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SCM600 Logistics and Supply Chain Management

Facility Layout Planning and Job Shop Scheduling – A survey

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Preface

This bachelor's thesis is written as a final assignment of the bachelor program in Logistics and Supply Chain Management at Molde University College – Specialized University in Logistics 2020.

We chose to focus our thesis on current research in the field of Facility Layout Planning and Job Shop Scheduling. This to help modern manufacturers by guiding future research opportunities.

We would like to thank everyone who has helped us during our work. There have been difficult questions and challenging times, all of which we could not have overcome without the generous help offered to us. We would also like to give a special salute to our supervisor Yury Redutskiy for his incredible guidance, both on an academic and personal level. Without him, there would be no thesis.

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Abstract

This paper starts by gently introducing the topic of facility layout and its impact on material handling costs. The different ways of approaching facility layout and the different classifications for layout are also introduced, such as product, process, and cellular layout. Three research questions are presented to lay the foundation of the thesis before the methodology used in this paper is described.

Some background into production as part of the supply chain, as well as providing the historical perspective of facility layout planning and job shop scheduling is given to create a more holistic view of the topics presented in this thesis.

A literature review that was done found that there is an absence of literature on facility layout planning compared to other subjects, such as leadership, employee motivation, supply chain management, and organizational change, even taking the specialized field of facility layout planning into account.

An analysis of the problem modelling used in facility layout planning and job shop scheduling was performed, and an appraisal of the papers analyzed was provided, showing a significant discrepancy in the modelling used by the researchers and attaining a score between 18 out of 35 and 34 out of 35.

It was found that the placement of the facilities in the plant area considerably impacts manufacturing costs, work in process, lead times, and productivity. Many studies, including those in this literature review, have been published to investigate the different methods used for addressing facility layout problems. However, these studies focus on a tightly specific aspect of layout problems, including those pertaining to material handling, dynamic layout problems, particular resolution approaches multi-floor facility, unequal-area facilities, multi-workshop facility, multi-objective facility layout, single row facility, and, stochastic dynamic facility.

In addition, sustainable operations management has been gaining attention not only among researchers but also among both businesses and practitioners. The concept of sustainable operations management is now seriously considered because of the increasing scarcity of natural resources and rapid change in climate and increasing social inequality. The

sustainable operations management field has been quickly replaced by the holistic term sustainable supply chain management. Sustainable operations decisions and specifically facility layout are crucial and have to be guided by low cost and environmental-related regulatory norms.

It is proposed that a hybrid integrated genetic algorithm for solving job shop scheduling problems that consider transportation delays and facility layout problems as an integrated problem is a possible solution. For some time now, the natural direction for work and research on facility layout planning and job shop scheduling has been the estimation of impacts of integrated methods on actual manufacturing systems. In future research, researchers can extend integrated methods by considering the dynamic nature of facility layout planning and job shop scheduling problems to better reflect today's dynamic manufacturing scenarios.

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1.0 Introduction

1.1 Background: Facility Layout and Job Shop Scheduling in Research and Practice

An effective and efficient facility layout is vital for manufacturing plants. Facility layout is defined as "the arrangement of machines/aisles, tools, etc., on the shop floor in an efficient way so that […] material movement and hazards can be minimized" (Kumar and Singh 2018). The layout design is a strategic issue that can strongly impact the performance of manufacturing and service firms (Kulturel-Konak and Konak 2013). Engineers, manufacturing employees, and company decision-makers are striving to achieve the optimal layout in order to optimize material flow distance, total product produced, cycle time, waiting time, and facility utilization, among others. Evidence shows that if a manufacturing plant has an efficient layout design, production costs reduce by 10% to 30%, while material handling costs (MHC) decrease by 15% to 40% (Kumar and Singh 2018). Here, it must be noted that aggregate MHC is an appropriate measure for evaluating the efficiency of the layout and accounts for 20% to 50% of the total manufacturing cost (Kulturel-Konak and Konak 2013).

There are different ways manufacturing firms approach facility layout. There are three general categories of facility layout, namely, static layout, dynamic layout, and robust layout (Moslemipour et al. 2011). With the static layout, the layout design is fixed for different periods, and there is no re-arrangement cost. The disadvantage of the static layout is that it lacks the flexibility needed for dealing with variations in products and their demands (Moslemipour et al. 2011). Therefore, to address issues associated with static facility layout, dynamic layouts have to be designed.

On the other hand, with the dynamic layout, MHC and re-arrangement costs for multi-periods are minimized while the layout design for each period is executed. Layout design for two periods is different, while re-arrangement costs accrue out of mantling/dismantling of machines. Meanwhile, the robust facility layout is designed to address issues pertinent to product variations that occur over the planning horizon. With the robust layout, demand is stochastic, and the expected value of demand is computed (Moslemipour et al. 2011).

There are also different classifications of layouts, product layout, process layout, and cellular layout (Nadia and Lai-Soon 2016). Product layout is sometimes referred to as the straight-line layout, commonly used for highly standardized and high-volume products. This means to say that product layout is not suitable for manufacturing plants with low volumes of production. In comparison, the process layout is typically used for standardized and low volume products. Usually, similar functions or processes are grouped together and labeled as departments. The cellular layout, which is a compromise between product and process layouts, is done according to group technology philosophy wherein similar parts in so-called part families are grouped together (Nadia and Lai-Soon 2016). These part families are subsequently designated to machine cells or groups of machines that undertake different functions. Cellular layout is more advantageous than the two other classifications because studies have shown its positive outcomes in the form of "reduced MHC, lead time, wastage, work-in-process inventory, hazards and [improvement in] productivity and quality" (Kumar and Singh 2018).

Despite these approaches to layout design, as well as well-established classification of facility layouts, facility layout problems (FLPs) are still notoriously ubiquitous. Researchers are often classifying FLP into deterministic and stochastic, as well as static and dynamic (Tayal et al. 2016). In the manufacturing environment, product flow could be uncertain, or it could be defined for multiple time intervals, both of which indicate that facility layout may need to adapt to changes. Some studies have also led to the identification of the dynamic facility layout problem (DFLP), which results from both demand and supply uncertainty. Existing literature shows different models, classifications, and theories on FLP, and their association with (a) quantitative criteria, such as shape ratio, MHC, re-arrangement cost, adjacency score, as well as, space demand; and (b) qualitative criteria, including, flexibility and quality (Tayal et al. 2016). However, there is little empirical knowledge about the appropriate approaches to FLP needed.

Over the past two decades, research into scheduling, particularly in its most common industrial form of job shop scheduling (JSS), has had increased significance because of the demands of industry (Schniederjans et al. 2013). Although considerable progress has been achieved academically, there are still persistent doubts about the transfer of the technology to fit the flexibility requirements of modern production facilities. In this regard, JSS has attracted attention in extant literature, although JSS is made more difficult because of the need to satisfy conflicting demands of both batch and continuous production (Arisha et al. 2001). Researchers have been able to develop many types of analytical techniques that will be discussed later in this study, including linear programming or heuristic approaches. Fairly recently, most of the studies have begun dealing with new solving techniques using simulation and artificial intelligence techniques (Schniederjans et al. 2013).

1.2 Limitations

The importance of finding solutions to FLPs and JSS through an integrated model cannot be emphasized enough. However, because of the complexity of both FLP and JSS, as well as the allotted time for the completion of this thesis, the use of modelling has been precluded. Notably, there is currently no singular modeling approach that applies to all types of FLP and would have been a valid and relevant study objective if not for the aforementioned constraints. Modeling has become beyond the scope of this thesis because modeling is an evolving process that requires repeated testing to attain optimal results. In light of constraints, this study instead seeks to achieve the next best thing, which is to review current models and solutions used for FLP, with attention to JSS. In relation to these, the real-life application of FLP and JSS have been disregarded for this study, which focuses instead on current knowledge about FLP and JSS.

1.3 Research Questions

In an effort to help future research and modern manufacturers, the following three research questions have been structured:

Q1. How is current research treating FLP?

Q2. How is current research treating JSS?

Q3. What is current research lacking?

Based on a cursory review of the literature, these research questions have been deemed sufficiently robust to accommodate a strong qualitative exploration of the research problem.

2.0 Methodology

This section discusses the methods used in conducting this study, which is the systematic literature review method. Notably, a researcher uses the literature review method in order to evaluate present theoretical and scientific knowledge about a given phenomenon (McCourt et al. 2013). Through this method, the researcher synthesizes what is known and what is unknown about that said phenomenon. The result of this method is a systematic and critical appraisal of the most important and relevant literature on a specific phenomenon, which for this study, pertains to JSS as an integration to FLP. This section on Methodology describes the literature review method, inclusion and exclusion criteria used for selecting studies to be reviewed, the result of the literature search, as well as, the critical appraisal tool used for the final selection of articles to be critically analyzed.

The literature review method is facilitated by the wealth of studies and articles in existing literature. Robinson and Reed (1998) explain that a literature review is "a systematic search of published work to find out what is already known about the intended research topic". For this Literature Review to be effective, it should thus be "a systematic and explicit methodology to identify, select and critically evaluate relevant studies, and collect and analyze the data emerging from the studies included in it" (Abalos et al. 2001). As mentioned earlier, this literature review covers relevant existing knowledge pertaining to FLP and JSS. Literature reviews are designed in this manner, based on the rationale that the more knowledge a researcher develops about the topic being studied, the better that phenomenon is understood. In other words, this literature review on FLP and JSS not only synthesizes existing literature but also facilitates a better understanding of models and solutions, and when they are best applicable.

For this literature review, a time frame 2011 to 2020 was selected to ensure that only relevant and current studies are included. The search for literature was conducted through electronic databases. Access to ScienceDirect was obtained. In addition, other databases searched were Taylor & Francis, Wiley, and SAGE. Inclusion criteria were used to select the articles, namely, (a) published in the last ten years to achieve relevancy; and (b) published in the English language with full-text accessibility. The search terms used were the following:

- Facility Layout
- Facility Layout Problem

- Facility Layout Problem + Solution
- Facility Layout + Model
- Facility Layout Problem + Model

On the other hand, search terms used for JSS were the following:

- Job shop scheduling
- Job shop scheduling + facility layout problem
- Job shop scheduling + FLP
- Job shop scheduling + facility
- Job shop + facility layout problem
- Job shop + facility layout
- JSS + facility layout problem
- JSS + FLP

Upon producing the results of this search, the methodology tool Critical Appraisal will be employed (Snyder 2019).

3.0 Production as Part of the Supply Chain

In today's age of globalization, global production networks connect multiple producers involved in fragmented manufacturing processes (Alexander 2019). To note, at the beginning of the 20th century, F.W. Taylor (1911) published *The Principles of Scientific Management*, proposing a highly efficient management system. In this system is the concept of division of labor that permits specialization and simplification. Taylor (1911) extended this concept by explaining a standardization paradigm, proposing the notion that planning and control functions may be effectively divided. Taylor's concept of standardization extended from objects to tasks of the idea that interchangeable parts increase efficiency. Notably, Henry Ford was one of the first successful businessmen to have applied scientific management effectively, developing a single-product assembly line production system that maximized production quantity attained under a given level of investment (Alexander 2019). Although it has been over a century since Taylor's book was published, scientific management has continued to expand in application around the world, adopted even in communist countries (Alexander 2019).

In time, Japanese businesses began studying and implementing scientific management and expand upon it. Subsequently, Japanese enterprises were able to develop management principles, starting with manufacturing and production, in alignment with the Japanese business culture. These include Company-Wide Quality Control, Total Preventive Maintenance, Japanese Institute of Plant Engineers, and Just-In-Time Production (Ishii 2013). These approaches allowed Japanese firms to attain a global leadership position in production until the end of the 20th century. Other countries also developed management standards, including the ISO 9000 and ISO 14000 standards (Ishii 2013). These standards utilize a cyclic model of management entailing iterative processes of planning, verifying, and acting (Ishii 2013). International management standards have changed to currently reflect changes in the global market for products wherein there has been a shift from being seller-driven to buyer-driven. Moreover, management standards now emphasize that manufacturing and production should be undertaken in a socially responsible manner. The customer-driven economy also reflects a shift of economic power from suppliers to customers (Ishii 2013).

Since the mid-20th century, the Association for Progressive Communications has been helping in developing numerous management tools for production. These tools encompass Material Requirement Planning, Enterprise Resource Planning, software for a supply-chain management system, Customer Satisfaction Management, and Customer Relationship Management (Ishii 2013). The success of these efficient management systems continues to affirm early management insight that producers must innovate or improve their production systems, including division of work or specialization, to remain competitive and sustain their market share.

It was around that time in the 20th century that supply chain management (SCM) emerged as a field under management. To note, SCM is defined as "the integration of key business processes from end-user through original suppliers" (Manzini et al. 2014). Two of the most essential issues for SCM are the (a) determination of the best performing logistic network configurations; and (b) identification of the appropriate management rules and procedures. Many companies around the world have had to face other issues relative to SCM, including, (a) defining the most convenient number of manufacturing and distribution facilities, such as production plants, distribution centers, transit points, hubs, and wholesalers; (b) selecting geographical locations; (c) assigning product demand from the demand points to the suppliers, such as distributors and wholesalers; (d) managing storage and inventory systems; (e) defining the most appropriate transportation modes; and (f) managing vehicle fleets with attention to loading, scheduling, and routing (Ishii 2013). These aspects of SCM highlight the need for configuration of a logistic network on the one hand, and the operations management and control on the other. Logistic managers now have to address challenges pertaining to measuring long-term strategic, mid-term tactical, and short-term operational decisions.

3.1 Productivity and Supply Chains

A supply chain is an interlinked network comprised of business units used for (a) acquiring raw material; (b) producing finished goods from raw materials; (c) adding value to the products; (d) distributing and promoting products; and (e) exchanging information among various related business firms (Shukla et al. 2009). Different players in a supply chain are suppliers, manufacturers, distributors, and customers, who coordinate with one another for financial and information exchanges, as well as for transportation provisions. All stages in a supply chain are typically designed to satisfy the market in the most effective manner. For example, if a customer wants on-time delivery of products at a low price without any compromise in the quality of the product, the primary goal of the supply chain is to satisfy customer needs while attaining profitability for all the interlinked business units (Shukla et al. 2009). In other words, the importance of the supply chain is to ensure efficiency and effectiveness in delivering products according to customers' preferences without compromising quality, while at the same time, ensure that all business units in that supply chain are profitable.

In an integrated supply chain environment, there are several stages or departments through which products are grouped into batches on the basis of their characteristics. For example, in the machining department, the products are batched together according to their shape, size, material, and dimension, among others (Shukla et al. 2009). Any batch is defined by its set of characteristics and specific lot-size and due-date. The operation time needed for stages in the integrated supply chain depends upon the characteristic of a batch processed in that stage. When the characteristics of two consecutive batches do not match in any stage, a setup modification is needed, entailing a given setup time and hinges on the characteristics of successive batches in that given stage. It is assumed in literature "that a common sequence of batches is processed in all the stages of the supply chain" (Shukla et al. 2009). Due to the common sequencing and different processing times for each batch, there are various time losses for the different stages of a supply chain, attributable to waiting, idling, and blocking of machines or batches in different stages.

Therefore, in terms of productivity, one of the main hurdles accosting manufacturers is achieving the appropriate coordination of their resources at minimum cost (Shukla et al. 2009). Goals of timely delivery, combined with cost minimization, may be achieved through the correct use of available resources that reduce variable time losses, including setup time, idling time, blocking time (Shukla et al. 2009). Blocking and idling times hinge upon the time it takes to process consecutive batches in consecutive stages. When blocking is done, buffers are used to store the batch. However, these buffers need to be maintained at all stages, thereby driving production costs higher. Dependence of all the variable time losses on the sequence in which batches are processed requires enterprises to find a more efficient sequencing mechanism in order to reduce cost and improve timely delivery.

3.2 Approaches in Control

Supply chain systems are typically complicated and may exist on a large scale in the real-world industries (Lu et al. 2005). Different studies show that supply chain systems are designed and analyzed according to different modelling approaches. These modelling approaches are generally categorized as (a) deterministic analytical model, where all variables are known and specified; (b) stochastic analytical model, in which at least one value of the variables is unknown and assumed to follow a specific probability distribution; (c) a simulation model, which is typically used for evaluating the effectiveness of different SCM control strategies; and (d) an agent-based model that has been studied in recent years and provides flexibility and responsiveness for real-time supply chain systems (Lu et al. 2005).

One of the traditional production control research centers on hierarchical and heterarchical control architecture (Lu et al. 2005). Hierarchical control is usually a centralized and top-down control system. Controllers at the higher levels are decision-makers who provide guidelines for lower-level controllers to follow. This control system incorporates a global view but is rigid and constrained within dynamic system environments. On the other hand, to make control more adaptable, a heterarchical control system has been proposed. The heterarchical system primarily focuses on interactions between same-level controllers to enable flexibility while at the same time, ignoring interactions between different-level controllers (Lu et al. 2005). The hierarchical and heterarchical control systems contrast with one another because they serve as two opposite extreme ends of a continuum of control architectures. Consequently, modern control architecture emphasizes a hybrid scheme amid the two extremes. Controllers, whatever their levels are, should be able to negotiate and collaborate with each other to make their own decisions.

Today's industrial leaders should realize that the more efficient their collaborations with their supply chain partners, the more significant advantage they could have over their market rivals (Lu et al. 2005). These collaborations result in mutually beneficial interdependence of players in the supply chain (Lu et al. 2005). Considerable evidence shows that partnerships enhance system performance in a supply chain (Lu et al. 2005). On the other hand, some companies also use agent-based models for control. Here, the term agent refers to an entity that can perform a task continuously and autonomously in a dynamic environment. Agent-based control systems are autonomously controlled by agents who make decisions in real-time, using a control architecture that significantly improves flexibility and responsiveness of production systems since these adapt to system fluctuations in real-time (Lu et al. 2005). Different studies have been done to test the concept of agent-based models for control in production, including, multi-agent architecture for integrating design, manufacturing, and shop-floor control activities; bidding-based process planning and scheduling scheme in a multi-agent system integrating design, process planning, and scheduling in a market environment; and, multi-agent approach in developing a distributed manufacturing architecture and defining the autonomous building blocks of that system (Lu et al. 2005).

4.0 Historical Perspective

4.1 Technological Revolution

Industrialization took place in the area of manufacturing and began in Great Britain and spread to Western Europe, the United States, and other countries commencing in the 18th century (Yao and Lin 2016). Consequently, manufacturing and production significantly transformed. Today in the 21st century, there is a new industrial revolution that has shifted to mass customization and even to mass personalization (Yao and Lin 2016). However, such a shift toward customization, particularly personalization, is still to be completed. Indeed, because of economic challenges, many manufacturing firms still use the assemble-to-order configuration in order to produce standardized products for a large number of grouped customers (Yao and Lin 2016). This is a difficult way of reaching the extent of market-of-one, particularly for individually customized products that fulfill affective and cognitive customer needs. Nevertheless, rapid advances in ubiquitous computing, the Internet of Things, as well as cloud computing, have been allowing manufacturing firms to produce one-of-a-kind products. An excellent example of this is the emergence of 3D printing, through which personalization has become a potentially disruptive strategy that makes the market-of-one a reality.

At the same time, the emergence of Enterprise 2.0, crowdsourcing, peer production, and Wikinomics, along with social networking tools such as blogging, social bookmarking, and Facebook and LinkedIn, are also currently helpful in enterprise environments, and at the same time, place an increased emphasis on social aspects (Yao and Lin 2016). It is important to note that industrial revolutions impact and are impacted by manufacturing paradigms, and manufacturing leadership relies on leading new technology paradigms (Yao and Lin 2016). For the emergent technology-oriented revolution, there are various visions coming from researchers, scholars, and practitioners, regarding the future industry. For example, some scientists believe that the new revolution that commenced in 2005, which they refer to as the Fifth Revolution, is defined by mass personalization, occurring after low-volume customization, low-volume standardization, mass production, or high-volume standardization, and mass customization.

4.2 Facility Layout Planning

The origins of FLP date back to the 1960s, although it was in 1985 that alternative approaches to the layout problem and solution through algorithms were earnestly studied (Liggett 2000). Since that time, commercial products have now become available according to these original algorithms, as well as on research pertaining to new solutions and techniques, including simulated annealing and most recently genetic optimization, that are being applied to the problem. Facility layout addresses the allocation of activities to space in order to meet specific criteria, such as for instance, area requirements and optimization of communication costs.

FLPs range in scale from assigning activities to cities, sites, campuses, or buildings, to locating personnel and equipment on a single floor of a building. A layout problem may emerge during the design and allocation of space in a new building or reassignment of space in an existing building (Liggett 2000). During the conceptual design stage, space is allocated within a new facility so that it can be used for testing alternative options for building configuration. Plans are assessed according to the best use of space to determine matters such as the optimal number of floors, the perimeter of the plan, and so forth. In an existing building, layout tools are utilized for problems of space management.

Most of the research and development pertaining to FLP focuses on the floor plan layout problem, the physical arrangement of space on a plan, also referred to as the block plan (Liggett 2000). However, there are also other applications of the space allocation problem, such as for instance, assigning activities to multiple floors of a building, also referred to as the stack plan problem. There are different approaches to spatial allocation problems, varying in terms of the type of problem addressed and the criteria used for generating, comparing, and evaluating solutions (Liggett 2000).

It is important to note that all space planning problems are comprised of activities to be located and the space within which they are to be located. Space is represented in different ways, thereby enabling classification of different types of layout problems. The following are examples:

a. Space that are discrete objects in one-to-one assignment problem;
b. Space as area in many-to-one assignment problem, including, a stacking problem; and
c. Space as area and shape in blocking or floor plan layout problem (Liggett 2000).

The appropriate definition and representation of physical space are crucial because these affect problem formulation and solution techniques. Meanwhile, the most straightforward layout problem requires the assignation of a set of discrete activities to a set of discrete locations in a manner that each activity is assigned to a single location (Liggett 2000). This is referred to as the one-to-one assignment problem or the equal area layout problem and has been studied and applied on both the micro and macro levels. For instance, the assignment of buildings to sites, or of employees to preexisting offices or workstations, may be accomplished through a one-to-one assignment. Here, issues of size and shape do not enter into the layout process (Liggett 2000). How activity areas are apportioned among floors and as such as crucial considerations in developing, implementing, and evaluating facility layout plans. In both of these cases, activity size remains a relatively simple issue because actual activity shapes are not in consideration.

Meanwhile, the most complex problems to represent are those at the block-plan level, wherein an activity is represented as a polygon on the plan (Liggett 2000). This polygon is supposed to be as adaptable in all forms of shape and location while at the same time, maintain the required activity area. In addition to these, methods for dealing with unequal areas also have a significant influence on the solution approach being taken.

4.3 Job Shop Scheduling

From the historical viewpoint, during the past decades, considerable investigations have been done in order to find a solution to JSS problem. The problem of JSS first became known in the mid-fifties in a company producing paper (Arisha et al. 2001). In the subsequent years, other studies began exploring for JSS solution. One of the challenges of the JSS problem is that it is NP-hard (nondeterministic polynomial time). Statisticians, mathematicians, and researchers have noted that the NP-hard is likely to be one of the most computationally intractable combinatorial problems to have emerged out of this area.

Consequently, over the past three decades, researchers have been able to develop different techniques to deal with the scheduling problem. These techniques may be grouped as either traditional techniques or advanced techniques. In turn, traditional techniques are classified under two main categories, namely, analytical techniques and heuristic techniques.

It should be noted that generally, the approach used by analytical methods is in considering the problem in its total system form of scheduling “n” jobs on “m” machines (Schniederjans et al. 2013). However, the relatively lack of success in using this approach for providing a general optimization method of broad applicability, has resulted into a switch in focus of attention from the total system to a more simple decomposed subsystem view of the problem wherein the job shop is regarded as a series of interrelated single machine scheduling problems (Schniederjans et al. 2013). There have been endeavors to bridge the gap between heuristic approaches and optimization approaches. Some researchers state that the solution is in local optimization. However, schedule evaluation can only be done through selective enumeration. Notably, the Lagrangian relaxation technique has also been used by researchers in order to obtain a more efficient enumeration method for a class of JSS problems.

4.4 Green Shift / Corporate Social Responsibility

Corporate social responsibility (CSR) reporting, also referred to as the triple bottom line, has increasingly been influential in the past decade, not only for its benefits to the economy, environment, and society but also for its business case for organizations. For example, the adoption of CSR among companies has massively grown – nearly three times from 2,000 in 2007 to roughly 6,000 in 2011 (Blanchard 2012). In particular, manufacturers have been adopting CSR not only to embrace sustainability initiatives according to the triple bottom line but also in order to keep their customers happy. This is because there is substantial evidence showing that customers prefer transacting with companies that have CSR initiatives.

An offshoot of this wide adoption of CSR is an entire industry of auditors and consultants who have emerged to advise manufacturers about the many regulatory efforts being enforced or are being developed for nearly every industry sector that has also adopted their respective green initiatives and advocacies. These include green initiatives and causes such as “free range, conflict-free minerals, Fairtrade, LEED, etc.” (Blanchard 2012). Firms can now monitor their carbon footprint not only for their own manufacturing activities, but also for their suppliers, transportation, distribution, and procurement activities (Blanchard 2012). As a result, a considerable part of CSR has been diversity and inclusion in hiring practices.

However, it must be emphasized that not all CSR reports are identical and created equal. Companies vary in the ways through which they report their CSR activities. For example, companies that excel in the economic facet of the triple bottom line, “are rewarded by Wall Street even if they come up a bit short on the people and planet side” (Blanchard 2012). Nevertheless, the momentum toward full disclosure of CSR activities has not been uniform among companies, with even the biggest and most successful firms being held accountable by their stakeholders for incomplete reporting.

The adoption of CSR has also been driven by efforts of large companies, such as for instance, Apple Inc. This company’s CEO, Tim Cook, says that “if there’s a production process that can be made safer, we seek out the foremost authorities in the world, then cut in a new standard and apply it to the entire supply chain” (Blanchard 2012). However, consumers and other business stakeholders could be demanding about CSR transparency, and this has impacted even Apple. Despite the company’s well-deserved reputation for supply chain excellence, Apple has been called out for its lack of transparency in fully disclosing how it measures its carbon emissions, as well as, how it monitors the activities of its global suppliers. The company also failed to participate in the Carbon Disclosure Project (CDP), an “independent global system for companies to measure, disclose, manage and share climate change and water information” (Blanchard, 2012). Roughly four thousand companies participate in the CDP worldwide, but Apple has not been part of it, making this company the “largest IT company in the world to not participate” in the CDP (Blanchard 2012). This has affected the reputation Apple has had in the eyes of the public and the business world.

5.0 Literature Review

5.1 Facility Layout Problems: Conceptual Overview

A problem of supreme importance to the manufacturing and service industry is the determination of facility locations in a plant with consideration of optimal shape and location (Tuzkaya et al. 2011). Layout problems are a significant challenge in manufacturing systems (Drira et al. 2007). Though not always, layout problems are generally related to the location of the facilities in a given plant (Drira et al. 2007). Facility placement matters with researchers estimating that good placement at facilities can increase overall efficacy to the extent that it reduces 50% of total operating expenses (Drira et al. 2007). Similarly, Ahmadi and Akbari Jokar (2016) estimate that high-quality layouts can lead to a 43% cost reduction in a short amount of time. Facility layout problem (FLP) is the terminology that references problems related to layout. Liu et al. (2018) defined FLP as "the problem of placing facilities in a certain shop floor so that the facilities do not overlap each other and are satisfied with some given objectives". FLP is concerned with finding the most efficient non-overlapping arrangement of interacting facilities (Tuzkaya et al. 2011). The applications for the real world are robust and include, but are not limited to, manufacturing systems, warehouses, hospitals, schools, airports, and circuit boards (Ahmadi and Akbari Jokar 2016).

One area within the context of FLP is the unequal area facility layout problem. This is important to note as it highlights the fact that while FLP is a blanket terminology, it has elements in its subsets that necessitate consideration in a focal capacity. Unequal areas and fixed shapes can be placed orthogonally on the shop floor with the objective of optimizing the material handling cost, adjacency value, and the utilization ratio of the shop floor (Liu et al. 2018). There are also variations that can manifest related to single and multiple floor layout paradigms (Ahmadi and Akbari Jokar 2016). Understandably, multi-floor construction presents more complicated layout design considerations.

Cell formation (CF) is another way that the group layout problem can be addressed. Cellular manufacturing embraces enhanced flexibility and efficiency (Ebrahimi et al. 2016). The integrated cellular manufacturing system (CMS) considers machine layout and scheduling problems at the same time rather than treating them as separate phenomena (Ebrahimi et al.

2016). These methods have been illustrated to minimize makespan, tardiness penalties, and material handling costs (Ebrahimi et al. 2016). The Lingo software is one way that this can be tracked. Changes using different solutions within this structure averaged between 14% and 17%, depending on the intervention (Ebrahimi et al. 2016). It is therefore a statistically significant workflow efficiency. According to Forghani, Fatemi Ghomi, and Kia (2020), CF is the process of grouping machines into machine cells and designated certain parts to them. When an ideal configuration is achieved, each of the machine cells should be entirely independent. This is the ultimate goal; however, in practice, it is challenging for this to actually happen. According to the authors, getting as close to this as possible is a more realistic goal for designers. When the system is optimized, but there are some parts that require manufacturing in more than one cell, this is referenced as the exceptional element. The authors conclude that simulated annealing that is enhanced by linear programming can be useful in solving integrated cell formation issues. Khaksar-Haghani et al. (2011) have previously explored models for designing multi-floor layouts for cellular manufacturing using novel integer linear programming. While producing some additional variables for consideration, this previous work is echoed by the mentioned data produced by Forghani, Fatemi Ghomi, and Kia (2020).

5.2 Scheduling and FLP Interaction

Job scheduling is a known problem that impacts the productivity and overall efficiency of manufacturing systems (Kamoshida 2018). In the generalized job scheduling paradigm, machines that are necessary for the operation of jobs are assigned to predetermined locations with specific time intervals (Kamoshida 2018). At the same time, the algorithms for maximizing efficiency for such models are limited if they do not consider actual factory layouts and associated constructs. For example, Kamoshida (2018) highlights that in real factories, portable machines can be used to perform several options. In these paradigms, it is common practice to relegate these portable machines to vacant locations in a factory (Kamoshida 2018). While this is often necessary and a function of practicality, it is not always the best option. FLP planning, therefore, can be used to maximize the workflows for such portable machines.

While in some arenas of work and manufacturing, tasks can be completed at the same time, there are often tasks in manufacturing where tasks cannot be performed simultaneously

(Kuhpfahl 2015). These require scheduling, which is a natural human working process that is conducted every day without much thought (Kuhpfahl 2015). Effective scheduling of processes leads to efficiency and by extension, profitability. Rather than looking at the problem in an integrated capacity, the bulk of existing research on the topic tends to separate scheduling and FLP.

In a traditional modality of layout planning and scheduling, these are performed sequentially in a manufacturing system with scheduling being executed after layout for the facilities are designed (Ripon et al. 2012). In other words, even though manufacturing companies spend a significant amount of time and money solving JSSs and FLPs, these are typically performed independently and sequentially, where JSS is done after layouts for the facilities are completed, indicating where the machines are placed. Scheduling comes after FLP because the goal of the latter is to design an effective workflow, with the workflow encompassing job shop scheduling.

The choice of layout for the facilities and scheduling impact the performance of one another and therefore necessitate coordination (Ripon et al. 2012). Once facilities have been selected with a fixed or semi-fixed layout, the degree to which they can be changed will be less than having selected a most suitable layout from the beginning. With elements like manufacturing, however, changes will be required, and having the necessary flexibility to initiate changes is something that should be worked into any layout planning paradigm. In business, as within many other facets of organizational function, change is constant. Organizations that are better equipped for change management will have an advantage over those who cannot readily adapt to change (Ancoa et al. 2004).

Ebrahimi et al. (2016) state that modern competitive manufacturing necessitates high functioning organizations to be capable of reacting quickly to unpredictable changes in the market. Flexibility, therefore, is critical. Flexibility is not only a way to be more competitive, but it is also a way to better meet customer needs (Houshyar et al. 2016). In the face of modern business landscapes, there are shorter product life cycles, a need for customized products, variable demand, and international competition (Houshyar et al. 2016). Nouri-Houshyar et al. (2016), state the modern paradigm "has prompted manufacturers in recent decades to seek new and better ways than the traditional way to cope with unexpected and often rapid changes and respond to customer needs".

In the present paradigm, layout planning and scheduling are handled independently (Ripon et al. 2012). There are ways that this can be overcome for better efficacy. For FLP alone and for FLP and scheduling modalities together, various models and solutions have been developed over the past four decades (Tuzkaya et al. 2011). The most popular method is based on the quadratic assignment problem, and linear and mixed-integer programming problems (Tuzkaya et al. 2011). The following section analyzes studies that address both integrated methods for solutions as well as isolated methods for solutions that add important distinctions to the research question and related problems.

5.3 Algorithms to Achieve Reasonably Good Solutions

Ripon et al. (2012) present an algorithm for solving FLP and Job Shop Scheduling Problems (JSSP) related elements of transportation delay. Their system allows for decision-makers to be more flexible and to have potential alternative choices (Ripon et al. 2012). Van Laarhoven et al. (1992) examined the practice of specialty algorithms several years before the Ripon et al. (2012) study. They found that algorithms can find shorter makespans than the more popular processes of secluding problems and making estimations. Even within the sphere of algorithms, there is variation in productivity. The best algorithms that have been successful are those that use heuristics, meta-heuristics, and hybrid approaches (Zhu et al. 2017). For example, the multi-objective particle swarm optimization (MOPSO) algorithm has shown high effectiveness and robustness in solving multi-objective problems (Liu et al. 2018). In a study of MOPSO on three sets of different situations in 62 facilities, the MOPSO has been illustrated to be efficient in reducing facility layout problems related to unequal area elements (Liu et al. 2018). Tuzkaya et al. (2011) concluded that both Genetic Algorithm (GA) and Simulated Annealing (SA) are popular techniques for combinatorial optimization, but they have both weaknesses and strengths when examined independently. The researchers found that methods that combine GA and SA in a hybrid algorithm increase their pure performance (Tuzkaya et al. 2011). The Giffler and Thompson (GT) algorithm is another methodology that is commonly used to solve the FLP problem (Kamoshida 2018). The degree to which it has been used, combined with peer-reviewed research, has made it good evidence-based practice (Kamoshida 2018).

Kia et al. (2014) also experimented with mixed programming models. Kia et al. (2014) present a mixed-integer nonlinear programming model for designing the group layout in unequal-area facilities in the cellular manufacturing sector. The method demonstrates statistically significant efficacy, and it directly addresses the needs for flexibility and efficiency in modern competitive manufacturing systems that are commonly unstable environments using existing layout configurations (Kia et al. 2014). While they help, the fixed elements of some modern manufacturing systems are such that they cannot reach an optimal strategy (Kia et al. 2014). Realistic expectations based on plausible efficiency designations should be at the forefront of decision making for management.

5.4 Research Gaps in the Areas of FLP and JSS

In general, when considering modern research on FLP, there is an absence of literature when compared to other subjects. This does not make it less critical. Other known elements to increase organization efficiency like leadership, employee motivation, supply chain management, and organizational change are all frequently studied subjects where evidence can be linked to better performance through maximization. FLP, admittedly, is more specialized and not as universal as some of these other more widely explored topics. Despite this, in consideration of its importance and its commonality, the amount of current literature, particularly that examines it in an integrated capacity, establishes a clear research gap for the necessary understanding of the subject.

According to Zhu et al. (2017), it had been nearly 20 years since the last major review of literature in the field of dynamic facility layout had been conducted (DFLP). In the span of 20 years, a great deal has changed both in terms of market, technology, and supply chain management. According to the researchers, the "review finds that the recent DFLP models consider more complex design features and constraints" with only a handful of DFLP models embracing exact methods (Zhu et al. 2017). Hybrid methods that employ various approaches within realistic considerations are necessary, and there is room for improvement in the current models that can further help to create more effective solutions (Zhu et al. 2017).

6.0 Problem Modelling

For FLP, the literature search described in Section 2.0 of this thesis yielded 80 articles, and after the application of inclusion and exclusion criteria, 19 articles were left for analysis. On the other hand, the literature search for JSS 76 articles, and the application of the inclusion criteria resulted in the selection of ten studies for analysis.

6.1 Final 19 Articles for FLP

The 19 articles for FLP are the following:

1. Ahmadi, Abbas, Mir Saman Pishvaee, and Mohammad Reza Akbari Jokar. 2017. "A Survey on Multi-Floor Facility Layout Problems." *Computers and Industrial Engineering* 107: 158–70. https://doi.org/10.1016/j.cie.2017.03.015.
2. Bozorgi, N., M. Abedzadeh, and M. Zeinali. 2015. "Tabu Search Heuristic for Efficiency of Dynamic Facility Layout Problem." *International Journal of Advanced Manufacturing Technology* 77 (1–4): 689–703. https://doi.org/10.1007/s00170-014-6460-9.
3. Ebrahimi, Ahmad, Reza Kia, and Alireza Rashidi Komijan. 2016. "Solving a Mathematical Model Integrating Unequal-Area Facilities Layout and Part Scheduling in a Cellular Manufacturing System by a Genetic Algorithm." *SpringerPlus* 5 (1). https://doi.org/10.1186/s40064-016-2773-5.
4. Guan, Chao, Zeqiang Zhang, Silu Liu, and Juhua Gong. 2019. "Multi-Objective Particle Swarm Optimization for Multi-Workshop Facility Layout Problem." *Journal of Manufacturing Systems* 53 (October): 32–48. https://doi.org/10.1016/j.jmsy.2019.09.004.
5. Hosseini-Nasab, Hasan, and Leila Emami. 2013. "A Hybrid Particle Swarm Optimisation for Dynamic Facility Layout Problem." *International Journal of Production Research* 51 (14): 4325–35. https://doi.org/10.1080/00207543.2013.774486.
6. Jolai, Fariborz, Reza Tavakkoli-Moghaddam, and Mohammad Taghipour. 2012. "A Multi-Objective Particle Swarm Optimisation Algorithm for Unequal Sized Dynamic Facility Layout Problem with Pickup/Drop-off Locations." *International Journal of Production Research* 50 (15): 4279–93.

https://doi.org/10.1080/00207543.2011.613863.

7. Kulturel-Konak, Sadan, and Abdullah Konak. 2013. “Linear Programming Based Genetic Algorithm for the Unequal Area Facility Layout Problem.” *International Journal of Production Research* 51 (14): 4302–24. https://doi.org/10.1080/00207543.2013.774481.
8. Matai, Rajesh, S. P. Singh, and M. L. Mittal. 2013. “Modified Simulated Annealing Based Approach for Multi Objective Facility Layout Problem.” *International Journal of Production Research* 51 (14): 4273–88. https://doi.org/10.1080/00207543.2013.765078.
9. McKendall, Alan R., and Wen Hsing Liu. 2012. “New Tabu Search Heuristics for the Dynamic Facility Layout Problem.” *International Journal of Production Research* 50 (3): 867–78. https://doi.org/10.1080/00207543.2010.545446.
10. Mohamadi, A., S. Ebrahimnejad, R. Soltani, and M. Khalilzadeh. 2019. “An Integrated Approach Based on a Bi-Level Genetic Algorithm and a Combined Zone-LP for the Facility Layout Problem.” *South African Journal of Industrial Engineering* 30 (4): 87–101. https://doi.org/10.7166/30-4-2192.
11. Navidi, Hamidreza, Mahdi Bashiri, and Masume Messi Bidgoli. 2012. “A Heuristic Approach on the Facility Layout Problem Based on Game Theory.” *International Journal of Production Research* 50 (6): 1512–27. https://doi.org/10.1080/00207543.2010.550638.
12. Ning, Xiu, and Pingke Li. 2018. “A Cross-Entropy Approach to the Single Row Facility Layout Problem.” *International Journal of Production Research* 56 (11): 3781–94. https://doi.org/10.1080/00207543.2017.1399221.
13. Peng, Yunfang, Tian Zeng, Lingzhi Fan, Yajuan Han, Beixin Xia, and Xinchang Wang. 2018. “An Improved Genetic Algorithm Based Robust Approach for Stochastic Dynamic Facility Layout Problem.” *Discrete Dynamics in Nature and Society* 2018. https://doi.org/10.1155/2018/1529058.
14. Şahinkoç, Mert, and Umit Bilge. 2018. “Facility Layout Problem with QAP Formulation under Scenario-Based Uncertainty.” *Infor* 56 (4): 406–27. https://doi.org/10.1080/03155986.2018.1424445.
15. Salmani, Mohammad Hassan, Kourosh Eshghi, and Hossein Neghabi. 2015. “A Bi-Objective MIP Model for Facility Layout Problem in Uncertain Environment.” *International Journal of Advanced Manufacturing Technology* 81 (9–12): 1563–75. https://doi.org/10.1007/s00170-015-7290-0.

16. Singh, S. P., and V. K. Singh. 2010. "An Improved Heuristic Approach for Multi-Objective Facility Layout Problem." *International Journal of Production Research* 48 (4): 1171–94. https://doi.org/10.1080/00207540802534731.
17. Singh, S. P., and V. K. Singh. 2011. "Three-Level AHP-Based Heuristic Approach for a Multi-Objective Facility Layout Problem." *International Journal of Production Research* 49 (4): 1105–25. https://doi.org/10.1080/00207540903536148.
18. Xiao, Y. J., Y. Zheng, L. M. Zhang, and Y. H. Kuo. 2016. "A Combined Zone-LP and Simulated Annealing Algorithm for Unequal-Area Facility Layout Problem." *Advances in Production Engineering And Management* 11 (4): 259–70. https://doi.org/10.14743/apem2016.4.225.
19. Zhu, Tianyuan, Jaydeep Balakrishnan, and Chun Hung Cheng. 2018. "Recent Advances in Dynamic Facility Layout Research." *Infor* 56 (4): 428–56. https://doi.org/10.1080/03155986.2017.1363591.

Table 1 below shows the summary of the FLP articles' models, Table 2 shows FLP solutions used, and Table 3 shows the objectives for each FLP article.

Table 1 FLP Articles' Authors and Models Used

Authors	**Discrete Formulation**	**Continuous Formulation**	**Data Envelopment Analysis**	**Mixed Integer Linear Programming**	**Linear Programming**	**Non-linear mixed integer mathematical model**	**Particle swarm optimization**	**Game theory**	**Monte Carlo simulation**	**Dynamic facility layout modelling**	**Cross-entropy approach**	**Quadratic assignment problem**	**Modified simulated annealing**
(Ahmadi et al. 2017)	✓	✓											
(Bozorgi et al. 2015)			✓										
(Ebrahimi et al. 2016)				✓									
(Guan et al. 2019)				✓									
(Hosseini-Nasab and Emami 2013)							✓						
(Jolai et al. 2012)						✓							
(Kulturel-Konak and Konak 2013)					✓								

(Matai et al. 2013)													✓
(McKendall and Liu 2012)												✓	
(Mohamadi et al. 2019)					✓								
(Navidi et al. 2012)								✓					
(Ning and Li 2018)											✓		
(Peng et al. 2018)									✓				
(Şahinkoç and Bilge 2018)						✓							
(Salmani et al. 2015)				✓									
(Singh and Singh 2010)												✓	
(Singh and Singh 2011)												✓	

(Xiao et al. 2016)				✓									
(Zhu et al. 2018)			✓										

Table 2 FLP Articles' Authors and Solutions Used

Authors	**Heuristic/meta-heuristic**	**Tabu search**	**Genetic algorithm**	**Swarm optimization algorithm**	**Simulated annealing meta-heuristic.**
(Ahmadi et al. 2017)	✓				
(Bozorgi et al. 2015)	✓	✓			
(Ebrahimi et al. 2016)			✓		
(Guan et al. 2019)				✓	
(Hosseini-Nasab and Emami 2013)				✓	
(Jolai et al. 2012)				✓	
(Kulturel-Konak and Konak 2013)			✓		
(Matai et al. 2013)	✓				
(McKendall and Liu 2012)	✓	✓			
(Mohamadi et al. 2019)			✓		
(Navidi et al. 2012)					✓
(Ning and Li 2018)	✓				
(Peng et al. 2018)		✓		✓	
(Şahinkoç and Bilge 2018)	✓				
(Salmani et al. 2015)	✓				
(Singh and Singh 2010)	✓				

(Singh and Singh 2011)	✓				
(Xiao et al. 2016)					✓
(Zhu et al. 2018)	✓				

Table 3 FLP Articles' Authors and Study Objectives

Authors	**Measure FLP**	**Determine dynamic facility layout**	**Minimize makespan, tardiness penalties, and material handling costs**	**Optimal exact coordinates of department -ts**	**Minimize the sum of handling and re-layout costs**	**Solve FLP**	**Arrange a number of facilities to minimize costs**	**Solve quadratic assignment problem**	**Efficiency and effectivene-ss for dynamic and uncertain values on department -t's dimensions**	**Select objective weight for facility layout**	**Review advances in dynamic facility layout research**
(Ahmadi et al. 2017)	✓										
(Bozorgi et al. 2015)		✓									
(Ebrahimi et al. 2016)			✓								
(Guan et al. 2019)				✓							
(Hosseini-Nasab and Emami 2013)					✓						
(Jolai et al. 2012)						✓					
(Kulturel-Konak and Konak 2013)						✓					
(Matai et al. 2013)						✓					
(McKendall and Liu 2012)							✓				
(Mohamadi et al. 2019)			✓		✓						
(Navidi et al. 2012)					✓						

(Ning and Li 2018)							✓				
(Peng et al. 2018)						✓					
(Şahinkoç and Bilge 2018)								✓			
(Salmani et al. 2015)									✓		
(Singh and Singh 2010)										✓	
(Singh and Singh 2011)						✓					
(Xiao et al. 2016)						✓					
(Zhu et al. 2018)											✓

6.2 Final Ten Articles for JSS

The final ten articles for JSS are the following:

1. Azadeh, A., T. Nazari, and H. Charkhand. 2015. “Optimisation of Facility Layout Design Problem with Safety and Environmental Factors by Stochastic DEA and Simulation Approach.” *International Journal of Production Research* 53 (11): 3370–89. https://doi.org/10.1080/00207543.2014.986294.
2. Ham, Andy M., and Eray Cakici. 2016. “Flexible Job Shop Scheduling Problem with Parallel Batch Processing Machines: MIP and CP Approaches.” *Computers and Industrial Engineering* 102 (November 2016): 160–65. https://doi.org/10.1016/j.cie.2016.11.001.
3. Lei, Deming, Youlian Zheng, and Xiuping Guo. 2017. “A Shuffled Frog-Leaping Algorithm for Flexible Job Shop Scheduling with the Consideration of Energy Consumption.” *International Journal of Production Research* 55 (11): 3126–40. https://doi.org/10.1080/00207543.2016.1262082.
4. Li, Jun Qing, Quan Ke Pan, and Jing Chen. 2012. “A Hybrid Pareto-Based Local Search Algorithm for Multi-Objective Flexible Job Shop Scheduling Problems.” *International Journal of Production Research* 50 (4): 1063–78. https://doi.org/10.1080/00207543.2011.555427.
5. Meng, Tao, Quan Ke Pan, and Hong Yan Sang. 2018. “A Hybrid Artificial Bee Colony Algorithm for a Flexible Job Shop Scheduling Problem with Overlapping in Operations.” *International Journal of Production Research* 56 (16): 5278–92. https://doi.org/10.1080/00207543.2018.1467575.
6. Naderi, Bahman, and Ahmed Azab. 2015. “An Improved Model and Novel Simulated Annealing for Distributed Job Shop Problems.” *International Journal of Advanced Manufacturing Technology* 81 (1–4): 693–703. https://doi.org/10.1007/s00170-015-7080-8.
7. Siebert, Matias, Kelly Bartlett, Haejoong Kim, Shabbir Ahmed, Junho Lee, Dima Nazzal, George Nemhauser, and Joel Sokol. 2018. “Lot Targeting and Lot Dispatching Decision Policies for Semiconductor Manufacturing: Optimisation under Uncertainty with Simulation Validation.” *International Journal of Production Research* 56 (1–2): 629–41. https://doi.org/10.1080/00207543.2017.1387679.
8. Soto, Ricardo, Broderick Crawford, Jose M. Lanza-Gutierrez, Rodrigo Olivares,

Pablo Camacho, Gino Astorga, Hanns de la Fuente-Mella, Fernando Paredes, and Carlos Castro. 2019. "Solving the Manufacturing Cell Design Problem through an Autonomous Water Cycle Algorithm." *Applied Sciences (Switzerland)* 9 (22): 1–22. https://doi.org/10.3390/app9224736.

9. Yang, Chang Lin, Shan Ping Chuang, and Tsung Shing Hsu. 2011. "A Genetic Algorithm for Dynamic Facility Planning in Job Shop Manufacturing." *International Journal of Advanced Manufacturing Technology* 52 (1–4): 303–9. https://doi.org/10.1007/s00170-010-2733-0.
10. Zhang, Sicheng, and Tak Nam Wong. 2017. "Flexible Job-Shop Scheduling/Rescheduling in Dynamic Environment: A Hybrid MAS/ACO Approach." *International Journal of Production Research* 55 (11): 3173–96. https://doi.org/10.1080/00207543.2016.1267414.

Table 4 shows the JSS articles' models, Table 5 shows JSS solutions used, and Table 6 shows the objectives for each JSS article.

Table 4 JSS Articles' Authors and Models Used

Authors	**Mixed-integer linear programming model**	**Simulated annealing algorithms**	**Flexible JSS**	**Multi-objective flexible JSS**	**Data envelopment analysis**	**Discrete-event simulation model**	**Metaheuristic**
(Azadeh et al. 2015)					✓		
(Ham and Cakici 2016)			✓				
(Lei et al. 2017)			✓				
(Li et al. 2012)				✓			
(Meng et al. 2018)			✓				
(Naderi and Azab 2015)	✓	✓					
(Siebert et al. 2018)						✓	
(Soto et al. 2019)							✓
(Yang et al. 2011)		✓					
(Zhang and Wong 2017)			✓				

Table 5 JSS Articles' Authors and Solutions Used

Authors	**Simulation –stochastic DEA–multi-attribute approach**	**Enhanc-ed mixed-integer program-ming and constrai-nt program-ming**	**Autonomous Water Cycle Algorithm**	**Shuffled frog-leaping algorithm**	**Hybrid Pareto-based local search algorithm**	**Hybrid artificial bee colony algorithm**	**Greedy algorithm**	**Lot targeting and lot dispatchi-ng decision policies**	**Genetic algorithm**	**Multi-agent system (MAS) and ant colony optimisati-on (ACO)**
(Azadeh et al. 2015)	✓									
(Ham and Cakici 2016)		✓								
(Lei et al. 2017)				✓						
(Li et al. 2012)					✓					
(Meng et al. 2018)						✓				
(Naderi and Azab 2015)							✓			
(Siebert et al. 2018)								✓		
(Soto et al. 2019)			✓							
(Yang et al. 2011)									✓	

(Zhang and Wong 2017)										✓

Table 6 JSS Articles' Authors and Study Objectives

Authors	**Address JSS with stochastic outputs and safety and environmental factors**	**Propose algorithm that can update the population size to manage trade-off between exploration and exploitation**	**Address flexible job-shop scheduling problem (FJSP) with parallel batch processing machines**	**Account for minimization of workload balance and total energy consumption in FJSP**	**Solve multi-objective FJSP**	**Extend single-facility scheduling problem to distributed multi-facility level**	**Propose a fluid-model lot dispatching policy that optimizes lot selection**	**Improve original layout plan**	**Evaluate performance of proposed solutions for scheduling and rescheduling under different types of disruptions**	**Select objective weight for facility layout**	**Review advances in dynamic facility layout research**
(Azadeh et al. 2015)	✓										
(Ham and Cakici 2016)			✓								
(Lei et al. 2017)				✓							
(Li et al. 2012)					✓						
(Meng et al. 2018)					✓						
(Naderi and Azab 2015)						✓					
(Siebert et al. 2018)							✓				
(Soto et al. 2019)		✓									
(Yang et al. 2011)								✓			

(Zhang and Wong 2017)									✓		

7.0 Results

After conducting the literature review and selecting the final sample, it is essential that a critical appraisal on the final sample be done (Snyder 2019). This means to say that after selecting a final sample, a standardized means of abstracting information from each article should be used, then afterward, these articles will be critically appraised for quality. Through the critical appraisal, the researcher can determine the effectiveness of the articles' investigators in addressing their research questions and prove or disprove their hypotheses. Depending on the review, different analysis methods may be used. Nonetheless, independent of the method of analysis, it is equally essential to ensure that each of the studies explain why the research question is answered or not.

Table 7 below is the critical appraisal for each of the articles selected for this literature review. Scores for the appraisal range from 1 to 5, with 5 being the highest score. The critical appraisal in Table 7 pertains to each study's contribution to the field, a well-developed research question, whether the study was conducted to the researchers' planned protocol, the testing of a stated hypothesis, the correct performance of statistical/numerical analyses, whether the data justifies the study's conclusion, and robustness of the analysis done. The individual scores for the sample range from 18 to 34.

The values reached in each criterion in the Critical Appraisal are the authors of this thesis' subjective opinion. Due to this, it is believed that other authors will evaluate these papers differently, giving different scores and value other goals. The methodology used to attain the values given is elaborated in the following part.

Contribution to field

This is a highly subjective criteria where the authors have compared the papers and given a score relative to the others. Elements such as the age of the paper and a novel approach was also used to ascertain the values.

A well-developed research question

There are several key elements used, that must be satisfied to attain a high value in this criterion. The research questions must be analytical and not descriptive, they must be clear and focused, and neither too broad nor too narrow.

Study performed according to the planned protocol

To attain a high value in this criterion it is essential that the importance of the research is clarified, as well as the research design, requirements and limitations of the study, and procedures used.

Test a stated hypothesis

This criterion tries to evaluate if the papers have a clear hypothesis that is answered through the research.

Statistical/Numerical analyses performed correctly

The objective of this criterion is to gauge the strength of the analyses done in the papers. The process of creating a numerical analysis is error-prone (Linz 1988), and this criterion tries to evaluate to what extent the researchers have justified their work.

Data justify the conclusions

The data referred to in this criterion is both used for the input data and the output values given in the research. The criterion then tries to assess if the data inputted can resemble real-life data, and if the output leads to the conclusions given in the papers.

Robustness

This criterion is a combination of the two preceding criteria but has a more holistic view of the research done. It tries to quantify the authors' belief of the real-world application of both the results produced and the data used in the paper.

Table 7 Critical Appraisal

Authors	**Contribution to field**	**A well-developed research question**	**Study performed according to the planned protocol**	**Test a stated hypothesis**	**Statistical/ Numerical analyses performed correctly**	**Data justify the conclusions**	**Robustness**	**Total Score**
FLP Articles								
(Ahmadi et al. 2017)	3	4	4	2	4	3	4	**24**
(Bozorgi et al. 2015)	4	4	5	2	5	5	5	**30**
(Ebrahimi et al. 2016)	5	5	5	2	5	2	3	**27**
(Guan et al. 2019)	4	4	4	1	4	3	5	**25**
(Hosseini-Nasab and Emami 2013)	4	4	5	2	5	5	5	**30**
(Jolai et al. 2012)	2	3	4	2	5	5	5	**26**
(Kulturel-Konak and Konak 2013)	5	5	4	5	5	5	5	**34**
(Matai et al. 2013)	5	5	4	5	5	5	5	**34**
(McKendall and Liu 2012)	3	4	3	1	4	3	3	**21**
(Mohamadi et al. 2019)	4	2	4	5	2	3	4	**24**

(Navidi et al. 2012)	4	4	3	1	4	3	2	**21**
(Ning and Li 2018)	4	4	5	1	4	3	5	**26**
(Peng et al. 2018)	4	4	5	1	4	5	5	**28**
(Şahinkoç and Bilge 2018)	2	3	4	2	3	2	2	**18**
(Salmani et al. 2015)	5	4	3	1	3	3	3	**22**
(Singh and Singh 2010)	5	5	5	2	5	2	3	**27**
(Singh and Singh 2011)	5	5	5	2	5	2	3	**27**
(Xiao et al. 2016)	4	4	5	1	4	3	5	**26**
(Zhu et al. 2018)	5	4	4	2	4	3	4	**26**
JSS Articles								
(Azadeh et al. 2015)	5	5	4	4	5	5	5	**33**
(Ham and Cakici 2016)	5	1	5	2	5	4	4	**26**
(Lei et al. 2017)	5	5	5	2	5	2	3	**27**
(Li et al. 2012)	5	5	5	2	5	2	3	**27**
(Meng et al. 2018)	4	3	4	2	4	5	4	**26**

(Naderi and Azab 2015)	5	5	5	2	5	5	5	**32**
(Siebert et al. 2018)	5	5	5	4	4	3	4	**30**
(Soto et al. 2019)	4	3	4	2	4	5	4	**26**
(Yang et al. 2011)	3	4	3	1	4	3	3	**21**
(Zhang and Wong 2017)	4	4	4	1	4	3	5	**25**

8.0 Discussion

8.1 Aim

In an effort to help future research and modern manufacturers, this study sought to address the following research questions:

Q1. How is current research treating FLP?

Q2. How is current research treating JSS?

Q3. What is current research lacking?

8.2 The Impact of Planning and Scheduling

Studying the articles selected for this literature review provides insight into the impacts of planning and scheduling. For instance, planning a facility's layout and scheduling of jobs in production generates substantial impacts. The placement of the facilities in the plant area, referred to as the FLP, considerably impacts manufacturing costs, work in process, lead times, and productivity. If the placement of facilities is effective, then the overall efficiency of operations will increase while total operating costs can decrease by as much as 50%. Unfortunately, FLPs have been notoriously complex such that there have been many solutions and methods developed so that manufacturing plants can deal with the complexities. Indeed, it cannot be overstated that a substantial body of research has been undertaken in the area of FLPs for decades now, with a considerable percentage of these studies being mathematical or statistical in nature. Many studies, including those in this literature review, have been published to investigate the different methods used for addressing FLPs. However, these studies focus on a tightly specific aspect of layout problems, including those pertaining to material handling, dynamic layout problems, particular resolution approaches, multi-floor facility, unequal-area facilities, multi-workshop facility, multi-objective facility layout, single row facility, and, stochastic dynamic facility. If FLP is planned appropriately, it can reduce manufacturing costs, facilitate work in process, improve lead times, and increase productivity. That has been the outcome attributed to FLP discerned from the articles selected for this literature review.

In comparison, JSS also generates the same positive impacts on costs and productivity. The JSS enables optimization in various manufacturing jobs that are assigned to machines at particular times while trying to minimize the makespan. Scheduling directs and positively impacts production efficiency and costs of a manufacturing system, which is why it has attracted a significant amount of research since 1956. Moreover, JSS is also considered in extant literature as a solution that is complicated by the requirement that it has to satisfy both batch and continuous production that are contrasting in nature. Previous studies show that researchers attempted to work on machine scheduling problem, hoping to find the optimal solution or even near-optimal for complex problems. The pursuit of finding these JSS solutions led to several analytical techniques, including linear programming and “Branch and Bound” or heuristic approaches like priority rules and neighborhood methods were investigated. Other analytical techniques and tools relative to JSS have been stochastic DEA and simulation approach, parallel batch processing, hybrid artificial bee colony algorithm, improved model and novel simulated annealing, lot targeting, and lot dispatching decision policies. As has been attested by this literature review, since 2011, most of the studies have turned to deal with new solving techniques. These methods represent a significant step forward in solving JSS problems with reduced computational efforts and more powerful results.

8.3 The Need for New Models

There appears to be even more need for newer models on FLP and JSS. An example of this is the need to develop new models that could help manufacturing plants achieve sustainable operations (Tayal et al. 2016). Indeed, sustainable operations management has been gaining attention not only among researchers but also among both businesses and practitioners. The concept of sustainable operations management is now being seriously considered because of the increasing scarcity of natural resources and rapid change in climate and increasing social inequality. In turn, these compel companies to revisit their operations management practices to address the triple bottom line (Tayal et al. 2016). Since the 1980s, many have been arguing that operations management practices can contribute towards sustainability (Tayal et al. 2016). Since then, over three decades, work on sustainable operations is still considered as in its infancy. The sustainable operations management field has been quickly replaced by the holistic term sustainable supply chain management (Tayal et al. 2016). Nevertheless, sustainable operations decisions and specifically facility layout are crucial and have to be guided by low cost and environmental-related regulatory norms. In other words, there is an urgent call for facility layout decisions in sustainable operations.

In recent years, it has been noted that most manufacturing units have been transferred to countries that have low labor costs and weak regulatory norms (Tayal et al. 2016). Currently, there is a rich body of literature on FLPs that do not only focus on costs, although research on FLP design from the perspective of sustainability is limited (Tayal et al. 2016). Therefore, new models are needed for holistic solutions to current problems, encompassing the three pillars of sustainability: economic, social, and environment, that have to be aligned in finding a desirable facility layout. A typical FLP involves the optimal placement of facilities through the minimization of material handling costs. However, because of fluctuations in economic and political situations and seasonal changes, production rates inevitably fluctuate. Here, a stochastic dynamic facility layout model integrates these variations as an expression of demand variability in the facility layout.

8.4 Competitive Advantage to be Gained from Integration

Layout design is a strategic issue because it significantly impacts the performance of a manufacturing or service industry (Tayal et al. 2016). Engineers, researchers, workers, and decision-makers have sought to obtain the best layout so that companies can optimize material flow distance, total product produced, cycle time, waiting time, facility utilization, and so forth. A company that can achieve this best layout has the potential to attain a competitive advantage because its production is efficient and effective.

However, it must be emphasized that FLP continues to be one of the most essential issues in industrial environments, especially since a proper layout can result in increased productivity, an effective arrangement of material flow, increased material flow speed, as well as, ease in the production process (Mohamadi et al. 2019). Simplifying the production process can also result in improved production and lower production costs. Currently, because of the development of a competitive environment among different enterprises, efforts to simplify the production process while lowering costs have been absolutely necessary, and one of the areas of attention is FLP and how it is executed. Thus far, this reality has incentivized researchers to study and proposing approaches in order to determine an optimal facility layout. Through the use of mathematical modelling, an appropriate layout is best achieved based on the intended objective.

Seeking to achieve autonomy of the entire manufacturing system has highlighted an urgent need to study and develop integrated FLP and JSSP approaches so that the layout for facilities and the job operations assigned to these facilities may be synchronized as much as possible (Ripon and Torresen 2014). However, many manufacturing plants remain traditional, such that FLP and JSS are performed independently. Oftentimes, transportation delay between two consecutive operations is overlooked in solving JSSPs. In light of these, a hybrid integrated metaheuristic algorithm for solving JSSPs that consider transportation delays and FLPs as an integrated problem is a possible solution. Experimental results validated the need for integrated models based on an efficient integrated framework capable of producing a set of trade-off solutions (Ripon and Torresen 2014). Previous research has also emphasized the need for integrated solutions to improve the best and average objective values, as well as optimization behavior. Based on these, an integrated method can clearly impact the productivity of a manufacturing system in positive ways. For some time now, the natural direction for work and research on FLP and JSS has been the estimation of impacts of integrated methods on actual manufacturing systems. However, unfortunately, because of the lack of practical data, it has not been possible to assess the performance of integrated molders on actual manufacturing systems (Ripon and Torresen 2014). This highlights the need for continued research on integrated models. In the future, researchers should be able to collect real-world data from practical manufacturing industries to derive a measure of the performance of the developed approaches, as well as identify other objectives related to integration. Moreover, in future research, researchers can extend integrated methods by considering the dynamic nature of FLPs and JSSPs to better reflect today's dynamic manufacturing scenarios.

9.0 Conclusions

To recall, this study sought to address these research questions:

Q1. How is current research treating FLP?

Q2. How is current research treating JSS?

Q3. What is current research lacking?

To answer *Q1* and *Q2*, based on the literature review results presented in Tables 1 through 6, current research on both FLP and JSS is strongly fragmented. It seems that there is no integrated approach that would allow manufacturing firms to attain a competitive advantage largely because researchers have no practical data to work on. Therefore, to answer the third question, current research lacks both FLP and JSS that are sustainable solutions, as well as new models that focus on integration.

A critical concern in manufacturing and service industries is the determination of facility locations in a plant with consideration of optimal shape and location. This much has been discerned from this study. Layout problems continue to be a significant challenge in several types of manufacturing systems. In most cases, layout problems are generally related to the location of the facilities in a given plant. Facility placement matters, and there seems to be consensus among researchers that effective placement at facilities can increase overall efficacy to the point that a company can reduce its total operating expenses by half. In addition to these, high-quality layouts can lead to nearly 50% cost reduction in a short amount of time. To recall, FLP is the term used to reference problems related to layout. It is a challenge in terms of placing facilities in a specific shop floor in order to ensure that the said facilities do not overlap one another. FLP is concerned about seeking out the most efficient non-overlapping arrangement of interacting facilities/units. Applications of FLP in the real world are robust and encompass manufacturing systems, warehouses, hospitals, schools, and airports, amongst other applications.

On the other hand, JSS is a known problem impacting productivity and overall efficiency of manufacturing systems. Generally, the job scheduling paradigm holds that machines that are needed for the operation of jobs are assigned to predetermined locations with specific time intervals. Algorithms are used to determine optimal efficiency for such models, although these algorithms may be limited if they do not consider actual factory layouts and associated constructs. Although in certain areas of work and manufacturing tasks can be completed at the same time, there are usually tasks in manufacturing that cannot be performed simultaneously. Therefore, these tasks entail scheduling, which is a natural human working process undertaken every day without much thought. In comparison, an effective scheduling of processes leads to efficiency and by extension, profitability. Hence, instead of considering this problem in an integrated capacity, most of existing research on the topic tends to separate scheduling and FLP. This much has been discerned in this literature review. At this point in time, it may be said that the choice of layout for the facilities and scheduling would powerfully impact each other's performance, thereby necessitating coordination that can be achieved through integration.

Studying the articles selected for this literature review provides insight into the impacts of planning and scheduling. Both FLP and JSS can be sources of potential competitive advantage because these can reduce manufacturing costs, improve work in process and lead times, as well as increase productivity. However, the challenge at hand is that FLPs have been notoriously complex that effective solutions and methods developed for manufacturing plants should be able to address these complexities. On the other hand, JSS also positively impacts costs and productivity. In spite of new models that emerge out of the work of researchers and practitioners, these models hardly address sustainable operations management, which could be a future area for research. Other future areas for research would be automated JSS that in time could lead to the autonomy of the entire manufacturing system.

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