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THESIS – BACHELOR'S DEGREE PROGRAMME
TECHNOLOGY, COMMUNICATION AND TRANSPORT

LAYOUT PLANNING

Hanza Toolfac Oy

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SAVONIA UNIVERSITY OF APPLIED SCIENCES

THESIS
Abstract

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Abstract

The client, Hanza Toolfac Oy, was looking for a new orientation of the equipment layout for the expansion project. The purposes of this project were to improve the production efficiency and the capacity. To reach the purposes, the planning of interior material transportation was assigned to the author. This thesis presents this planning activity.

The thesis followed the process of SLP, Systematic Layout Planning, to generate a resilient layout. Before the SLP, the selecting process of the software tool was followed by the method of MCDA, Multiple Criteria Decision Analysis.

The thesis result showed the current material transportation distance and its optimisation based on the current facility. The expansion part of the project was excluded due to the thesis schedule.

Keywords

Multiple Criteria Decision Analysis. Systematic Layout Planning.

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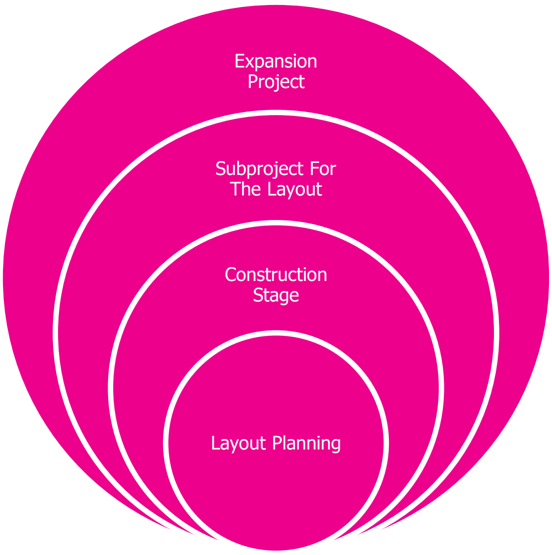
1 INTRODUCTION

In the February of 2022, the author had been assigned to work on the expansion project with the Hanza Toolfac Oy. This project was aiming at improving the production capacity and efficiency of the plant by integrating the service building and blank areas in between with the optimized equipment layout. The project time was from the end of 2021 until the June of 2023. From the assigning date, the author worked as a specialist for the planning of equipment which is under the supervision of the cluster president of Hanza Toolfac Oy. The agreement between the school and the author set the due date of the thesis at the beginning of May in 2022. The schedule for the project was not match with the thesis agreement. Therefore, this thesis describes the unreached part with the example to demonstrate the future intention on this planning activity from the chapter 3.2.9.

The background of the project described the current layout had been out of date since 2019. The plant upgraded the machines and introduced new products yearly. With the increasing orders, the machines were squeezed in the same area which was designed for smaller production rate. Another pressure came from those newly arrived machines which also required the room for their installations. The company was pushing the limit of the capacity until the end of 2021. After months of discussions, most of problems were settled. The construction company already offered a sufficient design to the cluster president and waited for the further confirmation. The thesis started when the facility was defined. In this stage, the company needed an optimized arrangement of the equipment which would base on current production routes. Therefore, the layout planning was a subproject to the expansion project. To demonstrate the whole picture of this subproject, the thesis presents from the view of the subproject to the construction stage inside it. Then, it describes the layout planning activity within this stage.



Before the official planning started, the company also requested the need of selecting a software for the use of planning. The detail of the software selection is introduced in chapter 2. Names of the software are not mentioned in this thesis for the protection of the company and suppliers. The thesis documented the process of ranking and selecting them, but the procurement process was done through the company's bureaucracy process. This process is not mentioned.

2 SOFTWARE SELECTION

2.1 Multiple Criteria Decision Analysis

In Multiple Criteria Decision Analysis, MCDA, a procedural approach (Figure 1) creates a reliable and logical selection in the end. According to the situation, some steps in the process can be omitted.

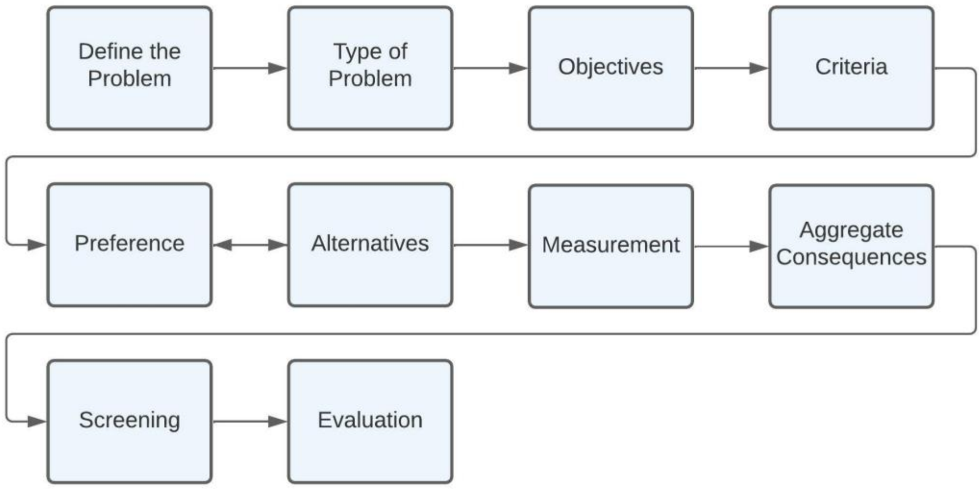


Figure 1. Multiple Criteria Decision Analysis Process. (Huang,2022)

From the beginning, defining the problem sets the direction for the Decision Maker, DM. This step provides background information and reconfirms the result in the end. According to the problem, there are three basic types of problem MCDA applies on (Chen et al, 2008):

- Choosing the best
- Sorting into groups
- Ranking alternatives

Different types of problems generate unique targets which needed special methods to solve. Then objects or factors bases on the problem shall be created under either brainstorming or applying standards. With the list of objects, further categorising them into criteria, which will be the first component of the analysis. There are two kinds of preference methods (Kao, 2009):

- The Priori Weights
- The Posteriori Weights

The application is based on whether there are predefined requirements or preferences before the measurement. The Posteriori Weights focuses on owning data first then reflecting the importance on the criteria in the end. But the Priori Weights influences the criteria bases on DM's decision or client's preference. When gathering knowledge from alternatives, DM usually know more details afterward. It is possible to modify criteria and preferences during the knowledge gathering. When the possible candidates, alternatives, are listed, the second component of the analysis is ready. With those two components, DM can start doing the measurement and receive consequences, resultant value. In the measurement, it is recommended to define the formulated assessment method to make calculated value reliable in each criterion. After the value is collected, the DM needs to aggregate the consequences to understand the overall performance on each alternative. The method to aggregate can be defined along with the preference. In case there are multiple alternatives, screening techniques (Figure 2) were introduced, such as Pareto Optimality (Figure 3). Under suitable number of alternatives, evaluation technique, such as Data Envelopment Analysis and the Sensitivity Analysis (Dulmin & Mininno, 2003), are applied according to the situation.

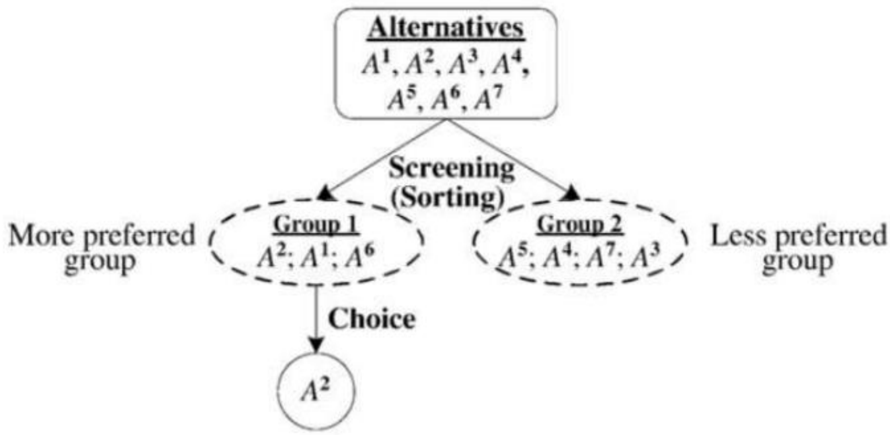


Figure 2. Screening Theory. (Chen et al,2008)

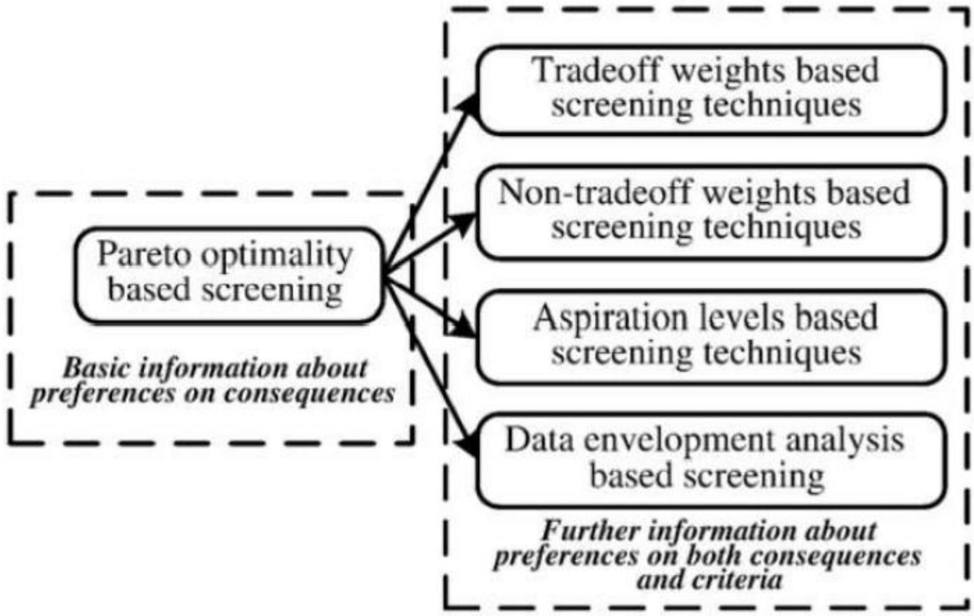


Figure 3. Screening Method. (Chen et al, 2008)

2.2 Application of MCDA

2.2.1 Defining the problem:

Selecting a proper layout planning software was required for the current project. The main target was the optimisation of transportation, such as material flow. Other functions were advantages but not necessary. One important factor was to reduce the time of training.

2.2.2 Type of problem:

This problem was related as choosing-the-best problem. Ranking result was required.

2.2.3 Objects:

The following items were chosen as the objects.

Software provider side included:

- The price
- Trainings
- Customer supports
- Backgrounds of providers

Necessary features on the software included:

- A friendly interface
- An intuitive operation principle
- The material flow analysis
- The diagram presentation
- The layout presents in 3D models
- The layout presents in 2D drawing
- The compatibility of other file types
- A sufficient model library
- A lower or medium hardware requirement
- A sufficient cost

Additional features included:

- The real-time animation
- The communication between hardware (Such as PLC)
- The digital twin simulation (Monitoring)
- Other statistical analyses
- Some high-quality 3D models

Project requirements included:

- A fast implementation
- Quick responses from supplier
- A long-term application of the software
- A balance between performance and price for a multi-user environment

- An easy application on problems
- Clear documents from the analysis

2.2.4 Criteria

After the objects were categorised, they could be listed as the following.

- The balance of price
- A reliable customer supports
- Sufficient training methods
- A user-friendly design (on both the implementation and the operation)
- Functions (Such as conversion between 2D and 3D)
- The hardware requirement
- Basic analyses
- Advance analyses
- The simulation and the control
- The compatibility
- Result presentations

The provider information was not weighted as a supplemental information.

2.2.5 Preference

The preference methods can be hierarchical (different levels) or/and sectional (same level). The thesis first divided the objects into two sections, the required one and the additional one. Then, the lower hierarchies were defined afterward. (Figure 4).

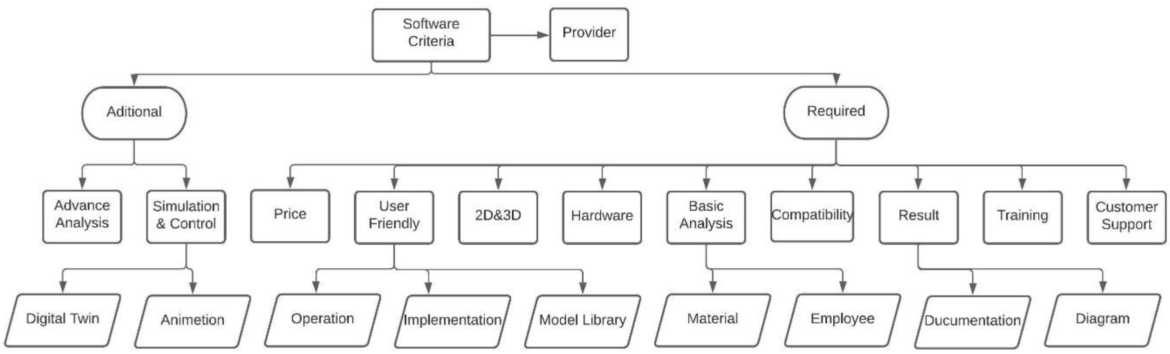


Figure 4. The first step of the preference. (Huang, 2022)

After the set of relations, the second step was to give weights. The project requirements were clear, so the author used priori weight into the analysis.

2.2.5.1 The weighting method

1. Additional and required sections were discussed separately.
2. Dividing the 100 by 9 (Sections) equals to 11.11.
3. Distributing 11.11 value into the Required sections.
4. Balancing weights according to the importance in the same level.
5. With the received weights, the DM further distributing them into the lower-level criteria according to the 4th step.

2.2.5.2 The result

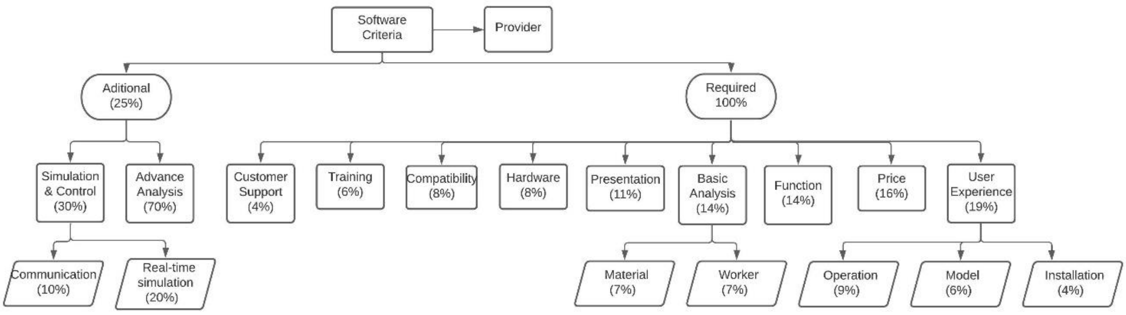


Figure 5. the second step of the preference. (Huang, 2022)

The calculation of the final value was based on the Formula 1:

$$V_f(A^i) = \sum W_j * V_j(A^i) \qquad (1)$$

The $V_f(A^i)$ denotes to the final value of the ith alternative. Then Wj is the weight of jth criterion. And $Vj(A^i)$ equals to the consequence of ith alternative in jth criterion. The value defined method was based on ranking. For example, when the alternative 1 dominated the other four alternatives, it received a consequence as 5. Then the second best in the example would receive 4, and so on. The software could receive a lower value, if there were multiple software with same consequences and dominated it, such as the consequence 3 was given when there were two 5 before.

2.2.6 Alternatives

The selected alternatives were:

1. Visu************
2. Vis*****
3. Factor**************
4. Tecn******
5. Fle****

2.2.7 Measurement and final aggregated value

Table 1. Software MCDA result. (Jun-Yuan, 2022)

MCDA Analysis (Jun-Yuan Huang, 2022) Layout Planning Software		Product		Visu******** ****	Vis*****	Fac-tor**********	Tecn******	Fle****
		Provider		Visu*********** Oy	Pl**** GmbH	Auto**** Inc	Tecno***** Technologies Ltd	Flex**** Soft-ware Products,
Criteria		Weight	Fee	33,600 €/Year	5,028 €/Year	5,710 €/Year	Unknown	38,000€/Perma-nent
User Experience	Model	6%		5	3	5	1	2
	Installation	4%		3	5	2	2	5
	Operation	9%		3	5	1	4	3
Price		16%		2	5	5	Unknown	3
Function		14%		5	3	5	2	2
Basic Analysis	Worker	7%		3	5	1	4	3
	Material	7%		1	5	4	3	2
Presentation		11%		1	5	4	4	2
Hardware		8%		1	5	5	3	3
Compatibility		8%		4	4	5	1	2
Training		6%		5	2	5	1	3
Customer Support		4%		5	2	2	3	5
Basic Value				3	4.22	3.94	2.21	2.61
Advance Analysis		70%		3	0	2	5	5
Simulation Control	Real-rime simu-	20%		5	0	0	4	4
	Communication	10%		5	0	2	4	3
Additional Value				0.9	0	0.4	1.175	1.15
Final Value (Basic Value+ 0.25*Additional Value)				**3.9**	**4.22**	**4.34**	**3.865**	**3.76**

The evaluation of the criteria focused on current project-layout delivery, the basic section, and the future application for optimisation, the additional section. The weight for the total additional value was based on the Formula 2:

$$W_{T_a} = \frac{100\%}{C_b} * C_a \qquad (2)$$

Inside the formula, C_b denotes the number of criteria in the basic section, and C_a indicates the number of criteria in additional section. This weight balanced the influence of the additional value in the final value.

2.2.8 Explaining the criteria

2.2.8.1 User Experience:

From what was interpreted in the meetings; the target of the software was to support agile application. Therefore, designs of software were evaluated here. There were three criteria. The model criterion indicated the availability of model libraries and the easiness to apply customised models into the software. The installation criterion meant the consumed energy and time to implement it into personal devices. The operation criterion showed whether this software had intuitive design when operating it. These criteria would shorten the time of layout planning.

2.2.8.2 Price:

There were many packages to choose in the market. The condition was considered between the price of two licences for a year and its influence on this project.

2.2.8.3 Function:

The function criterion focused on how sufficient the software would be in generating the plan for the project, such as switch between 2D and 3D layout.

2.2.8.4 Basic analysis:

Inside layout planning, many parameters are evaluated to fit and test different scenarios. For this project, the material flows and worker traveling distances were the main parameters to optimise. For both criteria, it was better if it was simpler to create analyses with more details in the result.

2.2.8.5 Presentation:

After the software calculation, how interpretable it presented its result was evaluated here. For example: A material flow was presented with a spaghetti diagram or a clear data sheet.

2.2.8.6 Hardware:

The requirement of the hardware to run this software smoothly was evaluated, especially, when it was under heavy calculation.

2.2.8.7 Compatibility

The compatibility criterion was evaluated and based on the transferability between this software and the company-owned software, such as the input of SolidWorks files.

2.2.8.8 Training

The materials of training could be offered by the suppliers or from the other parties. This criterion evaluated the materials from all sources. The consideration included the range of training, the availability without payment, and clarity of materials.

2.2.8.9 Customer Support

The author contacted the supplier during the analysing period. The consequences were decided based on the experience and the responsiveness from the suppliers.

2.2.8.10 Advance Analysis

This criterion was an additional evaluation, which means it didn’t affect the current project, but it might have future impact on the strategy of the company. Some analyses, such as the failure impact and the production statistic, would be influential to optimise layout in the future.

2.2.8.11 Simulation Control

If the layout planning software could use the finalised layout for monitoring efficiency and communicating with the real floor after the planning phase, the layout would be more interconnected with the production strategy. There were two criteria, the real-time simulation and the communication, to evaluate this advanced feature in the software. They were also additional evaluations.

2.2.9 Screening

The screening activity is used for eliminating undesired candidates systematically. According to situations, suitable applications usually contain large number of candidates. For example, selecting 3 out of 100 candidates for the purpose. The analysis only included 5 candidates; therefore, no further screening activity was required. This step in the MCDA process was omitted.

2.2.10 Evaluation

During the search for alternatives, it was found that layout planning software could be fit into a spectrum from spatial arrangement to real-time simulation (Figure 6). The closer to the spatial arrangement, there were more assists on 2D layout and static analyses, such as material flow. But on the simulation side, there were statistical analyses to present real-world condition on the production process and, sometimes, even closer to the digital twin with monitoring features.

According to the business strategy, there are many variants to implement a deliberate layout. But if the planner only take layout into consideration, the best practice shall be from the 2D layout (Spatial arrangement), 3D models (Detailed arrangement and presentation), to simulation (Production process optimisation and forecasting). Each of the processes shall be repetitive until the best layout is generated.

The spectrum based on the analysis is shown below:

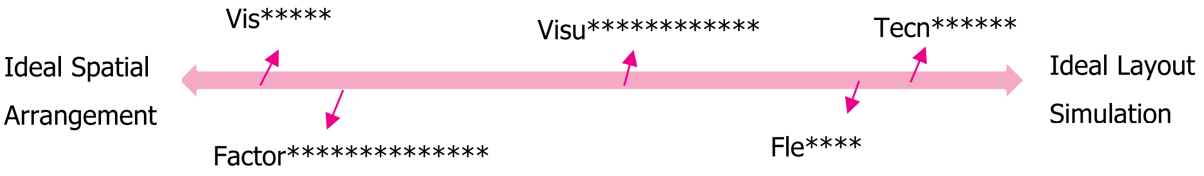


Figure 6. The software spectrum. (Huang, 2022)

Based on the analysis, there were 3 different solutions:

1. When the planner concerned both the current project and the future optimisation with one software, Factor************** was the best option with the highest overall score of 4.34.
2. When the planner only concerned the current project, the basic value was showing Vis***** the best option with the score of 4.22.
3. Applying the same concerns as in the first conclusion but applying two types of software this time. In this way, the best arrangement was Vis*****, highest basic score, with Tecn******, highest additional score.

In the solution three, it was possible to rent the simulator for a few months, which would reduce the project cost and increase the accuracy.

In the end, the company decided to take the solution 2 for this subproject. And the thesis applied the software, Vis*****, in the following content.

3 LAYOUT PLANNING

3.1 Introduction of layout planning

3.1.1 The essence of layout planning project

The layout planning is an activity which contains the spatial arrangement of equipment and the relationships between them (Moran, 2016). The planner's job is to organise all the constraints to approach the ideal layout as closely as possible. A successful layout planning project is considered as achieving the enhanced efficiency of the material flow and the transportation.

The characteristic of layout planning is based on engineering approach but not a scientific method, which means the result will be based on the planner's professional experiences. As the layout planner, an engineer, it is normal to deal with approximation but not certainty. But with the correct tools and data, limited approximation can be ensured. By constantly integrating knowledges and experiences, the layout will be more refined (Moran, 2015).

Even though, there is not the absolute answer or the path in this discipline, there exists some stages which were found in common. The stages are called the CDIO, which stands for conceive, design, implementation, and operation, for the engineering project life cycle (Moran, 2015).

Before diving into a more detailed common process for the layout planning, the planner is required to realise possible sources. For example, the automation applications: (Snow & Snow 2002.)

a. Process: Direct numerical control, Flexible manufacturing systems, Flexible manufacturing cell.

b. Warehouse: AS/AR, AGV

c. Production: CAM, CAD

d. Management: CIM (Computer integrated manufacture)

Any possible resources can simplify and verify the data gathering process and shorten the time of planning as the result. During the thesis period, there was data of previous layout in the company which could be accessed through the supervisor. But there was nothing that could be compared with the visiting of the plant, the first-hand source.

After identifying the sources, the planner will need to mark elements, such as moveable and unmoveable objects, process considerations and nature causes (Appendix 1). The element identification can reserve most of the time in the layout project. The author had spent hours in the factory to get familiar with the environment.

In a general description, a successful layout project needs to be fully and thoroughly connected to the real scenario. The longer to identify all the info correctly at the beginning, the more efficient for the planner operating his work until the end.

3.1.2 Common process for a layout planning project

An example is demonstrated from a pharmaceutical layout planning process: (Moran, 2015.)

1. Identify the project
2. Define the objects
3. Alternation
4. Elimination of undesired alternatives
5. Outline the rest alternatives
6. Gathering the data from
    a. Scientific areas
    b. Engineering areas
    c. The business strategy
7. Further elimination of alternatives
8. Working on
    a. The pilot projects
    b. The estimation
    c. Integrate business strategies
9. Selection of alternatives from the result
10. Finalising the pilot project.
11. Detailed Design
12. Including constraints
13. Verification of design
14. Monitoring the design
15. Improving & Optimisation the design

From the example, the general concept can be developed as follow: (Moran, 2016.)

- Concepting
- FEED study
- Detailed arrangement
- Construction
- Post activities

According to the size of the project, the planner can be assigned from organising partial interior layout to the plant design. The processes between them are similar, but the difference exists in the data.

During the concepting stage, the project owner shall generate the philosophy which the design will be based on, such as the production standards, and some general conditions, such as process locations and sizes. Then the FEED, Front End Engineering Design, is involved to establish scope, budget, risks…etc. The FEED is to make the project within the schedule and to reach the anticipation of quality. Before the next step, there is a sanctioning process for the approval of FEED study. When the schedule, the budget, and the quality are defined and qualified, the detailed arrangement simulates the overall process and assures the estimated financial target is under control. When the plan has enough theoretical suggestions, it is the moment to consider the construction. After the construction, the project owner rolls out a commissioning task to qualify the result. Then the post activities include operations and maintenances.

For this thesis, the concepting, the FEED study, and the detailed arrangement were greatly simplified. In fact, this thesis concluded them into the first chapter. These three stages take a significant influence on a new plant design, which is a layout-based construction, the buildings and other infrastructures are flexible and dependent on the layout. To qualify the project is profitable and justified before heavily invested, those stages are needed in detail. But this Hanza project was already preparing for the construction of the building when the thesis started. Therefore, it was a constrain-based layout, which means the layout is planned under existed and fixed constraints, on both the current layout and the expansion facility.

3.1.3 Roles in the project

In the process of layout planning, roles in different stages represent intentions. The changing of roles is common. And the roles can be divided into the project group with direct involvement and associative group.

For the project group, the site selection is a start. Then the process engineer and the consultant start to design, such as the conceptual design, and evaluate, such as the FEED study, for the project. The FEED study is mainly for the sponsors. When the sponsors sanction the project, the detailed design will usually be carried out by the EPC company. The detailed arrangement shall reach the ideal which ensures the financial limit for the project owner and construction suppliers. The design for construction offers a ready-to-build arrangement based on relations between equipment, utilities, suppliers, transporters…etc. The interchangeable information between the plant designer, the layout planner, the EPC company, and suppliers assures the quality in this stage. After the finishing of the construction, the owner of the project will carry out or subcontract a verification before operating it, which is called commissioning. The maintenance, trainings, and operations are belonged to post-commissioning, which is handled by the project owner and suppliers.

The following roles are within associative group which offers licences and auxiliary supports: (Moran, 2016.)

1. Regulatory Authorities for
    a. The Planning
    b. Pollutions
    c. Safeties
2. Emergency Service
3. Transporter
4. Quality Assurance Groups
5. Public and Presses
6. Insurance Companies
7. Equipment Suppliers
8. Raw Material Suppliers and Product End Users
9. Utility Suppliers

10. Waste Disposal Facility Suppliers
11. Construction Companies
12. Commissioning Teams (Subcontracted)
13. Operating and Maintenance Personnel

The change of roles depends on the project. If the project is a relocation on a new site, there usually will be reidentification required on most of roles. But for the current layout optimisation, the condition and roles can be remained unchanged.

The author was the layout planner for this Hanza project. The layout was based on the existed production process design by the production manager. There was a construction supplier involved for the new facility. There were no large relocations for this Hanza project, so the most of roles remained the same.

3.1.4 Layout project deliverables

To achieve the ideal layout, supplementary documents and analyses are needed. The layout is a composite of those studies. According to Maron (2016), the deliverables include:

1. Design Basis and philosophy
2. Specification
3. Process Flow
4. Equipment list
5. Function Design Specification
6. General Arrangement Drawing
7. Cost estimation
8. HAZOP study
9. Zoning Study (Hazardous Area Classification)

The design basis is the predefined limitation for the FEED study which is simplified and in general description, such as environment. The philosophy is a detailed application concept which the project will follow, such as industrial standards. The specification offers more numerical requirement on the result, such as production rate. The process flow gives an overview of how production processes are connected. The list of equipment is gathered for the management and the arrangement. The function design specification is the controlling method for the plant during the production process, such as the emergency process control. The general arrangement drawing is the drafts of layout planning. The cost estimation includes not only the project overall cost, but also the impact to the cost of future production and the product. The HAZOP study is the risk analysis to identify the weakness of the layout. The zoning study is the identification of possible hazard areas with toxic materials or any other dangers.

Those documents usually are analysed and gathered by a team to ensure the quality and efficiency. But there was only one layout planner who handled most of the work. Therefore, the priorities were defined. There would be documents for the process flow, the equipment list, the general arrangement drawing, and the zoning study as deliverables. Other documents were still considering against the schedule. This thesis demonstrates the process flow and drawings with less details than the version for the company. The equipment list was gathered, but it belonged to confidential information.

3.1.5 The essence of the layout planning activity

Layout projects can be placed on a spectrum where one side is under defined, and another side is fully defined. The closer to the boundary of fully defined, the more constraints exist. To build a production unit, which is closer to the under defined situation, required info is gathered and facilitated, such as from the production process, the layout orientation, to the plant design. To optimize a current production unit, which is closer to the fully defined condition, the ideal optimized solution is always the design with less modifications but with high effectiveness. The defined level influences the layout planning activity. This Hanza project was aiming at extending the production capacity with the new facility based on the current production units. The planner needed to connect the original site with the new section into one integrated layout. So, this project was in the middle of the spectrum. It had the quality of optimizing the known layout on a new site. The thesis started from digitalizing the current layout first, which had more defined data. Then, gathering the data from the new site. Finally, applying the optimization into the layout.

Applying a layout can be as simple as arranging equipment based on feelings. But a rigorous layout has thorough analysis and have been optimized to approach the business strategy. The difficulties of a design activity usually exist when the data is either unclarified or complicated (Maron, 2016). This difficulty had found at the beginning of the planning for this project. To clarify, the beginning of the schedule ensured most of the constraints by visiting of the plant periodically. Then, the knowledge of optimization started to involve. But the optimized concepts existed many of them. After doing the research, the thesis simplified the concept to the following:

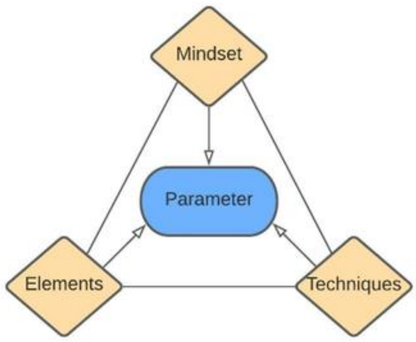


Figure 7. Optimization principle. (Huang, 2022)

This principle was based on mathematical approach since the math has the same quality of resolving and optimizing questions.

The mindset indicates the applied concept which the optimization will be based on. The techniques are the implementation methods of this concept. Then, the elements are the subjects to this concept. For example, the planner can apply Lean theory into the plan by using the technique 6s on the placement of auxiliary tools. The predefined parameter, such as the transportation effort according to the business strategy, will be influenced and enhanced before the evaluation. Finally, the selection for the most suitable solution is processed, which can be based on SLP.

3.2 Implementation

3.2.1 Systematic layout planning

The author applied the planning steps form the Systematic Layout Planning, SLP, into the construction stage as the following procedure (Suhardini et al, 2017):

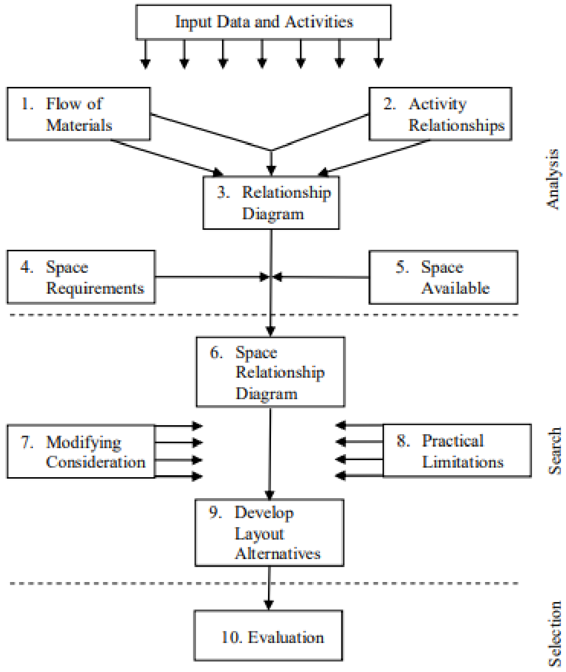


Figure 8. Systematic Layout Planning. (Suhardini et al, 2017)

There are five basic items are required before the layout generation (Suhardini et al, 2017):

- Product
- Quantity
- Route
- Service
- Timing

The author concluded them as the info of production group. Due to the existence of current layout, the schedule started from collecting the spatial information inside this layout as the priority. Then, a meeting based on it to identify other constraints. It was an opposite approach in the analysis step from the SLP, but the ideologies were the same.

3.2.2 Input data

The company offered a plant drawing in 2019 as a reference. The accuracy was in doubt because many placements and dimensions of machines were not match with the inspection result. Therefore, the 2019 drawing would not be taken into consideration for this thesis. As the loss of drawing, the priority was to create a new one. Other than the drawing, most of the software and its data were for production and management purposes. The usable data was limited at the beginning.

3.2.3 Mapping

The map had different versions. The first version was identifying the machines shape and location.

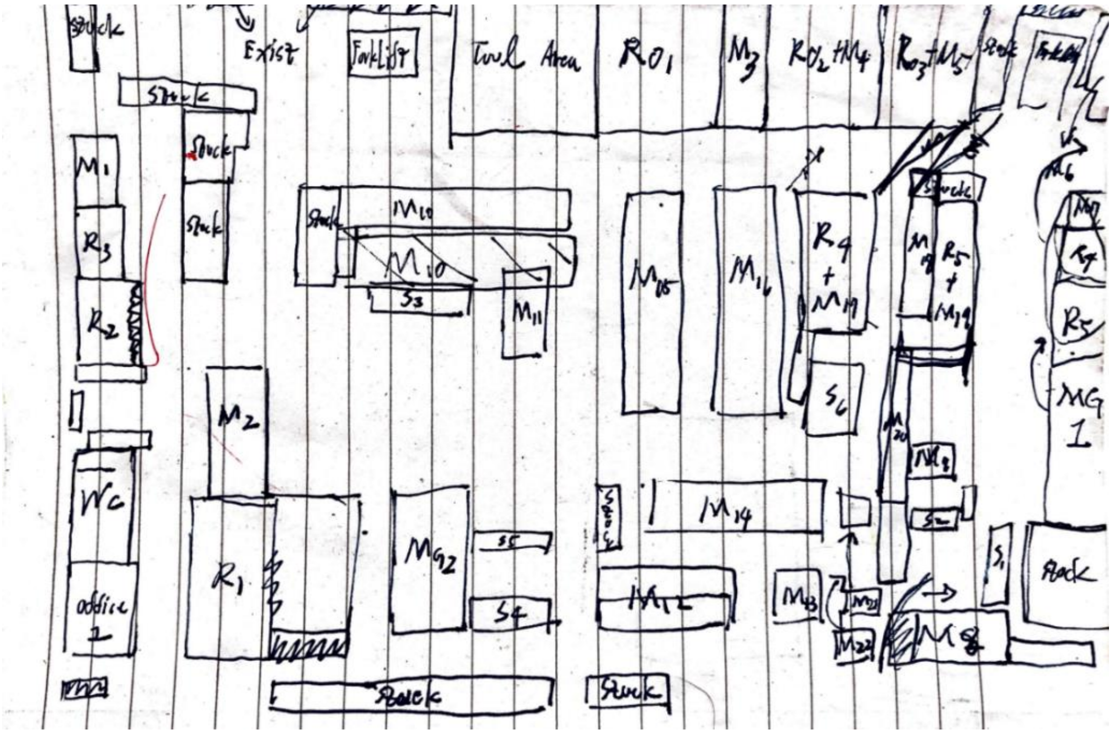


Figure 9. The first version. (Huang, 2022)

The second version had been organised into a more precise orientation with dimensions.

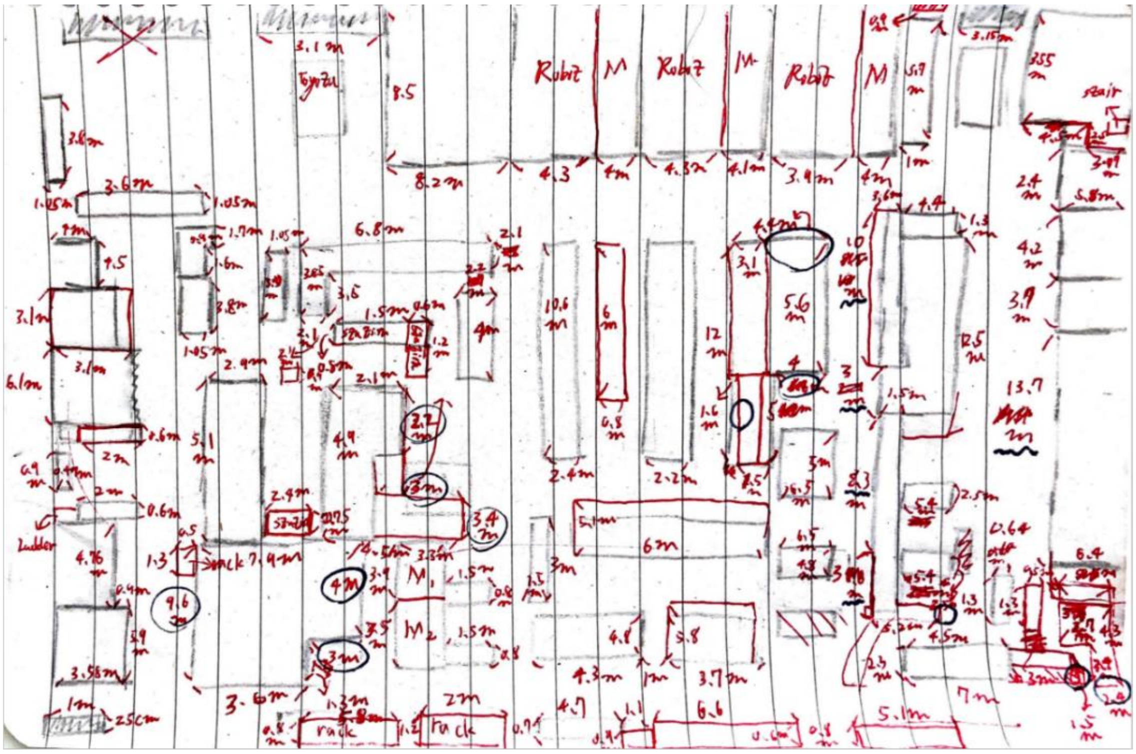


Figure 10. The second version. (Huang, 2022)

Then, digitalising the second version. The result is as following.

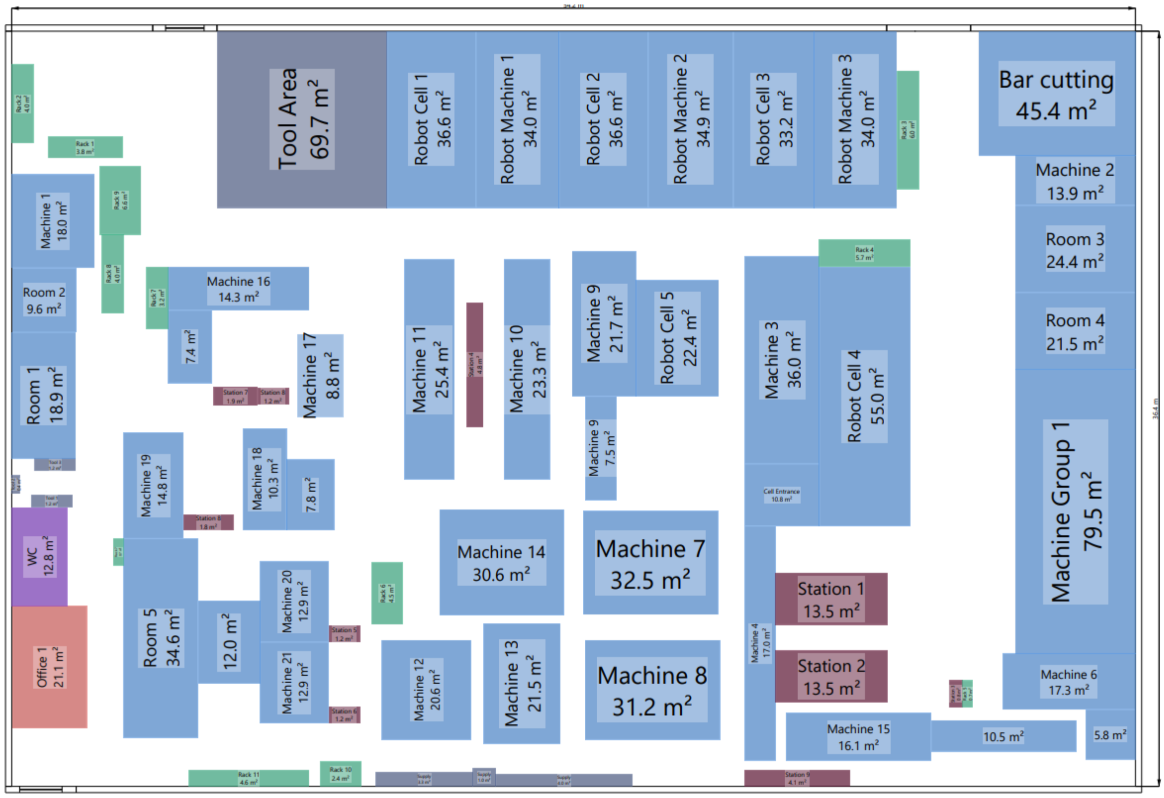


Figure 11. The third version. (Huang, 2022)

The fourth version applied coordinate system into the third version with measured distances. The numbers in the map corresponded to the equipment sheet which was gathered during the mapping.

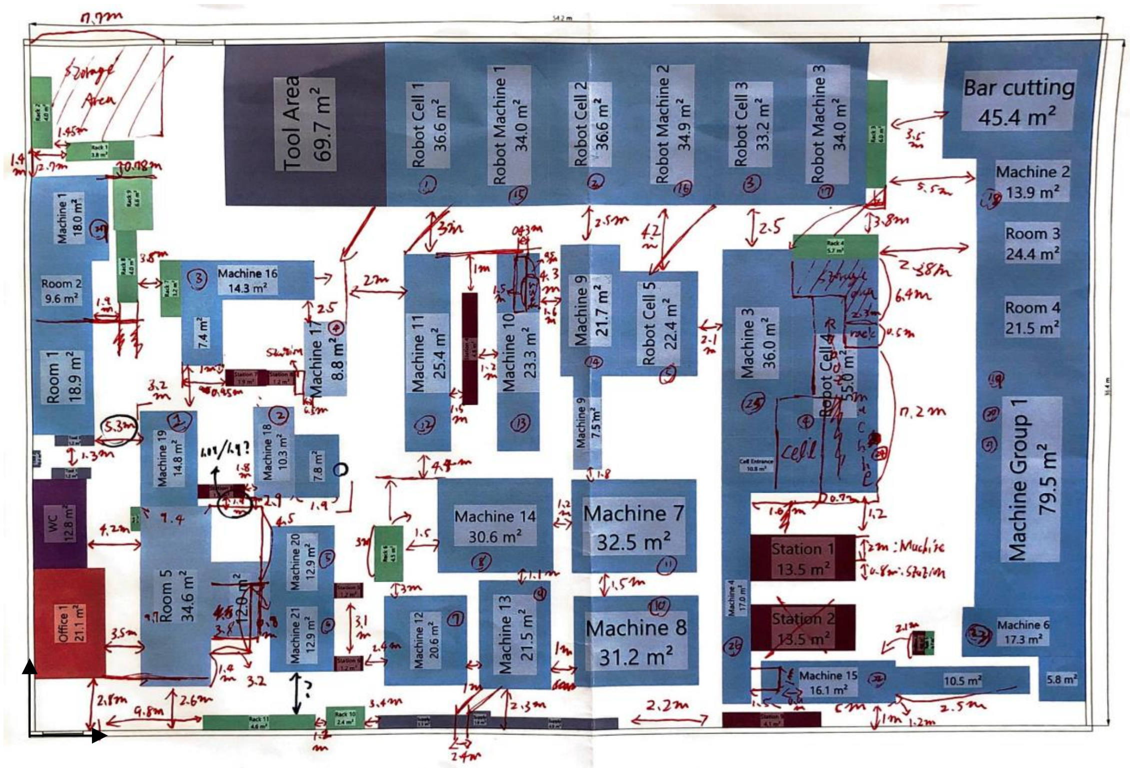


Figure 12. The fourth version. (Huang, 2022)

The fifth version was constructed by verifying the fourth version to ensure the accuracy.

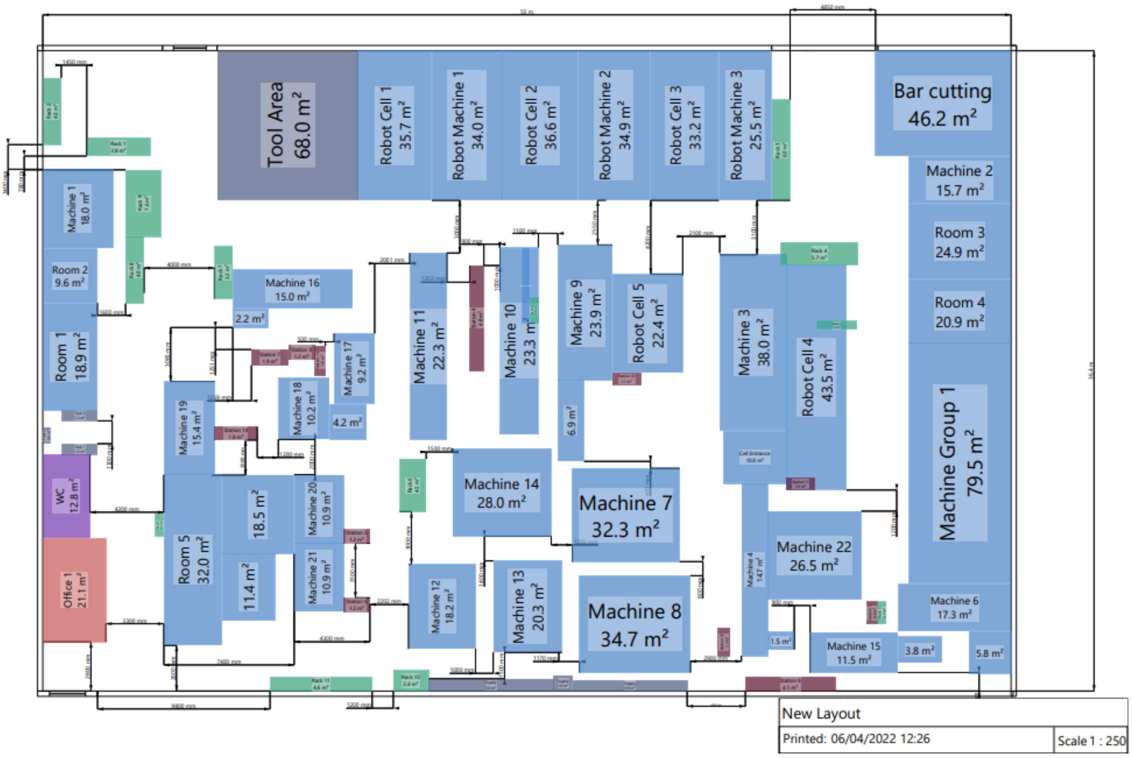


Figure 13. The fifth version. (Huang, 2022)

3.2.4 Measuring method

The measurement methods were evolved along the mapping process. At beginning, the method was using the 30m measuring tape to gather the data. But this method required 2 people to be efficient. Later than the tape, applying the laser device for the measurement of coordinate system. But the disadvantage happened when a slightly uneven surface could influence the traveling of the laser light to the reflector.

Figure 14. Measuring tape application. (Huang, 2022)

Figure 15. Placing the laser (Left) and placing the reflector (Right). (Huang, 2022)

After combining the data from the coordinate system and the machine dimensions into the software, the map appeared to be unrealistic. Therefore, a verification with a better method was needed. Improvements included the application of tripod for the laser and the measuring wheel.

Figure 16. Improved laser placement. (Huang, 2022)

In the verification process, the author inputted the data directly to identify mistakes immediately.

Figure 17. Mobile measuring station. (Huang, 2022)

3.2.5 Construction of alternatives

3.2.5.1 Data for the layout

Data varies from the project defined level. The planner will require a more theorical data to calculate the solution in under defined project. But the planner will take more time on measuring data in the fully defined project. In general, this thesis categorized four types of data which will be commonly required for both scenarios:

- Project Background
- Current Plan or Idea
- Equipment
- Process (Production group)

The project background gives the defined level of the project, the roles involved, and the expectations to the result. This will set the direction of planning. Then the current plan or idea gives the considerations from the project owner. It is vital to define between requirements and desires. Since the layout planning is based on the equipment orientation, it is recommended to gather as much information on those items as possible. The digitalized data of machines, such as CAD model, is convenient for the calculation and demonstration. The final one is the process which belongs to the production group information in the chapter 3.2.1. There are different types of layout principles to fit the characteristic of various processes. Identifying the characteristic from the production group is the duty of the planner.

Before the start of the planning activity, a meeting about this project was hosted to give the realization of layout background with the roles in it and the expected deliverables. The supervisor of the project described the plan and expectations on the new arrangement. Later, the planner took the measurement and machines' information directly form the plant in a hierarchical method, which will be explained. Then a generalized production routes was generated by discussions with the production manager.

Inside the Hanza plant, there were roughly 3000 types of products in different processes. The production manager generalized them into some production routes to do the material flow analysis on the following alternatives.

3.2.5.2 Considerations

Before the optimization, the alternatives should be applied on some required considerations. According to Maron (2016), considerations for a layout alternative includes:

- The process requirement
- Economic aspects
- The operability
- Control Requirements
- The maintenance
- The construction
- The expansion
- Escape routes
- Safeties
- Hazardous situations
- Environment impacts
- Product protections
- Insurance requirements
- The equipment stacking
- Off-site unites
- The communication

These considerations can be weighted in different projects. For the Hanza project, the top 7 considerations were:

- Process requirements
- Economic aspects
- The operability
- The maintenance
- The construction
- Escape routes
- Safeties

These considerations can be seen as the business strategy, then they were quantified and placed inside the parameter.

3.2.6 Hierarchical Approach

During the definition of the equipment space, this thesis took the hierarchical approach (Figure 18). This approach contained the space of the machine, the station, the movement, the auxiliary tools, and the maintenance. This hierarchy was based on the priority and the detail of the data. The higher the priority, the more urgent to receive those data and they were less particular.

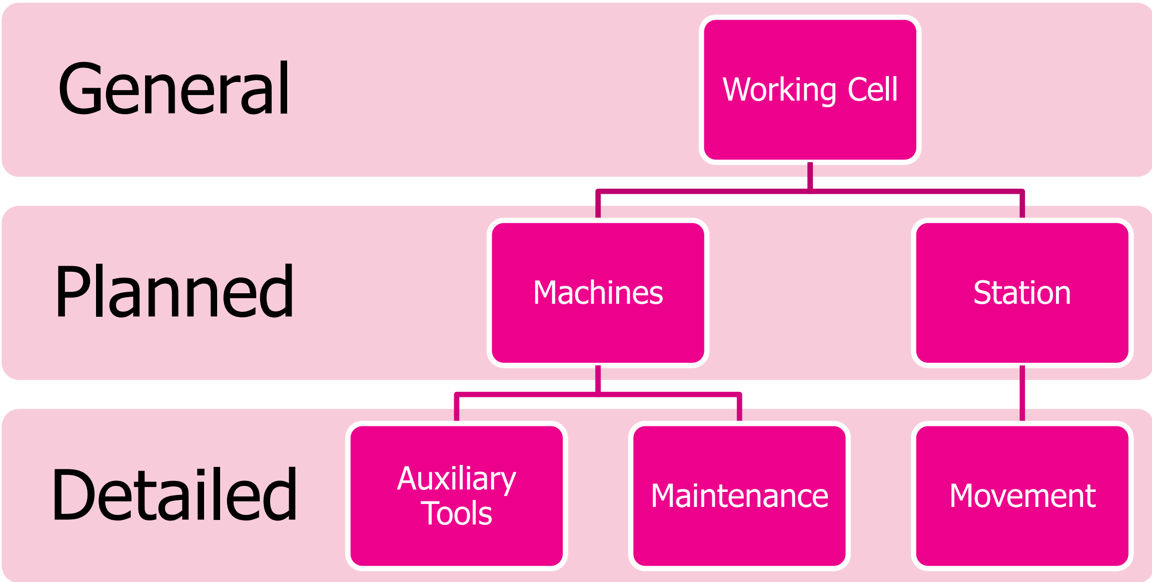


Figure 18. Hierarchy of data. (Huang, 2022)

The general level only measured or gathered the data from the working cell. This level offered the planner a rapid understanding of the plant elements. And it was foundation for the further discussion, such as the process route was discussed based on the working cell map for this thesis. Then the data contained machines and stations in the planned level. This data identified the operating space and the transporting effort inside the cell. The planned level could already offer a sufficient data to construct alternatives. The next one was the detailed level. This level was used for further analysis, such as collision detection. When the data in the detailed level was gathered, alternatives could be enhanced before the evaluation.

The data gathering methods and requirements were different in each level. For this project, a rough boundary measurement or definition was enough in the general level. Then, in the planned level, the machine space information was gathered by OEM documents and the measurements in detail. The CAD models were not accurate since it was mainly for demonstration. Information of stations required the cooperation of operators in the cells. The Detailed level was gathered by pictures and videos with the measurements around the cell.

3.2.7 Production processes

After the creating of the map, the following plan for the thesis was to gather the process data. With the combination of process and the equipment, the space relationship diagram was clarified. As mentioned, there were few generalized production routes in the plant. In the following demonstrations, the author chose the first two production group for the first and second step. Then, the final step contains all general groups to show the relationship and their affections in this thesis. Processes inside the route is replaced by the code name instead of the machine information for the company privacy.

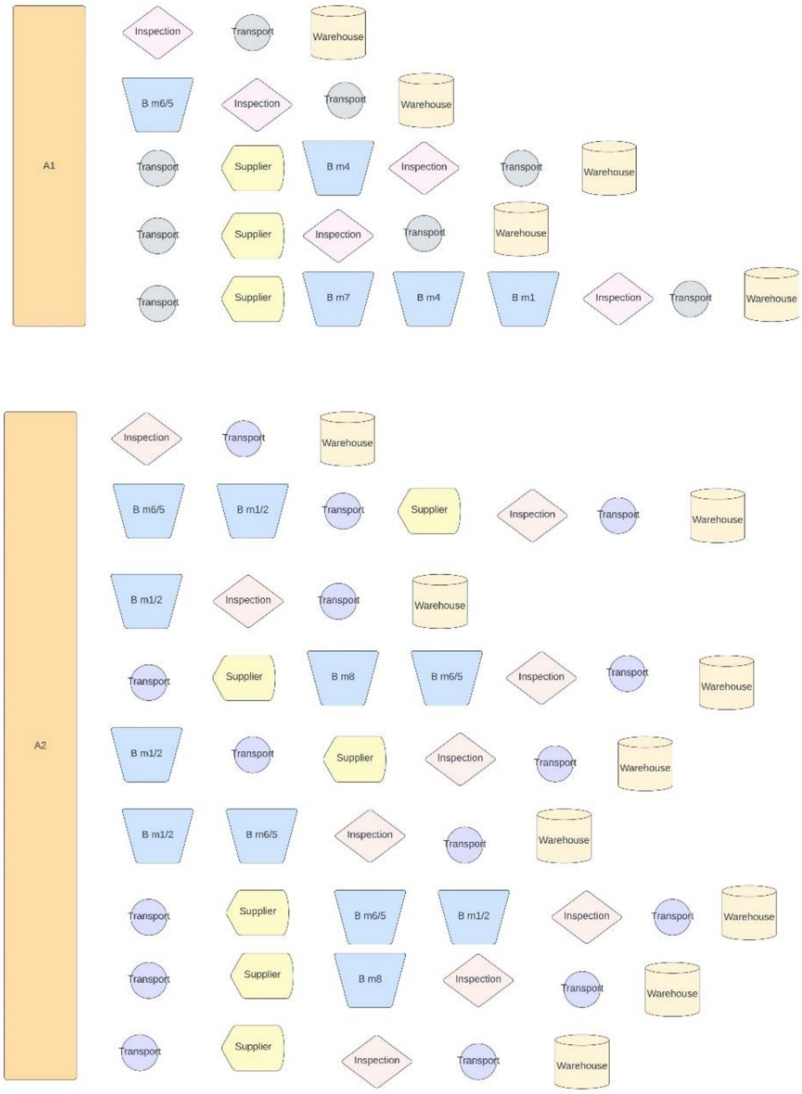


Figure 19. The first step for the organising of production routes. (Huang, 2022)

These routes were from the discussions with the production manager. But it still lacked the number of transportations, the transporting equipment, and the time for each process. The rest of required data will be collected after this thesis.

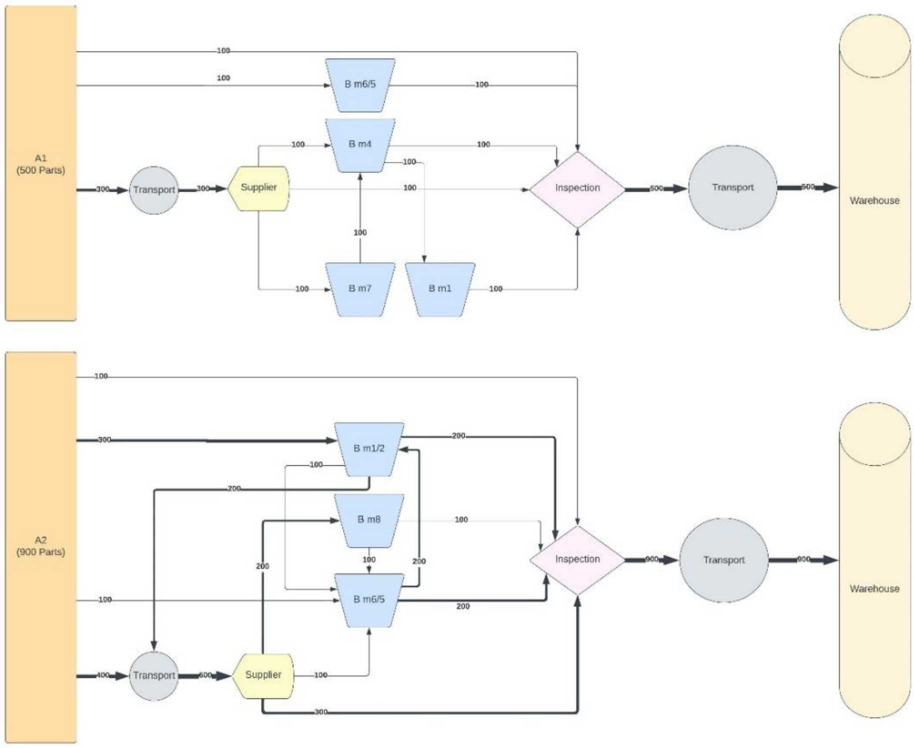


Figure 20. The second step for the organising of production routes. (Huang, 2022)

In the second step, it was assumed that 100 parts per route. Later, the work was required for further categorising them and summing up the overlapping connections. A clear diagram was generated for each group in the end.

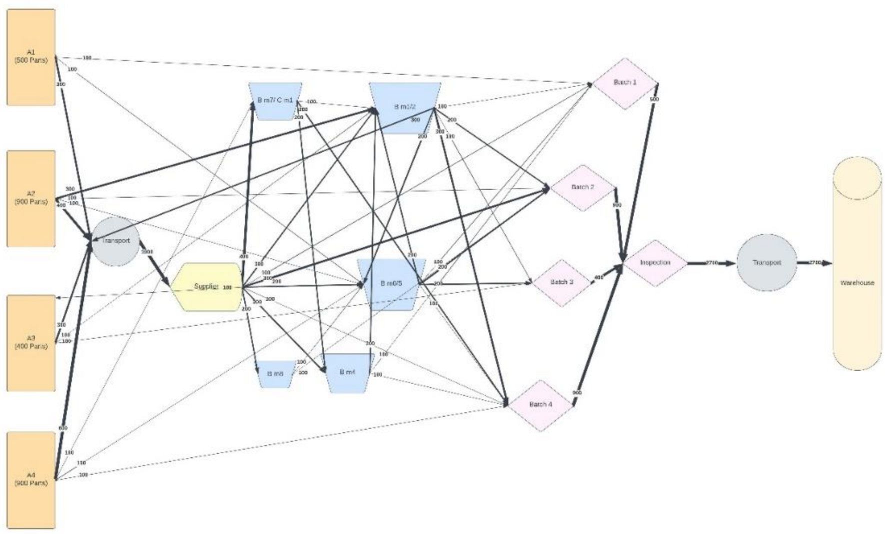


Figure 21. The final step for the organising of production routes. (Huang, 2022)

After combining the four groups, the importance of each process is demonstrated in this network. This network shows the layout cannot be process oriented, but a functional group can be suitable.

3.2.8 Current space relationship diagram

The space relationship diagram presents the traveling of materials to demonstrate the efficiency of the layout. From the original orientation, the generated traveling value was total 2.7 km for all the production groups.

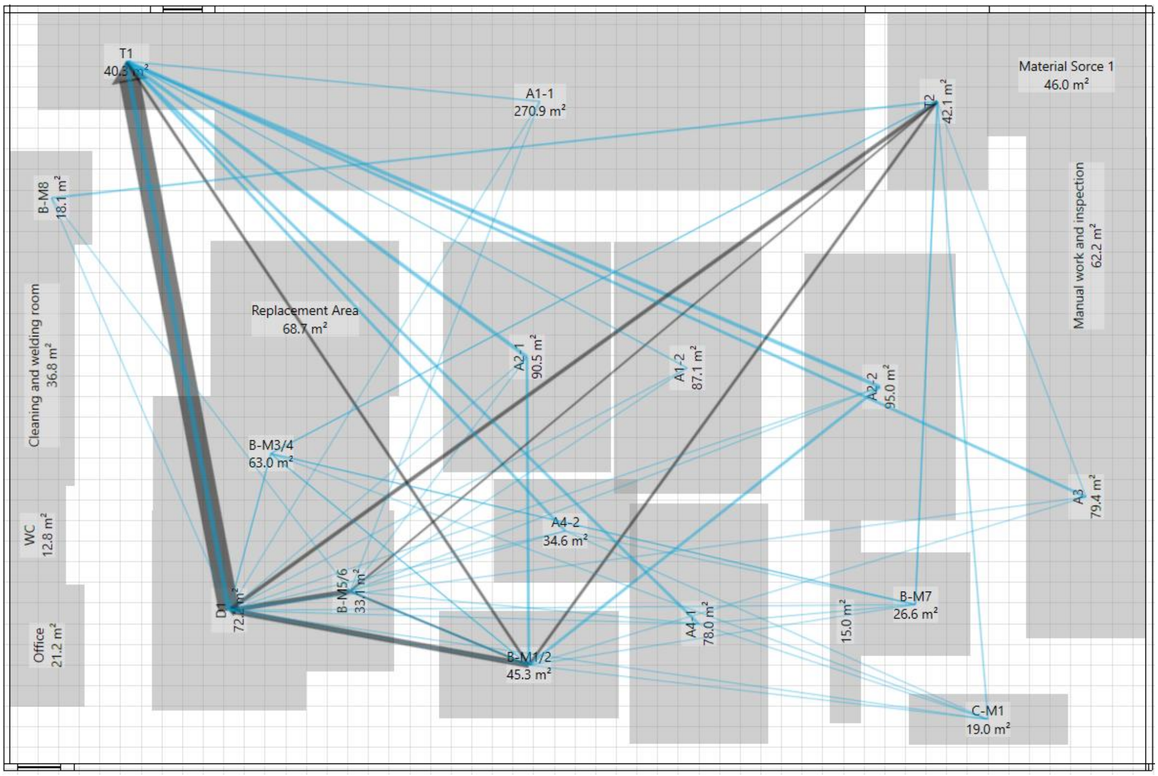


Figure 22. Space relationship diagram. (Huang, 2022)

This diagram was based on the working cells because it is easier to optimise the layout from the highest hierarchy, the general level, to the lowest one, the detailed level. This strategy reduces the time of planning. It is also stable and simple to apply from the data of higher levels. After the planner selects one of alternatives, the next step will be reorganising the locations of machines and stations inside the cell. The change of cells can influence the exterior shape. The planner shall judge whether to change the plan if that happens.

If the project is under defined, the working cell shall be estimated by the planner's experiences and knowledges. Then, repeating corrections along with the project. During the modifying of the cell interior, the best approach includes consulting with the operator of the cell and the machine providers.

3.2.9 Alternatives

3.2.9.1 Method

Due to the schedule of this thesis was not corresponding to the project schedule. There was still much of lost information. But for the thesis demonstration, the following alternatives (Figure 23, 24, 25), which excluded the expansion section, were still created as examples. From the network diagram, the examples were set that T1 and T2 were the fixed critical points, which was based on the understanding of the real situation. Then the other areas, which were not participating in the direct production, were also fixed.

To systematically identify the quality of an alternative, considerations are needed. But for the drafting, limiting them at the beginning is helpful. With the fixed areas, the three considerations were:

1. The traveling distance (Process Requirements)
2. A transporting path for the forklift between A1 and T1 (Process Requirements)
3. All cells should not be closed (Operability and Maintenance)

When alternatives are being generated, uncertainties will arise. It is common to repeat the correction until the alternative is qualified. Following alternatives are for demonstration use.

In the following alternatives, 3 items are specified:

- The material traveling distance is in blue and grey lines.
- The forklift traveling route is in pink lines.
- Planned escaping routes are in green lines.

The escaping route would be used on the evaluation sections, but not on the drafting.

3.2.9.2 Alternative 1

The total traveling distance is 2.04 km in this alternative. It lowers 25% of the transporting effort than the original one. The location of A1 is remained the same, so there is no need to change the original path for the forklift. The distribution of blue lines still scatters around the layout.

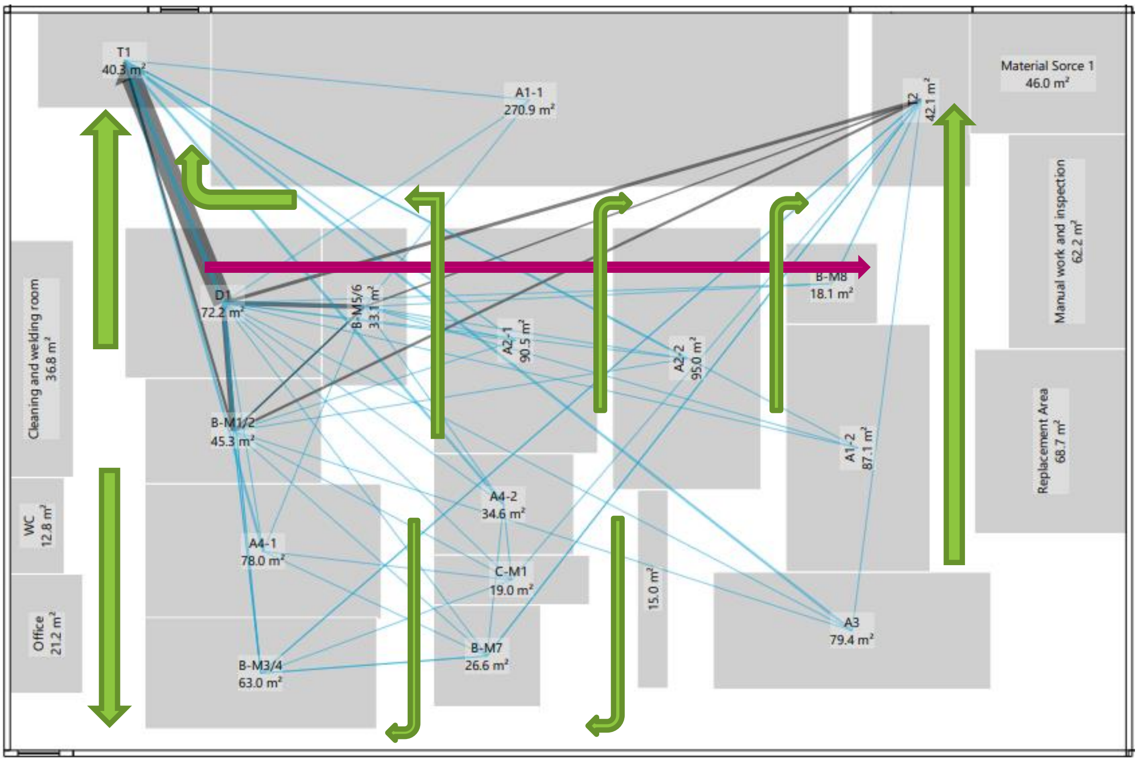


Figure 23. Alternative 1. (Huang, 2022)

3.2.9.3 Alternative 2

In this alternative, a relocation of the closest location, original position of A1, is applied for the other cells. The result shows the total distance is 1.8 km. This arrangement lowers 34% of the transporting effort. When moving the A1 away from the T1, a suitable transportation route for the forklift was considered.

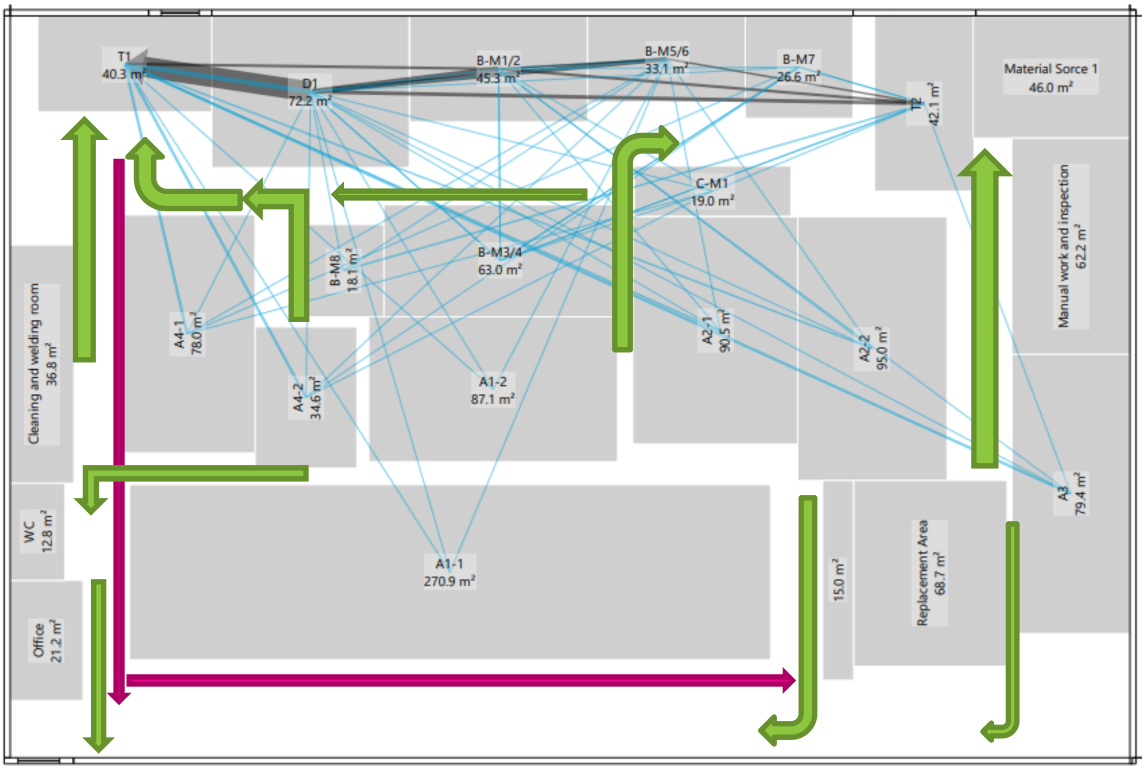


Figure 24. Alternative 2. (Huang, 2022)

3.2.9.4 Alternative 3

In this alternative, those high commuting cells are placed even closer to the T1 and T2. The result shows the total traveling distance is 1.79 km. This is 35% lower than the original orientation.

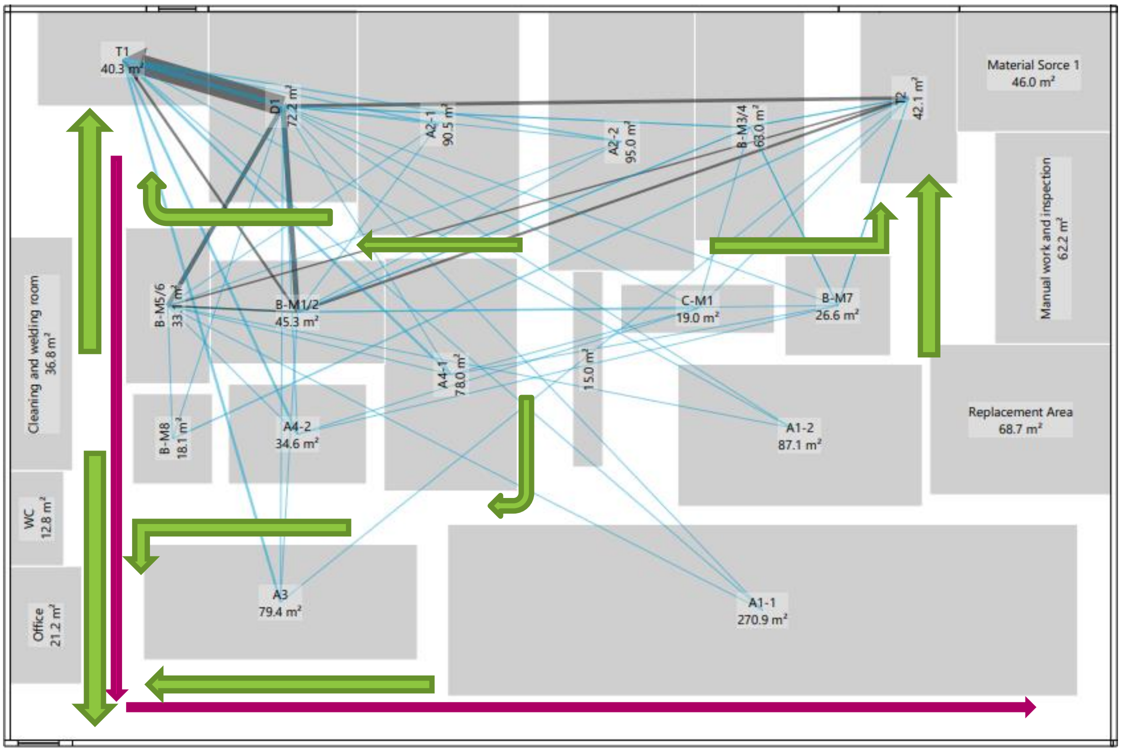


Figure 25. Alternative 3. (Huang, 2022)

3.2.10 Evaluation

In the following diagram, the process requirements and the economic aspects are represented together and were evaluated by the transporting efforts. The operability and the maintenance were based on the size of working and reserved spaces. Then the construction was based on the level of effort for the implementation. The escape routes were calculated according to employees per route. The safeties were evaluated by the density of the machines, the amount of safety design, and the percentage of overlapping spaces. Due to the difficulty of estimation on the Safeties criterion, the 0 was given to all alternatives.

Figure 26. An example for the evaluation. (Huang, 2022)

The point is from 0 to 1 with 0.2 intervals in the upper diagram. The rating refers to the compliance to the expectation. When the performance is near the expectation, the rating is closer to 1. It is worth noted that design is always subjective in a way that the product has the feature of the designer. It is difficult to argue about perfectness and ratings between designs without a systematic formula. Only the concepts were provided for those criteria in this thesis. With more data, it was possible to apply formulas instead of assumptions in this evaluation. For example, the formula for the Escape criterion could be:

$$The\ escape\ value = \frac{The\ maximum\ employees}{The\ most\ dense\ route\ area} + \frac{Exit_{Max} - Exit_{\ Min}}{The\ number\ of\ exits} \quad (3)$$

Inside the formula, $Exit_{Max}$ is the exit with the highest number of evacuators. And the $Exit_{\ Min}$ is the lowest number of evacuators instead. It is usually that the higher the rating indicates the lower the escape value, but the target of it can be set by the project owner.

3.2.11 Optimisation

The optimisation is applied to enhance the evaluation. As the concept described in the chapter 3.1.2, the mindsets can be:

- The Quality Management
- The Manufacturing System Development
- The Operational Management

The corresponding techniques includes:

- Quality Standards
- Methods for the Quality Inspection
- The Quality Function Deployment
- The Production System Optimisation
- Lean Principles and Methods
- Hazard Identification studies

A layout is concluded by many discipling. The method to optimise a layout will influence not only the orientation of equipment, but also relevant plans for the production, the operation, and the management. The planner either already knows everything in the plant, or he/she is going to be with the help of others.

Unfortunately, the author could not apply this step before the thesis due date. But the tools which the author might apply are listed above. The quality techniques offer the prevention of possible defects. Increasing application and qualification of standards can influence the layout. The Quality Function Deployment, QFD, is used for customer requirements. A layout project with the QFD and the value analysis can assure targets. The Production System Optimisation includes a few steps (Pyysalo, 2021):

- Observe
- Select
- Numerical
- Design
- Eliminate
- Assure

This can spot possible production process issues and increases the efficiency with the help of material analysis and the theory of constraint. The Lean Principles and Methods eliminates possible wastes and simplifies the processes. The Lean also includes environmental improvement, such as 6S method in chapter 3.1.2. Projects can include hazard productions, materials, or operations. Identifying them and organising the solution to assure the safety and quality.

After the planner applies possible techniques, the value in the evaluation will change. Optimising it until expectations are reached in the result of the evaluation.

3.2.12 Selection

Based on the above evaluation result, which excluded the expansion section, the final selection should be the alternative 1. This decision would move the project to the next stage for a more particular planning on lower levels. In the layout planning project, there are many selections based on the evaluations. From the first working cells to the auxiliary tools, the planner is required to iterate corrections which originated from any modifications. For example, after the selection of alternative 1, the next step was the planning of cells. This required much cooperation with operators. After the redesign of cells, this might influence the alternative 1, 2, and 3. A new evaluation and selection would roll up. This process should be proceeded until the layout includes the lowest level of elements.

4 OVERVIEW AND CONCLUSION

When the project started, materials, tools, and the schedule were undefined. The studies were carried out for the corresponding knowledge of the layout planning from the project overview to the planning activity. A discussion about the project background clarified the situation as the direction of studying and preparing. During the research, an analysis for the software selection was proceeding simultaneously. To input the correct information, contacts with sales employees from the suppliers and tests of trail versions took a lot of efforts and reserved time. Then, the input data was applied to the MCDA method to generate the result. Three solutions were proposed based on the result. The second solution was chosen in the end. The cluster president started to deal with the procurement process afterward. While waiting for the software implementation, measurements of the current arrangement and the gathering of production data were started. The production site was visited regularly. There were many times of measurements and qualifications. With the help of software, the digitalisation of the current layout was completed in a certain level. After the diagram was created, the focus shifted to the production data. Regular discussions with the production manager about the production routes were required. Production routes required many corrections because an extreme simplification was needed at the beginning phase. The collected data had been refined before it was applied into the software. With the initial data from the production routes, the first draft of the space relationship diagram was completed to identify and estimate the material traveling distance. From this moment, the thesis presented the following steps of the project by examples and estimations. After applying the following SLP process, the gathered data combined with limitations and expectations to create possible alternatives. Then, the evaluation and the optimisation showed the analysis methodology on those alternatives. This thesis became a framework of layout planning. It set the direction for the rest of the work inside this project.

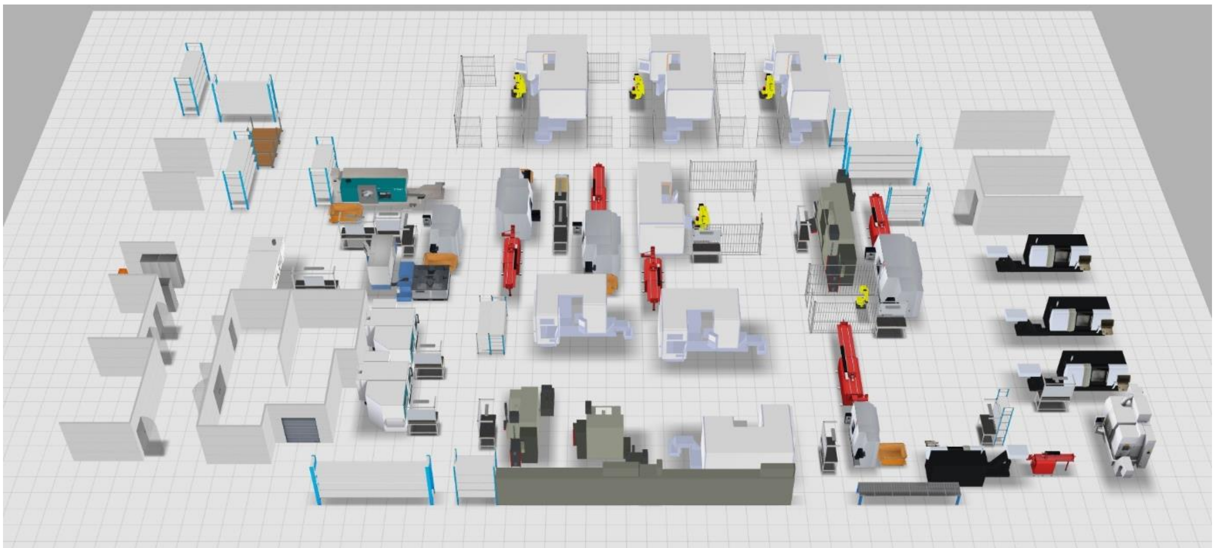


Figure 27. 3D model of the plant. (Huang, 2022)

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APPENDIX 1: LAYOUT DATA ELEMENTS

The following list is based on the “Plant Engineer’s Handbook” (Snow, 2001).

Project Clarify Question:

1. Roles in the project
    a. Designing sections
    b. Participants
    c. Suppliers (Constructor, consultant)
2. Responsibilities
    a. Expectation
    b. Deliverables
3. The schedule of the project

The current layout:

Unmoveable objects:

1. Equipment (Main and Auxiliary ones)
    - The space
    - Specific requirements (Additional supplement/maintenance…)
    - Consumptions (Electric, Gas…)
    - Hazardous items (Required standard or process)
    - Operators (Number of them, names…)
2. Building
    - The Location
    - The company organizational structure (Including maintenance)
    - Site features (Special service area)
    - The layout of the whole site (Size, safety routes)
    - Consumables (Spatial and non-spatial)
    - External constraints
3. Obstacles
    - Safety types
    - Service types
    - Inlets of mediums
    - Unnecessary items
4. Standards
    - Suppliers’ and customers’ requirements
    - The legislation structure (Required areas)
5. Effluents

Moveable

6. Employees:
    - Employment numbers and shifts

  - Working efforts (Hours inside and outside the company, suppliers)
7. Material
  - Special Requirements
  - The list of materials
8. Transportation equipment
  - Numbers (Capacity)
  - Sizes
  - Operators
9. Equipment (Main and Auxiliary)
  - The space
  - Specific requirements (Additional supplement/maintenance…)
  - Consumptions (Electric, Gas…)
  - Hazardous items (Required standard or process)
  - Operators (Number of them, names…)

Production information:

1. Stakeholders
   - Staffs
   - Investors
   - The management
2. Product groups
3. Routes
   - The flow of information
   - workers
   - materials
   - Vehicle movements (Inside and outside)

Nature issues

1. Noise
2. Heat
3. Humid

The new layout:

For the new layout, the planner needs to identify any possible changes from the previous elements.

1. Background Details
   - When
   - What
   - How
   - Why (Now)
2. New Areas
   - Sizes
   - Shapes

  - External constraints
3. Expectations
   - The flexibility
   - The extensibility
   - The stability
   - Features
   - Specifications
4. Integration to current layout
   - Safety Signs
   - Escaping routes
   - Lights
   - Traffic Routes