PEOPLE’S DEMOCRATIC REPUBLIC OF ALGERIA
الجمهورية الجزائرية الديمقراطية الشعبية

MINISTRY OF HIGHER EDUCATION
AND SCIENTIFIC RESEARCH

HIGHER SCHOOL IN APPLIED SCIENCES
--TLEMCEN--

ESSA
Tlemcen-تلمسان
المدرسة العليا في العلوم التطبيقية
École Supérieure en
Sciences Appliquées

وزارة التعليم العالي والبحث العلمي

المدرسة العليا في العلوم التطبيقية
-تلمسان-

Final degree project

For obtaining the Master Diploma

Field: Industrial engineering
Major: Industrial Management and Logistics

Presented by :
GAOUAR Rim Djazia
TERKI HASSAINE Mohieddine El-Hadi

Subject

Heuristic for Flexible Layout Design Problem

Publicly defended, on 07/ 07/2024, in front of the jury composed of:

Mrs. SEKKAL Nourelhouda	MCB	ESSA. Tlemcen	Président
Mr. MALIKI Fouad	MCA	ESSA. Tlemcen	Thesis Director
Mr. BRAHIMI Nadjib	Prof	Rennes Business School	Thesis Co-Directeur
Mr. SOUIER Mehdi	Prof	Univ. Tlemcen	Examiner 1
Mr. HADDOU BENDERBAL Hichem	Associate Professor	Univ. Aix-Marseille	Examiner 2

Academic Year : 2023 / 2024

Gratitude

First and foremost, we would like to thank "Allah," the Almighty and Merciful, who has given us the strength, will, and courage to complete this work.

We wish to express our sincere gratitude and deep appreciation to:

Our supervisor and academic leader, **Mr. Fouad MALIKI**, for nurturing us over these pleasantly spent three years. We are profoundly grateful for his guidance and for enriching our knowledge in this field.

Our co-supervisor, **Mr. Nadjib BRAHIMI**, for affording us this opportunity and for enhancing our understanding of the subject matter. We value immensely the invaluable advice and direction he provided throughout the execution of this modest work.

To the members of our jury **Mrs.Nourelhouda SEKKAL**, **Mr.Mehdi SOUIER**, **Mr.Hichem HADDOU BENDERBAL** for the esteemed honor they bestow upon us by agreeing to evaluate this modest effort.

We would also like to thank our dear professor who has been with us through these past three years, **Mr. Mohammed BENNEKROUF**, for giving us the opportunity to explore plentiful information and for his invaluable guidance and support throughout our journey.

To all our teachers who have contributed significantly to the relevance of our education.

Finally, we extend our thanks to all who have played a part, whether directly or indirectly, in the realization of this thesis. Your interest in our work is greatly appreciated.

Acknowledgement

I am deeply grateful to the people who have supported me during my academic studies.

First and foremost, I am very thankful to my parents, Hayet HADJ SLIMANE and Kamel GAOUAR, for their unwavering love and support. They have provided me with everything I needed to become the person I am today, and I am forever grateful for their sacrifices and encouragement.To my brothers Alaa, Abdessamad.

I also appreciate my extended family, including my aunts, uncles, and cousins, especially Yasmine, Amira, Rihem, and Ibtissem. They have been a constant source of support and inspiration for me since we were young.

To my second family Yasmine, Linda, Hadjer, Ghizlene, Feriel, and the family with whom I studied in the same class last 3 years, we have shared countless memorable moments and created a bond that I will cherish forever. To all my friends Nassim ,Nadir, Azeddine, Wadie, Salah, Jami, Youcef.

I would also like to thank my project partner, Mohieddine El-Hadi Terki Hassaine, for his hard work. Without him, i would not have been able to make it this far in our work.

Finally, I dedicate this work to the younger version of myself, who once thought this day would be so far away. I want to let her know that she has made it, and in the most wonderful circumstances.

Acknowledgement

I am deeply grateful to the people who have supported me during my academic studies.

First and foremost, I am very thankful to my parents, for their unwavering love and support. They have provided me with everything I needed to become the person I am today, and I am forever grateful for their sacrifices and encouragement.To my two sisters, Saliha and Awicha and to my brother Younes. Your presence in my life has been a source of joy, support, and inspiration. Your love and encouragement have pushed me to give my best.

I also appreciate my extended family, including my aunts, uncles, and cousins. They have been a constant source of support and inspiration for me since we were young.

I would like to extend my deepest gratitude to Nassim, Azedine, Nadir, Salah, Wadie, Youcef and Zinedine, who have been like brothers to me. Your presence has been a source of strength and inspiration, and I am truly grateful for all the moments we've shared. To all my friends Amina, Hadjer, Yasmine, Linda, Ghizlene, Feriel and the family with whom I studied in the same class last 3 years, we have shared countless memorable moments and created a bond that I will cherish forever.

To two wonderful individuals, who have always been there for me, even in the toughest times. Your genuine friendship and unwavering support have helped me overcome obstacles and persevere. Thank you for your precious friendship

I would also like to thank my project partner, Rim Djazia GAOUAR, for her perseverance and hard work. Without her, I would not have been able to make it this far in our work.

To my friends, my loved ones, and my 2024 Industrial Engineering class.

Contents

Abbreviation List

Abbreviation	Definition
ALB	Assembly-Line Balancing
AGV	Automated Guided Vehicules
DMS	Dedicated Manufacturing System
FLDP	Flexible Layout Design Problem
FMS	Flexible Manufacturing System
MS	Manufacturing System
MMS	Matrix-Structured Manufacturing System
RMS	Reconfigurable Manufacturing System
SALB	Simple Assembly Line Balancing

List of Figures

List of Tables

General Introduction

Heuristics serve a crucial role in problem-solving across various disciplines by providing practical and often approximate solutions when exact methods not feasible due to computational complexity or resource constraints. By using straightforward rules or strategies based on practical experience or specific insights into the problem, heuristics offer a practical way to achieve effective results quickly.

In fields such as optimization, heuristics offer a means to tackle NP-hard problems where finding an exact solution is exponentially complex with problem size. Instead of guaranteeing optimality, heuristics prioritize finding good solutions quickly, often sacrificing accuracy for speed. This approach is particularly valuable in domains like logistics, scheduling, and engineering design, where real-time decision-making and adaptability are crucial.

In this thesis, we will focus on presenting a heuristic for the line balancing of a flexible layout design problem (FLDP), which involves designing a flexible layout for an assembly segment. This includes the integrated problems of station formation and station location while also anticipating the operational AGV flow, particularly on the part where the MMS layout is introduced to the manufacturing system. We will work on the mathematical model already established by Grunow which takes into consideration a multi objective problem minimzing both the number of opened locations and the cost of transportation between the location secured by the AGV's. The proposed method is to make an initial solution for this problem by developing a construction heuristic which consists of four steps.

As part of the professional training for obtaining the **state master's diploma** in **the Industrial Engineering specialty** at the **Higher School of Applied Sciences of Tlemcen**, a two-month end-of-study internship was carried out within the **IMT Atlantique Nantes**. This internship was an enriching and instructive experience. It allowed us to gain a clearer understanding of the practical application of the theoretical knowledge acquired during our training.

For the structure of our thesis, we will focus on the flexible layout design problem. The work presented will be divided into parts that encompass everything we have learned or accomplished during our two-month internship and since the beginning of our journey at the university. This work will be divided into four chapters, each detailing the methodologies, techniques, and information utilized to achieve our objectives:

In Chapter 1, we will explore the evolution of manufacturing systems, starting from Craft Manufacturing and progressing to the Dedicated Manufacturing System, then to the Flexible Manufacturing System, and finally to the Reconfigurable Manufacturing System and the Matrix-structured Manufacturing System. Additionally, we will define the assembly line balancing problem, and establish a brief literature review on existing construction heuristics.

In the next chapter, we will present IMT Atlantique, the university where our internship took place, and specifically focus on the academic and professional history of the institution and its laboratory LS2N. This section aims to provide a comprehensive overview of their contributions and achievements in relevant fields of study and research.

In the third chapter, we will present our construction heuristic that is divided into four steps: Generating the general precedence diagram, Tasks and models assignment, Routes mapping and Flow allocation. Finally, we will present the datasets used to test and thoroughly discuss the results of the Mixed Integer Linear Programming (MILP) and our heuristic. We will conduct tests on 128 instances with time limits of 20 minutes for the MILP and only milliseconds for the heuristic.

Chapter 1

General Overview of Manufacturing Systems

1.1 Introduction

The manufacturing industry has undergone a remarkable transformation since its early days in the late 18th and early 19th centuries, marking the start of the first industrial revolution. Over the past two centuries, this sector has witnessed the emergence of various manufacturing systems, each with its own unique characteristics and capabilities. Among the most notable of these systems are Dedicated Manufacturing Systems (DMS), Flexible Manufacturing Systems (FMS), Reconfigurable Manufacturing Systems (RMS), and the focus of our study, Matrix-structured Manufacturing Systems (MMS).

The DMS, which dominated the manufacturing landscape during the early stages of industrialization, was highly specialized and inflexible, designed to produce a single product or a limited range of products. As the market became more diverse, and consumer preferences more varied, the need for more flexible and adaptable manufacturing systems became evident.

This led to the development of the FMS, a revolutionary approach that transformed manufacturing by enabling seamless transitions between the production of different products on the same assembly line. FMS integrated advanced computer-controlled machinery, robotics, and software to rapidly reconfigure production, allowing manufacturers to adapt quickly to changing market demands and offer greater product customization while maintaining the benefits of high-volume production. The adoption of FMS had a profound impact, improving operational efficiency, reducing inventory costs, and enhancing global competitiveness for manufacturers. It was a significant technological advancement in the manufacturing industry. It allowed manufacturers to adapt more quickly to changing market conditions and produce a variety of customized products on the same assembly line without extensive retooling. FMS integrated advanced computer-controlled machinery, robotics, and software systems that could be rapidly reconfigured, enabling manufacturers to respond effectively to fluctuations in demand and meet the evolving needs of their customers.

The RMS, on the other hand, represented a further advancement in manufacturing systems, offering the flexibility to adapt the production line to accommodate changes in product design or production volume.

The Matrix-structured Manufacturing System (MMS) is particularly well-suited for industries with short product lifecycles, where the need for rapid adaptation is crucial. This flexible layout allows manufacturers to easily reconfigure their production lines, enabling them to respond swiftly to changes in demand or product requirements.

In this study, we will explore our approach to the FLDP specific to our case. Our focus lies on the line balancing aspect of the MMS, which is essential for efficient and effective utilization of the system's resources. Building upon existing mathematical model, we strive to minimize the number of opened locations within the given layout and optimize the transportation between these locations. This innovative approach aims to enhance the overall performance and competitiveness of the MMS.

Through our comprehensive analysis and unique contributions, we believe we can significantly advance the understanding and application of Matrix-structured Manufacturing Systems, driving the ongoing evolution and transformation of the manufacturing sector.

1.2 Definitions

1.2.1 Manufacturing Systems

The modern manufacturing industry (Fig 1.1) thrives on the essential contribution of human workers and their ability to operate a collection of machines and tools to initiate the processes required to produce goods or services that cater to the needs of people. However, the success of a manufacturing system is determined by various characteristics such as efficiency, flexibility, quality, safety, and cost-effectiveness.

Efficiency is a vital factor in a manufacturing system as it ensures optimal utilization of resources and minimizes wastage. A manufacturing system that is flexible can quickly adapt to changing consumer needs and market demands, thereby enhancing customer satisfaction. Quality is another essential aspect as it ensures that the products or services produced are of high standards and meet the expectations of the consumers, leading to customer loyalty and repeat purchases. Safety is a crucial factor in a manufacturing system as it ensures the well-being of the workers and prevents accidents or injuries. A manufacturing system that prioritizes safety creates a conducive work environment that fosters productivity and job satisfaction. Moreover, cost-effectiveness is an essential factor as it ensures that the manufacturing system is profitable and sustainable in the long run.

Over the years, the manufacturing industry has undergone several revolutionary changes resulting in the emergence of different manufacturing systems. Each manufacturing system possesses its unique advantages and challenges. For instance, the mass production system introduced during the industrial revolution was highly efficient, but it lacked flexibility and produced standardized products. In contrast, the lean production system, which emerged in the 1990s, is highly flexible and emphasizes quality, but it requires a skilled workforce. The success of a manufacturing system is determined by its ability to meet the needs of the consumers while ensuring efficiency, flexibility, quality, safety, and cost-effectiveness. As the manufacturing industry continues to evolve, it is essential to embrace innovative technologies and best practices to remain competitive and meet the demands of the market.

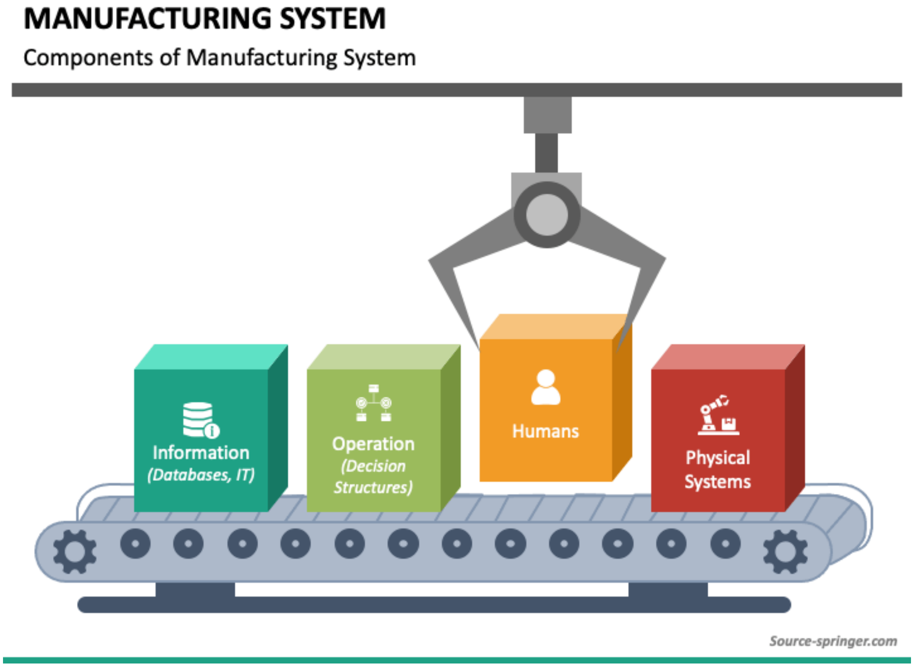


Figure 1.1: Manufacturing System source: sketchbubble

1.2.2 Craft Manufacturing

Craft manufacturing is a process that has been used for centuries, long before the introduction of automated manufacturing lines and systems in the 20th century. This method relies on the expertise of highly skilled workers and the use of simple but flexible tools to produce goods that meet the precise demands of the customer. In this process, the focus is on quality and attention to detail, with the aim of creating a unique product that stands out from the rest.

Craft manufacturing is a time-honored tradition that has been passed down from generation to generation. The skills and techniques used in this process are often learned through apprenticeships, where young workers are taught by experienced craftsmen. This process not only ensures that the craft is preserved, but it also helps to maintain the quality of the product. It is known for its attention to detail and precision. The craftsmen who work in this field take great care to ensure that each product is made to the highest standards. This often involves using specialized tools and techniques that have been refined over many years. The result is a product that is not only functional but also beautiful and unique.

One of the advantages of craft manufacturing is that it allows for a high degree of customization. Because each product is made by hand, the customer can work with the craftsman to create a product that meets their exact needs and specifications. This level of customization is not possible with automated manufacturing, which produces products in large quantities that are designed to meet the needs of the masses.

1.2.3 DMS(Dedicated Manufacturing System)

In the 1990s, there were two main types of manufacturing systems that were common in the industry (Fig 1.2) [GŚ12] . The first one was the Continuous Manufacturing system, which primarily involved producing goods for stock. This system relied on forecasting to estimate the likely demand for the products. The production process was standardized, and the inventory was managed through the first-in, first-out (FIFO) method. Additionally, the work carried out in this system was not diverse, and the workload was balanced. On the other hand, the second type of manufacturing system was called the Intermittent Manufacturing system. This system was designed to satisfy orders placed by customers. The production facilities were flexible enough to handle a wide variety of products and sizes. The storage was done between operations, and the system could accommodate small quantities of products that were flexible in nature. However, the workload in this system was unbalanced, and the production process was not standardized.

The Continuous Manufacturing system was ideal for companies that manufactured products in high volumes and had a stable and predictable demand for their products. This system allowed companies to achieve economies of scale and optimize their production processes. It was also ideal for companies that wanted to keep their inventory levels low and minimize the risk of holding excess stock. On the other hand, the Intermittent Manufacturing system was ideal for companies that produced a wide variety of products or had a constantly changing demand for their products. This system allowed companies to be more agile and responsive to their customers' needs. It also enabled companies to produce small quantities of products efficiently and cost-effectively.

Both the Continuous Manufacturing system and the Intermittent Manufacturing system had their unique strengths and weaknesses. Companies had to choose the system that was best suited to their production requirements and business goals. The decision to adopt a particular manufacturing system had a significant impact on the company's operational efficiency, profitability, and customer satisfaction. Therefore, it was crucial for companies to carefully evaluate their options before making a decision.

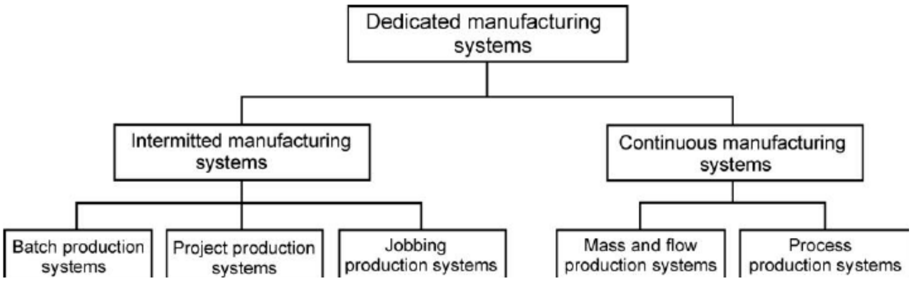


Figure 1.2: Dedicated Manufacturing System

1.2.4 FMS(Flexible Manufacturing System)

In the 1960s, the market competition was spiraling, and companies were struggling to keep up with the ever-changing demands of the consumers. It was during this time that FMS came into existence. It was a revolutionary concept that provided a fast and flexible response to unexpected changes in the market. FMS is a group of numerically controlled machinery that allows for the production of a large variety of small quantities of products. The system is designed to load and unload tools and workpieces automatically, which significantly reduces the need for human intervention. This means that the system can operate virtually unattended for long periods, making it incredibly efficient and cost-effective.

One of the most significant advantages of FMS is its flexibility. The system can quickly adjust to changes in demand, allowing companies to produce a wide variety of products without having to reconfigure their production line. This is particularly beneficial for companies that produce a range of products or have a fluctuating demand for their products.

FMS has become increasingly popular in recent years, and many companies have adopted this technology to improve their productivity and efficiency. The system has also helped companies to reduce their manufacturing costs, as it eliminates the need for manual labor and reduces the risk of errors in production. This MS has revolutionized the manufacturing industry by providing a fast, flexible, and cost-effective solution to the production of small quantities of products. With the growing demand for customized products and the need for quick response times, FMS is quickly becoming an essential tool for companies looking to stay ahead of the competition.

1.2.5 RMS(Reconfigurable Manufacturing System)

An RMS is a production system that is designed to be flexible and adaptable. It allows us to add, modify, delete, and exchange modules and machines, depending on the production needs and changes. This means that RMS can easily accommodate changes in production processes, and it can quickly adjust to new market demands.The primary focus of RMS is to produce part families. Part families are groups of parts that have similar characteristics, such as size, shape, or function. By grouping parts into families, RMS can optimize production processes and reduce the time and cost of manufacturing.

One of the key advantages of RMS is its ability to reconfigure itself quickly. This means that if a company needs to change its production processes, it can do so without having to invest in new equipment or machinery. Instead, it can simply reconfigure its existing RMS to meet the new requirements.Another benefit of RMS is that it can improve the quality of the products produced. By using advanced technology and automation, RMS can reduce the risk of errors and defects, which can lead to higher customer satisfaction and loyalty.

RMS is a flexible and adaptable production system (Fig 1.3) [And17] that can easily accommodate changes in production processes. Its focus on part families allows for optimization of production processes, and its ability to reconfigure quickly can save time and cost. Additionally, it can improve the quality of products produced, leading to higher customer satisfaction and loyalty.

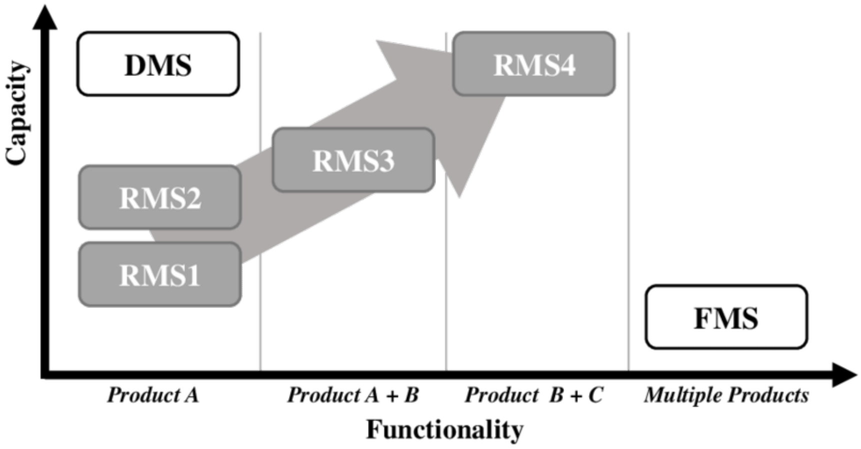


Figure 1.3: Reconfigurable Manufacturing System

In modern manufacturing, the need to remain competitive and adapt to rapidly changing markets has led to the development of advanced production systems. One such system is the RMS. This system has become increasingly popular in recent years due to its many advantages, including scalability, convertibility, customization, modularity, diagnosability, and integrability.

- **Scalability:** it's a key feature of an RMS, as it allows manufacturers to adjust production capacity according to the situation. This can be achieved by adding or removing machines, changing production lines, or reconfiguring existing equipment. By doing so, manufacturers can quickly respond to changes in demand, reduce lead times, and improve overall efficiency.

- **Convertibility:** is another important characteristic of an RMS. This refers to the ability to transform the functionality of the system to satisfy specific requirements. For example, an RMS may be configured to produce one product today and a completely different product tomorrow. This flexibility allows manufacturers to quickly adapt to changes in market demands, without the need to invest in new equipment or systems.

- **Customization:** is a feature of an RMS that is limited to part families. This means that the system can be tailored to produce a variety of products within a specific category, such as automotive parts or medical devices. This flexibility allows manufacturers to produce a wide range of products while maintaining their competitive edge.

- **Modularity:** is another key feature of an RMS. This refers to the ability to change parts of the machinery in order to respond to production changes. For example, an RMS may be designed with interchangeable tooling, allowing manufacturers to quickly switch between different product lines. This modularity also makes it easier to maintain and upgrade the system over time.

- **Diagnosability:** is an important characteristic of an RMS, as it allows for real-time diagnosing of product quality. By monitoring the production process and analyzing data, manufacturers can quickly identify and address any quality issues, reducing waste and improving overall efficiency.

- **Integrability:** is the final characteristic of an RMS, and refers to the ability to rapidly integrate modules by hardware and software interfaces. This allows manufacturers to quickly add new equipment or processes to the system, without the need for extensive reconfiguration or downtime. This flexibility is essential for maintaining competitiveness in today's rapidly changing manufacturing environment.

RMS types

RMS is a flexible and adaptable approach to manufacturing that allows for multiple types and configurations to meet the specific needs of a given production line. When first considering the implementation of an RMS, there are various criteria to consider, such as the type of product being manufactured, the volume of production, and the level of automation required.

- **Reconfigurable Flow Lines (RFL)**: These production lines consist of a series of workstations, each equipped with reconfigurable machines that can perform a variety of tasks (Fig 1.4) [YCGBD21]. This type of RMS is particularly effective in high-volume production environments where efficiency and speed are crucial. The flexibility of the RFL allows for quick changes in production processes, making it an ideal choice for companies that require a high level of adaptability.

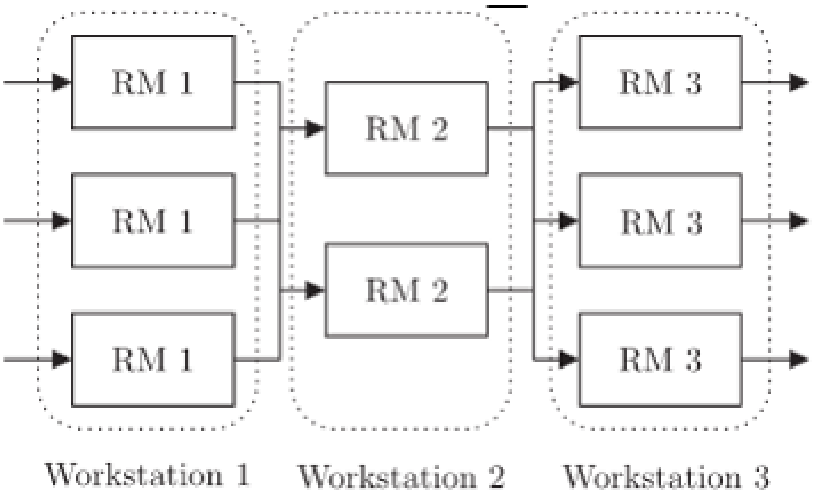


Figure 1.4: Flow line configuration

- **Reconfigurable Cellular Manufacturing System (RCMS)**: This type of production system is based on the concept of group technology, where a group of reconfigurable machines is organized into cells that share similar production tasks (Fig 1.5) [YCGBD21]. The RCMS is particularly effective in low to medium volume production environments where product customization is important. The ability to reconfigure the production line according to product demands makes the RCMS a highly versatile manufacturing system.

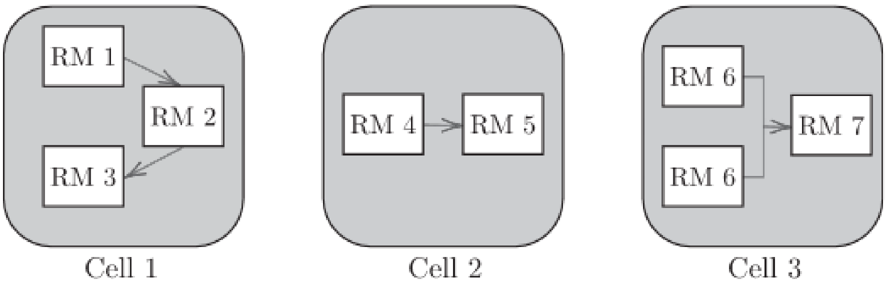


Figure 1.5: Reconfigurable Cellular Manufacturing system

- **The Dynamic Cellular Manufacturing System (DCMS):** is another type of RMS that applies the same principles as the RCMS. The only difference is that the DCMS is composed of movable machines instead of reconfigurable machines. This type of system is particularly effective in environments where space is limited, and production requirements are constantly changing.

- **the Rotary Machining System:** is a type of RMS that utilizes a rotary table to move the product through different modular machines (Fig 1.6) [YCGBD21]. This type of system is particularly effective in high-precision machining applications where accuracy and consistency are crucial. The modular design of the Rotary Machining System allows for easy reconfiguration and modification of the production line, making it an ideal choice for companies that require a high level of flexibility.

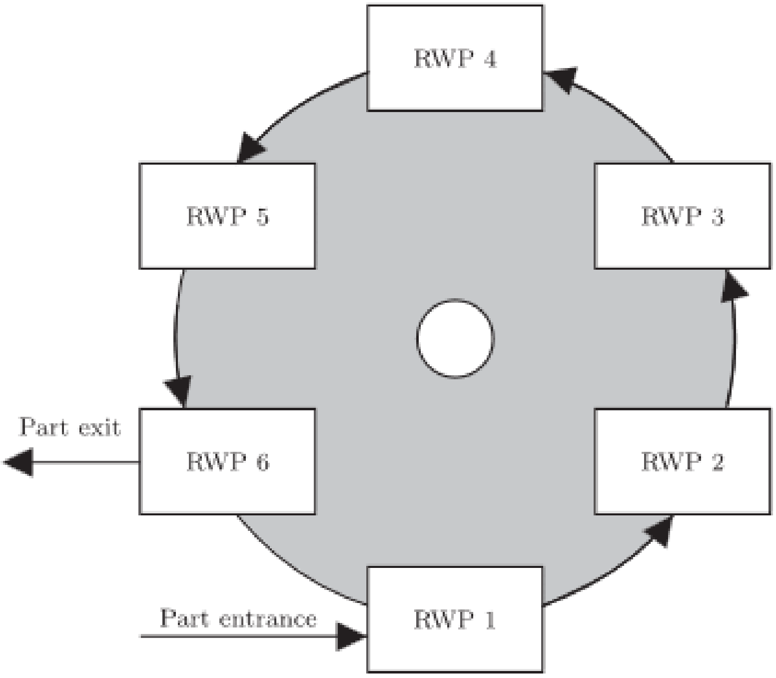


Figure 1.6: Rotary Machining System

1.2.6 MMS (Matrix-structured Manufacturing System)

The matrix manufacturing system, as the name suggests, has a matrix layout where all workstations are interconnected. The two main elements of this system are the products and the workstations. It has some unique principles that distinguish it from traditional manufacturing systems. For instance, each workstation has its own pace and cycle time, which helps prevent starvation and blocking. This system can produce multiple products using routing flexibility with Automated Guided Vehicles (AGVs) to transfer the product flow between workstations. This layout provides a great deal of flexibility for products and task assignment, within certain constraints.

As seen in the figure (Fig 1.7) [SHGT15], the difference between the classic manufacturing system (MS) and the matrix manufacturing system (MMS) is clear. For example, in the classic MS, product 1 must be completed before product 2 to minimize changeover time and maximize workstation utilization. However, in the MMS, a workstation can perform multiple tasks for multiple products, allowing a reduction in the number of workstations or an increase in the number of product types while maintaining high utilization.

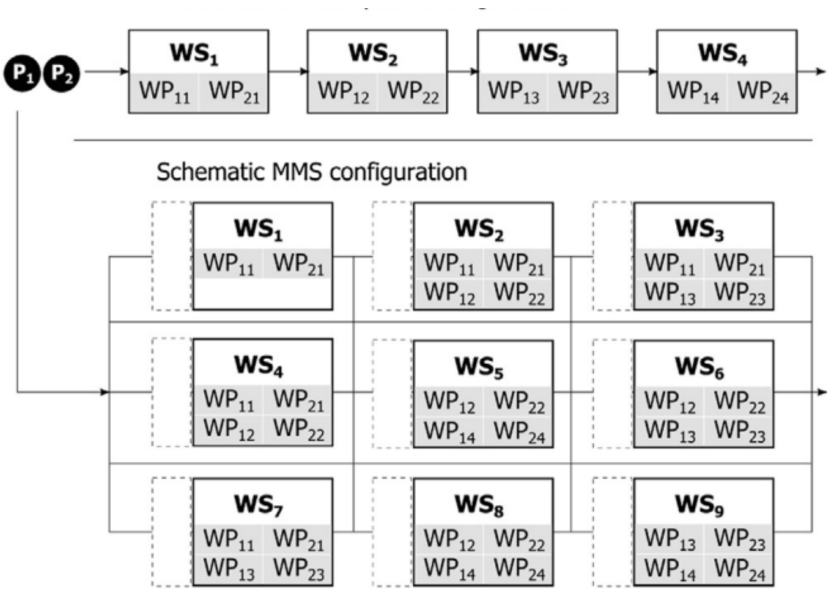


Figure 1.7: Comparison of a classic MS and a MMS configuration

1.3 Assembly Line Balancing

In the manufacturing industry, line balancing (Fig 1.8) [KM13] is an essential process that ensures optimal productivity and efficiency in assembly line operations. The goal of line balancing is to distribute workloads evenly across the production line, minimizing idle time and maximizing throughput. To achieve this, manufacturers must assign the appropriate number of employees or automated machines to each section of the assembly line. This process involves analyzing the cycle time of each station and determining the optimal number of workers or machines required to complete the task within that time frame.

Streamlining workflow is another crucial aspect of line balancing. This involves coordinating workstations and tasks to minimize unnecessary movement and improve the overall flow of the production line. Manufacturers must also continuously evaluate and improve their assembly line processes to identify and eliminate any bottlenecks or inefficiencies that may arise.

There are two primary types of line balancing methods: SALB-1 and SALB-2. SALB-1 focuses on minimizing the number of stations based on cycle time. This involves grouping similar tasks together and eliminating any redundant or unnecessary stations. By reducing the number of stations, manufacturers can minimize setup time and reduce idle time between tasks.On the other hand, SALB-2 aims to reduce cycle time by adjusting the number of stations. This method involves adding or removing stations to balance the workload across the production line. By optimizing the number of stations, manufacturers can achieve faster cycle times and improve overall productivity.

There are two main types of assembly line balancing problems - single-model and multi-model. In both types, there are four subcategories each based on whether the problem is deterministic or probabilistic and whether the assembly line is straight-type or U-type.

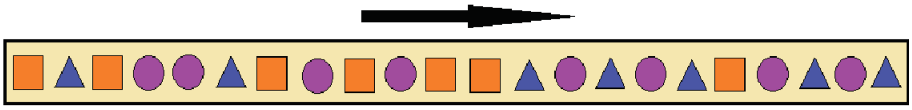
The first subcategory, SMDS or Single-Model Deterministic Straight-type, refers to a scenario where there is only one product being manufactured, and the production process is deterministic, meaning that the time required for each task is fixed and known in advance. The assembly line in this case is straight, meaning that the flow of work is linear. SMDU or Single-Model Deterministic U-type is similar to SMDS, but the assembly line is in a U-shape. This is often the case when there are constraints on the floor space available for the production process.

The third subcategory, SMPS or Single-Model Probabilistic Straight-type, is where the production process is not deterministic, and there is some variation in the time required for each task. This could be due to factors such as worker variability or machine breakdowns. The assembly line is still straight in this case. SMPU or Single-Model Probabilistic U-type is the same as SMPS, but the assembly line is in a U-shape.

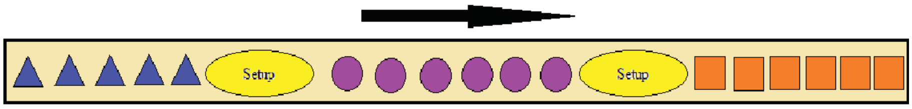
Moving on to the multi-model subcategories, MMDS or Multi-model Deterministic Straight-type is where there are multiple products being manufactured, but the production process is still deterministic. The assembly line is straight, and each product follows the same sequence of tasks. MMDU or Multi-model Deterministic U-type is similar to MMDS, but the assembly line is in a U-shape.

The seventh subcategory, MMPS or Multi-model Probabilistic Straight-type, is where there are multiple products being manufactured, and the production process is not deterministic. The assembly line is still straight, and there is some variability in the time required for each task. Finally, MMPU or Multi-model Probabilistic Straight-type is the same as MMPS, but the assembly line is in a U-shape.

(a) Single Model Assembly Line



(b) Mixed Model Assembly Line



(c) Multi Model Assembly Line

Figure 1.8: Diffrent Assembly Lines

1.4 The Flexible Layout and Design Problem (FLDP)

The Flexible Layout and Design Problem (FLDP) is a critical aspect of operations management that involves determining the optimal arrangement of various facilities within a physical space. The primary goal is to optimize the flow of materials, information, and people to minimize costs, maximize efficiency, and enhance overall operational performance. FLDP considers factors such as facility size, departmental interdependence, material movement, and ergonomics to create a layout that minimizes transportation, reduces bottlenecks, and ensures a smooth flow of operations. This can lead to significant cost savings, increased productivity, and improved quality, contributing to an organization's competitiveness and profitability.

FLDP is a complex process that often requires the expertise of specialists in fields like industrial engineering and supply chain management, who utilize analytical tools and techniques to explore and identify the most optimal solution. Efficient facility layout design has become increasingly crucial for organizations to maintain a competitive edge in today's fast-paced and highly competitive business environment.

1.5 Heuristic

A heuristic is a problem-solving strategy or method used to find a feasible and efficient solution to complex production and operational challenges. These methods do not guarantee an optimal solution but provide a satisfactory solution within a reasonable timeframe. Heuristics in manufacturing systems might involve simplifying assumptions, rules of thumb, or intuitive judgments to address issues such as scheduling, layout design, inventory management, and resource allocation, aiming to enhance productivity, reduce costs, and improve overall system performance.

Heuristics have applications across various fields, including:

- **Optimization:** Heuristics are widely employed to find near-optimal solutions for complex optimization problems, like the traveling salesman problem, vehicle routing, and scheduling tasks.
- **Artificial Intelligence:** In AI, heuristics aid decision-making processes, game playing (e.g., chess), and pathfinding algorithms (e.g., A* algorithm).
- **Operations Research:** They are applied in logistics, supply chain management, and facility layout planning to enhance efficiency and reduce costs.
- **Data Analysis and Machine Learning:** Heuristics assist in feature selection, clustering, and classification tasks, where exact methods might be computationally expensive.
- **Network Design:** In telecommunications and computer networks, heuristics optimize the layout and configuration of networks to improve performance and reduce latency.
- **Economics and Finance:** Heuristics are used in portfolio optimization, risk management, and market analysis to enable quick and effective decision-making.

1.6 Gurobi Optimizer

Gurobi Optimizer is a leading mathematical optimization solver, known for its exceptional performance in solving optimization problems. It excels in handling various types of problems such as linear programming (LP), mixed-integer programming (MIP), and quadratic programming (QP). The solver utilizes advanced algorithms to deliver high computational efficiency.

Key features of Gurobi include:

- **High Performance:** Utilizes parallel processing to achieve fast solution times, particularly for large-scale MIP problems.
- **Comprehensive Modeling Support:** Capable of solving LP, MIP, QP, and their variants, making it adaptable for different optimization scenarios.
- **User-Friendly Interfaces:** Offers multiple interfaces including Python, MATLAB, and Java, enhancing accessibility for users across various platforms.
- **Multi-Objective Optimization:** Supports the optimization of multiple objective functions.

Gurobi's robustness and speed make it a preferred choice in both academic research and industrial applications, ensuring reliable and efficient optimization solutions.

1.7 Literature Review

This study [TPG86] evaluated the effectiveness of 26 heuristic decision rules in grouping work tasks into workstations along an assembly line to minimize the number of workstations required. The decision rules vary in complexity, with some using backtracking or probabilistic search methods. The focus was on determining the minimum number of workstations for a given time limit at each workstation, in contrast with previous research that addressed the problem of finding the minimum cycle time for a given line length. The researchers compared their results with optimal solutions for a subset of the problems and provided novel solutions to previously unresolved issues, as well as guidance for optimizing industrial assembly lines.

The authors of this article[MRCC12a] have proposed straightforward heuristic methods to tackle the problem of assigning and balancing workers on an assembly line. This issue often arises in specialized workplaces designed for individuals with disabilities. Unlike the well-established assembly line balancing problem, the time required to complete each task depends on the worker assigned to it. They've developed a constructive heuristic framework that uses task and worker priority rules to determine the order in which tasks and workers are assigned to workstations. Several of these rules are presented, and their performance is evaluated in three different ways: as a standalone technique, as a generator for initial solutions in metaheuristic approaches, and as a decoder for a hybrid genetic algorithm. The results demonstrate that these heuristics are quick, produce good standalone solutions, and are effective when used to generate initial solutions or as a decoder within more complex methodologies.

In this article[MRCC12b], the authors propose straightforward heuristics for addressing the challenge of worker assignment and balancing on assembly lines, often encountered in sheltered work environments for individuals with disabilities. Unlike the well-known simple assembly line balancing problem, the time required to complete each task varies depending on the assigned worker. The authors develop a constructive heuristic framework based on prioritizing tasks and workers, determining the order in which they should be assigned to workstations. They present several such rules and evaluate their performance in three scenarios: as a standalone method, as an initial solution generator for metaheuristics, and as a decoder for a hybrid genetic algorithm. The findings indicate that the heuristics are computationally efficient, deliver strong results as a standalone approach, and prove effective when used to generate initial solutions or as a solution decoder within more complex methodologies.

The number of new model introductions has significantly increased over the past three decades. To manage this heightened customization, current automotive assembly platforms are designed to assemble a wide range of diverse models, transforming into mixed-model assembly lines (MMALs). Consequently, the tasks to be performed at each workstation are no longer constant but vary considerably with the model mix. This increases manufacturing complexity at the workstations and throughout the entire assembly system. This study [ZAL17] proposes a method to monitor manufacturing complexity at each workstation while balancing the MMAL. An entropy-based quantitative measure of complexity, accounting for the variability of each task duration, is developed. This measure is used to track the manufacturing complexity level at each workstation. An integrated mixed-line balancing and complexity monitoring heuristic is proposed to determine workload balance solutions, where manufacturing complexity is evenly distributed across the line's workstations. This approach is tested using real data provided by an automotive manufacturer. The outcomes have been meticulously compiled and extensively explored.

This study[BAU15] introduces a novel heuristic algorithm designed to address the Type 2 ALBP, focusing on single-objective optimization. The proposed algorithm directly assigns tasks to a fixed number of stations, with the primary goal of minimizing the cycle time. Traditionally, the Type 2 ALBP has been approached by solving the Type 1 problem first. However, this paper presents a direct methodology for the Type 2 ALBP, which has the potential to yield competitive results. To evaluate the effectiveness of the proposed algorithm, the researchers applied it to the Gunther problem, which involves 35 tasks and 45 precedence constraints. The task assignment for six stations was computed, demonstrating promising performance. Additionally, the number of fixed stations was varied, and the corresponding cycle times were calculated. The algorithm was also tested on a real-world industrial problem involving 24 tasks, further validating its ability to provide effective and near-optimal results.

This study [HG19] examines the initial configuration of such systems. The flexible layout design problem (FLDP) involves designing a flexible layout for a segment of the assembly of diverse vehicles. It combines station formation and station location issues. Additionally, the FLDP anticipates the operational flow allocation of the automated guided vehicles. The researchers formulate the FLDP as a mixed-integer linear program and develop a decomposition-based solution approach that can optimally solve small to medium-sized instances. Furthermore, they transform this solution approach into a matheuristic that generates high-quality solutions in a reasonable time for large-sized instances. They compare the efficiency of flexible layouts to mixed-model assembly lines and quantify the benefits of flexible layouts, which increase with vehicle heterogeneity.

1.8 Conclusion

In this chapter, we have explored the main manufacturing systems and their characteristics while reviewing some articles that have inspired us to develop our own proposed method, which will be discussed in the next chapters.

This chapter has enlightened us on the nature of manufacturing systems, their various types, and their evolution over time, while also providing an insight into the construction heuristics.

Chapter 2

Internship presentation

2.1 Introduction

In this chapter, we will discuss our internship at IMT Atlantique, where we have spent the past two months in a team called ”modelis” conducting research and development for this thesis. We will explore the different teams within the university and their respective areas of expertise.

2.2 IMT Atlantique

IMT Atlantique is one of the top 10 engineering schools in France, and one of the top 400 universities in the world in THE World University Ranking. It is a general higher engineering school financed by the Ministry of Economy,and the first Institut Mines Télécom ”Mines-Telecom” Technological university, founded on January 1st, 2017 from the merger of Mines Nantes and Télécom Bretagne.

Figure 2.1: IMT Atlantique Nantes

IMT Atlantique is:

- A Higher Education Institution with first-rate research potential, internationally recognized for its research (present in 5 disciplines in the Shanghai, QS and THE rankings).
- A resolutely multi-site institution reflecting the world in which we live. An institution with a strong local presence, and a commitment to contributing to local development.
- An institution which is aware of its environmental and societal responsibility. In 2019 it was awarded the sustainable development and social responsibility accreditation.
- And finally, an institution that trains executives capable of understanding and mastering the complexity of the highly interconnected systems of the future, by combining their knowledge of the systems with that of the networks that link them.

Their mission is to welcome and support the future generation of engineers those who aspire to live and develop professionally in a different way. All the indicators point to this desire in tomorrow's engineers, and they understand.This generation has questions about the role it will play in a world that is under attack, mistreated, weakened environmentally, politically and societally, and at the same time filled with advanced technologies, artificial intelligence and virtual realities. This generation is preparing to transform this future!

As a technological university for the Ministry of Industry and Digital Technologies, IMT Atlantique combines digital, energy and environmental technologies to meet these challenges.The research work carried out in the school's laboratories aims to bring together excellence in expertise and interdisciplinarity in order to provide concrete answers to the problems we all face.

2.3 Lab LS2N

The lab of digital sciences of Nantes ("Laboratoire des Sciences du Numérique de Nantes : LS2N" in French) is a new Joint Research Unit (UMR 6004) created in January 2017, resulting from the grouping of the IRCCyN (Communication and Cyber Research Institute), and LINA (Computer Science Laboratory).With a strong scientific talent at the heart of digital sciences, this large laboratory of 450 people participates fully in the digital revolution of our society on the scientific and technical subjects it implements. Research is performed consciously of the societal challenges that this revolution engenders, and remaining curious and openminded to other disciplines.

The complexity of the research objects that they are studying also forces them to adopt a global systemic approach in which computer concerns, automatic control, signal and image processing are interwoven in order to answer the questions asked by open, interactive, communicating and ubiquitous systems. The laboratory is an actor in innovation that values these objects with partners in its environment.

The LS2N is supported by 5 public institutions of Higher Education and Research: IMT Atlantique, Faculty of Science and Technology, Centrale Nantes, Polytech Nantes and IUT of Nantes.It is located in Nantes on 5 geographical sites. Its research activity is structured in 5 areas of expertise and 5 cross-cutting themes.
The LS2N research is carried out in 22 research teams, structured around 5 major scientific poles: Signals, Images, Ergonomics and Languages; Data and Decision Science; Software and Distributed Systems Science; Design and Control of Systems and Robotics, Processes, Calculation. To these 5 poles are added the 6 transversal themes of application: Industry and business of the future, Energy and environmental impacts, Life sciences, Vehicles and mobilities, Digital cultures and Digital Technology for Open Education.

2.3.1 Background

The ground which have led toward the merging of IRCCyN and LINA:

Cybernetic-Computer synergy at the heart of digital technology: taking advantage of interdisciplinary research activities at the interfaces with mechanics, digital creation and modelling of living organisms, it is expected that fusion will bring real synergy and dynamics to the renewal of teams. The objective is to boost the Nantes forces, which have come together to provide a framework for large-scale scientific reflection. The environment of each laboratory is rich (the Jules Verne and bcom IRTs, the CominLabs labex, the Robotex teams to mention only the objects of the future investment program).

The critical mass effect: our research environment is structured in coarse grain within the University of Brittany-Loire (UBL). In this environment, the future laboratory must become a must, alongside its large neighbours (IRISA, Lab-STICC and IETR).

A model of UMR uniting the research forces: the situation in Nantes was particular with the activity of the IRCCyN and the LINA shared by several institutions (including two schools: IMT-Atlantique and Centrale Nantes) and which is developing on several large (from 20 to 70 permanent positions) and distributed geographical sites (the most distant sites are about ten kilometres from each other). The question of the visibility of the establishments and the management of the teams within the whole deserved to be worked on and improved by proposing a governance and management model adapted to multi-site and multi-tutelles.

Seize the opportunity offered by the calendar: the idea of bringing together Nantes forces in the fields of cybernetics and information technology is old, but has always been rejected for reasons of complexity. The development of the new five-year contract 2017-2021 was an opportunity not to be missed to bring our community together in a sustainable way and project its development to the highest possible level.

2.3.2 The areas of expertise

CCS - Systems Design and Operation

The design of industrial systems is inextricably linked to the definition of the control and monitoring system that will make it possible to regulate, correct or even optimize their use, but also to the development of specifications describing the functions that will be performed by the system and the constraints to which it will be subject. The three concepts (system, control, specification) are developed in parallel in detail by partners, customers, design, test or production engineers during the design phase. They often continue to evolve during the system's use phase, to keep pace with technological, market or societal changes. Industrial systems are therefore first and foremost dynamic systems interconnected with their control systems, which must validate a set of specifications. Their design itself is also a complex and closed process, driven by project management methods and involving the definition and validation of achievable objectives.

Their realization emerges from the art of engineering, but the search for methods to organize and regulate complex systems has interested scientists since the very beginning. Archimedes, to quote one of the oldest, invented the odometer, a distance measuring machine, to better organize the movement of the troops of the tyrant Heron II of Syracuse and regulate walking times from one day to the next. He had also studied the optimization of the distribution of weapons and their use within the army. Closer to home, Monge studied the organization of backfilling and clearing works from 1776 onwards. In 1867, Maxwell submitted his thesis "On governors", considered to be the first study of the stability of an interconnected system. The beginning of the twentieth century saw the development of production management and control technologies. The Second World War caused both the systematization of their employment and the requisitioning of many scientists for their development. The following years saw the birth of the sciences of system design and control, with the work of Bellmann, Kantorovitch, Pontryagin, Simon, Wiener, to name but a few of the most famous precursors to the research currently carried out in the CCS cluster.

- **Positioning:** On the scientific level, the cluster produces its results mainly in the fields of automation and automation, production management, industrial engineering and embedded and real-time computing. He is also active in the fields of applied mathematics corresponding to these first fields of research, in particular in control and systems theory, operational research, theoretical computer science, as well as in some fields associated with applications subject to ongoing research: biomedical, electrotechnical, transport.

  At the national level, the positioning is centred on the contour of the MACS GoR, and also addresses those of the CIRP and EMR, RO, SEEDS GoR. The two PSI and Command teams are only attached to the CCS division. The STR team is also attached to the SLS pole, and the IS3P and SLP teams to the SDD pole. Synergies with the SDD and SLS poles are therefore clearly visible. There are also synergies with the RPC poles, in particular through the control or coordination of robots, and with SIEL, for the consideration of the human, in semi-automated systems, and societal and cultural issues. Among the transversal themes, the company of the future is at the heart of the concerns of three teams, IS3P, PSI and SLP, especially through knowledge extraction, modelling and simulation, design, management and control. We note the recent opening towards the service industries, and towards economic or even social systems, which makes the term company preferable to that of industry. This trend is set to continue, with the development of research on business improvement and knowledge engineering. The Vehicles and Mobility theme is addressed by the Command and STR teams from the perspective of the vehicle and the automation of certain aspects of driving, and from the perspective of network design and management in the IS3P, PSI and SLP teams. It will remain important for all teams in the coming years. The theme of energy management and the control of environmental impacts has become an important societal issue that is taken into account in all teams, particularly through applications. The control team is directly involved in issues related to the management of RTE's electricity network, and in developments around clean energy generation, and the PSI and SLP teams are involved in logistics studies for such projects.

Sustainability is also at the heart of the IS3P team's project, and controlling the consumption of embedded systems is at the heart of the STR team's project. This theme is likely to develop and the structuring into clusters should make it possible to detect useful synergies and cooperation, and to make them grow.

- **Issues and objectives:** The scientific issues highlighted in the five team projects have several similarities:
- A first axis taken up by all teams consists in enriching the models, in order to better respond to the complexity of the models encountered in applications.
- A second axis mentioned by all is the robustness of the designed system with respect to modeling errors or uncertainties, hazards or behavioural deviations from predictions, disturbances acting on the system.
- A third axis considered important by all concerns the control of complexity. The aim is to reduce the complexity of methods to enable their implementation, both in online ordering systems or information systems, but also to reduce the off-line design effort of systems.

For these last two points, we focus at the pole level on highlighting these converging problems, in order to benefit the questions of each other's solutions and vice versa. The obstacle to be overcome is the diversity of approaches and the specialization of knowledge, which often makes the points of confluence from one approach to another invisible to research actors, and makes it difficult to meet or confront ideas. It should be noted that the enrichment of the models concerns both the description of the system to be designed and that of its management, or the specification through the description of the problems to be achieved. The problem formulations in continuous automation, discrete automation, formal verification, operational research and industrial engineering are so different that the similarity of the issues is not exploited or even properly measured. At the cluster level, it is necessary to contribute to multiplying information and meetings to help build bridges between the different approaches, with a view to moving towards generalizations rather than new models, and towards a synthesis of the different approaches. The five teams are already very visible in their fields. This collective work allows them to continue to play a leading role both in France and internationally, both by introducing unifying concepts and broader methods of use, and validating them on innovative technologies, and to identify the Nantes cluster as a leader in the field of industrial systems design and management.

RPC - Robotics, Processes and Calculation

Whether in everyday life or in industry, robots are on the verge of positively invading our daily lives. Originally conceived as simple manipulators capable of performing repetitive tasks with greater efficiency than humans, and greater flexibility than machine tools, robots are nowadays becoming more interactive with their environment and may one day become (finally) autonomous and/or collaborate in a simple and daily way with humans.

To reach this horizon, long awaited by society and industry (robotics must spread to SMEs in order to improve their productivity and avoid relocation), robotics research must make new breakthroughs in both the fields of action (handling, locomotion) and perception (sensors, reconstruction of the environment, localization) as well as their integration into control loops (command) supervised by algorithms.

Taking advantage of the advances in robotics that it had largely contributed to initiate, the world of machine tools, and more generally of automated manufacturing, has considerably evolved in recent years and its integration into the factory of the future raises problems requiring a strong investment from the world of research.

In this futuristic context, the RPC cluster is composed of four complementary teams, three (ARMEN, ReV, RoMaS) contributing in parallel to the development of robotics and manufacturing processes and a fourth (OGRE) developing tools for guaranteed numerical calculation. Culturally, the first three teams are strongly rooted in the mechanics applied to industry and society, and focus on developing automated mechanical processes by focusing on their interactions with their environment (autonomous robotics and sustainable design of ARMEN), their relationships with living organisms (locomotion, perception and bio-inspired design in ReV), or with manufacturing (optimization of manufacturing processes in RoMaS).

Beyond these differences, these three teams contribute to jointly develop generic robotics tools (analysis, modelling, control) whose exploitation requires intensive use of optimization techniques. That is the reason why the OGRE team positions itself within the cluster. Made up of computer scientists with a solid background in applied mathematics, it develops guaranteed resolution algorithms for non-linear optimization problems under constraints. The relevance of these methods in robotics and automation is attested by several joint publications with the other three teams.

In addition to this cross-functional link, the division's three application teams are able to develop synergies by sharing their complementary points of view on specific subjects (ReV's bio-inspired solutions for the autonomy of ARMEN, design strategies and control for large workspace robots of RoMaS, the design of ARMEN's innovative industrial robots, ARMEN's control and reconstruction techniques for control schemes developed by RoMaS, ReV's exoskeletons for RoMaS' cobotics, etc.).

Finally, in the field of applications, all the cluster's teams jointly participate in the development of industrial and service robotics, notably in three of the laboratory's cross-cutting themes: "Enterprise of the future", "Energy management and control of environmental impacts","Vehicles and mobility".

SIEL - Signals, Images, Ergonomics and Languages

The SIEL pole groups together the laboratory's activities concerning signals, images, sounds, languages, writing, physiological measurements and human factors. Two strong convergences between the teams ensure the coherence of the cluster.

The first convergence is related to signal and data processing in specific application contexts, through the development of theories and methods in signal and image processing (in the broad sense), language and writing. The IPI, SIMS and TALN teams are users/designers of data analysis, decision, security or compression tools and implement processing methods dedicated to the specific data they process (close to the sensor for SIMS, image/video/write for IPI, language data for TALN). The challenges related to tools and methods include: developments in computational imaging, at the interface with observational sciences, from the infinitely large to the infinitely small, with applications close to the sensor, in non-destructive testing, in medical and biological imaging, in remote sensing; learning and recognition techniques for specific signals such as sound, writing, gesture or natural languages; methods for the compression, archiving and transmission of multimedia signals and perceptually optimized when these signals are intended for use by humans.

The IPI, SIMS and TALN teams therefore process data and signals produced by and/or for humans, whether visual, sound, internal to the body (muscles, brain) or related to language (writing and texts). Here we find one of the characteristics that illustrates the cluster's second convergence, relating to human factors. The term is used here in a broad sense, since it covers work carried out by the IPI SIMS, PACCE and part of DUKe teams in the fields of human-machine interactions, cognitive ergonomics and, more generally, the design and evaluation of digital interactive products and systems by putting the human being at the centre of the reflection. Three types of multidisciplinary activities and challenges are mainly considered. First of all, the design of interactive and cooperative systems, with a user-centred approach. The evaluation of systems is then an important activity of the cluster's teams, whether these systems are proprietary or designed by external partners: we will talk here about cognitive ergonomics, user experience, perceptual approach to the quality of experience, usage analysis. A final activity related to cognitive psychology, a skill specific to the PACCE team, theoretically and experimentally complements and reinforces the previous one by aiming at the analysis and modelling of the sensorimotor and cognitive processes underlying the activity. Several experimental capture and analysis platforms are also available in the cluster's teams, which also share similar or complementary experimental methodological approaches.

The cluster is thus intended to bring together skills in the disciplines covered by sections 7 (on its perimeters of processing, images, content, interactions, signals and languages) and 26 of the CNRS (Cerveau, cognition et comportement). There are lecturers and researchers from CNU 61, 27 but also 60 (on aspects concerning design engineering), 16 (Psychology) and 55 (Ophthalmology). Disciplinary cross-fertilization is therefore at the heart of the work of the cluster's teams.

The SIEL cluster is directly concerned by four of the laboratory's transversal themes:

- Life Sciences for its work in the field of health in signal processing and biomedical imaging, analysis of medical documents, analysis of the impact of technology on diagnostic quality, personalized medicine, design of tools for operating rooms, cognitive remediation for vulnerable populations, visual attention on populations with visual impairments.
- Digital creation, culture and society on its contribution to the digital humanities, to the analysis of the uses of digital technology, to the design of innovative interactions and couplings.
- Vehicles and mobility with regard to driver modelling and monitoring, as well as cooperation between drivers and automated systems, including the autonomous vehicle.
- The company of the future for issues related to operator assistance, cobotics, non-destructive testing, and the design of augmented and virtual reality systems adapted to the needs of the company, rendering systems and ergonomic simulations.

  It is part of the regional policy of two RFIs:
- Atlanstic2020, in particular in relation to one of its five fields of excellence "Content and interactions" (perception, uses, language and speech processing, multilingualism and multimodality, affective computing, virtual and augmented reality).
- RFI Ouest Industries Créatives, in particular in two of its four research areas: "Human interaction with digital objects in the field of culture and creation" and "Changes in tools and know-how in the field of culture and creation in a digital environment".

Among the privileged partners at the local level, we can mention the health actors (University Hospital, Clinics) for the imaging, gerontology, pain, ophthalmology axes; the Jules Verne IRT; the future interdisciplinary University Pole on digital cultures and associated creative industries; the IFSTTAR.

SLS - Software and Distributed Systems Science

Since the 2000s, the number and complexity of computers, from the simple object connected to the largest data centers, have increased dramatically. Over the same period, application and system services have naturally migrated from a mainly centralized to highly distributed world, making them increasingly complex to analyze, develop, fix and maintain. To address these new challenges, software science and distributed systems have gradually matched each other.

Drawing on the skills of the research teams concerned, the SLS cluster pays particular attention to programming, software and systems engineering, both in a buried and highly distributed context, by exploring the complementary aspects of languages, models and systems. The skills, scientific expertise and projects of the teams that make up the SLS cluster make it possible to define three differentiating orientations:

- Programming languages and modeling languages for the specification, verification and development of complex software. Programming languages research focuses on the definition and implementation of new concepts in the form of domain-specific languages and language elements, with an emphasis on the energy management of software and systems (greenIT), from micro-sensors to cloud computing. Research on modeling languages focuses on the structural and functional cutting paradigms of complex systems by formalizing architectural elements, trades, patterns, styles and finally the engineering approach in which these coherent and autonomous elements can be managed.
- Distributed systems and algorithms for the possible real-time management of IT capacities both at the application level (in the development of the social and semantic web for example) and at the system level (in the development of systems for the optimization of computing capacities, memory, disk, networks, etc.). The application domains are mainly the Internet of Things and Cloud Computing.
- The systems and software addressed by the cluster are, among other things, distributed, (a)synchronous, real-time, autonomous, dynamic, ubiquitous and therefore require the development (automatic or not) of models for analysis purposes for, among other things, correction, security, and performance, including energy. Indeed, the function of a model is to facilitate the analysis of a system by simplifying and interpreting it. It is by relying on its already proven internal skills (in life modeling, discrete event systems, model-checking, proofs, time-controlled, parameterized and probabilistic models, model-driven engineering, dynamic reconfiguration of software architectures, flow modeling, software evolution modeling) that the cluster intends to meet these challenges.

Over the next few years, the ever-increasing omnipresence of IT in our daily lives, whether in terms of services (from the Web to social networks) or objects (connected or not), raises many challenges on both the software, model and system aspects. The cluster's triple competence is a strength in meeting these challenges. We can mention here some of the challenges that are addressed: How to structure software for its evolution and composition? What methods and tools for the analysis, verification and validation of complex systems? How to administer, manage, optimize, program and evolve highly distributed infrastructures in a secure and secure manner?

SDD - Data Science and Decision-making

The links between statistical data processing and optimization have a long history; the importance of interdisciplinarity was underlined since the creation of the French Operational Research Society at the end of the 1950s by its first president who was a recognized statistician. Under sometimes different names, these links are now experiencing a new impetus, stimulated on the one hand by the confrontation of data management and processing specialists with ever-increasing volumes that require efficient algorithms, and on the other hand by the growing need to refine optimization models by integrating increasingly rich knowledge and to guide research processes in areas of increasing complexity. Publications and interdisciplinary workshops establish future directions for collaboration between data mining, learning, and combinatorial optimization. The relationships between these disciplines and bioinformatics are intrinsically linked to the development of the latter(4) and are now being renewed with the considerable changes in the scales of analyzable data associated with "omics" technologies. based on the skills and projects of the teams making up the SDS cluster, the following four orientations can be defined in particular, which transcend the particularities of the data processed in the various teams.

- **Enrichment of models:** at their construction, by learning specifications (e.g. constraints, objectives, preferences) from histories and taking into account hazard (uncertainty models, probabilities); in an evolutionary process, by integrating knowledge from the processing of activity data (e.g. traces, sensor data).
- **Learning of resolution strategies:** static and dynamic analysis of a research space and its evolution to guide off-line or on-line research; learning of parameters and automatic generation of tactics with the long-term objective of "autonomous research".
- **Analysis of search and learning algorithms:** improving the efficiency of classification and learning algorithms for metrics and structures; introduction of specifications in human in the loop search processes.
- **Addition of optimization and digging features:** visualization of traces of optimization heuristics and data mining observations.

Beyond the improvement of the approaches of the respective communities, fundamental questions arise transversely on the consideration in the modelling of the systems studied of the different observation levels: what are the relationships between the different observation levels? And how to build models that are "coherent" at different scales?

2.3.3 Team Modelis

The modelis team develops analytical methods for optimization and decision support in production, logistics and transport. The technological hurdles we seek to overcome concern the effective resolution of problems in the literature that are still poorly solved today. This is achieved through the development of appropriate optimization methods as well as modeling and solving new problems encountered in the industry and for which there is not yet a resolution method. The contribution of the team therefore includes the development of new approaches (heuristics, metaheuristics or exact methods), and also the modeling and solving of new complex problems. The main challenges are to model and solve large-scale problems by integrating the complex real constraints of companies.

The team has multiple themes to work on , we are going to mention them in the following :

Design, planning and scheduling of production and service systems

Some of the team's projects deal with scheduling and planning issues, which are widely encountered in the literature. On the one hand, the team endeavours to carry out various studies to identify and characterize new problems, emerging in current contexts whose concerns are evolving. A first part of the work, of a purely theoretical nature, can also be included in the transversal axis of the team, particularly around complexity approaches: identification of sub-cases, proof of NP-completeness in particular. On the other hand, work is carried out to remove the scientific obstacles around the resolution of dedicated problems by the proposal of resolution methods from Operational Research approaches: tree-based resolution methods, mathematical modeling, column generation models, but also different metaheuristics such as Limited Discrepancy Search, Large Neighborhood Search, Tabu Search...

The different contributions of the team are mainly structured in the field of production line design (reconfigurable, collaborative environments, etc...), parallel machine context workshop scheduling, batch processing, cross-processingdock...), project scheduling (taking into account competence, generalized precedence...), production planning (maintenance and joint production, multi-site planning, integration of financial risks, etc...) and human resources planning (appointment management, rotation of nurses, ...) and can find applications both in the sectors of the production of goods (or find examples in the production of metal parts or in the aerospace industry), in services (health system, project management for example).

Design and optimization of logistics and transport networks

The SLP team works on the development of models and algorithms for transport optimization. The tools developed are used on the one hand to support decision-making on a strategic level, mainly during network design (supply chain, distribution network/ transport). A second part of the contributions concerns the optimization of vehicle routes, with applications at the operational level or for the simulation of systems in development. The contributions of the transport optimization team find applications in passenger transport, goods distribution, transport within the supply chain or in services. The research aims either to improve the performance of algorithms for solving known problems, or to solve new problems.

Other themes

Many works are carried out between the axes of the team. The most important are integrated production and maintenance planning, which involves the integration of stochastic phenomena into the production planning process. In addition, independent or parallel theoretical contributions are made to the work carried out in the three historical axes of the team.

A first part is concerned with the design of meta-heuristics for solving optimization problems with one objective:

- Contribution to the solving of combinatorial optimization problems with the meta-heuristic ALNS: a large number of works are carried out with the meta-heuristic ALNS in vehicle touring and network design. They help to analyse more precisely the key components of the method and make it evolve. In particular, we study the hybridization of this method with PLNE.
- Contribution to the resolution of continuous optimization problems with the meta-heuristic PSO.

A second part addresses the current locks encountered in multi-objective optimization. It aims to propose new knowledge for solving large multiobjective optimization problems, either combinatorial or mixed numbers. Efficient algorithms are produced to facilitate the treatment of multiobjective NP-difficult problems in order to solve them effectively. In particular, it concerns algorithms based on polyhedral approaches, integrating cutting planes, generalizing bi-objective methods to multiobjective situations and going towards the implementation of branch-and-bound/cut multiobjective methods. Multiobjective metaheuristics complete this part, especially from the angle of hybridization or matheuristics. In particular, this work focuses on:

- Study of the links between relaxation and scalarization methods to determine bounding sets in a context of multi-objective optimization.
- Cutting method and branch-and-cut in a context of multi-objective optimization.
- Dynamic methods for choosing branching variables and choosing the active node for branch-and-bound and branch-and-cut multi-objective algorithms.
- Algorithms approached in combinatorial optimization multi-objective and articulation in a three-phase scheme.

2.4 Conclusion

As we have seen in this chapter, IMT Atlantique is a highly ranked university in research, with multiple teams dedicated to various aspects, each contributing their full potential to solving challenges through research collaborations with experts from across the country and around the world.

IMT Atlantique is one of the top-ranked universities globally, and it has been a privilege, especially working with the exceptional team we were part of and the remarkable people we have had the opportunity to meet.

Chapter 3

Construction Heuristic for FLDP

3.1 Introduction

In this chapter, we will dive into our proposed construction heuristic that we have established based on a mathematical model. The mathematical model is considered a FLDP where it is more enclosed around the MMS layout. For this particular case, we used [HG19] MILP in order to try and get a first solution using our construction heuristic.Then we will discuss the obtained results by comparing them with the results of the MILP model, and see the efficiency of our approach using our dataset. Each dataset has a specific number of tasks: Bowman has 8 tasks with a cycle time of 19, EX has 5 tasks with cycle times of 18 and 20, Jackson has 11 tasks with a cycle time of 8, Jaeschke has 9 tasks with a cycle time of 7, Mansoor has 11 tasks with a cycle time of 47, Mertens has 7 tasks with a cycle time of 8, and Mitchell has 21 tasks with a cycle time of 14.

Our solution approaches and the instances are implemented in a program application written in Python 3 and interfaced with Gurobi 11. All experiments are run on a computer using an AMD Ryzen 7 5700U with Radeon Graphics processor with 1.8 GHz and 16 GB RAM.

3.2 Construction Heuristic

In the next parts, we will propose a construction heuristic to solve the problem. We divided the heuristic into four steps to better address all aspects of the problem. We will start by creating a graph level for tasks from a general precedence diagram. Then, we will use this graph level to assign tasks and models to stations. Following this, we will assign locations to layout stations and map routes. Finally, we will allocate flow by solving a linear model.

3.2.1 Generating the general precedence diagram

In the first part of the heuristic, we will combine all the precedence diagrams of the models into one general precedence diagram. This is done by selecting all direct predecessors for all models for every task, starting from the last task and working backward to the initial task. We will take two models (Figures 3.1 and 3.2) as an example to explain this step. Task T11 has T6 as a predecessor for model 2, and T3, T4, T5 as predecessors for model 1.

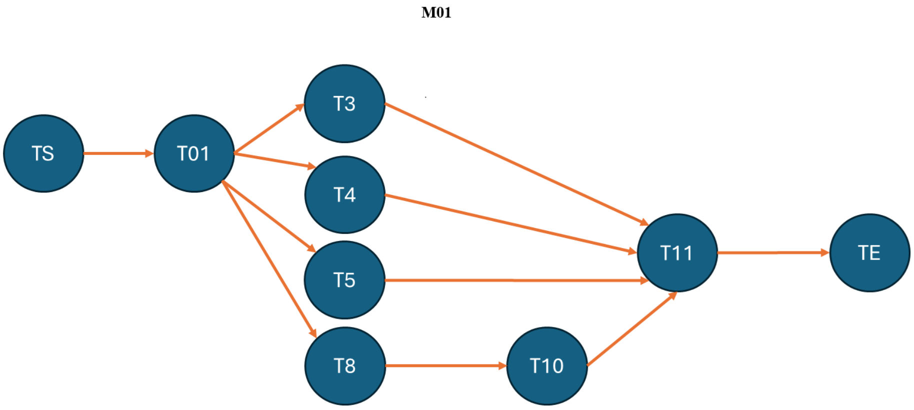


Figure 3.1: Precedence diagram for model M01

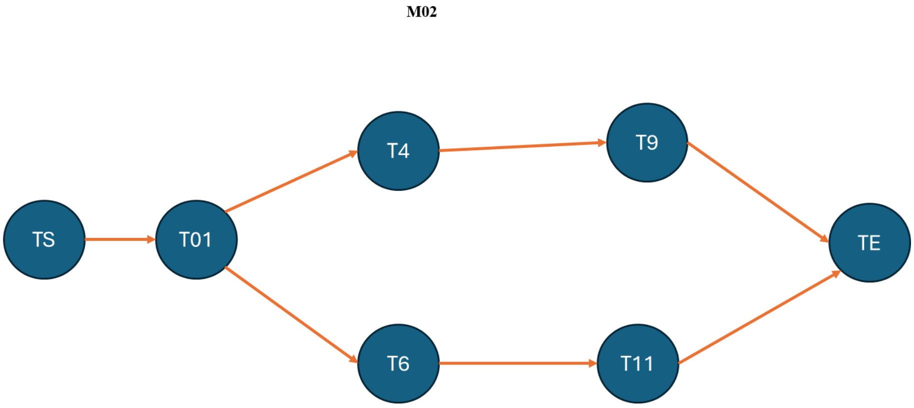


Figure 3.2: Precedence diagram for model M02

The general precedence diagram for M01 and M02 is then drawn as shown in Figure 3.3.

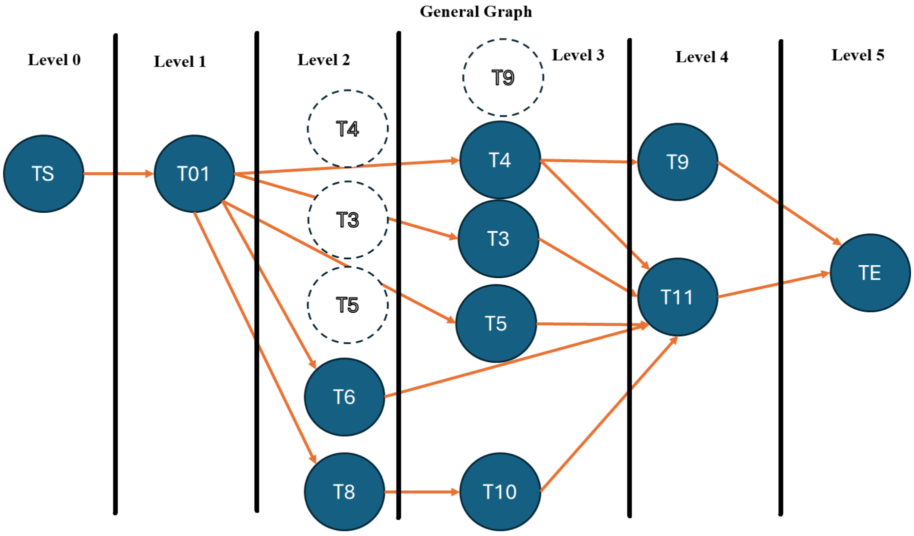


Figure 3.3: General precedence diagram

From this general diagram, we will create a graph of levels. This is done by iterating through the general precedence diagram, selecting tasks with no predecessors, and assigning them to the first level while removing them from the general precedence diagram (Figure 3.3). We will then repeat this process for the next level, continuing until all tasks are assigned to levels. Tasks will be assigned to the latest possible level, for example, task 9 has task TE as a successor and TE is the last task, task 9 can be assigned to level 3 or level 4 (taking into account its predecessors' level). We will assign it to the last possible level (4). By the end, each level will have its assigned set of tasks.
In the next step, we will count the number of successors for each task in each model. Then, for each level, we will sort the tasks in that level by the number of successors for each model that contains the task. By the end, we will have a set like this: level=2, tasks assigned: ('T08' of model 1 with 3 successors, 'T03' of model 1 with 2 successors, ...). We will store these in a variable named G.

3.2.2 Tasks and models assignment

As the starting point for the iterations, we derive a lower bound on the number of required stations N^{LB} (Eq 3.1).

$$N^{LB} = \left[\frac{Total\ workload}{Production\ time}\right] = \left[\frac{\sum_{m\in M} d_m \ * \ \sum_{t\in T_m} q_{m,t}}{\tau}\right] \tag{3.1}$$

d_m represents the demand of model m, $q_{m,t}$ is task time of task t for model m.
We then calculate a cycle time (Tc) (Eq 3.2), which will be our new station's capacity, defined as:

$$Tc = \left[\frac{Total\ task\ times}{number\ of\ required\ stations}\right] = \left[\frac{\sum_{m\in M}\sum_{t\in T_m} q_{m,t}}{N^{LB}}\right] \tag{3.2}$$

Now we will navigate G by level, assigning the first task to the first station while respecting the station's capacity. If a task for a given model exceeds the capacity, then the task and the model will be stopped, and we will move on to the next station.We will continue assigning non-stopped tasks and non-stopped models while respecting the capacity of each station until we have navigated all levels.
At this stage, we will revisit the graph G by level for the stopped models and the stopped tasks. For a given task and model, we will find the station that contains this task and assign the task with the remaining time until the station is saturated. Then, we will assign the remaining task time to a new station and continue this process until all models are assigned.
With this approach, we will ensure that all tasks for all models are assigned, while avoiding task duplication beyond two instances.
By the end, our solution S will be sorted by tasks and models in the order they were assigned:
S = {location 1: [{TS: M01}, {TS: M02}],location 2: [{T01: M01}, {T01: M02}], location 3: [{T08: M01}], ...}. This means that in location 1, we will find task T01 for model M01 and task T01 for model M02. In location 1, we will find task T08 for model M01.

3.2.3 Routes mapping

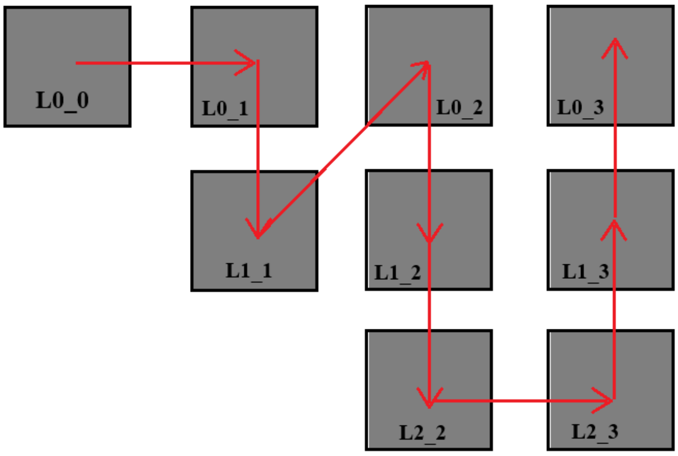


Figure 3.4: Longest possible route

We will start by fixing the locations in our layout. We will take the longest possible route as shown in fig 3.4 (section 3.2.2) and then assign stations found in S to the locations in layout (L0_0, L0_1...). The station that contains the final task ('TE') will always be assigned to the exit station (L0_3).

As for the next step, our main goal is to determine the routes the AGVs will take to meet the existing constraints and show the flow of models through our MMS layout between the locations.
To achieve this, we will use the previous solution found in S from allocating the

tasks to the locations. Since we already know which task of which model is assigned to each location, and the precedence relations are clear, we will map all possible routes and determine which ones are applicable to the obtained solution, choosing the route with the shortest distance. With this, we will ensure that all non-feasible routes are eliminated.
The solution will be stored in best_routes_mapped and will be like this:
best_routes_mapped = {'M03': [{route 'R50': [{location 'L0_0': ['TS', 'T01']}, {location 'L0_1': ['T04']}, {'L0_3': ['T16', 'TE'] }] }] }.

In the end, this step will provide a solution where each model has its own routes to follow, which could be one route or multiple routes, depending on the model. This will serve as the input for the next and final step.

3.2.4 Flow allocation

Now our final step is to determine the quantity the AGVs can transport through the identified routes to meet the demand of each model. We approach this problem by solving a linear program using Gurobi.

Our mathematical model includes the set of models $m \in M$ that need to be processed, the set of tasks $t \in T$ that need to be assigned to our set of locations $l \in L$ and the set of routes $r \in R$ through which they will flow, as shown Table 3.1. We have chosen for the parameters (Table 3.2) L_r representing the length of route r, D_m the demand to be distributed through the MMS layout for model m, $T_{t,m}$ representing the task time of task t for each model m , C_l the capacity of each location l. As for the decision variable (Table 3.3) we only have one $Q_{m,r}$ which indicates the quantity of flow that goes through route r for model m. The objective is minimizing the length of routes * flow going through these routes.

Index sets	
m $\in M$	Models
t $\in T$	Tasks
l $\in L$	Locations
r $\in R$	Mapped Routes

Table 3.1: Index sets

Parameters	
L_r	Length of the mapped route r
D_m	Demand of the model m
$T_{t,m}$	Task time t for model m
C_l	Capacity of location l

Table 3.2: Parameters

Decision Variables	
$Q_{m,r}$	Flow that goes through route r of model m

Table 3.3: Decision variables

$$Min\ Z\ =\sum_{r\in Rm}\sum_{m\in M} L_r *\ \ Q_{m,r} \tag{3.3}$$

$$\sum_{r\in Rm} Q_{m,r} = D_m \qquad \forall\ m\in M \tag{3.4}$$

$$\sum_{m\in M}\sum_{r\in Rm}\sum_{t\in T|t\in l} Q_{m,r} *\ T_{t,m}\ \leq C_l \qquad \forall\ l\in L \tag{3.5}$$

For our mathematical model we have 3.3 our objective function that needs to be minimized. Regarding constraints, we have only two, 3.4 ensures that the demand for every model m is met through the routes r, and 3.5 limits the quantity of flow through each station to not exceed their capacities.

Theses steps are summarized in this flow chart (fig 3.5).

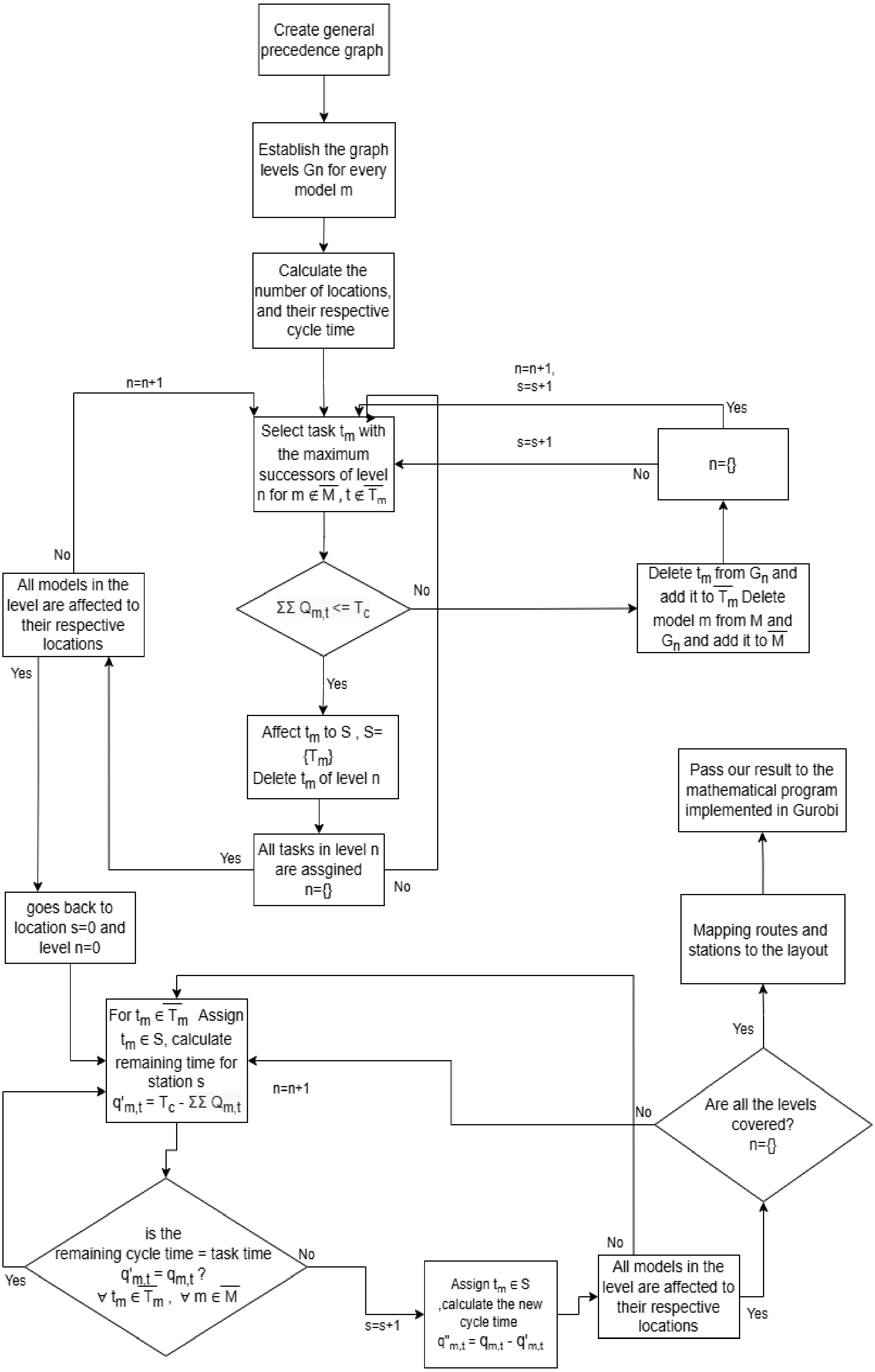


Figure 3.5: Heuristic Flow Chart

3.3 Results and Analyses

In this section, we will discuss the results obtained from simulating the MILP for 20 minutes alongside our heuristic. We will compare the performance of our proposed heuristic with the results of the FLDP, aiming to identify the underlying reasons for any observable differences between the two methods.
We will compare the results based on the number of stations found by each method and the GAP from lower bound for MILP and the GAP in heuristic calculated as follows (Eq. 3.6):

$$GAP = \left[\frac{Upper\_Bound\ (heuristic)\ -\ Upper\_Bound\ (MILP)}{Upper\_Bound\ (heuristic)}\right] \tag{3.6}$$

3.3.1 Bowman 8 tasks

OV	**TTV**	**MILP**		**Heuristic**	
		N° locations	**Gap (%)**	**N° location**	**Gap (%)**
00	00	4	00	4	15,32
	10	4	00	4	15,32
	25	4	00	4	15,32
	50	4	00	5	31,75
	Average	4	00	4,25	19,42
10	00	4	00	5	20,85
	10	4	00	5	25,99
	25	4	00	5	32,70
	50	4	00	5	32,70
	Average	4	00	5	28,06
25	00*	—	—	—	—
	10	4	00	5	22,92
	25*	—	—	—	—
	50	4	00	5	18,50
	Average	4	00	5	20,71
50	00	4	00	4	28,73
	10	4	00	4	28,73
	25	4	00	4	28,73
	50	4	00	5	21,95
	Average	4	00	4,25	27,03

Table 3.4: Bowman Heuristic

3.3.2 EX C=18, 5 tasks

OV	**TTV**	**MILP**		**Heuristic**	
		N° locations	**Gap (%)**	**N° location**	**Gap (%)**
00	00	2	00	3	00
	10	2	00	3	00
	25	2	00	3	00
	50	2	00	3	00
	Average	2	00	3	00
10	00	2	00	3	00
	10	2	00	3	00
	25	2	00	3	00
	50	2	00	3	00
	Average	2	00	3	00
25	00	2	00	3	00
	10	2	00	3	00
	25	2	00	3	00
	50	2	00	3	00
	Average	2	00	3	00
50	00	2	00	3	00
	10	2	00	3	00
	25	2	00	3	00
	50	2	00	3	00
	Average	2	00	3	00

Table 3.5: EX C=18 Heuristic

3.3.3 EX C=20, 5 tasks

OV	**TTV**	**MILP**		**Heuristic**	
		N° locations	**Gap (%)**	**N° location**	**Gap (%)**
00	00	2	00	3	00
	10	2	00	3	00
	25	2	00	3	00
	50	2	00	3	00
	Average	2	00	3	00
10	00	2	00	3	00
	10	2	00	3	00
	25	2	00	3	00
	50	2	00	3	00
	Average	2	00	3	00
25	00	2	00	3	00
	10	2	00	3	00
	25	2	00	3	00
	50	2	00	3	00
	Average	2	00	3	00
50	00	2	00	3	00
	10	2	00	3	00
	25	2	00	3	00
	50	2	00	3	00
	Average	2	00	3	00

Table 3.6: EX C=20 Heuristic

3.3.4 Jackson 11 tasks

OV	**TTV**	**MILP**		**Heuristic**	
		N° locations	**Gap (%)**	**N° location**	**Gap (%)**
00	00*	—	—	—	—
	10	6	1,04	6	16,80
	25	6	3,41	6	18,46
	50	6	7,23	6	11,78
	Average	6	3,89	6	15,68
10	00	6	12,5	6	34,07
	10	6	4,47	6	39,91
	25	6	0,30	6	15,08
	50*	—	—	—	—
	Average	6	5,75	6	26,68
25	00	6	0,13	6	23,59
	10	6	0,41	6	23,89
	25	6	0,49	7	23,10
	50	6	0,30	6	27,58
	Average	6	0,33	6,25	24,54
50	00	6	0,06	7	26,35
	10	6	0,29	7	26,25
	25	6	0,21	7	25,97
	50	6	0,20	6	34,21
	Average	6	0,19	6,75	28,19

Table 3.7: Jackson Heuristic

3.3.5 Jaeschke 9 tasks

OV	**TTV**	**MILP**		**Heuristic**	
		N° locations	**Gap (%)**	**N° location**	**Gap (%)**
00	00*	—	—	—	—
	10	6	1,79	6	22,16
	25	6	0,72	6	19,62
	50	6	0,51	6	9,95
	Average	6	8,68	6	28,70
10	00	6	1,09	6	23,10
	10	6	0,13	7	24,02
	25	6	0,23	6	15,25
	50	6	0,25	6	15,96
	Average	6	0,42	6,25	19,58
25	00	6	2,78	6	26,40
	10	6	0,39	6	26,65
	25	6	0,17	6	14,11
	50	6	0,18	6	35,88
	Average	6	0,88	6	25,76
50	00	6	4,18	7	34,66
	10	6	1,43	6	29,86
	25	6	3,35	7	35,84
	50	6	3,47	6	9,55
	Average	6	3,10	6,5	27,47

Table 3.8: Jeaschke Heuristic

3.3.6 Mansoor 11 tasks

OV	**TTV**	**MILP**		**Heuristic**	
		N° locations	**Gap (%)**	**N° location**	**Gap (%)**
00	00	4	00	4	31,75
	10	4	00	5	22,14
	25	4	00	4	31,75
	50	4	00	4	31,75
	Average	4	00	4,25	29,34
10	00	4	00	5	26,73
	10	4	00	4	15,32
	25	4	00	4	22,14
	50	4	00	4	22,14
	Average	4	00	4,25	21,58
25	00	4	00	4	33,52
	10	4	00	5	37,68
	25	4	00	4	33,52
	50	4	00	4	25,55
	Average	4	00	4,25	32,56
50	00	4	00	5	37,68
	10	4	00	5	37,68
	25	4	00	5	30,77
	50	4	00	5	36,16
	Average	4	00	5	35,57

Table 3.9: Mansoor Heuristic

3.3.7 Mertens 7 tasks

OV	**TTV**	**MILP**		**Heuristic**	
		N° locations	**Gap (%)**	**N° location**	**Gap (%)**
00	00	4	00	4	15,53
	10	4	00	4	15,53
	25	4	00	4	15,53
	50	4	00	4	00
	Average	4	00	4	11,64
10	00	4	00	5	00
	10	4	00	5	00
	25	4	00	5	00
	50	4	00	5	00
	Average	4	00	5	00
25	00	4	00	4	5,82
	10	4	00	5	5,82
	25	4	00	5	5,82
	50	4	00	4	00
	Average	4	00	4,5	4,36
50	00	4	00	5	00
	10	4	00	5	00
	25	4	00	5	10,88
	50	4	00	5	00
	Average	4	00	5	2,72

Table 3.10: Mertens Heuristic

3.3.8 Mitchell 21 tasks

OV	**TTV**	**MILP**		**Heuristic**	
		N° locations	**Gap (%)**	**N° location**	**Gap (%)**
00	00	8	74,20	8	-71,41
	10	8	44,60	8	-76,70
	25	8	56,30	8	-83,86
	50	8	25,70	8	-23,20
	Average	8	50,20	8	-63,79
10	00	8	66,40	8	-86,58
	10	8	28,40	9	17,84
	25	8	22,10	8	23
	50	8	18,50	9	28,55
	Average	8	33,85	8	-4,29
25	00	8	27,70	8	2,55
	10	8	14,40	8	33,34
	25	8	17,30	9	30,70
	50	8	16,20	8	30,67
	Average	8	18,90	53,83	24,31
50	00*	—	—	—	—
	10*	—	—	—	—
	25	8	1,95	9	41,16
	50*	—	—	—	—
	Average	8	1,95	56,95	41,16

Table 3.11: Mitchell Heuristic

From the previous tables, we can see that our heuristic worked for 120 out of 128 instances. However, the 8 instances where it did not work can be attributed to the cycle time calculated for the stations. We will now explore into a detailed discussion comparing the two methods.

From Bowman's C=19 instances (Table 3.4), we observe that the heuristic provided optimal solutions for the first objective in many instances. Regarding flow transportation, the results were quite satisfactory with a GAP of less than 33%. For EX C=18 and C=20 we can notice from Tables 3.5, 3.6 ,the MILP approach shows better performance in the first objective. However, both approaches exhibit no difference in the second objective, with both achieving a 0% gap. In our case, we consider these results very promising for a heuristic construction. It is noteworthy that the heuristic generates a solution in milliseconds, closely matching the MILP solution, which takes several seconds. For Jackson (Table 3.7), we can observe that the majority of instances achieved optimal results for the number of opened stations. Regarding the second objective, the results were satisfactory; for ov=00, the GAP did not exceed 20%. For our instance Jaeschke (Table 3.8), both methods generally produce similar results for the first objective, which is already a positive outcome for the heuristic. However, in terms of the second objective, the MILP approach tends to be closer to the optimal solution. Nevertheless, this does not discredit the solution found by our heuristic, considering that it can generate such solutions in milliseconds and typically achieves only a 20% difference from the optimal solution. Mansoor (Table 3.9) showed great results for ov=00, 10, 25 for objective 1. As for the second objective, the heuristic did perform with a GAP exceeding 30% in for ov=00, 50. The average GAP for ov=10 was 21%, which was more satisfactory compared to the variations in other parameters. Mertens (Table 3.10) has demonstrated that the MILP model generally outperforms the heuristic approach in the first objective, as it can find the globally optimal solution within the given time limit. However, the heuristic approach has shown impressive performance in the second objective, often achieving optimal or near-optimal solutions more efficiently than the MILP model. The results highlight the complementary strengths of the two methods. For Mitchell (Table 3.11), the heuristic has demonstrated its efficiency and productivity effectively. Specifically, for the parameter ov=00, all results show better performance than the MILP in the second objective, while achieving similar results in the first objective. This significant improvement from our heuristic, which generates solutions in milliseconds, underscores its effectiveness in this example.However, for ov=50, we observe that neither of the methods provides a satisfactory solution for the instances.

3.4 Conclusion

Within this chapter, we have detailed our heuristic approach and implemented our dataset to evaluate its efficiency, comparing it with results from the MILP. Through analysis, we observed varying outcomes depending on the configuration of each instance: sometimes the MILP performs better, while other times our proposed method shows significant improvements.

General Conclusion and Perspectives

Within our study, we have proposed a construction heuristic for the FLDP. We tested our method for 120 instances and compare them with MILP solutions generated in 20 minutes. We can draw the following conclusions:

- Our approaches can manage up to 21 tasks given the limited number of locations.
- The heuristic provided numerous near-optimal solutions, which can be integrated into a solver as initial solutions.
- The method achieved optimal solutions in terms of station numbers for 52 out of 120 instances, largely influenced by the calculated cycle time.
- The method demonstrated highly promising results for the flow transportation objective within a rapid computational timeframe.

We suggest some future research directions as follows:

- Explore alternative configurations of locations and routes.
- Improve the determination of the cycle time in a more appropriate manner to maximize station utilization.
- explore more instances with more tasks.
- Develop a meta-heuristic to refine and optimize this initial solution.

Bibliography

[And17] Ann-Louise Andersen. Development of changeable and reconfigurable manufacturing systems: supporting context-specific design of changeability. 2017.

[BAU15] PAKEEZA Bukhari, RIAZ Ahmed, and Muhammad Umer. A heuristic approach for type 2 assembly line balancing problem. *Applied Mechanics & Materials*, 2015.

[GŚ12] Arkadiusz Gola and Antoni Świć. Directions of manufacturing systems' evolution from the flexibility level point of view. *Innovations in Management and Production Engineering, Oficyna Wyd. Polskiego Towarzystwa Zarzadzania Produkcja, Opole*, pages 226–238, 2012.

[HG19] Andreas Hottenrott and Martin Grunow. Flexible layouts for the mixed-model assembly of heterogeneous vehicles. *OR Spectrum*, 41(4):943–979, 2019.

[KM13] Naveen Kumar and Dalgobind Mahto. Assembly line balancing: a review of developments and trends in approach to industrial application. *Global Journal of Researches in Engineering Industrial Engineering*, 13(2):29–50, 2013.

[MRCC12a] Mayron César O Moreira, Marcus Ritt, Alysson M Costa, and Antonio A Chaves. Simple heuristics for the assembly line worker assignment and balancing problem. *Journal of heuristics*, 18:505–524, 2012.

[MRCC12b] Mayron César O Moreira, Marcus Ritt, Alysson M Costa, and Antonio A Chaves. Simple heuristics for the assembly line worker assignment and balancing problem. *Journal of heuristics*, 18:505–524, 2012.

[SHGT15] Malte Schönemann, Christoph Herrmann, Peter Greschke, and Sebastian Thiede. Simulation of matrix-structured manufacturing systems. *Journal of Manufacturing Systems*, 37:104–112, 2015.

[TPG86] F Brian Talbot, James H Patterson, and William V Gehrlein. A comparative evaluation of heuristic line balancing techniques. *Management science*, 32(4):430–454, 1986.

[YCGBD21] Abdelkrim R Yelles-Chaouche, Evgeny Gurevsky, Nadjib Brahimi, and Alexandre Dolgui. Reconfigurable manufacturing systems from an optimisation perspective: a focused review of literature. *International Journal of Production Research*, 59(21):6400–6418, 2021.

[ZAL17] Luiza Zeltzer, El-Houssaine Aghezzaf, and Veronique Limère. Workload balancing and manufacturing complexity levelling in mixed-model assembly lines. *International Journal of Production Research*, 55(10):2829–2844, 2017.

Abstract

In this thesis, we introduce a four-step construction heuristic to address the Flexible Layout Design Problem (FLDP). The objectives are to minimize the number of stations and minimize the transportation flow. Initially, we develop a graph level for models, followed by assigning tasks to stations using the maximum successors rule. Subsequently, we map locations and routes to layout stations and employ a mathematical model to determine flow allocation. Finally, we will analyze the results and conclude with perspectives for future research.

Key words: Reconfigurable Manufacturing Systems, Matrix-structured manufacturing system, Assembly line balancing, Flexible layout design, Construction Heuristic

Résumé

Dans ce projet de fin d'études, nous introduisons une heuristique de construction en quatre étapes pour aborder le problème de conception de disposition flexible (FLDP). Les objectifs sont de minimiser le nombre de stations et le flux de transport. Tout d'abord, nous développons un niveau de graphe pour les modèles, puis nous affectons les tâches aux stations en utilisant la règle des successeurs maximaux. Ensuite, nous cartographions les emplacements et les itinéraires des stations de disposition et utilisons un modèle mathématique pour déterminer l'allocation des flux. Enfin, nous analyserons les résultats et conclurons avec des perspectives de recherche future.

Mots clés: Système de production reconfigurable, Systèmes de Fabrication à Structure Matricielle, Équilibrage de Lignes d'Assemblage, Conception de Layout Flexible, Heuristique de construction

ملخص

عرض في هذا مشروع التخرج، خوارزمية بناء من أربع خطوات مشكلة تصميم الهياكل المرنة (FLDP) ، الأهداف هي تقليل عدد المحطات وتقليل تدفق النقل. في البداية، نطور مستوى رسم بياني للنماذج، ثم نقوم بتوزيع المهام على المحطات باستخدام قاعدة اكبر لواحق. بعد ذلك، نرسم مواقع ومسارات المحطات في التخطيط ونستخدم نموذجًا رياضيًا لتحديد توزيع التدفق. أخيرًا، سنقوم بتحليل النتائج و نختتم بآفاق للبحث المستقبلي.

الكلمات المفتاحية: أنظمة التصنيع قابلة لإعادة التكوين، نظام التصنيع ذو الهيكل المصفوفي، توازن خط الإنتاج، تصميم الهياكل المرنة، خوارزمية بناء