ETM
ENGINEERING & TECHNOLOGY MANAGEMENT

Team Project Report:

Evaluation of Available Technology to Treat Ammonia Wastewater

Course: ETM 530/630 Decision Making

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1. Introduction

1.1 Problem Statement

In the endless pursuit of developing new products, Intel technology development cycle results in new semiconductor production process every two years. As the size of the circuit gets smaller, the manufacture process environment requires tighter controlled. The need of removal all impurities such as dust, organics, and residual filing in the fabrication process become critical to achieve high product yield.

The wafers usually are cleaned with ultra pure water and chemicals. One of the chemicals that semiconductor industry utilizes is ammonia. Ammonia and ammonium in wastewater can be toxic to the ecosystems. Toxic levels depend on ammonia concentration and waste water pH. In order to meet public own wastewater facility policy, wastewater which is containing ammonia must be treated before discharge into sewer. The rapidly changing and constantly tightening government regulation regarding water contamination gives birth to a unique situation which demands an ethical, technological and ecological solution to the problem of waste treatment.

1.2 Objective

This project focuses on identifying the most feasible technology to treat ammonia in wastewater measured as NH3-N (ammonia nitrogen) and the potential to reclaim water and ammonia for other usage. The influent concentration of a typical semiconductor company is about 10 to 70 mg/L [1]. The feasible technology must be able to reduce the ammonia concentration to 1 mg/L.

2. Project Deliverables

- Must able to treat 10 mg/L to 70 mg/L of ammonia aqueous concentration. Flow rate of the waste stream is about 50 gpm (gallon per minute)
- Effluent ammonia and ammonium concentration have to be 1 mg/L or less

- Technology must be commercially available for 50 to 60 gpm capacity
- System annual downtime have to be less than 5%
- Start time for system has to be less than 8 hours

3. Literature Review

The approach used to analyze the decision choices is the Hierarchical Decision Model (HDM) proposed by Dr. Dundar Kocaoglu. We have made an attempt to discuss the background and application logic of HDM to our decision-making problem.

3.1 Hierarchical Decision Model

HDM is a model that helps the decision maker by breaking down the decision problem into criteria and sub-criteria. Thereby, brining clarity in the various options available, and displaying lucidly the importance and utility of each option. HDM basically consists of stages that display the breakup of the decision problem [2].

3.2 Pair-wise Comparison

Pair-wise comparison method will be used to determine relative importance of each criterion. After the survey is conducted, relative scores will help us determine these weights of each criterion. These criteria will compared to each other in pairs, and the relative comparison will show us the ascending order of the victorious option.

Pair-wise comparison combined with the HDM will guide us through choosing the absolute relevant option while keeping in mind the selected criteria.

4. Available Technology Options

4.1 Biological treatment

<u>*Definition*</u>*:* The uniqueness of biological treatment lies in the fact that bacteria is introduced in the water intentionally so that it can feed on the waste and convert it to aerable gases, thereby freeing the water of its organic and ammoniacal waste. It's also called aeration/sewage treatment

<u>*Advantages:*</u>

- Considered Efficient and reliable
- Requires very less energy
- Extremely cost effective and suitable for large quantities of water

<u>*Disadvantages:*</u>

- Releases aerable gases including Carbon Dioxide
- Requires huge tanks (the volume of industrial ETP tank farms)
- Installation and construction is expensive.

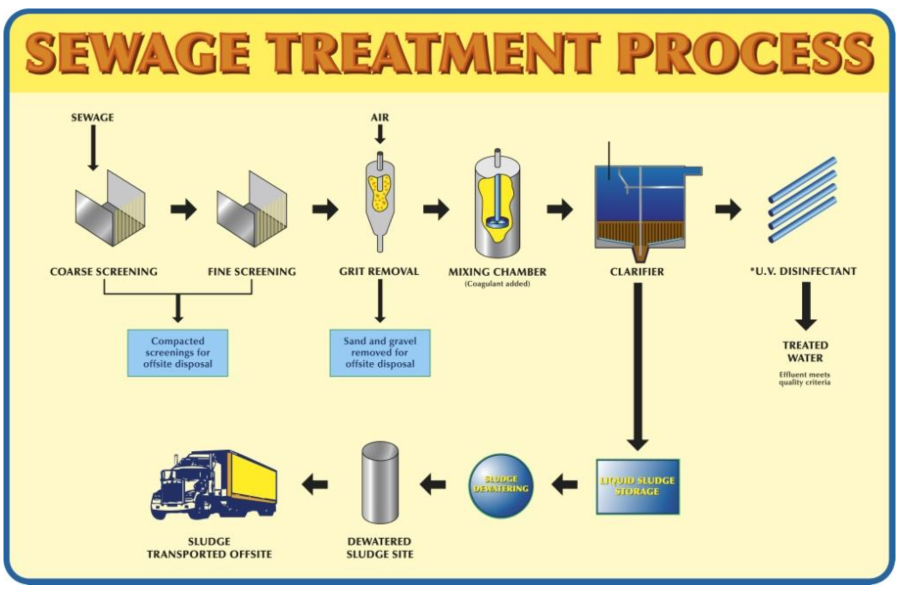


Figure 1: Sewage Treatment Process [16]

4.2 Volatilization

Definition: "Volatilization" is a method of treatment of water, by which ammonia is evaporated and extracted from the water, thereby neutralizing it and making it releasable in the environment. Volatilization is a relatively new method [16].

Advantages:

- Almost 100% efficient
- Is a proven technology and has been used in treatment of water in steel companies since two decades.
- Has been used in water treatment for lagoons and protected areas.

Disadvantages:

- Is considered dangerous, if Ammonia liberation is not controlled and monitored closely
- Requires high energy consumption in fast flowing treatment plants
- Ammonia requires sequesterization which has to be monitored (increases cost and footprint considerably)

4.3 Reverse Osmosis

Definition: A filtration method removes many types of large molecules and ions from solution by applying pressure to the solution when it is on side of a selective membrane. The result is that, the solute is retained on the pressurized side of the membrane and the pure water is allowed to pass to other side [4]

Advantages:

- Less chemicals required for this method
- Available for 50 gal/min capacity
- Filters to micron level
- Ideal process for contaminate removal [4]

Disadvantages:

- Impurities that are molecularly smaller than water can pass through
- For every gallon of water purified, it waste 2-3 gallons of water [6]

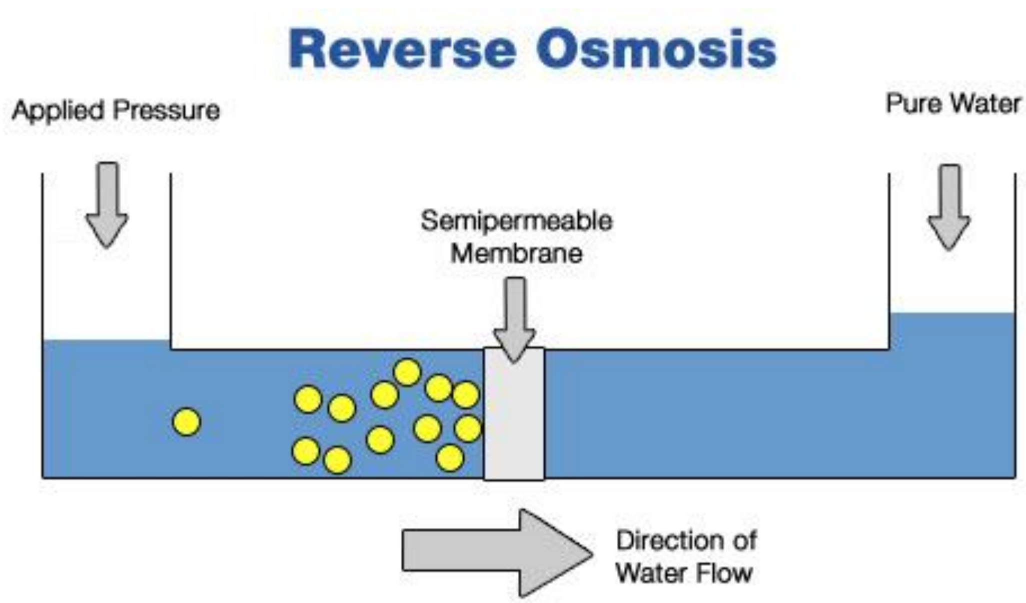


Figure 2: Reverse Osmosis Process Flow Diagram [14]

4.4 Ion Exchange

Definition: Carbon Ion Exchange is an effective versatile means of conditioning industrial wastewater. The term ion exchange is described as: water flows through a bed of ion exchange material; undesirable ions are removed and replaced with less objectionable ones.

Advantages:

- Universally used for water treatment
- High flow rates do not hamper efficiency

Disadvantages:

- Ion Exchange resin is required
- Resin has to be replaced
- Requires a very large foot print for installation of the equipment
- Frequent regeneration required [13]

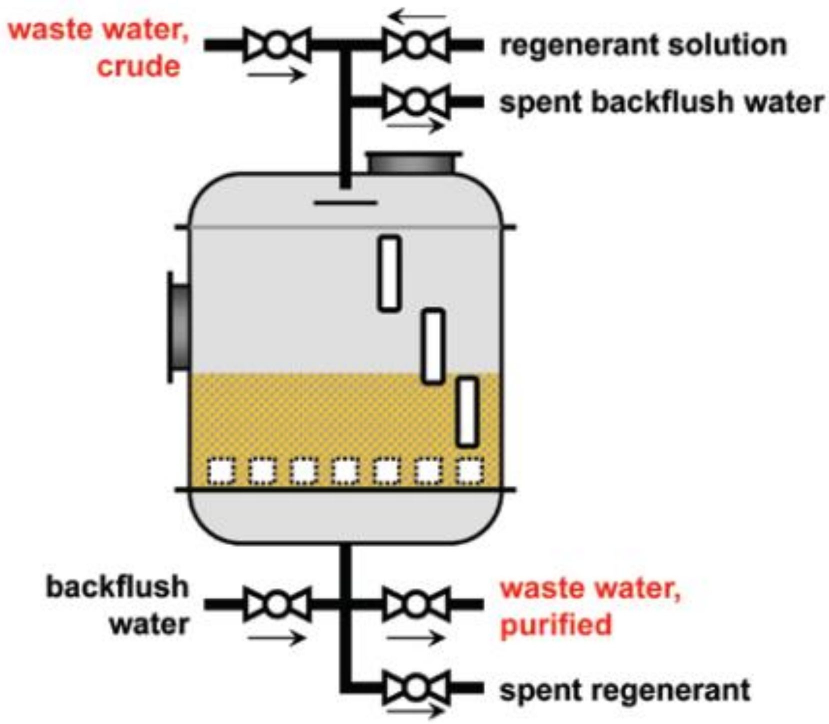


Figure 3: Ion Exchange Process Flow Diagram [15]

4.5 Catalytic Oxidation

Definition: Another technique used to separate organic compound from water is Catalytic Oxidation. This process pyrolyzes the organic compound to gaseous form. Using base metal series catalysts for nitrogenous compounds, organic compound decomposes into N2, CO2, and H2O.

Advantages:

- No waste stream

Disadvantages:

- The process is strongly temperature dependent, with NOx forming at higher temperatures. The ideal temperature for treatment is 325ºC with all NOx removed in the catalytic treatment system.
- Feed air must be preheated before entering the system; therefore, it requires higher energy cost
- Base metal catalyst was estimated to require annual replacement, and it is expensive; therefore, it requires higher operating cost [5]

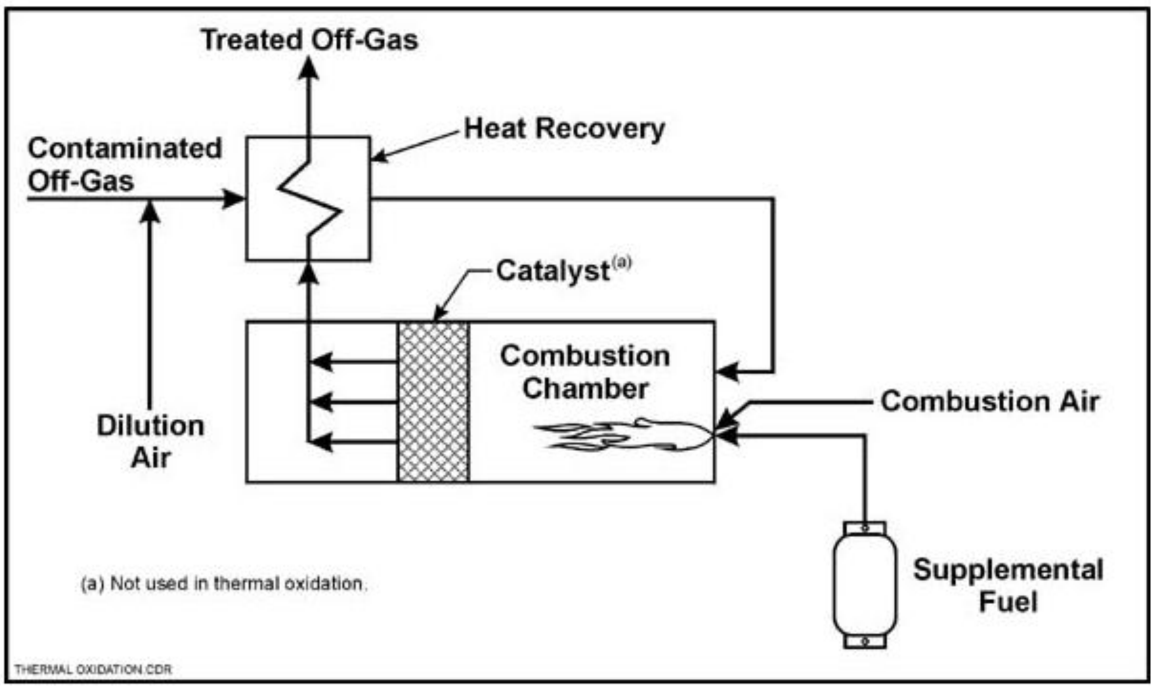


Figure 4: Catalytic Process Flow Diagram [6]

4.6 Electrodialysis

Definition: Electrodialysis is an electromembrane process in which ions are transported through ion permeable membranes from one solution to another under the influence of a potential gradient. The electrical charges on the ions allow them to be driven through the membranes fabricated from ion exchange polymers. Applying a voltage between two end electrodes generates the potential field required for this. Since the membranes used in electrodialysis have the ability to selectively transport ions having positive or negative charge and reject ions of the opposite charge, useful concentration, removal, or separation of electrolytes can be achieved by Electrodialysis [7].

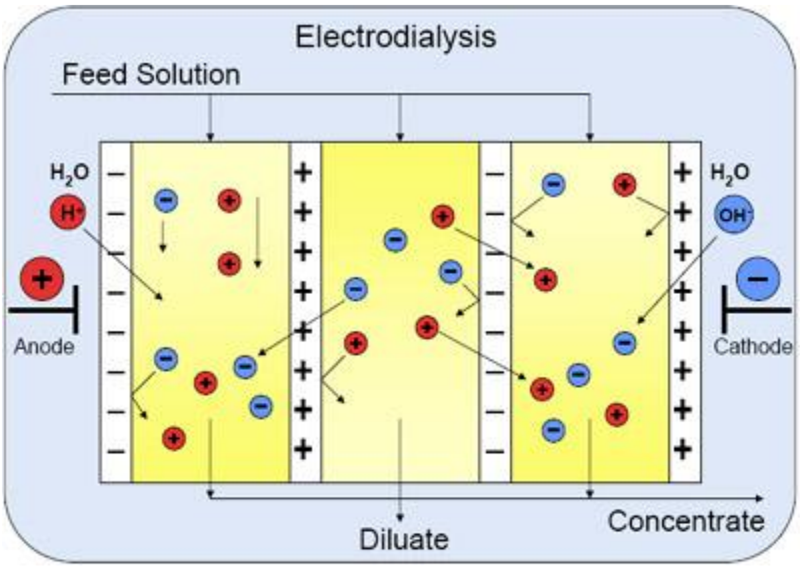


Figure 5: Electrodialysis Process Flow Diagram [8]

Advantages:

- Ability to recycle water and ammonia
- No phase change during separation process which results in relatively low energy consumption
- Proven technology. Many applications in different industry
- Scalable process

Disadvantages:

- Require pretreatment to prevent system stacks fouling
- Difficult to keep system at optimum condition

4.7 Air Stripping (Gas Absorption)

Definition: Air stripping is a technology in which volatile organic compounds (VOCs) are transferred from extracted water to air. Typically, air stripping takes place in a packed tower (known as an air stripper) or an aeration tank. The "air stripper" includes a spray nozzle at the top of the tower. It sprays groundwater that has been pumped to the surface over the packing in the column. As the water descends, air is forced up through the column, stripping off the volatile compounds. Packing or baffles within the tower increase the surface area of the contaminated water that is exposed to air, thus maximizing the amount of volatilization. A sump at the bottom of the tower collects decontaminated water. Auxiliary equipment may include an air heater to improve removal efficiency and air emission "scrubbers." [9]

Advantage:

- Low initial cost
- Low operating cost
- Ammonia stripped can be absorbed by HCl to form NH_4Cl which can be used a mother liquor or to be absorbed by sulfuric acid to produce byproduct of ammonium sulfate or to be absorbed by water to produce ammonia [10]

Disadvantages:

- Removal efficiency is limited by operating temperature [11]

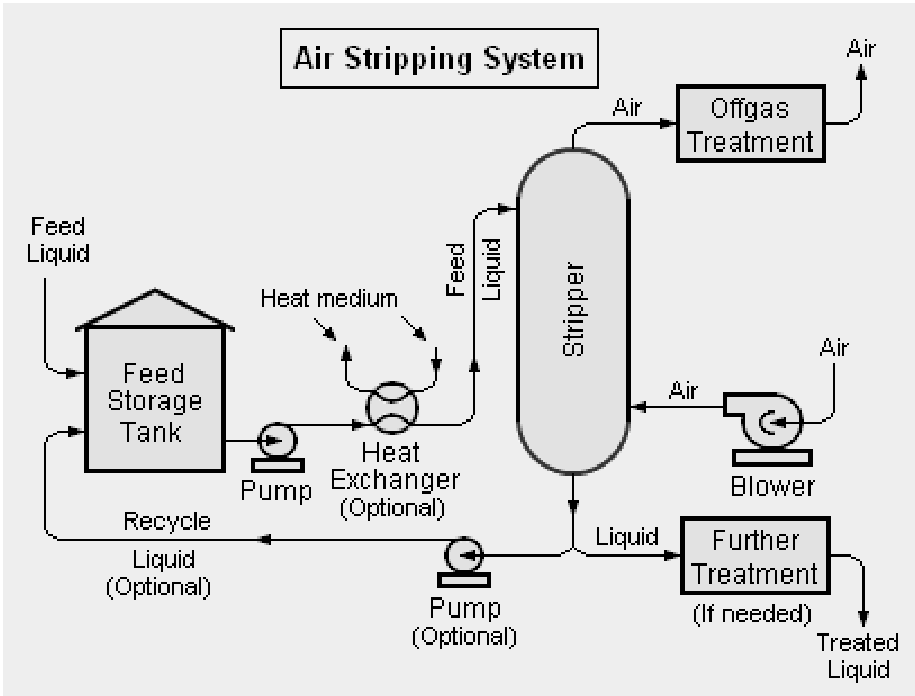


Figure 6: Air Stripping System Process Flow Diagram [12]

5. Methodology

Our model comprises of three different stages. The lowest of the stages lists the 7 technology options available. The second stage (after the mission) lists the three main criteria for selection of the technology. These criteria are Technological Feasibility, Usability and Finance. Under these three criteria is a stage that mentions detailed sub-criteria. The high-level objectives form the second stage of the model. All technology options will be rigorously analyzed and will have to successfully pass through all the three stages in order to reach the top most stage, which is the mission of selection the best water treatment technology.

In the first tier; the three criteria were examined by employees of the company after the survey we wanted to conclude which one was the most crucial for the company. This would allow us to examine the sub-criteria in thorough detail. Each of the sub-criteria was also examined using a survey which was inclusive of both employees as well as academic faculty.

The input from the academic faculty was very critical at this stage as complete technology knowledge was an essential participant in this process. The mix of academic and corporate participants within this methodology allowed us to come to an unbiased conclusion of selecting the best of the seven options available.

Since the mix of these participants was uniquely designed, we were very well placed to eliminate inconsistencies in this methodology. The combination of participants gave us valid and reasonable inputs of technology matching with important criteria. After conducting a thorough survey for all the criteria, sub-criteria and technology options, we derived that technological feasibility was most important for the user and usability (safety) stood second.

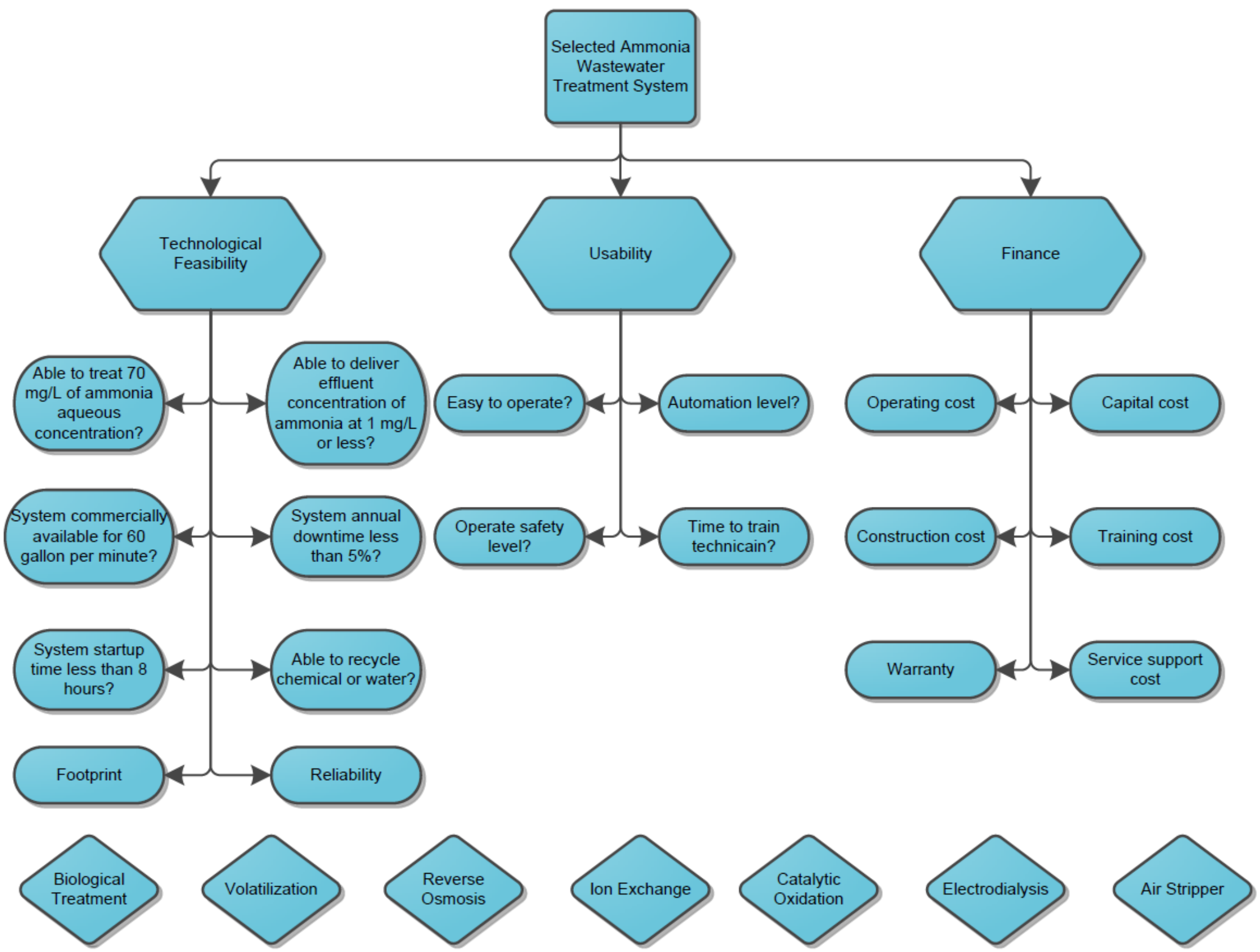
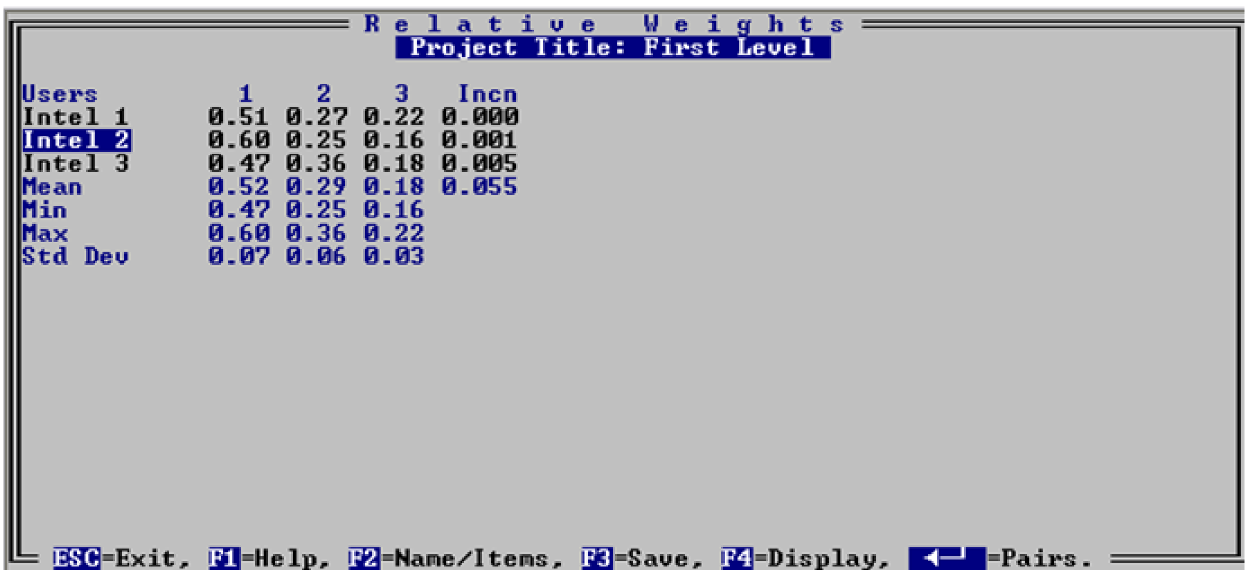


Figure 7: HDM for Evaluating the Most Feasible Technology to Treat Ammonia Wastewater

6. Review Panel and Survey

- 1 Intel Project Manager and 2 Intel Senior Environmental Engineers
- 1 PSU Environmental Engineering Professor
- 3 Chemical Engineering Students
- Intel's employees responded to both criteria/sub-criteria weights and scoring
- PSU professor and students only responded to criteria/sub-criteria scoring

7. PCM Results


Relative Weights

Project Title: First Level

Users	1	2	3	Incn
Intel 1	0.51	0.27	0.22	0.000
Intel 2	0.60	0.25	0.16	0.001
Intel 3	0.47	0.36	0.18	0.005
Mean	0.52	0.29	0.18	0.055
Min	0.47	0.25	0.16	
Max	0.60	0.36	0.22	
Std Dev	0.07	0.06	0.03	

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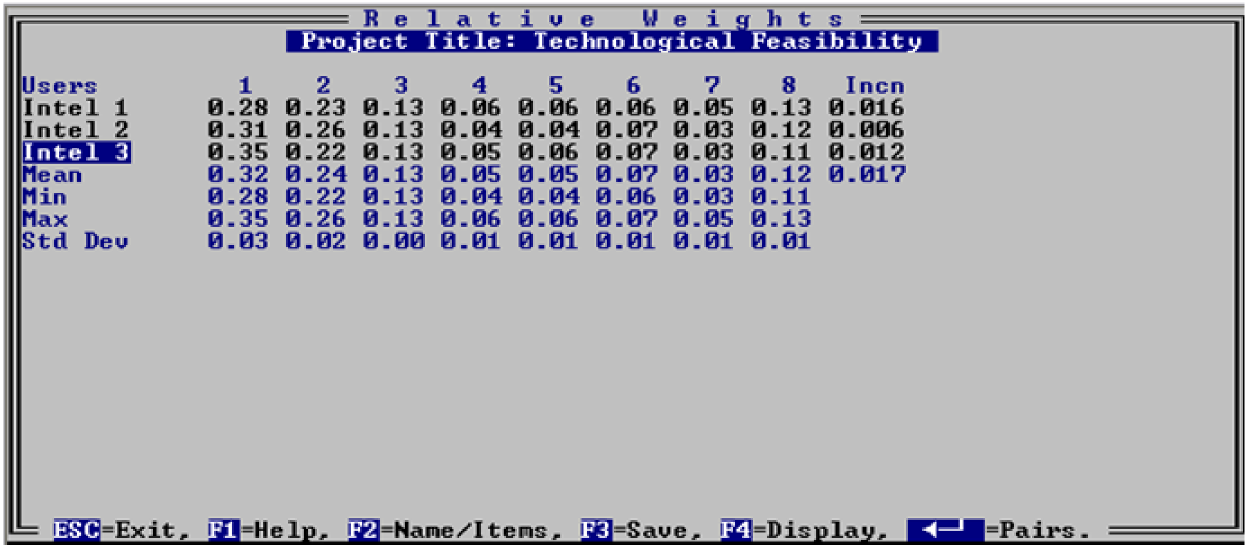
Figure 8: First Level Pair-wise Comparison

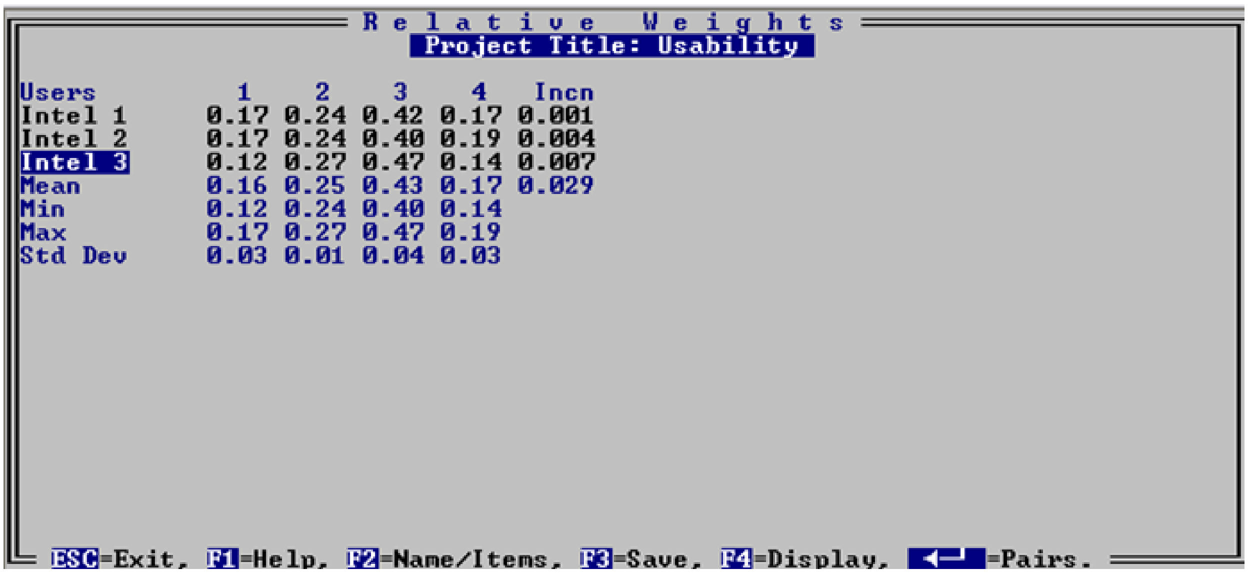


Relative Weights

Project Title: Technological Feasibility

Users	1	2	3	4	5	6	7	8	Incn
Intel 1	0.28	0.23	0.13	0.06	0.06	0.06	0.05	0.13	0.016
Intel 2	0.31	0.26	0.13	0.04	0.04	0.07	0.03	0.12	0.006
Intel 3	0.35	0.22	0.13	0.05	0.06	0.07	0.03	0.11	0.012
Mean	0.32	0.24	0.13	0.05	0.05	0.07	0.03	0.12	0.017
Min	0.28	0.22	0.13	0.04	0.04	0.06	0.03	0.11	
Max	0.35	0.26	0.13	0.06	0.06	0.07	0.05	0.13	
Std Dev	0.03	0.02	0.00	0.01	0.01	0.01	0.01	0.01	

Figure 9: Technology Feasibility Pair-wise comparison

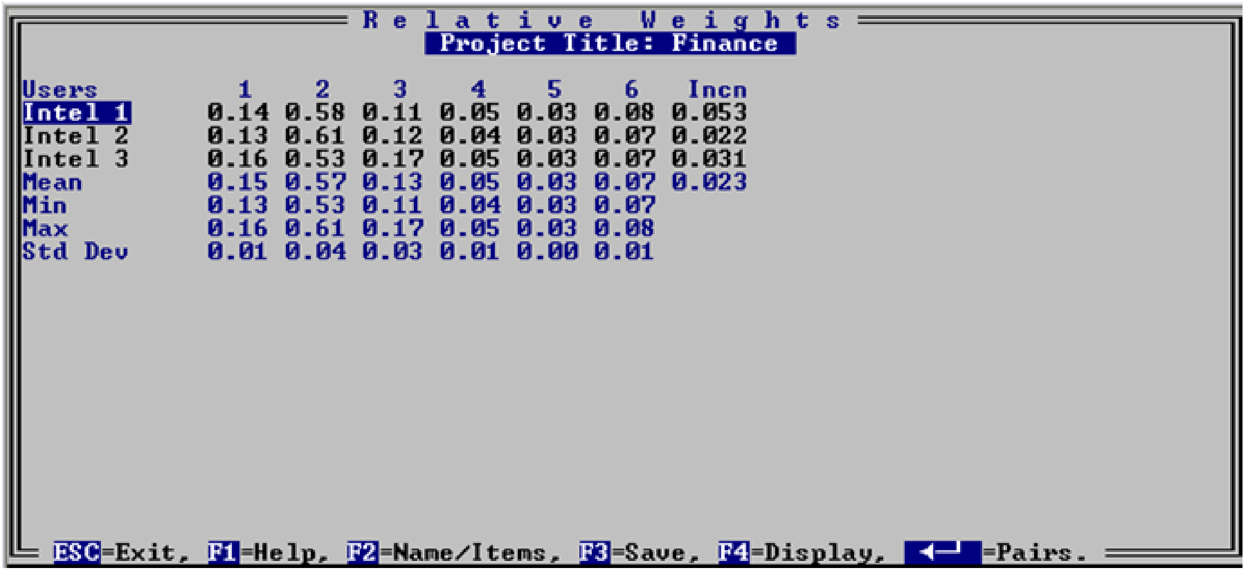


Relative Weights

Project Title: Usability

Users	1	2	3	4	Incn
Intel 1	0.17	0.24	0.42	0.17	0.001
Intel 2	0.17	0.24	0.40	0.19	0.004
Intel 3	0.12	0.27	0.47	0.14	0.007
Mean	0.16	0.25	0.43	0.17	0.029
Min	0.12	0.24	0.40	0.14	
Max	0.17	0.27	0.47	0.19	
Std Dev	0.03	0.01	0.04	0.03	

Figure 10: Usability Pair-wise Comparison



Relative Weights

Project Title: Finance

Users	1	2	3	4	5	6	Incn
Intel 1	0.14	0.58	0.11	0.05	0.03	0.08	0.053
Intel 2	0.13	0.61	0.12	0.04	0.03	0.07	0.022
Intel 3	0.16	0.53	0.17	0.05	0.03	0.07	0.031
Mean	0.15	0.57	0.13	0.05	0.03	0.07	0.023
Min	0.13	0.53	0.11	0.04	0.03	0.07	
Max	0.16	0.61	0.17	0.05	0.03	0.08	
Std Dev	0.01	0.04	0.03	0.01	0.00	0.01	

ESC=Exit, F1=Help, F2=Name/Items, F3=Save, F4=Display, ↵=Pairs.

Figure 11: Finance Pair-wise Comparison

The screen shots above show the results using the pairwise comparison method software (PCM). These weights were used for further analysis. We can also observe the above weights are very consistent as the right hand column shows very low inconsistencies (less than 0.06)

8. Final Results and Discussion

The following graph displays the pairwise comparison results for the first tier of the model. This tier is comprised of three important criteria, being technological feasibility, usability and finance. These inputs were based on the requirements of the company. This graph depicts what is most important for the company from the 3 criteria.

8.1. First level pair-wise comparison

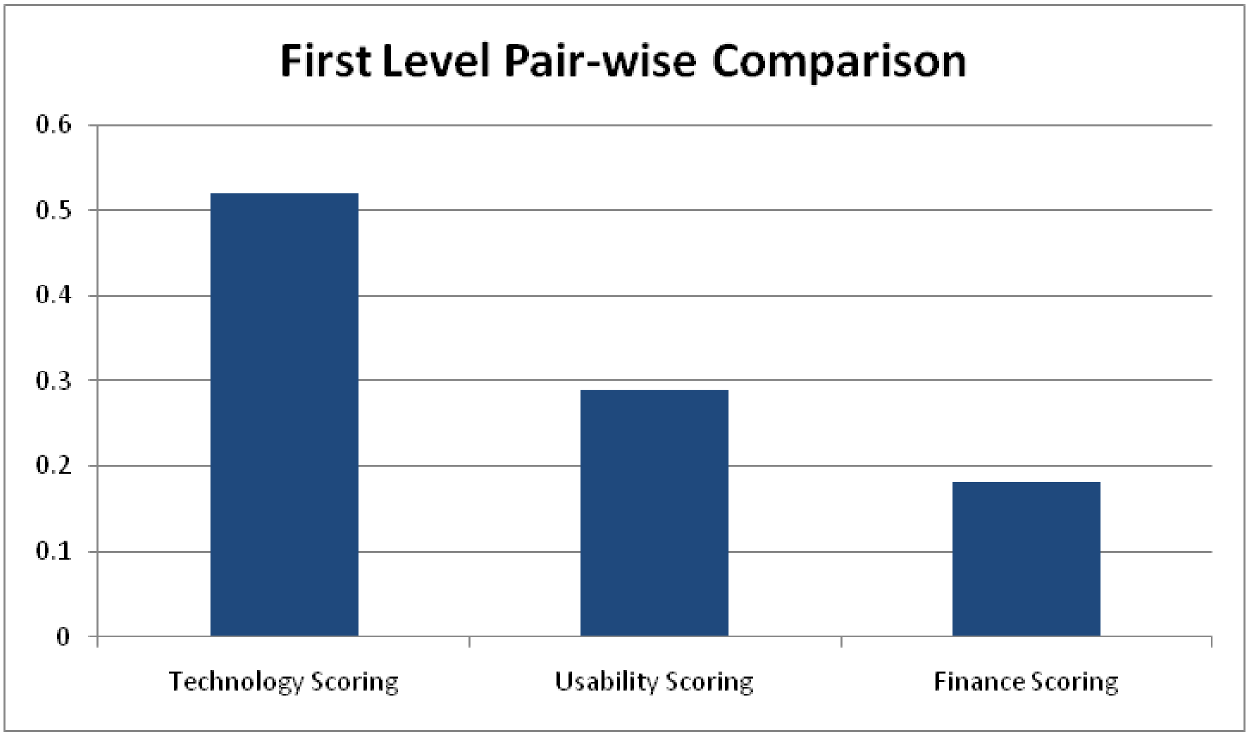


Figure 12: First Level Weight Plot

Only employees participated in the survey for this tier. It was essential that alien participants were kept outside of the scope of the survey. Keeping in mind the financialy sound purchaser the results were not surprising. Finance showed up at the least important of the three major critirias. Technology scoring was high and was seginificant for the fact that a certain level of quality in the water treatment process was essential to explicitly meet government regulation. Without which purchasing a technology would not make sense. Safety being inherently an issue with chemical engineering processes stood to be the second most important critiria.

8.2. Technology Feasibility pair-wise comparison

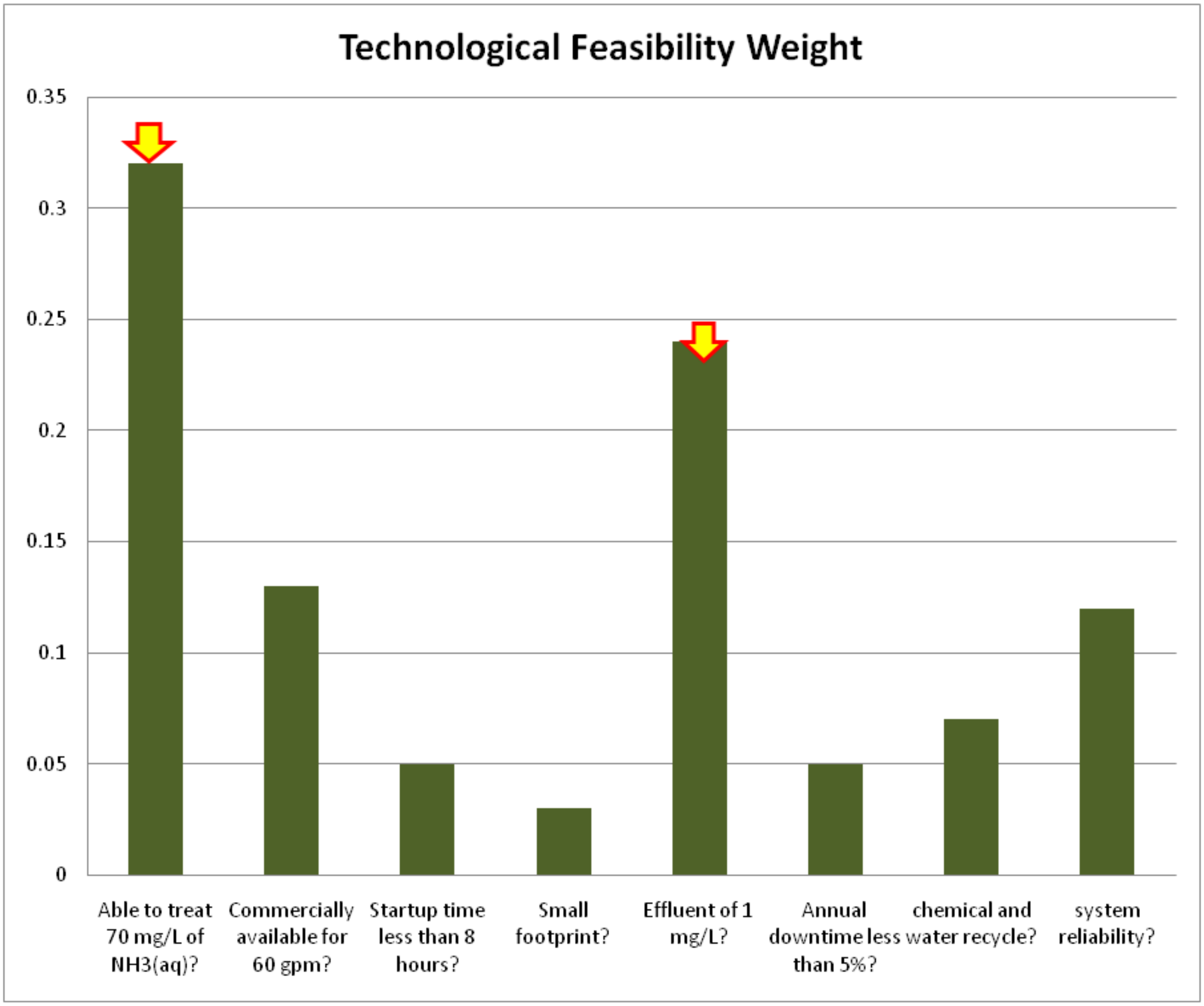


Figure 13: Technological Feasibility Weight Plot

Within the first criteria, our model has eight well-defined technology and process characteristics that were surveyed by both corporate employees and academic faculty. These eight sub-criteria were defined around creating a full-proof framework that would examine each technology with multiple technical perspectives. The United States environment protection agency (USEPA) has extremely stringent norms for permitting the release of industrial chemical process effluents. Hence, to a team of decision makers the result within these eight sub-criteria was not surprising. The top most score was for the technology to be able to treat 70 mg/L

NH3(aq), followed by effluent release of 1 mg/L followed by commercially available for 60 gpm. The rest of criteria were deemed to be of less importance compared to these top three.

8.3. Usability pair-wise comparison

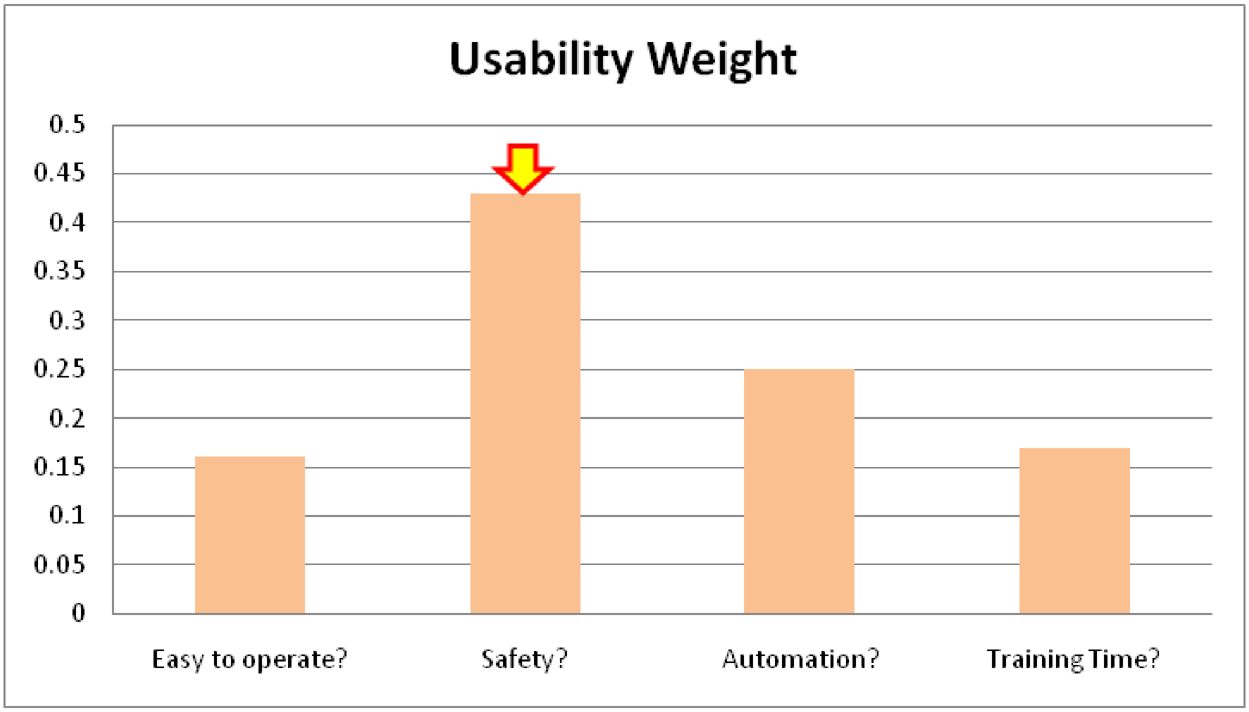


Figure 14: Usability Weight Plot

Chemical engineering process in any industry carries with itself a risk of contamination, explosion, inhalation and risk to harm the environment. Thus, the usability survey brought to our notice that the participant panel was aware of the importance of safety. Since safety stood first most important in the survey, it is most important that risks to human as well as environmental stake holders is profoundly understood so that the correct choice can be made. This also means that human interference should be eliminated to as much extent as possible. Thereby, meaning that automation should be the second most important sub-criteria.

8.4. Finance pair-wise comparison

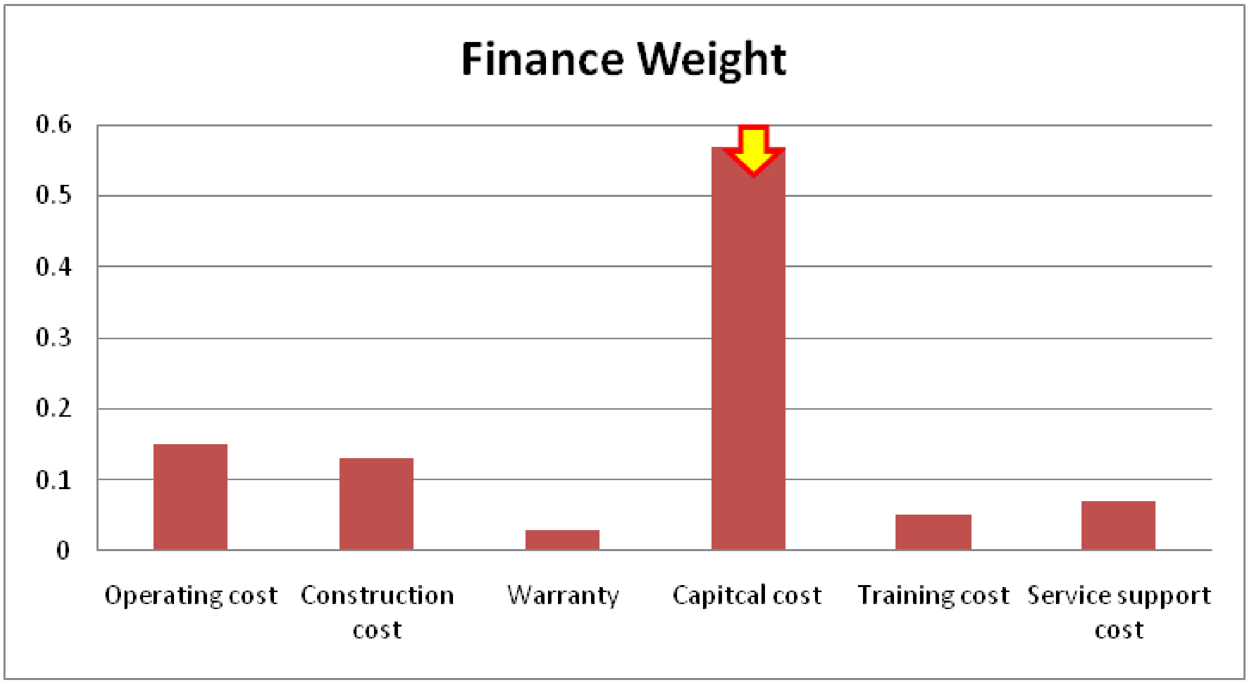
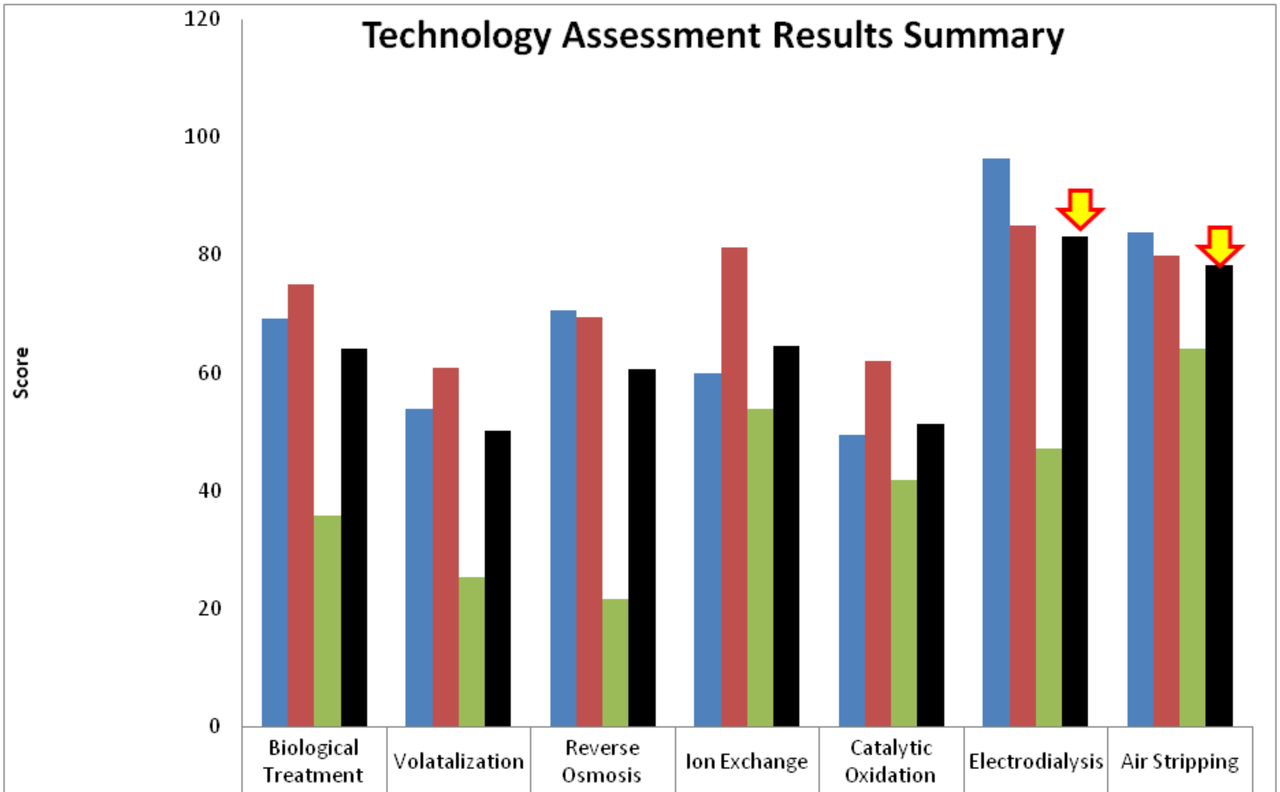


Figure 15: Finance Weight Plot

As it widely perceived, the said company is extremely financially sound and has in-house talent which is aware of various cost aspects in **technology assessment and acquisition** within the six sub-criteria, capital cost was of the top most priority followed by operating cost and construction cost. Having chemical engineering in the survey panel made a difference in these results because these three cost factors are the three foundation pillars in chemical engineering technology application and cost estimation.

8.5. Technology Assessment Result Summary



	Biological Treatment	Volatalization	Reverse Osmosis	Ion Exchange	Catalytic Oxidation	Electrodialysis	Air Stripping
Technology Scoring	69	54	71	60	49	96	84
Usability Scoring	75	61	69	81	62	85	80
Finance Scoring	36	25	22	54	42	47	64
Overall Scoring	64	50	61	64	51	83	78

Figure 16: Technology Assessment Result Summary Plot

After completed pair-wise comparison for all criteria and sub-criteria, the survey is sent out to all members of expert review panel. All members will have the opportunity to evaluate each sub-criterion by providing scores on the scale of 100. Each sub-criterion score will be multiplied with its weight that is calculated by pair-wire analysis. Then all sub-criteria scores will be added together to provide the scoring for each criteria. Figure XX below shows that Electrodialysis has the highest score under technological feasibility and usability. However, Air Stripping Technology has the highest score under finance. The scoring of each criterion will be multiplied with each weight calculated by first-level pair-wise comparison; then the sum of all three weighted scores is the overall scoring for each alternative technology. Electrodialysis and Air Stripping score 83 and 78 respectively. Both technologies have shown their strength in proving to be the most effective treatment systems with low maintenance requirements and low initial investment.

9. Conclusion and Recommendation

By working closely with Intel employees and university professors, the project team has successfully developed the decision model that is able to cover most important aspects to help decide which technology is the most effective to treat ammonia wastewater in the typical semiconductor company. After evaluating seven available technologies, Electrodialysis and Air Stripping System are the most feasible technologies to meet selection criteria and sub-criteria. These two technologies fit the triangular requirement of technological feasibility, usability, and the most cost effectiveness.

The recommends to Intel management is to focus project resource on in-depth study for these technologies only and compare side by side the advantages and disadvantages for both technologies. In order to get more detail information about the "real-life" treatments system, Intel management team needs to send out RFIs (request for information) and RFPs (request for proposal) to vendors/suppliers for both technologies. Then, Intel management team will be able to decide which technology is the most effective for the company's needs.

10. Lessons Learned and Future Work

From this study, the strength of the HDM (Hierarchical Decision Model) in evaluating the most feasible technology is clearly shown. It helps break down the complex problems into many sub-criteria that can be easier to compare or analyze. The model developed for evaluating the most feasible technology to treat ammonia waste can be modified and used for other technology evaluation projects in the future by changing the criteria/sub-criteria. In this particular project, the results of the study would have higher confident if there are more experts providing inputs. Nonetheless, the recommended technologies to Intel management team would save the company significant amount of time and money to eliminate unnecessary study in other five non-feasible technologies.

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12. Appendix

Survey Template:

Pairwise Comparison Survey: First level comparison – only distribute to Intel Project Manager, and Intel Senior Engineers

Second Level Comparison

Technological Feasibility:

1. Between "Ability to treat 70 mg/L of aqueous concentration" and "Able to deliver effluent concentration of 1 mg/L or less", which of these is more important?
   a. Ability to treat 70 mg/L of aqueous concentration ______________
   b. Able to deliver effluent concentration of 1 mg/L or less _______________
   TOTAL 100
2. Between "Ability to treat 70 mg/L of aqueous concentration" and "System commercially available for 60 g/min", which of these is more important?
   a. Ability to treat 70 mg/L of aqueous concentration ______________
   b. System commercially available for 60 g/min _______________
   TOTAL 100
3. Between "Ability to treat 70 mg/L of aqueous concentration" and "System startup time less than 8 hours", which of these is more important?
   a. Ability to treat 70 mg/L of aqueous concentration ______________
   b. System startup time less than 8 hours _______________
   TOTAL 100
4. Between "Ability to treat 70 mg/L of aqueous concentration" and "Space footprint", which of these is more important?
   a. Ability to treat 70 mg/L of aqueous concentration ______________
   b. Space footprint _______________
   TOTAL 100
5. Between "Ability to treat 70 mg/L of aqueous concentration" and "System annual downtime less than 5%", which of these is more important?
   a. Ability to treat 70 mg/L of aqueous concentration ______________
   b. System annual less than 5% _______________
   TOTAL 100
6. Between "Ability to treat 70 mg/L of aqueous concentration" and "Able to recycle chemical and water", which of these is more important?
   a. Ability to treat 70 mg/L of aqueous concentration ______________
   b. Able to recycle solvent and water _______________
   TOTAL 100

7. Between “Ability to treat 70 mg/L of aqueous concentration” and “Reliability”, which of these is more important?
   a. Ability to treat 70 mg/L of aqueous concentration ______________
   b. Reliability ______________
   TOTAL 100
8. Between “System commercially available for 60 g/min” and “System startup time less than 8 hours”, which of these is more important?
   a. Ability to treat 70 mg/L of aqueous concentration ______________
   b. System startup time less than 8 hours ______________
   TOTAL 100
9. Between “System commercially available for 60 g/min” and “Space footprint”, which of these is more important?
   a. Ability to treat 70 mg/L of aqueous concentration ______________
   b. Space footprint ______________
   TOTAL 100
10. Between “System commercially available for 60 g/min” and “Able to deliver effluent concentration of 1 mg/L less”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. Able to deliver effluent concentration of 1 mg/L less ______________
    TOTAL 100
11. Between “System commercially available for 60 g/min” and “System annual downtime less than 5%”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. System annual downtime less than 5% ______________
    TOTAL 100
12. Between “System commercially available for 60 g/min” and “Able to recycle chemical or water”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. Able to recycle chemical or water ______________
    TOTAL 100
13. Between “System commercially available for 60 g/min” and “Reliability”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. Reliability ______________
    TOTAL 100
14. Between “System startup time less than 8 hours” and “Space footprint”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. Space footprint ______________
    TOTAL 100
15. Between “System startup time less than 8 hours” and “Able to deliver effluent concentration of 1 mg/L less”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. Able to deliver effluent concentration of 1 mg/L less ______________
    TOTAL 100

16. Between “System startup time less than 8 hours” and “System annual downtime less than 5%”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. System annual downtime less than 5% ______________
    TOTAL 100
17. Between “System startup time less than 8 hours” and “Able to recycle chemical or water”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. Able to recycle chemical or water ______________
    TOTAL 100
18. Between “System startup time less than 8 hours” and “Reliability”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. Reliability ______________
    TOTAL 100
19. Between “Space footprint” and “Able to deliver effluent concentration of 1 mg/L less”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. Able to deliver effluent concentration of 1 mg/L less ______________
    TOTAL 100

20. Between “Space footprint” and “System annual downtime less than 5%”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. System annual downtime less than 5% ______________
    TOTAL 100

21. Between “Space footprint” and “Able to recycle chemical or water”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. Able to recycle chemical or water ______________
    TOTAL 100

22. Between “Space footprint” and “Reliability”, which of these is more important?
    a. Ability to treat 70 mg/L of aqueous concentration ______________
    b. Reliability ______________
    TOTAL 100

23. Between “Able to deliver effluent concentration of 1 mg/L less” and “System annual downtime less than 5%”, which of these is more important?
    a. Able to deliver effluent concentration of 1 mg/L less ______________
    b. System annual downtime less than 5% ______________
    TOTAL 100

24. Between “Able to deliver effluent concentration of 1 mg/L less” and “Able to recycle chemical or water” which of these is more important?
    a. Able to deliver effluent concentration of 1 mg/L less ______________
    b. Able to recycle chemical or water ______________

    TOTAL 100

25. Between “Able to deliver effluent concentration of 1 mg/L less” and “Reliability” which of these is more important?
    a. Able to deliver effluent concentration of 1 mg/L less ______________
    b. Reliability ______________

    TOTAL 100

26. Between “System annual downtime less than 5%” and “Able to recycle chemical or water” which of these is more important?
    a. Able to deliver effluent concentration of 1 mg/L less ______________
    b. Able to recycle chemical or water ______________

    TOTAL 100

27. Between “System annual downtime less than 5%” and “Reliability” which of these is more important?
    a. Able to deliver effluent concentration of 1 mg/L less ______________
    b. Reliability ______________

    TOTAL 100

28. Between “Able to recycle chemical or water” and “Reliability” which of these is more important?
    a. Able to recycle chemical or water ______________
    b. Reliability ______________

    TOTAL 100

Usability and Finance:

1. Between “Easy to operate” and “Operate safety level” which of these is more important?
    a. Easy to operate ______________
    b. Operate safety level ______________

    TOTAL 100

2. Between “Easy to operate” and “Automation level” which of these is more important?
    a. Easy to operate ______________
    b. Automation level ______________

    TOTAL 100

3. Between “Easy to operate” and “Time to train technician” which of these is more important?
    a. Easy to operate ______________
    b. Time to train technician ______________

    TOTAL 100

4. Between "Operate safety level" and "Automation level" which of these is more important?
    a. Operate safety level _____________
    b. Automation level _____________

    TOTAL 100
5. Between "Operate safety level" and "Time to train technician" which of these is more important?
    a. Operate safety level _____________
    b. Time to train technician _____________

    TOTAL 100
6. Between "Automation level" and "Time to train technician" which of these is more important?
    a. Automation level _____________
    b. Time to train technician _____________

    TOTAL 100

7. Between "Operating Cost" and "Construction cost" which of these is more important?
    a. Operation cost _____________
    b. Construction cost _____________

    TOTAL 100
8. Between "Operating Cost" and "Warranty" which of these is more important?
    a. Operation cost _____________
    b. Warranty _____________

    TOTAL 100
9. Between "Operating Cost" and "Capital cost" which of these is more important?
    a. Operation cost _____________
    b. Capital cost _____________

    TOTAL 100
10. Between "Operating Cost" and "Training cost" which of these is more important?
    a. Operation cost _____________
    b. Training cost _____________

    TOTAL 100
11. Between "Operating Cost" and "Service support cost" which of these is more important?
    a. Operation cost _____________
    b. Service support cost _____________

    TOTAL 100
12. Between "Construction Cost" and "Warranty" which of these is more important?
    a. Operation cost _____________
    b. Warranty _____________

    TOTAL 100
13. Between "Construction Cost" and "Capital cost" which of these is more important?
    a. Operation cost _____________
    b. Capital cost _____________

TOTAL 100

14. Between "Construction Cost" and "Training cost" which of these is more important?
    a. Operation cost ______________
    b. Training cost ______________

TOTAL 100

15. Between "Construction Cost" and "Service support cost" which of these is more important?
    a. Operation cost ______________
    b. Service support cost ______________

TOTAL 100

16. Between "Warranty" and "Capital cost" which of these is more important?
    a. Warranty ______________
    b. Capital cost ______________

TOTAL 100

17. Between "Warranty" and "Training cost" which of these is more important?
    a. Warranty ______________
    b. Training cost ______________

TOTAL 100

18. Between "Warranty" and "Service support cost" which of these is more important?
    a. Warranty ______________
    b. Service support cost ______________

TOTAL 100

19. Between "Capital cost" and "Service support cost" which of these is more important?
    a. Capital cost ______________
    b. Service support cost ______________

TOTAL 100

20. Between "Capital cost" and "Training cost" which of these is more important?
    a. Capital cost ______________
    b. Training cost ______________

TOTAL 100

21. Between "Service support cost" and "Training cost" which of these is more important?
    a. Service support cost ______________
    b. Training cost ______________

TOTAL 100

Technology Scorings:

Criteria	Weight	Biological Treatment	Volatalization	Reverse Osmosis	Ion Exchange	Catalytic Oxidation	Electrodialysis	Air Stripping
Able to treat 70 mg/L of NH3(aq)?	**0.32**	60	65	91	65	62	95	84
		65	63	89	58	60	97	89
		85	66	87	55	65	96	80
		70	60	80	52	62	95	80
		72	**63**	**86**	**56**	**64**	**96**	**84**
Commercially available for 60 gpm?	**0.13**	100	0	100	0	100	100	100
		100	0	100	0	100	100	100
		100	0	100	0	100	100	100
		100	0	100	0	100	100	100
		100	0	100	0	100	100	100
		100	0	100	0	100	100	100
		100	0	100	0	100	100	100
		100	**0**	**100**	**0**	**100**	**100**	**100**
Startup time less than 8 hours?	**0.05**	0	100	100	100	0	100	0
		0	100	100	100	0	100	0
		0	100	100	100	0	100	0
		0	100	100	100	0	100	0
		0	100	100	100	0	100	0
		0	100	100	100	0	100	0
		0	100	100	100	0	100	0
		0	**100**	**100**	**100**	**0**	**100**	**0**
Small footprint?	**0.03**	40	50	30	70	40	80	40
		41	52	30	80	40	85	50
		50	50	20	70	20	90	50
		53	40	15	70	20	85	50
		30	50	30	70	40	90	40
		29	50	30	66	15	92	35
		20	50	25	60	30	88	40
		38	**49**	**26**	**69**	**29**	**87**	**44**
Effluent of 1 mg/L?	**0.24**	80	70	100	70	40	95	100
		80	70	100	70	40	90	100
		80	80	100	70	40	92	85
		79	70	90	80	30	95	90
		80	70	80	70	20	94	85
		70	70	80	70	10	93	90
		80	70	100	70	60	90	60
		78	**71**	**93**	**71**	**34**	**93**	**87**
Annual downtime less than 5%?	**0.05**	0	0	0	100	0	100	100
		0	0	0	100	0	100	100
		0	0	0	100	0	100	100
		0	0	0	100	0	100	100
		0	0	0	100	0	100	100
		0	0	0	100	0	100	100
		0	0	0	100	0	100	100
		0	**0**	**0**	**100**	**0**	**100**	**100**
chemical and water recycle?	**0.07**	100	0	0	100	0	100	100
		100	0	0	100	0	100	100
		100	0	0	100	0	100	100
		100	0	0	100	0	100	100
		100	0	0	100	0	100	100
		100	0	0	100	0	100	100
		100	0	0	100	0	100	100
		100	**0**	**0**	**100**	**0**	**100**	**100**
system reliability?	**0.12**	50	70	10	50	60	90	80
		55	80	20	50	60	95	80
		50	80	0	50	60	85	90
		50	90	10	40	40	90	80
		50	80	20	40	60	90	80
		60	80	30	50	60	90	80
		40	100	20	60	60	88	80
		51	**83**	**16**	**49**	**57**	**90**	**81**
Technology Scoring		**69**	**54**	**71**	**60**	**49**	**96**	**84**

Criteria	Weight	Biological Treatment	Votalization	Reverse Osmosis	Ion Exchange	Catalytic Oxidation	Electrodialysis	Air Stripping
Easy to operate?	**0.16**	10	20	30	60	30	80	70
		20	20	30	70	40	70	80
		20	40	40	70	40	70	66
		20	30	40	70	40	70	65
		10	10	40	70	30	80	60
		30	10	30	60	30	88	60
		40	10	30	70	30	100	60
		21	**20**	**34**	**67**	**34**	**80**	**66**
Safety?	**0.43**	88	90	80	90	70	85	90
		89	85	85	95	65	90	84
		92	80	90	90	75	92	90
		75	88	95	85	80	94	86
		80	80	85	88	60	89	90
		85	78	80	78	65	88	95
		85	85	80	89	70	85	90
		85	**84**	**85**	**88**	**69**	**89**	**89**
Automation?	**0.25**	70	70	90	85	70	95	90
		75	80	95	90	65	96	88
		90	75	85	88	70	92	94
		85	78	90	86	68	93	93
		90	79	95	85	78	95	90
		75	75	85	88	80	90	95
		80	70	90	90	75	92	95
		81	**75**	**90**	**87**	**72**	**93**	**92**
Training Time?	**0.17**	90	20	20	70	50	60	50
		90	30	30	60	60	60	50
		90	10	50	60	50	50	40
		80	10	30	60	50	65	50
		80	10	30	60	50	70	40
		88	20	10	70	50	70	50
		100	20	30	71	50	60	50
		88	**17**	**29**	**64**	**51**	**62**	**47**
Usability Scoring		**75**	**61**	**69**	**81**	**62**	**85**	**80**

Criteria	Weight	Biological Treatment	Votalization	Reverse Osmosis	Ion Exchange	Catalytic Oxidation	Electrodialysis	Air Stripping
Operating cost	0.15	70	30	10	40	40	50	50
		70	40	5	40	40	60	50
		70	20	6	40	50	50	50
		74	30	6	50	40	50	50
		70	30	5	50	40	50	50
		71	30	2	50	40	60	50
		72	**29**	**8**	**44**	**41**	**54**	**51**
Construction cost	0.13	10	10	20	30	30	50	50
		20	10	30	40	30	50	30
		20	10	10	40	30	40	30
		20	10	10	40	35	55	30
		20	20	20	40	50	50	30
		25	20	10	30	40	50	40
		25	20	10	30	20	50	30
		20	**14**	**16**	**36**	**34**	**49**	**34**
Warranty	0.03	90	85	90	92	96	100	90
		95	80	86	94	90	98	92
		92	85	88	93	88	98	96
		95	88	90	95	88	96	95
		96	88	94	92	92	98	99
		95	90	90	98	90	99	100
		92	92	88	98	90	100	94
		94	**87**	**89**	**95**	**91**	**98**	**95**
Capitcal cost	0.57	10	20	30	70	50	30	80
		20	20	30	70	50	45	85
		20	20	30	70	50	50	80
		20	20	20	60	45	50	82
		20	30	20	60	40	50	78
		25	30	20	60	40	40	76
		20	30	20	60	40	40	80
		19	**24**	**24**	**64**	**45**	**44**	**80**
Training cost	0.05	70	20	20	40	20	40	30
		80	30	10	50	30	50	30
		70	40	10	50	30	50	30
		65	40	10	40	10	50	40
		70	40	20	40	30	50	40
		70	30	35	50	50	40	40
		70	50	55	40	20	50	40
		71	**36**	**23**	**44**	**27**	**47**	**36**
Service support cost	0.07	71	10	10	10	20	30	20
		70	20	10	20	30	35	25
		80	20	10	20	10	35	30
		80	30	15	10	30	40	25
		70	10	10	10	20	35	20
		70	10	10	10	30	40	20
		70	10	10	10	20	40	20
		73	**16**	**11**	**13**	**23**	**36**	**23**
Finance Scoring		**36**	**25**	**22**	**54**	**42**	**47**	**64**