Decision model for industrial cleaning

Extension to quantitative level

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Terminology

Terms used	Particulars of the term	Elements of the term	Definition in context
Site (Cleaning task)	On-site cleaning	Production company (Asset owners)	On-site cleaning refers to the cleaning operations happening inside of the production company's premises, or around the premises and is owned by the production company (Fig 1.3)
	off-site cleaning	Cleaning and recycling companies	Off-site cleaning refers to the cleaning operations happening outside of the production company's premises such as at external cleaning companies (Fig 1.3)
	In situ (In plant cleaning)	Production company (Asset owners)	In situ describe the cleaning process which happens in the plant itself and does not require the dismantling of the equipment
Cleaning equipment and materials from supplier to site	Leased cleaning equipment	Cleaning equipment supplier	Some cleaning equipment are far too expensive to purchase, so when the cleaning process is bound to happen, these certain cleaning equipment are leased from suppliers to go through with the process and then are returned
	Cleaning materials	Cleaning materials supplier	Cleaning materials indicate any material that need to be used for the cleaning process to happen, a good example of this would be the chemicals which are added into the cleaning process of acidizing
Transport	Vertical transport	Cleaning company	Vertical transport indicates the transport that is preformed vertically such as the lifting of the industrial equipment using a crane
	Horizontal transport	Cleaning company	Horizontal transport indicates the transport which is preformed horizontally such as through the transportation of the industrial equipment from the plant to the cleaning area

Executive summary

Industrial cleaning is a potent part in the industrial plants due to their ability to completely diminish some issues regarding their effectiveness which could happen to the equipment due to the nature of their processes. Therefore, cleaning processes are crucial for function reliability and efficiency. However, albeit their importance in the industry, they have several major environmental impacts arising from the use of water and energy resources, wastewater production, carbon footprint and many more.

Earlier this year, the organization KICMPI in collaboration with DOW, Evonik Antwerpen N.V. and the Hz University of Applied Sciences decided to take an initiative through allowing 2 university students to create a decision matrix that would allow for companies to select the more sustainable cleaning method. This is part of their effort to drive change and innovation in the maintenance-based process industry.

Although the decision matrix provided a solution for environmental-friendly cleaning method selection, it was completely based on qualitative information and lacked further dimensions such as the quantification of cleaning methods environmental impact, cost, quality and safety.

Subsequently, a thorough process was undertaken by the project leader to identify the elements relating to each of the factors, the development method of the quantification system to allow the user to achieve the most accurate numbers, selected designs for implementation into the quantification system, as well as a small extension in the qualitative decision matrix to provide the user with a wider selection of cleaning methods for specific pieces of equipment.

Thus, several methods were employed to tackle this project, including desk research, meetings and interviews with relevant stakeholders for data collection and guidance for the design selection process from the three different options in industrial cleaning. Consequently, this led to the development of a quantifying system with an example of high-pressure cleaning for functionality demonstration purposes.

This project represents the start of a pivotal point for industrial companies in the matter of sustainability. A set of subsequent projects will be in place for future students and IT personnel to build this system into an app and/or expert software.

Finally, this quantification system is a thorough and extensive system that contains all of the necessary elements for industrial companies to compare and quantify cleaning methods leading to environmentally friendly decision-making. The outcome contributes to the move toward a more sustainable and environmentally responsible direction.

1- Introduction

To help realize a more sustainable future, companies must adopt more sustainable practices. Thus, the ability to innovate in the domain of sustainability is a need in the industry. Although many companies are willing to rise to the challenge and evolve, they are often unknowing of actions to take. This highlights the need for guidance to identify and implement better practices.

With the overall goal to contribute to finding innovative solutions, this project is focused on the sustainability of cleaning methods. It addresses the environmental impact and potential harm associated with the methods used by cleaning companies. This work was conducted though a project organized by KICMPI in collaboration with HZ, DOW, and Evonik Antwerpen N.V., and funded by Interreg.

Since the organization KIC/MPI is a company who enables project to happen between different organizations for innovative solutions, there are many different goal statement for the variety of the projects available.

The goal statement of this project is to build a decision model that supports companies in the choice of industrial cleaning technologies to reduce the environmental footprint of the process industry in the south of the Netherlands and Flanders while gaining economic advantage.

1.1- Company introduction

KIC/MPI is an organization located in the Netherlands Terneuzen aimed at advancing maintenance in the process industry through its work on various projects. It stimulates collaborations between companies such as DOW and Evonik Antwerpen N.V. to achieve its goal of innovation and contribute to a better world.

2 -Problem statement

Industrial equipment go through processes that can lead to fouling in the equipment which affects their efficiency if not cleaned. Therefore, industrial cleaning processes are implemented to ensure the equipment operates at a great level of effectiveness. However, these cleaning processes cause environmental damage to the planet due to the energy, water, and chemical usages as well as the disposal of the wastewater and residue.

In an earlier project, a team which included myself was assigned to provide the organization KICMPI/Interreg with a decision matrix which would help the user ultimately choose a cleaning method that is deemed to be the least environmentally damaging in terms of its water, energy and chemical usages while also matching them with the equipment that can be cleaned by the specific cleaning methods. Additionally, it provided the company with a professional insight on what could be done with the final residue and waste water that resulted from the cleaning

process, as well as an equipment vs cleaning method compatibility sheet that allowed the companies to easily decide which cleaning methods works for specific parts of an equipment.

Nevertheless, this decision matrix is not quantitative with respect to the total environmental effect and does not include many other factors which have to be taken into account during the selection process. It lacks the cost, the safety of the cleaning method, and the quality of the cleaning.

Consequently, a new system must be created to allow for the quantification of cleaning methods with all of the factors mentioned.

3- Purpose of the project

As stated above in the problem statement, the decision matrix which had been created by the team doesn't take into account all elements of the process such as the cost, safety, quality and most importantly the associated environmental factors. Moreover, it didn't provide any thorough instructions on how to conduct the selected method on a certain piece of equipment. Therefore, the purpose of this project is to:

1- Complete an extended list of current and additional cleaning method and compatibility with equipment (Qualitative decision matrix)

2- Develop an approach to quantify the following factors: quality, costs, safety and most importantly the environmental impact and circularity which will be used to build the quantification system

3- Provide a quantification system with a thorough example on a certain heat exchanger cleaning with high pressure where the following factors will be analyzed and addressed:

a- The cleaning process flow where the team is going to calculate, the time, transport and distance

b- The total waste in light of all factors (Energy, costs, time), the total picture of the entire cleaning process which also includes the water usage and energy usage.

4- Initial thoughts on an expert system which can be built to facilitate the use of this decision matrix.

(Note: step 2 and 3 are the focus of the project, whereas step 1 is just an addition, step 4 are just initial thoughts on what the system could look like on an expert system)

3.1 Timeline

To achieve our goal our and execute the purpose of preforming this project , the team leader built up a timeline to follow to carefully manage the tasks that need to done and achieve the goal on time.

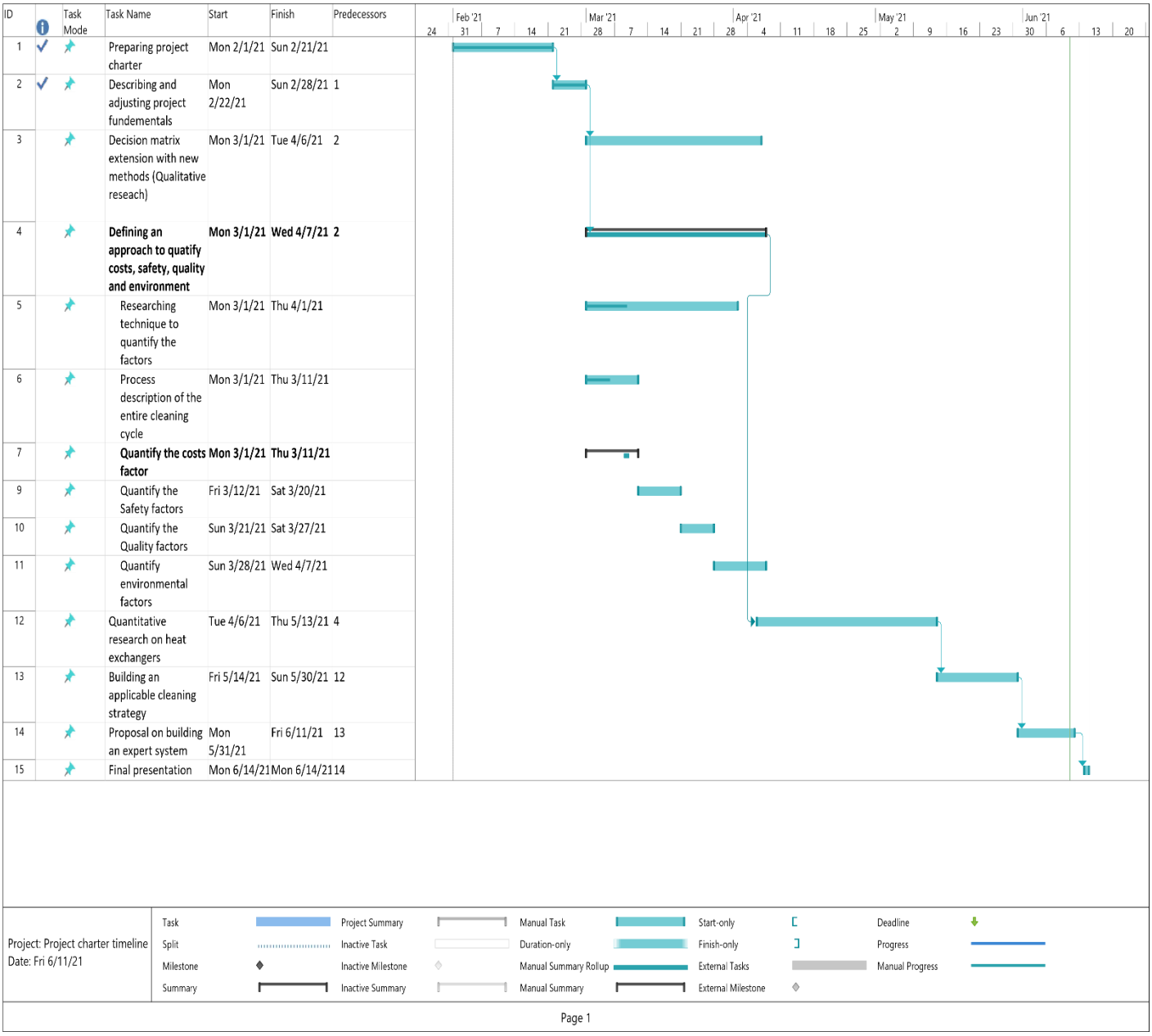


Figure 1.1: Timeline of planned achievements

3.2- Research questions

According to the problem statement and the purpose outlined for this project, a set of research questions have been identified to help define the project and set the team on track toward the achievement of the objectives. The research questions are as follows:

1- Regarding the current qualitative decision matrix:
   a- How can we facilitate the use it for the reader?
   b- What are the missing cleaning methods which could be added to the decision matrix?
2- Regarding developing an approach to quantify the factors:
   a- What elements belong to each factor to ensure the quantifying systems accuracy?
3- Regarding providing a quantification system with the example of high-water pressure cleaning on heat exchangers:
   a- What is the final design of the process that will be used from the different processes available?
   b- Which step of the final designed process require which elements of each of the factors?
   c- What are the possible parameters to be placed to ensure the accuracy of the calculations?
   d- Since the focal point is environmental effect, what are the factors that will decide what causes the impact on the environment (Ex: carbon footprint)
4- Regarding the initial thoughts on the expert system
   a- In what form will the initial proposal come in since it will be handed to an IT personnel?
   b- What sheet from the current (decision matrix) and future sheets (quantifying system) will come first and last?

3.3- Project scope

The main scope of this project will consist of the following parts, an approach on quantifying, the safety levels, the quality levels, the costs and **most importantly the environmental impact and circularity.** It also includes a thorough approach on an example of a certain heat exchanger with the pressure mechanical cleaning while stating all of the aspects that would affect it in the total cycle of cleaning such as the cleaning process flow, the total waste in terms of all factors, and lastly where further qualitative research will be done to extend the list of cleaning methods.

3.4- Stakeholders

Project funders (Interreg)

The Interreg is an organization found in the European Union (EU). In the case of this project, the countries involved in the funding are the countries of the Benelux region. Their main function is to provide funds for projects between different organization to promote the cooperation across borders. These projects are aimed to tackle current challenges which can be found in the EU countries, which consist of but are not limited to, issues and projects related to environment, research, education, transport, sustainable energy and more.

For this project, they are funding the sources for this project to identify a solution for the environmental impact in the industrial cleaning sector.

Core team

This project was conducted through an organization that consists of collaborating team members from different companies. A core team was identified to undertake this task. Bi-weekly meetings were held with the core team to review the progress and discuss any issues that could arise.

The core team consisted of 5 individuals including myself, 2 members namely Jos Dingemans from Evonik Antwerpen N.V. and Hans Borgt from DOW, which make use of the cleaning methods, a KIC/MPI member named Leendert Schouten who is responsible for this project and a Hz university teacher (Padraig Naughton) who is a supervisor for this project.

Cleaning companies

Since the focus of the entire project is based on sustainability in cleaning companies, an obvious stakeholder was cleaning companies. Their contribution allowed the core team to receive viable information regarding the project such as the cleaning methods they use, as well as numeric values on their usage standard. These companies included Mourik and HCI.

Recycling company (Pureblue)

Another important stakeholder in this project was a water recycling company, and their role consisted of providing information on what can be recycled and what can't, the rate of recycling, and what must the company do if recycling is not possible.

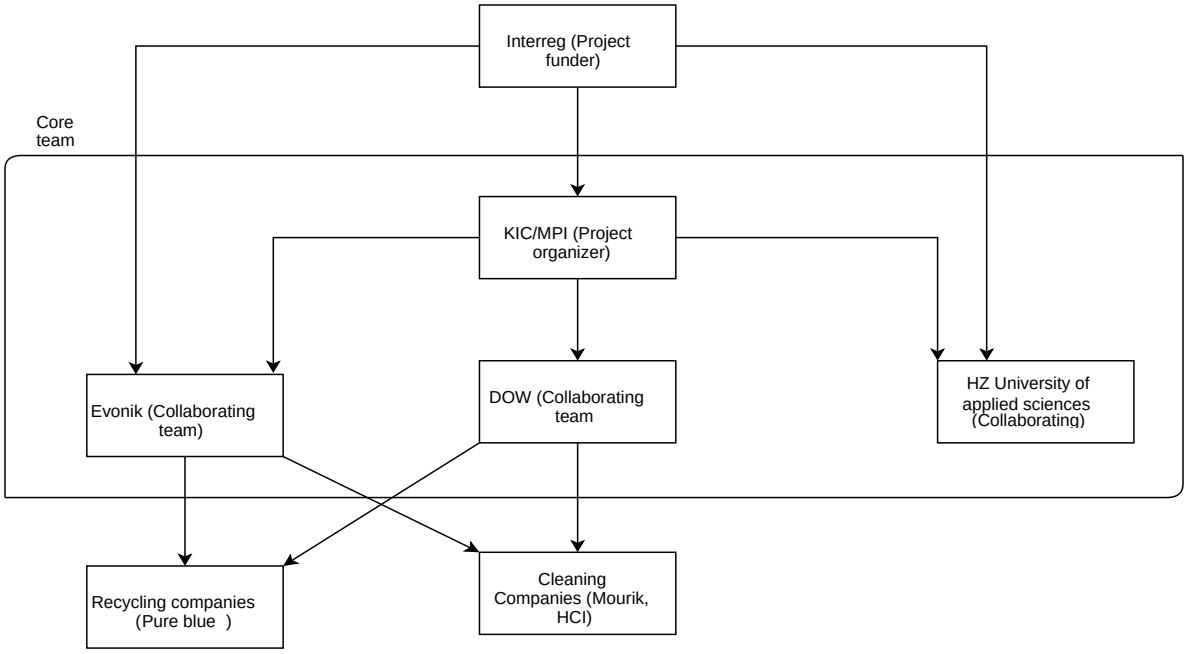


Figure 1.2 Organizational chart

4-Methodology

The team has adopted a robust methodology to ensure that the objectives of the project are achieved. The various methods undertaken are outlines below.

Meetings and interviews: Since this project was assigned by an organization that works through creating projects with different industrial companies for innovation in the maintenance related industry, meetings and interviews were the main source of data collection as many different organizations are involved on the projects. Additionally, the information required for the successful completion of this internship is often not found on the internet. Therefore, the most reliable option was to plan regular meetings with different cleaning companies and industrial companies, which allowed the collection of data required for market assessment in order to create an optimal solution for a quantifying system for cleaning methods.

Desk research: As mentioned in above part “meetings and interviews” finding valuable information through desk research for this industry can be difficult due to the confidentiality of the industry. However, that does not imply that we cannot collect information as we surely can sometimes find valuable information such the qualitative information. This only means that this was our second focus when it came to our methodology for data collection.

Data analysis: The main focus of the project was to build the quantification system to allow the quantification of different cleaning factors such as environmental impact, costs, safety and quality.

For this part, we analyzed the different contributing elements of each factor such as the time duration of each step, the distance covered per process step, the rate at which it consumes fuel/energy, as well as the conversion units which will be highly important as the quantification system is coded to directly convert the units as necessary, such as converting diesel fuel to CO2 (Quantification system- environmental impact sheet).

5- Requirements

The requirements that will be taken into account when building the quantification system are listed below. The optimal quantification system will be based on these requirements to allow for the best accuracy of the system as well as the values earned to complete the example of cleaning heat exchangers with high water pressure.

- Cleaning method vs environmental sheet process a large amount of cleaning methods to allow for use for multiple cleaning methods.
- Cleaning method vs environmental impact sheet must be easy to use for the user.
- Parameters for each of the factors must be fit enough to allow for accurate calculations.
- The quantifying system must be coded to diminish the possibilities of having calculation errors.
- Consulting experts to ensure the accuracy of relevant information.
- The new quantification system must allow for the use of both mechanical and chemical cleaning methods.

5.1- Design Constrains

Due to the variety of cleaning methods and equipment, the cleaning process can vary for some equipment, meaning that some may require more steps in the cleaning process and others require less.

The project will be focusing on the quantification on heat exchangers due to the limitation of the internship period. Hence, the other pieces of equipment might not need some of the steps mentioned.

On top of that, the lack of the information found through desk research due to the level of high confidentiality in this type of project with a lack of extensive professional experience could cause some challenges.

Therefore, the design constrains are:

- Focus of quantification will be on one piece of equipment, the heat exchangers
- Time scale limitation due to internship period
- High confidentiality level in the industry meaning lack of data on the web
- Lack of industry experience

6- Analysis

In the analysis, the team members will be working on providing information on all of the components of the project that are planned on being achieved and executing the tasks which have been stated in the purpose of the project. The analysis section contains all of the different parts which relate to the data collection, design options, final design and implementation.

The first part will focus on the qualitative decision matrix, while the second part (of much higher importance) will focus on the design options, final decision and implementation to build the quantifying system.

6.1- Qualitative research extension (Decision matrix)

This task is not a core element of this project but an addition complementary to the main objective. In the first semester of this academic year, the previous project group was tasked to create a decision matrix which was aimed to help out companies pick out the best environmentally friendly cleaning method through the description of some relevant factors which affect the environmental impact, such as the water, energy and chemical usages. Additionally, it would give out a description on the ways to recycle the water used as well as what could happen to the residue.

However, this decision matrix that was created was not comprehensive in the cleaning methods area and was slightly difficult to use from an external person's perspective.

For this reason, an extension on the decision matrix has been provided with a few new cleaning methods available as well as color coding with explanations and ratings based on the descriptions given, as well the complete page for the matching of the equipment needed to be cleaned, but before we get into that the project time will provide relevant information on the ratings that have been given.

It is important to know that the ratings given were based on the descriptions provided. Therefore, the next part of the project (6.4.1 – Quantification system with example (high pressure cleaning a heat exchanger) is deemed highly important for the final quantification of each area involved in the industrial cleaning cycle (environmental impact, safety quality, and costs).

This section's (6.1- qualitative research extension) main goal is to allow users to select the cleaning methods for the specific piece of equipment which will then allow the user to select the most sustainable cleaning methods according to the qualitative data and thus allowing them to take it to the quantification system which is the more important part of the project (6.4.1 – Quantification system with example (high pressure cleaning a heat exchanger)

6.1.1 – Methodology to determine environmental impact

Since the decision matrix will be provided in the final form after its extension has been given with the extra cleaning methods and color coding, it is important to provide the reader with information on what the ratings mean and how they have been given and what their RPN values

signifies. This includes the past cleaning methods as well as the new cleaning methods which have been added to extend and complete decision matrix.

In the final qualitative decision matrix, the user will provide the 3 different factors which have been used to describe the environmental impact, these 3 different factors which are water usage, energy usage, and chemical usage have been rated according to their description in the following manner:

Water usage: Mechanical cleaning is one of the majorly used cleaning methods which adds up to 80% (Appendix 1) of the cleaning methods used when it comes to cleaning industrial equipment. This water, if not dealt with in a sustainable manner, will end up resulting in harm to the environment, such as the boiling of waste water through incineration which will eventually lead to the increase of the carbon footprint of the company.

Therefore, the project team will be illustrating a firm description of the water usage per method of cleaning, as well as equipment, while also adding a ranking ranging from 1 to 10, where 1 being the lowest water usage and most favorable and 10 being the highest water usage and being the least favorable and least sustainable outcome (information on the rating can be found in decision matrix).

Energy usage: Since all of the cleaning methods require some form of energy to be put in use, it is higher important to have it in regard when calculating the environmental impact especially if its form of energy is fuel which would translate to a high amount of carbon footprint.

Now that the project team's motivation for taking in energy usage as a factor for calculating the impact of the cleaning methods on the environment has been stated, a description on the energy usage was added to each method used by the cleaning companies, as well as rating indicating the severity of the levels of energy usage on the environment ranging from 1 to 10, 1 being low and 10 being very high (information on the rating can be found in decision matrix).

Chemical usage: Lastly, comes the chemical usage. Chemicals, though are highly effective in cleaning, can cause a great amount of damage when it comes to the environmental impact if not sustained properly, and though it is only used in 15% of the cleaning processes (Appendix 1.1) the residue after cleaning requires a safe place for disposal as chemical have a highly visible negative impact towards the environment.

After analyzing the heavy effects of chemicals on the environment, a solid part of the decision matrix also revolves around the chemical usage, where a description of the chemical usage is identified per cleaning method, as well as a rating from 1 to 10, where 1 is negligible (indicating no chemical usage), 2 is minor, 7 is significant and 10 is severe (Information on the rating can be found in decision matrix).

6.1.2 RPN value description

Once all the factors which have been chosen by the team (water, energy, and chemical usage) have been described and given a rating, a final step must be performed to identify which methods have the highest negative environmental impact as well as the lowest environmental impact. This step must be performed through calculating the total **RPN.**

The RPN can be calculated through multiplying the three ranking number identifying the rate of water usage, energy usage and chemical usage. These will be given to each cleaning method found in the decision matrix, and therefore will enable the Team to identify the best and worst cleaning method in terms of environmental impact based on the descriptions given.

This will also be represented through color coding which ranges from light green being the most sustainable in terms of the total RPN calculated all the way to dark red which is the least sustainable.

The RPN value will also be added to the equipment vs cleaning methods sheets with the color coding as well as another new color which is blue, indicating the most favorable cleaning method per equipment in terms of sustainability.

And as for the RPN calculation, it is represented down below.

RPN calculation= Water usage (1-10) × Energy usage (1-10) × Chemical usage (1-10)

6.1.3 – Reducing the environmental impact

When it comes to reducing the environmental impact in this decision matrix, the user will be given 2 main ways on doing this which is through recycling the water, as well as ways to re-use the residue with their probabilities of them being possible to happen. It is important to note that the information collected on the decision matrix is provided through qualitative research information.

An explanation on the 2 ways of reducing the environmental impact is outlined below.

1- Recycling water: Recycling water is of high importance when it comes to reducing the environmental impact. This is due to the fact that the waste water could be re-used in some other form and would not have to be boiled which would lead to environmental damage due to the fouling which is present in the waste water. In the decision matrix, the user can find the description of what could possibly be done to recycle the waste water and at what percentage could the recycling process could be performed.
2- Re-using the residue: Another way to decrease the negative environmental impact is to find ways to re-use the residue which is left. This section is also provided in the decision matrix with an explanation for each method on how the residue could be re-used (if possible), as well as the possible probability of it happening.

6.1.4 – Equipment vs cleaning method sheet

Once the cleaning methods have been given a rating in terms of the factors mentioned on a qualitative level, a final RPN would be present as described earlier (RPN value description, 6.1.2).

And since not all the cleaning methods are applicable for all of the equipment that should be cleaned, an equipment vs cleaning method sheet has been partially built last semester and extended in this internship with color coding and new cleaning methods.

The usage of this sheet, is quiet simple where the number given indicates that the cleaning method could be used for that certain equipment, while an O indicates that a cleaning method cannot be used for that certain equipment.

And as for the color coding, the colors range from light green which is the more sustainable option all the way to dark red which is the least sustainable option. Another color which is outside the range of the colors mentioned which has been applied is the color blue which describes the optimal option when it comes to sustainability.

It is important to note that this sheet of "equipment vs cleaning methods sheet" serves a great purpose as it will be the first step in building an expert system (proposal for an expert system)

6.1.5 – Extended decision matrix

The reader must check the Excel file "DMIC_Decision Matrix (1)"

6.2- Design options - Quantitative research- Process analysis

In this part of the report, the project teams' full focus will be on the quantification of the factors mentioned which are environmental impact and circularity, safety, quality and cost. However, to do this, the user must first go through the process steps and design options that will be applied for the quantification system to get a better understanding on the cleaning process.

Therefore, to get a deeper understanding on the cleaning factors, the project team must first analyze and describe the total cleaning process from start to finish to the reader. The team leader will be thoroughly describing each step of the process listed down below and shown in a flow chart for the user to get a more visual idea on the cleaning cycle.

1- **Decision to take initiative to clean:** Before any of the steps required for the cleaning process to happen. An expert must decide whether the cleaning process to happen is due to happen, as well as what would be the cleaning method chosen, and this will be decided through checking the current quality of the equipment, and the quality and the cost of the cleaning method which is found to be best for this specific use.

2- **Shutting down production process:** For a cleaning company to be ready to clean a piece of equipment, the production process must be shut down hours before it can be dismantled, this is due to safety and production reasons since the last few couple of batches produced before the cleaning process starts, are not viable for use as a product and must be disposed.
3- **Preparing the equipment:** To get the cleaning process going, the piece of equipment that is needed to be cleaned must be safely prepared in most cases so that the cleaning method can take place. In most cases where the equipment needs to be dismantled, this step refers to vertical transportation (Terminology, p5)
4- **Transport the equipment from plant to cleaning site:** This step does not apply to all of the cleaning methods, as some methods could be done in plant. However, for many of the cleaning methods, the already dismantled piece of equipment must be transported to a cleaning site, which could be an on-site or off-site cleaning area.
5- **Transport of cleaning materials and cleaning equipment from supplier to the site (mobilization):** Once the equipment requiring cleaning has been transported to the cleaning yard (off-site or on-site), the cleaning equipment needed to perform the cleaning method must be transported from the cleaning company to the on-site or off-site cleaning area for the cleaning process to take place.
6- **Cleaning process:** Once the piece of equipment that needs to be cleaning has been transported to site, the cleaning process can finally take place, this could be done by many different methods (mechanical, chemical, thermal), where some might have higher safety risks than others.
7- **Transport of the equipment from cleaning site back to plant:** When the cleaning process is complete and the fouling has been removed, the cleaning company must then transport the piece of equipment back to the industrial company so that they can restart their production process once again. This step does not need to take place if the cleaning is happening inside the plant.
8- **Demobilization and transport materials and cleaning equipment from cleaning yard to supplier:** Now that the cleaning process has taken place, and the already cleaned industrial piece of equipment has been transported back to the plant's site, the cleaning equipment that have been used must be returned to the cleaning company from the cleaning yard.
9- **Installation:** Now that the piece of equipment has been transported back to the company, a team must be instructed to install the piece of equipment back in the production site where it needs to be safely and correctly through vertical transportation.
10- **Restarting production:** Now that the piece of equipment has been correctly placed in the production site, the production process can restart, however the first few batches which result from this process must be disposed and cannot be used as a product. Once these first few batches are taken away, the process is ready to produce viable products.

6.2.1 Flow chart of all design options

In the next page, a flow chart has been built to give a more visual representation of the total cleaning cycle from start to finish for all 3 different possible design options (Figure 1.3) with the factors involved and it is important to note that this is the specifically for the heat exchanger cleaning process meaning that cleaning a tank would not require to take all of those steps but only fewer ones.

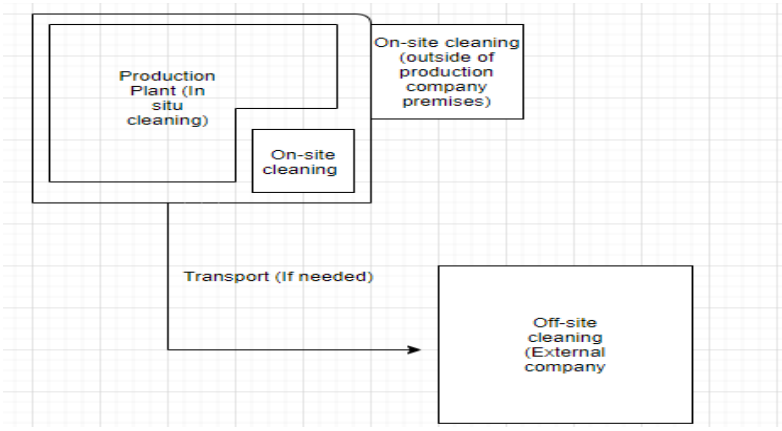


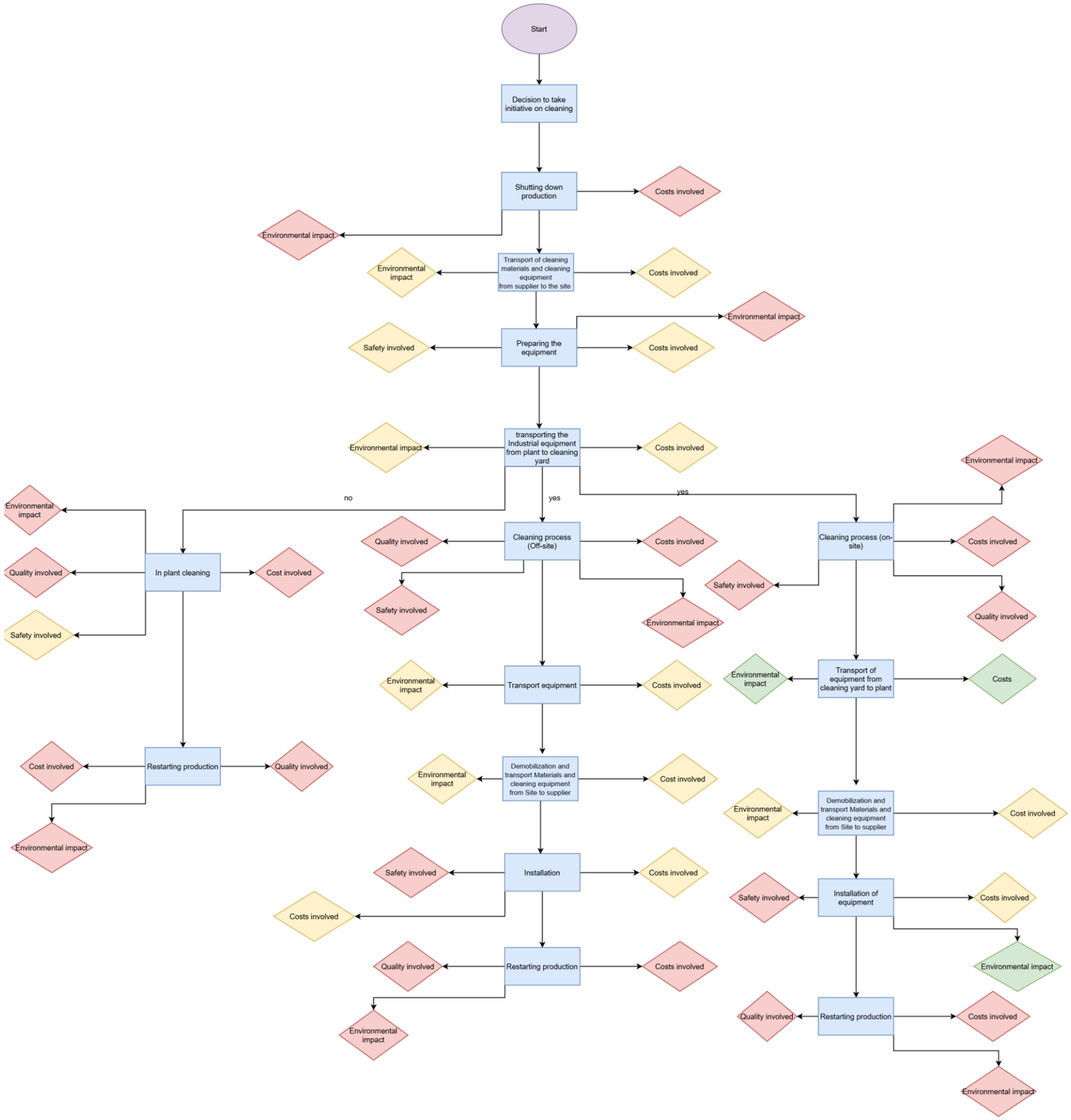
Fig 1.3: In situ, on-site and off-site cleaning

The colors for the factors allocated in the design below indicate the following:

Red: High level required

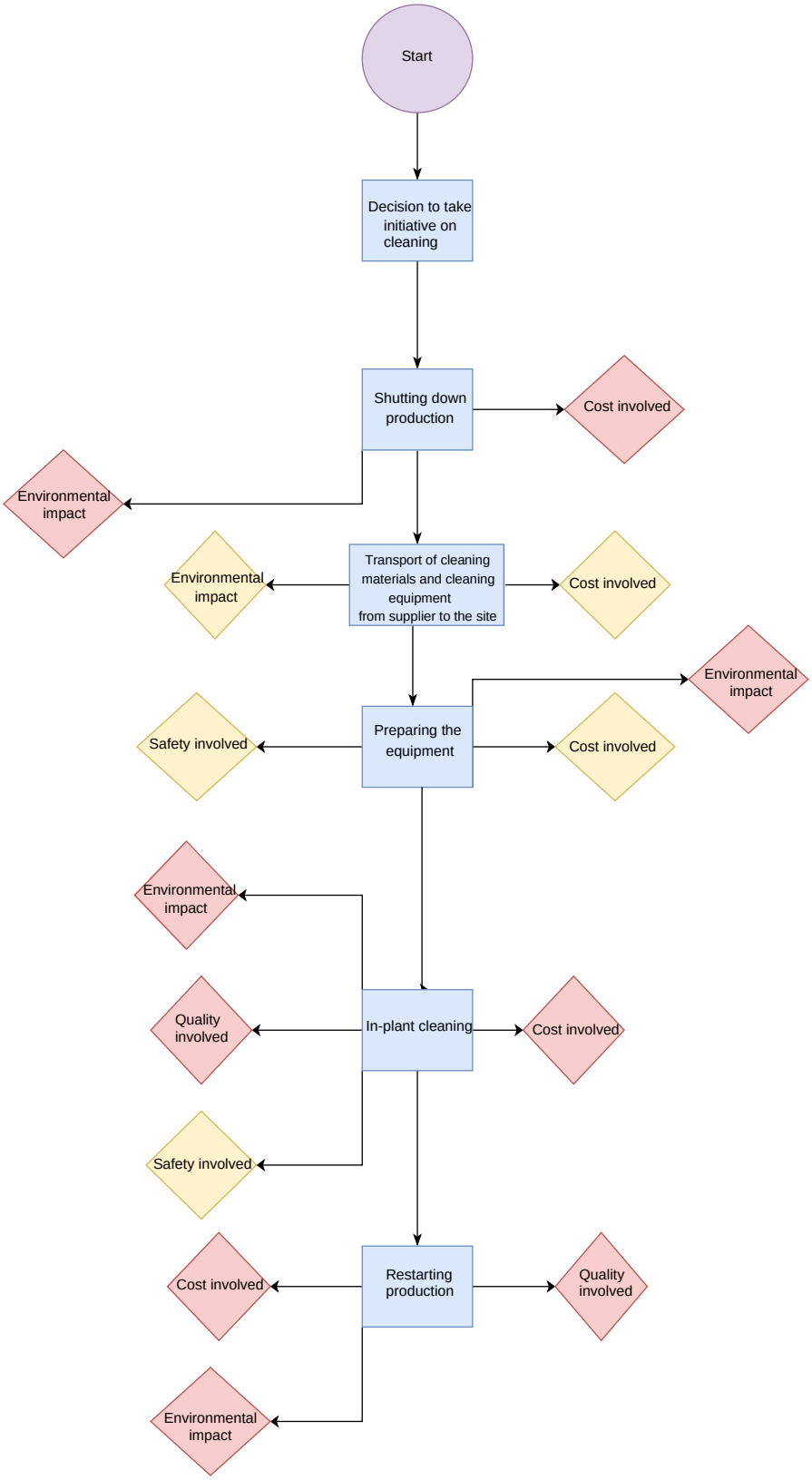
Orange: Medium level required

Green: Low level required


Start
Decision to take initiative on cleaning
Shutting down production
Costs involved
Environmental impact
Transport of cleaning materials and cleaning equipment from supplier to the site
Environmental impact
Costs involved
Preparing the equipment
Environmental impact
Safety involved
Costs involved
transporting the Industrial equipment from plant to cleaning yard
Environmental impact
Costs involved
no
yes
yes
Environmental impact
In plant cleaning
Quality involved
Cost involved
Safety involved
Cleaning process (Off-site)
Quality involved
Costs involved
Safety involved
Environmental impact
Cleaning process (on-site)
Environmental impact
Costs involved
Safety involved
Quality involved
Transport equipment
Environmental impact
Costs involved
Transport of equipment from cleaning yard to plant
Environmental impact
Costs
Restarting production
Cost involved
Quality involved
Environmental impact
Demobilization and transport Materials and cleaning equipment from Site to supplier
Environmental impact
Cost involved
Demobilization and transport Materials and cleaning equipment from Site to supplier
Environmental impact
Cost involved
Installation
Safety involved
Costs involved
Costs involved
Installation of equipment
Safety involved
Costs involved
Environmental impact
Restarting production
Quality involved
Costs involved
Environmental impact
Restarting production
Quality involved
Costs involved
Environmental impact

6.2.2 design option 1- In-situ cleaning

Note: For a better view, the user can zoom and the text will clear out



The in-situ (in plant cleaning) cleaning process design would allow for a high rate of usage for the quantification system by industrial companies as it shares the top spot of cleaning usage frequency with the on-site cleaning process (Shared 80% of cases).

The problem comes in the length of this process, where even though it is economically good, it does not allow to for having a high level of steps, as the quantification system must include all possible factors to receive accurate results.

To summarize, below can be found the Pros and Cons,

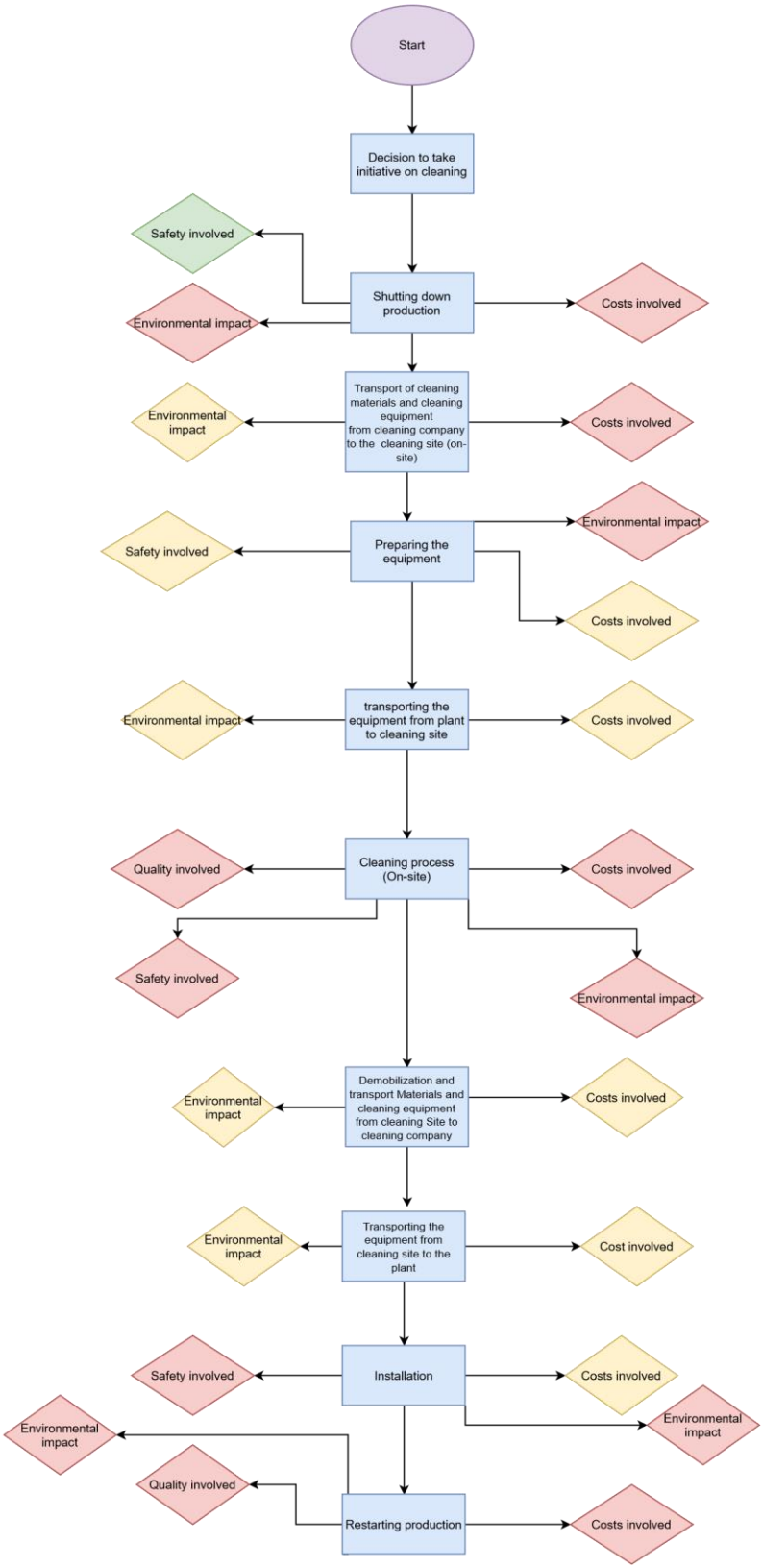
Pros:

- High frequency of usage of this process by industrial companies.

Cons:

- Does possess a high amount of process step, meaning less accurate if a the user wishes to use the quantification system.

6.2.3 design option 2- off-site cleaning



The offsite cleaning route shares the top spot with the on-site cleaning route which allows for more accuracy in quantifying the factors as it would include each factor that an industrial company would need to calculate due to the large amount of steps.

The down side of this cleaning process route is that it is not frequently used (Only in 20% of the cases), in fact its use is much less than the 2 other designs. Therefore if the quantification system is based on this design, the usage of the quantification will be low since industrial companies do not usually go through the off-site cleaning option.

To summarize, Down below can be found the list of pros and cons:

Pros:

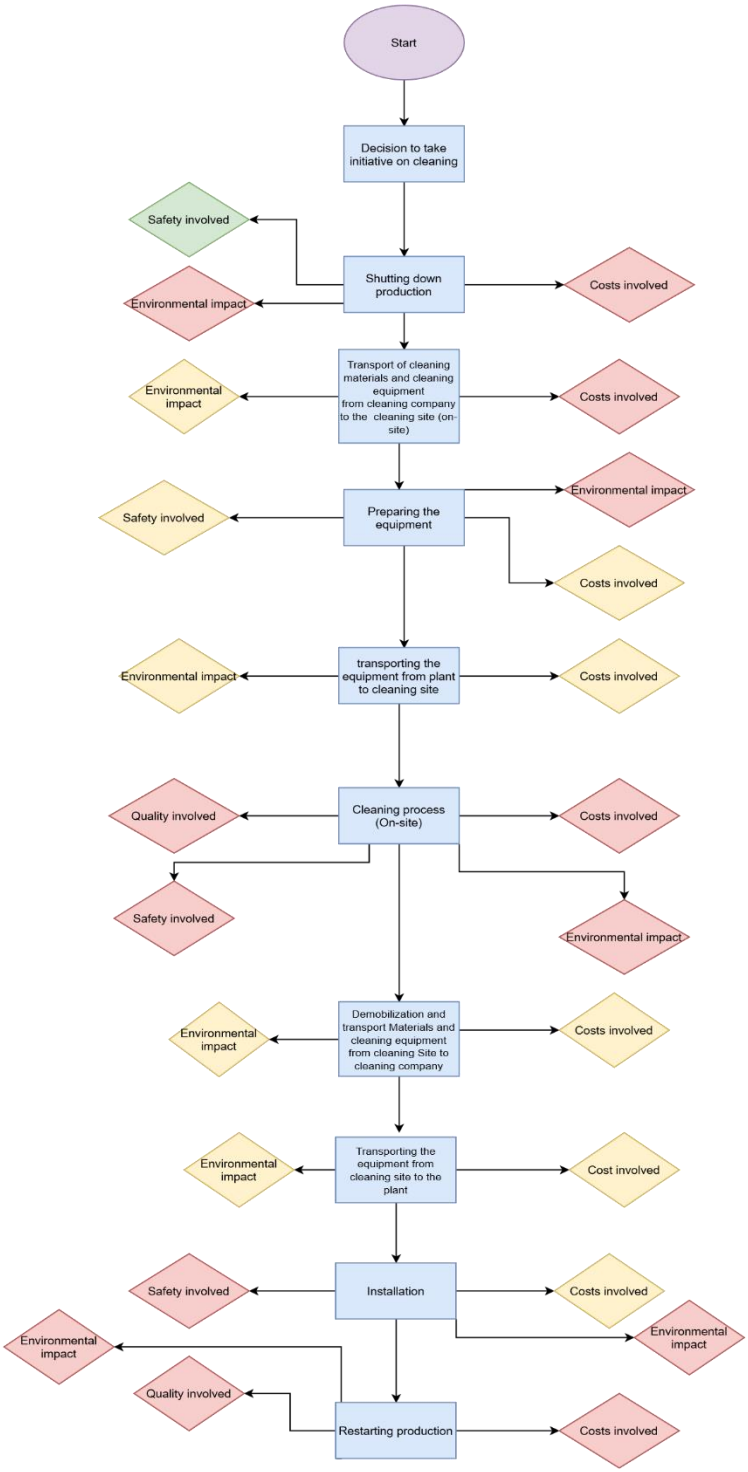
- Taking this design in account when creating the quantification system will result in a good level of accuracy.

Cons:

- Low level of off-site cleaning happening in industrial companies, meaning this would result in low level of usage of quantification system.

6.2.4 design option 3- On-site cleaning

Note: For a better view, the user can zoom and the text will clear out.



The on-site cleaning process goes through all of the cleaning process steps (Found in the process analysis) that can be taken into account to help effectively create an accurate quantifying system, it shares the top spot for the frequency of using this route for the process of cleaning with the in-situ cleaning (in plant cleaning) with the rate of a shared 80% of the cases between the 2.

It also allows for the use for the vast majority of the cleaning methods, meaning that taking this design into account when creating the quantifying system will lead to enabling the quantification for a great amount of cleaning methods by the user.

However one thing that slacks when taking this design is that it is more costly that in-situ cleaning, but this have a positive effect as more factors will be placed in the quantifying system which will allow for more accurate results when calculating the costs factors

Therefore to summarize, below can be found the list of pros and cons

Pros:

- High frequency of using this route meaning that taking this design will be highly effective for industrial companies when creating the quantification system.
- Allow for a vast majority of cleaning methods to be quantified.

Cons:

- Will result in more costs in the quantification system then In-situ cleaning

6.2.5 Final design (selected option to build quantification system)

Now that the design options that will be the basis of the quantification system have been drawn out and explained, a list of factors will be created to help us select which design are we going to choose.

The factors that will be used to access which design will be implemented in the quantification system are the following:

1- **The frequency of usage:** the frequency of cleaning refers to the amount of times a company relies on using said cleaning process route, the higher the frequency of usage, the higher the likeliness that the design will be implanted in the quantification system.
2- **Cleaning method possibility:** The cleaning method possibility refers to how many cleaning methods can be used by the each design, the higher the cleaning methods range of possibility of usage the higher the likeliness for it to be selected to be implemented into the quantification system.
3- **The length of the process:** The length of the process refers to how many steps need to be taken for the cleaning process to happen, the higher the length of the process the more likely it will be implemented into the quantification system, and this due to offering more options to fill in the factors leading to more accuracy.

The table below will determine which design will be selected to go forward with to build the quantification system.

The rating will be based from 1 to 5, 1 being the lowest and least favorable and 5 being the highest and the most favorable.

Criteria	Design 1 (In-situ)	Design 2 (On-site)	Design 3 (Off-site)	Weight	Total Design 1	Total design 2	Total design 3
Frequency of usage	5	4	1	5	25	5	20
Cleaning method possibility	3	5	5	3	9	15	15
Length of process	2	5	5	5	10	25	25
Total					**44**	**45**	**60**

Table 1.4: Decision making model

The final results demonstrate that the design 3 (On-site cleaning process) is the process that will be used in the implementation of the quantification system.

6.3- Developing an approach for quantifying factors

When it comes to providing an accurate quantification system for a certain factor, multiple different components have to be researched and through experts knowledge as well as desk research to find a guide on choosing all of the elements which will be factored into our quantification approach.

In this section the reader can identify which are the possible elements that could be placed in each factor, thus allowing the project leader to accurately build the quantification system.

6.3.1 Approach for quantifying the Environmental impact and circularity

The environmental impact and circularity is one of the main defining factors of this report, if not the actual main defining factor. Each and every step of the process has a certain environmental impact it could cause for the planet, going from the second step of the process to the last one.

However, each step of the process has different affect due to the nature of the process, as some may not cause as much harm as others and some could use the benefit of circularity which allows us to recycle the waste which would result in the final waste to be re-used.

In the following parts of this paragraph the project team is going to thoroughly expand on what these elements which would affect the environmental impact and circularity and in which step of the total process do they relate to (Excel file).

1- ***Energy usage:*** Energy is the basic form to get a process going in a cleaning method. This could simply be the electricity used if the cleaning method requires it. This part is important to mention as energy usage does affect the air and water pollution.
2- ***Water usage:*** For most of the mechanical methods in use by the company, water is a very frequent substance used for the cleaning methods. The reason for water usage being a significant element in the environmental impact factor is because once the waste water has been collected, if it is too toxic then it must be boiled instead of recycled, this would lead to a higher carbon footprint and synonymously lead to a higher level of pollution.
3- ***Chemical usage:*** Chemical cleaning method are some of the most effective cleaning methods that are in place in the cleaning industry. However, if the chemical cleaning residue is not handled properly, or the chemical cleaning itself is not handled properly, then the damage it could cause to the environment is of heavy cost, both to the price and our planet. For this reason, chemical cleaning is a strong element when it comes to quantifying the environmental impact and circularity factor.
4- ***Fuel:*** Apart from the fact that some cleaning methods require fuel for them to function, some of the other parts of the total process require fuel such as transport. The burning of fuel, depending on which fuel could cause various concerns for the environmental impact and pollution by leading to the release of gases such as carbon monoxide, carbon dioxide and nitrogen oxides. Though it is an essential part when providing the cleaning service, it holds its place when quantifying the environmental impact and circularity factor.
5- ***Recycling wastewater:*** Wastewater is a part of the final residue when the cleaning process has been taken place. Sometimes due to the toxicity of the wastewater, it must be boiled due to it not having a possibility for re-cycling. However, The product waste

water, often times can be recycled and re-used in the cleaning process, and if the waste is too dissolved in the water, then it can sometimes go into a process which will turn this dissolved water in a biological treatment for the next waste water batches. This is a strong element for the circularity part of the total factor.

6- ***Residue disposal:*** Once the recycling process has taken place the residue must be taken care of properly. Since 99% of the residue cannot be put to use, the residue is then disposed in the ocean or sewer systems. However, sometimes due to the level of toxicity, the company cannot dispose the residue and must go through a process called incineration.
7- ***Incineration*** As mentioned before the final product of the cleaning process is a final residue. However, re-using the residue is not always an option at times which would lead us to destroying the final waste which could be done through burning it. This of course affect the environmental impact factor due to the fuel levels used.

6.3.2 Approach for quantifying cost factors

Costs are one of the additional factors which have been added to the total general factors, and to successfully go through quantifying this factors the user must take into consideration all of the factors which are present through past documents as well as contact through experts.

After some thorough analyzing and researching the project leader has determined the factors which will decide on the final price of the total cleaning and all other relevant factors which fall under the total price of costs and these are the following:

1- ***Cost of the cleaning method:*** Each different cleaning method ranging from mechanical to chemical has a certain fixed price the company willing to do the cleaning job for the industrial companies. This costs factors in the energy levels, as well as the substance used to clean this certain equipment such chemicals or water.
2- ***Non-hazardous cost of disposal:*** Once cleaning has taken place, a final residue is left which needs to be dealt with. There are 2 different types of residues which need to be disposed, hazardous which could be extremely harmful for the environment and non-hazardous residues which do not cause as much risk to the environment. For the non-hazardous and can disposed more easily, However they still need to be factored into the costs as money is spend on them.
3- ***Hazardous cost of disposal:*** As stated earlier, there are 2 different types of residues which need to be disposed. And for the hazardous materials it is much more of a challenge as they could cause a much higher level of harm to the environment if not disposed correctly.
4- ***Costs of containment:*** Once the hazardous residue has been disposed successfully, it must be handled and contained extremely carefully, this also factors into the costs.
5- ***Man hour costs:*** Each and every step needed to be taken during the total cleaning process require people to complete these processes. Therefore the man hour costs represent the total costs of all hours per people working on that certain task which is related the cleaning process taking place.
6- ***Transport costs:*** Some processes requires that the equipment needed to be cleaned need to be transported to a certain area to be to cleaned safely and successfully, these amount

to some of the transport costs. Other transport costs fall also under the transport of the final residue which needs to be disposed once the cleaning has been completed. Another important note to have is that transportation is split into 2 different sections, horizontal transportation and Vertical transportation, and the difference between the 2 is that horizontal transportation deals with transportation on the road, and vertical transportation deals with vertical transportation types such as the use of cranes to lift the equipment to be cleaned.

7- ***Costs due to loss of production:*** Once a exchanger heater needs to be cleaned it must be dismantled and taken to the cleaning place and be cleaned. While this is happening the production must stop therefore causing the industrial company to lose production time. On top of that the first couple of batches that do end up coming from the first hours of production once the equipment has been cleaned can be used as a product therefore will amount to more costs for the company.
8- ***Costs due to time taken:*** another important factors which stands for all of these steps is the time taken. Each and every hour spent off from the production results in costs, the man hours spent for the workers to due to their job, whether be it transportation, cleaning or installation results in costs. Therefore, time stands high on the list of the cost factors, however, can be taken into account with the other factors.
9- ***PPE Costs (Personal protective equipment):*** Often times, when the person cleaning is at risk of injuring themselves when preforming a certain cleaning method, they are required to be wearing personal protective equipment (or respiratory air protection) to prevent that from happening. These PPE add on to the total costs of the cleaning process.
10- ***Rental of equipment:*** In the industrial cleaning industry, there are certain cleaning methods which require a certain piece of equipment which if purchased could end costing the coming a digit in the 6 figures range. For this reason, when that is the case, the company would end up leasing that certain cleaning method equipment and use it for the time being. This would also add up in the costs of the cleaning process if applicable.
11- ***Scaffolding:*** At certain times, working on heights s necessary for certain equipment to be cleaned, to ensure the safety of the cleaning operator, scaffolding must be present for the cleaning scene to take place. Therefore, scaffolding adds to the costs.
12- ***Long term vs short term pricing:*** Due to the effectiveness of some cleaning methods comparatively to others, they would need to preform one cleaning cycle per year comparatively to other which would require one per month. This comes at a higher initial cost, however if the monthly one costs where added together for the same period, then the long-term method would be less costly then he short term cleaning method. This could help to reduce the costs of cleaning when preparing for choosing a cleaning method.
13- ***Emergency ambulance and firefighters:*** At times, the cleaning method could potentially cause significant harm or injury to the person preforming it in case of an operational accident. For that reason, a standby emergency ambulance is required to be on site to potentially treat the person preforming the cleaning in case of an accident. The standby ambulance factors into the cost.

6.3.3 Approach for quantifying the Quality factor

The quality of cleaning is essentially the linking factor between all of the stated factors. It is important to accurately identify what are the quality elements which will be factored. Low quality will cost the cleaning company time, additional expenses and some heavy environmental effects if the cleaning must be done repetitively.

Therefore, the project team has analyzed and concluded all of the quality elements that should listed and calculated when it comes to the quantification of the quality factor to ensure a level of great accuracy. Below are the elements which have been decided to be fit for quantifying the quality factor:

1- ***Cleaning cycle length:*** When it comes to quantifying the quality the factor, the cycle length of a cleaning method is a fairly important indicator, as a higher quality cleaning method would result in a smaller cleaning cycle length (given the circumstance that the period of which the regular schedule of cleaning them is the same)
2- ***Cleaning cycle schedule:*** Different cleaning methods result in different cleaning schedule such as water jetting could be scheduled for every 3 weeks which a chemical cleaning method would be scheduled to take place every 9 months. The reason why these 2 cleaning methods have an extreme difference between is due to quality of cleaning which ensure that the component cleaned can operate for a larger time span before needing another cleaning cycle.
3- ***Effect on equipment:*** All industrial companies would want their equipment to stay in a sharp shape and intact when they are ready for use after a cleaning cycle. However, some cleaning methods (or perhaps transport), may lead to some damages to the equipment in the short term or long term depending on the cleaning method. For this reason, this effect they have on the equipment is a quality indicator when it comes to the total equipment cycle.
4- ***Timing of cleaning:*** The quality of cleaning could different between season and even the time of the day. This is due to having extreme cold or extreme heat which could affect the quality of cleaning. Night cleaning and morning cleaning also could cause a difference in the quality of cleaning due to the clearness for the cleaning operator.
5- ***Level of cleanliness:*** When cleaning a certain piece of equipment some cleaning methods work better for certain types of fouling, leading to a higher level of total cleanliness of the equipment a the end of a cycle. This part of the quality factor relates to the cleaning schedule as a longer schedule between he periods of cleaning cycles indicates that the level of cleanliness the cleaning method provides for that certain type of fouling is higher than the other compared method.
6- ***Concentration of the cleaning agent:*** When cleaning an equipment the concentration of the cleaning agent used could either lead to a higher or lower level of quality (due to damages) depending on the cleaning method. For this reason, quality depends on the concentration of cleaning agent being used whether it is chemical, mechanical or thermal.

Due to the quality factor having no numeric value, an evaluation will be made and a system will be built to quantifying it through calculating these factors, which will eventually lead to a certain scale where they can be rated according with a rating of 1 to 10, 1 being the worst rating, and 10 being the best rating.

6.3.4 Approach for quantifying the Safety factor

When preforming a cleaning method, safety is a very important factor to take into account, as the wellness and safety of the operator preforming the task is of major relevancy for the company.

However, as we know, different cleaning methods could pose different risks when it comes to the safety of the operator, thus the caution and measure that must be taken by the company and the operator highly vary from one cleaning method to another.

Therefore, in this section of the report, the project team will be identifying what are the relevant elements that should be taking into account when it comes to quantifying the safety factor, from the beginning of the process, until the end. These elements are the following:

1- ***Injury severity level:*** As stated above, different cleaning methods require different measure, and one of the main reasons for that is the injury severity level that could be caused by that certain cleaning method. Water jetting if not preformed properly could lead to the loss of a limb of the person preforming the task, and this is why it is important to know beforehand what could be the injury severity level from the cleaning method that is going to take place, to work on eliminating that possibility.
2- ***PPE requirements (Personal protective equipment):*** As it is known the basic level of PPE's are always required to be worn by the operator preforming the cleaning task (such as specific shoes and a helmet). However some other cleaning methods could require much more than that such as a respiratory such as respiratory air protection.
3- ***Emergency Specialists:*** While in many of the cases the cleaning method is relatively safer to preform after giving the operator the needed training. Sometimes a cleaning method could lead to high levels of danger where an emergency ambulance or fire fighters must there on sight before the cleaning method take places. This plays a major role in the safety factor.
4- ***Training level needed:*** Going from one cleaning category to another, the training level of the operator preforming the cleaning tasks will require varying levels of training when it comes to preforming the cleaning method. This is due to the knowledge needed on the hazards and how to exactly preform the task.
5- ***Possibility of injury:*** Other than the severity of the injury itself, the level of the possibility of an injury happening also plays a role when it comes to quantifying a cleaning method. If a cleaning method needs much less cleaning cycle and has a relatively low level of contact with the operator, then it could be considered safer than

a cleaning method which takes place on a more frequent level and has a good amount of contact between the operator and the cleaning method.

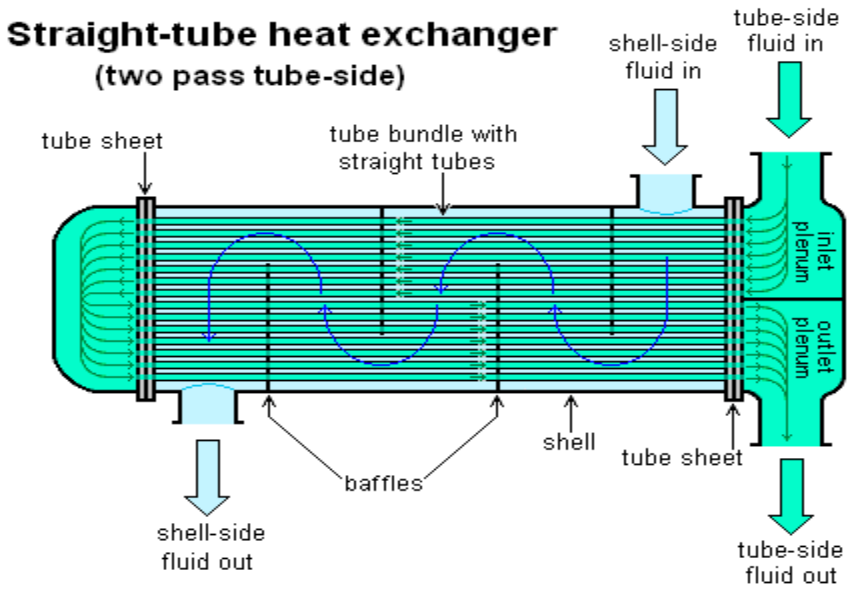
6- ***Working with heights:*** Some of the equipment which need to be cleaned require working on heights by the operators, this could pose some serious issues on the operators safety if the corrects measure are not taken into account. For this reason working on heights must be put as an element when calculating the safety factor.
7- ***Different physical safety aspects:*** Many different cleaning methods could pose different physical safety issues, some could potentially lead to blindness in the worst case scenario (affecting the eyes), whereas some others could lead to the loss of hearing (affecting hearing ability) or the loss of a limb (affecting the body parts). For this reason it is important to found out what are the potential risks on the different physical safety aspects to take initiative when preforming the cleaning method.

Due to the safety factor having no numeric value, an evaluation will be made and a system will be built to quantifying it through calculating these factors, which will eventually lead to a certain scale where they can be rated according with a rating of 1 to 10, 1 being the worst rating, and 10 being the best.

6.4- Quantification system on heat exchanger

Since the quantification of the factors has been thoroughly determined and confirmed, the next steps of the project is build the quantification system and to apply this knowledge that has been gained on quantification of the factors and apply it **cleaning heat exchangers using high pressure cleaning** on the selected design for the process of cleaning (On-site cleaning)

Due to the availability of various types of heat exchangers, the example that will be used is will be based on shell and tube heat exchangers, meaning that the numerical values found in the excel document signify high pressure cleaning a shell and tube heat exchanger.



(Shell and tube heat exchanger, Fig 1.3)

The project team will be building up the quantitative research of cleaning heat exchangers through researching the elements mentioned in the flow chart (Excel file) per step of the process thus gaining a final quantified table on the cleaning of heat exchangers using high pressure cleaning as an example on the functioning quantifying system.

6.4.1 –Implementation- Quantification system with example (high pressure cleaning a heat exchanger)

By taking into account, the determined factors and the selected example, the quantification system has been successfully built. Due to the inability of placing the excel file in a word document the files will be submitted through pdf files down below (note, please refer to the Excel file attached to the submission email):

the user must check excel file "Quantification system"

6.4.2– Building an applicable usage strategy -Guide- Factors vs process step

Since all of the quantifiable factors have been thoroughly analyzed and explained, a quantification system has been built with all of the 4 main factors which are: environmental impact and circularity, safety, quality and costs.

The first step was to create a page with all of the process steps and what possible elements could fit in each process step as seen below, the completed file can be found in "**Excel file (Factors vs process step (General information) "**

	Quantifiable factors			
Process steps	**Environmental impact/ Circularity**	**Costs involved**	**Quality involved**	**Safety involved**
1- Decision to take initiative on cleaning	X	1- Cost due to loss of production 2- Cost due to time taken	X	X
2 - Shutting down production	1- Energy usage 2- Production waste	1-Cost due to loss of production 2- Cost due to time taken	X	X
3 - Preparing the equipment	1- Fuel 2- carbon footprint	1- Cost due to time taken 2- Man hours cost 3- PPE costs 4- Costs due to loss of production 5- Vertical Transport costs (Fuel)	X	1- Training level needed
4- Transport of cleaning materials and cleaning equipment from supplier to the site (mobilization):	1- Fuel 2- carbon footprint	1- Cost due to time taken 2- Man hours cost 3- Horizontal Transport costs (Fuel) 4-Cost due to loss of production	X	X
5- Transporting the equipment from plant to cleaning site (Horizontal transport)	1- Fuel 2- carbon footprint	1- Cost due to time taken 2- Man hours costs 3- Horizontal transport costs (Fuel) 4- Costs due to loss of production	1- Effect on equipment	X

The goal of this page in excel is to provide the reader with what element (6.3, Developing an approach to quantifying factors) fits in which exact part of the factors mentioned per process step, this lay down every possible element that the user can utilize to achieve a final accurate quantifying of the factors per process step and a total of the entire cleaning method.

And once all of the elements in each factor have been filled in, 4 different sheets have been created covering all of the main discussed factors, with a coded system which allows the user to make the changes in the cells they wish and always end up with an accurate number. A further explanation can be found below each factor and their sheet.

6.4.3– Building an applicable usage strategy - Guide- Environmental footprint and circularity

The use of this quantification system is quiet simple and contains general information as well as specified information which could be changed by the user if they wish to figure out their factors costs, environmental impact, safety rating and quality rating. This system is coded through excel and will automatically change if any values have been changed to provide the maximum amount of accuracy to receive the final quantified factors.

An explanation will be provided down below starting with the environmental factor quantification, with a picture which allows reader to understand more on this concept for the quantification of the factors.

Process step	Elements involved (Environmental impact)	Time required (In hours)	Production period	Distance travelled (In kilometers)	Units required	Sub-totals	Carbon foorprint (kg CO2)	Totals CO2 kg	Chemical environmental hazard	Totals Water Litres
							2.62			
6- On-site cleaning process	Pump Fuel	6.00	X	X	1	736.01	1928.34			
	Water usage	6.00	X	X	1	46800				
	Chemical usage	0	X	X	X	0				
	recycling of water	X	X	X	-1	-30420				
	Incineration	1	X	X	X	659	1726.58			
	Electrical generation (during incineration)	1	X	X	-1	-500	-116			
	Environmental footprint							3538.92	0.00	16380

As seen from this picture, the research group decided to showcase the cleaning process part as it is the most important in the entire process, the user can find the entire document in **"6.4.1 Quantification system with example (Environmental impact)".**

Each and every element needed to calculate the environmental impact is present on the Y axis, while the factors which would ultimately decide on the value that the elements will provide are found on the X axis. Since the project team has decide to use example of cleaning heat exchanger through high pressure cleaning, the timing required for the cleaning operation that has been selected was 6 hours, and the units required were 1 pump, the excel file has been coded to directly give us a sub-total as seen in the picture which would ultimately lead us to get our answer with its specified unit as seen marked in red.

As seen in "recycling of water" the units value is a negative number due to the reason that it will be subtracted from the total water used.

Each red note placed on the elements symbolizes important information such as what the units are, and other related information such why there are negative numbers.

The X letter symbolizes that that the certain element select in the factor does not require that part for the calculation.

Once the subtotals have been calculated, the excel file will automatically determine the carbon footprint, the chemical environmental damage and the total water usage, which are our main indicators for the environmental factors.

At the bottom of the document in the final row, a final total of the environmental determining factors (carbon footprint, the chemical environmental damage and the total water usage) can found as seen in the picture above.

6.4.4– Building an applicable usage strategy - Guide- Costs

As mentioned in the environmental impact quantification sheet, the use of this quantification system is quiet simple, this is due to the current coding of the excel file which allows you to alter the number that are mentioned to the degree of the industrial cleaning in terms of costs.

The X axis refers to the parameters needed to be put in use to calculate the elements that have been mentioned in each process step (6.4.2 Building an applicable strategy-guide- factor vs process step), while the Y axis refer to all of the process steps as well as the elements required for the quantification of the costs factors

Process step	Elements involved (Costs factor)	Costs (j) per hour	Transport cost	parameter per cubic meter	Time taken (in hours)	Units required	Rental package	Costs (j) per Distance covered (KM)	Total distance covered (KM)	Subtotal (j)
7- Demobilization and transport Materials and cleaning equipment from Site to Cleaning company	Truck usage cost	2	X	X	X	1	X	X	18.7	37.4
	Costs due to loss of production	2000	X	X	0.5	X	X	X	X	1000
	Horizontal transport costs (Fuel)	X	X	X	X	1	X	0.375	18.7	7.0125
8- Transporting the equipment from cleaning site to plant (Horizontal transport)	Labor costs	16	X	X	1	1	X	X	X	16
	Costs due to loss of production	2000	X	X	0.5	X	X	X	X	1000
	Truck usage cost	2	X	X	X	1	X	X	3	6
	Horizontal transport costs (Fuel)	X	X	X	X	1	X	0.375	3	1.125
	Vertical transport costs (Fuel for cranes)	54	X	X	0.5	1	X	X	X	27
	Vertical transport costs (Fuel for forklifts)	40.5	X	X	0.5	1	X	X	X	20.25
9- Installation	Vertical transport costs (Fuel for cranes)	54	X	X	0.5	1	X	X	X	27
	PPE Costs	56.47	X	X	X	1	X	X	X	56.47
	Vertical transport costs (Fuel for forklifts)	40.5	X	X	0.5	1	X	X	X	20.25
	Technician	100	X	X	1	2	X	X	X	200
	Costs due to loss of production	2000	X	X	0.5	X	X	X	X	1000
	Labor costs	32.58	X	X	1	3	X	X	X	97.74
10-Restarting production	Costs due to loss of production	2000	X	X	24	X	X	X	X	48000
Total cost										83278.235

What this quantification system allows for any user to alternate the information in the following slots and still achieve the final quantification of the cleaning method that they are using, with all of the needed parameters and elements of the factor (costs) needed.

This works through placing your information matching both the elements and parameters (placed on the X axis)needed to achieve a final calculation, and once all of the calculations have been placed in the correct spot, the subtotal will them be automatically calculated, later leading on the having the total costs of the entire cleaning process as well as the loss of production when stopping and restarting production as the few couple of batches and the last few couple of batches from the production process cannot be used as a product.

6.4.5– Building an applicable usage strategy - Guide- Quality

When it comes to the quantification of the quality process, a different approach is taken due to there being no numerical values to be taken into account when calculating the level of quality that a cleaning method provides. Therefore, the parameters that have been selected to provide the best insight on what quality a cleaning method provide have been selected after heavy and thorough discussions with the core team and cleaning companies and build a quantification system while deciding their rating system depending on how good or bad of a quality they would indicate.

	possible damage rating analysis		Time required for cleaning rating	Visual Assessment	Eddy current test rating	Frequency of cleaning rating	Final rating analysis
	The possible damage indicates what could be the worst that could happen to the equipment per process step as different step could possibly cause different damage		Since the cleaning time has been given, a rating system has been created to decide the apporiate rating that should be given to the steps which require the element "cleaning cycle length"	One of the most relied on ways that companies use to assess the quality of cleaning is thorugh a simple visual assessment which ultimately provides the company with the quality level of cleaning, it is either cleaned to the working standard or not clean and must go through the cleaning process again	The eddy current test, is a way that companies determine the level of fouling inside the tubes of heat exchangers as it is used to detect non ferrous/ non magnetic materials, this will determine the level of cleanliness inside of the tubes.the final eddy current figure comes in a percentage form, and the eddy current test cannot take place unless the the clealiness level of the pipes is over 80%	The fequency of cleaning indicates how often does a cleaning method needs to take place. The lower the frequency the higher the rating of quality	The final rating is the calculated total rating for each process step, at the bottom can be found the the total rating of the entire cleaning process, the higher the rating the better the quality, below can be found final total quality of the cleaning from a scale
	Corrosion of pipes = 2		1 to 2= 2	Not approved = 0	> 80% = 0	1 to 5 = 2	
	interior pipe damage = 4		3 to 6 = 4	approved = 10	80% to 90%= 5	6 to 11 = 4	
	Exterior pipe damage = 6		1 to 2= 6		91% to 100%= 10	1 to 2 = 6	
	Little to no damage = 8		6 to 11 = 8			3 - 5 = 8	
			1 to 5 = 10			6 and above = 10	

Elements involved (Quality)	Possible damage	Time required for cleaning in hours	Time required for cleaning rating	Visual assessment	Eddy current test	Frequency of cleaning	Final rating
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
Effect on equipment	8	X	X	X	X	X	8
Effect on equipment	6	X	X	X	X	X	6

Once the parameters have been selected and the ratings have been decided on, a description of each parameter have been given in the yellow parts as seen in the parts and notes on the values which have been given in the squares of the values (red triangle on the edges). Once all of the parameter essentials have been built in the excel file on the X axis, the process steps as well as the elements deciding on the factor of quality have been placed on the Y axis so that each step can be matched with appropriate parameters and thus leading us to achieve a final rating for each step and then late on once that is decided, a final rating will be given to the entire process.

6.4.6– Building an applicable usage strategy - Guide- Safety

Similarly to the quality factors quantification, the rating on the parameters that have been identified do not contain numerical values, this led the team to thoroughly examine what were the possible safety risks and build an appropriate rating system which allows the user to achieve a final rating in terms of the safety of the cleaning method. A subtotal would be created for each element which would then lead the user to achieve a final total for the entire safety factor of the cleaning method chosen to be gone forth with.

		Injury severity level rating analysis	Frequency of possibility of injury	PPE and emergency rating analysis	Traning level needed (Training period)	Final rating analysis
		Different cleaning methods pose different risks on the human body if not preformed correctly. This is a major safety indicator depending on what each cleaning method could pose on the operator if cleaning is not preformed correctly.	Depending on the amount of times a cleaning method needs to take place, this could increase risk of an injury happening due to the frequency of the cleaning having to take place, for the this reason, frequency is an indicator of the safety levels of a cleaning method, (The higher the rating the safer the	When it comes to personal protective equipment, different cleaning methods require different measures of ppe and emergency set, the more dangerous the cleaning method, the more PPE are required.	Different process steps require different amount of training for the operator to be eligible to work with them, depending on the time needed	The final rating is the calculated total rating for each process step, at the bottom can be found the the total rating of the entire cleaning process, the higher the rating the better the safety, below can be found final total quality of the cleaning from a scale of 1 to 10
		Highly severe = 1	1 to 3= 2	extremely high= 2	3 to 8= 2	
		severe = 3	3 to 6= 4	High = 5	1 to 2= 4	
		Moderate = 6	7 to 12 = 6	medium = 8	1 to 4= 6	
		Minor = 10	1 to 2 = 8	basic= 10	2 to 5= 8	
			3 or more = 10		1= 10	

Process step	Elements involved (safety)	Injury severity level	frequency of possibility of injury	PPE and emergency requirements	Training level	Total rating
1- Decision to take initiative on cleaning	X	X	X	X	X	X
2 - Shutting down production	X	X	X	X	X	X
	Training level needed	X	X	X	2	2

As seen in the image above the list of process steps and elements involved in each of the process steps on the Y axis, while the parameters which are going to be used to decide on the appropriate rating of the certain elements are placed on the X axis.

Each and every parameters contains a description on the chosen parameter which is has been chosen to be a part for the assessment for the rating of the elements as seen in the yellow boxes shown above, while the pink boxes signify what exactly does each rating represent as shown in the image below,

Due to the assessment that was made to build the ratings of the following parameters, “injury severity level rating analysis” and “PPE and emergency rating analysis”, a terminology sheet has been built which allows the reader to understand what each of the parameter ratings basis mean down below,

Terminology:

Parameter	Term used	Description
Injury severity level rating analysis	Highly severe	A highly severe injury indicates a possible fatality from the cleaning method

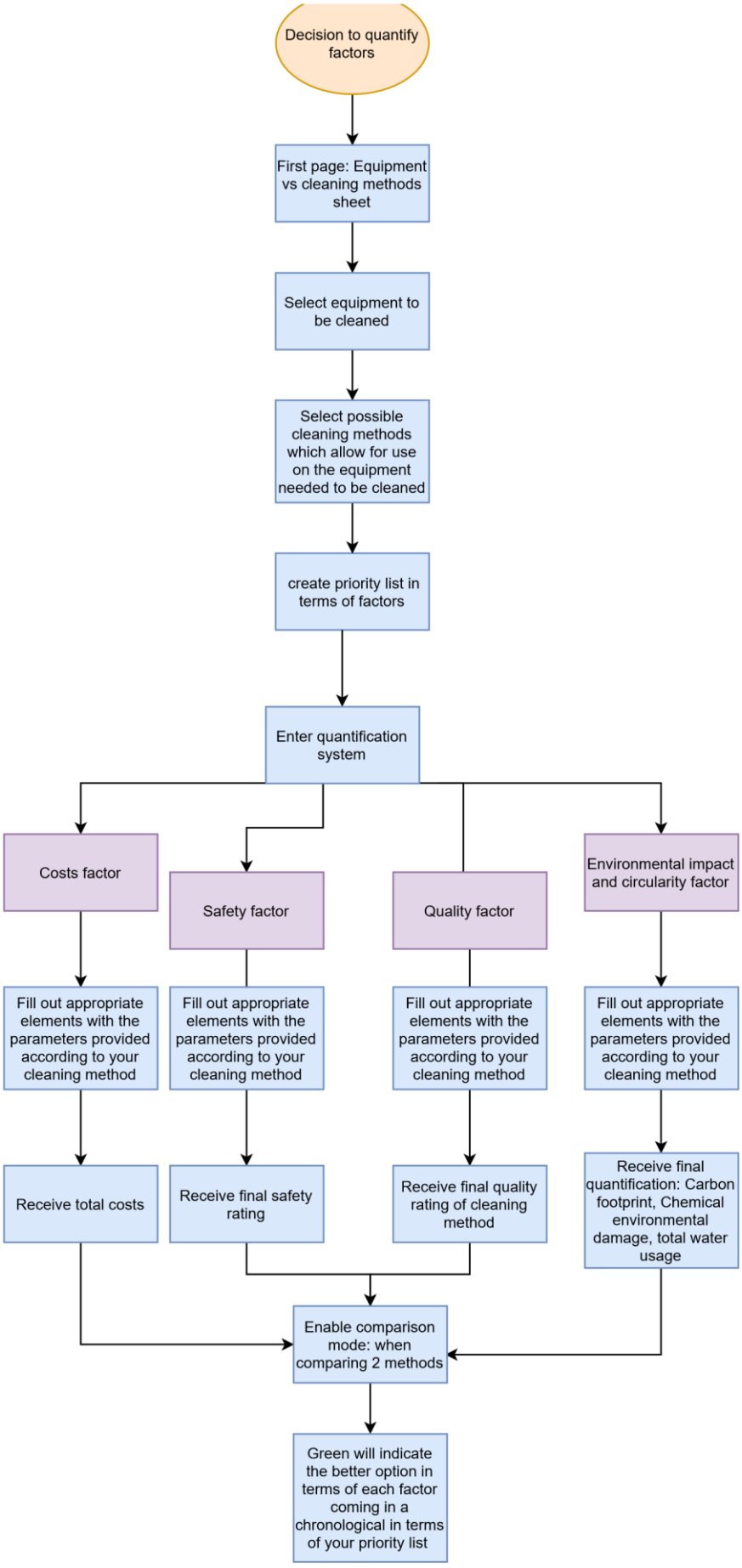
	severe	A severe injury indicates a lifelong injury, such as the loss of a limb or burns due to acid.
	Moderate	A moderate injury is one where the operator can heal from, such breaking a bone.
	Minor	A minor injury indicates a small injury such as a cut which is easily treatable
PPE and emergency rating analysis	Extremely high	An extremely high level of this parameter would require an ambulance and/or firefighting team to be there on standby due to the dangerous level of the cleaning operation
	High	A high level of PPE would include breathing protection as well as oxygen tank, due to the radioactivity of the fouling being cleaned
	Medium	Medium level PPE would include a water shield and a higher safety level helmet
	Basic	Basic PPE describes the basic PPE's worn for any cleaning method, such as safety boots, helmet and protection glasses

6.5– Proposal for an expert system

Since the main objective of the report has been completed and thoroughly checked. A proposal on an expert system will be made to allow an IT personnel to build a software or an application which can be accessed through a computer or a tablet, that way the user of the quantifying system has straight access to it from their work place and will just automatically have to fill out the lots needed to calculate the cleaning method that they please to go with and even compare it with other cleaning methods.

If we take an example that an industrial company wishes to clean their equipment but would like to go with the most environmentally friendly cleaning method given that the prices are not extremely different from one another, the will have to go through the following scheme (which is the one that will be built in an expert system).

The diagram found below will give the user a step by step guide on how a system or an app developer will go through with building this system from using the “equipment vs cleaning method” sheet to check which cleaning methods are applicable for the equipment needed to be cleaning all the way to providing a comparison between cleaning methods and indicating which cleaning method is better in terms of each filled in factor.


Decision to quantify factors
First page: Equipment vs cleaning methods sheet
Select equipment to be cleaned
Select possible cleaning methods which allow for use on the equipment needed to be cleaned
create priority list in terms of factors
Enter quantification system
Costs factor
Safety factor
Quality factor
Environmental impact and circularity factor
Fill out appropriate elements with the parameters provided according to your cleaning method
Fill out appropriate elements with the parameters provided according to your cleaning method
Fill out appropriate elements with the parameters provided according to your cleaning method
Fill out appropriate elements with the parameters provided according to your cleaning method
Receive total costs
Receive final safety rating
Receive final quality rating of cleaning method
Receive final quantification: Carbon footprint, Chemical environmental damage, total water usage
Enable comparison mode: when comparing 2 methods
Green will indicate the better option in terms of each factor coming in a chronological in terms of your priority list

7- Recommendations

Since the final implementation has been made on the final design of the flowchart process that has been chosen and thus allowed for building a quantifying system, the project leader will be proceeding to the recommendations part, where all relevant advice and recommendations will be made, to extensively explain why the use of this quantifying system should be of high priority for all industrial companies:

The following are the recommendations are drawn from the implemented product of the main report which is a well-functioning quantification system:

- This quantification system could be used by any industrial company that is trying to become more sustainable as it allows for quantifying any cleaning method considered for use.
- The use of the environmental impact and circularity page system allows for simple and accurate use for quantification, thus also enabling comparison between different cleaning methods.
- The cost quantification system allows for calculating total prices and allowing the user to select the more economic option according to their preference.
- The quality sheet has been built and reviewed by experts to ensure the closest possible ratings to accuracy. Thus, allowing the user to see which cleaning method could provide a better quality.
- The extended qualitative decision matrix serves as a great basis. It allows the user to see which cleaning methods works with equipment requiring cleaning. Hence, enabling the companies to choose appropriately between the different cleaning methods that would work for the certain piece of equipment they would like to clean.
- The quantifying system has been developed to a great extent and an approach to build it into an expert system has been provided. Therefore, it is highly advisable for an IT personnel to take up the job to build it into a software to facilitate the use for the industrial companies.

8- Conclusion

The industrial organizations are becoming increasingly aware of the sustainability issues that are arising and are planning on put a stop to the continuous damage that is affecting the globe in the following years or decade. Accordingly, KIC/MPI, an organization focused on developing projects on innovation in the maintenance-based industry, has decided to initiate this project as part of its efforts to drive change.

The main focus of this research was to build an applicable system that allows companies to calculate their environmental impact and reduce the harm caused. Additionally, this system provides other quantifying sheets for the 3 other factors (Costs, quality and safety) which are deemed important for companies to make of when choosing a cleaning method. The outcome is undoubtedly highly beneficial to the industry with implications that contribute toward a more sustainable industry.

Moreover, a further improved and extended decision matrix was developed. Additional features such as color coding were added, allowing easier use, and more importantly to be taken into account when an IT personnel decides to take up the job to build this into an expert system for more simple use.

This quantification system in addition to the qualitative decision matrix are a stepping stone to move to a more sustainable future. The system can be further developed into an expert system for use across the industry. Finally, this will help organizations move toward sustainability through operational optimization, benefiting them and the society.

9- References (APA)

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10-Appendices

Appendix 1.1

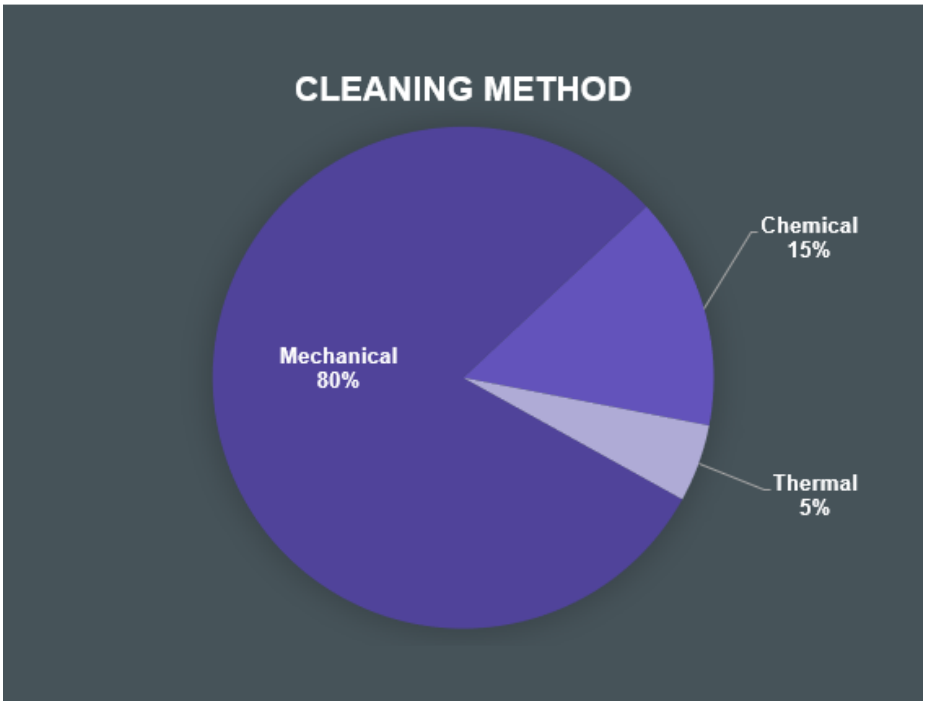

Image source: (Aiche, 2020)