, waiting time, auxiliary services, building, and future changes. This aggrupation is similar to Muther (1955) , one of the most cited books for a facility layout design. These two sources have been considered as an input for characterizing FLP in a BL context.

According to Muther (1955) there are aspects to consider for each factor in a FLP. They are considered and detailed in section 3.4. for the characterization.

3.3. Forward, Reverse and Bi-directional Logistics Characteristics

There are some characteristics that have been identified in the bibliography for FL and RL that can help to understand BL in a FLP. Most articles focused their content on RL and the differences with forward flows. RL flow is reactive (Rajagopal, Sundram & Naidu, 2015).

Topcu et al. (2013) emphasize variables that must be considered in remanufacturing facilities such as yield rates, the volume of returned products, the demand for refurbished items, and the storage capacity and space allocation. The authors also highlight processes that are carried out in these types of facilities, such as disassembly, remanufacturing, refurbishing and reassembly.

Suzanne et al. (2020) detail the subsequent industrial steps in remanufacturing facilities: disassembly, manufacturing/remanufacturing processing, and reassembly. The authors emphasize uncertainties on the quantity and quality of returned products and sub-products, as well as lot sizing problems because of the integration of disassembly processes with remanufacturing and reassembly.

According to Sangwan (2017) the major activities of RL involve collection, inspection-sorting, and product recovery. Barker and Zabinsky (2008) point out that processes in RL facilities may include reuse, refurbishment, spare parts recovery, raw material reprocessing and waste disposal. Processes identified for RL by Zhao et al. (2008) are collection, inspection/separation, reprocessing/disassembly, redistribution and disposal. Expanding on these insights, Alarcón, Cortés-Pellicer, Pérez-Perales and Sanchis (2020) reviewed the literature on this matter and concluded that the widely accepted alternative dispositions are: (1) direct reuse and resale, (2) repair, (3) refurbishing, (4) remanufacturing, (5) cannibalization, (6) recycling, (7) incineration and (8) landfilling. Building on this, Alarcón et al. (2021) have regrouped the RLP macro activities from the literature into three: collection and transport, inspection and sorting, and product disposition.

Authors also highlight complexities such as uncertainties in timing, quantity and quality of products (Omatseye & Urbani, 2022; Zamani et al., 2020; Topcu et al., 2013); and operational difficulties such as recovery processes, life cycles and characteristics of the products, required resources and facilities capacity (Topcu et al., 2013). Most of the identified characteristics found in the literature are related to the processes that must be performed in returned products or their parts or pieces. Uncertainties are also highlighted regarding the quality and quantity of products, as well as the necessity of space for storage and operations. Those characteristics have also been considered as an input for characterizing FLP in a BL context.

3.4. Framework for Facility Layout Problem Characterization in a Bi-directional Logistics Context

A framework of classification and categorization has been built for the FLP characterization in BL. It contains all the factors and aspects presented by Muther (1955) and Monga and Khurana (2015), and a new factor called process has been added due to the information found in the bibliography. Each element has been qualified with detailed considerations as: "N/A" for irrelevant, "+" for strong relation and "–" for weak relation between FLP and BL.

It is important to note that much of the literature categorizes aspects of BL under the term of RL. The focus of this paper is to highlight relevant aspects that enterprises should consider when introducing reverse flow in a FLP designed originally for FL. Table 4 presents the detailed characterization.

The characterization could be defined as follows: The FLP in a BL context must coordinate the two-way flows of materials: forward and reverse, in a facility that was initially designed for a forward flow. This could be especially complex when the space is limited and necessities for storage and processes like inspection/separation, reprocessing/disassembly, manufacturing/remanufacturing, re-assembly and others emerge. The facility must be adapted to uncertainties attending the forward flow with the incorporation of the RL; product (also parts and pieces) characteristics, special machinery, labour safety conditions, different flow movements, space for storage and classification, specific building needs and RL processes must be considered in the new scenario.

Factor	Aspects to consider	Bi-directional logistics	Author's considerations	Bibliography considerations	Source
Material	Project and product specifications	–	Products, part or pieces design may change recovery processes		
Material	Physical and chemical characteristics	+		Product Physical Characteristics: dimensions/size, volume, weight, fragility	Topcu et al., 2013
Material	Physical and chemical characteristics	+		Product not uniform packaging, possible poor quality or damaged items	Rajagopal et al., 2015
Material	Quantity and variety of products	+		Production variety and volume	Drira et al., 2007; Monga & Khurana, 2015; Hosseini-Nasab et al., 2018
Material	Quantity and variety of products	+		Complexity and heterogeneity in materials	Otsuki, 2024
Material	Quantity and variety of products	+		Large quantities of standardized items in FL vs small quantities of products in RL and BL	Singh, Singh & Walia, 2011
Material	Quantity and variety of products	+		Uncertain quantity of the returned products	Omatseye & Urbanic, 2022; Zamani et al., 2020
Material	Components and the way they are combined	+		Uncertain condition or quality of the items (Work to be performed in the returned products)	Topcu et al., 2013; Omatseye & Urbanic, 2022; Zamani et al., 2020
Machinery	Production process or method	–	Process design may change specific needs in machinery		
Machinery	Machinery, tooling and equipment	+		Required materials or equipment depending on the items condition	Topcu et al., 2013
Machinery	Machine utilization	–	Recovery processes may change machinery utilization		
Machinery	Machinery and process requirements	+	Recovery processes may need specific machinery		

Factor	Aspects to consider	Bi-directional logistics	Author's considerations	Bibliography considerations	Source
Labour	Labour and safety conditions	+		Safety and health risks for the people	Pérez-Gosende et al., 2023
	Labour need	–	Labour need may change according to reverse processes		
	Labour utilization	–	Labour utilization may change according to reverse processes		
	Other conditions: incentive payment, psychological and personal considerations, supervision	N/A			
Movement	Circulation pattern or model	+		Flow-line layouts movements: backtracking and bypassing	Drira et al., 2007
	Unnecessary driving reduction	N/A			
	Combined driving	+		One way product flow in FL vs Two-way product flow in BL	Singh et al., 2011
	Space for movement	+		General flow of parts depends on the necessary disassembly, cleaning, and testing processes	Topcu et al., 2013
	Management methods analysis	N/A			
	Driving equipment	N/A			
Waiting time	Storage and waiting points location	+		Variable processing times dependent on age, wear, and condition	Topcu et al., 2013
	Space for waiting points				
	Storage method	N/A			
	Devices safety and equipment for storage	N/A			
Auxiliary Services	Labour services (access roads, offices, lighting, etc.)	N/A			
	Material services (quality control, production control, scrap and waste control)	+	Space at the facility for classification may be needed		
	Machinery services (maintenance and auxiliary services)	N/A			

Factor	Aspects to consider	Bi-directional logistics	Author's considerations	Bibliography considerations	Source
Building	Special building or general purpose	–	Special building may be needed for RL processes		
	Single or multi-story building	+		Multifloor layout (option)	Drira et al., 2007
	Shape	+		Four types of organization: fixed product layout, process layout, product layout and cellular layout	
				Two facility shapes: regular (generally rectangular) and irregular (generally polygons)	
				Layout configuration into categories: single-row, multi-row, double row, parallel-row, loop, open-field, and multi-floor	Drira et al., 2007; Hosseini-Nasab et al., 2018
	Elements: windows, floors, covers and roofs, elevators, etc.	N/A			
	Storage spaces, external constructions for wells, tanks, pumps, etc.	+		Pick-up and drop-off locations	Drira et al., 2007
Future Changes	Material changes (product design, materials, demand, variety)	+	Product characteristics in RL processes may change facility requirements		
	Machinery changes (process and methods)	+	BL and RL processes may change machinery requirements in the facility		
	Labour changes (working hours, organization and supervision, skills)	N/A			
	Auxiliary services changes (driving, storage, services, building)	+	Space for storage and classification at the facility may be needed		
	External changes and facility limitation	+	FL original facility may be limited for RL and BL processes		

Factor	Aspects to consider	Bi-directional logistics	Author's considerations	Bibliography considerations	Source
Processes	Types of processes	+		A typical remanufacturing facility includes disassembly, manufacturing/remanufacturing processing, and reassembly.	Suzanne et al., 2020
		+		The processes of RL consist of collection, inspection/separation, reprocessing/disassembly, redistribution and disposal stages.	Zhao et al., 2008

Table 4. Framework for Characterization of FLP in BL contexts

3.5. Application Case on a Jewelry Factory

To illustrate the proposed framework, an application case has been conducted in a jewelry manufacturing facility. The factory primarily produces gold jewelry with precious stones, utilizing a process distribution facility layout. Returned products are received for various reasons, including: 1. adjustments for size and fit, such as resizing rings; 2. the recovery of raw materials, such as gold and precious stones, from antique jewelry for reuse or reprocessing into new products; and 3. reprocessing unsold finished goods, often for the purpose of recovering gold.

This type of business possesses distinct characteristics, particularly regarding the high value of raw materials and the emphasis placed on their recovery through reverse logistics. In the factory under analysis, specific features of the BL processes include the following: 1. A dedicated area, referred to as the "after-sales", is required for the classification and disassembly of returned goods 2. Gold, a critical material, undergoes external melting, refining, and processing to achieve the necessary purity levels for new products. 3. Certain processes, such as cleaning and assembly, are performed manually at designated workstations 4. Some processes, like rhodium plating, polishing, and manual handling, are shared between FL and RL 5. Recovered materials can be stored until required for production 6. Certain returned items require specialized processing, with an initial analysis conducted in the after-sales department before proceeding with further steps.

Factory forward and reverse flows and processes have been analyzed to exemplify the proposed framework for FLP characterization in a BL context. Figure 1 presents a scheme of the jewelry facility layout and detailed flow for rings: 1. Forward flow of an example of these products without precious stones, 2. Reverse flow for reparation, for example, adjustments for size and fit. 3. Reverse flow for raw material recovery with an external supplier, for example, from antique jewelry or unsold products.

Table 5 provides detailed remarks for each aspect and consideration of each factor in this application case, highlighting the most important points. The results reflect the specific conditions and realities of this jewelry factory, demonstrating the application of the characterization framework.

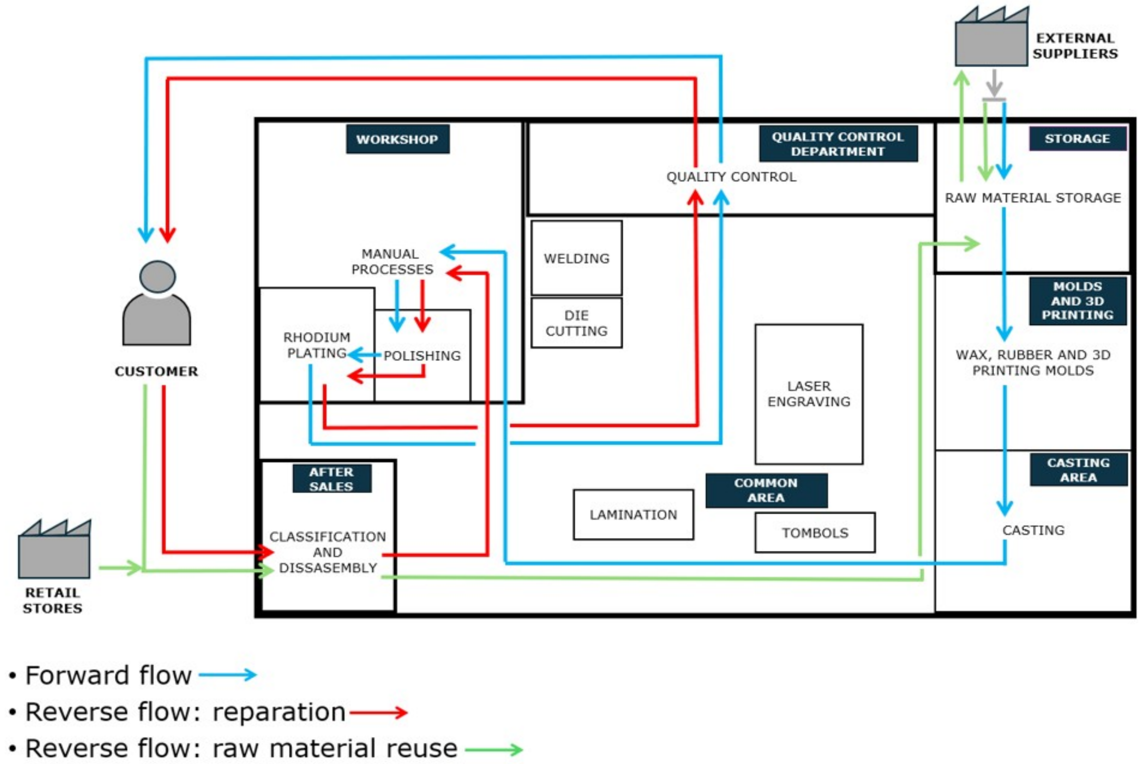

Figure 1. Scheme and flows of the facility layout of the jewelry factory in the application case

Factor	Aspects to consider	Considerations	Application case remarks
Material	Project and product specifications	Products, part or pieces design may change recovery processes	Raw materials are recovered according to final goods needs
	Physical and chemical characteristics	Product Physical Characteristics: dimensions/size, volume, weight, fragility	Special attention to fragility and product value
		Product not uniform packaging, possible poor quality or damaged items	Most of returned items can be repaired
	Quantity and variety of products	Production variety and volume	Volume of returned items is not high. Variety can be controlled through melting and casting
		Complexity and heterogeneity in materials	Returned gold may present heterogeneity
		Large quantities of standardized items in FL vs small quantities of products in RL and BL	Products are not standardized, most of the processes are craft manuals
		Uncertain quantity of the returned products	Returned items are eventual
	Components and the way they are combined	Uncertain condition or quality of the items (Work to be performed in the returned products)	There is variety on the materials and precious stones of returned products

Factor	Aspects to consider	Considerations	Application case remarks
Machinery	Production process or method	Process design may change specific needs in machinery	Specific processes and elements are needed for gold rod
	Machinery, tooling and equipment	Required materials or equipment depending on the items condition	Most of the processes for RL use FL equipment
	Machine utilization	Recovery processes may change machinery utilization	It depends on the production mix
	Machinery and process requirements	Recovery processes may need specific machinery	Most of the processes for RL use FL equipment
Labour	Labour and safety conditions	Safety and health risks for the people	Recovery processes use chemicals such acids, there are specific safety needs for people
	Labour need	Labour need may change according to reverse processes	It is the same, cause workstations are the same for FL and RL
	Labour utilization	Labour utilization may change according to reverse processes	It changes depending on the disassembly and recovery needs. Workload may change
	Other conditions: incentive payment, psychological and personal considerations, supervision	N/A	N/A
Movement	Circulation pattern or model	Flow-line layouts movements: backtracking and bypassing	It changes with circulation of RL items
	Unnecessary driving reduction	N/A	N/A
	Combined driving	One way product flow in FL vs Two-way product flow in BL	There is a combination of forward and reverse flow
	Space for movement	General flow of parts depends on the necessary disassembly, cleaning, and testing processes	The circulation space is the same for forward and reverse flow
	Management methods analysis	N/A	N/A
	Driving equipment	N/A	N/A
Waiting time	Storage and waiting points location	Variable processing times dependent on age, wear, and condition	They are necessary for recovered material until it is used
	Space for waiting points		
	Storage method	N/A	N/A
	Devices safety and equipment for storage	N/A	N/A
Auxiliary Services	Labour services (access roads, offices, lighting, etc.)	N/A	N/A
	Material services (quality control, production control, scrap and waste control)	Space at the facility for classification may be needed	A workstation for classification and disassembly is used at the beginning of the reverse flow
	Machinery services (maintenance and auxiliary services)	N/A	N/A

Factor	Aspects to consider	Considerations	Application case remarks
Building	Special building or general purpose	Special building may be needed for RL processes	There is no modification in the building for RL
	Single or multi-story building	Multifloor layout (option)	There is no modification in the building for RL
	Shape	Four types of organization: fixed product layout, process layout, product layout and cellular layout	There is no shape modification
		Two facility shapes: regular (generally rectangular) and irregular (generally polygons)	
		Layout configuration into categories: single-row, multi-row, double row, parallel-row, loop, open-field, and multi-floor	
	Elements: windows, floors, covers and roofs, elevators, etc.	N/A	N/A
	Storage spaces, external constructions for wells, tanks, pumps, etc.	Pick-up and drop-off locations	Original storage spaces are used for FL and RL products. But more room is necessary
Future Changes	Material changes (product design, materials, demand, variety)	Product characteristics in RL processes may change facility requirements	Specific needs or work to be done in products may be required
	Machinery changes (process and methods)	BL and RL processes may change machinery requirements in the facility	New processes may need specific machinery
	Labour changes (working hours, organization and supervision, skills)	N/A	N/A
	Auxiliary services changes (driving, storage, services, building)	Space for storage and classification at the facility may be needed	There is no need cause the low volume of returned products
	External changes and facility limitation	FL original facility may be limited for RL and BL processes	The space will be limited when new technology is introduced
Processes	Types of processes	A typical remanufacturing facility includes disassembly, manufacturing/ remanufacturing processing, and reassembly.	Classification, disassembly, material and parts recovery, remanufacturing and reassembly are performed
		The processes of RL consist of collection, inspection/separation, reprocessing/disassembly, redistribution and disposal stages.	

Table 5. Application case: Characterization of FLP in BL context in a jewelry factory

4. Discussion

The proposed framework and accompanying case study aim to highlight the broader impact of RL in the FLP. The framework is a valuable tool for enterprises, enabling them to identify key considerations based on specific characteristics of their facility layouts when integrating BL. Each factory will have unique requirements depending on its products, processes, and operational intricacies.

When an enterprise aims to apply this framework, it must detail information as remarks for each aspect of every factor according to its specific case, evaluating the considerations highlighted in the literature and by the authors. This approach allows the enterprise to pinpoint the main aspects to address when integrating BL into a facility layout.

Once the framework is completed, the enterprise can identify critical aspects to consider for each factor. Thoroughly filled remarks containing detailed information should be prioritized in the decision-making process, while empty fields can generally be disregarded.

After reviewing the key remarks, the enterprise can determine the next steps to take for each factor, focusing on immediate actions that align with its needs and constraints. By integrating these prioritized considerations, companies can more effectively navigate the complexities of BL implementation, optimizing layout decisions that support strategic goals.

In the case study, used as an illustrative example, the framework revealed several critical insights: the company should focus on material flow, establish a station for classification and disassembly, and manage shared processes between forward and reverse logistics. These findings underscore the importance of careful planning and adaptation when integrating RL into a forward facility layout to enhance operational efficiency and optimize resource utilization.

5. Conclusions

Uncertainty best characterizes the FLP in the context of BL. In this article, the key attributes of FL, RL, and BL have been analyzed, classified, and categorized according to FLP factors, enabling the identification of the main problem addressed in this work.

A framework for characterizing FLP within a BL context has been proposed, offering a structured approach for enterprises integrating RL into their existing FL operations. This framework provides valuable guidance for addressing the challenges and complexities associated with the incorporation of reverse flows into traditional forward logistics facilities.

There is a notable absence of articles directly linking the concepts of BL and FLP. However, this article attempts to bridge that gap by examining the characteristics of RL and FL found in the existing literature. Through this analysis, it seeks to establish a connection between BL and FLP, contributing to a better understanding of their relationship in manufacturing facilities.

Most of the existing literature on RL focuses on supply chain networks, modeling, and facility location. However, only a limited number of these articles have been applicable for characterizing FLP within the context of RL and BL. This highlights the need for further research that directly addresses the integration of FLP in RL and BL environments.

The academic and practical implications of this article include a deeper understanding of BL and its potential impact on facility layout when reverse flows are introduced into facilities originally designed for forward logistics. This research provides insights into how the integration of RL can affect the original forward flow and its operational efficiency, space utilization, and processes, offering valuable guidance for both scholars and practitioners in logistics and facility planning.

Future lines of research, derived from this work, would focus on developing practical tools to solve the facility layout problem on a bi-directional logistics problem; or, if applicable, adapting existing elements, such as models, to this field.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

References

Agrawal, S., Singh, R.K., & Murtaza, Q. (2015). A literature review and perspectives in reverse logistics. *Resources, Conservation and Recycling,* 97, 76-92. https://doi.org/10.1016/j.resconrec.2015.02.009

Alarcón, F., Cortés-Pellicer, P., Pérez-Perales, D., & Sanchis, R. (2020). Sustainability vs. Circular Economy from a Disposition Decision Perspective: A Proposal of a Methodology and an Applied Example in SMEs. *Sustainability,* 12(23), 10109. https://doi.org/10.3390/su122310109

Alarcón, F., Cortés-Pellicer, P., Pérez-Perales, D., & Mengual-Recuerda, A. (2021). A Reference Model of Reverse Logistics Process for Improving Sustainability in the Supply Chain. *Sustainability,* 13(18), 10383. https://doi.org/10.3390/su131810383

Barker, T.J., & Zabinsky, Z.B. (2008). Reverse logistics network design: a conceptual framework for decision making. *International Journal of Sustainable Engineering,* 1(4), 250-260. https://doi.org/10.1080/19397030802591196

Chen, I.J., & Paulraj, A. (2004a). Towards a theory of supply chain management: the constructs and measurements. *Journal of Operations Management,* 22(2), 119-150. https://doi.org/10.1016/j.jom.2003.12.007

Chen, I.J., & Paulraj, A. (2004b). Understanding supply chain management: critical research and a theoretical framework. *International Journal of Production Research,* 42(1), 131-163. https://doi.org/10.1080/00207540310001602865

Choudhary, A., Sarkar, S., Settur, S., & Tiwari, M.K. (2015). A carbon market sensitive optimization model for integrated forward-reverse logistics. *International Journal of Production Economics,* 164, 433-444. https://doi.org/10.1016/j.ijpe.2014.08.015

Cortés-Pellicer, P., & Alarcón-Valero, F. (2018). Identification of reverse logistics decision types from mathematical models. *Journal of Industrial Engineering and Management,* 11(2), 239. https://doi.org/10.3926/jiem.2530

Dey, A., LaGuardia, P., & Srinivasan, M. (2011). Building sustainability in logistics operations: a research agenda. *Management Research Review,* 34(11), 1237-1259. https://doi.org/10.1108/01409171111178774

Ding, L., Wang, T., & Chan, P.W. (2023). Forward and reverse logistics for circular economy in construction: A systematic literature review. *Journal of Cleaner Production,* 388. https://doi.org/10.1016/j.jclepro.2023.135981

Drira, A., Pierreval, H., & Hajri-Gabouj, S. (2007). Facility layout problems: A survey. *Annual Reviews in Control,* 31(2), 255-267. https://doi.org/10.1016/j.arcontrol.2007.04.001

Heckmann, I., Comes, T., & Nickel, S. (2015). A critical review on supply chain risk - Definition, measure and modeling. *Omega,* 52, 119-132. https://doi.org/10.1016/j.omega.2014.10.004

Hosseini-Nasab, H., Fereidouni, S., Fatemi-Ghomi, S.M.T., & Bagher-Fakhrzad, M. (2018). Classification of facility layout problems: a review study. *International Journal of Advanced Manufacturing Technology,* 94(1-4), 957-977. https://doi.org/10.1007/s00170-017-0895-8

Mentzer, J.T., DeWitt, W., Keebler, J.S., Min, S., Nix, N.W., Smith, C.D. et al. (2001). Defining Supply Chain Management. *Journal of Business Logistics,* 22(2), 1-25. https://doi.org/10.1002/j.2158-1592.2001.tb00001.x

Monga, R., & Khurana, V. (2015). Facility Layout Planning: A Review. *International Journal of Innovative Research in Science, Engineering and Technology,* 04(03), 976-980. https://doi.org/10.15680/IJIRSET.2015.0403027

Münch, C., von der Gracht, H.A., & Hartmann, E. (2021). The future role of reverse logistics as a tool for sustainability in food supply chains: a Delphi-based scenario study. *Supply Chain Management: An International Journal,* 28(2), 262-283. https://doi.org/10.1108/SCM-06-2021-0291

Muther, R. (1955). *Practical plant layout* (1st ed.). New York: McGraw-Hill.

Omatseye, O., & Urbanic, R.J. (2022). System reconfiguration for reverse logistics: A case study. *IFAC-PapersOnLine,* 55(10), 115-120. https://doi.org/10.1016/j.ifacol.2022.09.377

Otsuki, A. (2024). Chapter 26 - Future perspectives on non-destructive material characterization methods towards sustainability and circular economy. In Otsuki, A., Jose, S., Mohan, M., & Thomas, S. (Eds.), *Non-Destructive Material Characterization Methods* (783-790). Elsevier. https://doi.org/10.1016/B978-0-323-91150-4.00002-1

Pérez-Gosende, P., Mula, J., & Díaz-Madroñero, M. (2021). Facility layout planning. An extended literature review. *International Journal of Production Research,* 59(12), 3777-3816. https://doi.org/10.1080/00207543.2021.1897176

Rajagopal, P., Sundram, V.P.K., & Naidu, B.M. (2015). Future Directions of Reverse Logistics in Gaining Competitive Advantages: A Review of Literature. *International Journal of Supply Chain Management,* 4(1), 39-48.

Rubio, S., & Jiménez-Parra, B. (2014). Reverse Logistics: Overview and Challenges for Supply Chain Management. *International Journal of Engineering Business Management,* 6, 2. https://doi.org/10.5772/58826

Sangwan, K.S. (2017). Key Activities, Decision Variables and Performance Indicators of Reverse Logistics. *Procedia CIRP,* 61, 257-262. https://doi.org/10.1016/j.procir.2016.11.185

Singh, D., Singh, H., & Walia, N. (2011). Weighted Flow Distribution Model of the Reverse Logistics System. In *Proceedings of the World Congress on Engineering*, London, UK (pp. 6-8).

Somapa, S., Cools, M., & Dullaert, W. (2018). Characterizing supply chain visibility - a literature review. *The International Journal of Logistics Management,* 29(1), 308-339. https://doi.org/10.1108/IJLM-06-2016-0150

Suzanne, E., Absi, N., & Borodin, V. (2020). Towards circular economy in production planning: Challenges and opportunities. *European Journal of Operational Research,* 287(1), 168-190. https://doi.org/10.1016/j.ejor.2020.04.043

Topcu, A., Benneyan, J.C., & Cullinane, T.P. (2013). A simulation-optimisation approach for reconfigurable inventory space planning in remanufacturing facilities. *International Journal of Business Performance and Supply Chain Modelling,* 5(1), 86-114. https://doi.org/10.1504/IJBPSCM.2013.051656

Wardani, S.A., Handayani, N.U., & Wibowo, M.A. (2022). Barriers for implementing reverse logistics in the construction sectors. *Journal of Industrial Engineering and Management,* 15(3), 385-415. https://doi.org/10.3926/jiem.3539

Zamani, M., Abolghasemi, M., Seyed-Hosseini, S.M., & Saman-Pishvaee, M. (2020). Considering pricing and uncertainty in designing a reverse logistics network. *International Journal of Industrial and Systems Engineering.* [Online]. Retrieved JuLy 10th, 2023. https://doi.org/10.1504/IJISE.2020.107554

Zhao, C., Liu, W., & Wang, B. (2008). Reverse Logistics. In *2008 International Conference on Information Management, Innovation Management and Industrial Engineering* (349-353). Taipei, Taiwan. https://doi.org/10.1109/ICIII.2008.42

Zsidisin, G.A. (2003). A grounded definition of supply risk. *Journal of Purchasing and Supply Management,* 9(5), 217-224. https://doi.org/10.1016/j.pursup.2003.07.002