

A Sequential Simulation-Heuristic Framework for Facility Layout Evaluation and Line-Side Feeding in a Petrochemical Filling Plant

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Abstract

This study addresses the integrated problem of facility layout planning and line-side material feeding operations for a new filling plant under construction at a large petrochemical company. The filling plant comprises multiple filling lines, also called machines, with varying container sizes and filling speeds, stretch wrappers, and a picking conveyor system, all designed from scratch as part of a major capacity-expansion project. Due to the technical complexity and multi-disciplinary nature of the project, a sequential solution approach is adopted, decomposing the problem across three decision levels: strategic layout design, tactical capacity determination, and operational feeding planning. In the tactical phase, a discrete-event simulation model developed in Rockwell ARENA evaluates the performance of the proposed layout under alternative stretch wrapper processing speeds and conveyor speeds, measuring stretch wrapper utilization, pallet queue length and waiting time, and total production completion time. In the operational phase, a greedy-type constructive heuristic algorithm generates replenishment schedules and assigns forklifts to feeding trips under three alternative assignment policies: resource minimization, fair workload distribution, and dedicated assignment. Experiments across eight production plan scenarios reveal that the stretch wrapper processing speed has a more decisive impact on system performance than conveyor speed, and that the proposed layout with appropriately configured stretch wrappers eliminates pallet congestion. The heuristic results demonstrate consistent forklift requirements across production plans and highlight trade-offs between resource minimization and workload balance. The study contributes a structured, industry-validated decision framework applicable to greenfield filling plant design.

Keywords

Facility layout planning, Discrete-event simulation, Material feeding operations, Constructive heuristic, In-plant logistics.

1. Introduction

Motivated by the business problem of a large petrochemical company, this paper considers two main subjects: facility layout design (aka layout planning) and material (parts) feeding operations for an upgraded filling plant (called simply the plant in this paper) when it is designed from scratch. The construction and design phases are carried out as part of a comprehensive engineering project; this paper covers only studies within the scope of industrial engineering and decision-making for the company that operates an extensive nationwide distribution network consisting of gas stations, fuel terminals, airport supply units, and an LPG terminal. As a business, the company refuels a quarter of a million aircraft per year, has a million cubic meters of fuel storage capacity, and generates billions of dollars in annual sales revenue. The filling plant is home to filling lines (FL), also called machines, with various features, including the container size to be filled, the container feeding station, the filling speed, the number of filling stations, the conveyor speed, etc. The machines perform all operations, including container labeling, container (bottle) control and positioning, filling, capping, cap control and laser writing, weighing, packaging (batching and positioning) small

containers into retail packages (if necessary), and palletizing filled containers. In addition to FLs, stretch wrappers (SW) are used to stretch pallets with filled containers at the end of the production process.

There are some identified problems and drawbacks regarding the existing filling plant as follows. The existing plant is insufficient to meet the increased demand with its current production capacity. Besides, machine breakdowns are frequently observed on the FLs due to outdated machines. However, the company is unable to add new machines due to the limited space in the existing filling plant. In the existing plant, extended time and effort are needed to stretch pallets with filled containers to move them between FLs and SWs at the end of the filling process. The layout of the existing plant is not suitable for performing operations common across lines, such as stretching pallets and transferring them to the warehouse. To address all identified problems, the company initiates a capacity-expansion and plant-upgrade project. The company works with one of the top engineering firms on a project spanning various disciplines, including civil engineering, architecture, regulations and codes, logistics, and industrial engineering. As part of this upgrade project, the existing FLs will be disassembled and removed from the plant, and the existing filling plant will be demolished. Afterward, the debris will be removed from the field. The site will be prepared for construction, and a new, larger building will be built (see Figure 1a). The project is concluded with the layout design of the new plant and integrating it with the other units surrounding it in the production facility. In the projected layout, the company and the engineering team plan to locate the FLs in parallel to the north of the plant and place a picking conveyor in the west-east direction at the exit of each FL. By doing so, pallets leaving the FLs move through the picking conveyor and arrive at the SWs. In the proposed design, production and stretching operations are integrated via a picking conveyor arranged in two parallel lines across the plant. A rough layout is shown in Figure 1b.

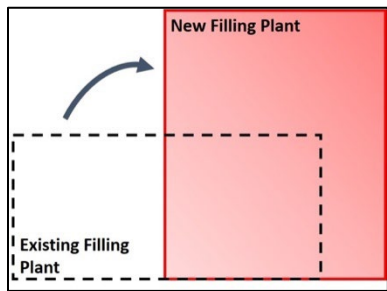


Figure 1a. Representation of Existing and New Filling Plant (scaled approximately)

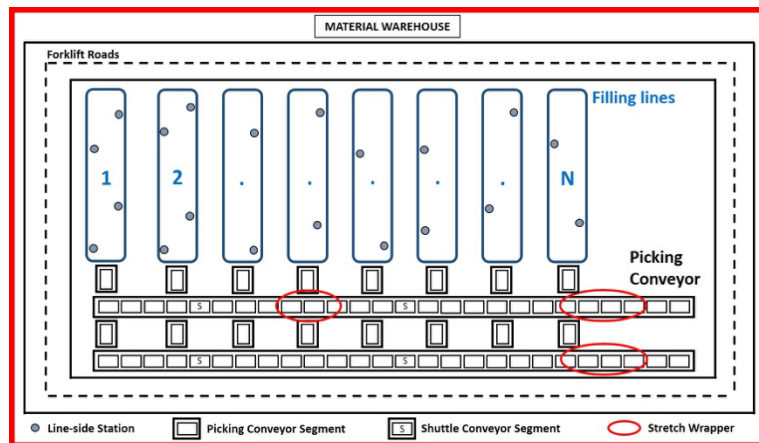


Figure 1b. Rough (Proposed) Layout of New Filling Plant

This paper presents a real-world case study of a business problem involving multiple aspects, including designing the plant layout, determining the capacity of stretching operations, and planning material handling (feeding) for inputs and outputs across the plant. The content of this problem corresponds to two well-known topics in industrial engineering literature as follows: (1) the plant layout design problem, and (2) material handling operations.

A plant layout problem, also referred to as the facility layout design problem (FLD), is formally defined as the process of physically arranging all production factors within a production system to ensure that an organization's strategic objectives are met efficiently (Pérez-Gosende et al. 2020, Pérez-Gosende et al. 2021). Alternatively, since FLD is introduced as the quadratic assignment problem for the first time ever, it assigns or locates n machines and n locations; there are $n!$ feasible solutions for such a problem setting if there are no additional constraints (Koopmans and Beckmann 1957, Wang et al. 2008). Even with its plain version, FLD is an NP-hard combinatorial optimization problem. FLD is considered one of the most important design decisions within business decision-making (Pérez-Gosende et al. 2020, Pérez-Gosende et al. 2021). A well-designed layout is vital for a firm's competitiveness because it directly influences productivity and efficiency (i.e., increased throughput), operational performance (i.e., shortened lead times, improved resource utilization), safety and morale of employees in any manufacturing or production environment (Hosseini-Nasab et al. 2018). The most significant driver for optimizing facility layout is reducing material handling costs (MHC), which are often non-value-added activities (Rizqi and Aulia 2019). It is widely

estimated that 20% to 50% of manufacturing operating expenses are attributable to material handling. Effective facility layout designs can reduce these operating costs by 10% to 30% (Wang et al. 2008, Zúñiga et al. 2020).

There are comprehensive review papers proposing taxonomy systems to classify published work on the facility layout problem (Hosseini-Nasab et al. 2018, Pérez-Gosende et al. 2020, Pérez-Gosende et al. 2021). To communicate with the reader effectively, we classify the first aspect of the studied problem using the proposed taxonomy in these review papers. The *type of problem* is “Greenfield design”, a *robust layout* intended for use with any combination of FLs on any shift throughout the year. The focus of this work is the *detailed layout* of a *single facility* on a *single floor*, considering *bidimensional space* in the building rather than a block layout. The FLs have *regular shapes*, *equal areas*, and *fixed dimensions*. Material handling system configuration is a type of *multiple-row (column) configuration*. Alternative layouts are generated through *experts’ knowledge*, and layouts are evaluated using *simulation*.

An important aspect of this business problem concerns the material feeding operations in the plant's production process. These operations involve the delivery of any kind of materials, including empty containers (or bottles), caps of containers, labels, packages and boxes for placing small containers, separators used between rows of products on the pallets, empty pallets to load filled containers (end product) from the material warehouse to the stations located on the sides of the FLs in the refilling plant. The pickup of empty containers of materials from the line-side stations is also included in the scope of the material feeding operations. The line-side stations have sufficient space for a single pallet only, with additional reserve capacity for the machines; the next pallet of material must be delivered to the station on time to avoid stopping the FLs. Feeding operations must be carefully planned and executed with high consistency and punctuality. This feeding policy is known as “line-side stocking”, “continuous supply”, “continuous replenishment”, and “point-of-use storage systems” and is considered the oldest feeding policy (Kilic and Durmusoglu 2015). Material handling activities are estimated to account for 20% to 50% of total operating cost in many manufacturing facilities (Tompkins et al. 2010).

To restate the problem definition, the filling plant layout is determined by locating the machines, forklift roads in and around the production area, the parts (segments) of the picking conveyor, the location of the shuttle conveyor on the picking conveyor, and the number and location of SWs. We also decide the processing speed of the SWs, the picking conveyor, and the shuttle conveyor within the problem. Besides, the frequency and timing of feeding operations, the forklift assignment for each feeding operation, and the total number of forklifts needed to perform all feeding operations in any production setting. Given the complexity of the facility layout problem, considering the additional aspects of production operations and material feeding operations makes it even more complex. To solve such a complex problem, it is important to choose an effective solution approach. We consider a sequential solution approach in which each aspect of the problem is addressed one at a time and discussed in more detail in the following sections.

1.1 Objectives

The primary objective of this paper is to address the business problem of a large petrochemical company, focusing on the detailed plant layout and material feeding operations. The study aims to develop a solution method that includes a simulation model to solve the plant layout problem and a heuristic algorithm to determine feeding operations in the plant. In addition to the primary objectives provided above, the study also aims to: (i) Determine the detailed layout of the filling plant (exact locations and order of FLs in the facility), (ii) Determine the number and the operating speed of SWs, (iii) Determine the picking conveyor speed and shuttle conveyor speed, (iv) Determine the fixed route of each feeding operation (replenishment trip) to each line-side station in the plant, (v) Determine the timing of each feeding operation (the schedule), given that the production planning (which machines run) in each shift, (vi) Assign forklifts to each replenishment trip and determine how many forklifts are needed to perform all feeding operations in each shift without disrupting the production plan.

The contribution of this study is summarized in three aspects: Practically, it employs real on-site data from a major petrochemical company and delivers actionable decisions across all three phases of the project. Methodologically, the study proposes a structured three-phase decision framework that systematically classifies the integrated problem using established FLD taxonomies. A discrete-event simulation model of a pallet-conveying system is presented, and a constructive heuristic with three alternative assignment policies for line-side feeding is introduced. Managerially, the study demonstrates quantitatively how SW capacity and conveyor speed interact to determine production time and pallet congestion - a trade-off that has direct implications for capital investment decisions in similar upgrade projects.

The remainder of this paper is organized as follows: Section 2 provides a concise overview of the literature on facility layout and material feeding operations. Section 3 discusses the proposed solution method and its components, including the simulation model and the heuristic algorithm when tackling the phases of the integrated problem. We summarize the process for collecting the data to solve the problem in Section 4. The simulation model and heuristic algorithm results are provided in Section 5. Section 6 concludes the paper and frames the future research directions.

2. Literature Review

When reviewing the literature, we consider three main streams that are directly or partly related to the business problem addressed in this study. These streams are (1) facility (or plant) layout design, (2) in-plant logistics (including material handling and planning feeding operations), and (3) integrated planning of plant layout and material feeding. In the first stream, we begin with the review papers to frame the literature (Hosseini-Nasab et al. 2018, Pérez-Gosende et al. 2020, Pérez-Gosende et al. 2021). It is followed by studies in which the alternative layouts are generated using experts' knowledge rather than an analytical methodology (Yang et al. 2012, Al-Hawari et al. 2014, Potočník et al. 2014, Azadeh et al. 2015). Simulation is a popular approach for evaluating alternative layouts due to its advantages (Pérez-Gosende et al. 2021). As part of the literature review, we examine studies that consider simulation-based facility layout design. Aleisa and Lin (2005) discussed the order of two solid approaches to effective facilities planning: layout optimization and simulation, comparing the two paradigms "layout then simulate" and "simulate then layout". Among these papers, some study facility layout design and follow the first paradigm of "layout then simulate". These studies generated a very limited number of alternative layouts, either only one (Smutkupt and Wimonkasame 2009, Rizqi and Aulia 2019) or two (Lin et al. 2015, Tearwattanarattikal et al. 2008, Zhang et al. 2019), and then evaluated them using a method. Unlike the first group, there are fewer studies that embrace the second paradigm, named "simulate then layout" in the literature (Altinkilinc 2004). There is an alternative solution approach, in addition to the two paradigms, called simulation optimization, in which optimization (layout) and simulation are used simultaneously in a back-and-forth manner. In these studies, the simulation phase is used to evaluate an objective function that includes complex measures (e.g., material handling cost, average cycle time) of the layouts generated by the optimization phase (e.g., genetic algorithm) (Wang et al. 2008, Azadivar and Wang 2000, Zúñiga et al. 2020).

In the second stream, we focus on the second aspect of the problem, material feeding operations. Material feeding operations are studied under various terms in the literature, including in-plant/in-house logistics, internal or intra logistics, shop-floor logistics, internal part supply or logistics, delivery-to-line, material flow, and assembly line feeding. There are comprehensive papers that the reader can refer to for reviewing assembly line parts feeding policies (Kilic and Durmusoglu 2015), assembly line feeding problems (Schmid and Limère 2019), and part logistics specifically in the automotive industry (Boysen et al. 2015). Besides, Avitabile (2022) reviews the studies with a perspective on the task assignment process for a fleet of vehicles feeding production systems and the impact of Logistics 4.0 principles on task assignment. Most studies in this field focus on AGVs and tow trains (milk runs); some address line feeding operations and forklift resource allocation. Internal transport problems are often characterized by high uncertainty, short travel times, and high vehicle utilization (Le-Anh 2005). Boysen et al. (2015) describe feeding operations as a phase of the in-house part logistics process and refer to it as delivery-to-line (DL) in the automotive industry. DL1 refers to the use of forklifts and is further divided into two problems: partitioning transport jobs among available forklifts (referred to as DL1-assignment) and determining the sequence of transport jobs per forklift (referred to as DL1-sequencing). The study states that both problems are parallel machine scheduling problems with additional objectives, namely minimizing the number of forklifts required and minimizing part inventory at the stations (consistent with the JIT philosophy). In studies focusing on DL, a mixed-integer linear programming (MILP) model integrating vehicle-type selection (including forklifts) with assembly-line feeding decisions is proposed, minimizing fleet size and acquisition, as well as maintenance, costs across different vehicle types (Adenipekun et al. 2025) and an optimization model integrating production, transportation, and inventory decisions within in-plant logistics examining whether available resources are adequate to maintain an efficient system (Büyükożkan et al. 2025). Becerra-Fernandez et al. (2024) formulate the forklift assignment problem as a resource allocation for a logistics distribution center, given restricted aisle dimensions, and propose an assignment model through a discrete-event simulation.

There is a third group of studies in which the facility layout problem is coupled with additional design elements related to facility planning and/or manufacturing operations and studied in a single problem setting, usually called an integrated design problem. Although these papers use the same naming, "integrated design problem," and share some common features in their coupled problems, it is quite difficult to identify similarities and group them into categories. The underlying reason is that these problems are mostly motivated by real-life cases observed in a company and solved

primarily for that company. In most cases, the facility layout problem is merged with the material handling system (or network) design (Peters and Yang 1997, Aiello et al. 2002, Klausnitzer and Lasch 2019). A block layout is constructed for interacting facilities (e.g., machines, cells, or departments), the locations of pickup and delivery points (P/D or I/O stations) are determined, and the direction of flow paths or material flow networks (also called aisle design) is designed in these studies. Some fixed structures, such as the spine and perimeter configurations, are compared in the study (Peters and Yang 1997). Klausnitzer and Lasch (2019) shows that lower travel distances and fewer nested aisle structures can be achieved by integrating subsequent design elements in the early stages of facilities planning. Castillo and Peters (2002) combined department formation and layout design in their integrated layout design problem. The department formation problem includes assigning machines to department locations, and layout design only considers flows between departments and determines unit load sizes. Movements within departments are deliberately ignored. Alternatively, Vonolfen et al. (2012) combined warehouse picking and forklift routing into a single problem for a manufacturer. The forklift routing problem is considered a dynamic pickup and delivery problem with time windows and solved via a genetic algorithm.

3. Methods

We tackle the company's business problem in a sequential approach for reasons related to size, content, and problem complexity. The proposed solution method is summarized in Figure 2, which presents all phases in the business problem, the corresponding decision-making level, and the solution approach of this study. In the first phase of the business problem, plant layout design, also known as layout planning, is considered. The layout design includes decisions about the type and number of FLs, the order of FLs (the exact locations of the machines) in the plant, the locations, length, and the intersections of forklift roads in and around the FLs, the length and location of the picking conveyor, the shuttle conveyor segments on the picking conveyor, and the number and the location of SWs that will be located on the picking conveyor. The construction of the new building of this plant is also a part of the design process. These decisions are types of property, capacity, and investment decisions and correspond to long-term (strategic) decisions within the decision-making context. Layout design is the most complicated part of this engineering project due to its content and scope; for this reason, the plant layout design is determined by all the teams involved in the project (i.e., civil engineers, architects, technicians) based on sound judgment and consensus after a couple of meetings, rather than following an analytical method in the decision-making process. This corresponds to the phenomenon of generating the layout alternatives based on experts' knowledge, as also emphasized in the introduction. There are several reasons and limitations behind this regarding the facility, and these points can be summarized in the following paragraphs.

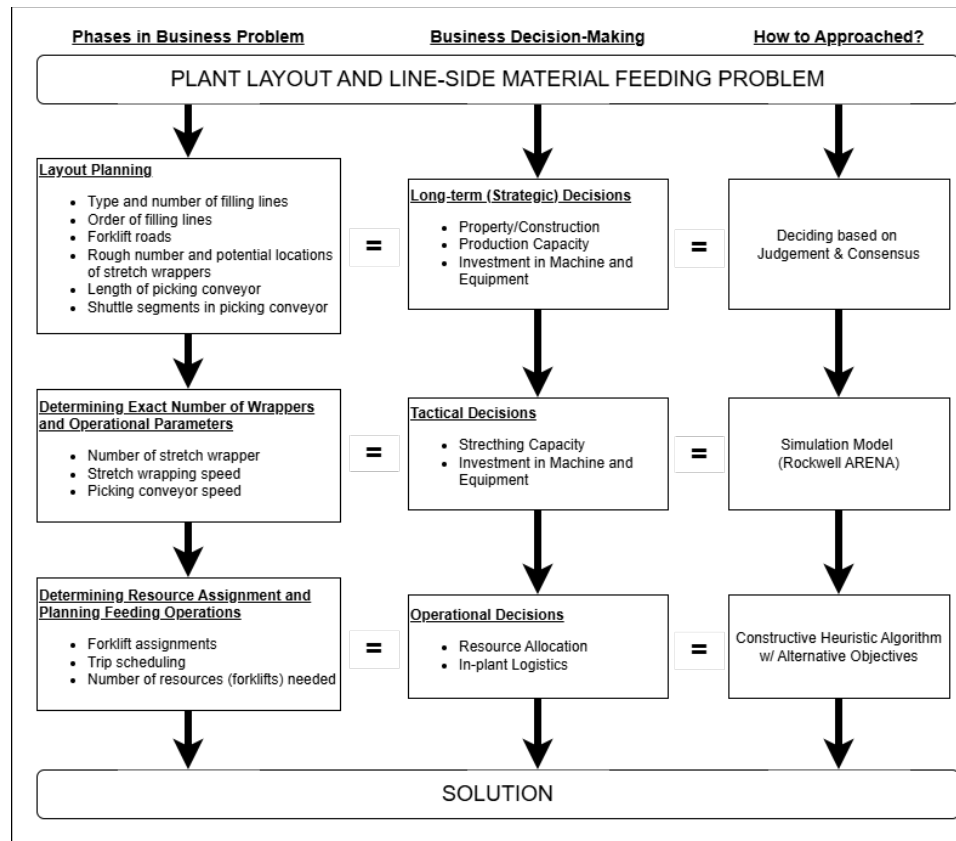


Figure 2. Proposed Solution Approach

As stated earlier, the filling plant is part of a large production facility for the company; therefore, the total available area is limited by surrounding buildings and infrastructure. The filling plant must be positioned in a specific way, taking into account the location of the material warehouse and the pipelines around it. By doing so, the entrances can be located on the north side of the building, allowing material flow from the warehouse. Besides, the filling units of the lines can be positioned accordingly to enable the efficient flow of lubricant oil from the large containers. These are the underlying constraints for constructing the new building. The teams designing the new building layout also consider the material flow from the warehouse to the line-side stations during production. To enable material flow, forklift roads and necessary spaces should also be included between the FLs, in addition to roads surrounding the production area in the new building. The machines to be purchased must be of certain types, in a minimum number, and have a minimum capacity to meet the increasing demand in the lubricant oil market.

Due to the static (structural) nature of the new building and the technical features of the FLs, certain units of certain machine types cannot be positioned at specific locations because they overlap with the building's columns. There are also technological ties among certain types of machines; for instance, machines that share common units, such as an empty container feeder, must be located next to each other in the new layout. When determining the order of machines, that there are $n!$ possible sequences of FLs in the building, where n denotes the number of machines. This leads to a huge number of layout designs to test against an evaluation metric. However, all the constraints discussed above affect the number of feasible layouts for the new layout. Besides, some observations further reduce the total number of alternative layouts, as follows. The company will purchase more than one machine of some types; there is no difference in locating either machine of the same type. This leads to the elimination of some combinations. The production speeds of the FLs are not equal; faster machines have higher throughput, meaning more pallets are moved to the picking conveyor. Thus, locating faster machines closer to the SWs reduces pallet accumulation on the picking conveyor. For all the stated reasons, only a limited number of feasible layouts are generated and accepted as candidate layouts for team meeting discussions. All teams involved in this engineering project have decided to continue with one particular layout among the candidates on consensus. Testing and evaluating a limited number of candidate layouts

is common in the literature because extensive effort is required to create a simulation model for each candidate (Pérez-Gosende et al. 2021, Zúñiga et al. 2020). In the following phases of the method, this layout is evaluated against the performance measures, and all tactical-level and operational-level decisions are made accordingly. The aim of all analyses conducted in the second and third phases is to evaluate and validate the designed layout in the first phase. In this study, we also follow the “layout then simulate” paradigm because, as already discussed in detail above, managerial philosophies, production technologies, and capacity are predetermined. The overall design of the new filling plant is constrained by the technical features and available space of the remaining units across the company's entire production facility. The overall technology requires a specific layout type, and a simulation methodology is used to validate the layout and determine the tactical decisions and the operational parameters.

In the second phase of the problem, the number of SWs and their processing times, and the speed of the picking conveyor are determined in the project. These decisions correspond to capacity decisions and are among the tactical decisions in the decision-making spectrum. In the second step, a simulation model in Rockwell ARENA software is developed, and capacity decisions regarding the picking conveyor and SWs are made based on an experiment with the model using alternative parameter values. The entire development process and details of the simulation model, including the conceptual model, logical model, and simulation model itself, are discussed in Section 3.1. As Burgess et al. (1993) suggested, simulation is the only methodology robust enough to examine the role and impact of overall complexity and other factors on performance. Other studies in the facility layout design literature also support this argument (Rizqi and Aulia 2019, Zhang et al. 2019, Zúñiga et al. 2020). Specifically, the simulation is used to compare layout configurations, identify bottlenecks before implementation, and account for long-term demand uncertainty. The third phase of the problem focuses on the operational decisions regarding the material feeding from the material warehouse to the line-side stations during the production process. These decisions involve determining the number and timing of replenishment trips for all material types and assigning (or allocating) resources (forklifts) to all replenishment trips during production. A greedy-type constructive heuristic procedure is proposed to solve the last part of the problem, and this is discussed in detail in Section 3.2.

3.1 Developing a Simulation Model

When developing the simulation model, we follow the basic steps of simulation modeling, namely conceptual model, logical model, and simulation model. The first step in the conceptual model is to define the study objectives and determine which questions the simulation study addresses. The *questions* to be answered are mainly about the operation of the PC and the capacity of the stretch wrapping. The detailed questions are as follows: (1) How many SWs are needed to stretch all pallets produced in a shift when all machines are running? (2) What is the minimum speed that SWs need to stretch all pallets produced in a shift? (3) How many pallets are accumulated on the PC in front of the SWs? (4) What is the minimum operating speed of the PC supposed to be? (5) What is the minimum operating speed of the shuttle conveyor supposed to be? The *assumptions* that also determine the level of detail of the simulation model are as follows: The production speeds of the new FLs are assumed to be the same as those of the existing lines, as this information is not yet known. It is assumed that the FLs run perfectly within their standard production time, without any breakdowns or stochastic variation, as requested by the company. There are sufficient SWs on the PC; thus, one can be used as a spare in case of a single wrapper breakdown during any shift. The possibility of a breakdown in any segment of the PC is discussed; however, the presence of two parallel lines and intersections at the exit of any FL makes alternative pallet routing on the PC possible. The *performance measures* utilized in the simulation experiment are: (1) Queue length, time in queue (seconds), and utilization rate for each SW, (2) queue length and time in queue (seconds) for each shuttle conveyor segment, (3) throughput of the entire system (time it takes to stretch all pallets in any shift). The last step in the conceptual model is to determine the elements and their relationships in the simulation model. Table 1 summarizes the basic elements of the simulation model, describes them, and finally provides information on how each element is incorporated into the simulation model. While discussing the logical model, we also refer to the simulation model because it cannot be illustrated with an ARENA screenshot. As one might expect, it is impossible to visualize such an extensive model comprising many modules. Similarly, it is not easy to present the full view of the logical model. For this reason, we divide the model's logic into parts and illustrate the specific logics (that are repeated multiple times) in the simulation model to give an idea of the model. To keep the simulation model's complexity manageable, we intentionally exclude the production process that covers container feeding, labeling, filling and capping, weighing, packaging, palletizing, and leaving FL. The pallets move to the PC, get stretched, and exit the system. The simulation model starts with the arrival of pallets produced (pallets just left the FL) at the PC.

Table 1. Conceptual Model: Elements of Simulation Model

Element	Description	Reflection in Simulation Model
Entity	Containers (in various sizes and machine)	Use a separate create module for each type
Attribute	Container size, stretch wrapper ID, time spent on PC segment or shuttle conveyor	Use assign modules
Resources	Stretch wrappers (SW), shuttle conveyor (SC) and conveyor cells (CC)	Define SW in the resource sheet, seize it in the process module Define SC as a transporter (data sheet) Define CC in the conveyor (data sheet)
Variable	Completion time of the last pallet	Defined as global variable
State	Status of (busy/idle) conveyor cells, shuttle conveyor, and stretch wrappers (SW)	Access and exit modules for CCs Enter and Leave modules for SC Seize-Delay-Release Modules for SW
Event	Arrival of pallets produced, departure of stretched pallets, start/end of stretching, arrival/departure of shuttle conveyor, loading/unloading for picking conveyor	N/A
Activity	Stretching, transferring on SC and PC loading/unloading time for SC	Process module for stretching process Convey module for the PC segment Delay module for SC

The picking conveyor is designed as two parallel lines from the west side to the east side of the building. The conveyor consists of rectangular conveyor segments and square diverter conveyors across the lines. There are also perpendicular conveyor segments and diverter conveyors connecting the two lines in the north-south direction, aligned with the FLs. The two SWs are located at the end of the two parallel lines, and one SW is located at the midpoint of the picking conveyor (illustrated as a rough layout in Figure 1b). The logical flow of the simulation model is illustrated in Figure 3, which covers only part of the model and shows pallets leaving filling line 1 (FL1) and entering the picking conveyor, moving along its segments. The logical model for pallet movement from other FLs is the same as the architecture shown in Figure 3. The simulation logic on any picking conveyor (PC) segment and shuttle conveyor (SC) segment is left as a black box and presented in more detail in Figures 4 and 5, respectively. The stretching operation itself is depicted in Figure 6.

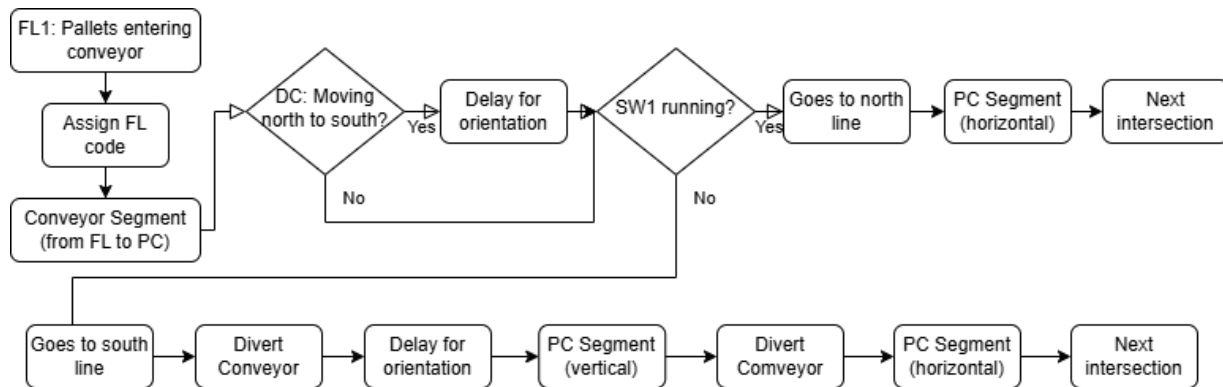


Figure 3. Logical Flow in ARENA for Pallets Leaving Filling Line 1 (replicated multiple times, see Figure 1b)

We develop the model using the ARENA simulation software from Rockwell Software. The simulation model is a terminating simulation; it begins when the FLs start production and stops when the last pallet leaves the system. An experiment is designed to include all pairwise comparisons between two PC speeds and three SW speeds. Let V_s and V_t denote the processing time of the SW (in seconds per pallet) and the PC speed (in meters per minute), respectively. Three alternative values (e.g., 1x, 0.8x, 0.53x) are tested for the SW processing time, denoted V_s^1 , V_s^2 , and V_s^3 in decreasing order. Moreover, two alternative values are considered in the experiment for PC speed, denoted V_t^1 and V_t^2 while V_t^2 represents a 50% increase over V_t^1 . The experiment results are presented and discussed in Section 5.



Figure 4. Logical Flow in ARENA for any Picking Conveyor Segment (replicated multiple times, see Figure 1b)



Figure 5. Logical Flow in ARENA for any Shuttle Conveyor Segment (replicated multiple times, see Figure 1b)

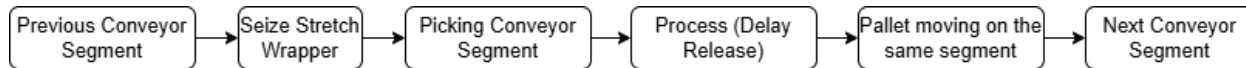


Figure 6. Logical Flow in ARENA for Stretch Wrapping Process (replicated multiple times, see Figure 1b)

3.2 Modeling Material Feeding Operations

We propose a greedy-type constructive heuristic algorithm that makes all decisions within the scope of material feeding operations. The most important input data for the algorithm is the production plan, which is known in advance but varies from day to day. A different combination of machines is operated in each production plan, depending on market demand. There are some assumptions to frame the material feeding operations as follows. The time spent in the warehouse (picking time) to locate the material pallet and move it to the exit is neglected. We assume that the pallet to be transported to the production line-side station is ready for pickup at the warehouse entrance (picking up area). Total number of line-side stations: between five and seven per machine, depending on the product type, since some containers are placed into large packages, while others are not. There is a fleet of forklifts (resource) for material handling, and the aim of this step is to determine the total number of forklifts needed to perform all feeding operations. The routes from the material warehouse to each line-side station are fixed. It is assumed that any forklift that arrives at the warehouse entrance picks up the pallet, follows the fixed route, drops off the pallet, and returns to the warehouse following the same route in the return trip. The flow of the proposed algorithm is presented as pseudo-code in Table 2. The algorithm reads the production plan, generates all replenishment trips with their scheduled times, and sorts them in ascending order of departure. Three assignment approaches are then applied sequentially: (1) minimize the number of resources, (2) fair resource assignment, and (3) dedicated assignment utilizing the fair assignment. The output of Approach 1, the total number of forklifts, is incorporated as an input into Approach 2. In the end, all replenishment trips and forklift assignments are reported as an outcome. A fourth approach- regional assignment, also known as zoning- was explored during the design phase; however, the irregular forklift geometry and multi-access structure of the plant prevent a clean zone delineation, making this approach infeasible in the current configuration. Zone-based assignment is therefore identified as a direction for future work, contingent on establishing a suitable partitioning criterion for this plant type.

Table 2. Pseudo Code of Constructive Heuristic Algorithm (with alternative designs)

Initialization Read raw data (production plan and material requirement for all running machines) For each filling line For each material type (empty container, cap, empty pallet, separator, package) Calculate the required time at the station (delivery time) Create a replenishment trip for each material feeding operation (departure and arrival times) Sort all replenishment trips based on departure times in ascending order Approach 1: Minimize the Number of Resources (Forklift) For each replenishment trip	Approach 2: Fair Resource Assignment for Solution Obtained via Approach 1 For each replenishment trip Find the resource with the minimum number of assignments and assign it to the next replenishment trip Return resource assignments and the total number of discretized resources Approach 3: Dedicated Assignment (with Fair Resource Assignment) For each filling line For each replenishment trip Find the resource with the minimum number of assignments and assign it to the next replenishment trip
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If there is no available resource (forklift) Create a resource (forklift) Assign the resource to the next replenishment trip Else Get the first available resource and assign it to the next replenishment trip Return the resource assignment and the total number of discretized resources	Create a resource whenever necessary (if one does not exist or is not available) Return resource assignments and the total number of discretized resources <i>*The overall computational complexity $O(T \log T)$, dominated by the trip-sorting step, where T denotes the total number of replenishment trips. For the production plans tested, T ranges from 212 to 316, and all three approaches complete in well under a few seconds on a standard personal computer.</i>
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4. Data Collection

The data collection process was carried out in three streams. The first data set, provided directly by the company, encompasses product specifications (container sizes from 0.5L to 30L, packaging types, and pallet layer configurations) and product parameters (filling time, pallets per shift, and annual shifts per FL). The second set of data we collected: processing times for each operation observed on a production line. The data collection process is demonstrated to the engineering firm's team and practiced by them when collecting the third data set. The last set of data was collected by the engineering firm that executed the company's entire upgrade project. This set includes SW alternatives with their stretching speed and alternative conveyor speed. The exact dimensions of the new building, the exact locations of the machines, and the length of conveyor and shuttle segments were also provided by the architecture department of the engineering firm. The engineering firm's role also includes collecting detailed data on each FL, including conveyor length, speed, and processing times, using video recordings. We decode the records and convert them into data values for analysis. There is also an additional data set that includes the transformed data from raw data, which is then verified by the company's team for use in analysis. This data set includes the total number of pallets of each material to be fed to each FL. The total number of pallets equals the total number of replenishment trips and is an essential input to the proposed heuristic algorithm. The layout can also be classified as an input and determined by consensus, as presented in Figure 1b, and the types and order of machines are provided in Table 3. Due to the confidentiality of the business problem, most information about the problem elements, such as machines, SWs, and FLs, is anonymized, and only a limited set of data is disclosed in the paper. As part of the data collection, there is no need to conduct an input analysis, since any stochastic nature of the process is assumed to be outside the scope of the study. Since all input parameters are treated as fixed constants and no stochastic distributions are used, the simulation model is fully deterministic. Under these conditions, multiple replications produce identical outputs, and a single run per model version is both necessary and sufficient to observe system performance (Law 2015).

Table 3. Simulation Model Parameters (Order and Type of Machines)

Line	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Line 7	Line 8
Machine type	MC3	MC2.1	MC4	MC1.1	MC5	MC6	MC2.2	MC1.2
Filling time (min/pallet)	30	6.67	20	8	18	5	6.67	8
# of pallet/hour	2	9	3	7.5	3.33	12	9	7.5

5. Results and Discussion

The results of the simulation experiment are presented in Table 4. The six versions of the simulation model are listed in the rows, and the total simulation time (hours), stretch-wrapper utilization rate in percentage, time-average queue length, and time-average time in queue in seconds at the SWs are provided for three SWs in the columns, respectively. The picking conveyor speed (V_t) does not have as significant an effect on total production time as the processing time (V_s) of the SWs. Given that the faster the stretching processing time, the more expensive the SW, it makes more sense to make a significant investment in SW. The stretch wrapping operation should be performed at a maximum speed of V_s^2 seconds per pallet. In all versions of the simulation model, the production cannot be completed within an 8-hour shift. Overtime exceeds one hour for versions 1 and 4 and is less than half an hour for versions 3, 5, and 6. Simulation model versions 1 and 4 are not feasible considering the number of pallets waiting in the queue of the second SW (SW2). Meanwhile, the third SW (SW3) is considered a spare, so no values are shown in the results table. Additionally, there is no need to purchase identical SWs for the new plant; the second SW should be of V_s^3 ; however, any speed would be sufficient and an appropriate solution, given the cost-benefit trade-off. If the newly purchased SWs are

supposed to be identical in the new plant, then the SWs must have a processing speed of V_s^3 since a setting of SWs in type of V_s^3 would be a very tight and risky solution in terms of the number of pallets accumulating in front of SWs.

Table 4. Results of the Simulation Experiment

Version	V_t	V_s	Run Time	Utilization Rate (%)			Average Queue Length			Avg. Time in Queue (sec)		
				SW1	SW2	SW3	SW1	SW2	SW3	SW1	SW2	SW3
MV1	V_t^1	V_s^1	9.79	56.55	88.05	-	0.42	38.59	-	50.96	3024.08	-
MV2	V_t^1	V_s^2	8.56	55.31	86.13	-	0.34	12.29	-	35.80	841.84	-
MV3	V_t^1	V_s^3	8.16	48.21	75.06	-	0.25	0.78	-	24.93	51.23	-
MV4	V_t^2	V_s^1	9.40	56.37	87.77	-	0.40	31.19	-	46.86	2345.67	-
MV5	V_t^2	V_s^2	8.21	54.79	85.31	-	0.33	4.38	-	33.80	287.70	-
MV6	V_t^2	V_s^3	8.13	45.43	70.75	-	0.23	0.65	-	23.16	42.04	-

The results of the heuristic algorithm are presented in Table 5, which displays eight different production plans with varying numbers of machines as noted in the last column. For each approach of the algorithm, the number of forklifts utilized in the material feeding operations, the minimum and maximum number of trips assigned to forklifts utilized in the corresponding production plan. As the results show, Approach 1 requires the fewest forklifts, while Approach 3 requires the most resources. While Approach 1 provides the best solution in terms of the number of resources, Approach 2 improves the result and allocates the total number of replenishment trips fairly across the resources used. The transformed data, replenishment schedules, and forklift assignments generated by the proposed heuristic were reviewed in detail by the company's IE team. The team confirmed that the results are consistent with operational expectations and domain knowledge accumulated from years of managing the existing plant. Furthermore, the selected layout and the recommended SW configuration were formally adopted as the basis for the construction and procurement phase of the upgrade project, thereby constituting real-world acceptance of the study's outputs as industry validation.

6. Conclusion

This study presented a sequential simulation-heuristic solution framework for the integrated facility layout and line-side material feeding problem – a problem class underrepresented in the literature, where most integrated design studies focus on block layouts or aisle network design rather than operational feeding logistics in greenfield plants. The proposed approach decomposed the problem into three phases aligned with the strategic, tactical, and operational decision levels inherent in greenfield industrial projects. In the layout phase, the detailed arrangement of FLs, forklift roads, PC, and SWs was established through expert consensus under tight structural and technological constraints. The simulation phase confirmed that SW processing speed is the dominant driver of system performance: selecting V_s^2 over V_s^1 reduces average queue time at SW2 by over 70% and brings overtime below 30 minutes, while the PC speed can be set at the lower value V_t^1 without compromising production completion time. The heuristic algorithm successfully generated replenishment schedules and forklift assignments for all eight production plans tested, requiring between five and 24 forklifts, depending on the number of running FLs and the assignment policy applied. Approach 1 minimizes the number of forklifts; Approach 2 distributes the workload more equitably with the same number of resources; and Approach 3 offers operational predictability through dedicated assignments, at the cost of a larger fleet.

Table 5. Number of Forklifts in Alternative Solutions and Approaches of the Proposed Algorithm

# of Lines	Approach 1			Approach 2			Approach 3			Running Line IDs (Machines-MC) with container types (c. liter)
	# of Fork.	# of Trips		# of Fork.	# of Trips		# of Fork.	# of Trips		
		Min	Max		Min	Max		Min	Max	
3	5	1	212	5	58	59	7	14	71	3, 1.1, 1.2
4	5	1	226	5	69	70	9	14	71	3, 1.1, 5 (c5), 1.2
5	5	12	245	5	94	95	13	14	71	3, 2.1 (c4), 1.1, 5 (c5), 1.2
5	6	1	245	6	78	79	14	14	71	3, 2.1 (c4), 1.1, 5 (c7), 1.2
6	7	2	299	7	99	100	17	14	71	3, 2.1 (c3), 1.1, 5 (c5), 2.2 (c3), 1.2
7	7	10	306	7	107	108	19	14	71	3, 2.1 (c3), 1.1, 5 (c5), 2.2 (c3), 1.2
8	8	8	306	8	111	112	22	14	71	3, 2.1 (c3), 4, 1.1, 5 (c5), 6, 2.2 (c3), 1.2
8	10	1	316	10	95	96	24	14	71	3, 2.1 (c4), 4, 1.1, 5 (c7), 6, 2.2 (c4), 1.2

From a managerial standpoint, the study demonstrates that operational-level decisions, such as conveyor speed and wrapping capacity, substantially affect capital investment decisions, and that these interactions should be evaluated before finalizing equipment procurement. Future work will extend this framework towards a simultaneous optimization approach that integrates layout evaluation with feeding operations under stochastic conditions, including machine breakdowns, forklift congestion, and variable demand.

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Biography

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