

The Environmental Impact Assessment of Cal Poly's Manufacturing Laboratory

Yoonho Mark Kim

Advisor: Dr. Trevor Harding

California Polytechnic State University, San Luis Obispo

Materials Engineering Department

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Abstract

The purpose of the study is to obtain basic understanding of the sustainability of Cal Poly IME 144 laboratory. Since the general condition of the lab prevents precise, efficient data collection, fuzzy logic is used to provide an overview of the laboratory's sustainability. Aluminum chips, brass chips, and paper waste are identified as primary waste streams. Electric usage of the laboratory is approximately calculated based on the machines' running time. Fuzzy logic system with three inputs and one output is designed in the Matlab software environment with Simulink to simulate a model for the laboratory's sustainability. Also the study suggests a few alternatives to improve the sustainability based on the model.

Keywords: Materials, Engineering, Sustainability, Environmental Impact Assessment, Fuzzy Logic, Fuzzy Simulation

1 Introduction

Since the industrial revolution in the late 1700s and early 1800s, major industrial, technological developments have been achieved; transportation and manufacturing fields have experienced dramatic developments over time. As the efficiency of industrial tools have increased, concerns for the environment have followed the same trend. The nature's self purification ability and its resources are limited. Reckless exploitation of finite natural resources such as woods and ores should be prevented. Sustainability has become a keyword for engineers whose new responsibility becomes efficient use and preservation of limited resources. Various methods has been proposed to evaluate and control sustainability of industrial environments. A relatively modern approach, environmental impact assessment based on fuzzy logic, has been conducted to obtain baseline understanding and evaluate the sustainability of the Cal Poly's IME 144 laboratory.

1.1 Environmental Impact Assessment

An Environmental Impact Assessment (EIA) is a process used to predict environmental consequences of a selected system or project. The assessment begins with screening process; this is a step to ensure that the proposed project or system has significant environmental impact. If it is decided that the system has significant impact, scoping process takes place. Purpose of the step is to identify components or waste streams of the system while defining assumption and limitation of the whole process. Third step, environmental impact evaluation, identifies the component with the most significant environmental impact by analyzing and measuring an environmental impact of each component. Since the step requires calculation based on various quantified values, it is considered to be the most difficult and technical step during the process. Scholars proposed numerous methods to

evaluate the environmental impact. Generally, they can be divided into two categories: traditional and modern approach. Fourth step of the assessment proposes alternatives to improve the sustainability of the system. Stakeholders and decision makers can rely on the impact evaluation and choose alternative ways to improve the sustainability of the system or project. If the alternatives are considered to be feasible physically, economically, and systemically, proposed changes can be made to prevent negative environmental consequences by reducing environmental impact.

2 Assessment Procedure

An EIA with the four basic steps was conducted on the IME 144 laboratory: screening, scoping, environmental impact evaluation, and alternatives.

2.1 Screening

IME 144, Introduction to Design and Manufacturing, is a course where a student can have hands-on experience with conventional machining process such as lathes, mills, and computer numeric control (CNC) as well as computer-aided design (CAD) with the SolidWorks software. The course is taken by engineering students from various departments such as Materials, Industrial, Manufacturing, and Aerospace. Every quarter, the course accommodates more than a hundred students; students are to spend six hours per week in the laboratory to learn the conventional industrial manufacturing process. Since it is a large course that lets students to work on manufacturing environment, waste and chips from the laboratory resemble industrial solid waste from a manufacturing line.

The course is taught in the main machining lab (Building 41, room 107). The laboratory has 10 Leblond manual lathe (Figure 1), 6 Kent knee mills (Figure 2), broach,

centerless grinder with assorted drill presses, brakes, presses, 1 HASS CNC 4 axis mini mill (Figure 3), and 1 HASS CNC HL-2 lathe. The laboratory is mainly used by students from IME 144. There are 10 lab sections of IME 144 while other classes only have two or three sections per week. Therefore, it is reasonable to assume that the IME 144 course has more significant environmental impact than any other course does.

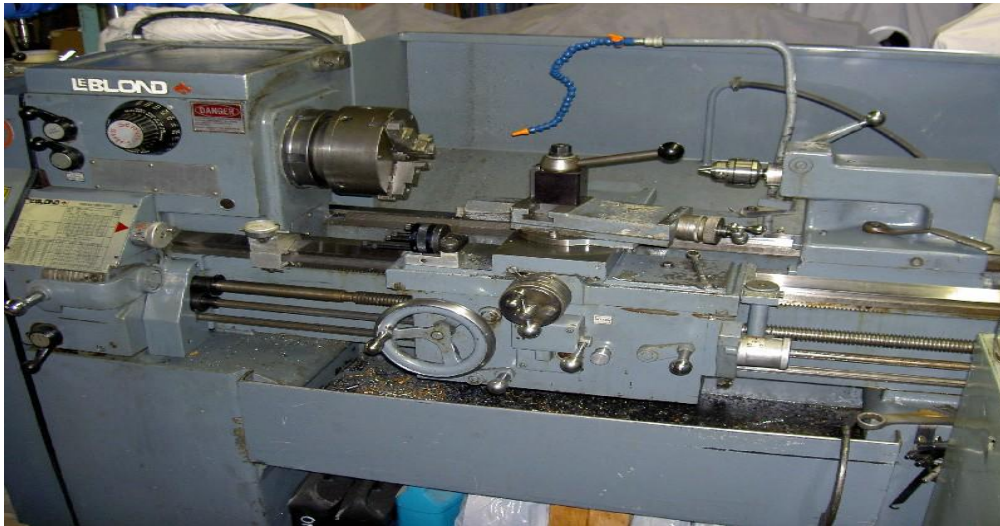


Figure 1. A Leblond manual lathe. Note that it has a chip pan on the bottom.

2.2 Scoping

Manual lathes were the most frequently used machines by the IME 144 students. Instructors calibrated each lathe to a specific setting to work on specific materials such as aluminum and brass. Each lathe had a chip pan on the bottom (Figure 1). The aluminum chips from lathes were not contaminated by chips and impurities from other machines. The chips were collected at the end of the day and sent to the junk yard behind the building. Waste contractor hired by Cal Poly came at the end of the quarter to collect the recyclable materials from the yard. The aluminum chips from lathes were identified as the first solid waste stream from the laboratory and its amount was measured using a portable electronic fish scale (Appendix A).

Knee mills were also used by the students to work on aluminum and brass parts. Unlike the manual lathes, the mill did not have a chip pan on the bottom. When a student worked on the machine, chips fell to the floor and contaminated by other metal chips and impurities such as hair, dirt, and dust. At the end of every class section, students were responsible for cleaning the floor and discarding the waste under the machines to trashcans; the solid waste generated by the mills were not recycled since it was impractical to manually sort the materials from the trashcans. The total amount of chips in trashcans were measured and relative amount of aluminum chip and other wastes were estimated (Appendix A). Aluminum chips in trashcans were identified as the second waste stream while other waste in trashcans were identified as the third.



Figure 2. A Kent knee mill. Note that it does not have a chip pan or waste container.

CNCs were rarely used by the IME 144 students. The machines were mostly used by students from upper classes. Therefore, solid waste generated by the CNCs was assumed to be less influential in the sustainability of the IME 144; therefore, the waste stream was not included in the environmental impact evaluation.

2.3 Environmental Impact Evaluation

Solid waste streams from the IME 144 laboratory were identified during the scoping process; observation on the solid waste flow were made and the amount of each waste stream were measured; the three waste streams were aluminum chips in lathes, aluminum chips in trashcans, and other waste in trashcans. Environmental impacts of each waste stream were evaluated based on the observation and data.

2.3.1 Traditional Approach

A traditional method to evaluate environmental impacts relies on a Leopold matrix (Figure 3). The matrix requires precisely measured, quantified values as a magnitude of each component. Environmental impacts are calculated based on the magnitude and importance, which is a weighting factor that represents each component's level of significance. Also the matrix needs a large set of data as inputs to produce reliable results.

Modified Leopold Matrix
(after UNEP EIA Training Manual, 1996)

Environmental Effects	SOCIAL ENVIRONMENT									
	Recreation	Landscape/visual	Historical/cultural	Societal values	Risks and anxieties	Existing land uses	Land value	Settlement	Employment	Public participation
Waste Disposal Activity										
Treatment										
Comminution										
Sedimentation										
Millscreening										
Oxidation ponds										
Activated sludge										
Trickling filter										
Nutrient removal										
Chlorination										
Further offsite treatment										
Disposal --- Land										
Rapid infiltration										
Surface flooding										
Spray irrigation										
Disposal --- Inland Water										

Figure 3. An example of a Leopold matrix. The row represents environmental effects while the column represents environmental activity of each component. Each cell is filled with magnitude and importance.

Unfortunately, measuring all environmental impacts of solid waste can be impractical.

Spending excessive time and money to precisely measure amount of each waste stream is not an efficient approach to start the environmental impact evaluation. Due to the complicated nature of the solid waste flow system, environmental evaluators need to take missing or insufficient data into account when conducting the environmental impact evaluation. Since obtaining quantified data on all waste streams is not ideal, evaluators rely on estimation based on various observation of the system. However, such observation can be subjective. In order to quantify environmental impacts of subjective nature, fuzzy logic, a mathematical set theory

that helps evaluators to make decision in uncertain environment, is implemented in the EIA process.

2.3.2 Modern Approach

A modern approach to evaluate environmental impacts is to implement fuzzy logic to the traditional method. The use of fuzzy logic eliminates the requirements of the traditional evaluation process. Since obtaining a large set of quantified data is not necessary, the modern approach is more practical and efficient than the traditional method. Therefore, the evaluation with fuzzy logic was conducted to calculate the environmental impacts of waste stream in the IME 144, where only three sets of data were obtained.

Fuzzy logic is a mathematical set theory that uses membership functions and linguistic variables to classify and quantify data that are subjective in nature. Fuzzy logic utilizes fuzzy sets, which is different from crisp sets that is frequently used in engineering fields. The both types of set interpret information differently. If a decision maker wants to evaluate steepness of two slopes, he can choose to rely on one of the two types of set (Figure 4). Based on the crisp sets, the threshold for a steep slope is defined as 20%; any slope above the threshold is considered as steep. The two slopes are differ by only 2%, but the crisp sets analyze the blue slope as steep and the red slope as not steep. As the value of the slope approaches the threshold, the uncertainty of whether the slope is steep or not increases dramatically. The slope analysis based on the crisp sets does not accurately describes the reality.

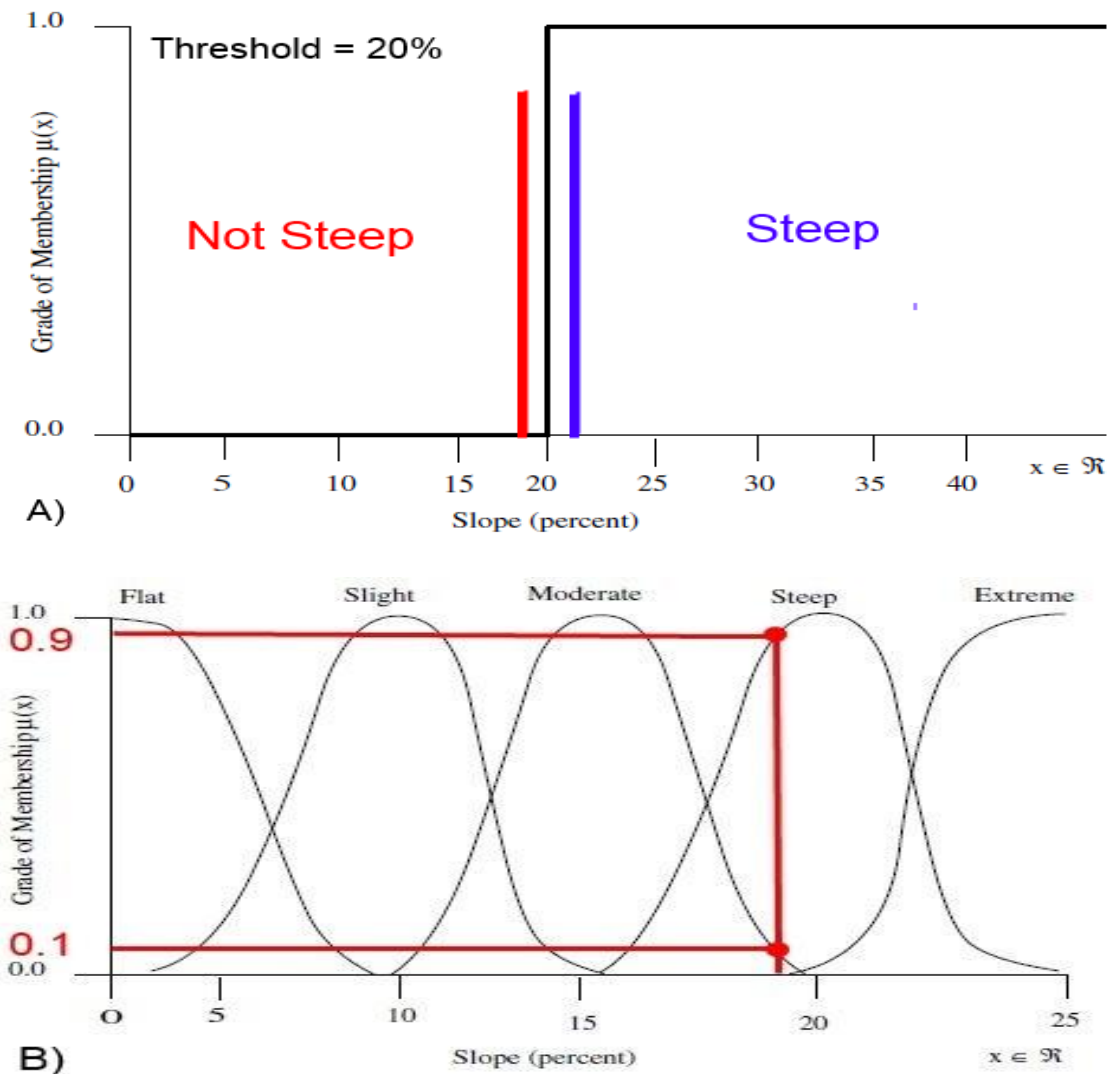


Figure 4. Example of (A) a crisp set and (B) a fuzzy set that describe steepness of a slope. The red line represents a slope whose steepness is 19% while the blue line represents a slope whose steepness is 21%.

Fuzzy logic does not rely on a specific arbitrary threshold. It uses linguistic variables and membership functions to analyze data. Slope steepness can be described by five linguistic variables (flat, slight, moderate, steep, and extreme) and membership functions. The fuzzy sets analyze the red slope of 19% as steep to [0.9] and moderate to [0.1]. With the fuzzy sets, the uncertainty of including and excluding the slope as steep slope spread uniformly across the entire sets. The sets do not have a discontinuous value where it is impossible to determine set membership.

In order to evaluate environmental impacts of solid waste from the IME 144, a fuzzy model was built using MATLAB and its Simulink component. Simulink model was built to show the flow of data processing (Figure 5).

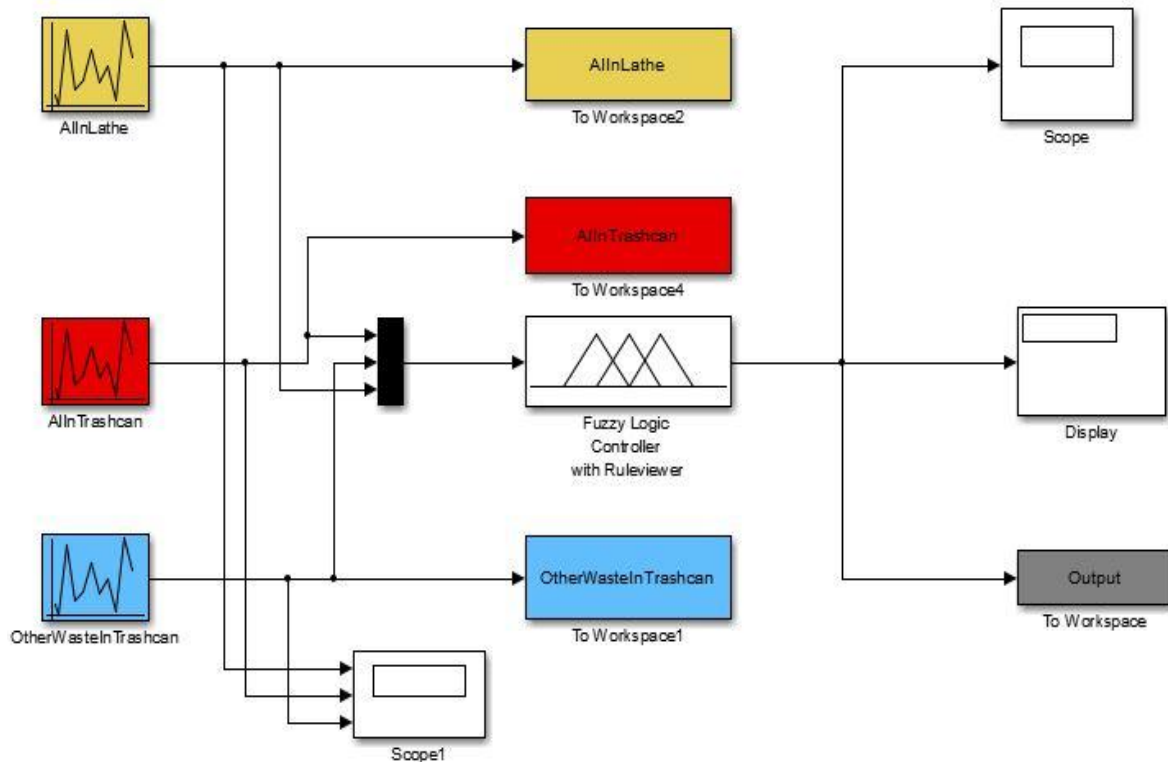


Figure 5. Fuzzy logic Simulink model built in MATLAB. The yellow, red, and blue block each represents the measured amount of aluminum chips in lathes, the estimated amount of aluminum chips and other waste in trashcans, respectively.

The fuzzy logic controller is a tool that creates and modifies fuzzy inference system. Fuzzy inference system utilizes linguistic variables, membership functions, and rules to analyze data and generates outputs. A Gaussian curve is commonly used for membership functions when conducting an environmental impact assessment, because it has an inflection point; the grade of membership decreases and increases quickly below and above the inflection point. The responses resemble the tendency of environmental component to change with other factors in the system. IF-THEN rules, which is the most common computer-based logic, are also used to assign an element to a particular fuzzy set. IF refers to an antecedent

while THEN refers to a consequent. More than one antecedents can be combined with AND operator for more accurate results. The rules are derived from experience of an environmental practitioner who is familiar with the selected environment.

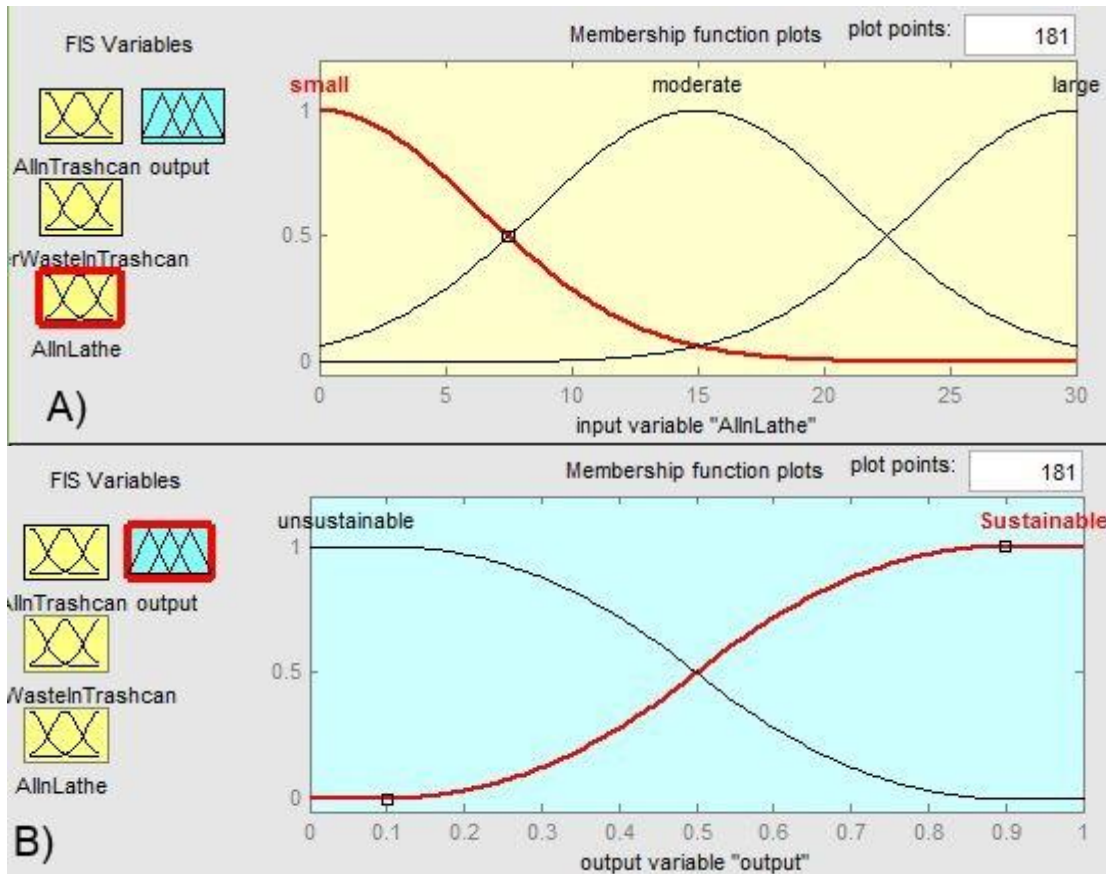


Figure 6. Membership functions of inputs and output of the fuzzy logic inference system. (A) Each input has three linguistic variables represented by Gaussian membership functions. (B) Output has two linguistic variables. It shows the level of sustainability in a scale of 0 to 1. Higher value implies that the system is sustainable.

Fuzzy inference system for the IME 144 laboratory was created. The three sets of data (i.e., amount of aluminum chips from lathes, amounts of aluminum chips and other waste in trashcans) were considered as inputs (Figure 6). IF-THEN rules were created based on observations made in the laboratory (Appendix B). The generated outputs were scaled from 0 to 1; higher number showed higher level of the laboratory's sustainability.

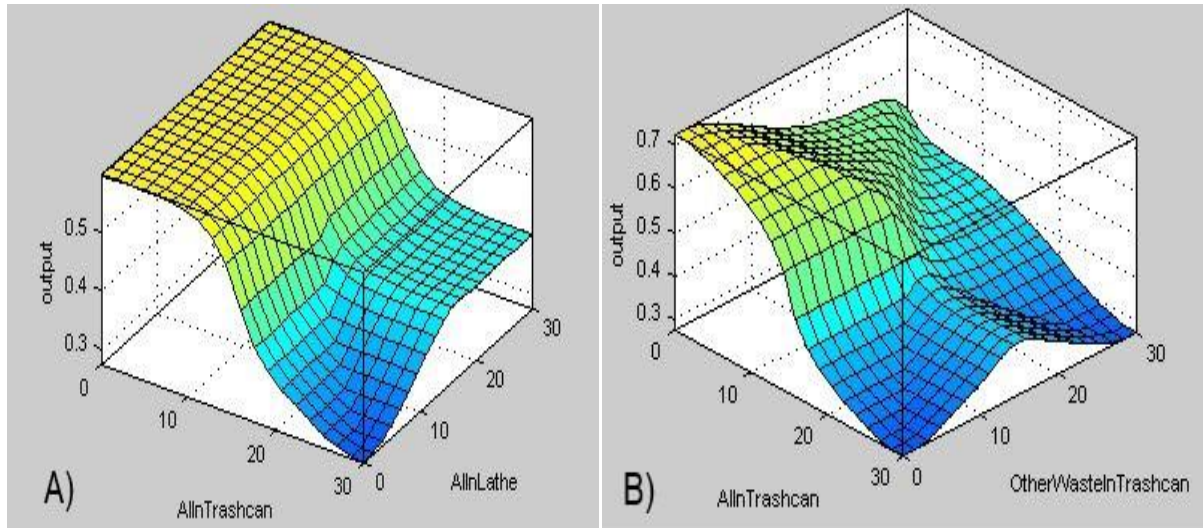


Figure 7. Surface view of inputs and output of the fuzzy logic inference system. The x and y axis represents solid waste from the IME 144 laboratory while the z-axis represents the output, the level of sustainability.

The inputs and outputs were graphed in order to observe any trend among the amounts of each waste and the laboratory's sustainability (Appendix C). However, it was difficult to recognize relationship between inputs and output. Therefore, the three-dimensional surface view was created (Figure 7); certain relationship between the amounts of waste stream and the level of sustainability could be easily observed through the graphical representation of the results. One clear observation made from the surface views was that the amount of aluminum chips had the highest environmental impact; change in the level of the sustainability appeared to be most sensitive to the change in the amount of aluminum chips in trashcans.

2.4 Alternatives

Through the environmental impact evaluation process, the aluminum chips thrown into the trashcans were identified as the waste stream whose environmental impact was the most significant. Therefore, proposed alternatives were aimed to reduce the particular solid waste. First, installing partitions between the knee mills were considered to prevent aluminum chips being contaminated with impurities and other metal chips from neighboring

machines. However, the mills were closely placed to each other; partitions between mills would be obstacles for students who need enough space to safely work on machines. Secondly, installing chip pans under mills were considered. The pans would make it possible to recycle solid waste from the machines without manual sorting process. Thirdly, an alternative material that has lower environmental impact can be used instead of aluminum. Relatively larger amount of energy is required to produce aluminum. Carbon steel can replace aluminum as an alternative material, since its energy consumption is lower than that of aluminum and it can be easily recycled. Lastly, professors and instructors can encourage students participation in recycling. In one of the upper IME classes, students are rewarded with a barbeque party at the end of each quarter if they all participated in recycling metal chips generated from the class. Professors and course instructors can facilitate the atmosphere where students care about the environmental sustainability by providing incentives in terms of grade or entertainment.

3 Conclusion

- A modern EIA was conducted to obtain basic understanding of sustainability of the IME 144 laboratory.
 - ◆ Aluminum chips from lathes, aluminum chips in trashcans, and other waste in trashcans were identified as solid waste stream of the laboratory.
 - ◆ By using fuzzy logic, the aluminum chips generated by lathes were identified as the waste stream with the most significant environmental impact.
- Alternatives to improve the sustainability of the IME 144 by reducing the waste stream with the most significant impact (i.e., aluminum chips from lathes) were considered.

- ◆ Installing chip pans under the knee mills can increase the laboratory's recycling rate.
 - ◆ Carbon steel, a material that can be easily recycled and whose energy consumption is lower than that of aluminum, can replace aluminum to improve the overall sustainability.
 - ◆ Professors can encourage students participation in recycling by providing awards.
- The modern approach, which implemented fuzzy logic to the EIA, is an innovative approach to identify and evaluate solid waste streams and their environmental impacts. It does not require precisely measured data; thus, it prevents the necessary of obtaining such data, which can be costly and time consuming.

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5 Appendices

5.1 Appendix A - amounts of solid waste streams from the IME 144

	Al chips in Lathe (lb)	Al chips in Trashcan (lb)	Other waste in Trashcan (lb)
	18.3	6.6	18.3
	22.9	20.4	15.7
	22.9	28	25.2
	19.9	15.6	25.2
	16.1	1	29
	17.5	15.9	20.1
	22.4	0.2	22.8
	22	2	27.5
	24.4	20.6	15.5
Average	20.7	12.3	22.1
Total	207.1	122.6	221.4

5.2 Appendix B - List of IF-THEN Rule in the fuzzy inference system

1. If (AllnTrashcan is small) and (OtherWasteInTrashcan is small) and (AllnLathe is small) then (output is Sustainable) (1)
2. If (AllnTrashcan is small) and (OtherWasteInTrashcan is small) and (AllnLathe is moderate) then (output is Sustainable) (1)
3. If (AllnTrashcan is small) and (OtherWasteInTrashcan is small) and (AllnLathe is large) then (output is Sustainable) (1)
4. If (AllnTrashcan is large) and (OtherWasteInTrashcan is small) and (AllnLathe is small) then (output is unsustainable) (1)
5. If (AllnTrashcan is large) and (OtherWasteInTrashcan is small) and (AllnLathe is moderate) then (output is unsustainable) (1)
6. If (AllnTrashcan is large) and (OtherWasteInTrashcan is small) and (AllnLathe is large) then (output is unsustainable) (1)
7. If (AllnTrashcan is large) and (OtherWasteInTrashcan is large) and (AllnLathe is small) then (output is unsustainable) (1)
8. If (AllnTrashcan is large) and (OtherWasteInTrashcan is moderate) and (AllnLathe is small) then (output is unsustainable) (1)
9. If (AllnTrashcan is large) and (OtherWasteInTrashcan is large) and (AllnLathe is moderate) then (output is unsustainable) (1)
10. If (AllnTrashcan is large) and (OtherWasteInTrashcan is large) and (AllnLathe is large) then (output is unsustainable) (1)

5.3 Appendix C - Graph of amounts of waste streams and the level of sustainability

