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Simulation Game for production planning and design.

Master Thesis

Study programme: N2301 Mechanical Engineering
Study branch: Manufacturing Systems and Processes

Author: **Saikrishna Gopinath**
Thesis Supervisors: Ing. František Koblasa, Ph.D.
Department of Manufacturing Systems and Automation

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Master Thesis Assignment Form

Simulation Game for production planning and design.

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The goal of this thesis is to develop a simulation game focusing on production design and planning to educate average labour about selected Industrial Engineering methods. This topic includes knowledge from both Manufacturing Systems and Pedagogy.
1. Literature review on production planning, design and management.
2. Literature review on education board games focused on Industrial Engineering topics in the field of manufacturing design and production planning.
3. Definition of key methods and areas suitable for applying simulation game as Education tool.
4. Selection of the methods and principles to implement in a developed simulation game.
5. Design of simulation game including main game mechanisms (rules, performance indicators etc.) and components (minis, cards, boards, rulebook, walkthrough).
6. Making a prototype of the simulation game.
7. Test and review the possible impact of a simulation game on improving knowledge about the selected topic.
8. Define time demand for simulation to be included in technical education and approximate manufacturing budget.

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[1] CUSHMAN – ROISIN, Benoit, Norman J. Rice III a Michael A. MOLDAVER. A Simulation Tool for Industrial Ecology: Creating a Board Game. Journal of Industrial Ecology [online]. 1999, 3(4), 131 – 144. ISSN 1530-9290. doi:https://doi.org/10.1162/108819899569601.
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[5]BENSON, Roy Michael. Games Based Learning. Warwick, 2014. Dissertation thesis. University of Warwick.

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August 30, 2022 Saikrishna Gopinath

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ABSTRACT

The topic presented in this thesis is Simulation Game for production planning and design. The goal of the study is to develop a simulation game focusing on production design and planning to educate average labour about selected Industrial Engineering methods. The topic includes knowledge from both Manufacturing Systems and Pedagogy. The content starts with the literature review of Production management, planning and design, review on Education (serious) games, Definition of the simulated topic and key activities followed by selected topic Line balancing, Design of Line Balancing game and finally prototype and testing of the game. Line Balancing Game is designed and prototyped, which is suggested for students and working professionals for better understanding of Line balancing concept and this game also can be used for study material.

KEYWORDS

Production planning, Lean Manufacturing, Line Balancing, Cycle Time, Takt Time, Assembly Line, Education (serious) Game, Lean games.

ABSTRAKT

Tématem této závěrečné práce jsou Simulační hry v oblasti plánování a projektování výroby. Cílem této práce je vytvořit simulační hru zaměřenou na projektování a plánování výroby pro potřeby vzdělávání průměrného zaměstnance či studenta vybranou metodu Průmyslového Inženýrství. Téma zahrnuje znalosti jak z oblasti Výrobních systémů, tak pedagogiky.

Práce nejprve popisuje poznatky z oblast plánování, řízení a projektování výroby společně s poznatky z oblasti vzdělávacích (vážných) her. Následuje hlubší rozbor vybraného tématu balancování linek. Je vytvořena simulační hra a to včetně návrhu prototypu a jeho otestování s ohledem na využití jak studenty tak pracujícími odborníky. Práce obsahuje analýzu průběhu hry a obecný rozbor ekonomických nákladů této hry.

Klíčová slova

Plánování výroby, Štíhlá výroba, Balancování linek, Vážné (výukové) hry.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

APS – Advanced Planning and Scheduling
BD – Balance Delay
BE – Balance Efficiency
BGG – Board Game Games
BOM – Bill of Materials
CDIO - Conceive – Design – Implement – Operate
CPR – Construction Products Regulation
CT – Cycle Time
DLBP - Disassembly Line Balancing Problem
ERP – Enterprise Resource Planning
GALBP - Generalized Assembly Line Balancing Problem
JIS – Just in Sequence
JIT – Just in Time
KPI – Key Performance Indicators
LBR – Line Balancing Rate
LCR – Largest Candidate Rule
MINS - Minutes
MPS – Master Production Scheduling
MRP – Material Requirement Planning
OEE - Overall Equipment Effectiveness
OOE - Overall Operating Efficiency
PC – Personal Computer
PCC – Production Planning and Control
RPW – Rank Positional Weight Method
RRPS – Resource Requirement Planning Systems
SALBP - Simple Assembly Line Balancing Problem
SI – Smoothness Index
Sti - Time of Each work station
Sti_{Max} - Largest Work Station Time
TLBP - Transfer Line Balancing Problem have developed
TM - Theoretical Minimum Number of Work Station
TOQ – Total Quality Control
Tsi (Max) – Maximum Station Time
Tsi (min) – Minimum Station Time
TT – Takt Time
VALBS - Visual Assembly Line Balancing Software
Wb – Standard Time
WIP - Work-in-process

1 Introduction

The application of production simulation games to educate students and workers in the manufacturing industry the principles of lean production is becoming more popular. This thesis describes board game using experiences. The board game is suitable for teaching those who have a basic understanding of lean concepts. The training benefits and facilitates an immersive environment between board games and the workplace for both students and industrial employees.

Serious games are increasingly recognized as an innovative and effective teaching strategy in a variety of fields, and more recently, they have also entered the fields of manufacturing and engineering education. By placing players in a specialized learning setting where they may take various roles in a manufacturing company, serious games give learners chances. The entertaining elements and educational elements are here flawlessly incorporated.

The effectiveness of learning games in the educational process is explicable in terms of our understanding of learning principles. The game provides the students a mental state that allows for optimum enjoyment and concentrate on participating in or following a procedure. Basically, anytime the game is effective, all of the learning principles are followed. This is the reasoning behind the growing usage of educational games in the classroom.

The goal of this thesis is to create a game that can help people understand how the pull production mechanism is organized using the Line Balancing Concept. This thesis examines the body of research on line balancing and offers a variety of models and solutions for manufacturing lines.

The aim of the study is to create a Simulation game based on production planning and design. Thesis works includes:

- Current state analysis on production planning, design, management and education board games focused on Industrial Engineering.
- Selection of the methods and principles to implement in a developed simulation game.
- Design of simulation game including main game mechanisms and components.
- Making a prototype of the simulation game, testing and review the possible impact of a simulation game on improving knowledge about the selected topic.
- Define time demand for simulation to be included in technical education and approximate manufacturing budget.

2 Review On Production Management, Planning and Design

This chapter talks about all the required information we need for theoretically understanding the practical work and conclusion of this thesis work. The explanation for the all the principles of Production Planning, Control, Design and Management.

2.1 Production Management

Production management is the application of management concepts to a factory's production function. To look at it another way, production management entails the planning, organizing, directing, and managing of the manufacturing process[1].

The three advances have resulted in the application of management to the area of production:

1. The first is the evolution of the factory manufacturing mechanism. There was no such thing as management as we know it prior to the creation of the industrial concept. True, people ran businesses of all kinds, but for the most part, these people were company owners who did not consider themselves to be managers.
2. Essentially, it stems from the first, namely, the growth of big corporations with many shareholders and the need to employ employees to run the company.
3. It stems from the efforts of many of the scientific management leaders who were able to explain the importance of some of the methods they were developing in terms of success and benefit.

2.1.1 Definition of Production Management

It has been observed that the starting and end points of Production Management in an establishment are indistinguishable. The explanation for this is that it is interconnected with numerous other corporate functions, such as marketing, banking, and labour relations policy.

Production management, on the other hand, is not independent of marketing, financial, or staff management, making it impossible to come up with a single appropriate definition[2].

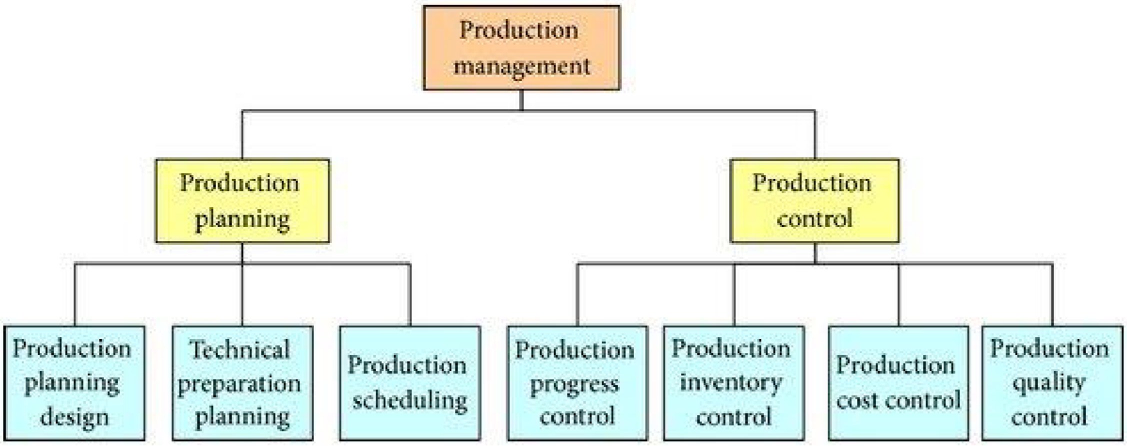


Figure 1: Production Management[2]

2.1.2 Function of Production Management

The meanings defined above specifically indicate that the term "output control" refers primarily to businesses that produce products and services. Previously, these businesses were mainly one-man operations with minor supply management issues.

However, as production organisations in the form of factories developed and expanded, more complex issues such as location and layout, inventory management, quality control, routing and planning of the manufacturing operation, and so on appeared, requiring a more detailed study and research of the phenomena[3]. The functions of production management are classified as shown in (Figure 2).

Figure 2: Functions of Production Management[3]

The development of supply control in the field of factory management occurred as a result of this. The primary role of production management at the beginning was to regulate labour costs, which accounted for the majority of production costs at the time.

However, as manufacturing systems became more mechanized and automated, indirect labour costs increased significantly in addition to direct labour costs, such as product design and packing, processing and inventory management, plant layout and location, transportation of raw materials and finished goods, and so on. All of these tasks required more expertise and special procedures to plan and control.

2.1.3 Horizontal, Vertical Matrix Management

A matrix management structure involves employees reporting to multiple bosses instead of one. By doing so, most firms eliminate the one-boss, vertical system and replace it with a system where employees have multiple superiors across functions and projects. In a matrix management system, employees from different functional divisions work together on product/project teams with colleagues from other functional divisions. For example, in a specific project/product team, we may have employees from engineering, sales, and customer success collaborating to deliver the product or project. Matrix management has the advantage of being more efficient than traditional vertical management structures. The CEO is at the top of a vertical management structure, followed by supervisors, and then regular employees in various divisions who report to one supervisor[4].

During the Dot-com era of the 1990s, companies too small to afford large "vertical" organizations began forming "horizontal" companies in response to the observed and perceived weaknesses of vertical companies. Between the CEO and front-line employees in horizontally oriented companies, there are relatively few layers of management. It is believed that decisions can be made more rapidly when there are fewer people in the chain of command. This new management philosophy led to greater layoffs among middle managers in "vertical" organisations.

Between the CEO and the front line, a "vertical" corporation is recognised for having a sizable group of intermediate management. Lines of authority in a vertical corporation, which predominated in organisations for much of the mid- to late-20th century, grow outward from the top down like a tree's roots. Depending on certain business lines, each vice president oversees the operations of the workforce below them. In the 1930s and 1940s, vertical organisations emerged to counter the propensity for cronyism and nepotism in privately held firms[5].

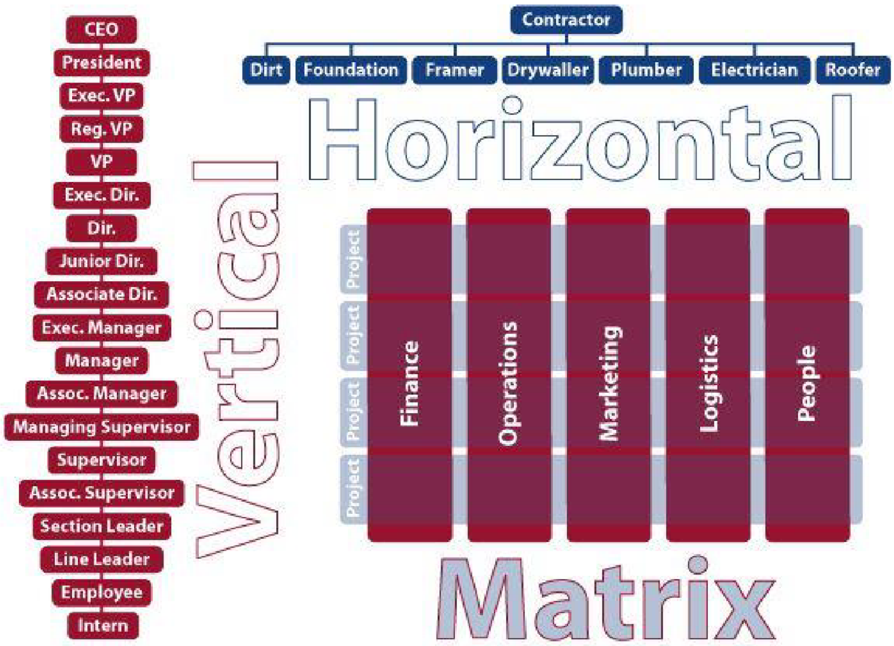


Figure 3: Horizonal and Vertical Matrix[6]

2.2 Production Planning

The preparation of design and assembling modules in a company or industry is known as production planning. It makes use of resource sharing of staff tasks, supplies, and manufacturing resources to satisfy various clients. Production preparation differs depending on the type of production process used, such as single item manufacturing, batch production, mass production, continuous production, and so on. Production planning may be combined with production management to form production planning and control, or with enterprise capital planning to form production planning and control.

Production planning is the way of the future. It may aid in the productive production of goods or the establishment of a manufacturing facility by encouraging the necessary requirements. A production schedule is created on a regular basis for a particular time frame, which is referred to as the planning horizon.

Figure 4: Production Planning[7]

The following are some of the main steps in the production plan's development:

1) Analysing customer demand.
2) Determining production capacity & timelines.
3) Evaluate raw materials, output volume etc.
4) Production control, quality control, accounting.
5) Evaluation & improvement of production system.
6) Complete final production of finished goods.

The following activities should be included:

- To meet the demands of consumers, determine the appropriate product mix and factory load.
- Finding a way to match the desired amount of output to the available capital.
- The real job to be begun in the production plant is scheduled and chosen.
- Setting up supply orders and sending them to production facilities.

The production planner or production preparation team would collaborate closely with the marketing and sales departments in order to develop production schedules. They will give you revenue projections or a list of your customers' orders. The "job" is normally chosen from a wide range of product categories, each of which may require different resources and service different consumers. As a result, the collection must maximize both customer-independent and customer-dependent success metrics, such as processing time and on-time delivery. "Accurate estimation of the efficient capability of available resources, despite being one of the most difficult activities to do well," is a critical component in production planning. Material supply, labour availability, and experience of potential demand should all be taken into consideration when planning production[7].

2.2.1 Production Planning and Control

Production Planning and Control (PPC) is the process of allocating, time scheduling, and controlling a firm's resources for future manufacturing activities in order to produce the intended products on time and at the lowest total cost. PPC, essentially consists of planning production activities before the actual start of production and exercising control activities to ensure that the planned production is realized in terms of quantity, quality, delivery and cost[8].

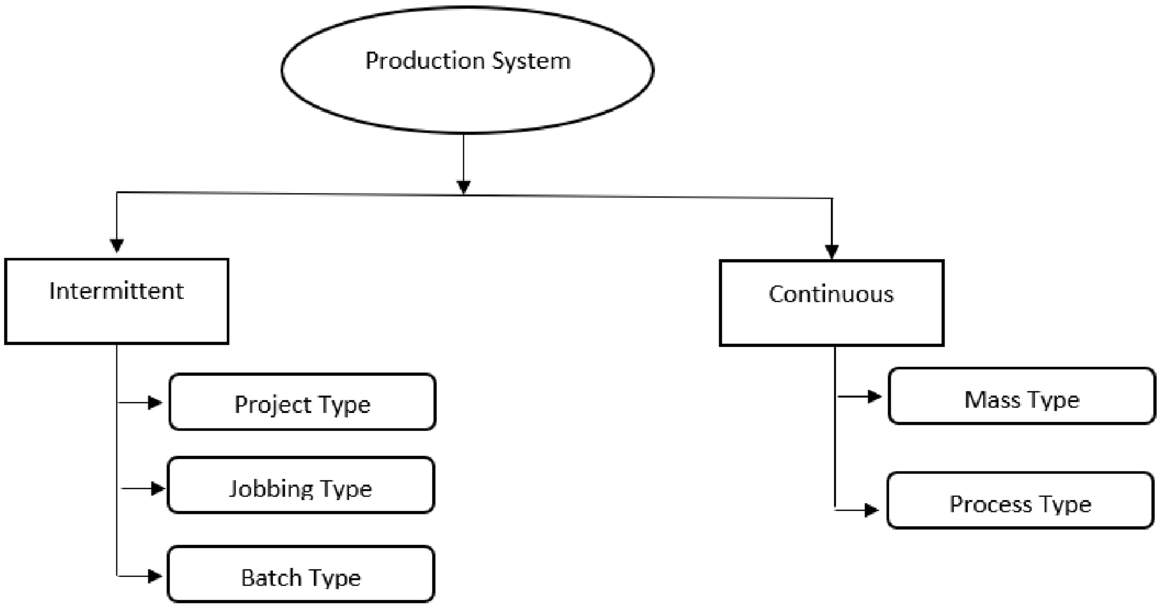


Figure 5: Production System [Source: Own]

2.2.2 Push System

The goal in a push system is on managing material flow by utilizing information about consumers, suppliers, and production. The name "push system" comes from how the system works. Materials and parts are manufactured and then sent to the place where they will be needed next (which is another stage in the manufacturing process or inventory), allowing the system to push material through the production process. This pushing, on the other hand, is done on time. The push method is largely reliant on the MPS's scheduling accuracy. These schedules, in turn, are dependent on the accuracy of client demand and lead times information. As a result, a new system called the Resource Requirements Planning System was created to collect this data (RRPS).

All planning directed at determining the amount and timing of production resources (personnel, money, materials, and manufacturing capacity) required in the short-term planning horizon is referred to as RRPS. MPS, CRP, and MRP are key components of this system[9]. Push systems are utilized in virtually all types of manufacturing, although they have significant advantages in job shop conditions. The push system delivers complete information to enhance short-run production and management choices in these situations.

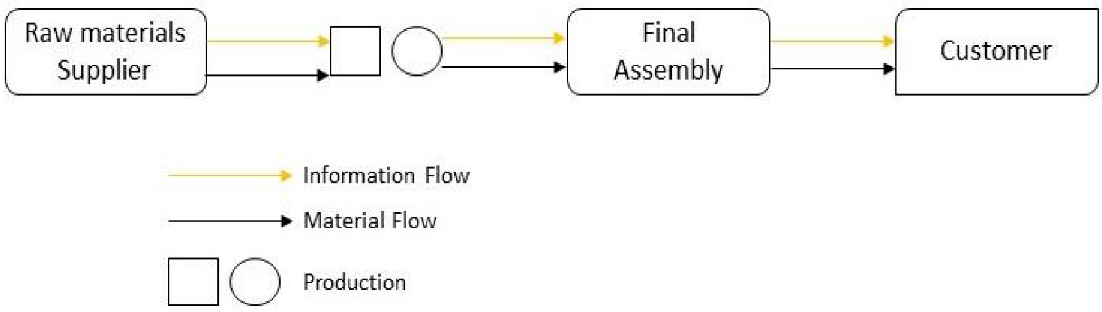


Figure 6: Push System [Source: Own]

2.2.2.1 MRP

MRP (Material Requirements Planning) is a common supply planning technique that assists organizations, especially product-based manufacturers, in understanding inventory requirements while balancing supply and demand. MRP systems, which are subsets of supply chain management systems, are used by businesses to efficiently manage inventories, schedule production, and deliver the correct product on time and at the best price.

Based on demand and bill of materials (BOM), an MRP system accelerates the manufacturing production process by calculating what raw materials, components, and subassemblies are required, as well as when to assemble the finished goods[10].

Manufacturing companies depend extensively on MRP as a supply planning system to plan and control inventory, scheduling, and production, but MRP is also used to balance supply and demand in a variety of other industries. MRP are classified in (Figure 7).

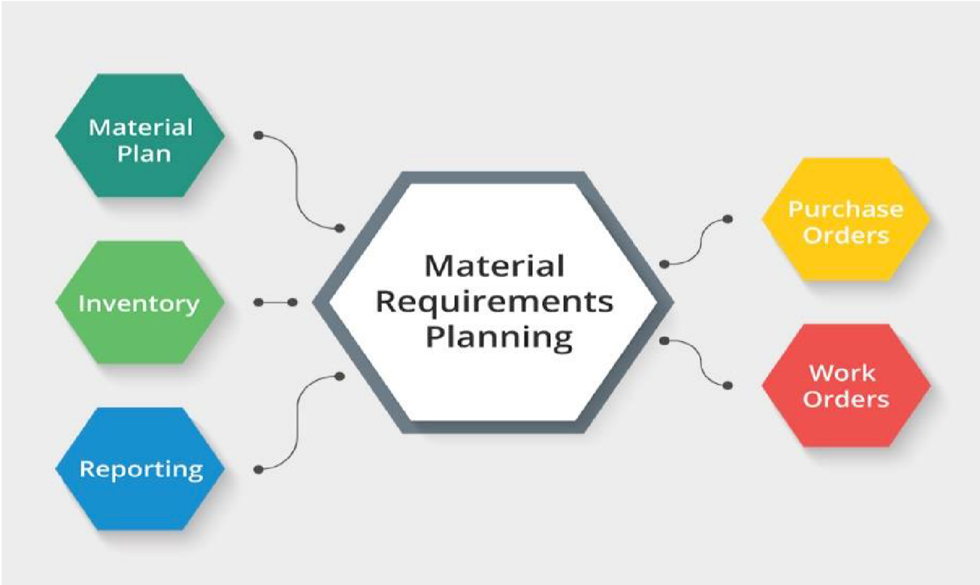


Figure 7: Material Requirements Planning[10]

2.2.2.2 MRP II

Manufacturing resource planning (MRP 2) is a technique for optimizing the procurement, storage, and deployment of all resources required in a manufacturing run. Raw materials, components from suppliers, production equipment and employees, spare parts – any resource required to finish the manufacture of a finished good – are examples of these. To distinguish it from material requirements planning, manufacturing resource planning is abbreviated "MRP 2" (or "MRP II") (MRP 1). MRP 2 includes all of the features of MRP 1, which focuses on a manufacturer's raw materials and supplied components inventory. MRP 1 calculates the quantity and timing of new incoming goods purchases using inventory data, manufacturing orders, and bill of materials (BOM) data[11].

The concept of "dependent demand" is used in manufacturing resource planning to describe how the demand for a raw material or intermediate component is influenced by the demand for the completed product. A manufacturer forecasts demand for a completed product – known as "independent demand" since it comes from an outside source, such as a customer or a make-to-stock order – and MRP software estimates material need based on that prediction.

Today's industrial resource planning is frequently linked to just-in-time (JIT) scheduling and just-in-sequence (JIS) techniques, which aim to reduce inventory levels and the time a material spends in storage or near the processing equipment that will use it. To minimize inventory shortages or production halts, such techniques must guarantee that sufficient inventory is on hand.

Figure 8: MRP II [11]

2.2.2.3 ERP (Enterprise Resource Planning)

Enterprise resource planning (ERP) is a management and integration approach that helps businesses manage and integrate many of their operations. Many ERP software solutions are advantageous to organisations because they help them implement resource planning by integrating all of the operational processes necessary to run their companies into a single system. Planning, purchasing, inventory, sales, marketing, finance, and other operations can all be connected by ERP software.

- ERP software is capable of integrating all of a company's procedures.
- ERP systems have progressed throughout time, and many are now web-based programs that users may use from anywhere.
- A few benefits of ERP include accurate, real-time data reporting, a single source of information, and open communication between business sectors.
- If an ERP system isn't implemented properly, it might be ineffective.

ERP software also makes it easy for different departments to communicate and share data with the rest of the company. It gathers data on the activity and status of various divisions and makes it available to other sections so that it may be used efficiently. By connecting information about manufacturing, finance, distribution, and human resources, ERP software may help a company become more self-aware. An ERP solution may remove costly duplicate and incompatible technology by connecting multiple technologies utilized by different parts of an organization. Accounts payable, stock control systems, order-monitoring systems, and customer databases are frequently integrated into one system[12].

2.2.2.4 Advanced Planning and Scheduling

Raw materials and processing resources are optimally distributed to satisfy demand in the manufacturing management process. Simpler preparation approaches cannot effectively solve dynamic trade-offs between conflicting interests in contexts where APS is particularly well-suited. Due to the (approximately) factorial dependency of the size of the solution space on the number of items/products to be produced, production scheduling is immensely difficult[13].

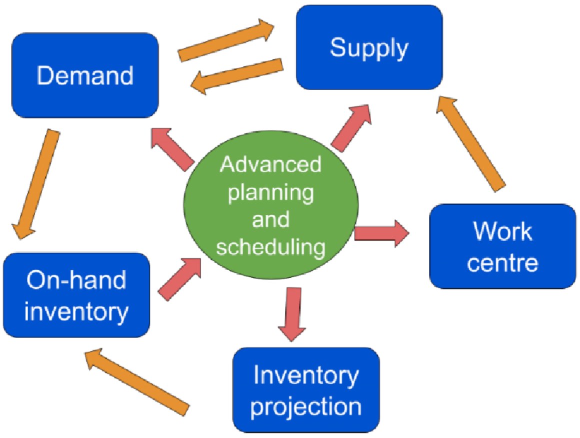


Figure 9: Advanced Planning and scheduling[13]

Advanced planning and scheduling help in the oversight of some parts of the manufacturing operation. They are

- Enhancement of advance schedule.
- Controlling of advanced materials.
- Make to order planning.
- Make to stock planning.
- Visualization of assemble process.
- Advanced constrain modelling.
- Bill of Materials (BOM) level planning.
- Master production schedule creation.
- Visualization of interactive schedule.

2.2.3 Pull System

Everything in a Pull System is focused on the next level of production and what's required there (Customer Order Driven). It is produced what is required for the next step of production. The term Pull System comes from the fact that raw materials and parts are pulled from the back of the company to the front, where they are transformed into completed items. As a result, the ideal of producing at the same rate as customers use the items is realized in a Pull system.

Pull systems is known as many names like the common name is Just in time (JIT), Toyota Production System, Stockless Production. Pull System is the opposite way to push system.

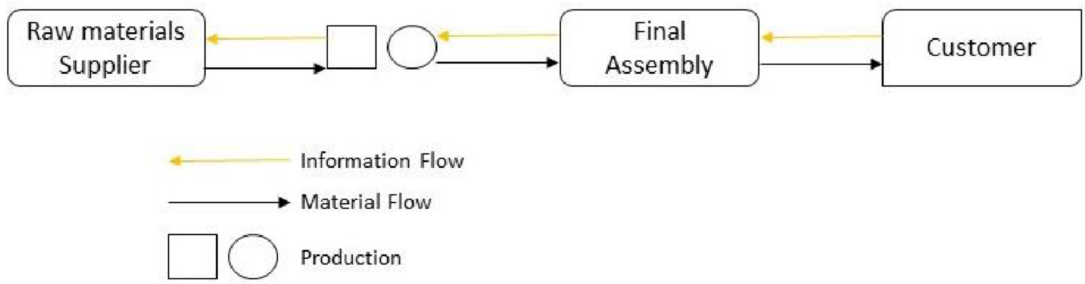


Figure 10: Pull System [Source: Own]

2.2.3.1 Just-In-Time

Just-in-time is a Lean thinking concept that emphasizes demand-based manufacturing, as well as the creation of high-quality goods and continuous improvement across the company. It's a method that aims to eliminate all waste in the production process by allowing companies to predict demand and create items accordingly. Customers will receive what they require in the amount and timing that they require. It was created by Toyota Motor Company employee Taiichi Ohno in the 1970s. It was designed to assist the firm satisfy customer demand in the shortest period possible by reducing delays. It swept across Japanese industrial factories when it was first introduced. JIT is now widely used all over the world[14].

JIT (just-in-time) is a manufacturing method that aims to boost a company's return on investment by lowering in-process inventory and related carrying costs. The process depends on signals or Kanban between different stages in the process to notify production when to create the next part in order to fulfil JIT targets. Kanban are typically referred to as 'tickets,' but they may also be simple visual indicators, such as the presence or absence of an item on a shelf. JIT focuses on continuous improvement and may increase a manufacturing company's return on investment, quality, and efficiency if done correctly. Flow, staff participation, and quality might be major areas of attention for continuous improvement.

2.2.3.2 Kanban

Kanban was developed in the 1940s by Taiichi Ohno, a Toyota industrial engineer, who attempted to replicate the supermarket shelf-stocking process. In its engineering, Toyota used this strategy as a basis for a "Just-in-Time" development method. The aim is to only do what needs to be done, when and to the extent that it is needed. The Kanban method isn't just for production; it's also used in project management and Lean Six Sigma in a wide range of industries to provide a visual, quick workflow that keeps each team member focused on the most important tasks at the right time[15].

Teams will see who is working on a task, the project elements are being managed, and how the team's capability is distributed in this visual workflow. This pull system, in which work is pushed to completion by a team member or a machine, eliminates the need to drive tasks forward on a pre-determined schedule.

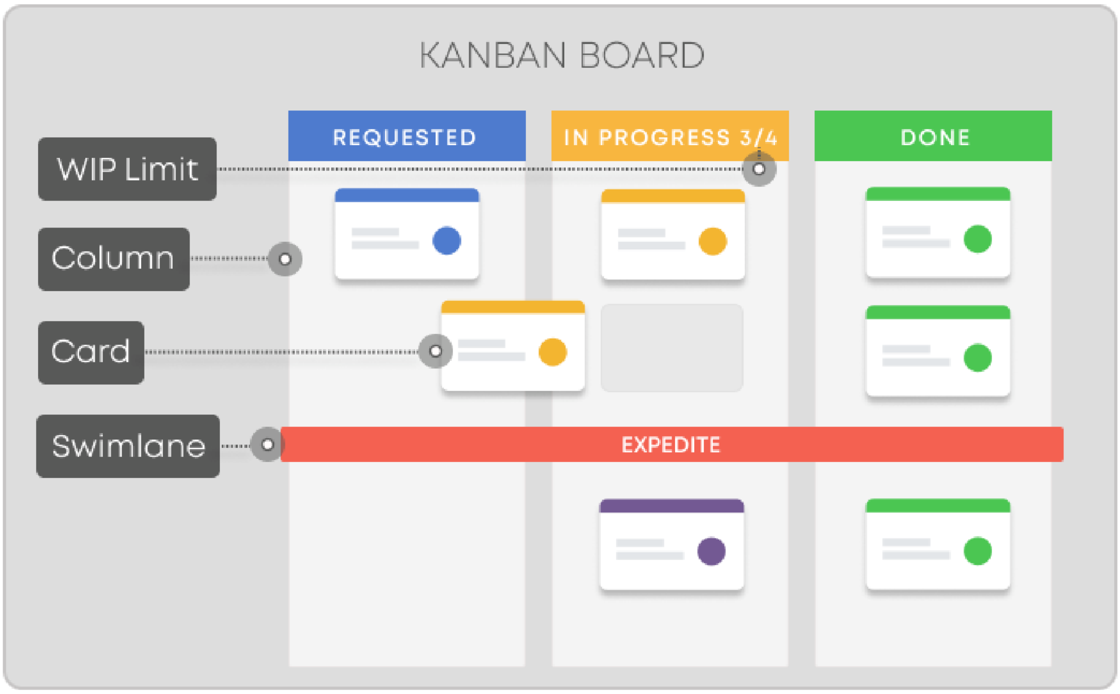


Figure 11: Kanban[16]

The digital age has aided Kanban adoption, as widely available online platforms allow project managers in every industry to implement this procedure through a virtual board, unlike previous eras that required an actual sign board. Each card represents an individual role in this visual management tool, and cards are arranged by stage (or section), priority, and delivery.

For example, Stages could be set up as follows:

- Pending
- In progress
- Completed

The Kanban board changes as workflows change, giving you a real-time view of the project's individual activities. The volume of work is controlled by specifying work-in-progress limits, resulting in streamlined production, greater productivity, improved real-time insight into the process, and less waste.

Visualizing should be used at a department or portfolio level to provide a more strategic perspective, rather than only for a single project. Remember that the same Kanban principal applies to all levels:

- Visualization of the work flow
- Work-in-progress is limited.
- Management of the work flow
- Processes that are clear
- Feedback loops that are open
- Continuous Collaboration and improvement.

Project managers can use Kanban to handle activities and continually optimize the flow for more effective, timely, and successful projects, regardless of their project management methodology.

2.2.3.3 Heijunka

Heijunka is a Lean method for reducing unevenness in manufacturing processes and avoiding overburdening. The Japanese word Heijunka literally means "levelling." It can help you respond to demand variations and make the most of your available capacity.

You may stop generating work in batches and start processing orders based on client demand by using Heijunka. You'll be able to lower your inventory expenses since you'll have less products in reserve waiting to be purchased when order volume is low.

Your process and team, on the other hand, will be safeguarded from overburdening when demand rises since you'll be creating value according to your takt time, or, to put it another way, your average sale rate. Toyota is the most well-known firm to use Heijunka. The Japanese automaker has long abandoned the traditional batch manufacturing method in favour of scheduling car assembly in a production line based on demand[17].

Heijunka enables you to consistently manufacture and provide value to your customers, allowing you to respond to changes in demand based on your average demand. The technique includes two means of levelling production for this purpose:

- **Levelling by Volume**:

  You must stop processing work in batches when establishing a continuous flow of work in order to create only what was required and keep your inventory expenses low.

  In its purest form, Lean emphasizes that new work should only be started when an order is received. However, for businesses that get a continuous stream of new orders and must simply adjust their process to match demand, this may not be a viable choice.

  Heijunka allows you to level your output based on the number of requests you receive on a regular basis.

- **Levelling by Type**:

  Heijunka is also useful if you're in charge of a product portfolio. It enables you to plan your work around the average demand for each product in the portfolio and level output accordingly. The idea remains the same, make enough of each item to fulfil the average consumer demand for the product line.

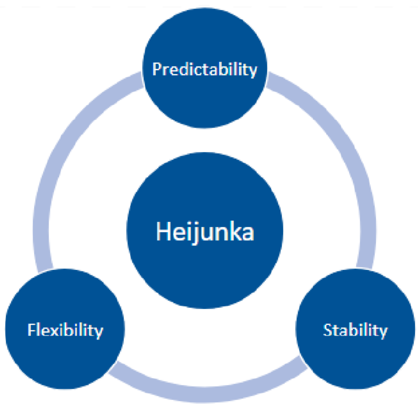


Figure 12: Heijunka[17]

2.3 Facilities Design

After decisions regarding the design of the product, process, and schedule have been established, the facilities planner must arrange the data, come up with alternative designs for the layout, handling, storage, and unit load, and then evaluate those designs. To optimise the influence of the facilities design effort on such aims and goals, the facilities planner must be aware of senior management's objectives and goals. Breakthroughs in production cost, on-time delivery, quality, and lead time are a few common corporate goals. Some techniques that quality practitioners typically utilise, such the Pareto chart, can be particularly helpful in attempts to plan facilities. As an approach for enhancing planning and implementation efforts, the seven management and planning tools have gained popularity. The total quality control (TQC) movement in Japan and operations research work conducted after World War II are the sources of the instruments. The tools were developed and tested by a committee of engineers and scientists in Japan in the middle of the 1970s as a support for process improvement as suggested by the Deming cycle[18].

The composition of the activities or planning departments among which materials move determines the type of material flow system. Four different types of production planning departments exist:

1. Production line departments
2. Fixed materials location departments
3. Product family departments
4. Process departments

2.3.1 Production Line Layout

The processing order for the parts being produced on the line is the basis for the layout of a production line department. Usually, materials move immediately from one workstation to the next one next to it. This high-volume, low-variety environment is typically the outcome of nice, well-planned flow pathways. Such layouts will be referred to as production line layouts[18].

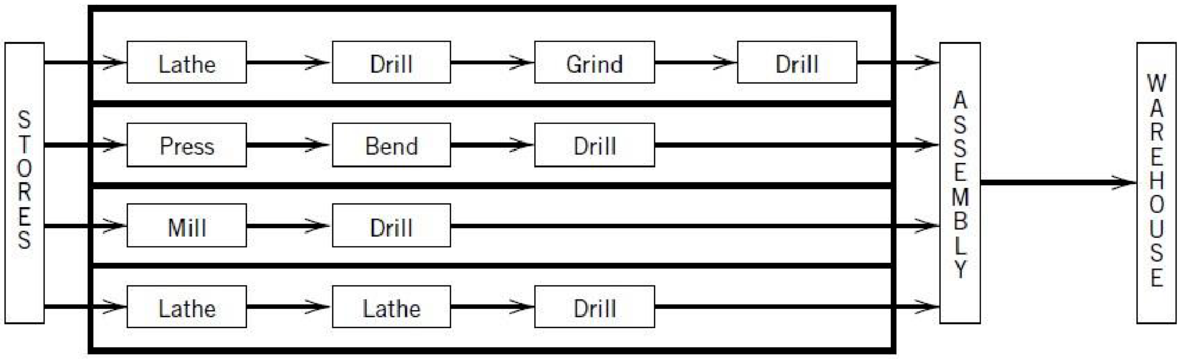


Figure 13: Production Line Layout[18]

2.3.2 Fixed Product Layout

A fixed material location department's layout is conceptually different from the other three. In contrast to the other layouts, which bring the material to the workstation, the fixed material location departments bring the workstations to the material. It is utilised in the majority of construction projects, shipbuilding, and aircraft manufacturing. The arrangement of workstations around the material or product is part of the fixed material location department's layout. Even though fixed material location departments are typically associated with very large, bulky objects, they can be used for a variety of purposes. For instance, while building computer systems, it is common practise to bring the materials, subassemblies, housings, peripherals, and components to a systems integration and test workstation, where the final result is then "built" or put together and tested. We'll refer to these layouts as fixed product layouts.

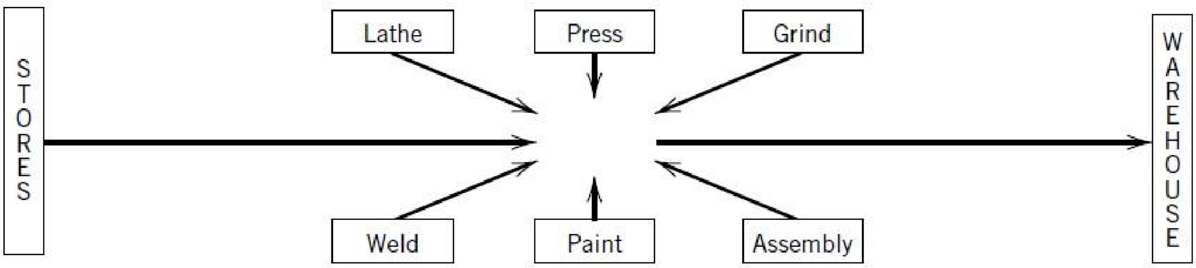


Figure 14: Fixed Product Layout[18]

2.3.3 Product Family Layout

The arrangement of components into product families serves as the foundation for the design of a product family department. Based on similar processing procedures, shapes, material compositions, tooling needs, handling/storage/control needs, and other factors, non-identical parts may be categorised into families. A pseudo-product layout is created and the product family is considered as a pseudo-product. A manufacturing cell contains all of the processing tools needed to create the fake product. The resulting plan, which is also known as a group technology layout or a product family layout, often has little to no interdepartmental flow and a high degree of intradepartmental flow.

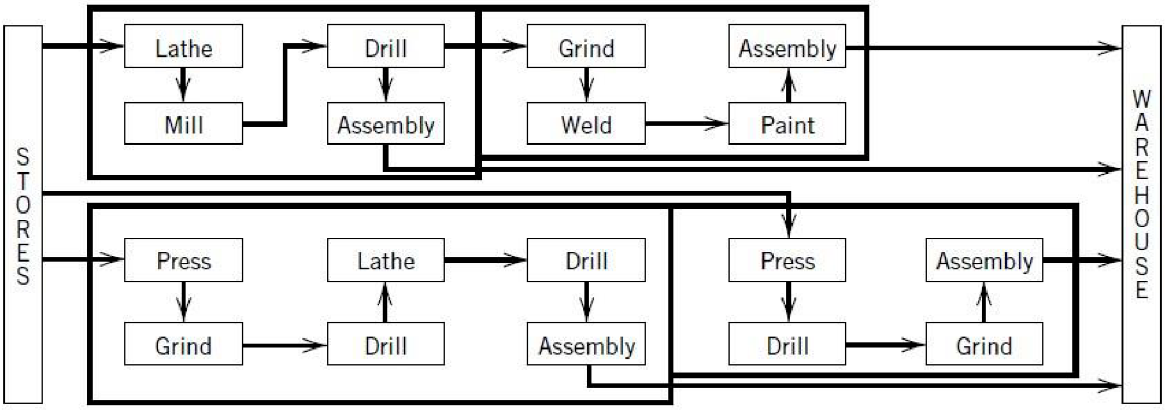


Figure 15: Product Family Layout[18]

2.3.4 Process Layout

A process department's layout is created by grouping related processes together and positioning separate process departments in relation to one another based on departmental flow. Typically, there is limited intradepartmental flow and a significant degree of interdepartmental movement. When the volume of activity for specific parts or groups of parts is insufficient to warrant a product layout or group layout, a process layout also known as a work shop layout is utilised instead[18].

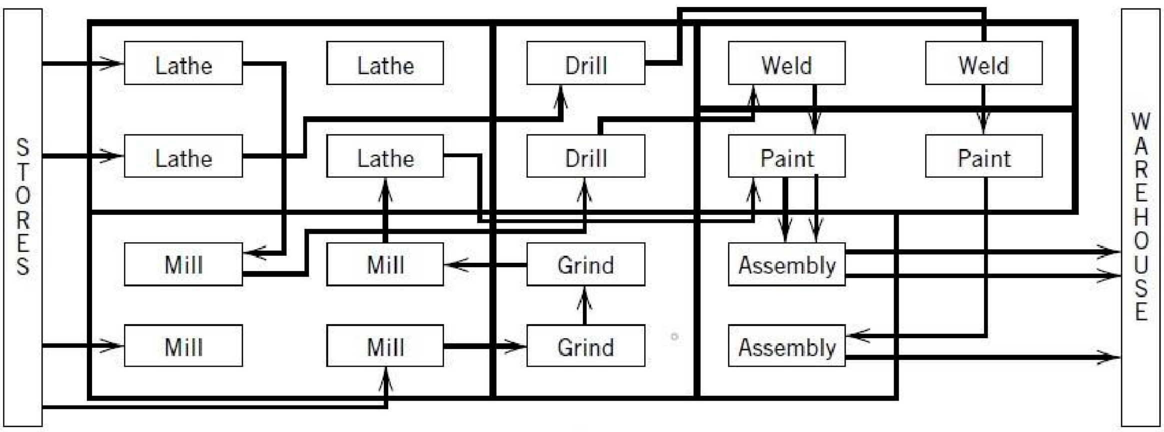


Figure 16: Process Layout[18]

2.3.5 Cellular Manufacturing System

Another important JIT element is group technology, often known as cellular manufacturing. According to the Cellular Production System, segmented and product-focused manufacturing is considerably easier than linear process-oriented manufacturing[19].

Figure 17: Cellular Manufacturing System[19]

To this purpose, JIT employs strategic capacity management strategies such as numerous tiny machines rather than a single bulky machine that requires continual output for profitability, among others.

2.4 Conclusion of Reviewed topics

From previous review we decided to adopt lean manufacturing techniques based on a previous review of literature on production management, production planning, and facility design which had been conducted previously. Moreover, from the viewpoint of the Cellular Manufacturing System, we will also discuss in depth the concept of line balancing based on the framework of the Cellular Manufacturing System, which is a vital component of the process.

3 Line Balancing

Lean manufacturing is a quality management method for removing waste from the manufacturing process. Lean manufacturing also focuses on cost savings by reducing wasteful work through a management philosophy that focuses on finding and eliminating waste at each stage of the manufacturing process. Reduced inventory, less process waste, less rework, shorter lead times, cost savings, and improved process efficiency are all benefits of lean manufacturing. A company must control the manufacturing line using standardized strategies or procedures in order to achieve optimum output. Line balance practice is one of the techniques. The use of line balancing techniques is seen to improve the company's productivity.

According to Becker and Scholl, an assembly line, is a series of workstations where activities relating to product assembly are completed. The general goal for assembly line balancing, according to Agpak and Gokcen, is to reduce the number of workstations for a given cycle period and to reduce cycle time for a given number of work stations[20].

A flow line is made up of a series of workstations that execute the same activities on different items. These lines are utilized in a variety of manufacturing applications, including machining, assembly, and disassembly. Because of the high initial investment and ongoing operating expenses, the design (or re-design) of such lines is critical. In flow line design, a number of critical decisions must be taken, including product design, process selection, line layout design, and line balance. Because of their complexity, these issues are usually approached one at a time.

The first two steps, product design and process selection, provide information on the work that must be done in the flow line being designed, i.e., a collection of indivisible tasks linked by constraints. The technology employed, economic and environmental issues, and ergonomic factors for the labour can all be causes of these limits. The following step is to select a line arrangement (straight, U-shaped, with circular transfer, asymmetric, etc.). This specifies the location of the workstations on the line, as well as the flow directions and regulations to be followed. Line balancing is the final and most important phase. Workstations and resources that will be deployed on the line are assigned tasks here. This is a complex combinatorial issue to solve. The efficiency of the line designed is largely determined by its solution.

The goal is to assign all jobs according to priority and cycle time limits while keeping the number of workstations to a minimum. Baybars [20] called this problem the "Simple Assembly Line Balancing Problem" (SALBP). In general, SALBP is known to be NP-hard. To assess the computational complexity of specific SALBP instances, a number of indicators have been proposed. A single straight assembly line for only one type of product is considered by the SALBP. Other line configurations, production contexts, and performance criteria were generalized to solve this challenge. Each new formulation necessitated additional considerations, restrictions, and/or optimization goals. As a result, many definitions for the Generalized Assembly Line Balancing Problem (GALBP), Disassembly Line Balancing Problem (DLBP), and Transfer Line Balancing Problem have developed (TLBP). However, there are certain parallels between them, such as the fact that both assembly and disassembly lines can have a U-shaped architecture, many workplaces, and employ employees with various talents. For machining, assembly, and disassembly operations, precedence restrictions with standard and exclusive (OR-) relations might be useful.

As a consequence, simply glancing at the mathematical model of a line balancing problem does not always reveal whether the model was created for assembly, disassembly, or machining. As a result, the goal of our study is to propose a new taxonomy that is broader and more applicable to a variety of industrial setups that employ flow lines.

The objective is to generate a novel taxonomy that can be used to analyse recent studies released after 2006 and identify the major flaws and unexplored areas in current research. To further elucidate these points, certain before to 2007 sources will be included. The five components that make up this taxonomy are as follows:

1) Number of lines to be balanced
2) Task attributes
3) Workstation attributes
4) Constraints that a feasible solution must adhere to.
5) Criteria for determining whether solutions are better or, if feasible, the best.

The number of decision variables whose values must be determined is significantly influenced by the first three criteria. They provide an estimate of the magnitude and structure of the problem. The remaining two factors, (4) and (5), identify the type of issue to be addressed, whether linear or nonlinear, as well as whether the problem is single-objective or multi-objective.

3.1 Line Balancing: General Principles

Since the research on line balancing has repeatedly examined distinct manufacturing aspects of flow lines,

I. Industrial environments:

The following are the main industrial environments in which line balance issues are considered:

- Machining: Drilling, milling, reaming, and other machining processes are used to finish a part. In comparison to an assembly/disassembly process, there may be many less precedence relationships between such processes. However, there may be a number of tolerance restrictions that force operations to be assigned to the same workstation, as well as incompatibility requirements that prevent specific operations from being assigned to the same workstation due to technical incompatibilities. Typically, such lines are highly automated.
- Assembly: A finished product is created by putting together a variety of components. The precedence graph might include a lot of starting nodes, but it generally only has one final node. These lines can be configured in a variety of ways, ranging from manual to fully automated, with workers allocated to each workstation.
- Disassembly: An initial product yields a large number of pieces or sub-assemblies. In most cases, reversing the initial assembly precedence graph will not yield the precedence graph. Furthermore, because the final state is not always predetermined, such lines are generally manual nowadays[20].

II. Number of product models

- Single-model lines: The line produces a single, homogenous product. All of the tasks that must be completed for a product item are known. Each workstation is responsible for a subset of these responsibilities. This subgroup is consistent over all cycles. As a result, the specified list of all jobs must be partitioned across the line's workstations, with each workstation having just one subset.
- Mixed-model lines: Several versions from a basic product family are produced simultaneously period. The primary procedures for the models are relatively similar, as they change mainly in terms of specific traits and optional options from the base product. As a result, by linking a subset of each model with each workstation, a given

set of all jobs must be partitioned across the workstations. As a result, the number of subsets connected with each workstation equals the number of models created.

- Multi-model lines: Several products are made in different batches. The line can be rebalanced for each batch in this case. Between the lots, setup times must be considered.

III. Line layout

The rules for task processing at workstations are defined by line layout. These criteria are mostly taken into consideration in line balancing as problem limitations. In the literature, the following line arrangements are frequently explored.

- **Basic straight lines:**

  As indicated in Figure 18, each workpiece visits a sequence of work stations in the order of their installation. Each workstation is given a set of responsibilities. The duties are carried out one by one.

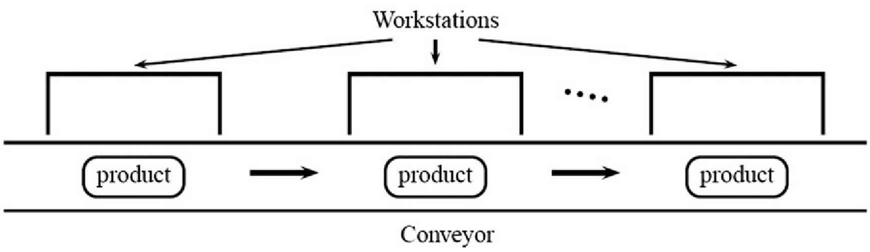


Figure 18: Basic straight line[20]

- **Straight lines with multiple workplaces:**

Workstations are arranged in the order depicted in Fig 19. However, a number of parallel workplaces, serial workplaces, or mixed activated workplaces are installed at each workstation in such a way that the workers or pieces of equipment associated with each workplace can perform on each workpiece simultaneously, sequentially, or in a series-parallel way.

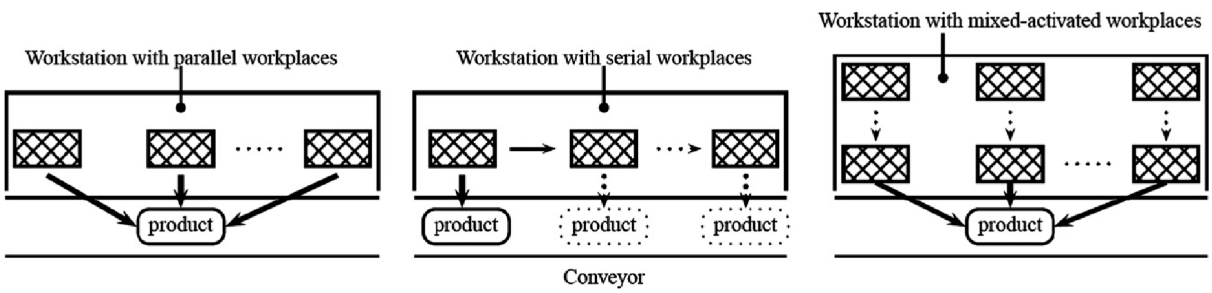


Figure 19: Straight lines with multiple workplaces[20]

- **U-shaped lines:**

  Both the entry and exit are located in the same location on these lines. The majority of them are manual. Workers in the middle of the line are allowed to stroll from one leg to the next, as indicated in Fig 20. As a result, they may simultaneously operate on two (or more) workpieces. In this example, a single worker performs numerous subsets of activities connected with distinct workstations. Priority and cycle time requirements are not considered the same way in these lines' mathematical models as they are for straight lines.

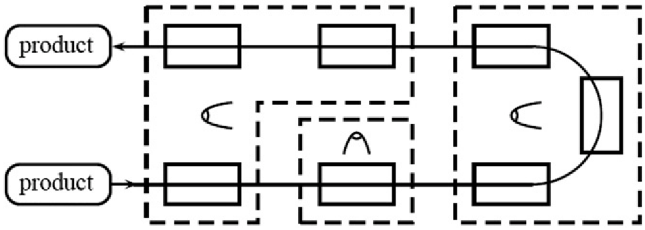


Figure 20: U-Line[20]

- **Lines with a circular transfer:**

  Workstations are arranged around a rotating table (see Fig.21) that is used for loading and unloading parts as well as shifting them from one workstation to the next. The lines with single and multi-turn circular transfer may be separated based on the number of turns a portion waits on the table before being finished. This arrangement is equal to a basic straight line if just one component side is handled at each workstation and a single turn is required for finishing a product. This configuration is similar to a line with numerous parallel workspaces if many sides of the component may be serviced simultaneously. The collection of tasks allocated to a workstation must be partitioned into the different cycles corresponding to the number of turns of the table in the case of multi-turn transfer.

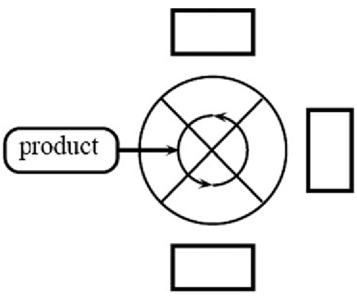


Figure 21: Lines with circular transfer[20]

- **Asymmetric lines:**

  Asymmetric lines can be used to postpone product differentiation in order to keep all manufactured items on the same line for as long as feasible. This technique decreases the risks associated with growing product diversity, but in order to identify the final line configuration, the relevant line balance issue must be solved in conjunction with a layout optimization problem. The main and secondary feeder lines may also be seen in this diagram.

- **Multi Model Assembly Line:**

  The regularity of the assembled products and the production system are not as important in this form of assembly line in order to incorporate the validation of the various products and their output levels. The assembly is typically divided into groups to save time and money. This enables the short-term manufacturing difficulties that were created in batches from groups of product models and their effects on the assembly levels. When there is a significant difference in how each model is put together, it is employed. Groups are utilized to reduce setup time faults between models; however, this causes disposal issues[21]. Basic features of several types of assembly lines are shown in Figure 22.

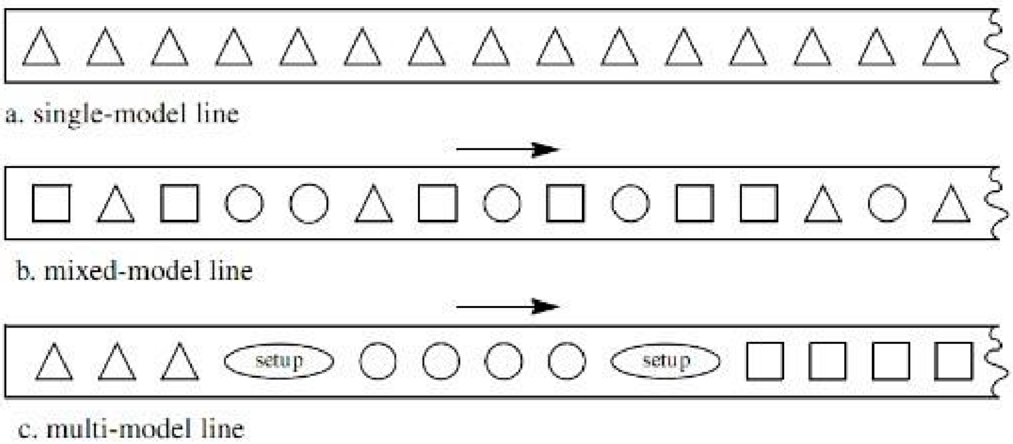


Figure 22: Multi Model Assembly Line[21]

3.2 Problem Constraints of Line Balancing

Constraints are used to determine which tasks can be assigned to which workstations. They might be the result of technical, economic, or ergonomic factors. They can also express the decision maker's preferences. They aren't precisely limits in this situation, but the system designer has opted to include them based on previous experience. They can be considered during the construction of a solution or for a solution acquired in a solution technique. The main limitations employed in flow line balancing issues are mentioned in this section.

1. Assignment Constraints
2. Constraints concerning workstation attributes
3. Constraints on workstation-specific performance measures
4. Cycle time Constraint

3.3 Objective Functions

An objective function, also known as a goal function, assesses the quality of possible solutions and selects the best one. SALBPs commonly employ the objective functions listed below.

1) Keep the number of workstations to a minimum.
2) Reduce line Cycle time
3) Increase the efficiency of the line
4) Increase "system utilization," a measure of "line efficiency," which is calculated as the ratio of the minimum needed number of workers to those actually allocated.
5) Reduce the line smoothness index as much as possible (SI). None of the foregoing functions necessitate a system with well-balanced workstations, i.e., workstation processing times that are equivalent.

3.4 Assembly Line Balancing Problem

Analysing the production jobs and their integral motions was the first step in applying Lean thinking to boost assembly line productivity. The second step, known as a time and motion study, involved keeping track of each motion, the physical effort required, and the amount of time it takes. Then unnecessary motions, also known as non-value-added tasks, can be avoided, and any room for process improvement must be found. The tools must then be redesigned and all the standard tasks necessary to complete the product must be defined in a logical order. The line must be balanced in order to accommodate many stations, if necessary. There must be a consistent distribution of labour among each of these stations. By implementing a dedicated material handling system, productivity can be increased. This enables assembly workers to focus on the crucial duties. The following list includes some of the most important components of an assembly line:

- Process design or standardization

- Line balance
- Material handling
- Parts procurement and feeding
- Work-in-process management
- Man power
- Line size
- Line configuration

In order to meet cycle time requirements and precedence limitations, the task elements will then be sequentially assigned to these number of stations.

3.5 Steps in Assembly Line Balancing

The Five steps in assembly line balancing are given below:

I. Create a precedence diagram for your workstation sequence.

This method entails breaking down the whole manufacturing process into sections. A product cannot go from one segment to the next until each workstation's task is completed. A precedence diagram is a table that depicts the tasks that must be completed during the course of a production project. You may make overall or partial precedence diagrams that display the entire project or just a section of it. Your chart should show the production processes, events, and their interdependencies.

II. Calculate the amount of time each workstation will take for cycle.

To figure out how long it takes to accomplish each activity in the production line, you'll need to conduct time studies. The cycle time is the maximum amount of time it takes for each workstation to complete a job. Divide the necessary product units by the available manufacturing time in a day to get this exact figure. At the present machine rate and manpower, this provides you the duration (in minutes) between each workstation. The entire number of units produced each day is considered in a single line for calculating cycle time. For accuracy, composite cycle time estimates using digitized line balance instruments are required when the same product is manufactured on multiple lines.

$$Cycle\ Time = \frac{Available\ Time}{Desired\ Output} \quad (1)$$

III. Determine the approximate number of workstations you'll require.

Based on the cycle times, this calculation will assist in achieving a balanced workload allocation in each of the workstations. Divide the total of your work timings by the intended real times to get the number of workstations you'll need. In this scenario, algorithmic calculations using P-graph frameworks on a line balancing program are frequently more reliable. Multi-period operations, machine/employee performance, and redundancies are all taken into account. The formula for manual calculations is as follows:

$$Number\ of\ workstations = \frac{\sum Task\ Time}{Desired\ Actual\ Time} \tag{2}$$

IV. Assign jobs to workstations until all process times are the same.

Rearrange the tasks in such a way that excess capacity and production bottlenecks are reduced. This entails transferring personnel from stations with low workloads to stations with high workloads. This procedure aids in the reduction of wait times in overcrowded stations. Attempt to intelligently distribute the quantity of work among the number of operators in a line, with the goal of maximizing machine usage. To achieve synchronization, each job should take the same amount of time. Note that Takt time calculations will be required to guide your task distribution in order to satisfy client demand efficiently.

The Takt time is a measurement of how long it takes a skilled worker or an autonomous machine to complete a task. You risk overproduction and waste if you execute keg line balancing to the point where production exceeds takt time. Producing slower than takt time, on the other hand, might result in delays, idle time, and dissatisfied customers.

$$Takt\ Time = \frac{Total\ Available\ Production\ Time}{Average\ Customer\ Demand} \tag{3}$$

V. Run your production line through its paces to see how efficient it is.

Following a well-balanced task distribution, the next stage is to assess the project's effectiveness. Testing can assist in identifying other areas that require efficiency improvements and rebalancing. The below is the assembly line efficiency formula:

$$Line\ Efficiency = \frac{Sum\ of\ Task\ Times}{(Number\ of\ workstation * Desired\ Cycle\ Time)} \quad (4)$$

You may adjust factors like machine timings, Takt Time, and set up time if you need more balance.

For example, you may significantly reduce cycle time by enhancing machine time through balanced upgrades and worker training. Resizing line segments (raising or decreasing the number of workstations in each division) can also help with lean manufacturing by lowering total work time[22].

3.6 Methodology

The time it takes to complete a process is known as cycle time. It covers the interval between which an operator begins a process and when the job is able to be moved over to the next person. The Yamazumi chart is a method for advancing Kaizen for line balancing. Yamazumi chart is a bar chart that displays the total cycle time for each operator in the process flow.

Yamazumi graphs are projected on boards on the production lines. They're highly important in customer controls, where the whole production process can be observed in order. Yamazumi shows a significant visualization of individual production steps that are well divided into colour columns. Applying the technique perfectly illustrates the openness of a process that can be accessed and changed at any time[23]. The methodology of line balancing flow chart is shown in (Figure 23).

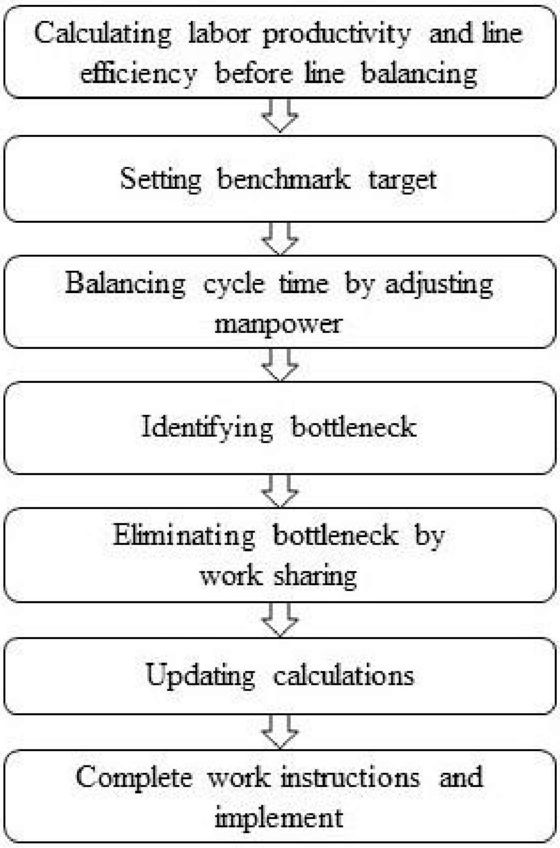


Figure 23: Methodology of Line balancing [Source: Own]

In terms of the charting process, the specifics of the assembly process must be acquired at the beginning. The simplest method is to create a video on which you can read the assembly steps times accurately. The data from the video can be analysed and a bar graph generated.

Line balancing is not properly designed if the assembly stations exceed the specified takt time. As a result, we can assume that the production line exceeds consumer demand. If not, operation times must be less than or equal to the takt time.

To reduce the column differences, the stations must be balanced in this situation. The fact that the times are the same, that they have the same cycle time, and that they are within the tact time limit is also the most apparent arrangement of graphs. To unbalance the cycle time on the assembly stations, it's a smart idea to adjust the assembly process and move individual operations to assembly stations with a shorter cycle time. This movement is shown in Below (Figure 22)

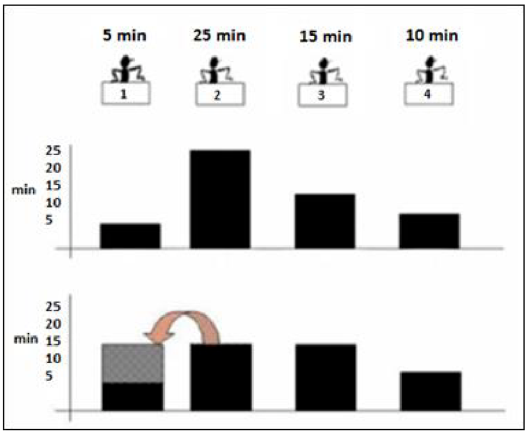


Figure 24: Method of moving installation[23]

The balancing method is very challenging and it is difficult to change anything that is almost perfect. The technology of operations, in particular, must be valued. Reduced processing times can be accomplished by increasing machine efficiency (faster overclocking) to speed up the melding process (based on available options) or moving some of the operations to another assembly station if the technical process remains unchanged.

When it comes to process control and measurement, Yamazumi finds work that does not alter the product's shape to be superfluous. In cases where the solution is in electronic systems, such as cameras that can record the storage of pieces or their absence, cycle time can also be minimized. We need to know a few key factors to optimize and balance the process, namely: time for individual assembly operations, tact time, Aim cycle time, The time of a cycle.

Time measurements are taken at the assembly stations from the beginning to the end of the assembly process in order to achieve correct cycle time. Tact time is the concept that all of a company's activities are regulated by a pulse set by consumer demand. Tact time is the concept that all of an activity of the company are coordinated by a pulse set by consumer demand.

Takt time defines the pace of the Production System, which is the rate of sales, connects production output to actual consumer demand, and ensures that all production activities are coordinated from the first to the last assembly phase. Takt time is the frequency at which a part or component must be manufactured in order to satisfy consumer demand. Takt time is determined by monthly production demand; as demand rises, Takt time falls; as demand falls, Takt time rises, implying that the output interval rises or falls.

The term "takt time" refers to the relationship between customer demand and available time. For the consumer, time is an important consideration. The takt time shows how quickly the supplier will supply the appropriate number of gears to the customer. Takt time may also refer to the rate at which a consumer consumes a company's product.

The consideration of task time fluctuations, according to Monden, is due to human factors or various delays, which results in a U-line balancing issue. The inconsistency in task time is primarily due to human inconsistency in terms of work rate, skill, and motivation, as well as the failure susceptibility of complex processes.

According to Becker and Chiang, a source of variability that describes the worker conducting the task as well as the environment in which the task is done. The movement cost of men and machines is minimized to monitor these causes of uncertainty. In the manufacturing process, man-machine efficiency is accomplished by the free movement of material and information.

The networking time per day and the number of gear units per day are specified for the equation above. The aim of optimization is to match the cycle time to the cycle's target time while ensuring that the target cycle time is not exceeded. We can prevent the creation of bottlenecks on the assembly line by concentrating on certain moments.

3.7 Procedures Line Balancing

Line balancing is a method of balancing that involves allocating job components from an assembly line to a work station in order to reduce the number of work stations and the amount of time that each station spends idle for a given output level. The time requirements per unit of product stated for each task, as well as the sequential relationships, must be taken into account when balancing these tasks[24]. There are steps to follow while using the line balancing approach. The procedures that should be performed include:

1. Make the Precedence Diagram

   The precedence diagram illustrates the sequence of work operations to facilitate the control and planning of activities related to it. Precedence diagram is made with:

- A node symbol in the shape of a circle that contains letters or numbers makes it easier to identify the operating procedure that separates the various work pieces in a production line.

- Arrows are used to indicate the order and direction of the operations. It is desired that work at the arrow's base be completed before work at the tip.
- Standard time (Wb); is above the circle symbol (node), which is the time needed to complete each operation.

2. Cycle Time

The average turnaround time for an operational process is known as cycle time. Here, the cycle time is solely used to tally up the workstations.

$$Cycle\ Time = \frac{Production\ Time}{Target\ Production} \tag{5}$$

3. Theoretical Minimum Number of Work Station (TM)

This calculation demonstrates the bare minimal amount of workstations that should be present on a production line.

$$TM = \frac{Total\ of\ Task\ Time}{Cycle\ Time} \tag{6}$$

4. Balance Efficiency (BE)

The effectiveness of the line balancing approach will be determined by the computation of line balancing efficiency.

$$BE = \frac{Total\ Work\ Station\ Time}{TM} * 100\% \tag{7}$$

5. Balance Delay (BD)

The percentage of idle time in a production line caused by an uneven distribution of operations between stations is known as balance delay.

$$BD = 100\% - BE \tag{8}$$

6. Smoothness Index (SI)

An indicator of a production line's relative idle time is the smoothness index. The smoothness index has a minimum value of zero (perfect balance). The production line is becoming more balanced if the smoothness index value is decreasing and approaching zero.

$$SI = \sqrt{\Sigma(Sti_{Max} - Sti)^2} \quad (9)$$

Where:

Sti_{Max}= Largest Work Station Time

Sti = Time of Each work station (i=1,2 …, n)

3.7.1 Line Balancing Problem Model Data

In this chapter all the methods of line balancing problems are explained with the examples. Here are some data of time for a small component assembly line unit has demand of 1,600 units per week. The line operates 40 hours, 5 shifts per week and 8h hours per shift. A company has assembly line and assembly work contains the following work elements given in below table.

Machine	Time(min)	Predecessor
1	1	-
2	0.5	-
3	0.8	1,2
4	0.3	2
5	1.2	3
6	0.2	3,4
7	0.5	4
8	1.5	5,6,7

Table 1: Data

3.7.2 Rank Positional Weight

The Rank Positional Weight method and the Large Candidate Ruler method are integrated in this strategy. The rank positional weight value is calculated based on the position of each work element in the precedence diagram and the work element itself[25]. The rank positional weight approach involves the following steps:

1) From the operation process chart, create a network diagram or precedence diagram.
2) Calculate cycle times.
3) Creating a path matrix based on precedence diagrams.
4) The number of times an operation and the operations that come after it are taken into account when calculating the position weight of each operation.
5) Sort activities from the heaviest operational weight to the lightest.

6) Calculate the minimum number of work stations.
7) Make a flow diagram for the minimum work station, then load the operation on the work station starting from the largest to the smallest operating weight. The criteria that the total operating time is smaller than the desired cycle time.
8) To obtain the most effective track, practice trial and error.
9) Calculate the balance delay.

Example Problem of Rank Positional Weight Method,

1) The precedence diagram of the assembly process in the assembly line can be seen in Figure below.

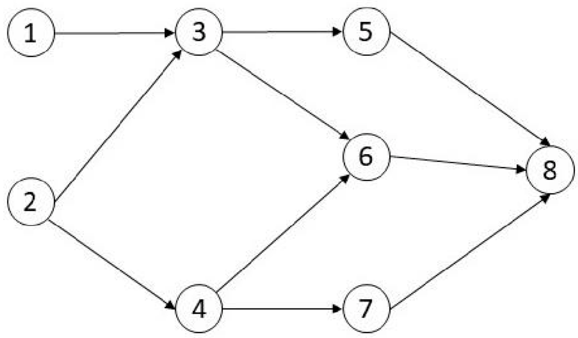


Figure 25: Precedence Diagram [Source: Own]

2) Calculate Cycle Time

$$Cycle\ Time = \frac{Production\ Time}{Target\ Production} \tag{10}$$

$$Cycle\ Time = \frac{40 * 60}{1600}$$

Cycle Time = 1.5 minutes

3) Calculating the position weight of each operation is calculated based on the number of times the operation and the operations that follow it from right to left.

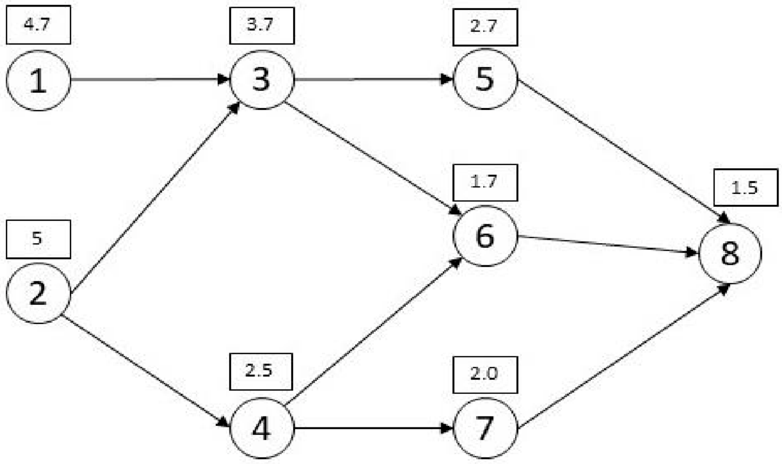


Figure 26: RPW Diagram [Source: Own]

4) List the tasks Ranked according to their Ranked Position Weight (RPW)

Machine	RPW	Time(min)	Predecessor
2	5	0.5	-
1	4.7	1	-
3	3.7	0.8	1.2
5	2.7	1.2	3
4	2.5	0.3	2
7	2	0.5	4
6	1.7	0.2	3,4
8	1.5	1.5	5,6,7

Table 2: Precedence Table

5) Work task assigned to stations according to the RPW values

Station	Machine	Time(min)	Predecessor	Station Time
I	2	0.5	-	1.5
	1	1	-	
II	3	0.8	1,2	1.3
	4	0.3	2	
	6	0.2	3,4	
III	5	1.2	3	1.2
IV	7	0.5	4	0.5
V	8	1.5	5,6,7	1.5

Table 3: RPW Table

6) Balance Efficiency

$$BE = \frac{Total\ Work\ Station\ Time}{n * Cycle\ Time} * 100\% \quad (11)$$

$$BE = \frac{6}{5 * 1.5} * 100\%$$

BE = 80%

7) Balance Delay

$$BD = 1 - BE \quad (12)$$

$$BD = 1 - 0.8$$

BD = 0.2

8) Smoothness Index

$$SI = \sqrt{\Sigma(Sti_{Max} - Sti)^2} \quad (13)$$

$$SI = \sqrt{(1.5)^2}$$

SI = 1.5 min

3.7.3 Largest Candidate Rule

The largest candidate rules method's fundamental tenet is to integrate processes by ordering them from the longest operation processing time to the shortest operation time. It is necessary to decide how many cycle periods will be used before combining. When merging operations at a single work station, this cycle time will be used as a limitation[25]. The following are the steps of the largest candidate rules method:

1) Create a production line precedence diagram
2) Sort the work components according to their size and time to completion.
3) The order with the longest turnaround time is used for the work items at the first work station. When the quantity of work elements exceeds the cycle time, the work element is sent to the following work station.
4) For each further station, repeat steps 3 and 4 until all elements of the task are in place, the work station duration does not exceed the cycle time, and the station satisfies the criteria for the precedence diagram sequence.

Example of Largest candidate rule method,

1) Precedence diagram

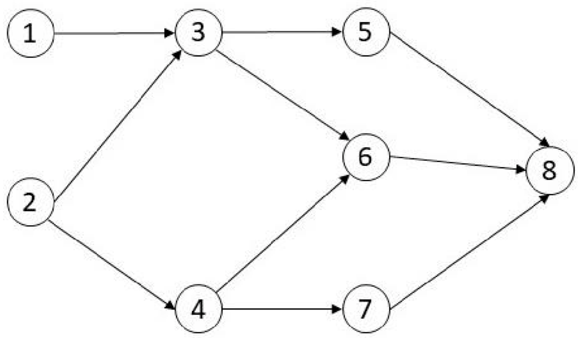


Figure 27: Precedence Diagram [Source: Own]

2) Calculate Cycle Time

$$Cycle\ Time = \frac{Production\ Time}{Target\ Production} \tag{14}$$

$$Cycle\ Time = \frac{40 * 60}{1600}$$

Cycle Time = 1.5 minutes

3) In general, the strategy is to use a rule that assigns tasks that either have a large number of followers or are long in duration because they effectively limit the balance that can be achieved. The following is our primary rule in this case. Prioritize tasks in the order of the greatest number of subsequent tasks.

Machine	Time(min)	Predecessor
8	1.5	5,6,7
5	1.2	3
1	1	-
3	0.8	1,2
2	0.5	-
7	0.5	4
4	0.3	2
6	0.2	3,4

Table 4: Precedence Table

4) Start at the top of the job and work your way down to allocate the elements to the first station. A feasible element is on which satisfies the precedence requirements. Thus, the sum of the task time of all elements at that station should not exceed the cycle time.

Station	Machine	Time(min)	Predecessor	Station Time
I	1	1	-	1.5
	2	0.5	-	
II	3	0.8	1,2	1.3
	4	0.3	2	
	6	0.2	3,4	
III	5	1.2	3	1.2
IV	7	0.5	4	0.5
V	8	1.5	5,6,7	1.5

Table 5: LCR Table

5) Balance Efficiency

$$BE = \frac{Total\ Work\ Station\ Time}{n * Cycle\ Time} * 100\% \quad (15)$$

$$BE = \frac{6}{5 * 1.5} * 100\%$$

BE = 80%

6) Balance Delay

$$BD = 1 - BE \quad (16)$$

$$BD = 1 - 0.8$$

BD = 0.2

7) Smoothness Index

$$SI = \sqrt{\Sigma(Sti_{Max} - Sti)^2} \quad (17)$$

$$SI = \sqrt{(1.5)^2}$$

SI = 1.5 min

3.7.4 Kilbridge-Wester

The preferred precedence diagram's position determines which work elements are assigned to a work station using the Kilbridge-Wester technique, a heuristic procedure (regarding work station time and work elements)[25]. The Kilbridge-Wester approach involves the following steps:

1) Create a production line precedence diagram.
2) Create columns in the precedence diagram from left to right for the work elements.
3) Arrange the work components in ascending order of longest operating time to shortest operating time.
4) Prioritizing the work items in the first column that take the longest to complete is how the work elements are grouped.
5) Go to the next column if all of the work elements in the preceding column have been arranged into work stations.
6) As long as it does not go against the precedence diagram, replace the old workstation if the workstation time is longer than the cycle time.

7) Steps 5 and 6 should be repeated until all work elements have been positioned in the work station.

Example for Kilbridge & Wester Method

1) Precedence diagram

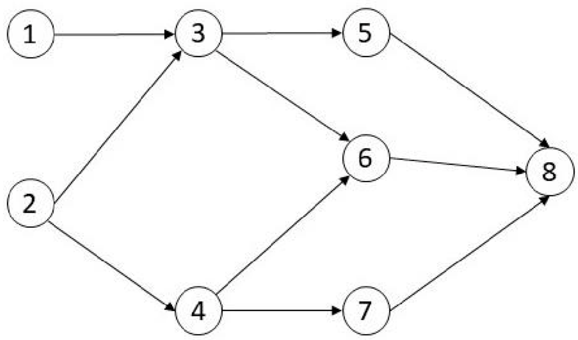


Figure 28: Precedence Diagram [Source: Own]

2) Calculate Cycle Time

$$Cycle\ Time = \frac{Production\ Time}{Target\ Production} \tag{18}$$

$$Cycle\ Time = \frac{40 * 60}{1600}$$

Cycle Time = 1.5 minutes

3) The precedence diagram's work elements are divided into columns going from left to right.

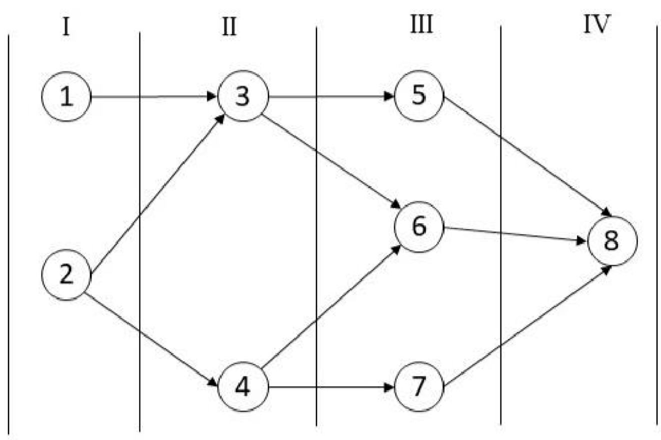


Figure 29: Kilbridge & Wester method [Source: Own]

4) The process of ranking the job elements in the first column based on their largest completion time is known as grouping.

Machine	Column	Time(min)	Predecessor
1	I	1	-
2	I	0.5	-
3	II	0.8	1,2
4	II	0.3	2
5	III	1.2	3
7	III	0.5	4
6	III	0.2	3,4
8	IV	1.5	5,6,7

Table 6: Precedence Table

5) If the workstation time exceeds the cycle time, replace the workstation's existing workstation with the following work station as long as it does not violate the precedence diagram.

Station	Machine	Column	Time(min)	Station Time
I	1	I	1	1.5
	2	I	0.5	
II	3	II	0.8	1.3
	4	II	0.3	
	6	II	0.2	
III	5	III	1.2	1.2
IV	7	III	0.5	0.5
V	8	IV	1.5	1.5

Table 7: Kilbridge & Wester Table

6) Balance Efficiency

$$BE = \frac{Total\ Work\ Station\ Time}{n * Cycle\ Time} * 100\% \tag{19}$$

$$BE = \frac{6}{5 * 1.5} * 100\%$$

BE = 80%

7) Balance Delay

$$BD = 1 - BE \tag{20}$$

$$BD = 1 - 0.8$$

BD = 0.2

8) Smoothness Index

$$SI = \sqrt{\Sigma(Sti_{Max} - Sti)^2} \tag{21}$$

$$SI = \sqrt{(1.5)^2}$$

SI = 1.5 min

3.7.5 Moodie Young

The Moodie Young method is a line balancing method with two phases (stages) of analysis. The first step is to organise workstations based on a matrix of element relationships. The results of phase one were used to revise phase two. In phase one, a precedence diagram for the matrix P and the matrix (which depicts the predecessor and following work elements) is created. For example, the F matrix depicts the relationship between the preceding work elements and the matrix (depicts the relationship between the following work elements. The work elements are then placed on the workstation. Which work element is placed first in the production line according to the rule, if two work elements can be selected, then the work element with the longest time is placed first[25]. Phase two is carried out to evenly distribute idle time for each station as a result of phase one. Phase two involves the following steps:

1) Determines the longest work station time and the shortest work station time.
2) Using the formula, calculate half of the difference between the two-goal values (GOAL).

$$GOAL = \frac{Tsi(\max) - Tsi(\min)}{2} \tag{22}$$

3) Defines a work element (station time) maximum that is less than the GOAL value and which work element is moved to the work station in the shortest amount of time while not violating the precedence diagram rules.
4) If there is a work element at the maximum work station that is less than the GOAL value, move it to a workstation with a longer minimum time.
5) Perform steps 4 and 5 until there are no work elements that can be moved.

3.7.6 Discussion of results

Based on the three methods and results discussed above, namely the Rank Positional Weight Method, the Largest Candidate Rule, and the Kilbridge & Wester Method, it has been demonstrated that the effectiveness of all three approaches is almost identical, despite the fact that the steps differ for each. However, the second method was chosen precisely because the gaming mechanisms in this method are easier to understand than the other two methods, which are considered more challenging.

4 Review On Education (Serious) Games

Gamification and experiential learning are becoming more common in education because they provide an engaging experience that engages students and encourages them to learn more deeply. Computer simulations and interactive games are widely used in industrial engineering education to teach basic skills in supply chain management and production planning. They encourage students to adapt theories learned and focus on the consequences of their decisions when used in comparison with other teaching methods. Other “hands-on” games will help to learn professional skills like coordination, teamwork, and communication. This paper examines cases of experimental gaming and game-based learning in industrial engineering to address the advantages and disadvantages of games as education materials[26].

Traditionally, engineering education has emphasized technical skills and knowledge. However, modern curricula go beyond core engineering topics to deliver up-to-date knowledge in a fast-changing world as well as broader professional skills[27]. Designing, analysing, improving, and installing structures that integrate humans, products, knowledge, machinery, and energy is the goal of industrial and systems engineering. It combines mathematical, physical, and social sciences to determine, forecast, and measure the success of processes. Furthermore, the international CDIO Initiative (which stands for Conceive – Design – Implement – Operate) emphasizes that engineering education should be rich in design-build-test programs, incorporate technical skills such as collaboration and communication, emphasize constructive and experiential learning, and continually develop[28]. With these concepts in mind, it's clear that production engineering education has a difficult challenge ahead of it: preparing the next generation of engineers with expertise and information that go beyond the conventional emphasis on technological subjects.

The seminar led by experts in the sector is a favourite formula of industry for educating its executives and managers in new areas (e.g., total-quality management a few years ago). A simulation tool, as an add-on to a lecture or workshop, can improve the learning process by including participants in multi-modal learning activity, which includes hearing, seeing, communicating, and performing. According to the authors, "simulation is a critical component of effective learning labs for developing systems theory and promoting organisational learning." This is because participants who have had (simulated) success and loss recall the lessons learned more clearly and more likely to incorporate them later in their career activities.

As a result, it's no wonder that simulation training is becoming increasingly common in corporate settings.

Board games are cost-effective, inspiring individual game designers and researchers to design and develop them. Researchers in the fields of archaeology and anthropology have primarily documented the interaction between board games and human interaction. Board games contributed to the creation of the environment, shaped, described human thought, and relationships, according to research in these areas.

Since players must understand the mechanism in order to communicate or connect with the games, gameplay is related to learning. Researchers in a variety of fields are gradually researching at board games as learning spaces, based on this idea. Because of the simplicity of the games' mechanics, an increasing number of researchers see board games as promising spaces for understanding learning.

Boardgames are ideal for casual learning environments due to their affordability and usability. New learning activities and resources for exploring learning in board game settings are provided through board games aim to educate.

The growing interest in board gaming in a variety of disciplines and settings not only underlined the importance of examining scientific evidence on board gaming and learning, but also the need to analyse these results within the area of game studies. Moreover, research indicates that playing includes learning as players interact with the game and discover new ways to deal with it. Participating in, playing with, and/or communicating in and about the game is all part of the learning experience. As a result, learning isn't just about acquiring new information or changing one's action. Learning happens as a result of the different activities and experiences that players engage in when playing a board game.

This study examines current board game studies and focuses on the following key questions: What kind of learning happens when you play board games? What skills/knowledge do people gain from playing games on a board? During board game play, what practices do players engage in?

The ultimate aim of this review is to describe the board gaming and learning in recent literature from different disciplines and areas, and to find areas for further analysis. The researchers looked at studies of a wide range of participants. To demonstrate the connection between board gaming and learning, specific information from the studies were presented. Finally, based on the differences in previous studies, the study describes the need for expanding research on board games and learning. Before getting into the methodology and results, it's a good idea to define board games in comparison to other terminology used in the literature[27].

4.1 Recognising Board Games, Tabletop Games, Analog Games:

Given the prevalence of concepts like non-digital gaming, tabletop games, and analogue games in the literature, it is necessary to describe these terms in order to situate this analysis within the area of game studies. For example, the word "analog games" would refer to any non-digital game, while "tabletop games" refers to board games.

Board games, according to game studies, are games with rules, a playing surface, and tokens that allow players to engage when looking down at the playing surface and facing each other.

In contrast to digital games, player participation in board games is not mediated by a machine, which distinguishes them from digital games. The platform is the primary distinction between board games and digital games. Board games are traditionally designed to be played on a tabletop, with all of the game's actual parts enclosed in a cardboard box.

By emphasizing the medium, some game researchers differentiate their concept of board games from other fields. Board games, according to some cognitive psychologists, are games with a consistent set of rules that decide the number of pieces on a board, the number of positions for certain pieces, and the possible moves players may make.

These features distinguish board games from card games or lottery games, with the addition that a board game's playing materials, including the board, game pieces, dice, game rules, and game context are what characterize it. A board game is a game that is played face to face using physical objects such as dice, a board/playing field, cards, and tokens when sticking to a set of rules. In the gaming literature, the term "tabletop games" refers to a wide genre of games that are played on a tabletop. Tabletop games are those that are played at a table without the use of any technology. Tabletop games, like most games, have rules, structures, and components, but they "depend on interactions between tokens or playing pieces rather than actual interactions between player bodies." As a result, board games like Monopoly, Poker, Dungeons and Dragons, and Pandemic are classified as tabletop games.

In the field of engineering, researchers looked at board games and learning. Students who developed or changed a board game to teach their peers engineering principles outperformed their peers who took a standard evaluation exam, according to the results. As a result, board game design improved knowledge and understanding of these engineering principles.

4.2 Simulation Board Games and Motivation to Learn

Simulation Board games is also been used to motivate students to learn. Taspinar[29] discovered that board games inspired college students in Germany to understand theory in an information management course. Learning theory-based material was made more fun by using board games, which inspired students to learn.

Studies have documented board games as learning environments and found board gaming to be beneficial in the development of engineering thought and communication skills. The impact of board games on the relational experiences of participants with disabilities could indicate that board games have the ability to build inclusive learning opportunities for a wide range of learners[30].

Gameplay has the ability to inspire students to learn while also engaging them in computational thought. Motivation has mostly been explored for digital games in game study. These results suggest that further research into motivation is required. The findings also indicate that research on board games is still dominated by games with a learning or teaching objective, which are referred to as serious board games in modern game studies terms. This study validates observations of researchers and game designers working to create board games that teach or help illustrate complicated real-world challenges and processes.

4.3 Simulation Games in Manufacturing Design and Production Planning

The efficiency of lean implementation procedures depends largely on how each process participant perceives them. Numerous educational games have been developed up until this point in order to make this concept as clear as possible. Both students researching the topic and employees at businesses that adopt the Lean Manufacturing technique can benefit from them. Games that required players to quickly identify shapes were created to help people understand the 5S method's efficacy. There are a large number of companies that use these games. Other games highlight the need of establishing flow in working processes. The games are played in rounds, and each one shows single-unit flow with pull, traditional layout, and cell layout[31].

The game "The Lean Lemonade Tycoon" by L. Ncube[32] has groups of students making and selling lemonade. Business operations are continuously improved by utilizing the key Lean tools.

A game created by Yazici [33] enables students to understand layout modelling and assess various manufacturing and labour-allocation techniques.

An assembly line balancing decision trainer to support the users' line balancing skills was created by Mazziotti et al [34]. They concentrated on a manual assembly line that creates textile items in that simulation.

In order to teach assembly line balance, Hesieh [35] presented a web-based problem-solving environment. 67 students assessed the suggested analytical and simulation models, and the system assisted them in visualizing assembly line balance principles.

An Excel-based assembly line balancing application known as a fast ergonomic evaluation approach was introduced by Baykasolu et al [36]. For university students, the program's goal is to promote the teaching of ergonomic risk assessment approaches, the features of various techniques, and the ability to compare the outcomes of various procedures.

Y. Demir and H. Ylmaz [37] For educational purposes, a newly created production planning program called Visual Assembly Line Balancing Software (VALBS) is launched. The software's purpose is to aid in the teaching of assembly line balancing procedures, make it easier to comprehend the unique qualities of various assembly lines and problem-solving strategies, and make it possible to compare the outcomes of these approaches. The suggested VALBS is simple to utilize in a variety of production settings and is appropriate for supporting the instruction of line balancing techniques to undergraduate students.

Lynn [38] presented the creation of six DUPLO® "dogs," the assembly-line balancing mini-demonstration using DUPLO® blocks offered here helps students expand their grasp of operations management principles and abilities.

5 Design of Line Balancing Game

This chapter talks about the goal and design of Line balancing game, key performance indicators of the Line balancing game, game mechanics, components of the game and game steps.

5.1 Teaching Goals of Line Balancing Games

The main objective of this line balancing game is to educate the students and company workers for the better understanding of the line balancing concept. In, this game both largest candidate rule method and normal line balancing method is used for the game concept. The Line Balancing game is a simple but effective way for students to learn about how mixing several products together in manufacturing lines and production cells. The goal of the game is to help students understand how the line balancing concept works. By playing the game, students will learn how to optimize an assembly line in order to maximize efficiency.

5.2 Mechanisms of Simulation Game

The rules and procedures that guide the player and the game's reaction to the player's moves or actions are known as the mechanics of a game. You determine how the game will function for the individuals who plays it through the mechanisms you build. To be more specific, the mechanics define both the rules that the player must follow and the rules that the game must obey.

1) **Open Drafting:** In games where players choose cards (or tiles, resources, dice, etc.) from a common pool in order to gain an advantage (immediate or long-term) or to put together collections that are utilized to accomplish game goals, open drafting is employed[39]. Games in which cards are simply drawn from a pile are not drafting games; drafting implies that players have some sort of choice and the ability to draught a card that another player might want, thus denying them something they might have wanted.

2) **Worker Placement:** Players use tokens (usually the classic person-shaped "meeple") to initiate one of the many actions that are available to them, which are normally done one at a time and in turn order. Each player often has a certain number of tokens to use in the game.

3) **Score and Reset Game:** A game in which players play until they reach a stop condition, at which point they record their scores, reset the game, and play one or more additional rounds. The game ends after a certain number of rounds, and the cumulative score is used to determine the winner.

4) **Paper and Pencil:** The game is created with paper and pen to mark and save responses or attributes that will be used to score points and determine the winner at the end of the game. A paper-and-pencil mechanism is not used in a game that simply keeps score on a sheet of paper.

5) **Contracts:** Players must complete Contracts in order to earn rewards. These take the form of special goals that necessitate more coordination and planning than simply being "first past the post." These can be public, where all players compete to be the first to complete them, or private, where only the player who owns them can complete them.

6) **Victory Points as a Resource:** Victory Points (VPs) are a form of cash that may be used to alter the direction of a game. Common examples of this mechanism are business or economic games that include money and award the victory to the participants with the greatest money.

7) **Real Time:** Subject to certain limitations, players play as rapidly as they can until the game or phase is over.

8) **Market:** Markets, where players can buy and sell resources. This is frequently a primary feature of economic games, but it is not always the case. Many games use a "market" to price cards, tiles, and other items that players can buy permanently[39].

5.3 Key Performance Indicators in Line Balancing Game

There are several manufacturing KPIs that are considered standard practice in the industry. That isn't to say that they should all be applied to every company making a product. While many of them are relevant, some aren't. It's even possible that a standard manufacturing metric doesn't exist for the metric you're looking for. There are a few things to consider if you're planning to construct your own production metric.

- Every KPI must have a well-defined aim. What exactly are you attempting to accomplish? Is it even possible to do this? What timescale do you want to attain your objective through? Set specifications that clearly identify your aim and be explicit. This objective must be measurable in numerical (quantitative not qualitative).
- It's essential that you're able to objectively track your progress toward your goal. This entails gathering and analysing data. This leads to the following criterion.
- Data. There must be a well-defined data source and a precise protocol for measuring or collecting the data. There should be no room for interpretation in this case.
- It's just as important to report your data as it is to gather it. The reporting frequency for various manufacturing KPIs will differ. Reporting should be done on a weekly or monthly basis, and a manufacturing reporting software solution is frequently used.

Considering lot of key Performance Indicators in Line Balancing concept. The selected 15 KPI's are listed below;

1. **Cycle Time** – Although the cycle time KPI is fundamental in nature, it may be modified to become a powerful tool. In the manufacturing industry, cycle time is the average length of time it takes to create a product. Isn't it straightforward? It's possible that it's not as simple as you think. The cycle time metric can be used to determine the time required to produce a finished good, each component of the final products, or even the amount of time needed to transport the good to the end consumers. As a result, cycle time may be used to measure the overall efficiency of a manufacturing process on a macro scale as well as discover inefficiencies on a micro scale.

$$Cycle\ Time = Process\ End\ Time - Process\ Start\ Time \tag{23}$$

2. **Changeover Time** – At its most basic, changeover time refers to the time it takes to transition from one job to another. It primarily refers to the amount of time lost when a manufacturing production line is switched from one product to another. It could also refer to how much time is spent switching shifts.

$$ChangeOver\ Time = Net\ Available\ Time - Production\ Time \tag{24}$$

3. **Takt Time** – This manufacturing KPI is extremely useful when it comes to scheduling production orders or deciding whether or not to accept a client's order. Takt time is the

maximum amount of time that may be spent developing a product while still meeting a client's deadline. Takt is short for "taktzeit," which means "cycle time" in German.

$$Takt\ Time = \frac{Total\ Available\ Production\ Time}{Average\ Customer\ Demand} \tag{25}$$

4. **Throughput** – This is certainly one of the most basic, as well as one of the most significant, KPIs for the manufacturing business. The Throughput KPI assesses a machine's, line's, or plant's production capability, or how much they can generate in a given time period.

$$Throughput = \frac{Number\ of\ Units\ Produced}{Time\ (hour\ or\ day)} \tag{26}$$

5. **Capacity Utilization -** The rate at which potential output levels are met or used is referred to as capacity utilisation. It essentially tracks how much of a company's manufacturing capacity is currently in use.

$$Capacity\ Utilization = \frac{Actual\ Output}{Maximum\ Possible\ Output} * 100 \tag{27}$$

6. **Overall Equipment Effectiveness** (OEE)- Overall Equipment Effectiveness measures the proportion of planned manufacturing time that is productive. OEE is calculated by multiplying availability, performance, and quality by a percentage and only takes into account scheduled time. An OEE of 100 percent indicates that a manufacturer is producing only good parts as quickly as possible, with no downtime.

7. **Machine Downtime Rate -** Machine downtime rate refers to both planned and unplanned downtime when the machinery is not usable for production. Because downtime is the leading cause of lost production time in the industrial industry, this is a critical measure.

$$Machine\ Downtime\ Rate = \frac{Total\ Uptime}{(Total\ Uptime + Total\ Downtime)} \tag{28}$$

8. **Work-in-Process** - A company's partially finished products that are awaiting completion and ultimate sale are known as work-in-process. It comprises the expenses of raw materials, labour, and overhead associated with items in the middle of manufacturing.

$$WIP = Beginning\ WIP + Manufacturing\ Cost - Cost\ of\ Goods\ Manufactured \quad (29)$$

9. **Line Balancing Rate** – The operator balance chart, also known as a percent load chart, operator loading diagram, cycle time/takt time bar chart, or line balance analysis graph, shows how equalized operation time is distributed among workers within a process, line, or cell. The line balance rate (LBR) and the associated line balance loss rate (100 percent minus the LBR) measure how effectively or badly a line is balanced[40].

A lack of line balance frequently results in wasted time and/or excess production. It can also lead to over-processing, in which operators do "apparent work" rather than waste time waiting. Continuous flow is impeded by line imbalance.

Consider LBR a simple analytical tool. Use it when it makes sense.

$$LBR = \frac{Total\ net\ time\ od\ all\ process}{(Highest\ process\ time * Number\ of\ Workers)} * 100 \quad (30)$$

Example: Using the data reflected in the operator balance chart below Figure 32:

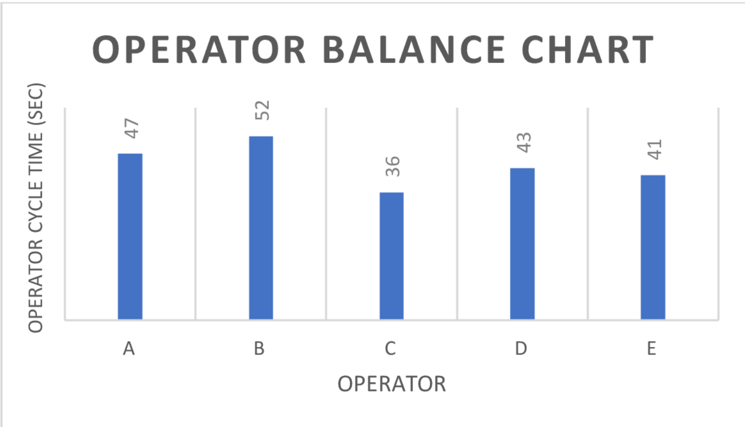


Figure 30: LBR Chart [Source: Own]

$$LBR = \frac{(47 + 52 + 36 + 43 + 41)sec}{(52\ sec * 5)} * 100\% = 84.2\% \quad (31)$$

From the analysis of key performance indicators of line balancing concept, it was concluded that the cycle time, takt time and line balancing rate are the most important factors to consider when selecting key performance indicators for this type of game. These three factors will give you the most accurate information on how well your line is balanced and how efficiently it is running.

5.4 Game Design

This game is for 1 to 4 players and it is designed to help teach line balancing problems. In the game, players are assigned work to different workstations and they have to try to balance the work by buying machines and workers. The goal is to have the least amount of idle time at each workstation. By playing this game, players will learn how to properly balance a line and how to assign work in an efficient way. The game is played by placing workers on workstations, then buying machines to place on those workstations. The player who has the most balanced line at the end of the game wins.

The game is designed to be a strategic game that allows the player to make choices in terms of acquiring new machines, hiring new employees and making other investments in order to get the most profit possible. The design of the game is such that there are many different ways to achieve the goal, and it is up to the player to figure out the best way to do so. There are also different difficulty levels so that players can challenge themselves as they play. The player is also rewarded for successfully completing levels in the form of bonuses that can be used to buy new upgrades or machines. The game was created to be a line balancing game that would be both educating and fun for people who played it.

5.4.1 Game Set-Up

The steps of the game set-up are discussed below,

1) Keep the Main board at the centre of the players, refer (Figure 31).
2) Each player will get separate activity board and worksheet.
3) Arrange the set of task cards in descending order from Level 8 to 1 and keep the cards upside down on the task card area in main board.
4) Each player will receive 5 sets of node tokens (1 set = 10 node tokens) and 40 dices.
5) Place the worker tokens, machine tokens and Money tokens in the Main board to their respective places.
6) At the start of the game each player will receives 1000 points (like 10*100 money tokens) from bank and remaining money should be kept near the main board. At the end of each round players can collect the money from that money.
7) The younger player goes first and the task card once chosen, players should follow the selected deck for next levels.
8) Each players draw the task cards from board one by one.

9) Game time starts once the last player picked the task card from the deck. For measuring time, players can use mobile phone or stop watch.

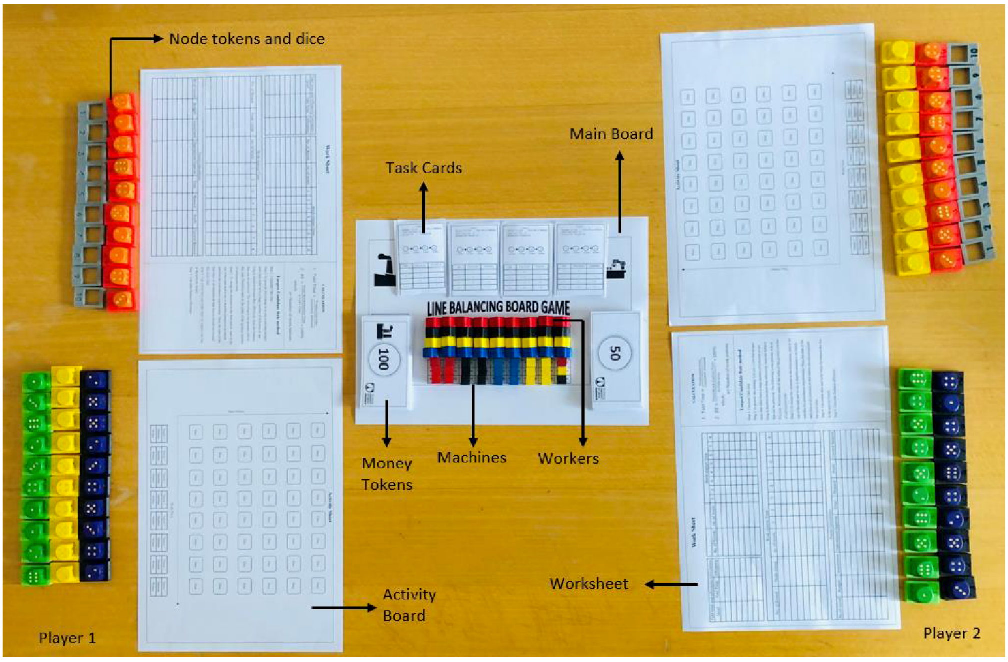


Figure 31: Game Set-up [Source: Own]

5.4.2 Game Components and their use

The game includes one main board, one activity board, four decks of task cards, worker tokens, machine tokens, money tokens, worksheet, Node tokens and 40 coloured dice.

1) Main Board

The main board is placed at the centre of the game. In the main board Task cards, worker tokens, machine tokens and money tokens will be placed in it.

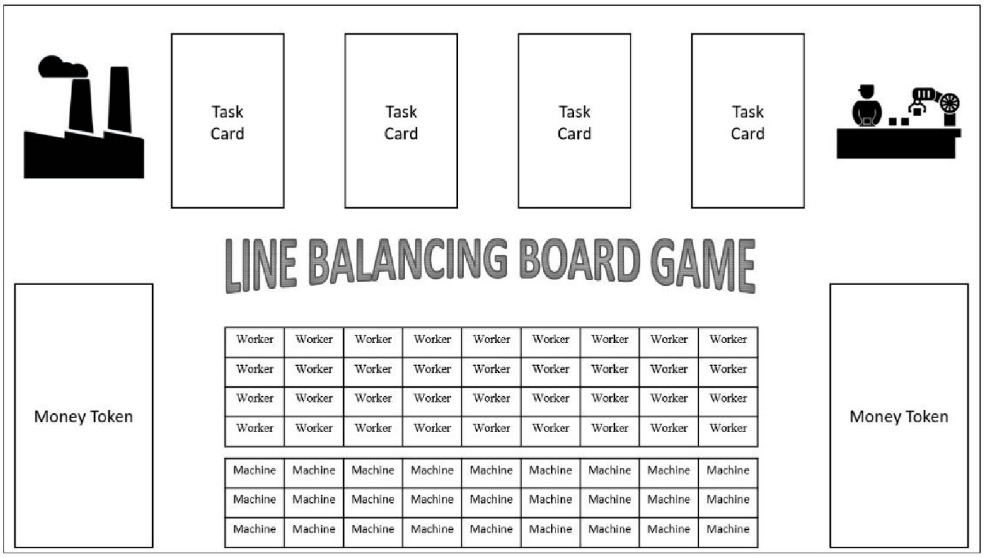


Figure 32: Main Board [Source: Own]

2) Activity Board

Activity board acts like a Production assembly line and it is used for balancing the line using nodes and dices. In activity board the workers tokens, machine tokens, nodes and dices will be placed while playing the game. Activity board consists of two axis lines horizonal line indicates the work floor which consists of machine, worker and work station, vertical line indicates the cycle time of each work station.

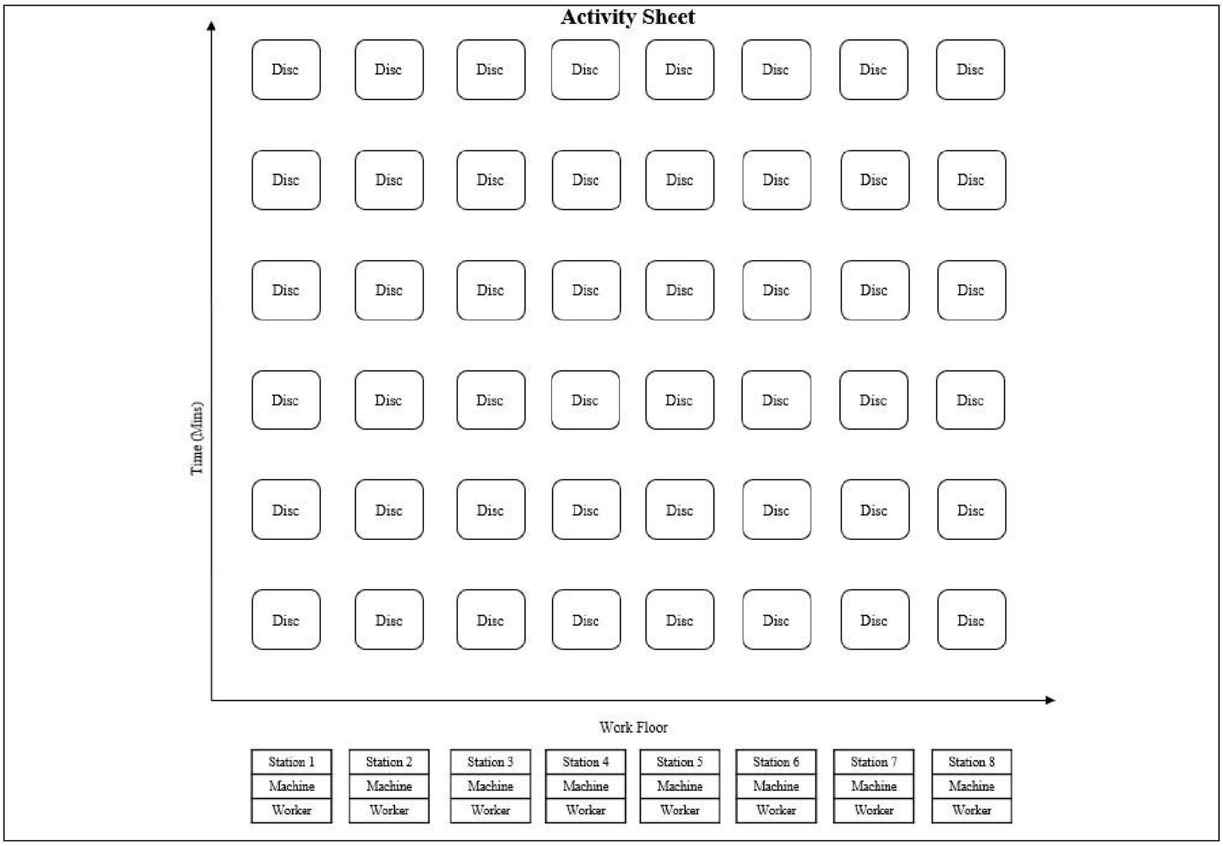
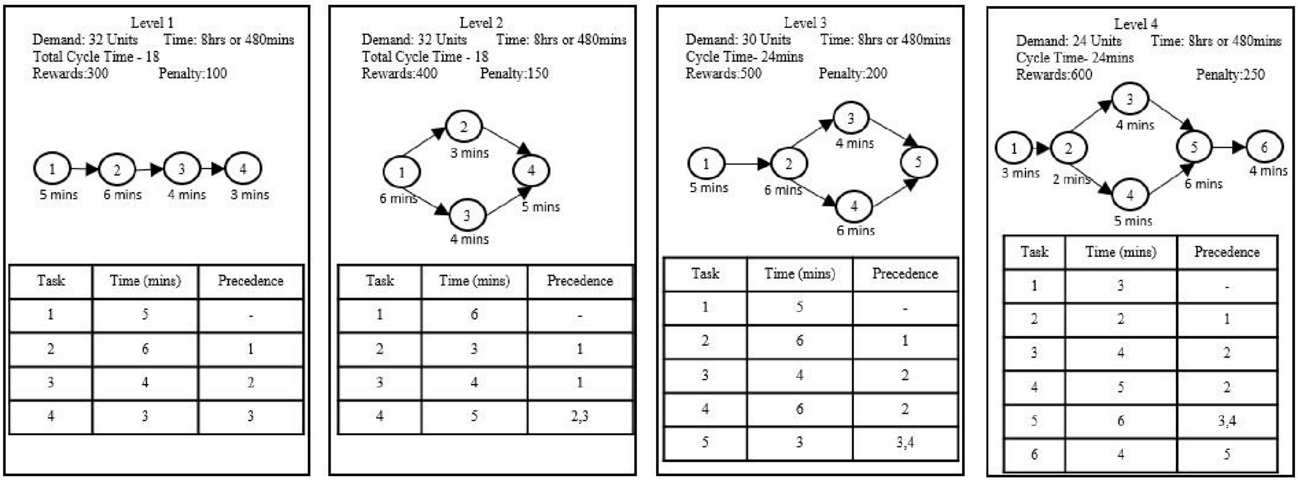


Figure 33: Activity Board [Source: Own]

3) Task Cards

Task cards consists of customer demand, production time, operations cycle time, number of operations and precedence diagram. Using task card, the takt time can be calculated. While balancing the line, player have to follow the precedence of the line, if precedence is wrong the player have to pay the penalty. The 4 set of task cards used in the game, in 1st level task cards all the four types task cards have same precedence but different customer demand and cycle time.



Task	Time (mins)	Precedence
1	5	-
2	6	1
3	4	2
4	3	3

Task	Time (mins)	Precedence
1	6	-
2	3	1
3	4	1
4	5	2,3

Task	Time (mins)	Precedence
1	5	-
2	6	1
3	4	2
4	6	2
5	3	3,4

Task	Time (mins)	Precedence
1	3	-
2	2	1
3	4	2
4	5	2
5	6	3,4
6	4	5

Figure 34: Money Tokens [Source: Own]

4) Worker Tokens

Worker tokens represents the worker in the assembly line. Each workstation consists of one worker. Workers can be hired from the main board. The price of hiring worker is 100 points per shift and wages of worker per shift is 100 points.

Figure 35: Worker Tokens [Source: Own]

5) Machine Tokens

Machines can reduce the actual cycle time in one task by 1 min. In each task only one machine can be used. The price of the machine is 150 points. Machine have maintenance cost of 50 points for reusing it in other rounds. Machines can shift from one task to another but, with a one-time cost of 100 points which can also be understood as setup cost of the machine.

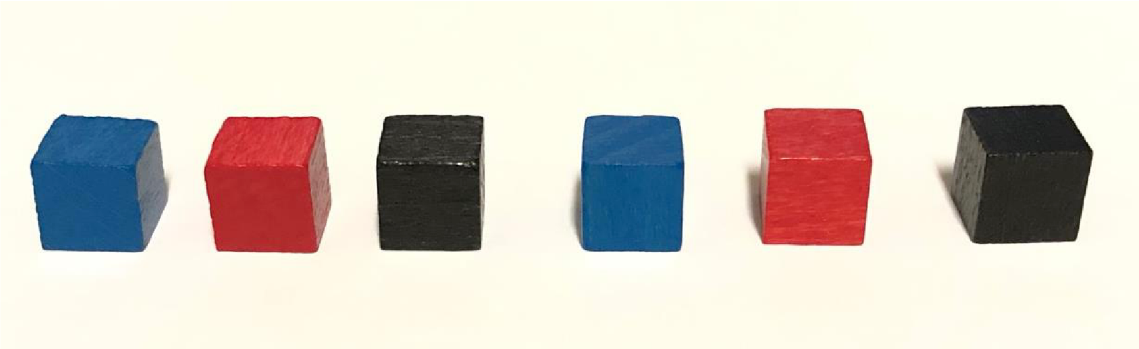


Figure 36: Machine Tokens [Source: Own]

6) Money Tokens

Money tokens represents points. Each player is given 1000 points at the start of the game. Money tokens are used for buying machines and workers. The 4 types of money tokens used in the game, are 50 points, 100 points, 500 points and 1000 points. The player with the highest money points declared the winner of the game.

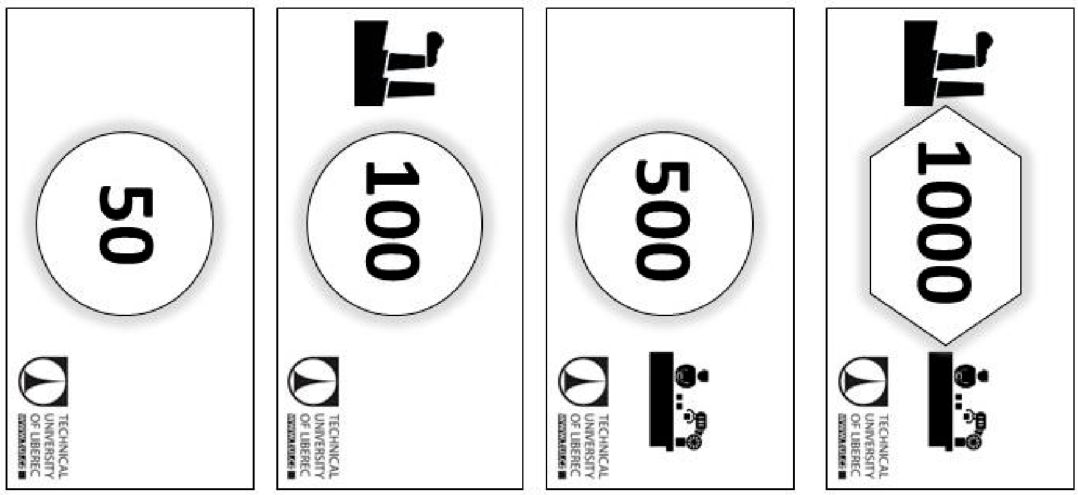


Figure 37: Money Tokens [Source: Own]

7) Worksheet

Worksheet is used for calculation of Takt time and efficiency, records of work station time, expense and Points. The formulas of takt time and efficiency are mentioned in the worksheets. The largest candidate rule method working steps are written in the worksheet.

Work Sheet

Takt time and efficiency Calculation		
Level	Takt Time	Efficiency

Work station Time										
No. of Round	Node colour	no. of levels	1	2	3	4	5	6	7	8

Expense Calculation						
No of round	No of workstation	Price per w/s	Total	No of machine	Price per machine	Total

Points Calculation							
No of round	Budget	Investment	Operational Expense	Total	Reward	Profit	Current Balance

CALCULATION

1. $Takt\ Time = \frac{Production\ time}{Customer\ Demand}$
2. $BE = \frac{Total\ Work\ Station\ Time}{n * Highest\ process\ time} * 100\%$

which:

n= Number of work stations

Largest Candidate Rule method

Step 1: Calculate Takt time

Step 2: In general, the strategy is to use a rule that assigns tasks that either have a large number of followers or are long in duration because they effectively limit the balance that can be achieved. The following is our primary rule in this case. Prioritize tasks in the order of the greatest number of subsequent tasks

Step 3: To assign the elements to the first station, start at the top of the task and so on. A feasible element is on which satisfies the precedence requirements. Thus, the sum of the task time of all elements at that station should not exceed the cycle time.

Step 4: Use colour dice and node token for balance the line in the activity board.

Step 5: Calculate Balance efficiency.

Figure 38: Worksheet [Source: Own]

8) Node Tokens

Node tokens represents the individual operations of the task. Node tokens are used to identify the precedence. And each level has a different colour node token to make it easy to identify the level. In the node token, a dice is placed which indicates the cycle time of the operation.

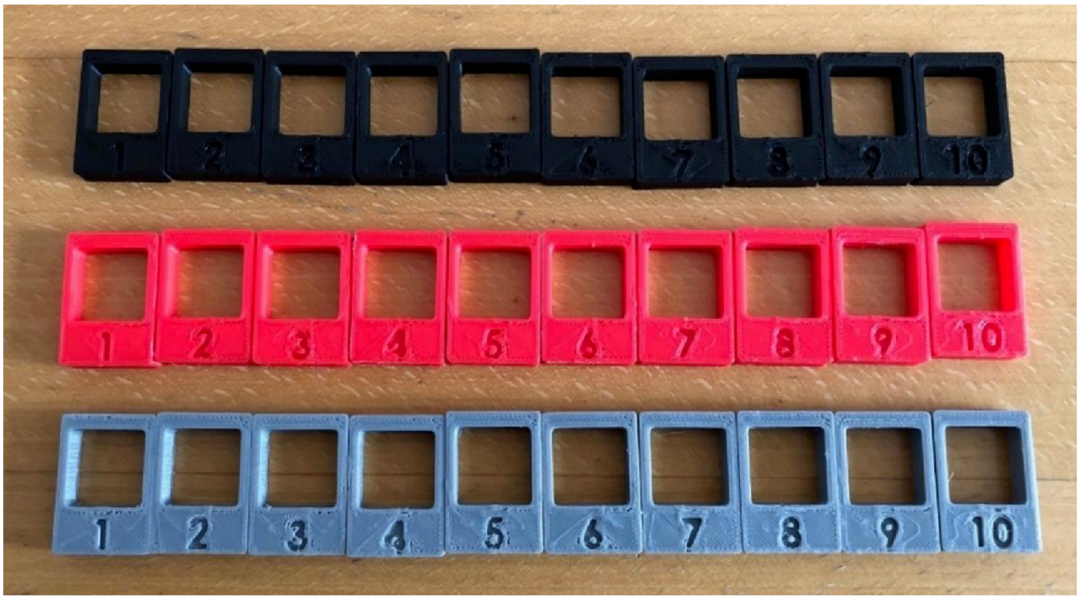


Figure 39: Node Tokens [Source: Own]

9) Coloured Dice

Dices are used for balancing the assembly line. Face number of dice indicates the operation time of the task. Dice will be placed in node token to indicate the operation time of task.

Figure 40: Coloured Dice [Source: Own]

5.4.3 Game Play

Each step of the game play is explained in detail below,

1. **Picking starting player -** The younger player goes first and the task card once chosen, players should follow the selected deck for next levels.
2. **Job card drafting -** Each players draw the task cards from main board one by one.
3. **Time Track -** Game time starts once last player picked the task card from the deck. For measuring time, players can use mobile phone or stop watch.
4. **Calculating Takt time -** Calculate the takt time from data given in the task cards. Line balancing can be done by both the methods normal method and largest candidate rule method, its player discission. For normal rule player have to just follow the precedence, there is not specific conditions like LCR method. The LCR method explained below

4.1. In general, the strategy is to use a rule that assigns tasks that either have a large number of followers or are long in duration because they effectively limit the balance that can be achieved. The following is our primary rule in this case. Prioritize tasks in the order of the greatest number of subsequent tasks

4.2. To assign the elements to the first station, start at the top of the task and so on. A feasible element is on which satisfies the precedence requirements. Thus, the sum of the task time of all elements at that station should not exceed the cycle time.

4.3. Use colour dice and node token for balance the line in the activity board.

5. **Preparing nodes and dices for job -** For each level each colour node token should be used and dice should be placed in the node tokens as shown in Figure 42, face number of dice indicates the operation time.

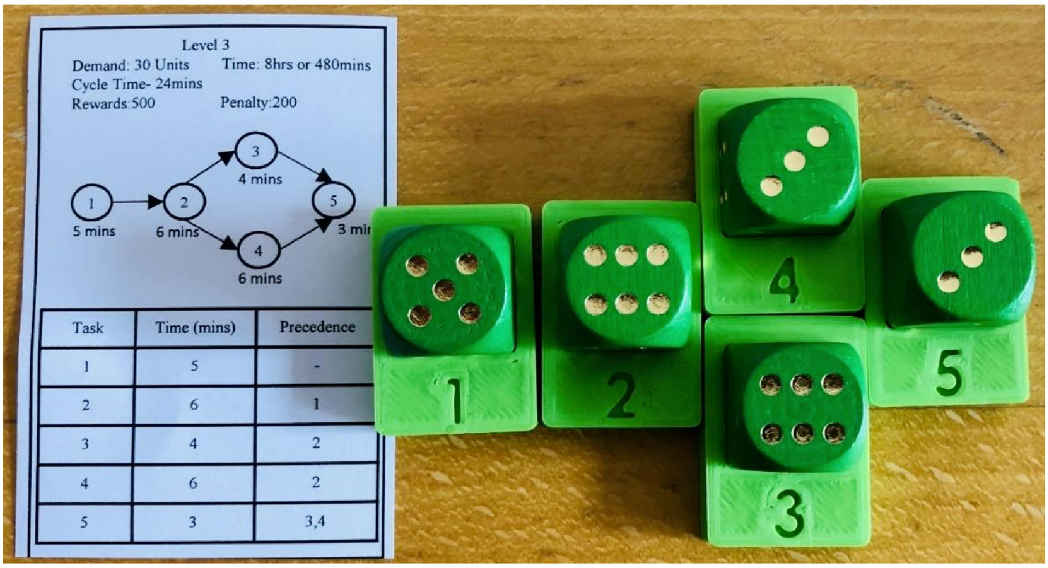


Figure 41: Preparation of node and dice [Source: Own]

6. **Line Balancing -** Try to balance the line by using takt time data. Operations should meet the takt time according to it try to balance the line. Use the colour dice and node token to balance the line, the face numbers in the dice represents the Time (Minutes) of the operation.
7. **Hiring workers and buying machines -** Look on the conditions on task cards and buy the machines and hire the workers using given points. And place workers tokens on activity sheet in the workstation where workstation cost 100points. Where, workstation is not a physical component it named in activity board as Station, to place the worker in station player have to buy station and station is fixed once workstation is bought it can be used for all the rounds. Machines can be placed in the node token next to the node number. Depends on requirement players can hire workers (Hiring worker= 100points) and machines (150 points) in between the game is allowed. Once machine is brought, they can be used for next rounds by paying maintenance cost and it can be shift to other operations by paying change or set up cost. For example, refer Figure 43, player is playing on 3rd round, in 3rd round player hired a worker, two machines and one work station are the investment.

$$Investment = cost\ of\ workers + cost\ of\ machines + cost\ of\ workstations \tag{32}$$

Investment= 100+300+100

Investment= 500 points

The remaining points of the 3rd round is 1200points after investment for 3rd round the remaining balance will be 700points.

$$Remaining\ balance = Budget - Investment \tag{33}$$

=1200-500

Remaining balance = 700 points

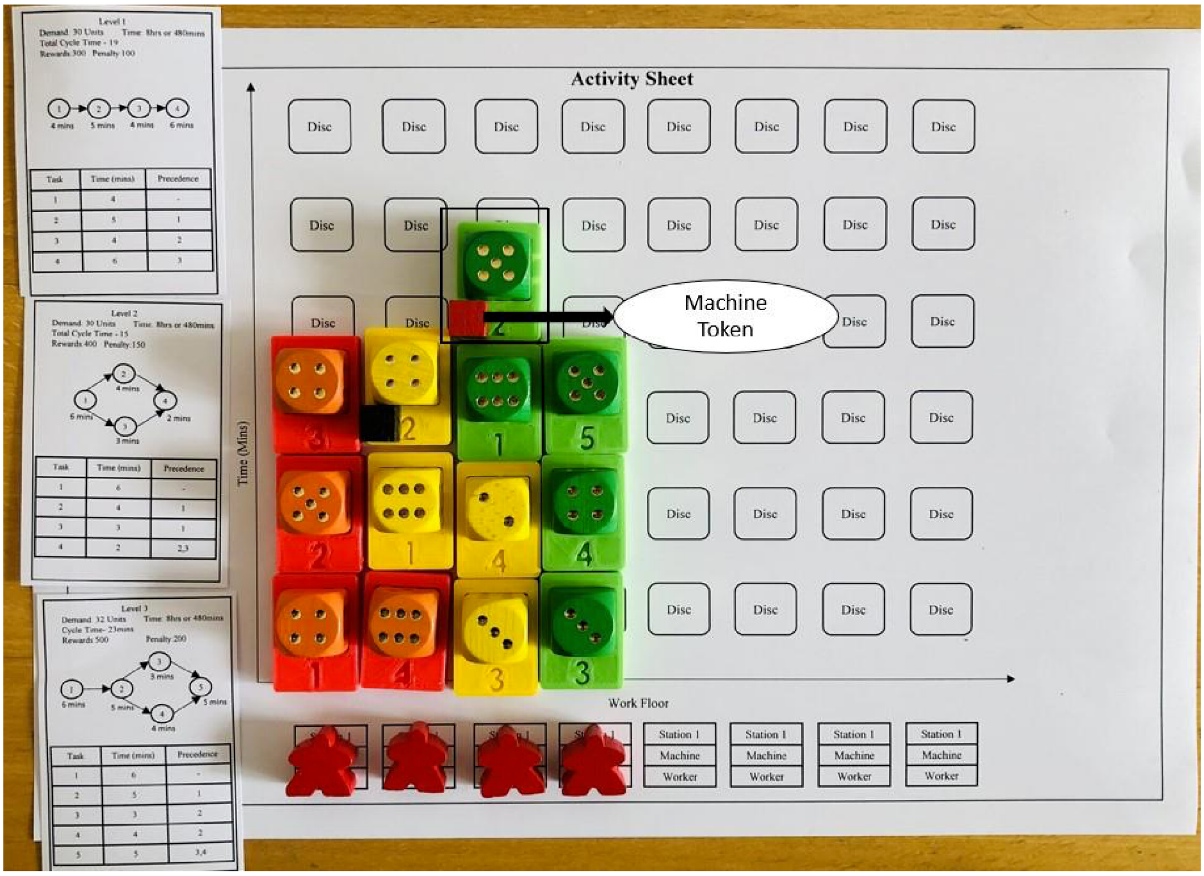


Figure 42: Machine Placement [Source: Own]

8. **Checking takt time with board -** Once balancing is done, check the takt time with the board, work station should not exceed the takt time and check the precedence. In group play, other players will check the balancing. If the takt time is not met, the player has to pay penalty as well as for the wrong precedence and exceed time limit.

9. **Calculate Efficiency -** Once line is balanced, Calculate the efficiency of the line on worksheet using the given formula and enter the results data in work sheet, depending on the efficiency of the line, bonus rewards will be provided at end of the game.
10. **Reward -** If balancing is successfully done. Collect the reward from the bank, the rewards points are mentioned in task cards. If played didn't balance the line, wrong precedence, exceeded time limit they have to pay the penalty which is mentioned in task cards as shown in Figure 44. When combining two levels together if task is fulfilled rewards will be cumulative of the task cards. And previous round machines and workers will be the operational expense. New workers, workstation and machines will be denoted as investment, the Figure 44 shows the example for operational expense and investment. For reward calculation example look at the Figure 44. Another player is playing the 3rd level,

in this case the level 3 didn't meet the takt time so player have to pay the penalty for level 3, remaining two levels are perfectly balanced. For calculating the reward, the remaining point for the 3rd round is 1200points.

$$Operational\ expense = cost\ of\ workers\ wages + cost\ of\ maintanence \tag{34}$$

= (4*100) + 0

Operational expense = 400 points

Reward points of 3rd round is cumulative of level 1, level 2 and level 3, but in this case, player have to pay penalty for level 3, so total reward will be 1000 points (300+400+500-200).

$$Reward\ points = (Level\ 1\ reward + level\ 2\ reward + level\ 3\ reward - level\ 3\ penalty) \tag{35}$$

= (300 + 400 + 500 – 200)

Reward points = 1000 points

At the end add budget and reward points together and subtract the investment and operational expense (1200+1000-350-300). At the end remaining balance in had will be 1450points.

$$Remaining\ balance = (Remaining\ points\ of\ previous\ round + Reward\ points - Investment - Operational\ Expense) \tag{36}$$

= (1200 + 1000 + 350 – 400)

Remaining balance = 1450 points

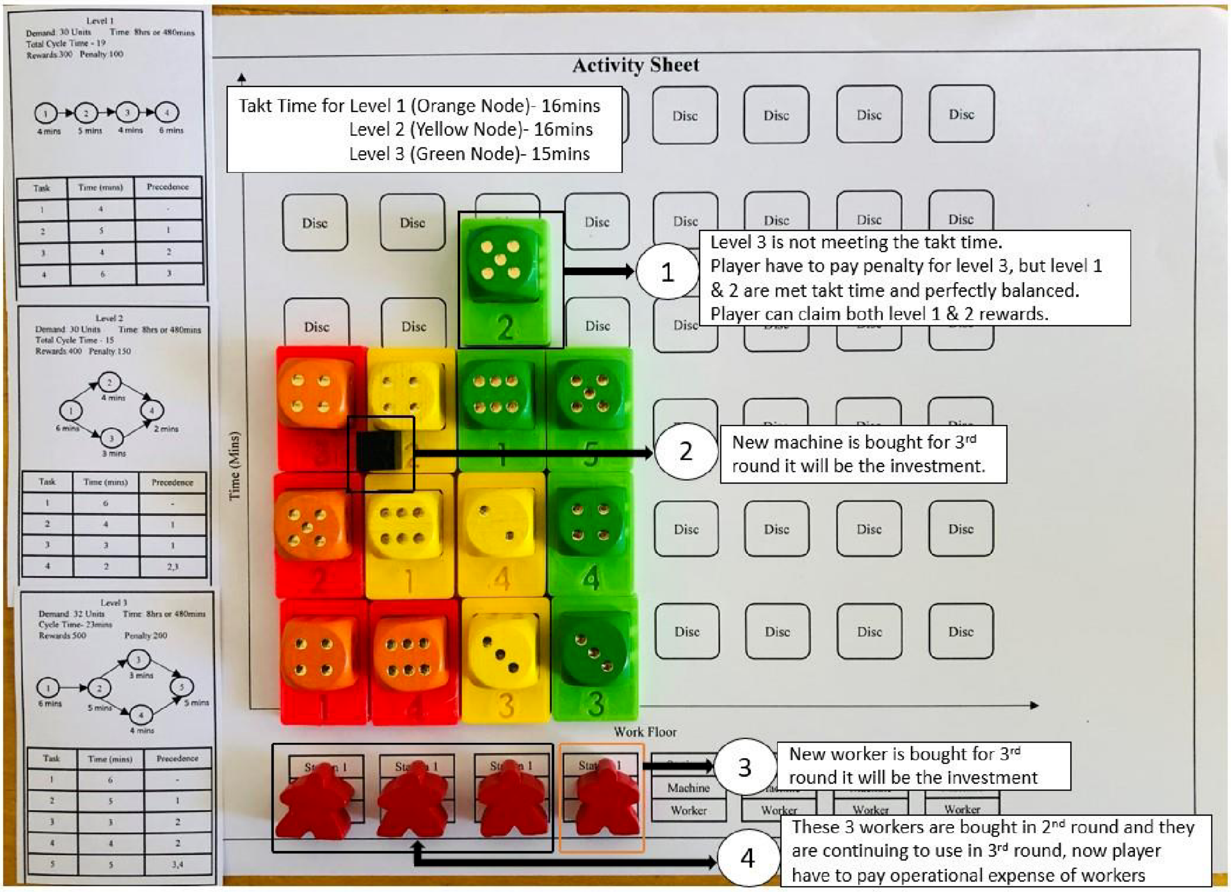


Figure 43: Reward Calculation [Source: Own]

11. **Worksheet data -** Enter the balance points in hand at the end of each round in work sheet and enter the all the results and data in worksheet.
12. **Next Round -** For next round draw the level 2 task cards from board and combine the both levels together but its players discission to combine levels together, if yes match the both the levels takt time together as shown in Figure 44 and repeat the same steps. If player combine two levels together, they will be rewarded for both the levels.

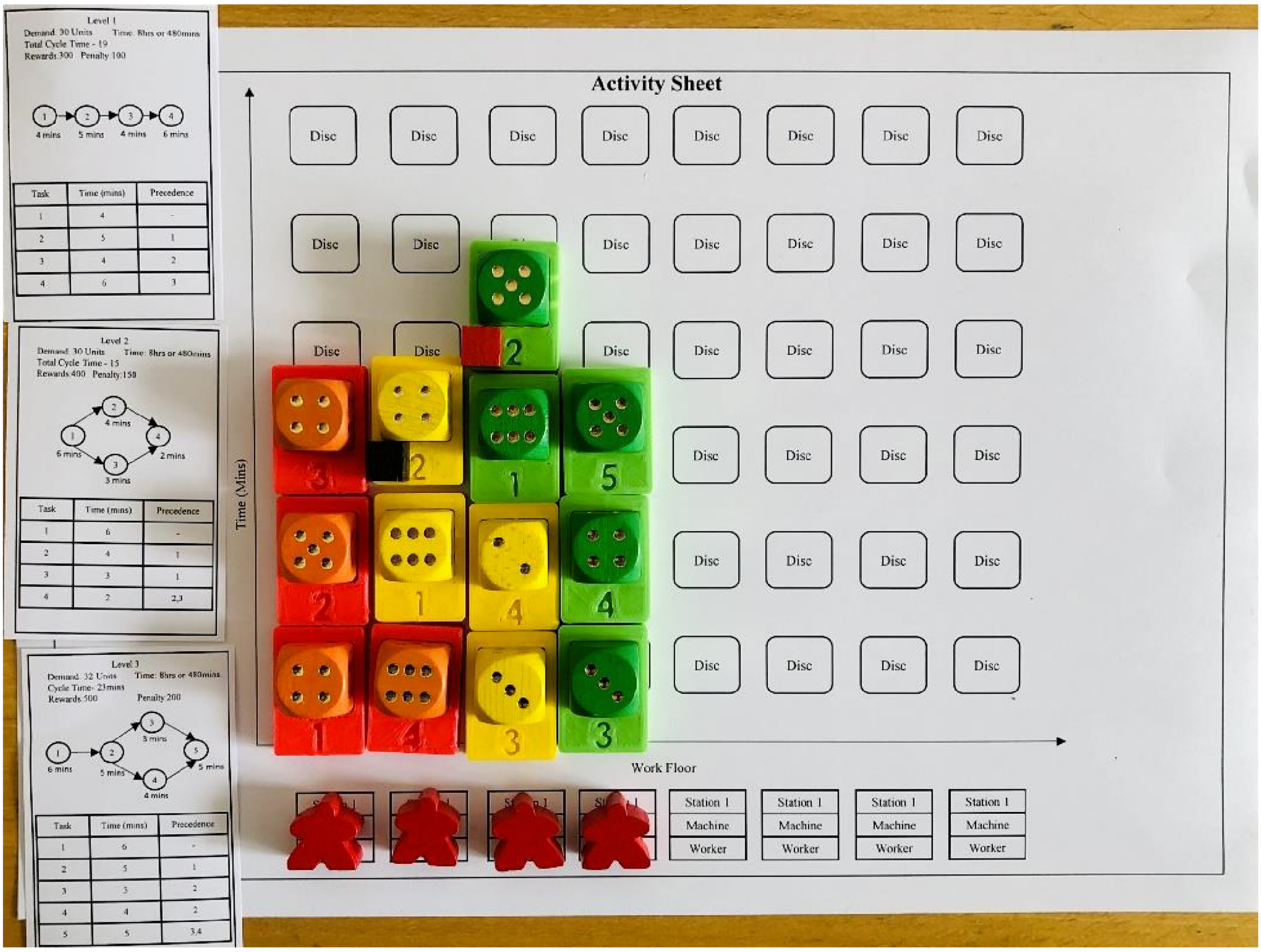


Figure 44: Combining three levels together [Source: Own]

13. Final rewards - At the end of the eight rounds calculate the remaining points in hand. And collect the bonus rewards of each round efficiency.

14. End of the game - Which player is having more points will be winner of the game.

The flow chart of the line balancing game explained in detail in (figure 46).

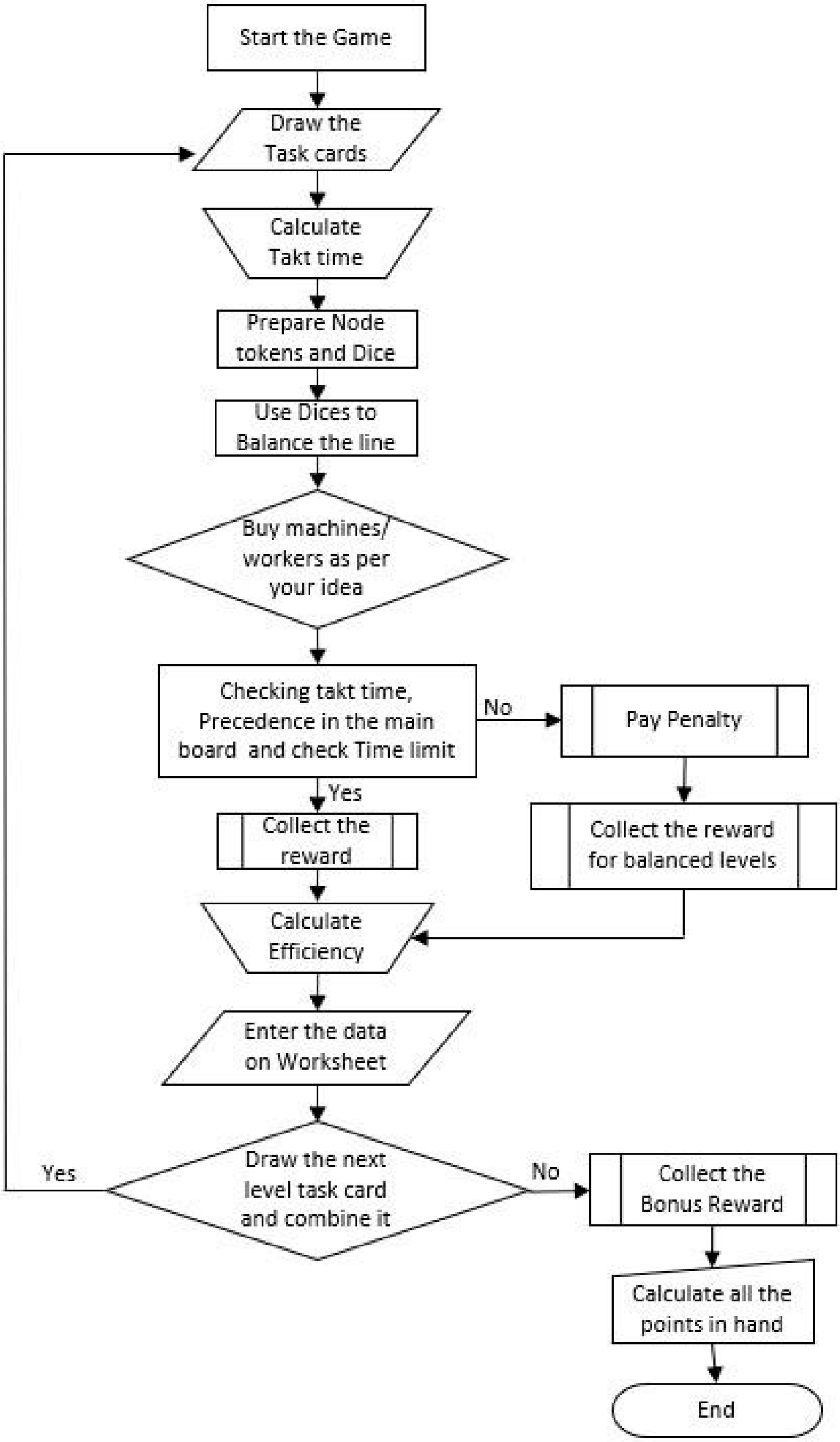


Figure 45: Game flow diagram [Source: Own]

5.4.4 Points and Rewards of the Game

The money tokens are used to purchase worker and Machines. The player acts as the banker. Reward money can be taken from the main board's money token deck, and money for paying fees and penalties should be stored in the main board's money deck. The points and rewards system are discussed below,

1) At beginning of game each player receives - 1000 points
2) Worker Cost - 100 points per Day
3) Machine Cost - 150 points
4) Change or setup cost of machine - 100 points (Changing of machine from operation to another)
5) Maintenance of machine – 50 points per day
6) Each level reward points will be written on the task cards.
7) Workstation Cost- 100 points
8) Bonus Rewards

   Efficiency:

   a. 96-100% - 500 points
   b. 91-95% - 400 points
   c. 81-90% - 300 points
   d. 71-80% - 200 points
   e. 51-70% - 100 points
   f. 0-50% - 50 points

5.4.5 Rules of the Game

1) Each task can have only one machine, where machine can reduce 1 min of actual cycle time of the work station.
2) Game play time is 120 minutes where each round has 10mins totally 80mins and for checking balancing and precedence 30 mins.
3) If task is not fulfilled or wrongly balanced or has incorrect precedence player have to pay penalty.
4) To use work station player, have to pay 100 points for each Workstation. Maximum 8 work stations can be used.
5) Each has 10mins time limit, if time exceeds 10mins played have to pay penalty.
6) Each level should have different colour node tokens.
7) Player can combine the levels together and can remove the levels as their wish.

6 Analysis of Education game

This chapter talks about the Game play analysis and economic analysis of line balancing game.

6.1 Play Analysis

The Line Balancing Game is a game that simulates the process of balancing an assembly line. This thesis explains how the game is played and why it can be helpful for people to understand how the concept works. The game that was created is a line balancing game that is based on the real-world process of assembly lines. The player's goal is to balance the assembly line so that it runs smoothly and efficiently. The player must put the correct number of workers on each station, and make sure that there are enough workers to keep the line moving. If the line gets backed up, it will cause problems for the rest of the factory. The game will be based on an assembly line where players will have to balance the flow of materials in order to avoid bottlenecks. By playing the game, people will be able to learn about the importance of line balancing and how it can improve efficiency in a production setting. The game is a good way to learn about how Line balancing in assembly lines work, and how to optimize them for maximum efficiency. The game is still in development, but it has the potential to be a valuable tool for people who want to learn about line balancing.

Line balancing game is played for 4 times for the testing it includes both solo play and group play. Over all five players played this game. Several rounds are played and each time the efficiency and expenses differ from player to player. At the start of the game players felt little difficult to understand the concept, after two levels players got better idea of playing. One of the players is proficient at board games and has a deeper understanding of industrial engineering. The game is played with various types of professionals. Another player had a background in industrial engineering, and both of them thought that the game was simpler in the early levels and a little more challenging later on. Two more players are from the textile engineering department, and they had some difficulties understanding the concept of line balance. The line balancing lecture is given to them as a result, and after they were okay with the concept, players felt comfortable playing the game.

When it comes to time management, there is a 10mins time restriction for each level, and in group play, there is a 3mins time limit for checking. Total time needed for group play to finish the game is 104mins. Each level has a 10mins time restriction for solo play. However, the length of time needed for testing for solo play varies depending on the player; we generally took 2mins. Total playing time for solo play is 96mins.

With playing experience in line balancing game is fun to lean. The effectiveness of learning games in the educational process is explicable in terms of our understanding of learning principles. The game provides the students a mental state that allows for optimum performance by activating all necessary cognitive functions required for that task. In this way, the student can learn more deeply and perform better academically. In addition, line balancing game specifically helps to improve problem-solving skills, strategic thinking and hand-eye coordination. All of these skills are important in the educational process. All of these benefits make learning games an excellent tool for educators to use in the classroom.

Advantages of the game:

- The game can help people to understand how assembly lines work.
- The game is based on a real-world process, so it can be helpful for people to understand how line balancing works in the real world.
- The game is a fun and interactive way to learn about line balancing.
- Can be used by multiple people at once.
- The game is a good way to teach people about process improvement and line balancing.
- The game can be used as a tool to help people understand the principles of Lean Manufacturing.
- The game can be played in a classroom or as a team-building exercise.

Disadvantages of the game:

- Some people may find the game is too challenging.
- Requires some understanding of line balancing before playing.
- Some people may find the game to be boring or not worth their time.
- The game may not be realistic enough for some people to understand how assembly lines work in the real world.
- Setting up the game is too long.
- Line balancing game can be time consuming.
- Possibilities of losing the components.

6.2 Economic Analysis

The topic covers the economic analysis of the line balancing game. The List of all the component is showed in Appendix D. The overall Expected manufacturing expenses per set of the line balancing game is shown in the table (Table 8) below and the cost of the individual components. In one set of line balancing game 4 players can play the game. The prices of the tokens are calculated by market value. The coloured dice, worker tokens and machine tokens are bought from online. The node tokens are designed and 3-D Printed in the Technical University of Liberec, the cost of the node tokens is calculated by material cost and labour cost. Each player will have 40pcs of coloured dice, 5 sets of node tokens (1 set = 10 node tokens). Node token Cost calculation is explained in Table 9. For companies and institutions seeking to adopt the concept of line balancing, the game is a wise investment.

Game Components for 4x Players				
Name	Material	Total no. of Pcs/box	Price/Piece (CZK)	Total Price (CZK)
Main Board	Paper	1	2	2
Activity Board	Paper	5	2	10
Work sheet	Paper	5	2	10
Coloured dice	Plastic	160	4.5	720
Worker Tokens	Wood	40	3	120
Machine Tokens	Wood	27	0.83	22.41
Task Cards	Paper	32	0.25	8
Money Tokens	Paper	150	0.16	24
Node Tokens	PLA	200	17	3400
Game Manual	Paper	1	2	2
Grand Total:				4318.41

Table 8: Expense List

(Note: There will be a master copy of Worksheet and Activity board, players have to make a photocopy of Worksheet and Activity board for further plays)

Name of filament	Plasty Mladeč PLA
Filament price [Kč]	399.00
Amount [Kg]	0.50
Used length for one token set (1-10) [m]	6.30
Material price of one Token set [Kč]	14.87
Printing time of one set [hod]	1.75
Printer hour price rate [Kč/hod]	50.00
Printing cost of one set [Kč]	87.50
Worker wage [Kč/hod]	200.00
Labour price [Kč]	66.00
Total set price [Kč]	168.37

Table 9: Node Token Cost Calculation

7 Conclusion

The objective of the thesis is to create a Simulation Game for production planning and design. The thesis has been divided into four parts, theoretical part, analyse part, design part and testing part.

The first part of the thesis starts with the literature review about production management, production planning, facility planning, education (serious) games and line balancing.

The second part is to analyse the literature review of production management, Production planning and facilities design, lean manufacturing techniques. Based on the analysis of research Lean manufacturing technique was chosen and furthermore, under the concept of cellular manufacturing system the line balancing concept was chosen. The Line balancing has three methods and the effectiveness of all three approaches are nearly identical, despite the fact that the steps are different for each, based on the three methods the second method largest candidate method is chosen specifically because it has simple gaming mechanics than the other two methods, which are thought to be more difficult.

The third part of the thesis deals with the design of a simulation game, in which the game mechanics, game design, key performance indicators of the game, and steps that must be taken to play the game are all explained in detail. Then a new simulation game has been designed, based on the line balancing concept for educating students.

The fourth part of this thesis deals with playing experience of the line balancing game. It is fun to lean. We can explain the usefulness of learning games in the educational process by using the concepts of learning. By engaging every thinking activity required for the task, the game puts the students in a mental state that allows for their best performance. The learner will be able to study more completely and do better in class this way. These abilities are all crucial for the educational process. Education games are a great tool for teachers to use in the classroom because of all these benefits.

The game that was created in this thesis is a simple but effective way for students to understand how the Line Balancing Concept works. The game is still in development, but it has the potential to be a valuable tool for people who want to learn about line balancing.

The game was successful in doing this, as it allowed players to see how different factors can impact the efficiency of an assembly line. By playing the game, students were able to learn about the importance of line balancing and how it can be used to improve productivity.

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Appendices Index

Appendix A - Mechanisms of Simulation Game

There are various Board game Mechanics listed below, but among them few of the board game has been taken and explained referring to BGG (Board Game Geek), since it is one of the famous online websites (https://boardgamegeek.com/)[39] for board games.

The following table represents the list of Board Game Mechanics:

Board Game Mechanics			
1	Acting	92	Action Drafting
2	Action Points	93	Action Queue
3	Action Retrieval	94	Action Timer
4	Action/Event	95	Advantage Token
5	Alliances	96	Area Majority / Influence
6	Area Movement	97	Area-Impulse
7	Auction/Bidding	98	Auction: Dexterity
8	Auction: Dutch	99	Auction: Dutch Priority
9	Auction: English	100	Auction: Fixed Placement
10	Auction: Once Around	101	Auction: Sealed Bid
11	Auction: Turn Order Until Pass	102	Automatic Resource Growth
12	Betting and Bluffing	103	Bias
13	Bingo	104	Bribery
14	Campaign / Battle Card Driven	105	Card Drafting
15	Card Play Conflict Resolution	106	Catch the Leader
16	Chaining	107	Chit-Pull System
17	Closed Economy Auction	108	Command Cards
18	Commodity Speculation	109	Communication Limits
19	Connections	110	Constrained Bidding
20	Contracts	111	Cooperative Game
21	Crayon Rail System	112	Critical Hits and Failures
22	Cube Tower	113	Deck Construction
23	Deck, Bag, and Pool Building	114	Deduction
24	Delayed Purchase	115	Dice Rolling
25	Die Icon Resolution	116	Different Dice Movement
26	Drafting	117	Elapsed Real Time Ending
27	Enclosure	118	End Game Bonuses
28	Events	119	Finale Ending
29	Flicking	120	Follow
30	Force Commitment	121	Grid Coverage
31	Grid Movement	122	Hand Management
32	Hexagon Grid	123	Hidden Movement

33	Hidden Roles	124	Hidden Victory Points
34	Highest-Lowest Scoring	125	Hot Potato
35	I Cut, You Choose	126	Impulse Movement
36	Income	127	Increase Value of Unchosen Resources
37	Induction	128	Interrupts
38	Investment	129	Kill Steal
39	King of the Hill	130	Ladder Climbing
40	Layering	131	Legacy Game
41	Line Drawing	132	Line of Sight
42	Loans	133	Lose a Turn
43	Mancala	134	Map Addition
44	Map Deformation	135	Map Reduction
45	Market	136	Matching
46	Measurement Movement	137	Melding and Splaying
47	Memory	138	Minimap Resolution
48	Modular Board	139	Move Through Deck
49	Movement Points	140	Movement Template
50	Moving Multiple Units	141	Multiple Maps
51	Multiple-Lot Auction	142	Narrative Choice / Paragraph
52	Negotiation	143	Network and Route Building
53	Once-Per-Game Abilities	144	Order Counters
54	Ownership	145	Paper-and-Pencil
55	Passed Action Token	146	Pattern Building
56	Pattern Movement	147	Pattern Recognition
57	Physical Removal	148	Pick-up and Deliver
58	Pieces as Map	149	Player Elimination
59	Player Judge	150	Point to Point Movement
60	Predictive Bid	151	Prisoner's Dilemma
61	Programmed Movement	152	Push Your Luck
62	Race	153	Random Production
63	Ratio / Combat Results Table	154	Re-rolling and Locking
64	Real-Time	155	Relative Movement
65	Resource to Move	156	Rock-Paper-Scissors
66	Role Playing	157	Roles with Asymmetric Information
67	Roll / Spin and Move	158	Rondel
68	Scenario / Mission / Campaign Game	159	Score-and-Reset Game
69	Secret Unit Deployment	160	Selection Order Bid
70	Semi-Cooperative Game	161	Set Collection
71	Simulation	162	Simultaneous Action Selection
72	Singing	163	Single Loser Game
73	Slide/Push	164	Solo / Solitaire Game
74	Speed Matching	165	Square Grid
75	Stacking and Balancing	166	Stat Check Resolution
76	Static Capture	167	Stock Holding

77	Storytelling	168	Sudden Death Ending
78	Take That	169	Targeted Clues
79	Team-Based Game	170	Tech Trees / Tech Tracks
80	Three-Dimensional Movement	171	Tile Placement
81	Time Track	172	Track Movement
82	Trading	173	Traitor Game
83	Trick-taking	174	Tug of War
84	Turn Order: Auction	175	Turn Order: Claim Action
85	Turn Order: Pass Order	176	Turn Order: Progressive
86	Turn Order: Random	177	Turn Order: Role Order
87	Turn Order: Stat-Based	178	Variable Phase Order
88	Variable Player Powers	179	Variable Set-up
89	Victory Points as a Resource	180	Voting
90	Worker Placement	181	Worker Placement with Dice Workers
91	Worker Placement, Different Worker Types	182	Zone of Control

Table 10: Board Game Mechanics[39]

Appendix B - Task Cards

All the level of task cards are presented here. Totally 32 cards for 4 players.

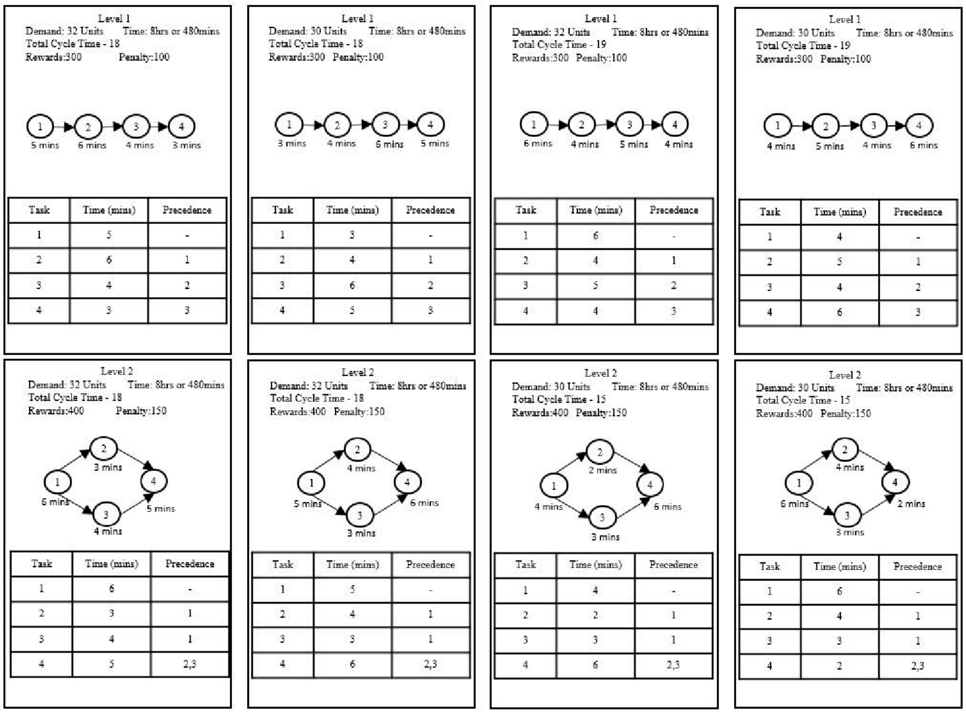


Figure 46: Task Cards [Source: Own]

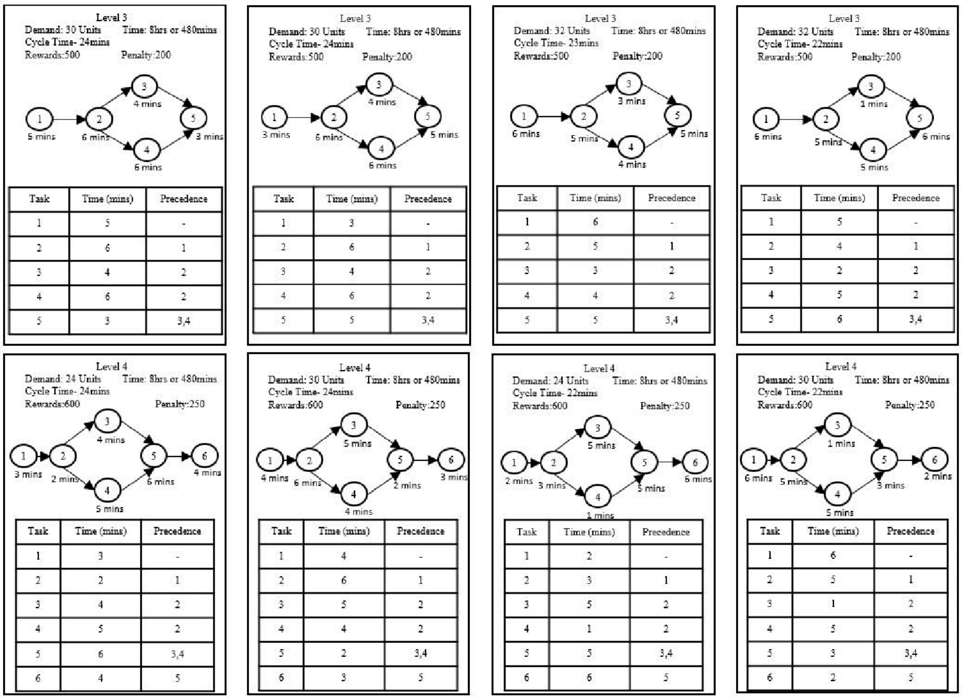


Figure 47: Task Cards [Source: Own]

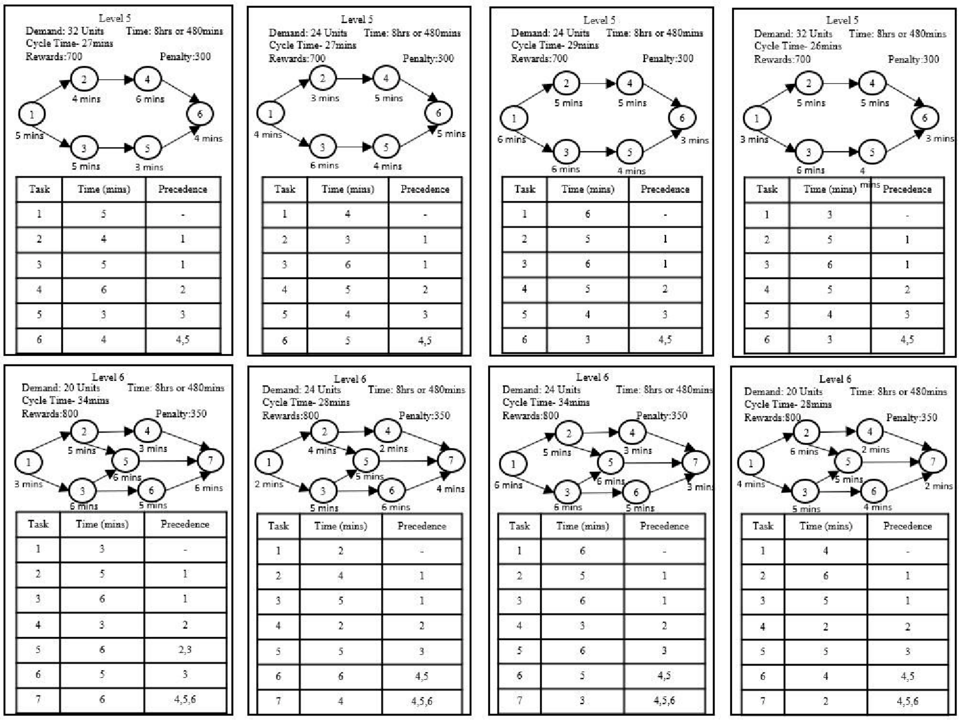
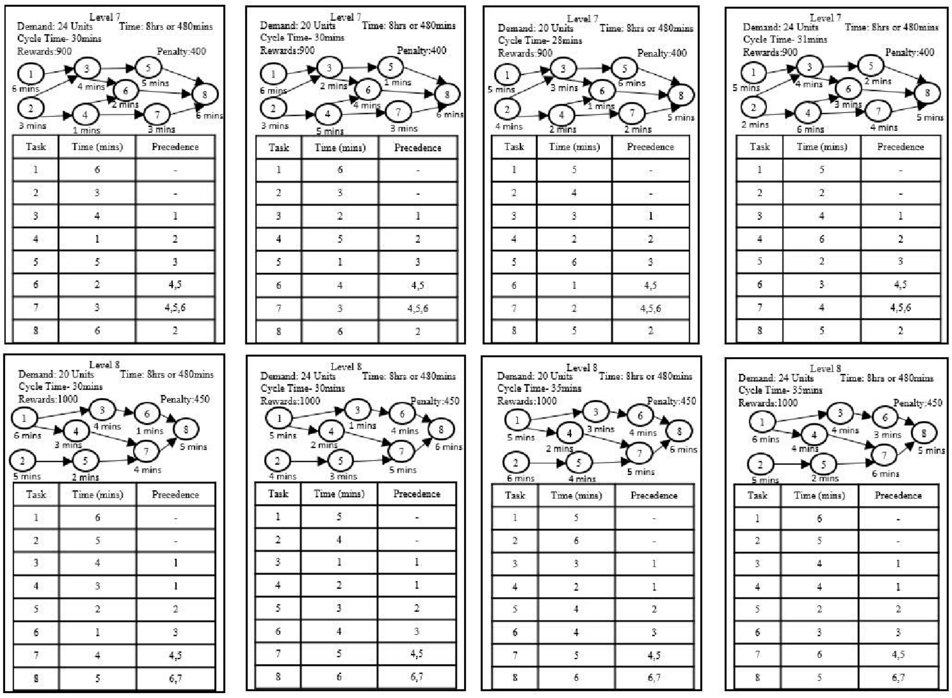


Figure 48: Task Cards [Source: Own]



Task	Time (mins)	Precedence
1	6	-
2	3	-
3	4	1
4	1	2
5	5	3
6	2	4,5
7	3	4,5,6
8	6	2

Task	Time (mins)	Precedence
1	6	-
2	3	-
3	2	1
4	5	2
5	1	3
6	4	4,5
7	3	4,5,6
8	6	2

Task	Time (mins)	Precedence
1	5	-
2	4	-
3	3	1
4	2	2
5	6	3
6	1	4,5
7	2	4,5,6
8	5	2

Task	Time (mins)	Precedence
1	5	-
2	2	-
3	4	1
4	6	2
5	2	3
6	3	4,5
7	4	4,5,6
8	5	2

Task	Time (mins)	Precedence
1	6	-
2	5	-
3	4	1
4	3	1
5	2	2
6	1	3
7	4	4,5
8	5	6,7

Task	Time (mins)	Precedence
1	5	-
2	4	-
3	1	1
4	2	1
5	3	2
6	4	3
7	5	4,5
8	6	6,7

Task	Time (mins)	Precedence
1	5	-
2	6	-
3	3	1
4	2	1
5	4	2
6	4	3
7	5	4,5
8	6	6,7

Task	Time (mins)	Precedence
1	6	-
2	5	-
3	4	1
4	4	1
5	2	2
6	3	3
7	6	4,5
8	5	6,7

Figure 49: Task Cards [Source: Own]

Appendix C - Main Board

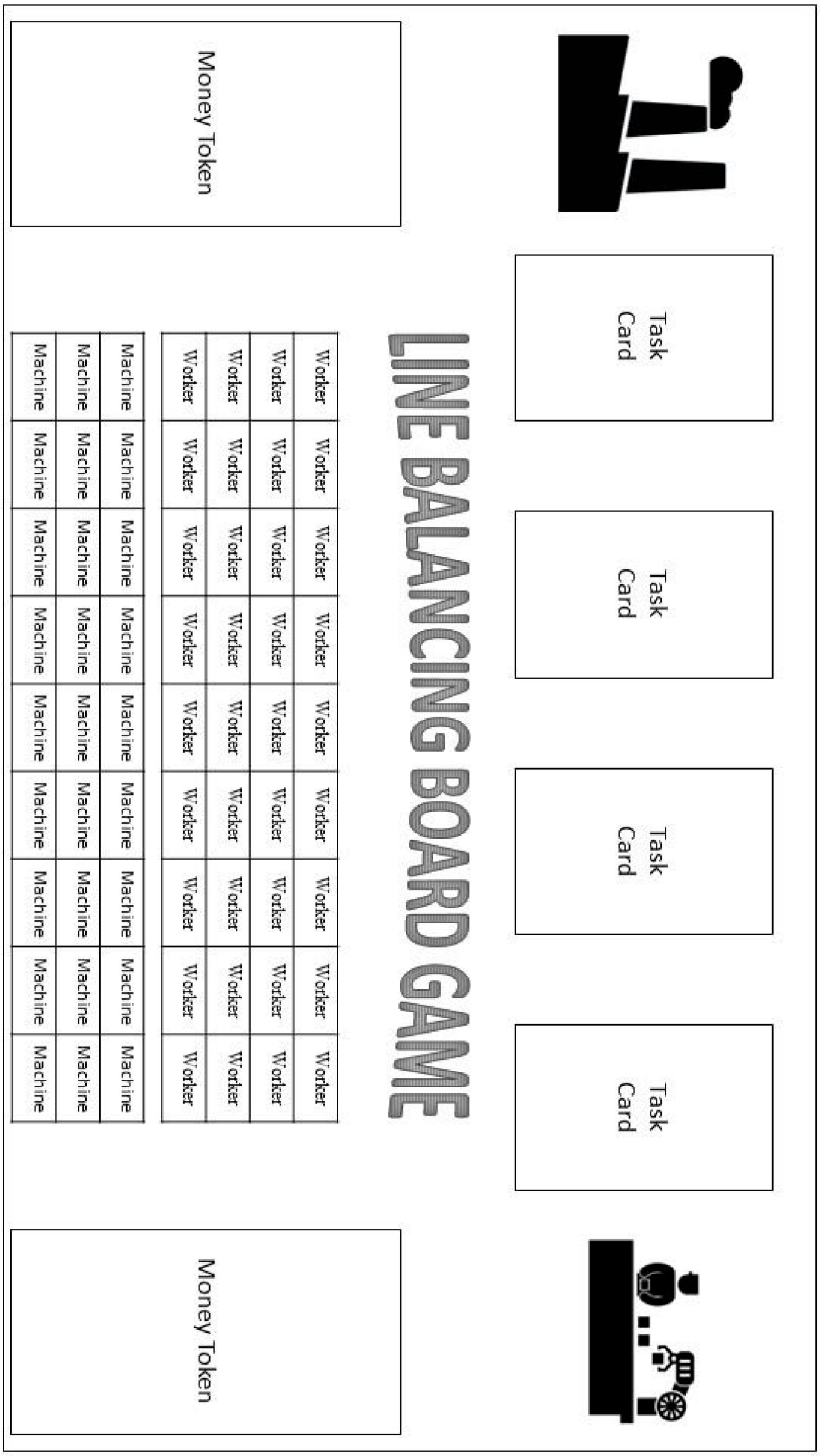


Figure 50: Main Board [Source: Own]

Appendix D - Activity Board

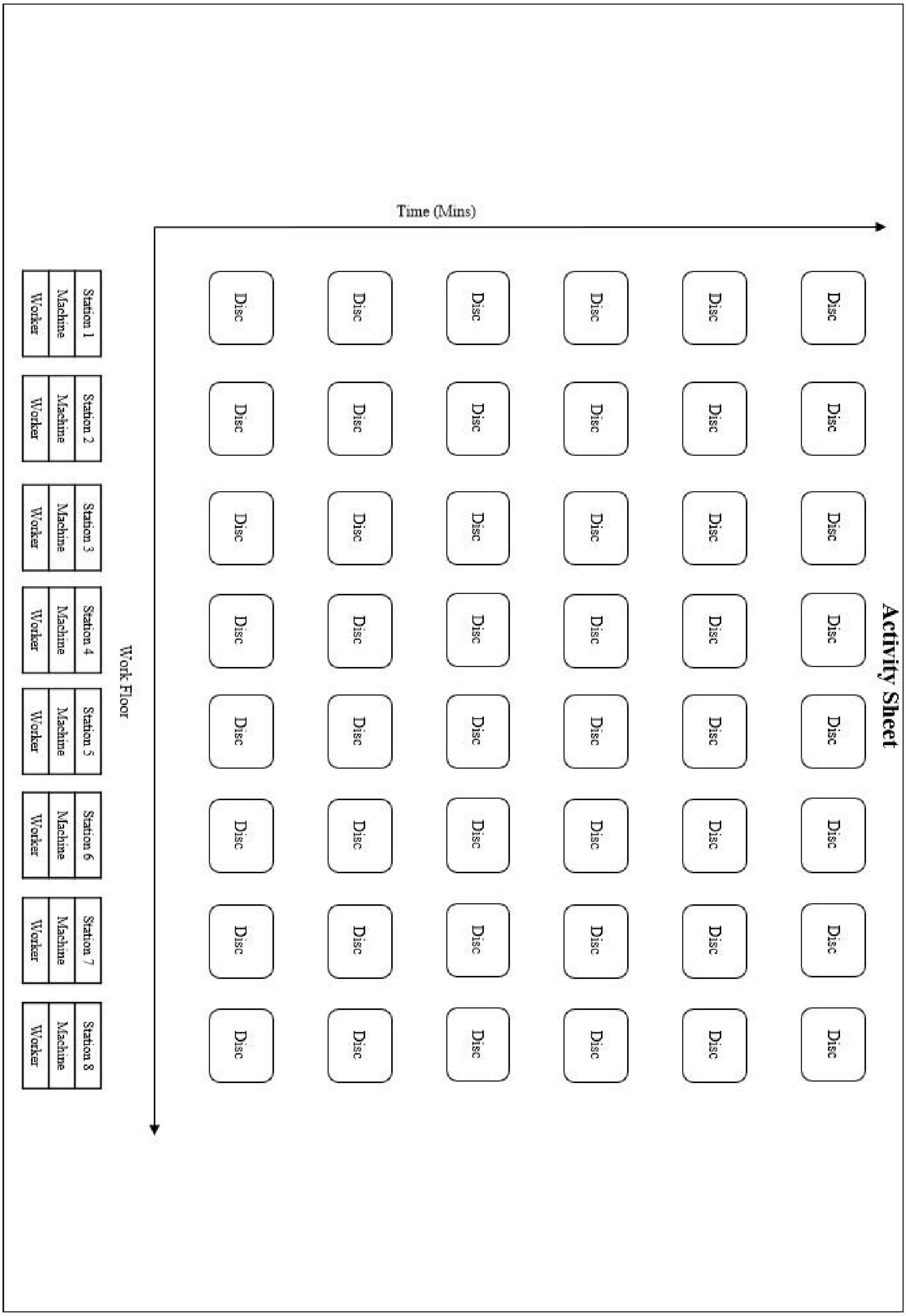


Figure 51: Activity Board [Source: Own]

Instruction
For 1- 4 Players
Age- 16+
Time – 90 minutes

Object
Understanding of Line Balancing concepts, Finding the bottleneck, balancing assembly line and increasing the efficiency of assembly line.

Contents
1 main board, 4 activity board, 4 set of Task cards(total 32 task cards), Worker Tokens, Machine Tokens, coloured dices, Money Tokens, Node Tokens, Worksheet.

Game Setup
1) Keep the Main board at the centre of the players.
2) Each player will get separate activity board and worksheet.
3) Arrange the 4 set of task cards in descending order from Level 8 to 1 and keep the cards upside down on the task card area in main board. Each player will receive 5 sets of node tokens (1 set = 10 node tokens) and 40 dices. Place the worker tokens, machine tokens and Money tokens in the Main board to their respective places.
4) At the start of the game each player will receives 1000 points from bank and remaining money should be kept near the main board.
5) At the end of each round players can collect the money from that money.
6) Game time starts once the last player picked the task card from the deck.
7) For measuring time, players can use mobile phone or stop watch.

Points System
1. At beginning of game each player receives- 1000 points
2. Worker Cost- 100 points per Day
3. Machine Cost- 150 points
4. Change or setup cost of machine - 100 points (Changing of machine from operation to another)
5. Maintenance of machine – 50 points per day
6. Workstation Cost- 100 points
7. Bonus Reward
   - 96-100% - 500 points
   - 91-95% - 400 points
   - 81-90% - 300 points
   - 71-80% - 200 points
   - 51-70% - 100 points
   - 0-50% - 50 points

Rules of the game
1) Each task can have only one machine, where machine can reduce 1 min of actual cycle time of the work station.
2) Game play time is 120 minutes where each round has 10mins totally 80mins and for checking balancing and precedence 30 mins.
3) If task is not fulfilled or wrongly balanced or has incorrect precedence player have to pay penalty.
4) To use work station player have to pay 100 points for each Workstation. Maximum 8 work stations can be used.
5) Each has 10mins time limit, if time exceeds 10mins played have to pay penalty.
6) Each level should have different colour node tokens.
7) Player can combine the levels together and can remove the levels as their wish.

Game Play
1) The younger player goes first and the task card once chosen, players should follow the selected deck for next levels. Draw the Task cards from the Task cards deck.
2) Game time starts once player picked the task card from the deck. For measuring time, players can use mobile phone or stop watch.
3) Calculate the Takt time Using given formula (Use phone or calculator for calculating) (paper and pen is used for writing the results)
4) Use the dice and node token to balance the line. For example, using dice face numbers, you can set the operation time in secs and can use multiple dice and Node token represents each operation.
5) Buy workers and machines as per the requirement of the task.
6) Balance the line till Task is fulfilled.
7) Once balancing is done, check the takt time with the board, work station should not exceed the takt time and check the precedence. In group play, other players will check the balancing.
8) Once task is fulfilled calculate the Line balance efficiency (formula given) depend on the percentage of the results bonus rewards will be given at end of the game. enter the all the results and data in worksheet.
9) Once round one is finished, the player can either advance to second round.
10) Collect the reward points.
11) Draw the next level task card, its player discission to combine the both task cards together. If player combine two levels together, they will be rewarded for both the levels.
12) Use the reward points and balance points for the next round.
13) Repeat the same steps as carried out in round 1. (In round 2 difficulty of the game is increased).
14) Note down the data in worksheet.
15) Collect the bonus rewards for the efficiency of each level at the end.
16) At the end of the game calculate the remaining points in hand and compare the points with the other players.
17) Player with the highest remaining points is the winner of the game.

Figure 52: User Manual [Source: Own]

Appendix F - List of all the Component

List of components	
Name of the components	Total no. of Pcs/box
Main Board	1
Activity Board	5
Work sheet	5
Blue dice	25
Yellow Dice	25
Green Dice	25
Red Dice	25
Orange Dice	25
Violet Dice	35
Red Worker Token	10
Black Worker Token	10
Yellow Worker Token	10
Blue Worker Token	10
Red Machine Token	10
Black Machine Token	10
Yellow Machine Token	10
Blue Machine Token	10
Task Cards Level 1	4
Task Cards Level 2	4
Task Cards Level 3	4
Task Cards Level 4	4
Task Cards Level 5	4
Task Cards Level 6	4
Task Cards Level 7	4
Task Cards Level 8	4
50 Money Tokens	48
100 Money Tokens	48
500 Money Tokens	48
1000 Money tokens	12
Yellow Node Tokens	20
White Node Tokens	20
Green Node Tokens	20
Blue Node Tokens	20
Red Node Tokens	20
Orange Node Tokens	20
Black Node Tokens	40
Gray Node Tokens	40

Table 11: List of each Component

Appendix G - Design of Node

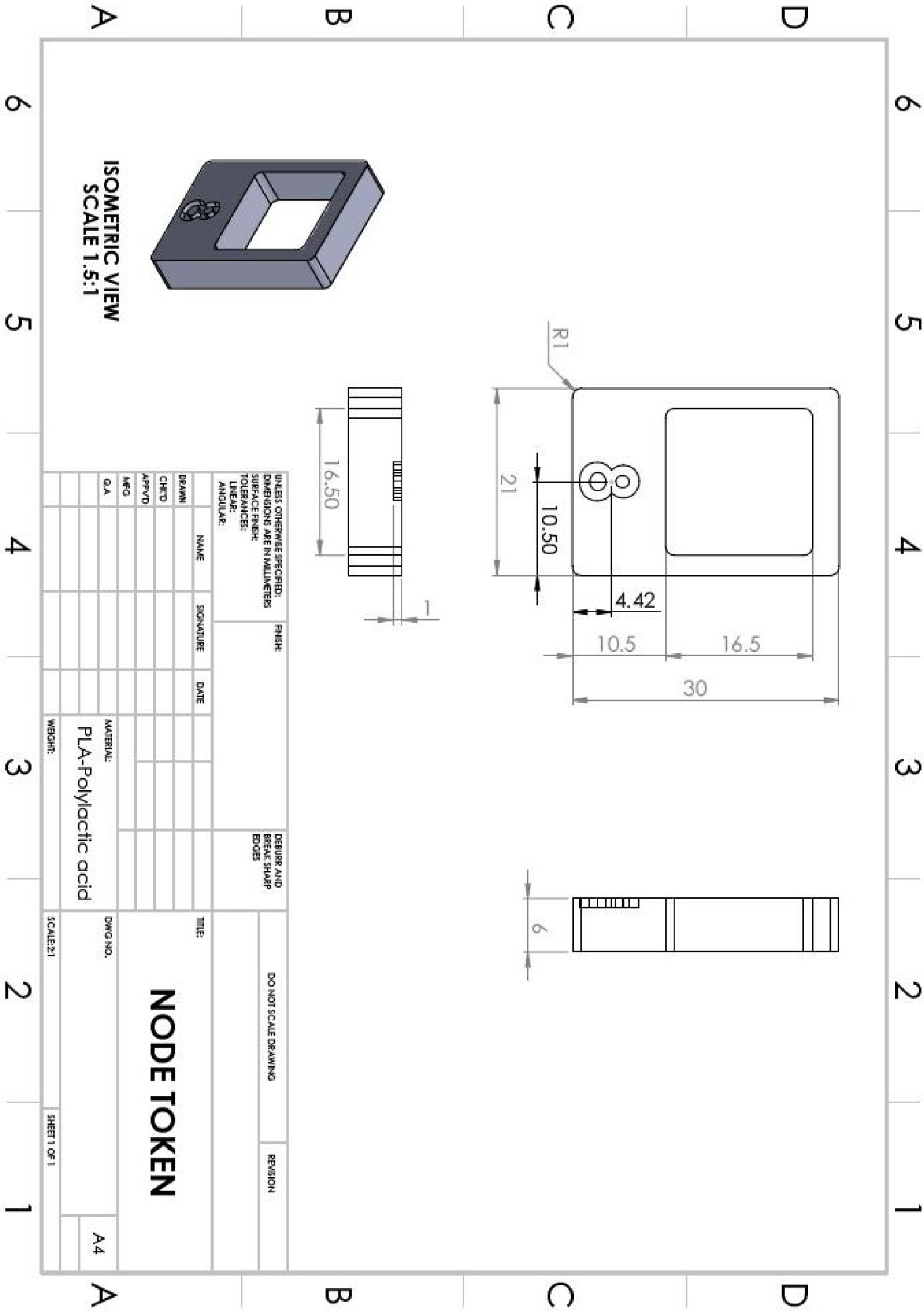


Figure 53: Design of Node [Source: Own]

Appendix H - Money Tokens

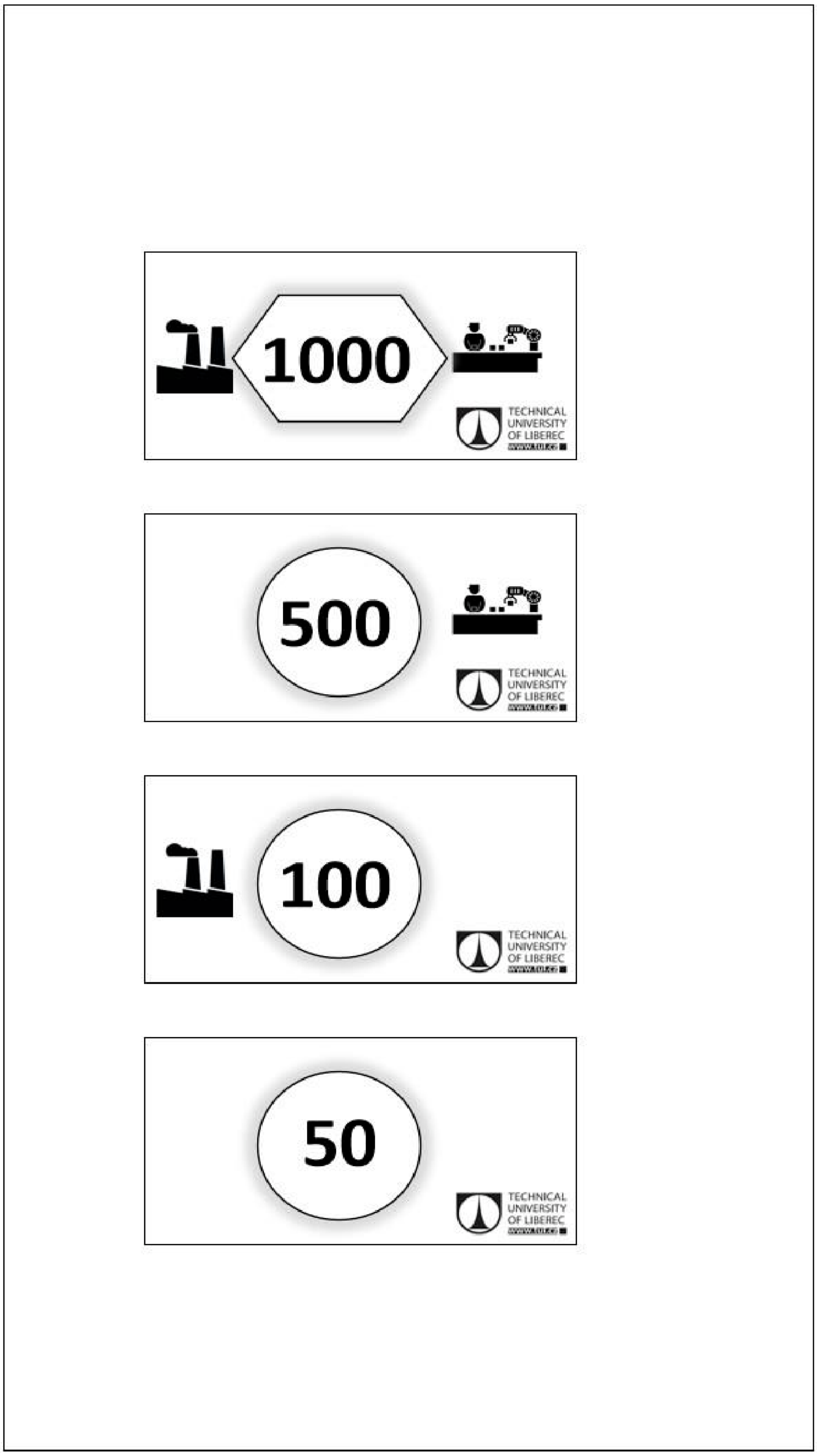


Figure 54: Money Tokens [Source: Own]

Appendix I - Worksheet

Work Sheet

Takt time and efficiency Calculation		
Level	Takt Time	Efficiency

Work station Time										
No. of Round	Node colour	no. of levels	1	2	3	4	5	6	7	8

Expense Calculation						
No of round	No of workstation	Price per w/s	Total	No of machine	Price per machine	Total

Points Calculation							
No of round	Budget	Investment	Operational Expense	Total	Reward	Profit	Current Balance

CALCULATION

1. $Takt\ Time = \frac{Production\ time}{Customer\ Demand}$

2. $BE = \frac{Total\ Work\ Station\ Time}{n * Highest\ process\ time} * 100\%$

which:

n= Number of work stations

Largest Candidate Rule method

Step 1: Calculate Takt time

Step 2: In general, the strategy is to use a rule that assigns tasks that either have a large number of followers or are long in duration because they effectively limit the balance that can be achieved. The following is our primary rule in this case. Prioritize tasks in the order of the greatest number of subsequent tasks

Step 3: To assign the elements to the first station, start at the top of the task and so on. A feasible element is on which satisfies the precedence requirements. Thus, the sum of the task time of all elements at that station should not exceed the cycle time.

Step 4: Use colour dice and node token for balance the line in the activity board.

Step 5: Calculate Balance efficiency.

Figure 55: Worksheet [Source: Own]