AN ABSTRACT OF THE THESIS OF

Fidel Delgado for the degree of Master of Science in Electrical & Computer Engineering presented on December 5, 2000. Title: A Fuzzy Logic Controller Design and Simulation for a Sawmill Bucking System.

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Abstract approved: ______ ______________________

Mario E. Magaña

This document investigates, justifies, designs, and simulates the application of a fuzzy logic controller/optimizer in a sawmill bucking system application that is the first production station where stems coming from the mountains are processed in a sawmill.

One of the areas of success in the application of fuzzy logic is in control systems. Fuzzy logic controllers are based on approximate reasoning of crisp (physical) variables to provide a possible output. Fuzzy controllers' decisions, if appropriate, try to simulate common sense decisions that a human will make after evaluating a set of data. Fuzzy control systems are designed with the intention of replacing an expert operator with a ruled-based system.

In this specific application the stems are sorted out in the sawmill yard as stems for Mill “A”, Mill “B” and Green End before they arrive at the bucking station. Mill “A” is a dimensional sawmill, Mill “B” is a stud sawmill and Green End is a Veneer mill. After the bark is removed from the tree, it passes through a bucking station where there are a length, and a diameter measurement system to provide an operator with some stem information so he/she can make a decision on what blocks he/she should cut.

The operator bucking solutions are based on his/her and other operators past experiences, the data provided by the length and diameter measurement systems and his/her visual inspection on the shape (sweep & taper) of the stem. The decisions of the operator are not exact but good enough or appropriate. His/her decisions have a common goal that is to recover the most wood out of every tree. This type of bucking system has been in practice for at least 50 years, and therefore, there is a very well established set of rules applied by the operator to obtain the most wood out of every tree.

The fuzzy logic controller simulations were designed with three fuzzy controller engines, one engine for each mill. This was due to the computing time and the simplicity of the design. Each one of the fuzzy controllers mentioned above was simulated using Matlab with the Fuzzy Logic Toolbox, and Simulink until the required design specifications were met.

A Fuzzy Logic Controller Design and Simulation for a Sawmill Bucking System

by

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APPROVED:

Redacted for Privacy

Major Professor, representing Electrical and Computer Engineering

Redacted for Privacy

Head of Department of Electrical and Computer Engineering

Redacted for Privacy

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Fidel Delgado, Author

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DEDICATION

This thesis is dedicated to God, my wife Carmen, and my three daughters Diana, Carmen, and Karen for all their support and understanding.

A Fuzzy Logic Controller Design and Simulation for a Sawmill Bucking System

1. INTRODUCTION

1.1 Problem Definition

This thesis addresses an alternative solution of the sawmill bucking problem using fuzzy logic. This is the first production station area where the stems are processed in a sawmill plant. The stems are sorted out and scaled in the sawmill yard as stems for Mill "A", Mill "B" and Green End before they arrive at the bucking station. Mill "A" is a dimensional sawmill, Mill "B" is a stud sawmill and Green End is a Veneer mill. The stems are placed on in-feed decks from where they are fed into a debarker machine. After the bark is removed from the tree, it passes to a bucking station where there are saws, lifts, stops, and sweeps to buck the stem and dispatch it to its corresponding destination. Length and diameter measurement systems installed in the same area provide the operator with some information to make a decision on what blocks he/she should cut out from every stem.

Every mill has different block requirements based on length, diameter, taper and sweep. For example, Mill "A" needs blocks of lengths from 12.1 to 20.1 feet, diameter from 7 to 50 inches, sweep from 0 to 20%, taper from 0 to 30%. Some of the stems require that defects be trimmed off the ends, these trims are usually small, and they vary between 1 and 6 inches (1, 3, and 6 inches). This cut ends are called lilypads. The operator bucking solutions are based on his/her and other operators past experiences, the data provided by the length and diameter measurement systems and his/her visual inspection on the shape (sweep & taper) of the stem. The decisions of the operator are not exact but good enough or appropriate. His/her decisions have a common goal that is to recover the most wood out of every tree. The operator has to go through a large database in his memory to fit the needed blocks in every stem. This type of bucking system has been in practice for at least 50 years. Thus, there is a very well established set of rules applied by the operator to buck the stems.

The problem defines the design of a control system to replace the human operator bucking decision-making part with an automatic controller that provides with all the different bucking solutions for the different mills mentioned above. The current operation is manual, and the goal will be to automate it. The controller will provide the bucking solutions to a Programmable Logic Controller system that will set the appropriate machinery to buck the stems automatically. The reason why the controller was chosen to be of the fuzzy logic type was because of its inherent capacity to make hierarchical decisions based on a set of data that comes from a base of expert rules. Below is a concise list of variables and their precedence. These are the inputs to the fuzzy logic controllers and provide the reader with some initial information of the structure of the system.

The input data variables supplied to the stem bucking fuzzy logic controller are:

Stem Destination	(Supplied by the operator)
Stem West Lily Pad Trim	(Supplied by the operator)

Stem East Lily Pad Trim	(Supplied by the operator)
Stem Length	(Supplied by the scanner system)
Stem Diameter	(Supplied by the scanner system)
Stem Taper	(Supplied by the scanner system)

These variables will be collected as the stem travels through the new bucking system line of about a quarter of a mile long.

Once all the variables are collected and the stem is at a specific physical location in the production line, the fuzzy logic controller will be asked by a Programmable Logic Controller to provide a bucking solution for these input data variables. The bucking solution is defined as the number of block combination that will provide the best wood recovery. This solution is, as mentioned before, based on a set of expert rules.

Due to the large amount of data to be analyzed, the fuzzy logic controller design and simulations are divided into three controllers, one for each mill. Furthermore, one of the mills fuzzy logic controllers was subdivided into two fuzzy logic controllers to represent two different bucking procedures for the same type of logs. Each one of the fuzzy controllers is composed of a set of expert rules representative of the decision the operator will make. The simulations are performed using Matlab, Simulink, and the Fuzzy Logic toolbox.

1.2 Justification

One of the most successful areas of application of fuzzy logic is in control systems. Fuzzy logic controllers are based on approximate reasoning of crisp (physical) variables to provide a possible output. Fuzzy controllers' decisions, if appropriate, try to simulate common sense decisions that a human will make after evaluating a set of data.

Fuzzy control systems are designed with the intention of replacing an expert operator with a ruled-based system. The fuzzy controller accepts crisp or defined inputs from sensors and the controller changes these signals to linguistics or fuzzy membership functions. This is called fuzzification. These variables are then processed by a set of IF-THEN rules (called inference engine) to result in some fuzzy outputs. These outputs are changed back to crisp values through another process called defuzzication to obtain an approximate output

The stem bucking application in question therefore justifies the use of fuzzy logic to obtain the desired stem bucking solutions. Crisp input data will be gathered from an operator data entry and a scanner system. Then based on a well established set of expert-rules, the fuzzy logic controller will solve for the best bucking stem solution for the required mill, and will provide crisp block solutions in a form of a data file as an output to another system for further stem handling.

1.3 Organization of Thesis

This thesis is organized in five chapters. Chapter one presents the introduction, justification, and organization of the thesis. Chapter two presents a review of the fundamentals of Fuzzy Logic needed to design and simulate the Bucking Fuzzy Logic Controllers. It begins with an introduction to Fuzzy Control. Next, classical and fuzzy sets are explained followed by a description of fuzzy set operations and properties. Next, the extension principle, fuzzy relations, and operation on fuzzy relations are discussed. Then, the Fuzzy Rule Base Expert Systems (FRBES) are revised with their graphical computational techniques. Finally, the chapter ends with a review of the deffuzification process. This literature review is necessary to understand the following chapters. Chapter Three deals with the analysis and design of the Bucking Fuzzy Logic Controllers. It begins with a statement of intention of the thesis, and a detailed block diagram of the Bucking Fuzzy Controller is supplied. Next, the system inputs, outputs and specifications are presented. Then, The Mill "A" Bucking Controller: Continuous and discrete type, Mill "B" and Veneer Mill Bucking Controllers are analyzed and designed. Chapters four and five contain the simulations of all Mills Fuzzy Logic Controllers. Simulation diagrams are shown and explained. Finally Chapter six provides with a summary of the thesis and a paragraph for future development.

2. FUZZY LOGIC LITERATURE REVIEW

2.1 Introduction

Fuzzy logic is a multilevel logic and is the foundation of any logic. The spectrum of fuzzy values varies from zero (0) that is false to one (1) that is true, and all the values between 0 and 1. Thus the spectrum of logical values is therefore infinite.

Fuzzy logic tolerates inexactness and imprecision to reach the goal of a system. For example, to design a system that sorts lumber based on length where the steps in material produced are in feet, we do not need to include in our design a length measurement device with a resolution of a thousand of a inch. A fuzzy controller will take into consideration the length constraint and operate based on the appropriate accuracy. Fuzzy logic was invented to provide a strong computational tool to analyze systems through modes of reasoning that are appropriate and not exact [1]. In fuzzy logic, the exact reasoning is considered to be the boundaries or limits of the approximate reasoning.

In fuzzy logic, the fuzziness of a property lies in the lack of well -defined boundaries of the set of objects to which the property applies. For example, if we talk about a set of long logs in a sawmill (where sawmill is the universe X and long logs are a subset A of X); thus we are dealing with the set of logs having the property of being long. To describe this set mathematically in fuzzy logic, we start assigning degrees of membership to the long log property. These degrees of membership will vary from 0 to 1; zero representing the logs that are short and one representing the logs that are long. Then the logs that are between short and long will have a membership value between 0 and 1. Fuzzy sets are represented mathematically by using a membership function that provides a degree of membership within the set. This function maps the elements of the universe X (the sawmill) that are long logs into a numerical value within the range [0,1], and it is represented as follows:

$$\mu_A(X) : X \longrightarrow [0, 1]$$

The representation of the variables through a membership function is also called linguistic representation of variables. It provides a range of possible values of the variables.

In a graph the long logs membership function will look as follows:

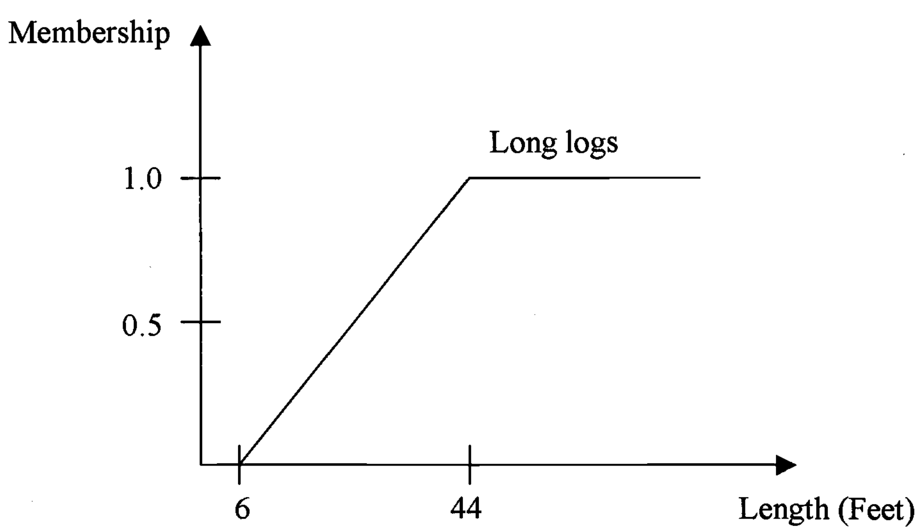


Figure 2.1. Long Logs Membership Function

2.2 Fuzzy Control

Fuzzy Control provides a formal methodology for representing, manipulating, and implementing a human heuristic knowledge about how to control a system [2]. The Fuzzy Logic Controller has four main components: (1) The rule-base holds the knowledge in the form of a set of rules of how best to control the system. (2) The inference mechanism evaluates which control rules are relevant at the current time and then decides what the input to the plant should be. (3) The fuzzification interface simply modifies the real world inputs so that they can be interpreted and compared to the rules in the rule-base. And (4), the defuzzification interface converts the conclusion reached by the inference mechanism into the inputs to the plant.

A fuzzy controller is presented in figure 2.2 below:

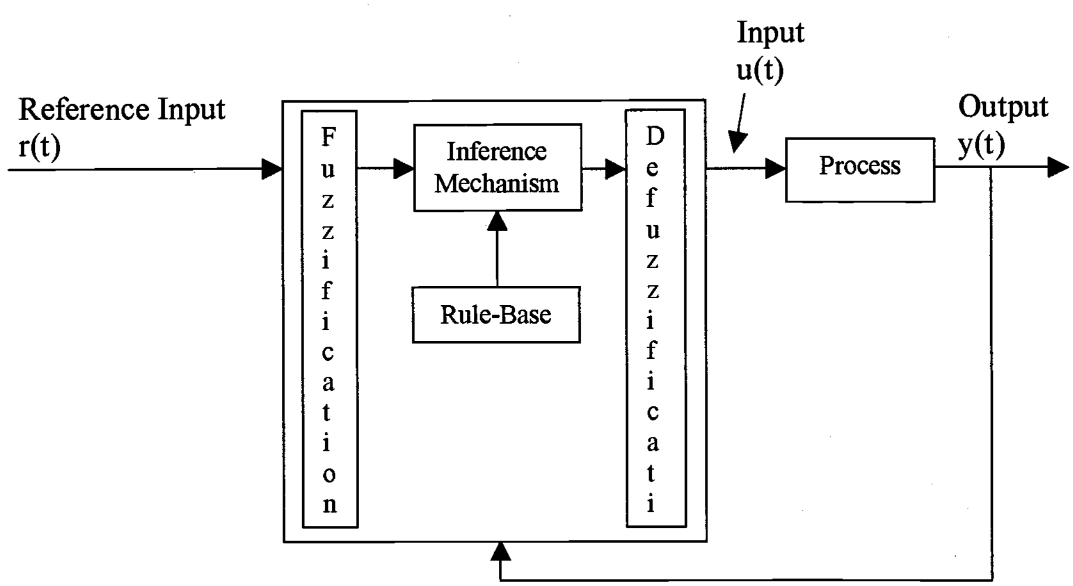


Figure 2.2. Block Diagram of a Fuzzy Logic Control System

Fuzzy set theory is a broader theory than classical set theory, because it considers an infinite number of degrees of membership in a set other than discrete values 0 and 1 as in classical set theory. The boundary of a fuzzy set is ambiguous, vague and fuzzy. A fuzzy set contained in a universe of elements does not have finite boundaries.

2.3 Classical Sets and Properties

The universe of discourse is defined as the set of elements with the same characteristics; where its elements can be discrete and finite or continuous and infinite. The total number of elements in X is called the cardinality number n_X. Let's define A and B as subsets of X, then the following hold:

$A \subset B$ then A is contained in B; $A \subseteq B$ then A is fully contained in B; $A = B$ then $A \subseteq B$ and $B \subseteq A$. The null set is defined as the set that does not contain elements.

There is a special set called the power set that is composed from any subset which has cardinality defined as $n_{p(x)}$.

Below is a list of properties of Classical Sets,

Commutativity $A \cup B = B \cup A$
$A \cap B = B \cap A$

Associativity $A \cup (B \cup C) = (A \cup B) \cup C$
$A \cap (B \cap C) = (A \cap B) \cap C$

Distributivity $A \cup (B \cap C) = (A \cup B) \cap (A \cup C)$
$A \cap (B \cup C) = (A \cap B) \cup (A \cap C)$

Idempotency $A \cup A = A$
$A \cap A = A$

Identity $A \cup \varnothing = A$
$A \cap X = A$
$A \cap \varnothing = \varnothing$
$A \cup X = X$

Transitivity If $A \subseteq B$ and $B \subseteq C$ then $A \subseteq C$

Involution $\bar{\bar{A}} = A$

Excluded-Middle Laws:

1. Law of excluded middle $A \cup \bar{A} = X$
2. Law of contradiction $A \cap \bar{A} = \varnothing$

DeMorgan's Laws:

1. $\overline{(A \cap B)} = \bar{A} \cup \bar{B}$
2. $\overline{(A \cup B)} = \bar{A} \cap \bar{B}$

2.4 Mapping of Classical Sets to Functions

Mapping can be used to map elements or subsets on one universe of discourse to elements or set in another universe. For example, the tracking of a stem on a belt or chain can be done by mapping the stem divided in feet to a bit shift register where 1 means 1' of stem and 0 means no stem.

A mapping is represented by f: $X \rightarrow Y$ which means that the elements of X such as x corresponds to an element in Y. The characteristic function X_A is defined as:

$$X_A(x) = \begin{cases} 1, x \in A \\ 0, x \notin A \end{cases}$$

where X_A means membership in set A for the element x in the universe of discourse. The membership idea maps an element x of X to one of the two elements in Y (0 & 1).

Define two sets on the universe X, sets A and B. Then the union of these sets in terms of function-theoretic terms is given by,

Union: $A \cup B \rightarrow X_{A \cup B}(x) = X_A(x) \vee X_B(x) = \max(X_A(x), X_B(x))$

Interception: $A \cap B \rightarrow X_{A \cap B}(x) = X_A(x) \wedge X_B(x) = \min(X_A(x), X_B(x))$

Complement: $\bar{A} \rightarrow C_{\bar{A}}(x) = 1 - C_A(x)$

Containment $A \subseteq B \rightarrow X_A(x) \leq X_B(x)$

2.5 Fuzzy Sets

A fuzzy set is a set containing elements that have varying degrees of membership [3]. This membership function describes vagueness & ambiguity. The elements of a fuzzy set are mapped to a universe of membership values using a function theoretic form. If A is a fuzzy set, the membership function maps the elements of the fuzzy set A to a real number in the interval [0,1]. Then $\mu_A(x) \in [0,1]$ and $A = (x, \mu_A(x)/x \in X)$.

These mappings are shown in figures below for crisp and fuzzy sets respectively:

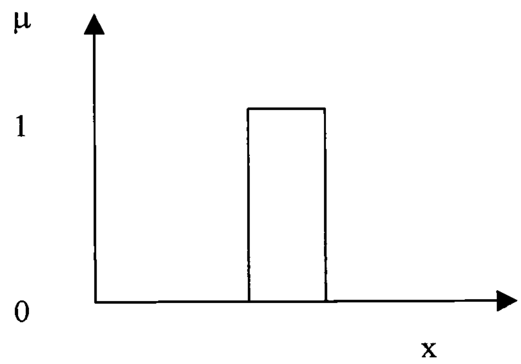


Figure 2.3. Membership Function for a Crisp Fuzzy Set A

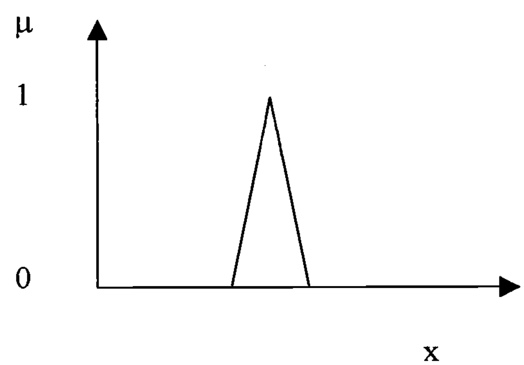


Figure 2.4. Membership Function for a Fuzzy Set A

Notations for fuzzy sets,

$A = \sum \mu_A(xi)/\ xi$; for a universe of discourse, X, discrete and finite

$A = \int \mu_A(xi)/\ xi$; for a universe of discourse, X, continuous and infinite

For both notations, the slash bar is not a quotient, but rather a delimiter. The numerator is the membership value in set A associated with the elements of the universe indicated in the denominator of each term. The summation symbol is not an algebraic summation, but rather is denoting a fuzzy union; hence the summation signs in the first notation, are not an algebraic add, but rather function -theoretic union. In the second notation the integral sign is not an algebraic integral, but rather a set of union notation for continuous variables.

2.6 Fuzzy Set Operations

Define three fuzzy sets A, B, and C on the universe X. For a given element x of the universe, the following function-theoretic operations for the set-theoretic operation of union, interception and complement are defined,

Union: $\mu_{A\cup B}(x) = \mu_A(x) \vee \mu_B(x)$

Interception: $\mu_{A\cap B}(x) = \mu_A(x) \wedge \mu_B(x)$

Complement: $\mu_{\bar{A}}(x) = 1 - \mu_A(x)$

Venn diagrams for the above formulations are as follows:

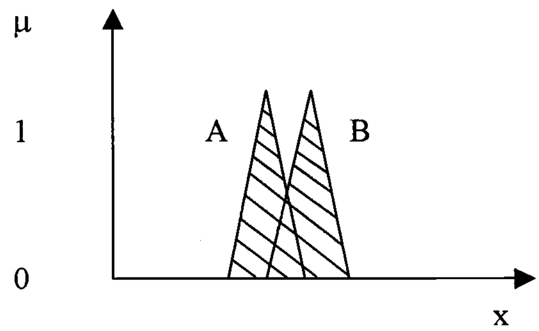


Figure 2.5. Union of Fuzzy Sets A & B

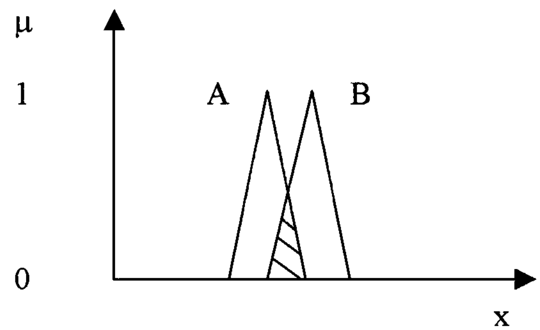


Figure 2.6. Interception of Fuzzy Sets A & B

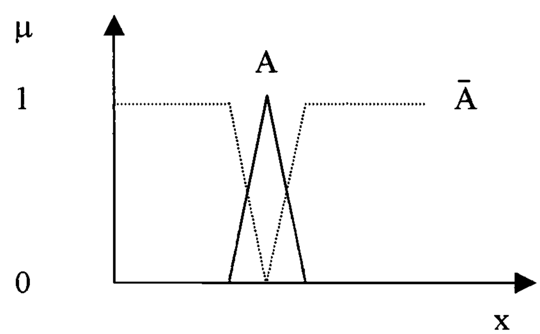


Figure 2.7. Complement of Fuzzy Set A

The membership value of any element x in the null set $\varnothing$ is 0, and the membership value of any element x in the whole set X is 1. The representation for the above ideas is as follows:

$A \subseteq X \rightarrow \mu_A(x) \leq \mu_X(x)$

$\forall\, x \in X,\ \mu_\varnothing(x) = 0$

$\forall\, x \in X,\ \mu_X(x) = 1$

The collection of all fuzzy sets and fuzzy subsets on X is denoted as the fuzzy power set P(x). The cardinality of P(x) is infinite.

Cardinality of P(x) $\longrightarrow$ $n_P(x) = \infty$

DeMorgan's Laws are hold for fuzzy sets,

1. $\overline{(A \cap B)} = \overline{A} \cup \overline{B}$
2. $\overline{(A \cup B)} = \overline{A} \cap \overline{B}$

The middle laws do not hold because of the fact that fuzzy sets can overlap. Then,

$\overline{A} \cup A \neq X$

$\overline{A} \cap A \neq \varnothing$

2.7 Features of the Membership Function

The features of the membership function are described in Figure 2.8 below:

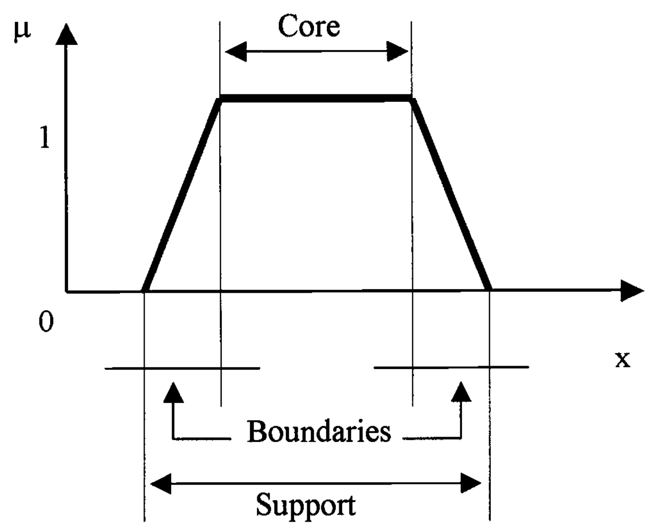


Figure 2.8. Core Support and Boundaries of a Fuzzy Set

The ***core*** is comprised of those elements of the universe, where $\mu_A(x) = 1$. The ***support*** is defined as that region of the universe that is characterized by non-zero membership in the set A, where $\mu_A(x) \neq 1$. The ***boundaries*** are defined as the elements of the universe, X, where $0 < \mu_A(x) < 1$ and are these elements of the universe the ones with some degree of fuzziness.

A ***normal*** fuzzy set is one where the membership function has at least one element of the universe, X, whose membership value is one. When the fuzzy set has one and only one element such that $\mu_A(x) = 1$ then it is typical referred as the ***prototype*** of the set, or the prototype element.

2.7.1 Convex Fuzzy Set

For all elements in a continuous fuzzy set A where $x < y < z$, and where $\mu_A(y) \geq \min [\mu_A(x), \mu_A(z)]$. Then A is said to be a ***convex*** set. As a result the interception of two fuzzy convex sets is also a convex set.

2.7.2 Extension Principle

The extension principle allows us to extend the domain of a function of fuzzy sets.

Let f: u → v where u are elements of the universe U and v are elements of the universe V.

Define $A \subset U$ and

$$A = \mu_1/u_1 + \mu_2/u_2 + \ldots + \mu_n/u_n$$

Then the extension principle asserts that, for a function **f** that maps one element in universe U to one element in universe V,

$$f(A) = f(\mu_1/u_1 + \mu_2/u_2 + \ldots + \mu_n/u_n) = A = \mu_1/f(u_1) + \mu_2/f(u_2) + \ldots + \mu_n/f(u_n)$$

This mapping is said to be one to one.

Example. Let a fuzzy set A be defined on the universe U = {8.1', 9.1', 10.1'} where U represents the length of blocks of Mill B. We wish to map elements of this fuzzy set to another universe, V, where V represents the length of blocks of the Veneer Mill, under the function $v = f(u) = u + 0.5$ which implies that V = {8.6', 9.6’, 10.6’}. If the fuzzy set A is given by U = 0.1/8.1 + 1/9.1 + 0.5/10.1 then the membership function for v = f(u) = u + 0.5, would be,

f(A) = 0.1/8.6 + 1.0/9.6 + 0.5/10.6

The membership function is kept for the elements of the universe U and V. For cases where this functional mapping f maps products of elements from two universes, say U_1 and U_2, to another universe V, and we define A as a fuzzy set in the Cartesian space $U_1 x U_2$ then,

$f(A) = \{\min [\mu_1(i), \mu_2(j)] / f(i, j) \setminus i \in U_1, j \in U_2\}$

The complexity of the extension principle increases when we consider if more than the combination of input variables U_1 and U_2 are mapped to the same variable in the output space V. In this case we take the maximum membership grades of the combination mapping to the same output variable.

$\mu_A(u_1, u_2) = \max[\min \{\mu_1(u_1), \mu_2(u_2)\}]$

$v = f(u_1,u_2)$

2.7.3 Relations Among Fuzzy Sets

A fuzzy relation R, is a mapping from the Cartesian space XxY to the interval [0,1], where the strength of the mapping is expressed by the membership function of the relation from ordered pairs from the two universes, or $\mu_R(x,y)$.

The cardinality of fuzzy relations between two or more universes is infinite.

2.7.4 Operations on Fuzzy Relations

Let R, S and T be fuzzy relations on the Cartesian space XxY. The following applies,

Union: $\mu_{R\cup S}(x,y) = \max(\mu_R(x,y),\ \mu_S(x,y))$

Interception: $\mu_{R\cap S}(x,y) = \min((\mu_R(x,y),\ \mu_S(x,y))$

Complement: $\mu_R(x,y) = 1 - \mu_R(x,y)$

Containment: $R \subset S \Rightarrow \mu_R(x,y) \leq \mu_S(x,y)$

The operations of commutativity, associativity, distributivity, involution and idempotency are all valid for fuzzy relations. The DeMorgan's Laws are also valid for fuzzy relations. The only ones that are not valid are the Excluded Middle Laws because there is an overlap between a relation and its complement.

Because fuzzy relations are fuzzy sets, we can define the Cartesian product between fuzzy sets. Let $A \subset X$ and $B \subset Y$; then the Cartesian product between sets A and B is:

$A \times B = R \subset X \times Y$ with membership function, $\mu_R(x,y) = \mu_{AxB}(x,y) = \min((\mu_A(x),\ \mu_B(y))$.

2.7.5 Fuzzy Compositions

Let R be a fuzzy relation on the Cartesian space X x Y, and S a fuzzy relation on Y x Z, and T a fuzzy relation on X x Z. The fuzzy max-min compositions is given by,

$$T = R \circ S$$

$$\mu_T(x,z) = \vee_{y \in Y} (\mu_R(x,y) \wedge \mu_S(y,z))$$

and the fuzzy max-product composition is define as,

$$\mu_T(x,z) = \vee_{y \in Y} (\mu_R(x,y) \bullet \mu_S(y,z))$$

2.8 Fuzzy Rule-Based Expert Systems (FRBES)

Complexity in systems models arises as a result of factors such as

1. High dimensionality
2. Too many interacting variables, and
3. Un-modeled dynamics, such as non-linearities, time variations, external noise or disturbance, and system perturbations.

All the available pieces of knowledge should be considered is the overall decision making process when designing a control system.

Fuzzy mathematics, which comprises of fuzzy set theory, fuzzy logic, and fuzzy measures provides the mathematical tools that help the investigator to formalize the ill-defined description in the form of linguistically stated IF…THEN… rules into mathematical equations realizable on the conventional digital computers. The ill-defined systems are described by fuzzy relational equations. These are expressed in the form of sup-min., max.-prod, or inf. max fuzzy compositions. These operations are executed on classes of membership functions defined on a number of overlapping partitions of the space of possible inputs, possible mapping restrictions, and possible consequent output responses.

To reduce a fuzzy relational equation to a simple canonical form, some fundamental assumptions are made:

1. Input variables are assumed to be non-iterative
2. The membership functions of the points in the state space of the system are assigned based on the degree of similarity of the corresponding output to a prototype output point
3. The membership functions are assumed linearly dependent in the net distance to a prototype-input point. Thus, the membership functions will be in one of the rectangular, triangular or trapezoidal forms.
4. Appropriate non-linear transformations and/or sensory integration on inputs and outputs spaces are often used.

2.8.1 Graphical Computation Techniques for FRBES Models

A fuzzy system with two non-interactive inputs x_1 and x_2 and a single output y, is either described by a system of disjunctive or conjunctive relational equations as shown in equation (1).

$$y^K = x_1 \text{ o } x_2 \text{ o } R^K \quad \text{for } k = 1,2,\ldots, r \tag{1}$$

where "o" stands for Max-Min or Max-Product composition of fuzzy relations or it may be described by a collection of linguistic IF...THEN... propositions as in equation (2).

$$\text{IF } x_1 \text{ is } A^k{}_1 \text{ and } x_2 \text{ is } A^k{}_2 \text{ THEN } y^K \text{ is } B^K \text{ for } k = 1, 2,\ldots, r \tag{2}$$

Next, four cases are considered, i.e.,

1. The inputs to the systems are sharply defined
2. The inputs to the system are represented by fuzzy sets
3. The input x_1 and x_2 and the system are described in non-fuzzy way.
4. The input x_1 and x_2 are fuzzy sets and the system is characterized by the function $f: X_1.X_2 \rightarrow Y$

1. Inputs x_1 and x_2 are sharply defined. The system is described by equation (1), so we will have:

$$\mu(x_1) = \delta(x_1 - \bar{x}_1) = \begin{cases} 1, \text{ for } x = \bar{x}_1 \\ 0, \text{ otherwise} \end{cases} \quad (3)$$

$$\mu(x_2) = \delta(x_2 - \bar{x}_2) = \begin{cases} 1, \text{ for } x = \bar{x}_2 \\ 0, \text{ otherwise} \end{cases} \quad (4)$$

the aggregated output is,

$$\mu_Y(y) = \text{Max}_k \{\text{Max}_{x1 \in X1} \{\text{Max}_{x2 \in X2} \{\text{Min}[\mu_{X1}(x_1), [\mu_{X2}(x_2), \mu_R^k(x_1, x_2, y)]\}\}\} \quad (5)$$

Substituting (3) and (4) in (5) we have

$$\mu_Y(y) = \text{Max}_k [\text{Max}_{x1 \in X1} \{\text{Max}_{x2 \in X2} \{\text{Min}[1, 1, \mu_R^K(x_1, x_2, y)]\}\}\}$$

$$\mu_Y(y) = \text{Max}_k [\mu_R^k(\bar{x}_1, \bar{x}_2, y)] \quad (6)$$

Thus in order to find the value of the aggregated output at any point Y, we have to find the values of all fuzzy relations R^k for $k = 1, 2, \ldots, r$ evaluated at $x_1 = \bar{x}_1$, $x_2 = \bar{x}_2$, and $y = \bar{y}$ and then take the maximum value. For the case where the fuzzy systems is described by a set of linguistic IF…THEN rules as in equation (2), based on Mamdani's implication, this will turn out to,

$$\mu_y(y) = \mathrm{Max}_k \{\mathrm{Min}\,[\mu_{A_1}^{k}(\bar{x}_1), \mu_{A_2}^{k}(\bar{x}_2), \mu_B^{K}(y)]\} \qquad (7)$$

The graphical interpretation of equation (7) is illustrated in figure 2.9 below,

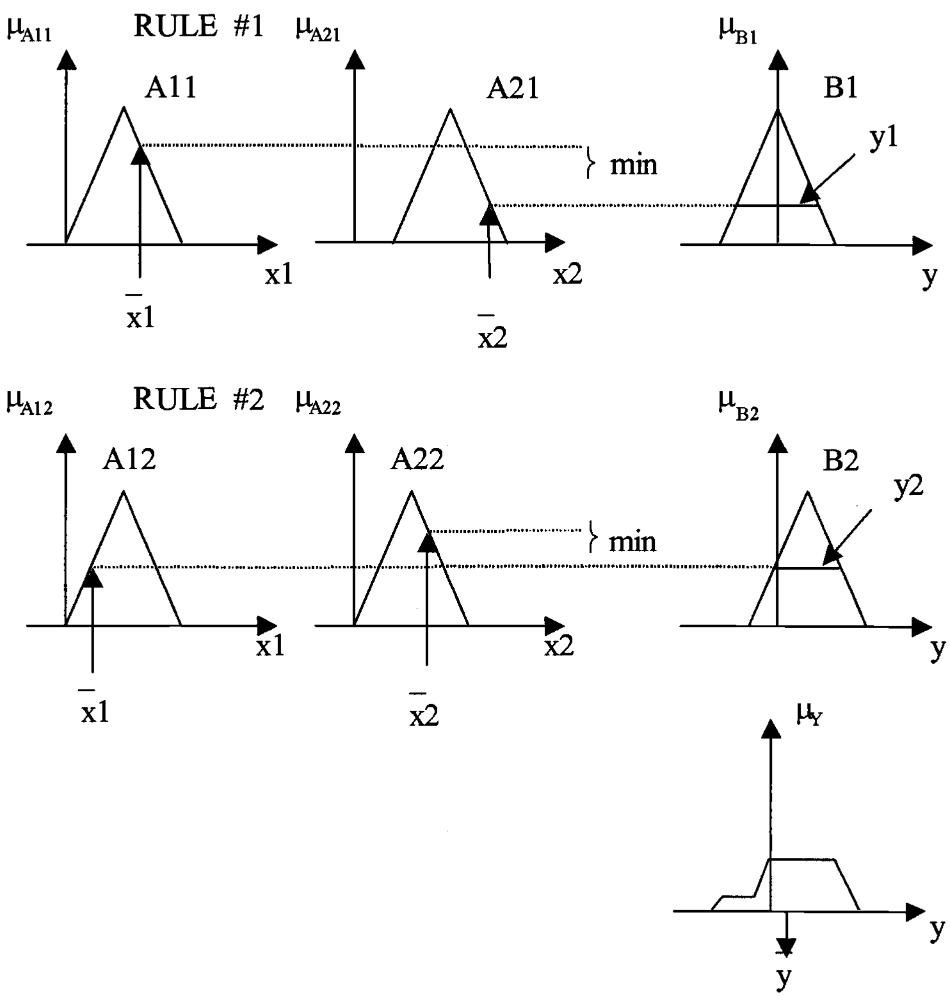


Figure 2.9. Graphical Max-Min Inference Method

In order to find a sharp crisp value for the aggregated output, some appropriate defuzzification technique could be employed [4], i.e.,

$$\bar{y} = \text{DEFUZZ}\,[\mu_Y(y)] \tag{8}$$

2. Input x1 and x2 are fuzzy variables and represented by membership functions. The output is given by:

$$\mu_Y(y) = \text{Max}_K \{ \text{Max}_{x1 \in X1} \{ \text{Max}_{x2 \in X2} \ldots\ldots\ldots \{\text{Min}\,[\mu_{X1}(x_1), \mu_{X2}(x_2), \mu_{Rk}(x_1, x_2, y)]\}\}\} \tag{9}$$

For the case where the fuzzy system is described by a set of linguistic IF…THEN… rules, based on Mamdani's implication relations, this will turn out to be given by:

$$\mu_Y(y) = \text{Max}_k\{\text{Max}_{x1 \in X1} \{\text{Max}_{x2 \in X2} \{\text{Min}\,[\mu_{X1}(x_1), \mu_{X2}(x_2), \mu_{A_1^k}(x_1), \mu_{A_2^k}(x_2), \mu_{B^k}(y)]\}\}\} \tag{10}$$

The graphical interpretation of equation (10) is given in figure 2.10 below,

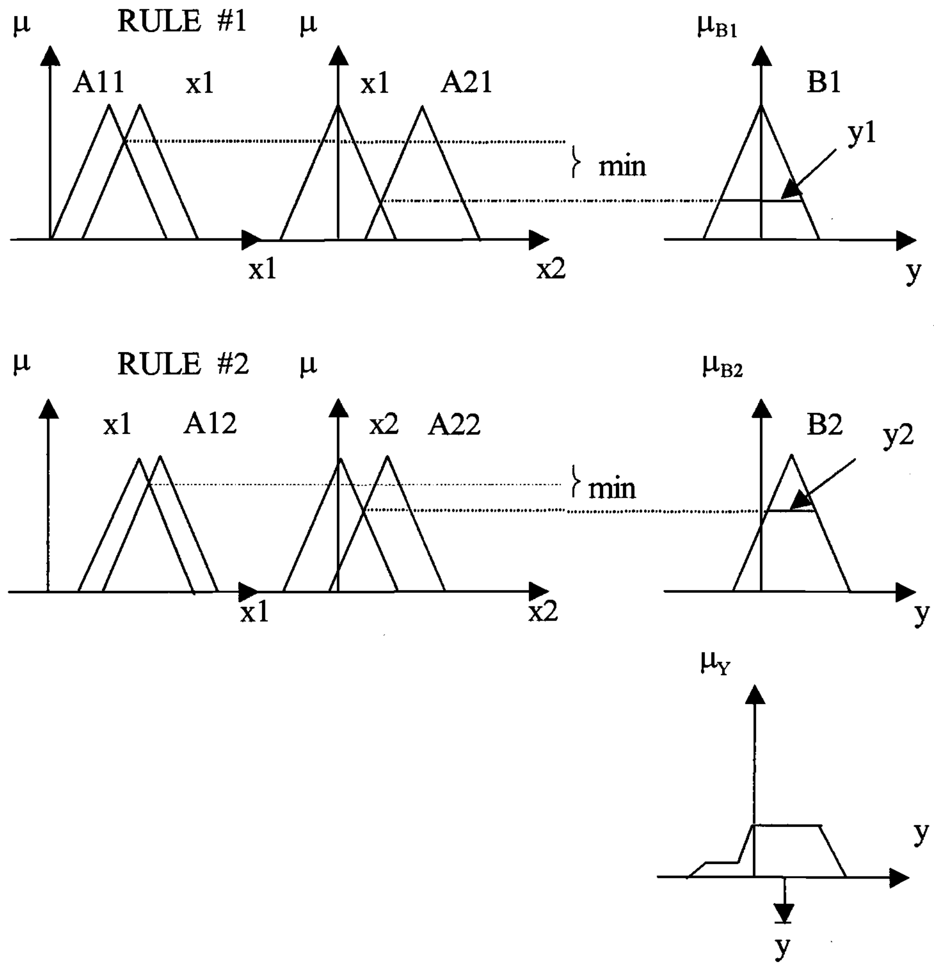


Figure 2.10. Graphical Max-Min Method for Fuzzy Inputs

In order to find a sharp crisp value for aggregated output, some appropriate defuzzification technique could be employed, i.e.,

$$Y = \text{DEFUZZ}\ [\mu_Y(y)] \tag{11}$$

3. For the case where the input x, output y, and the systems are described in non-fuzzy way, based on $\mu(x_1) = \delta(x_1 - \bar{x}_1)$ and $\mu(x_2) = \delta(x_2 - \bar{x}_2)$, the output will turn out to be as follows:

$$\mu_Y(y) = \text{Max}_{x1 \in X1}\{\text{Max}_{x2 \in X2}\{\text{Min}[\delta(x_1 - \bar{x}_1), \delta(x_2 - \bar{x}_2), \delta\, y,(\bar{x}_1, \bar{x}_2)]\}\} \qquad (12)$$

$$\text{where } \delta\, y, (\bar{x}_1, \bar{x}_2) = \begin{cases} 1, \text{for } (\bar{x}_1, \bar{x}_2) = f^{-1}(y) \\ 0, \text{otherwise} \end{cases}$$

If the system is described as $y = f(x_1,x_2)$ equation (12) leads to

$$\mu_Y(y) = \begin{cases} 1, \text{for } y = f(\bar{x}_1, \bar{x}_2) \\ 0, \text{otherwise} \end{cases} \qquad (13)$$

So we get back to crisp form of the system described by $y = f(x_1,x_2)$ and this proves that the conventional crisp mathematics could be considered as a special case of the fuzzy mathematics.

4. Input x_1 and x_2 are fuzzy sets and the system is being described by a crisp functions, eg.,

$y = f(x_1, x_2)$. The output is found based on Zadeh's Extension principle,

$$\mu_Y(y) = \text{Max}_{(x1,x2) \in f\text{-}1(y)}\{\text{Min}[\mu_{x1}(x_1), \mu_{x2}(x_2)]\} \qquad (14)$$

The output is generally a fuzzy set which could be defuzzified if desired, i.e.,

$$Y = \text{DEFUZZ}[\mu_Y(y)] \qquad (15)$$

2.8.2 Defuzzification Process

The conversion of a fuzzy quantity represented by a membership function to a precise or crisp quantity is defined as the defuzzification process [4].

Three defuzzification techniques are described below:

1. Max Method. When the membership function of the fuzzy quantity has a unique peak point, the crisp value corresponding to the peak of the function is taken to be the best representative value of the fuzzy quantity, i.e.,

   $\bar{y} = \text{DEFUZZ}\,[\mu_Y\,(y)]$,

   where

   $$\text{Max}_{\,y\,\in Y}\;[\mu_Y(y)\,] = \mu_Y(\,\bar{y}\,) \qquad (16)$$

   Figure 2.11 illustrates this method of defuzzification

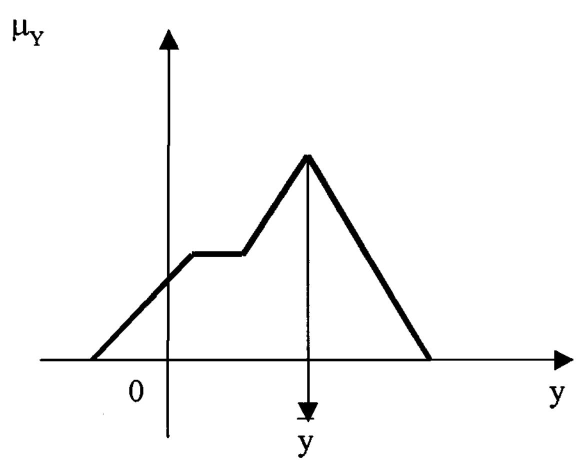


Figure 2.11. Maximum Membership Method of Defuzzification

2. Centroid Method. The weighted average of the membership function or the center of gravity of the area bounded by the membership function curve is computed to be the most typical crisp value of the fuzzy quantity, i.e.,

$$Y = \int \mu_Y(y) . y \; dy / \int \mu_Y(y) \, dy \qquad (17)$$

Graphically this method is shown in figure 2.12.

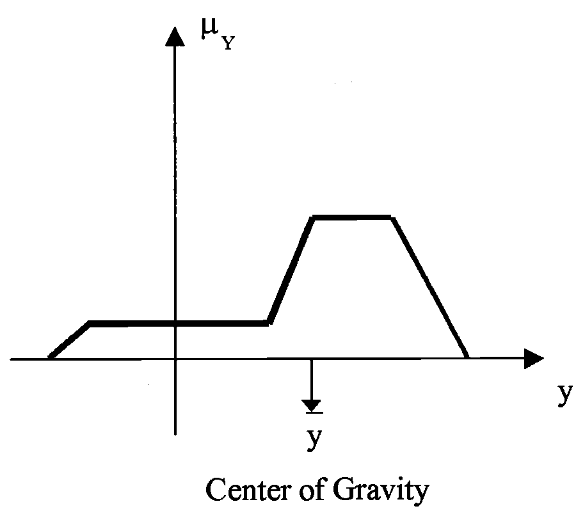


Figure 2.12. Centroid Method of Defuzzification

3. Height method. This technique is valid only for the case where the output membership function is an aggregated union result of symmetrical functions

$$\text{If } \mu_Y(y) = \text{Max}\,[\mu_{y1}(y), \mu_{y2}(y), \ldots, \mu_{yr}(y)] \qquad (18)$$

$$\mu_y^k(\bar{y}^k) = \text{Max}\,[\mu_y^k(y)] \qquad (19)$$

Then, the defuzzified output is,

$$y = \Sigma\, \mu_y^k(\bar{y}^k) . \; \bar{y}^k / \Sigma\, \mu_y^k(\bar{y}^k) \qquad \text{for } k = 1, 2, \ldots, r \qquad (20)$$

Figure 2.13 below illustrates this method for r = 2

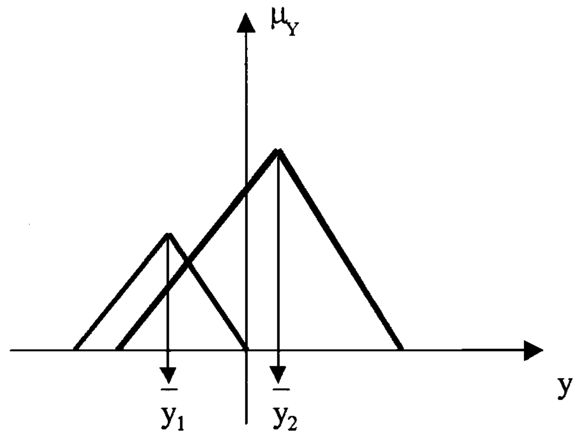


Figure 2.13. Height Defuzzification Technique

3. FUZZY BUCKING CONTROLLER SYSTEM DESIGN

The objective of the design of the bucking fuzzy logic controller is to replace the human operator bucking decision-making part with an automatic controller that provides all the different bucking solutions for Mill "A", Mill "B", and the Green End or Veneer mill with the most wood recovery.

We will begin with an explanation of the process itself to provide an understanding where the bucking fuzzy logic controller fits in the production line, how the controller inputs are gathered as the stem moves through the production line and where the resulting blocks of the bucking process will be delivered based on the bucking solutions produced by the controller. We will use stem or log indistinctively through out the thesis.

After the stems are sorted out and scaled in the sawmill yard as stems for Mill "A", Mill "B", and Green End, they arrive at the in-feed of the bucking station. Mill "A" is a dimensional sawmill, Mill "B" is a stud sawmill, and the Green End is a Veneer mill. The stems are placed on the in-feed decks from where they are fed into a 50 inches Barker machine that removes the bark off the stems. While the stem is in the 50" Barker or on the barker out-feed chain, the operator will specify its destination by pressing a push button on his console. The log will be tagged as Mill "A", Mill "B", or Veneer mill. He/She will also tag the stem with any needed end trim requirements due to defects at the ends of the log. Valid end trims are 1", 3", and 6" at any or at both log ends. Photocells on the 50" Barker in-feed chain will determine and alert the operator if a log is oversize in diameter (greater than

26") and/or length (grater than 44'). If the log is over the maximum diameter of 26", the operator must manually buck it and send it straight into Mill "A" as per existing system. If the log is over its maximum allowable length of 44', the operator must buck it into two sections, tag each section with a destination, and sweep each section into the sequencing deck at the out-feed of the 50" Barker where the automation will take over again.

At the 50" Barker out-feed a Programmable Logic Controller (PLC) has tagged the stem with the operator-supplied data, and will track the stem from this point on. Upon sweeping the stem off onto the sequencing deck, it will advance in sequence until loaded onto the 50' conveyor after the PLC program has determined by reading photocells, and an encoder a proper gap from the prior log. It will then move forward and onto the 140' conveyor. As the log travels on this conveyor, it will pass through a scanning system that will provide log length and X-Y diameters of the log every inch, so that a stem model can be built with information the bucking fuzzy logic controller needs. On the 140' conveyor and before the scanner location there is another input of veneer logs prominent from the 27" Barker. When the log is 15' away from the end of the 140' conveyor, the PLC will present the fuzzy logic controller with the input data collected at the operator station and the scanner, and it will ask for a bucking solution. Then, after the controller has found a bucking solution, it will pass it back to the PLC in the form of a structured data file. Communications between the PLC and the fuzzy controller computer are done using Ethernet. Then the PLC will set the appropriate downstream machinery, including the new bucking system, to buck the stem and dispatch the resulting blocks according to the solution provided by the bucking fuzzy logic controller. The downstream machinery consists of sweeps, linear positioners, saws, cradles, gates, pin stops, belts, chains, and a step feeder. An explanation of the operation of this machinery is omitted because is beyond the scope of this thesis.

3.1 Fuzzy Bucking Controller System Inputs/Outputs Definitions and Specifications

To proceed with the Fuzzy Bucking Controller design, it is necessary to define the system inputs, outputs, specifications and the vocabulary used in the Forest Industry.

3.1.1 System Inputs

The bucking fuzzy logic control system inputs are defined below as well as its source of information is given,

1. Stem Length (SL) is the longitudinally tree measurement in feet. The stem length varies from 10 to 44 feet. A scanner provides this input.
2. Stem Large End Diameter (LED) is the end of the tree with the largest diameter measured in inches. It ranges from 4 to 27 inches. A scanner provides this input.

3. Stem Small End Diameter (SED) is the end of the tree with the smallest diameter measured in inches. It ranges from 4 to 27 inches. A scanner provides this input.
4. Stem Destination (SD) refers to the mill or mills where the cut blocks are dispatched. There are four possible destinations,

   Mill "A": Dimensional Lumber manufacturing mill

   Mill "B": Stud Lumber manufacturing mill

   Veneer: Veneer manufacturing mill

   Rejects: Reject bin or pocket for stems rejected by the operator

   An operator provides this input
5. Stem Near End Lily Pad Trim (SNELP) is a small trim cut off the leading end of the stem. Valid lily pad trims are 1, 3, and 6 inches. An operator provides this input.
6. Stem Far End Lily Pad Trim (SFELP) is a small trim cut off the trailing end of the stem. Valid lily pad trims are 1, 3, and 6 inches. An operator provides this input.
7. Taper is a measurement of the stem's slope. A positive slope means that the LED is in the stem-leading end. It is computed from SED, LED, and the stem length.
8. Saw kerf is the thickness of the saw that is converted to dust when it makes a cut. The kerf is 0.75 inches. An operator provides this input.

3.1.2 System Outputs

The outputs of the fuzzy bucking controller are the block cut solutions resulting from the fuzzy inference process. The block lengths are different for every manufacturing mill due to different bucking rules and specifications. For example, Mill "B" solutions consist up to five blocks while Mill "A" solutions consist of a maximum of 2 blocks. The length of these blocks is different for every mill as described later in the paper. Lily pad cuts belong to the block solutions even though they are processed through a discrete type of logic filter they need to be included as part of the bucking solution.

After the PLC received the fuzzy bucking solution, it generates a Stem block data file with Saw Cuts Sequence output that refers to a list of blocks to be cut off the stem and the position of the Saw to execute these cuts. Included in this file are lily pads and other information needed to set the appropriate machinery.

The design of the Fuzzy Bucking Controller was subdivided in three fuzzy controllers. One for Mill "A", one for Mill "B", and one for the Veneer mill. Furthermore Mill "A" bucking controller was divided into two additional controllers, a continuous and a discrete type.

This break down of various fuzzy controllers was done to make the design simpler and to accelerate the solution making process. An acceptable solution time from the controller is 1.5 seconds or less. This is because the stems are moving from a maximum speed that varies from 300 to 350 linear feet per minute (FPM) in a production line and at that speed there is much time to wait for a solution. Thus the constraint to provide with an accurate bucking solution in the least possible time is critical. Each one of the fuzzy bucking controllers is explained in the following pages.

3.1.3 System General Specifications

Stem Input Length:	10 to 44 feet
Stem Maximum Diameter:	6 to 26 inches
Stem Sweep:	10 to 20 inches
Stem Taper:	5 to 40 inches
Lily pads:	1, 3 and 6 inches on the leading and/or the trailing end of the stem
Blocks Accuracy:	½ inch

Maximum Fuzzy Bucking Controller Solution Time: 1.5 seconds

Detail Specifications for every fuzzy bucking controller are presented when each fuzzy bucking controller is analyzed.

3.2 Mill "A" Continuous Type Bucking Controller

Mill "A" is a dimensional mill. This means that the manufactured product varies in length, width, and thickness. Mill "A" can produce boards with a variety of sizes, 2" x 12" x 12', 2" x 12" x 20', 1" x 3" x 16', 2" x 4" x 14', etc. A 2" x 12" x12' board means 2 inches thick, 12 inches wide and 12 feet long.

The Mill "A" bucking system has the following stem inputs and block output lengths specifications:

Stem Input Length (Feet)	Large Diameter Block Length (Feet)	Small Diameter Block Length (Feet)
44	2/20	Any excess length trimmed
42	2/20	Any excess length trimmed
40-41	2/20	Any excess length trimmed
38-39	1/20	1/18
36-37	1/20	1/16
34-35	1/20	1/14
32-33	1/20	1/12
30-31	1/18	1/12
28-29	1/16	1/12
26-27	1/14	1/12
24-25	2/12	
20-23	1/20	Any excess length trimmed
18-19	1/18	
16-17	1/16	
14-15	1/14	
12-13	1/12	

Table 3.1. Mill "A" Bucking Solutions

In the above table, 1/16 means one block of 16 feet, similarly 2/12 means two blocks of 12 feet each. The minimum nominal block length cuts are 12’ 1”, 14’ 1”, 16’ 1”, 18’ 1”, and 20’ 1”. The maximum Mill “A” allowable block length cut is 20 = 20’ 4”. All the lengths in table 3.1 are nominal and they do not include kerf or lily pad trims. The system will be set up for 44’ maximum length processing capability and 26” maximum diameter.

The continuous type bucking system for this mill is based on the fact that the bucking decisions will continuously split the difference between two blocks in half. For example, a stem of 28' 6" long (twenty-eight feet and six inches) long is bucked in approximately 1-16' 3", and 1-12' 3" blocks long. The exact minimum block length cuts are 16' 2" and 12' 2", thus for a stem of 28' 6", the extra wood is equally divided between the two block solutions. Another example is a stem of 28' 10" long (twenty-eight feet and ten inches) that is bucked in 1-16' 5" block, and 1-12' 5" block. As we can determine from the previous examples, the fuzzy controller is not exact, because the block lengths vary in relation to their exact nominal cuts. Instead, it provides an output that is good or close enough based on a set of expert rules.

Now that we have a basic idea of the Mill “A” bucking solutions, it is necessary to start explaining the different parameters that are taken into consideration to arrive to a bucking solution.

Taper is an input parameter to the system. It provides information of the location and size of the large end, and the small end diameters of the stem.

Mathematically the taper as shown in the figure below can be represented as the tree slope,

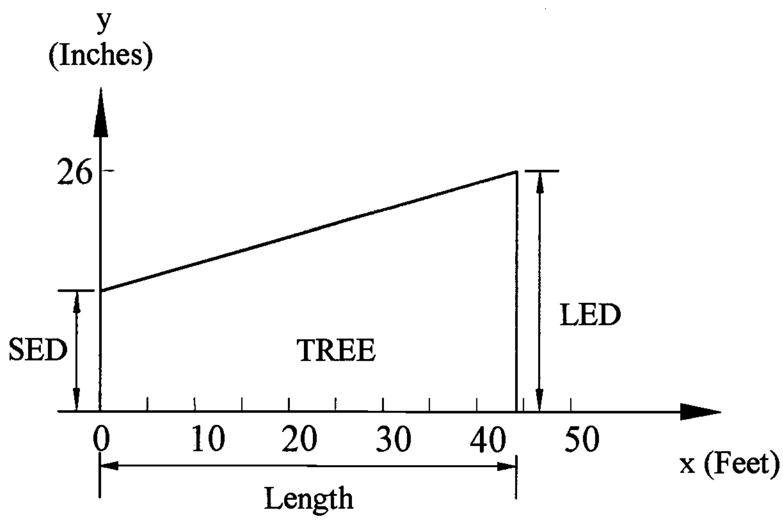


Figure 3.1. Tree Model

The following formula is used to calculate the taper,

$$\text{Slope} = \text{Taper} = \frac{\text{Large End Diameter (LED) - Small End Diameter (SED)}}{\text{Length}}$$

Slope is an important parameter to consider when making a bucking decision. The longest block is cut from the stem end that has the large diameter. For our system, a positive taper indicates a stem with the large end diameter on the West Side. Thus, the large block should be cut from the West End. Similarly, if the slope is negative, the large block should be cut from the East End. In other words, the slope will switch the stem bucking solution towards the stem end that has the large end diameter.

The sweep, the defects (holes, rotten wood, etc.), and the dispatch mill information are other important parameters for the bucking solution that will be input by the operator and combined as a whole as the stem destination.

Another input to the controller is the lily pad that is a piece of wood trimed of either end of the stem to remove bad ends. Lily pads are small trim cuts that vary from 1" to 6". The operator will enter this input, after he has visually inspected the ends of the stem while this is in the debarker.

Finally, the saw kerf must be considered, For every saw cut made on the stem, the thickness of the saw is converted to dust, and it should be subtracted from the total Stem length before any bucking solution is made.

Typical examples of Mill "A" logs parameters to be used for a bucking solution are:

1) A stem of 34’ 7” long with a positive slope, and a lily pad of 3" in both ends
2) A stem of 26’ 11” long with a negative slope, and a lily pad of 3" on the west end.

The length to be input to the bucking controller is called nominal length, and it is defined as the total stem length minus lily pad cuts and number of block cut kerfs.

For example 1, the nominal length would be calculated as follows,

Total raw stem length 34' 9" = 417"

Saw kerf = 3/4” = 0.75"

West lily pad = 3"

End lily pad = 3"

For the lily pads the saw kerf is included in them. This means that the saw position will be set at 3"- 0.75" = 2.25" from each end of the stem.

Then, the nominal stem length is = 417 – 2 * (3 - 0.75) – 0.75 = 411.75"

In this example, the saw kerf was subtracted once because the stem was divided in two blocks. Thus for our fuzzy bucking controller the stem is 411.75" = 34.3125' long. The controller will solve for a 14.15625' block on the West end, and a 12.15625' block on the East end. When the controller provides a bucking solution, it fits the minimum block length required and, if it does not match, the next cut is fitted until a valid bucking cut is reached. The above is a very general explanation of what the bucking controller will have to do to solve a Mill "A" stem.

The importance of the fuzzy controller solutions here is on the boundaries of the minimum block cuts. For example, if a stem has a nominal length of 28' 1.9", the bucking controller knows what the system requirements for minimum cuts are. However, because its decisions are based on wood recovery, instead of cutting one block at 14'1" where the remainder 14' 0.9" will not qualify for a 14' block, but for a 12' block, the bucking controller will generate two blocks of 14' 0.95" each, making both qualify as 14' blocks, because 14' 0.95" is acceptable and close to the minimum block length (14' 1") for a 14' block. Thus the bucking solution made by the bucking controller provided two more feet of usable wood. This feature was made possible due to the fuzziness at the overlapping boundaries of the membership function that are not exact but approximate.

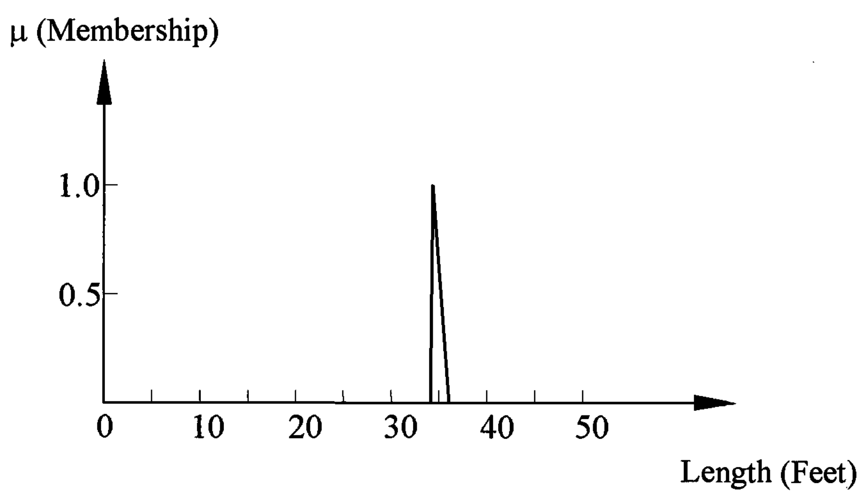
Mill "A" bucking controller was designed with the trapezoidal membership function to map the nominal input lengths to the fuzzy controller. For the outputs, the generalized bell membership function was utilized. This membership provided a smooth transition between the bucking cuts.

The input lengths were subdivided in ranges to form the membership function that provided the correct output. For example, a length between 32 and 34 feet has three input membership functions labeled Inshort 34, Inlong 34 and 3234' (between 32' and 34') and they are represent in Figure 3.2 below,

Inshort 34 (34 34 34.1 36)

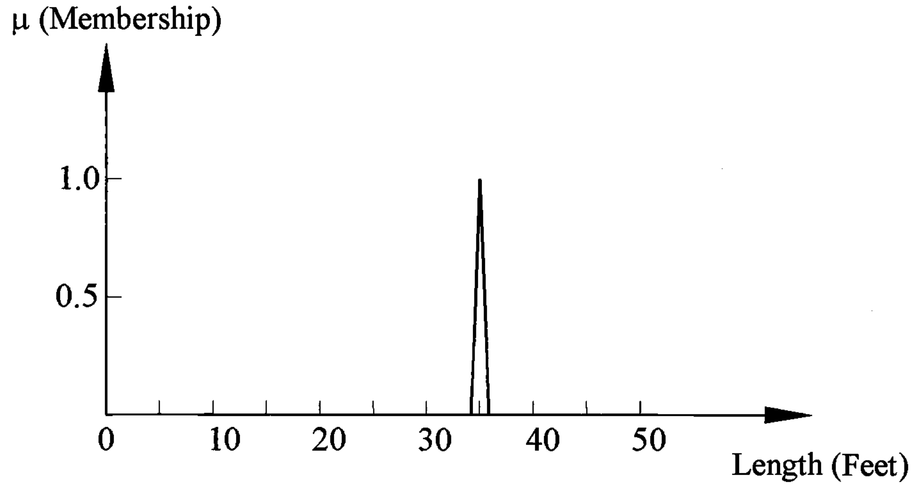
Inlong 34 (34.09 35.9 36.09 36.09)

3234' (34 34 34.09 34.09)

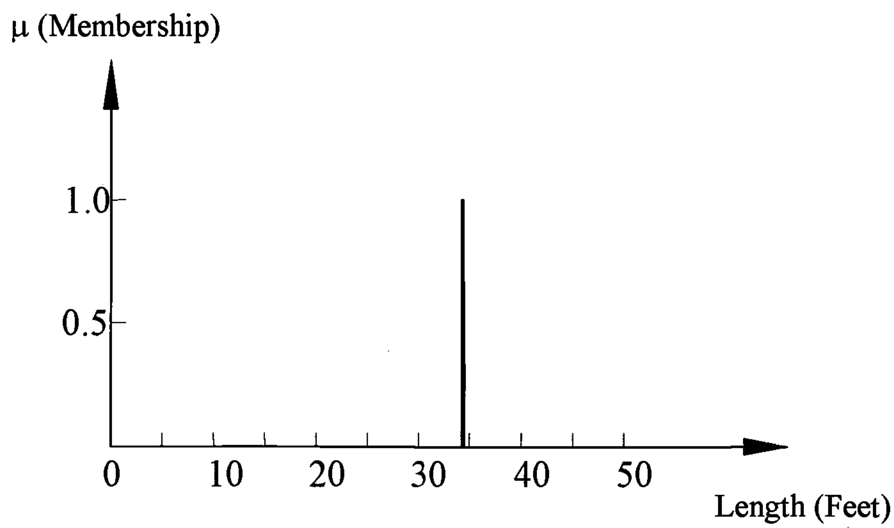


(a) Inshort 34.

Continued



(b) Inlong 34



(c) 3234'

Figure 3.2. Input Length Membership Functions. (a) Inshort 34, (b) Inlong 34, and (c) 3234'

The output block was also subdivided into three membership functions, as presented in figure 3.3 below for a 12' block length

Very small 12 (0.25,2.5,11.25)

Small 12 (0.25,2.5,12.5)

Large 12 (0.25,2.5,13.5)

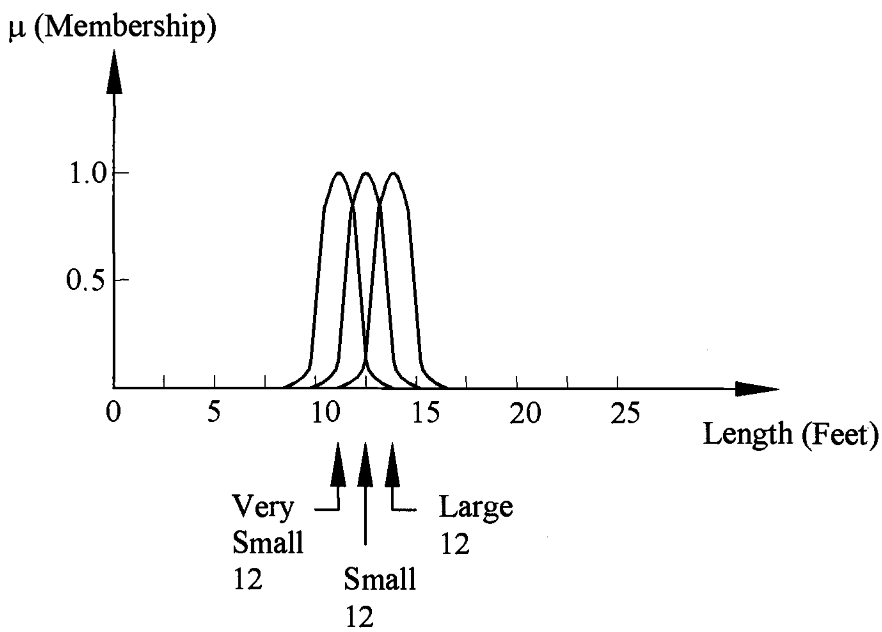


Figure 3.3. Bell Type Output Membership Functions

Taper has two triangular functions (positive taper, and negative taper) with values of –2 1 0 and 0 1 2. There is no overlap between these two membership functions because we want the value of these functions to be negative, positive or zero meaning no taper. These membership functions are shown figure 3.4 below,

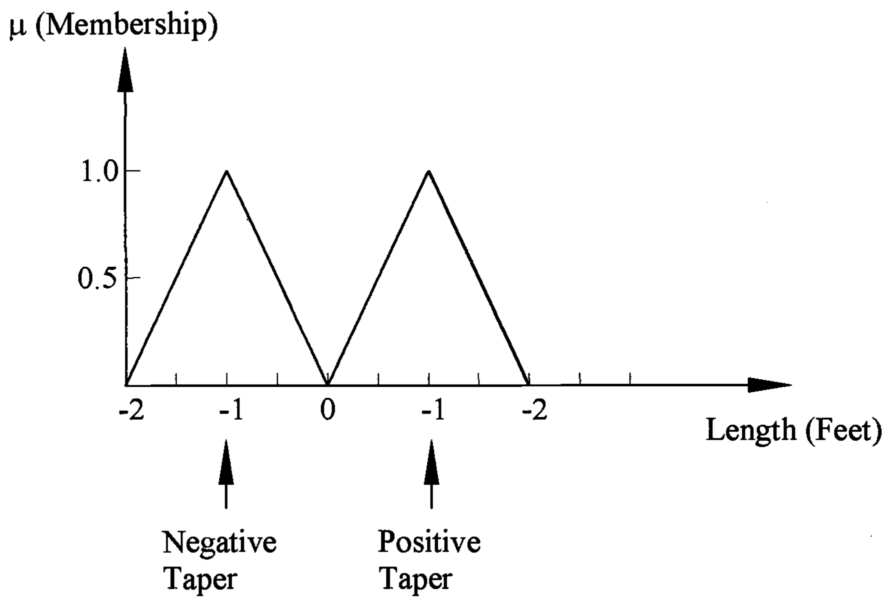


Figure 3.4. Taper Triangular Membership Functions

Finally, the rules were made to provide with all the block combinations for different tapers. A total of 106 rules were developed for this bucking controller and they are shown explicitly in appendix A.

3.3 Mill "A" Discrete Type Bucking Controller

This controller provides similar bucking solutions to the continuous type. It was designed based on past bucking practices. This system provides a better wood recovery because it takes care of inaccuracies in the length measurement system. The philosophy is very simple and is as follows: only the block on the stem large end diameter needs to be cut with the exact block length and the remaining of the stem can be left as it is unless it does not meet the maximum block length cut requirements.

To clarify this concept, let us consider the following example. A stem is misread as a 30' long, where it should have been read as 30' 2" long. The continuous type of bucking controller would have cut one block as 16' 1" + 12" (16' 12"), and the remaining would be cut as 12' 1" + 12" (13' 12"). Now, for the discrete type, only the first block would be cut out at 16' 1", and the remaining would be left as it is (14' 1"). Therefore, in the second method we gain 2' of usable wood because inaccuracies of the measured length did not lead to any material waste. The discrete type of bucking controller needs only to provide the exact length of the second block if the block is grater than 20' 4" long. This is due to the fact that the machinery downstream is set up for a maximum block length of 20' 4".

Mill "A" discrete type controller was designed using trapezoidal membership functions to map the nominal input length to the fuzzy controller variables. For the outputs, the trapezoidal membership functions were also used. After several evaluation tests, these membership functions offered a sharp transition between the sought bucking cuts. The testing to find the membership functions that provided the desired output took a large portion of the time involved in the design process. The membership functions used are:

[Input1]

Name='AInLength'

Range=[0 50]

NumMFs=17

MF1='AIn012':'trapmf',[0 0 12.09 12.1]

MF2='AIn12':'trapmf',[12.1 12.1 14.09 14.1]

MF3='AIn14':'trapmf',[14.1 14.1 16.09 16.1]

MF4='AIn16':'trapmf',[16.1 16.1 18.09 18.1]

MF5='AIn18':'trapmf',[18.1 18.1 20.09 20.1]

MF6='AIn20':'trapmf',[20.1 20.1 24.19 24.2]

MF7='AIn24':'trapmf',[24.2 24.2 26.19 26.2]

MF8='AIn26':'trapmf',[26.2 26.2 28.19 28.2]

MF9='AIn28':'trapmf',[28.2 28.2 30.19 30.2]

MF10='AIn30':'trapmf',[30.2 30.2 32.19 32.2]

MF11='AIn32':'trapmf',[32.2 32.2 34.19 34.2]

MF12='AIn34':'trapmf',[34.2 34.2 36.19 36.2]

MF13='AIn36':'trapmf',[36.2 36.2 38.19 38.2]

MF14='AIn38':'trapmf',[38.2 38.2 40.19 40.2]

MF15='AIn40':'trapmf',[40.2 40.2 40.7 40.71]

MF16='AIn407':'trapmf',[40.71 40.71 42 42]

MF17='AIn4071':'trapmf',[42 42 50 50]

[Input2]

Name='Taper'

Range=[-2 2]

NumMFs=2

NegTaper':'trimf',[-2 -1 0]

PosTaper':'trimf',[0 1 2]

[Output1]

Name='ABlock1'

Range=[0 22]

NumMFs=7

MF1='ANocut':'trimf',[-0.1 0 0.1]

MF2='A12':'trimf',[11.6 12.1 12.6]

MF3='A14':'trimf',[13.6 14.1 14.6]

MF4='A16':'trimf',[15.6 16.1 16.6]

MF5='A18':'trimf',[17.6 18.1 18.6]

MF6='A20':'trimf',[19.6 20.1 20.6]

MF7='A203':'trimf',[20 20.5 21]

[Output2]

Name='ABlock2'

Range=[0 22]

MF1='A12':'trimf',[11.6 12.1 12.6]

MF2='A14':'trimf',[13.6 14.1 14.6]

MF3='A16':'trimf',[15.6 16.1 16.6]

MF4='A18':'trimf',[17.6 18.1 18.6]

MF5='A20':'trimf',[19.6 20.1 20.6]

MF6='A203':'trimf',[20 20.5 21]

MF7='ANoCut':'trimf',[-0.1 0 0.1]

[Output3]

Name='ABlock3'

Range=[0 22]

NumMFs=1

MF1='ANoCut':'trimf',[-0.1 0 0.1]

Input lengths were subdivided to cover a broad range of lengths. For example an input length between 24 and 26 feet has a trapezoidal membership functions with values of 24.2 24.2 26.19 26.2 as shown in figure 3.5 below,

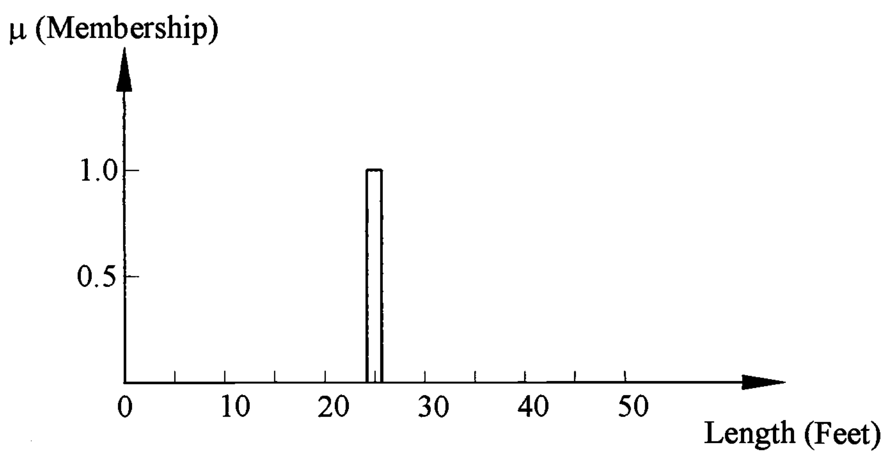


Figure 3.5. Membership Function for a 24 Feet Input Length

The ranges of input lengths were chosen with relation to the different combination of possible output blocks. The output block membership functions were constructed using trapezoidal membership functions for the different possible outputs. For example, a 12 feet block has the following membership function shown in Figure 3.6 below,

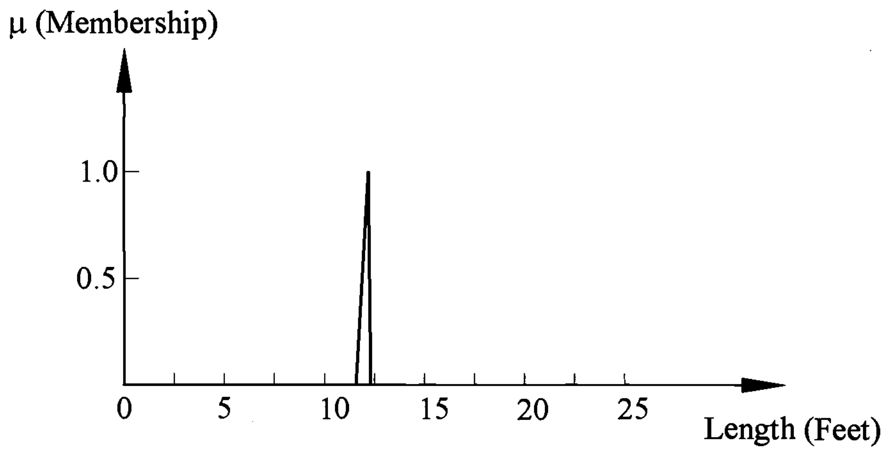


Figure 3.6. Membership Function for a 12 Feet Output Block

The values of the end points of the membership function were found by iterating different values several times until the closest one that provided the require output was found.

The taper was kept the same as in the continuous case because there were not changes in the decision making part for the taper input.

Next the rules were made to provide the system with the different buck combinations, resulting in a total of 32 rules for positive and negative taper. This was another area of the design process that required a fair amount of testing to obtain the correct outputs from the bucking controller. The rules are shown explicitly in appendix B.

It is obvious that from the appendix B the number of rules utilized in the Mill "A" discrete type was much less than the continuo type. This resulted in a faster response of the system due to less processing time needed to solve for a bucking block set.

Three block outputs were created in spite that only two were needed in the Mill "A" bucking controller. This was due to a software problem in the Fuzzy Logic Toolbox that is not able to display in the viewer mode two output blocks.

3.4 Mill "B" Bucking Controller

Mill "B" is a Stud mill. This means that the manufactured product varies in length and width, while thickness remains constant. There are only three lengths (8', 9', and 10') and two widths (4" and 6") produced by the mill in question. Typical boards fabricated are 2" x 4" x 8', 2" x 4" x 9', 2" x 4" x 10', 2" x 6" x 8', 2" x 6" x 9', and 2" x 6" x 10'. A 2" x 4" x 8' board means 2 inches thick, 4 inches wide, and 8 feet long.

The Mill "B" bucking system has the following input, and output lengths,

Stem Input Length (Feet)	Large Diameter Block Length (Feet)	Small Diameter Block Length (Feet)
42 - 43	2/9	3/8
41	1/9	4/8
40	5/8	
39	3/10	1/9
38	2/10	2/9
37	1/10	3/9
36	4/9	
35	3/9	1/8
34	2/9	2/8
33	1/9	3/8
32	4/8	
30 - 31	3/10	Any excess length trimmed
29	2/10	1/9
28	2/10	1/8
27	1/12	
26	2/9	1/8
25	1/9	2/8
24	3/8	3/8
20 - 23	2/10	Any excess length trimmed
19	1/10	1/9
18	2/9	
17	1/9	1/8
16	2/8	1/12

Table 3.2. Mill "B" Bucking Solutions

In the above table, 1/9 means one block of 9 feet; similarly 2/8 means two blocks of 8 feet each. The exact block lengths for Mill "B" blocks are:

8 feet = 8 feet, 1 inch (8'1")

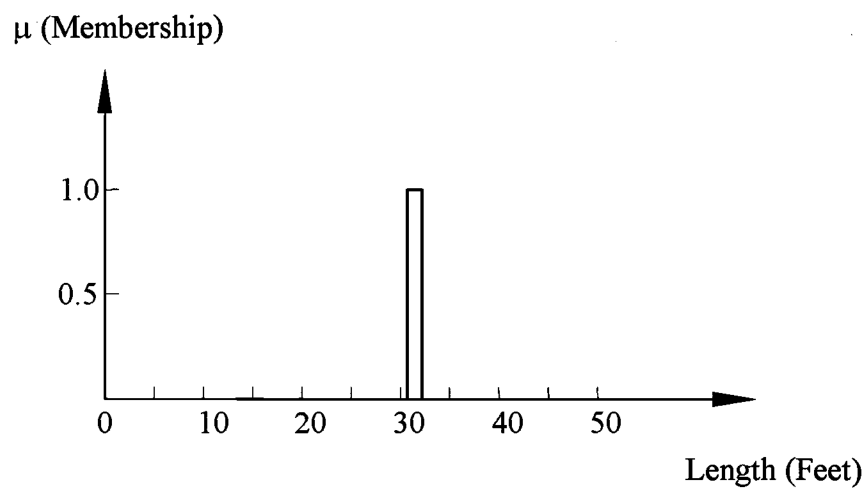
9 feet = 9 feet, 1 inch (9'1")

10 feet = 10 feet, 1 inch (10'1")

All the lengths in table 3.2 are nominal and they do not include trim. The system will be set up for 43' 8" maximum processing capability. The maximum system allowable block length for a 10' block is equal to 10' 2". This last statement makes the system very restrictive for block cuts. It does not allow any block grater than 10' 2" block because the machinery downstream is set up for that maximum length.

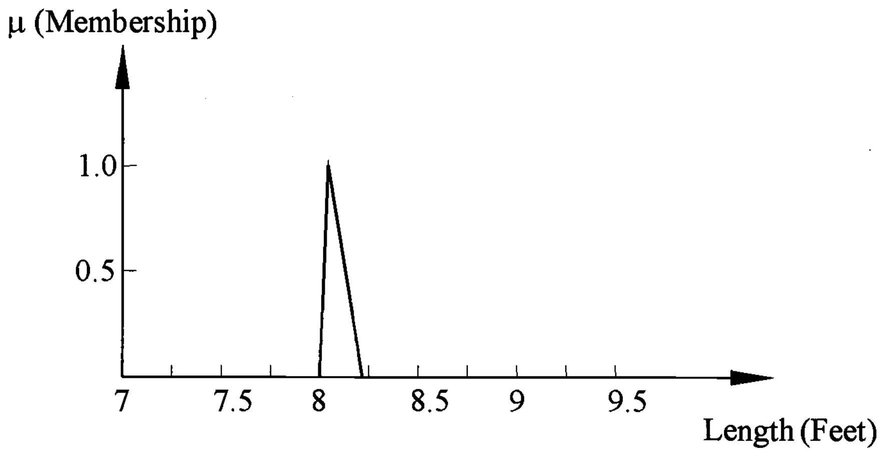
The bucking system for this mill needs to provide exact block lengths based on input stem length acquired from the scanning system. For example, a stem of 20' 8" long (twenty feet and eight inches) is bucked in two of 10'1" the remaining stem length (6") is trimmed as waste. For this mill the bucking controller should provide exact block length cuts. These block lengths are not exact but have a very limited range variation. For example, an 8' feet block may vary between 8' 3/4" and 8' 11/4". The same applies for the 9' and 10' blocks with a maximum block length of 10' 2". The same explanations for the stem parameters given in Mill "A" bucking controller continuous type such as nominal length, small end diameter, large end diameter, taper, destination, and lily pads applies for Mill "B" bucking controller.

For the Mill "B" fuzzy bucking controller, 29 input trapezoidal membership functions were needed to cover the range of all nominal input lengths that varies from 16' up to 43'. Mill "B" can have up to five block cuts for a stem 43' long. Thus, five block outputs were included in the controller design. The output blocks were subdivided into three membership functions, one for 8', one for 9', and one for 10' blocks, respectively. The taper was also considered in the bucking system design, and trapezoidal membership functions were used. In figure 3.7 below, there is an example of the membership functions used for input length, output length, and taper.

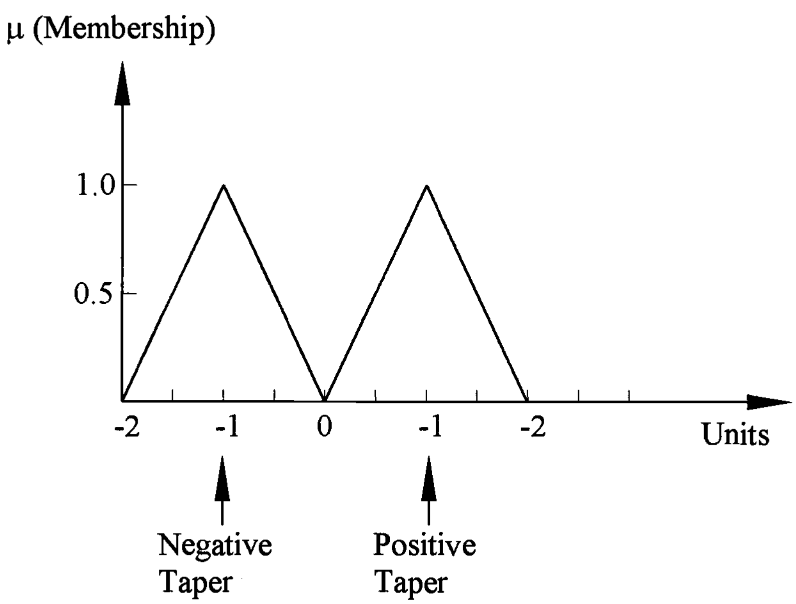


(a) Input Length

Continued



(b) Output Length



(c)Taper

Figure 3.7 Mill "B" Membership Functions (a) Input Length, (b) Output Length and (c) Taper

All the membership functions and their end values were chosen after iterating several different combinations of both values and membership functions until a reasonable output that met the specifications was obtained. A total of 56 rules were needed to provide the required block outputs. The rules are shown explicitly in appendix C.

3.5 Veneer Mill Bucking Controller

The manufactured product in this mill is a thin layer of wood utilized to make plywood. The block cuts vary in length and diameter. The logs sorted to make peeler blocks have low taper and sweep that results in blocks that are almost cylindrical. The block lengths cut are 8', 9', and 10'. The block lengths are exact to provide the machinery downstream with exact pre-positioning sets that in turn gives the mill more throughput (blocks per minute) by reducing the machinery cycle times. The exact block length cuts are 8' 6", 9' 6", and 10' 6". 8' 6" means a block of 8 feet and 6 inches long.

The Veneer mill bucking system has the following input and output lengths,

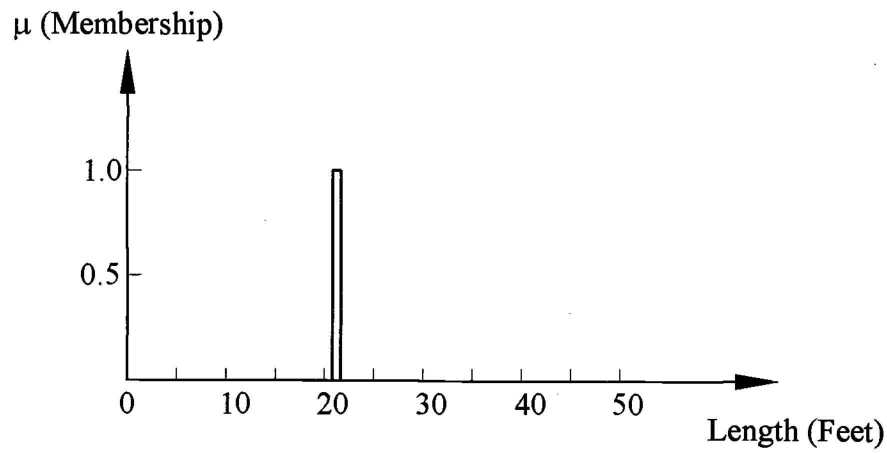
Stem Input Length (Feet)	Large Diameter Block Length (Feet)	Small Diameter Block Length (Feet)
43.5	1/9	4/8
42.5	5/8	
42	4/10	
41	3/10	1/9
40	3/10	1/8
39	2/10	1/9, 1/8
38	2/10	2/8
37	1/10	1/9, 2/8
36	2/9	2/8
35	1/9	3/8
34	4/8	
32.5 –33.99	N/A	N/A
31.5	3/10	
30.5	2/10	1/9
29.5	1/10	2/9
28.5	1/10	1/9, 1/8
27.5	2/9	1/8
26.5	1/9	2/8
25.5	3/8	
22 – 25.49	N/A	N/A
21	2/10	
20	1/10	1/9
19	2/9	
18	1/9	1/8
17	2/8	

Table 3.3. Veneer Mill Bucking Solutions

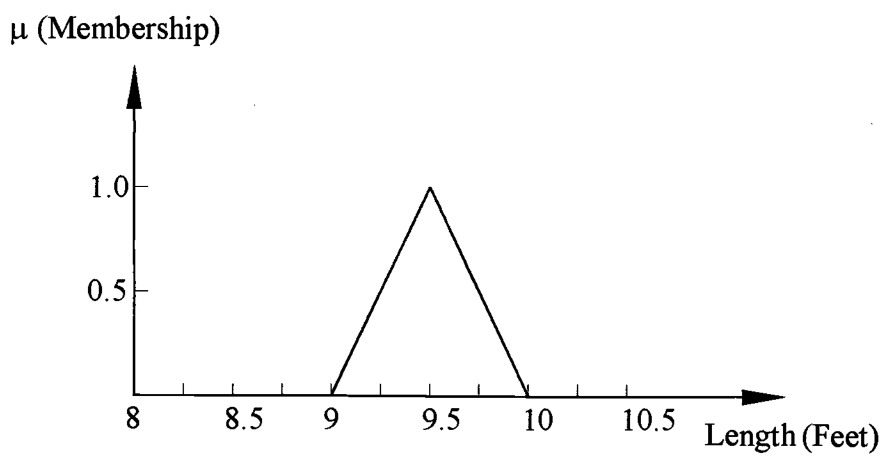
In table 3.3, 1/9 means one block of 9 feet 6 inches. Similarly 2/8 means two blocks of 8 feet 6 inches each. Where the table shows N/A means that is not a bucking solution due to an invalid input stem length. All the lengths in table 3.3 are nominal and they do not include trim. The system will be set up for 43'8" maximum processing capability. The maximum system allowable block length is 10 = 10' 6". Another restriction the system has is its maximum waste piece. It should not exceed 12 inches.

As mentioned earlier, the bucking system for this mill needs to provide exact block cuts based on input stem length acquired from the scanning system. For example, a stem of 35' 5" long (thirty five feet, five inches) long is bucked in one 9' 6", and three 8' 6' blocks, the remaining stem length (5") is trimmed as waste. For this mill the bucking controller should provide with exact block length cuts. Actually, these block lengths are not exact but have a very limited range of variation. For example, an 8' 6" feet block may vary between 8' 6 3/4" and 8' 7 1/4", the same applies for the 9'6" and 10' 6" blocks. The same explanations given in Mill "A" bucking system continuous type for the stem parameters such as nominal length, small end diameter, large end diameter, taper, destination and lily pads applies for the veneer bucking controller.

For the veneer mill fuzzy logic bucking controller, 28 input trapezoidal membership functions were needed to cover the range of all nominal input lengths that varies from 17' up to 43' 6". The veneer mill can have up to five block cuts for a stem 43' 6" long. Thus, five block outputs were included in the controller design. The output blocks were subdivided in three membership functions, one for 8' 6", one for 9' 6", and one for 10' 6" blocks respectively. The taper was also considered in the bucking system design, and trapezoidal membership functions were used. In figure 3.8 below, there is an example of the membership functions used for input length, output length, and taper.

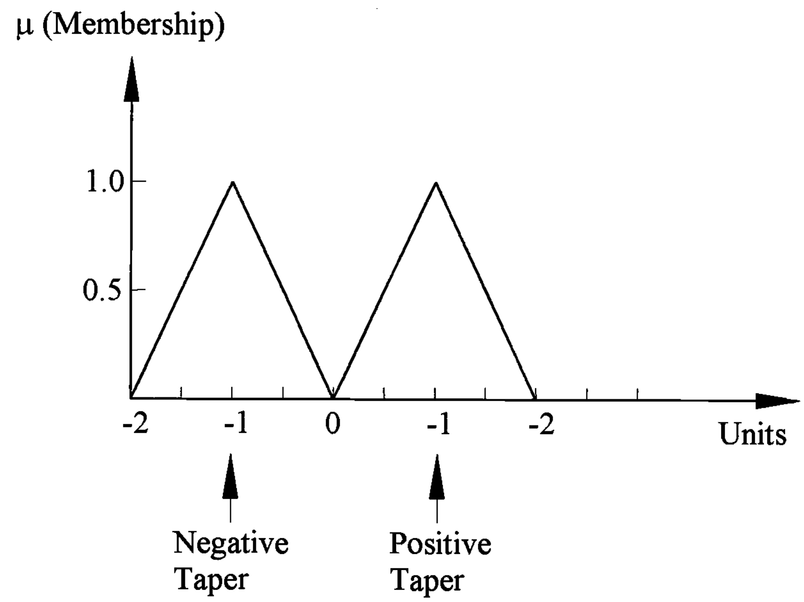


(a) Input Length



(b) Output Length

Continued



(c) Taper

Figure 3.8. Veneer Membership Functions (a) Input Length, (b) Output Length and (c) Taper.

The membership functions and their end values were chosen after iterating several different combinations of both values and membership functions until a reasonable output that met the specifications was obtained. A total of 56 rules were needed to provide the required block outputs. The rules are shown explicitly in appendix D.

4. MILL "A", MILL "B", AND VENEER MILL FUZZY BUCKING CONTROLLERS SIMULATION

The simulation was performed using a Pentium III, 500 Mhz, 128 Mbytes ram computer and using Matlab, Simulink and the Fuzzy Logic toolbox software. The simulation of the different plants was carried out independently, however, a similar procedure was utilized for the simulation of every plant. The bucking controller simulation consists of the fuzzy controller and the entire bucking controller simulation. The fuzzy controller simulation started by constructing the membership functions for the inputs and outputs. All the fuzzy controllers have two inputs (length and taper). Next the rules were made and tested to verify the correct solution for the different inputs. To choose the membership functions, several different combinations and several values were tested until the ones that produced the best results were found. This step in the design process was the most critical during the system design because it maps the real world input into fuzzy variables used by the fuzzy controller [2]. Then the construction of the if-then rules followed. Finally, the rule viewer feature of Matlab Fuzzy Logic toolbox was used to test the fuzzy controller. Errors were found and corrected by adjusting and changing parameters as well as changing, deleting, and creating new rules.

Before we proceed with an explanation of the front end of the fuzzy logic toolbox, we explain the Matlab Fuzzy Logic toolbox inference system used in the simulation. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic [1]. The mapping then provides a basis from which decisions can be made or patterns discerned. The fuzzy inference system (FIS) displays high-level information about the system. With that in mind, we continue explaining Figure 4.1 that shows the front end of the Veneer fuzzy controller simulation under the Matlab 5 Fuzzy Logic toolbox. At the top of the figure is a diagram of the system showing clearly the inputs and outputs used. Five outputs were needed for the Veneer Fuzzy Controller. Below the diagram is a text field indicating the name of the current FIS (VeneerBuck). At the right hand side, the FIS type choices are shown. They are the Mamdani and Sugeno type. These two types of inference systems vary somewhat in the way outputs are determined. Descriptions of these two types of fuzzy inference systems can be found in [Jan97, Man75, Sug85]. Mandami's fuzzy inference expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each fuzzy variable that needs defuzzification. In the Sugeno fuzzy inference system, it is possible to use a single spike as the output membership function rather than a distributed fuzzy set. After testing the bucking application in both systems, the Mandani type provided better results because some of the bucking solutions require to be defuzzified from a distributed fuzzy set as it is the case for Veneer bucking. In the lower right of Fig. 4.1 are fields that provide information about the current variable, that is, name, type, and range of the variable. In the lower left hand side are selections and information about the AND/OR, implication, aggregation, and the type of defuzzification method.

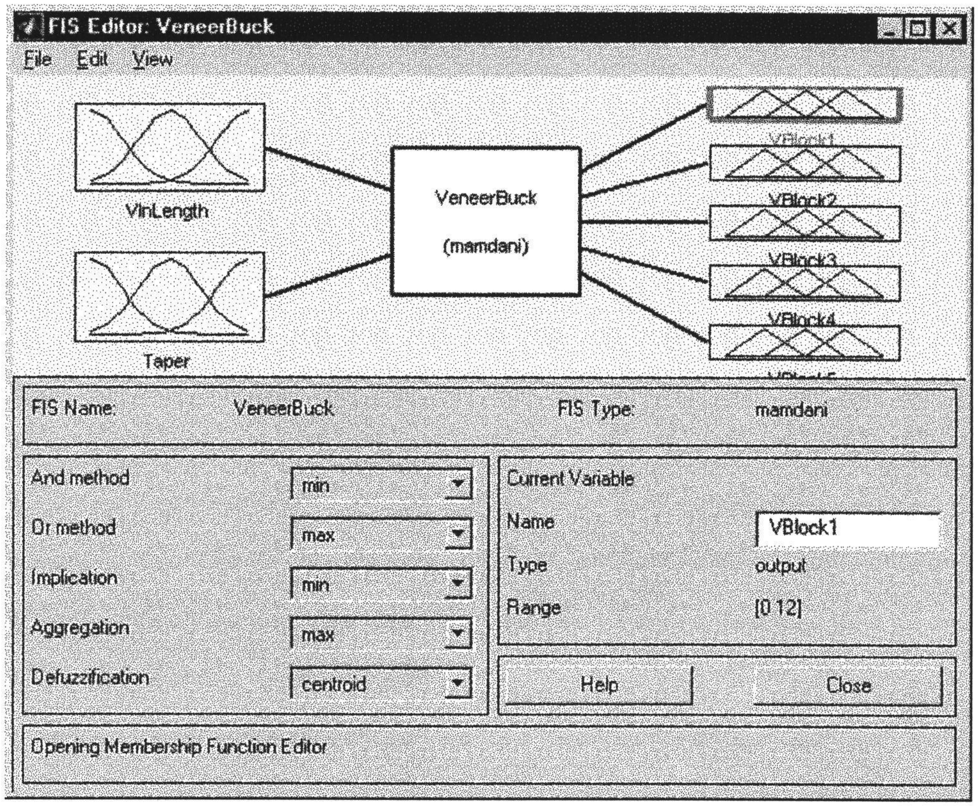


Figure 4.1. Veneer Fuzzy Logic Viewer Toolbox

The membership function editor was used to create every membership function; Fig. 4.2 shows the editor and we proceed to a brief explanation.

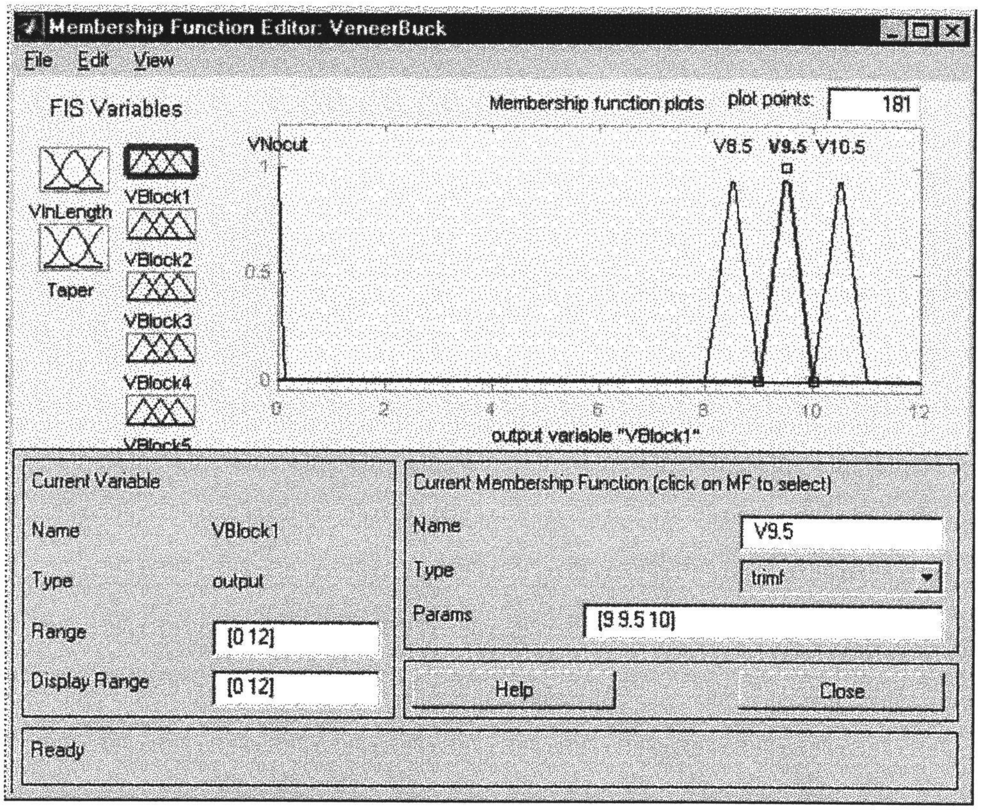


Figure 4.2. Veneer Fuzzy Logic Membership Function Editor

The membership editor shown above is for the Veneer Bucking Controller. On the right hand side we can see all the membership functions used for output VBlock1. The highlighted membership function (V9.5) is a triangular membership (trimf) function for a 9 feet block length with parameters [9 9.5 10]. Note there is not overlap among all the membership functions including the one at zero (VNoCut). That is because we want the output Vblock1 have a near zero value as a valid output. There are no membership functions between 0.1 and 8 because an output for that range does not exist. The VNoCut (zero) membership function is a sharp triangular that was needed to provide an output value range very close to zero. On the bottom left area of the membership function editor is necessary to provide with the output range for all the output blocks (0 12). The membership functions for Vblock2, Vblock3, Vblock4 and Vblock5 outputs are similar, thus there is no need to explain them again. The design process of all the membership functions for Veneer was based upon the output block specifications. Different types of membership functions were tested until the triangular membership function provided the correct results.

The rules for all fuzzy logic controllers were constructed using the Matlab 5 Fuzzy Logic toolbox graphical rule editor interface and it is shown in Fig. 4.3 for Veneer Fuzzy Bucking Controller. As we can see, it is self-evident how to use it. Based on the descriptions of the input and output variables defined with the FIS editor, the rule editor allowed us to construct, modify and tune the rule statements. The connection selected was 'and' [2] as indicated in the connection box of the rule editor.

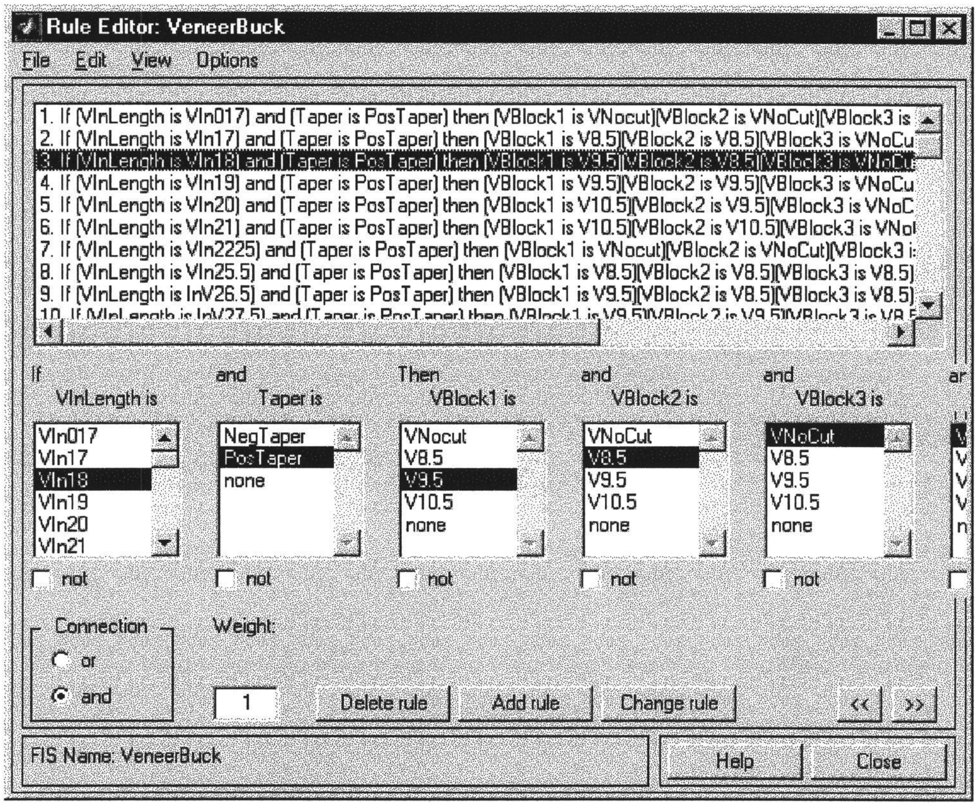


Figure 4.3. Veneer Fuzzy Logic Rule Editor

At this point, we have completely defined the Veneer Fuzzy Logic Controller inference system, such that the variables, membership functions, and the rules necessary to compute the output block lengths are in place. Now we proceed to verify that everything is behaving according to the mill specifications. This validation was done by using the Matlab 5 Fuzzy Logic Rule Viewer. This provided the tool to simulate the Bucking Controller as shown in Figure 4.4a and Figure 4.4b. The rule viewer displays a road map of the whole fuzzy inference process. The rule viewer allows us to interpret the entire fuzzy inference process at once. The rule viewer also shows how the shape of certain membership functions influences the overall result and displays the implication, aggregation and deffuzification processes in action.

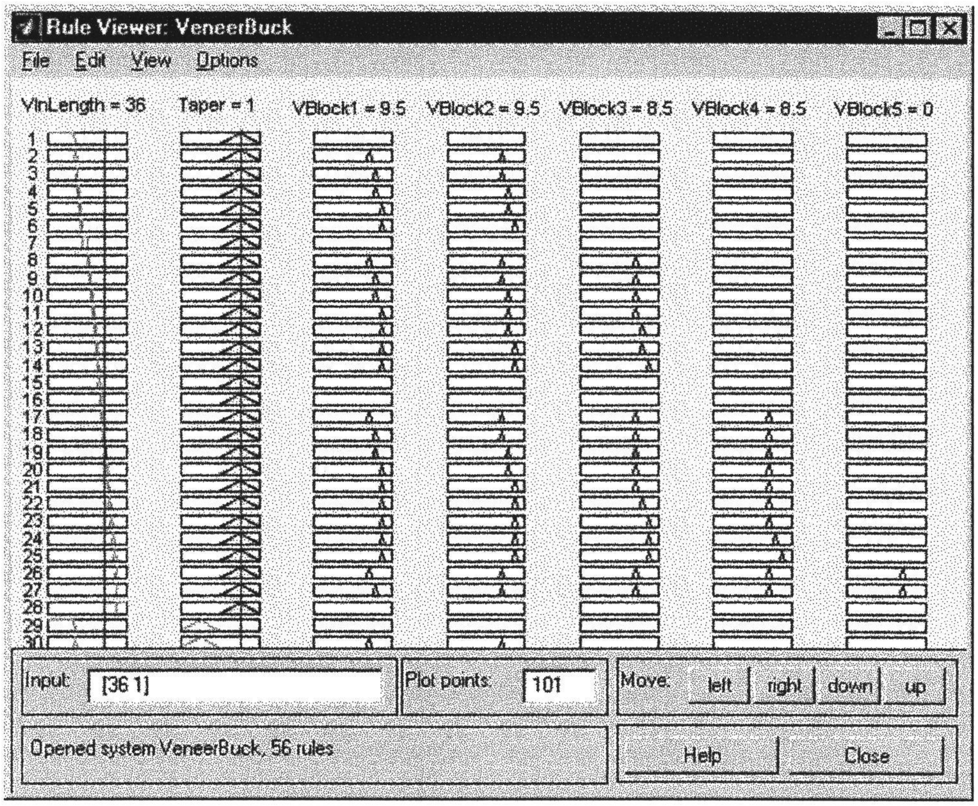


Figure 4.4a. Veneer Fuzzy Logic Rule Viewer

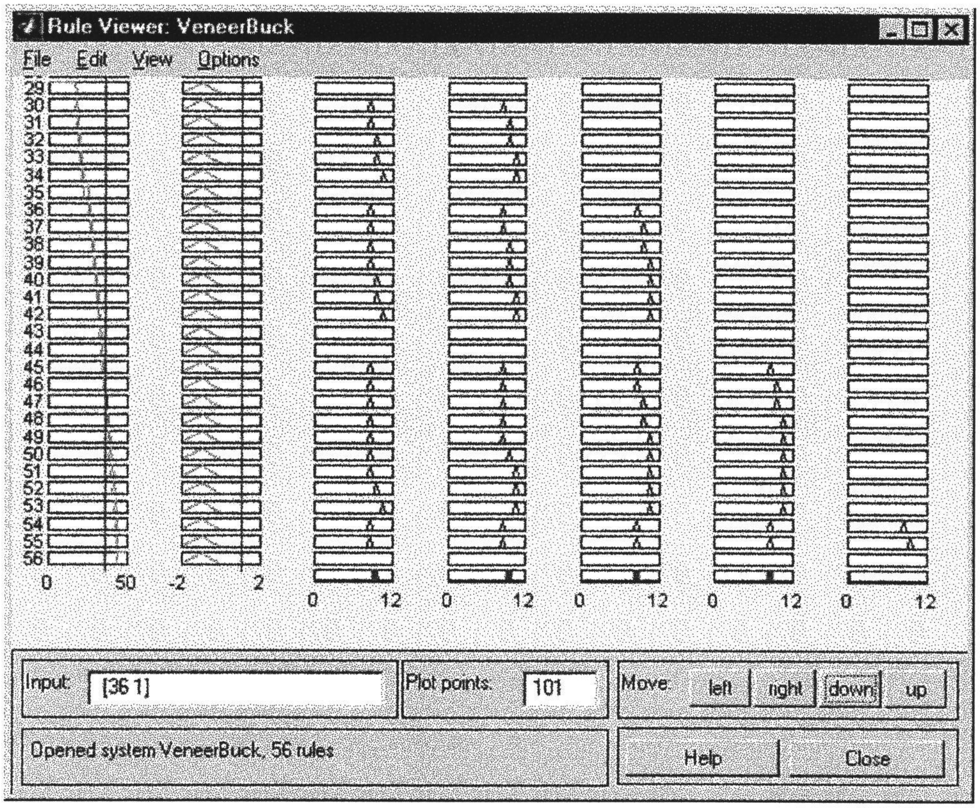


Figure 4.4b. Veneer Fuzzy Logic Rule Viewer

By changing the input parameters (length and taper), the rule viewer provided a different block output using the inference process. We simulated and analyzed every input combination. We checked what rules were providing the desired outputs. We went back to modify, tune input/output membership functions, and rules until the desired results were obtained. For example, in Fig. 4.3 for an input length of 36' and a positive taper (1), the outputs VBlock1 is equal to 9.5', Vblock2 is equal to 9.5', Vblock3 is equal to 8.5', Vblock4 is equal to 8.5', Vblock5 is equal to 0'. Rule 19 was the predominant rule used to provide this solution. For Veneer

Fuzzy Logic Controller, five outputs were needed. The input length shown is nominal and it is obtained by subtracting from the fuzzy controller raw length all the lilypads and saw kerfs. In figure 4.4b we can see the result of the aggregation process for each output.

Finally, the surface viewer was utilized to represent graphically in a three-dimensional curve the mapping from any two inputs to any one output of every mill controller. The surface viewer helps to understand the behavior of inputs and outputs. It provides a graphical perspective of the fuzzy controller. Once the fuzzy controller was designed, a simulation of the entire system with the inputs and outputs as provided in the real time application was performed. To achieve this, it was needed to use the Simulink program of Matlab [4]. In Simulink, signal conditioning blocks (filtering blocks) were created at the input and output of the Fuzzy Logic controller. The Simulink block diagram used is shown in figure 4.6. On the left hand side the raw stem input length is entered as a ramp function to test the entire length range of Mill "A" controller. The remaining inputs, except the log slope, are entered into the input filter block where they are combined to produce a nominal length that the Fuzzy controller uses to produce its outputs. These outputs are entered into the output-filtering block to produce a block of output data with the information that the real time system needs downstream to realize the log bucking.

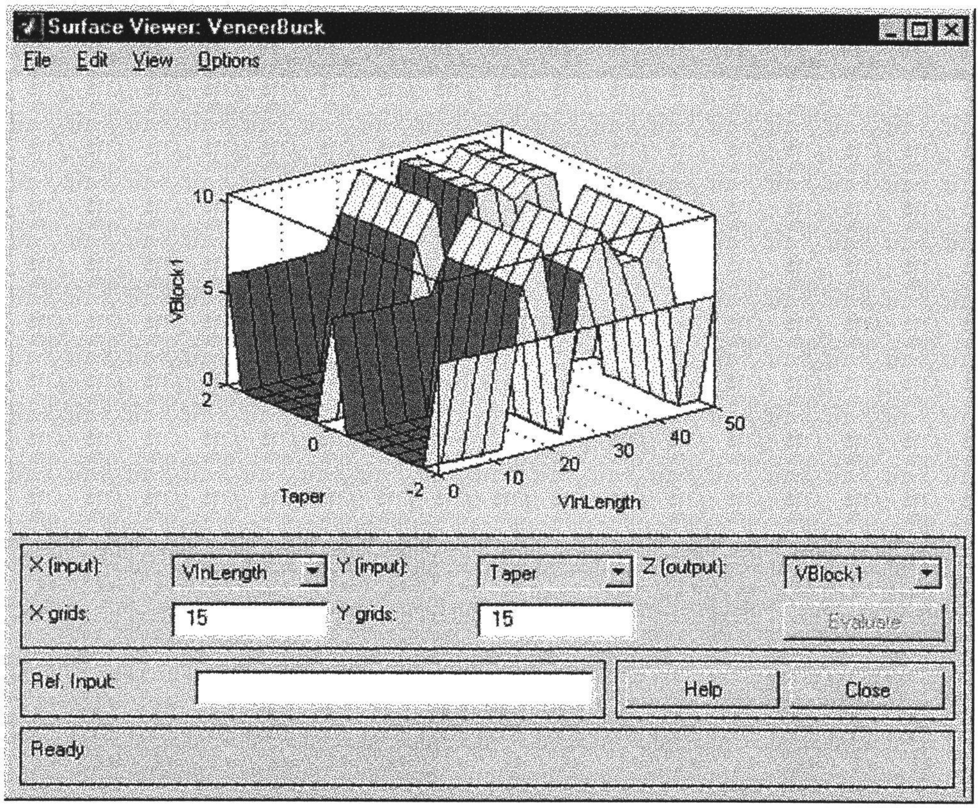


Figure 4.5. Veneer Fuzzy Logic Surface Viewer

The simulation of the Veneer and the Mill "B" controllers was done following the same guidelines explained previously for Mill "A". The differences among these three controllers vary depending on the bucking procedure and requirements for each mill as it was explained in sections 3.2, 3.3, 3.4, and 3.5. The filter blocks like the fuzzy logic controllers have all the changes to reflect the bucking process of each mill. There were numerous changes made to the different blocks until the required specifications for each plant were met. The simulation diagrams for every controller are presented in figures 4.6 through 4.19.

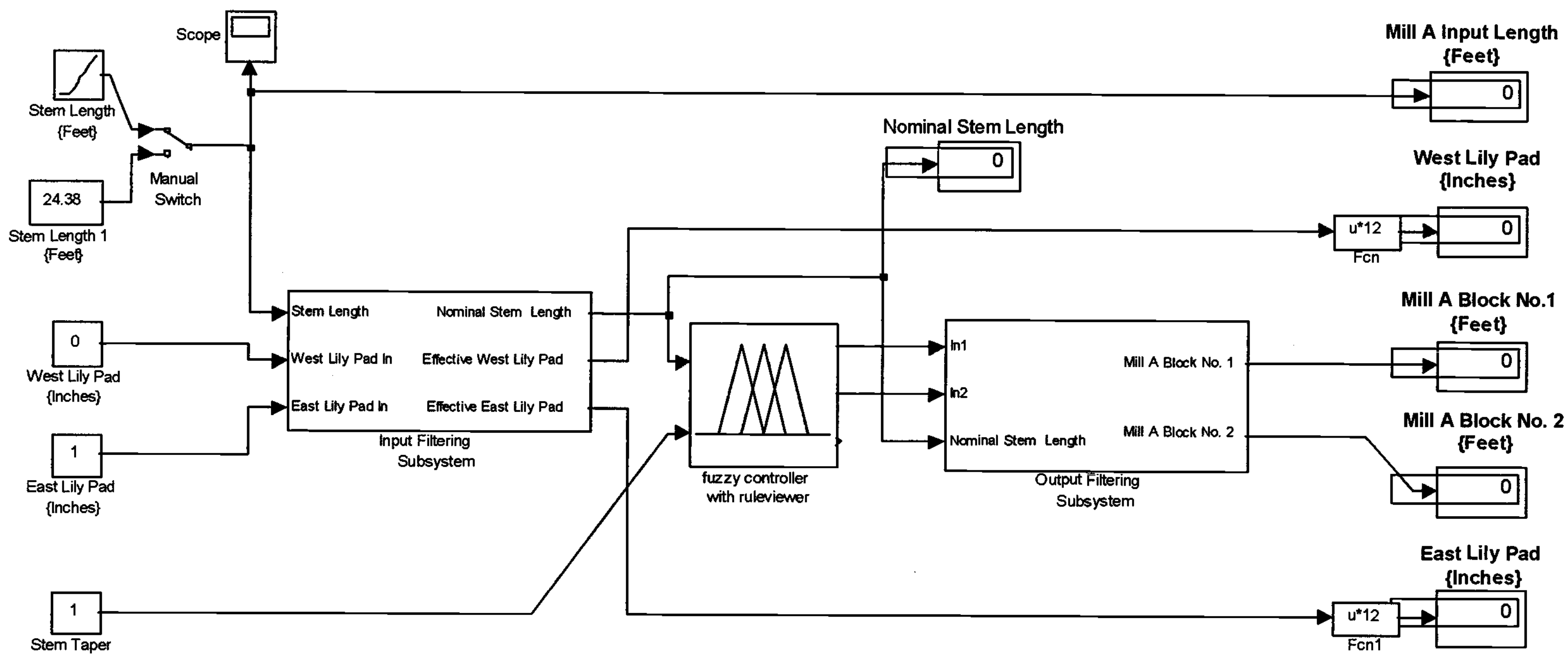


Figure 4.6. Mill “A” Continuous Type Fuzzy Logic Controller Stem Bucking Solution Simulation Diagram

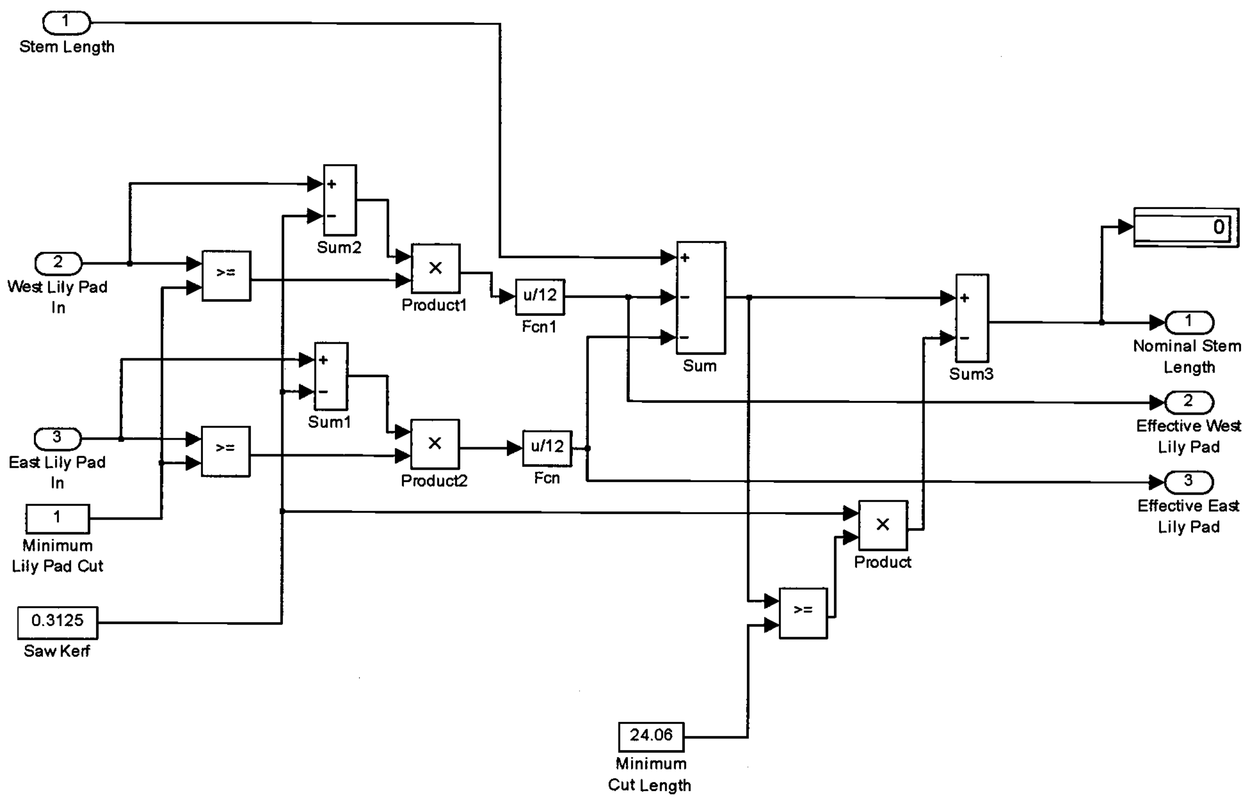


Figure 4.7. Mill “A” Continuous Type Fuzzy Logic Controller Input Filtering Simulation Diagram

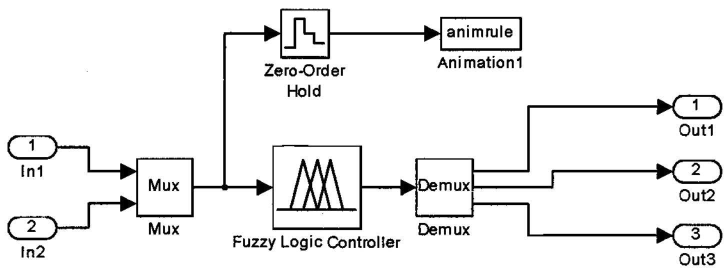


Figure 4.8. Mill "A" Continuous Type Fuzzy Logic Controller Simulation Diagram

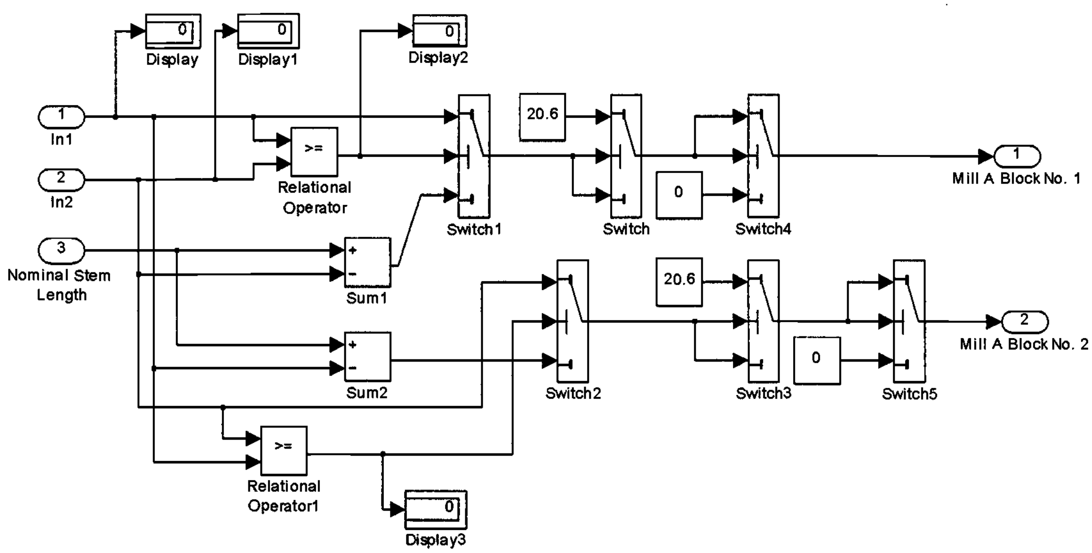


Figure 4.9. Mill "A" Continuous Type Fuzzy Logic Controller Output Filtering Simulation Diagram

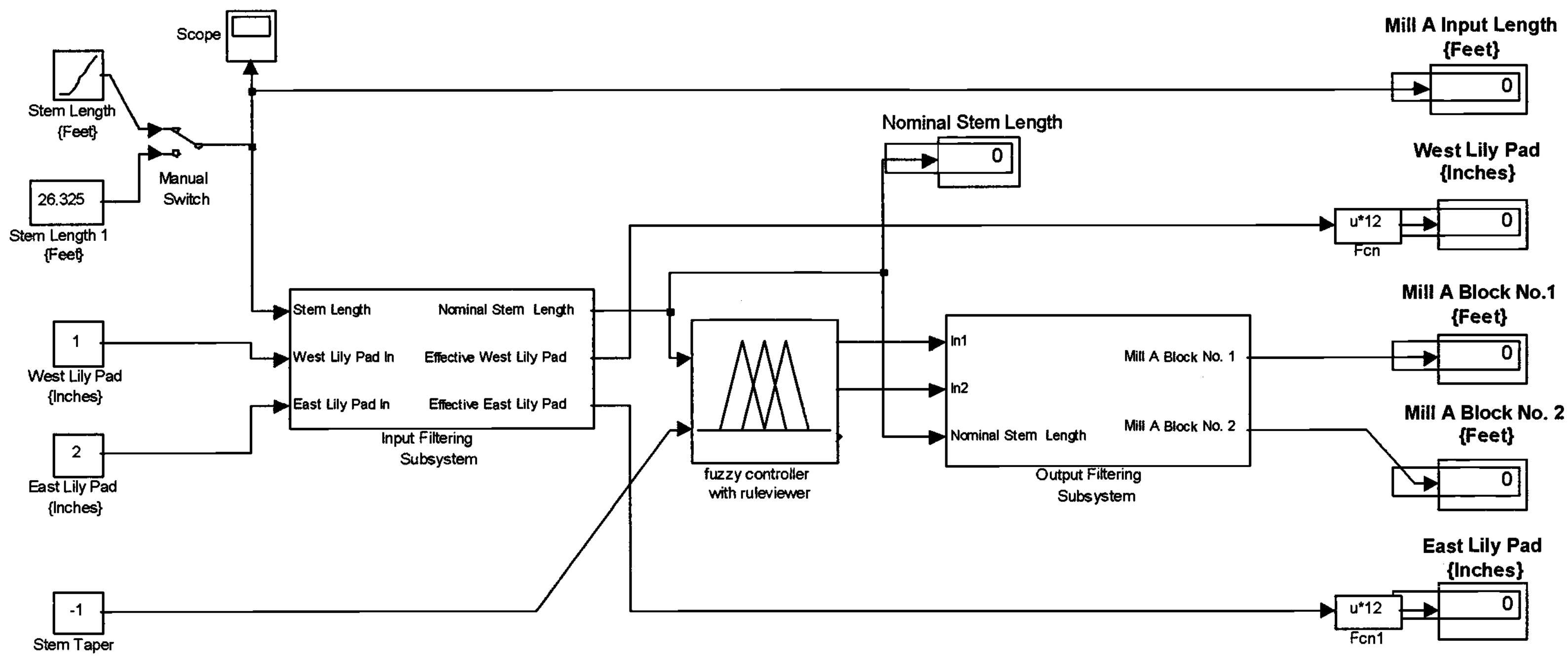


Figure 4.10. Mill "A" Discrete Type Fuzzy Logic Controller Stem Bucking Solution Simulation Diagram

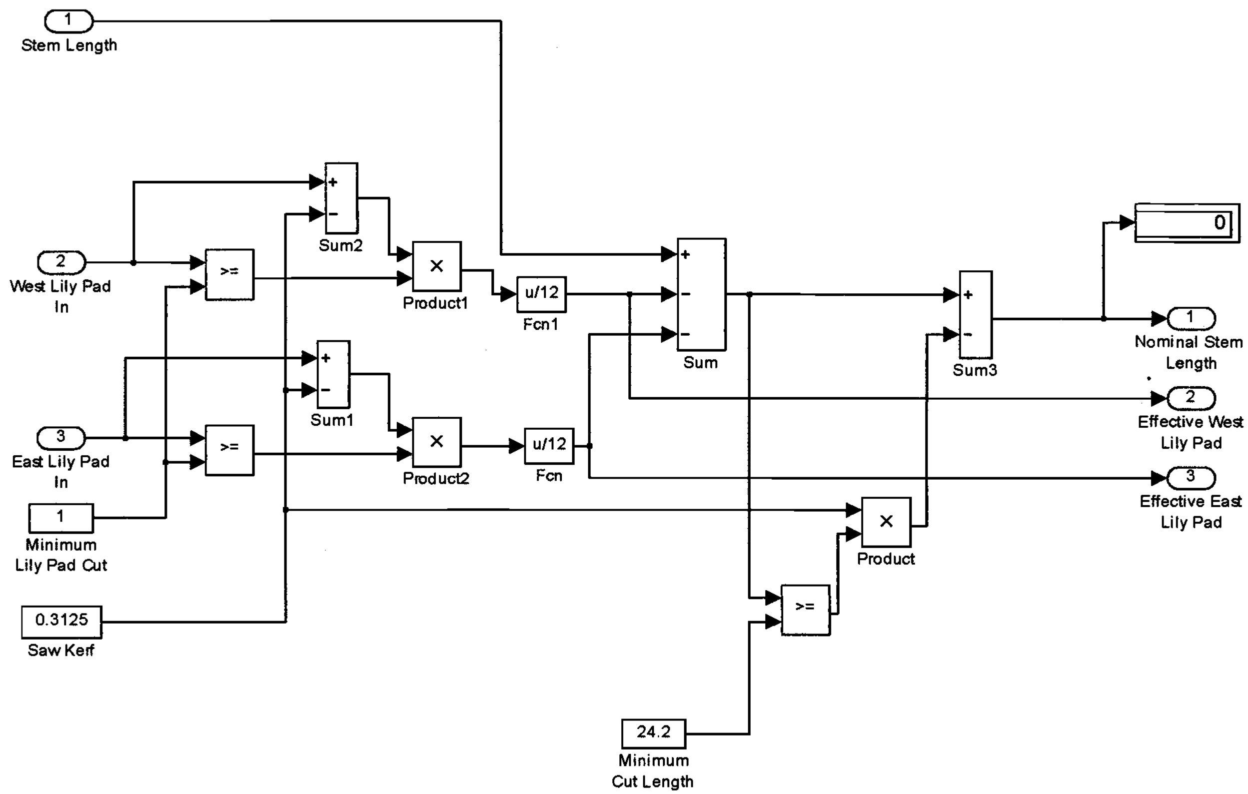


Figure 4.11. Mill “A” Discrete Type Fuzzy Logic Controller Input Filtering Simulation Diagram

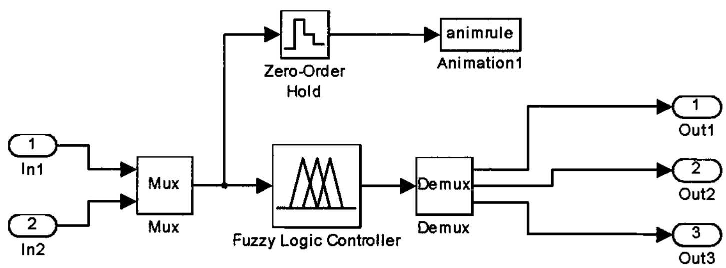


Figure 4.12. Mill "A" Discrete Type Fuzzy Logic Controller Simulation Diagram

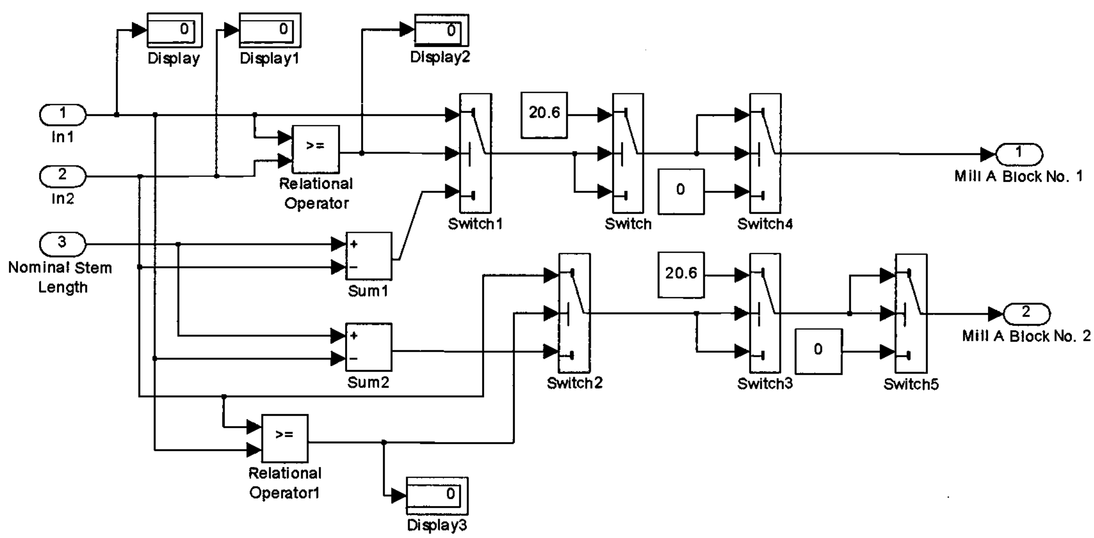


Figure 4.13. Mill "A" Discrete Type Fuzzy Logic Controller Output Filtering Simulation Diagram

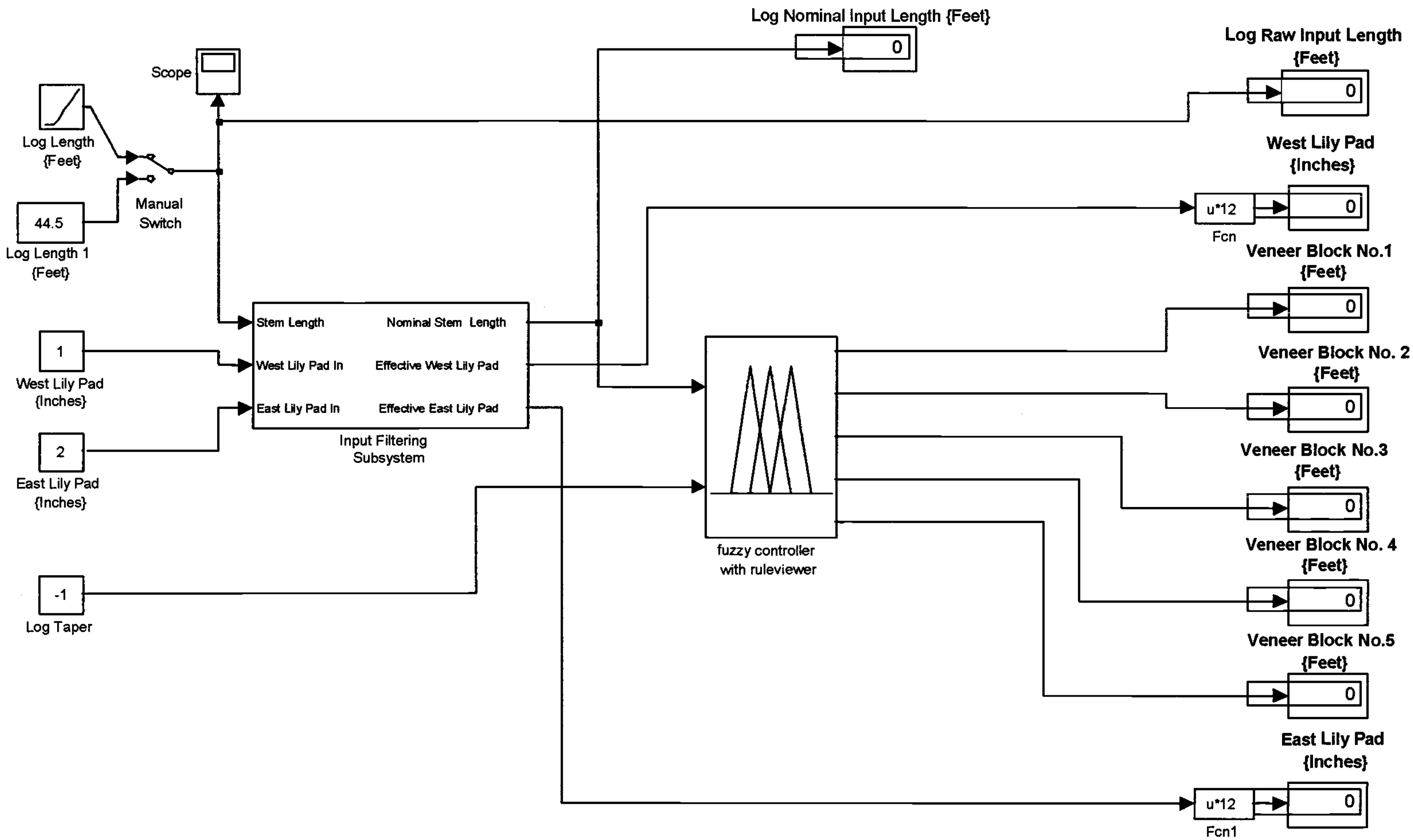


Figure 4.14. Veneer Fuzzy Logic Controller Stem Bucking Solution Simulation Diagram

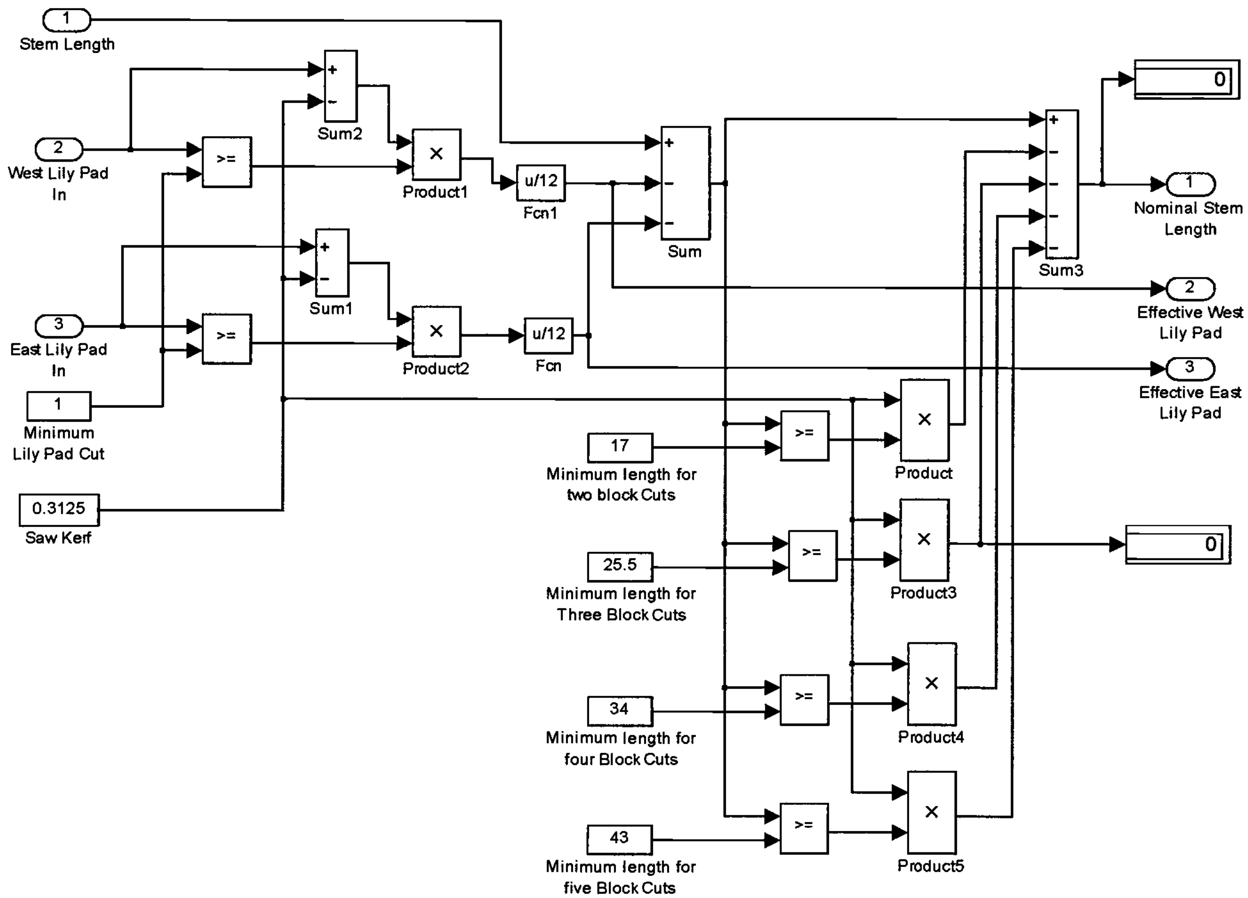


Figure 4.15. Veneer Fuzzy Logic Controller Input Filtering Simulation Diagram

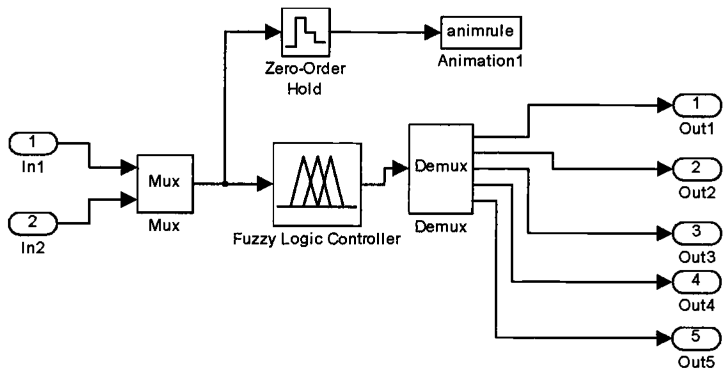


Figure 4.16. Veneer Fuzzy Logic Controller Simulation Diagram

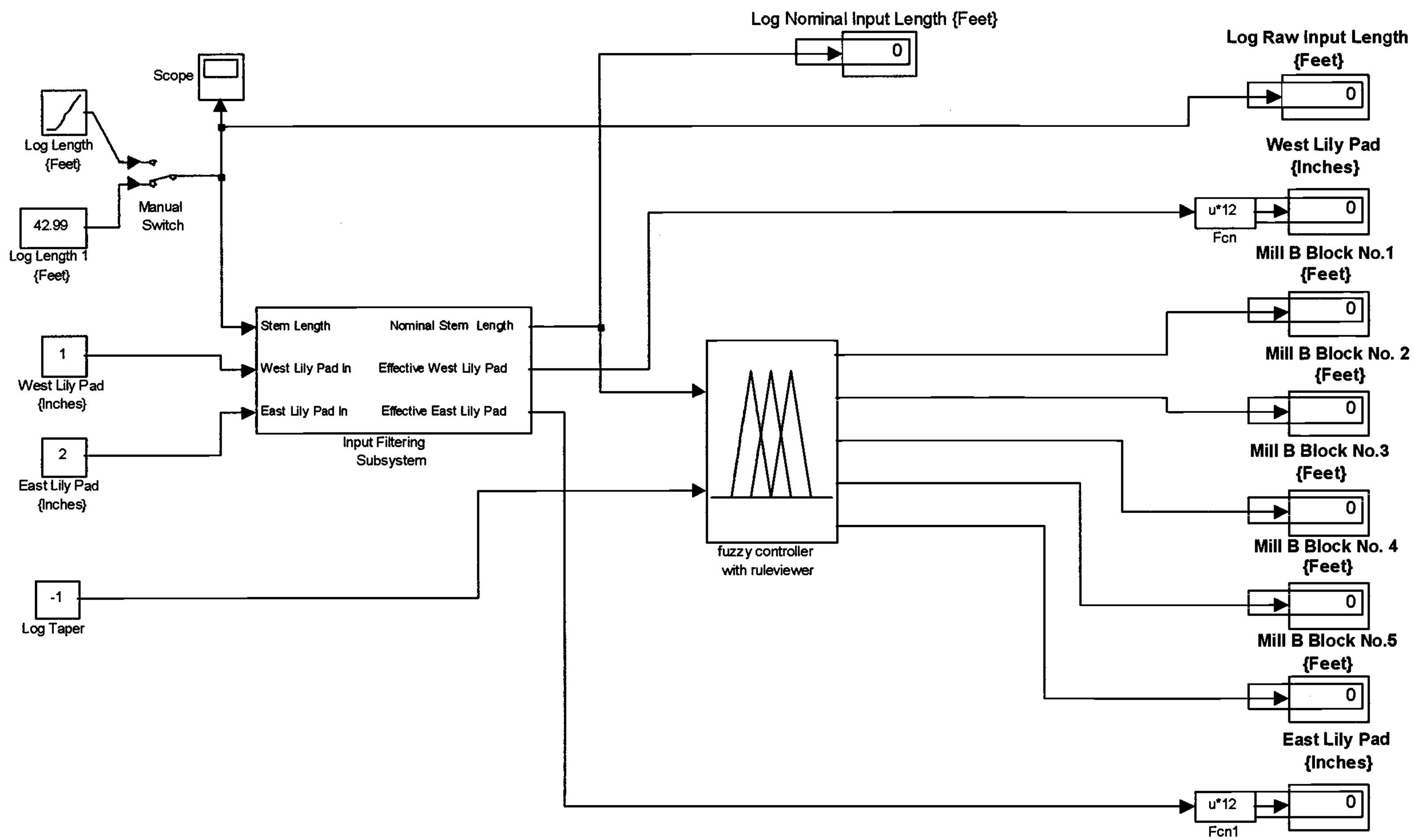


Figure 4.17. Mill “B” Fuzzy Logic Controller Stem Bucking Solution Simulation Diagram

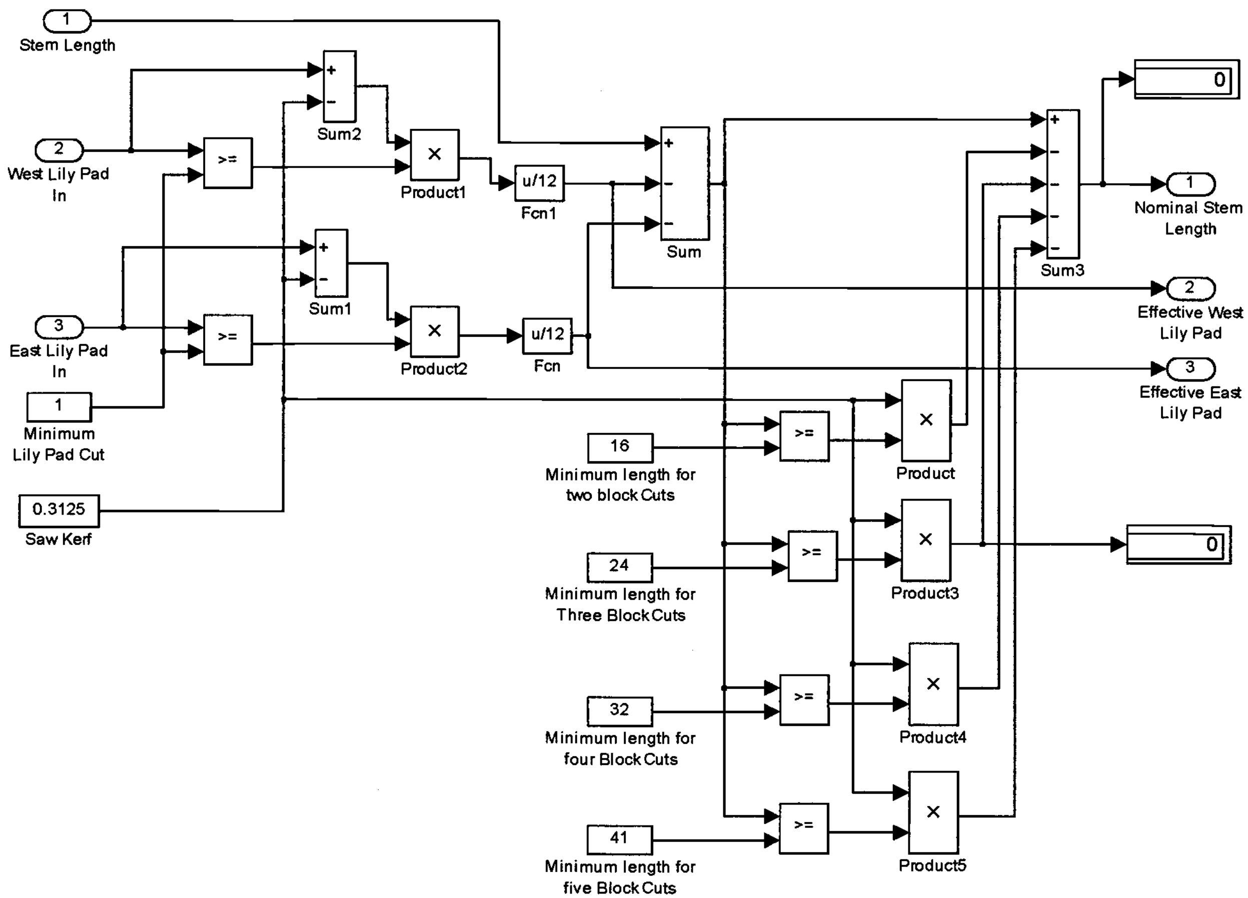


Figure 4.18. Mill "B" Fuzzy Logic Controller Input Filtering Simulation Diagram

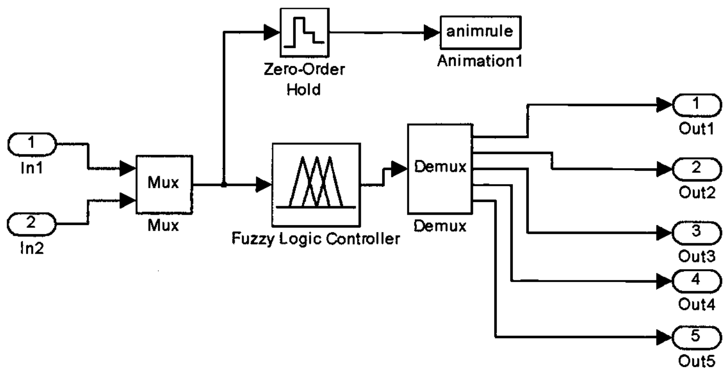


Figure 4.19. Mill "B" Fuzzy Logic Controller Simulation Diagram

5. SIMULATION RESULTS

Next the results are presented in graphical and table forms for each mill. Results with block solutions for Stems with the large diameter on the West and on the East End are shown below. There is not a need to present the graphs with lilypads because they are removed from the raw length before it is presented to the Fuzzy Logic Controller as nominal length, thus producing similar results with the only difference that the lilypads are installed back in the output file without the saw kerf. In the tables the lilypads are shown and the entries used are 1-inch lilypad on the West when the LED is on the West and 1-inch lilypad on the East when the LED is on the East. We could have used 3 or 6 inches lilypads but similar results would have been obtained because the nominal length is used in the Fuzzy Logic Controllers.

5.1 Results for Mill "A" Continuous Type Fuzzy Logic Controller

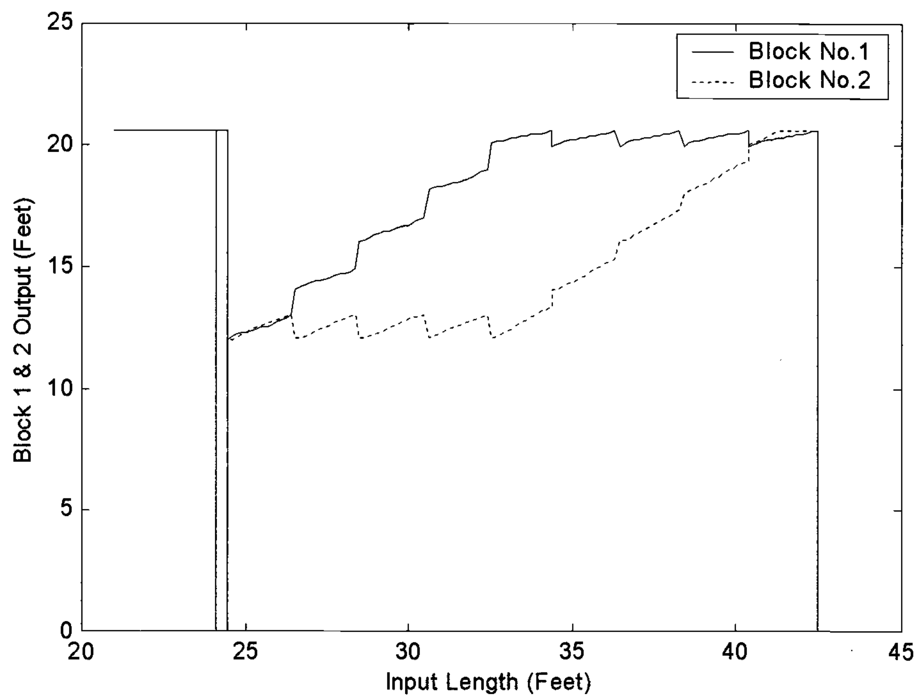


Figure 5.1. Mill "A" Continuous Type Fuzzy Logic Controller Solutions for Stems with Large End Diameter and 1" Lily Pad on the West (Positive Taper).

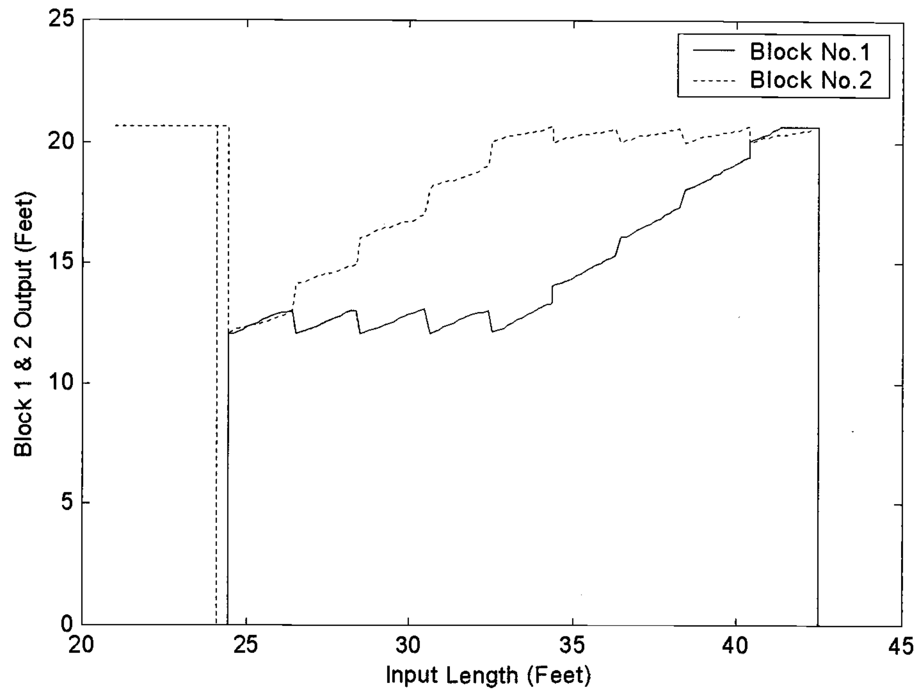


Figure 5.2. Mill "A" Continuous Type Fuzzy Logic Controller Solutions for Stems with Large End Diameter and 1" Lily Pad on the East (Negative Taper).

Simulation results are presented in tabular in appendices E and F. The simulation time that took the Fuzzy Logic Controller to provide a new output in response to input change was less than 100 milliseconds.

5.2 Results for Mill "A" Discrete type Fuzzy Logic Controller

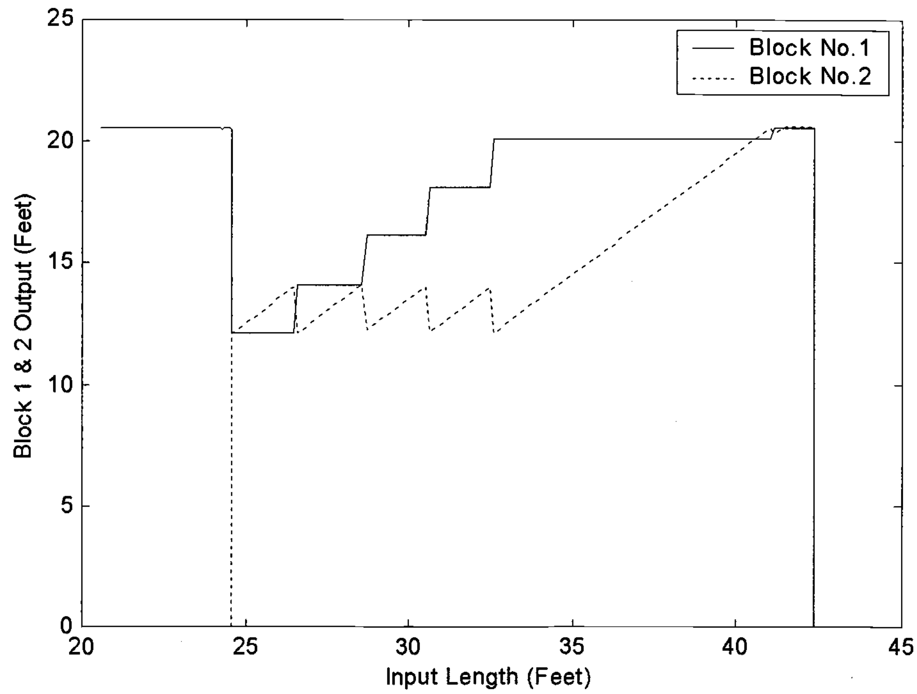


Figure 5.3. Mill "A" Discrete Type Fuzzy Logic Controller Solutions for Stems with Large End Diameter and 1" Lily Pad on the West (Positive Taper).

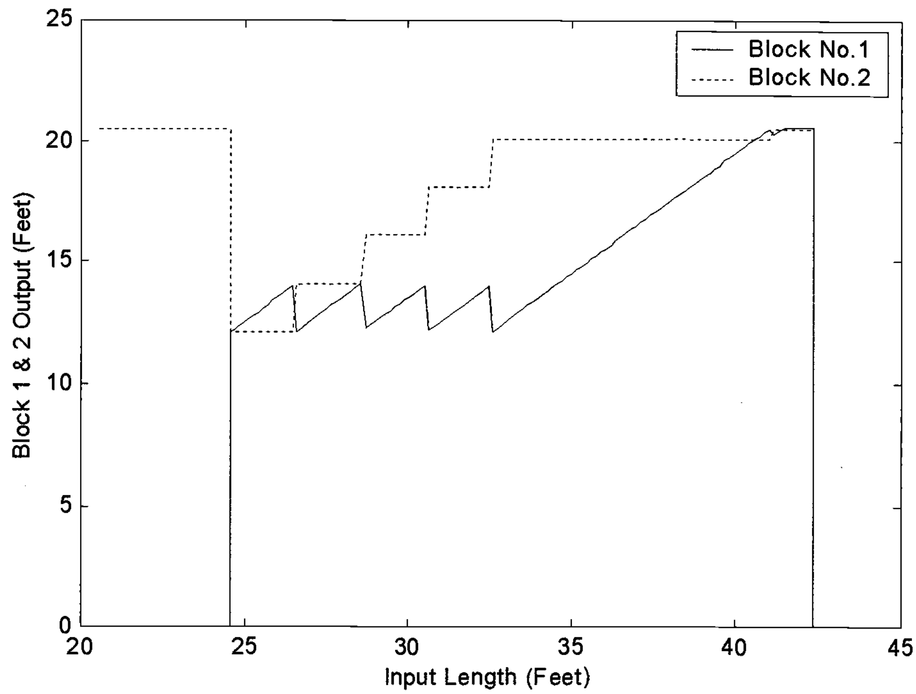


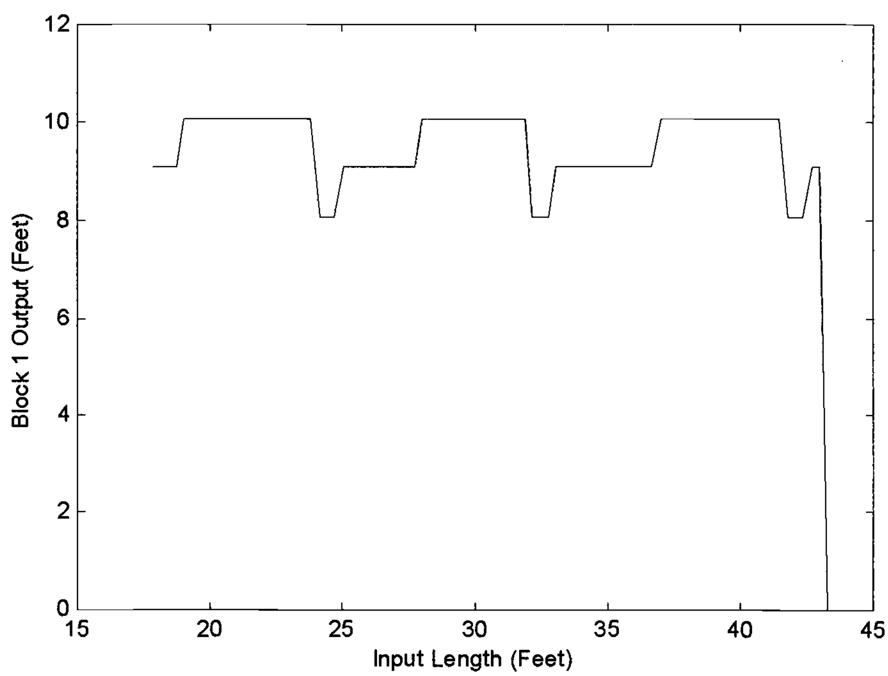
Figure 5.4. Mill "A" Discrete Type Fuzzy Logic Controller Solutions for Stems with Large End Diameter and 1" Lily Pad on the East (Negative Taper).

Simulation results are presented in tabular form in appendices G and H. The simulation time that took the Fuzzy Logic Controller to provide a new output in response to an input change was less than 100 milliseconds.

From the results of figures 5.3, 5.4 and appendices G and H, we can conclude that the LED location (West or East) inverts the bucking block solutions. The continuous type of Fuzzy Controllers generates smooth transitions from 12', 14, 16', 18' and 20' for both block lengths. We also notice that both blocks are adjusted for every nominal input length while in the discrete type only one of the block solution changes continuously for every input length the other block solution remains unchanged until the input length is sufficiently large to switch it to the next step up.

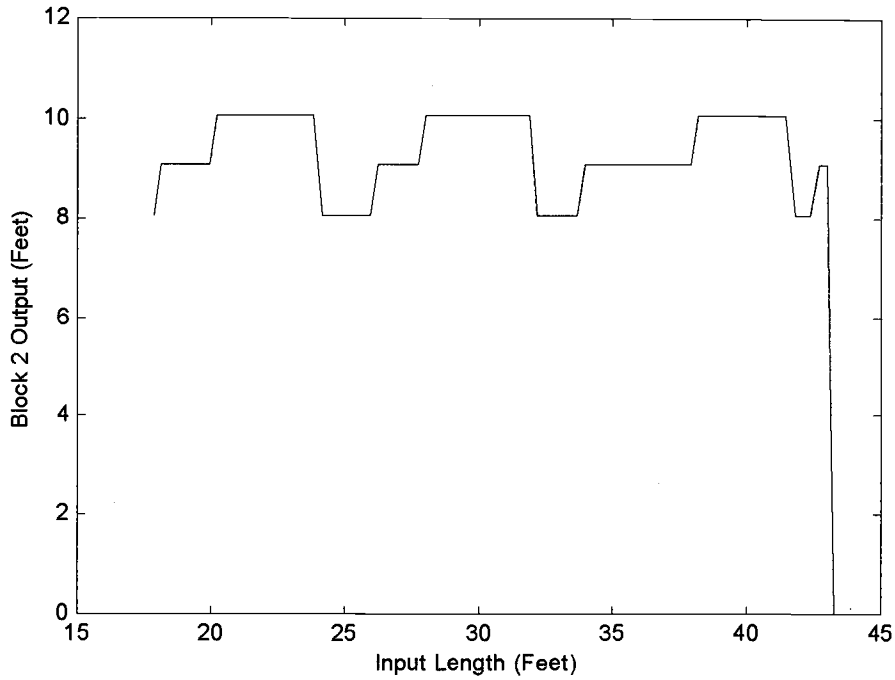
Long tables were generated to prove the veracity of the results with respect to the tables provided in the specifications in chapter 3. Comparing appendices G and H with table 3.1 we can see that the specifications were met. There was no need to solve for input length shorter than 20' because they are deliver as they come. The specifications shown in table 3.1 show 1-foot steps between the input lengths that had to be filled in the fuzzy logic controller to meet the specifications taking in consideration the valid output block lengths.

5.3 Results for Mill "B" Fuzzy Logic Controller

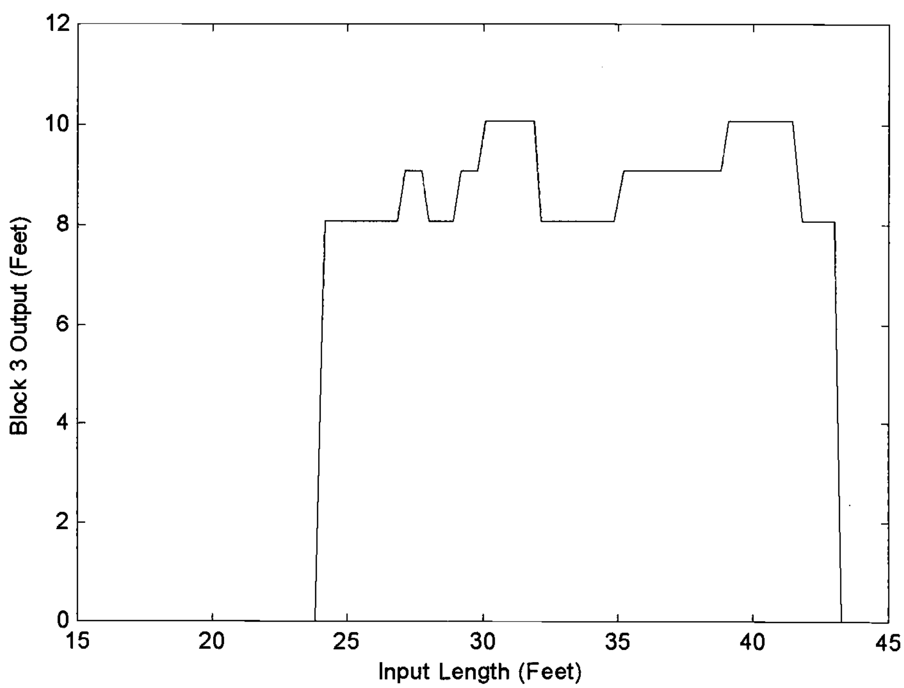


(a) Block 1

Continued

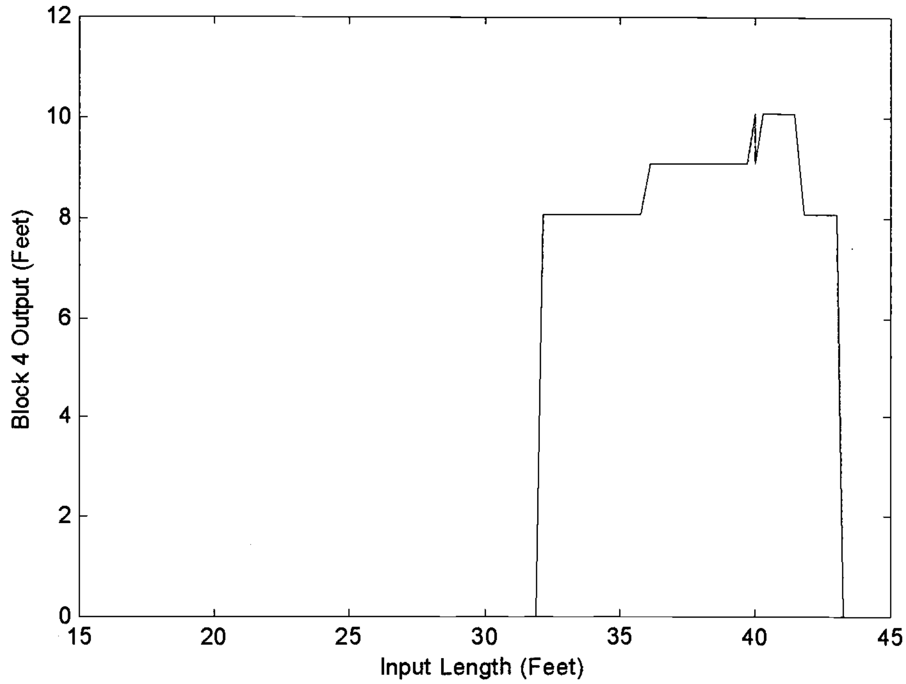


(b) Block 2



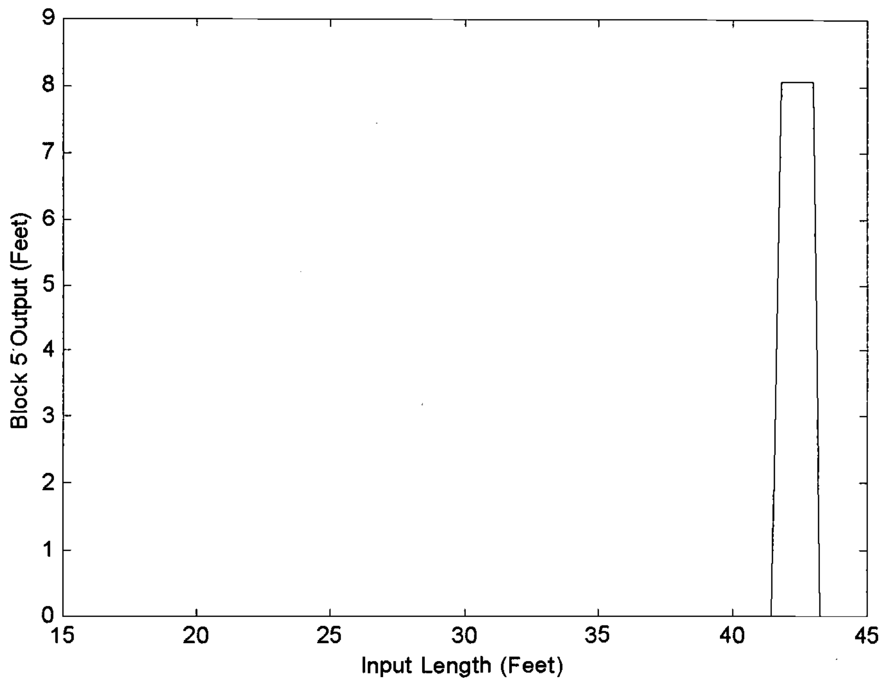
c) Block 3

Continued



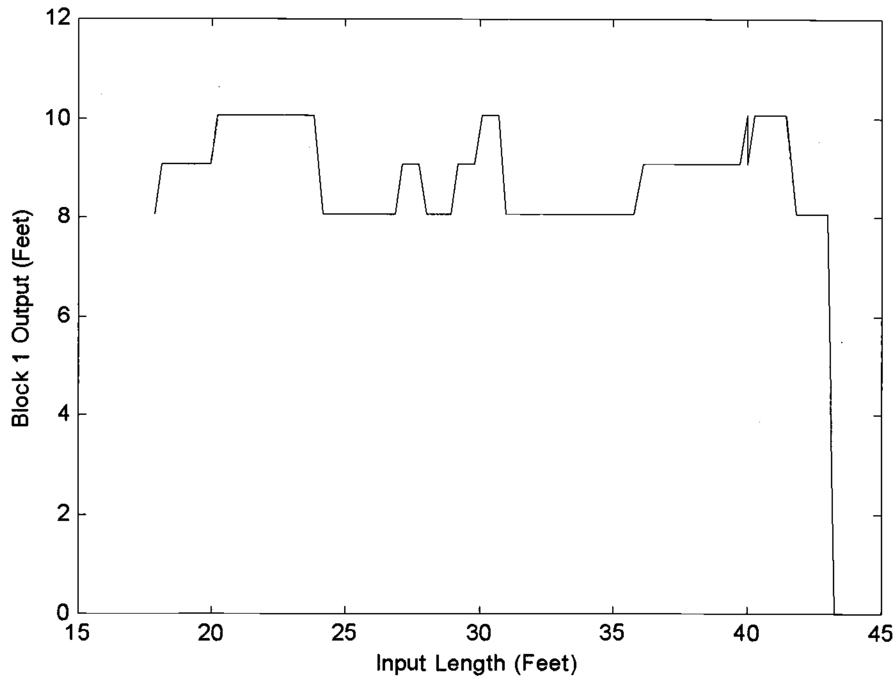
(d) Block 4

Continued

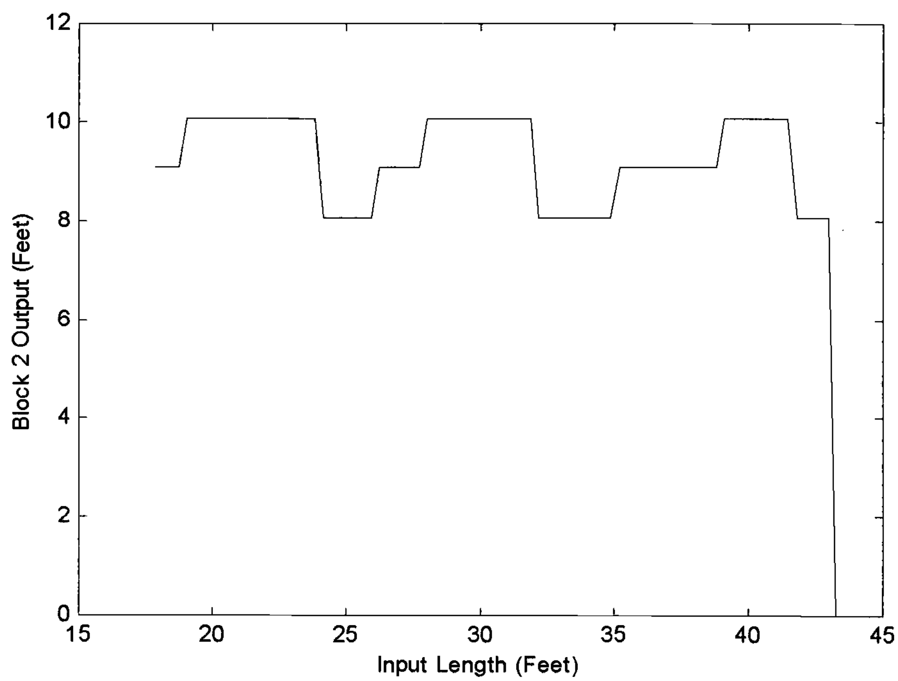


(e) Block 5

Figure 5.5. Mill "B" Fuzzy Logic Controller Solutions for Stems with LED and 1" Lily Pad on the West (Positive Taper). (a) Block 1, (b) Block 2, (c) Block 3, (d) Block 4, and (e) Block 5

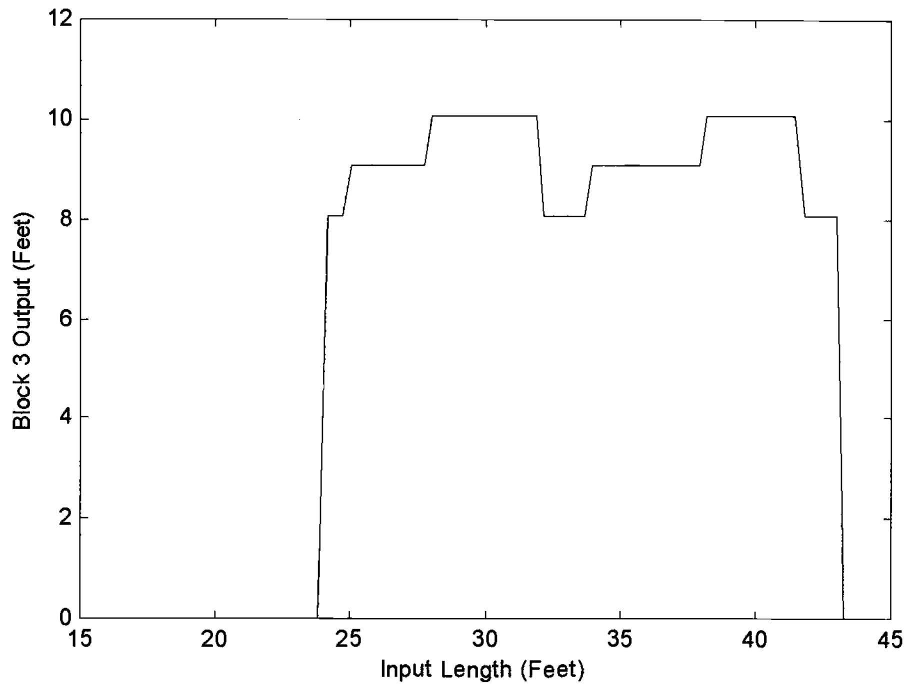


(a) Block 1

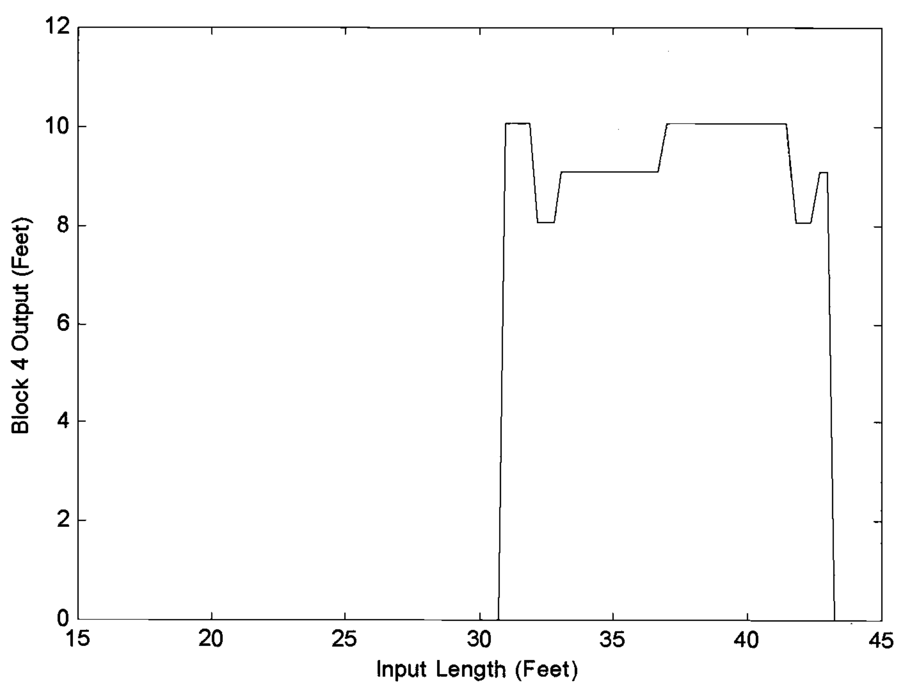


(b) Block 2

Continued

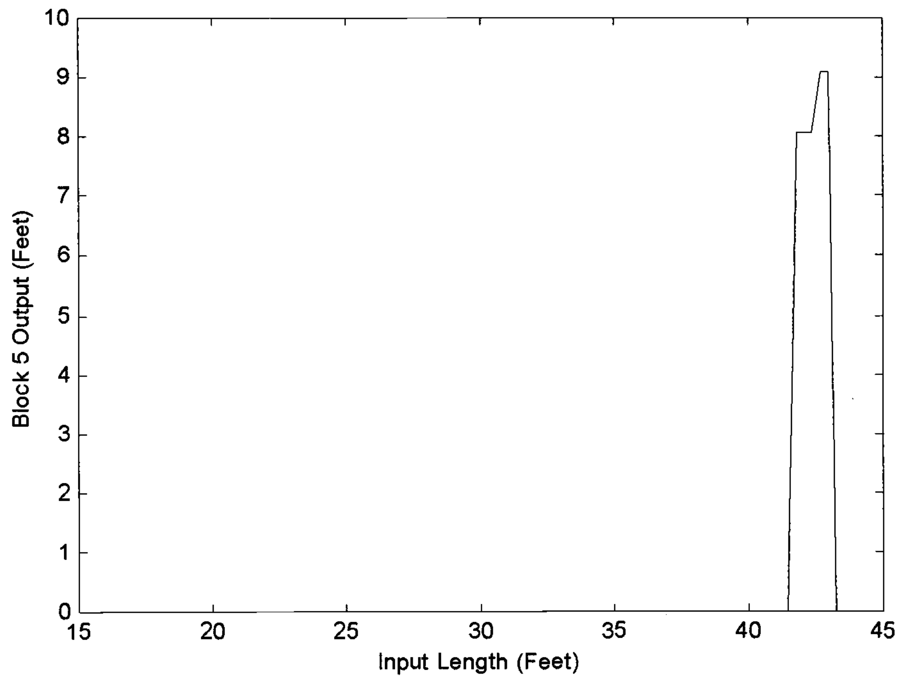


(c) Block 3



(d) Block 4

Continued



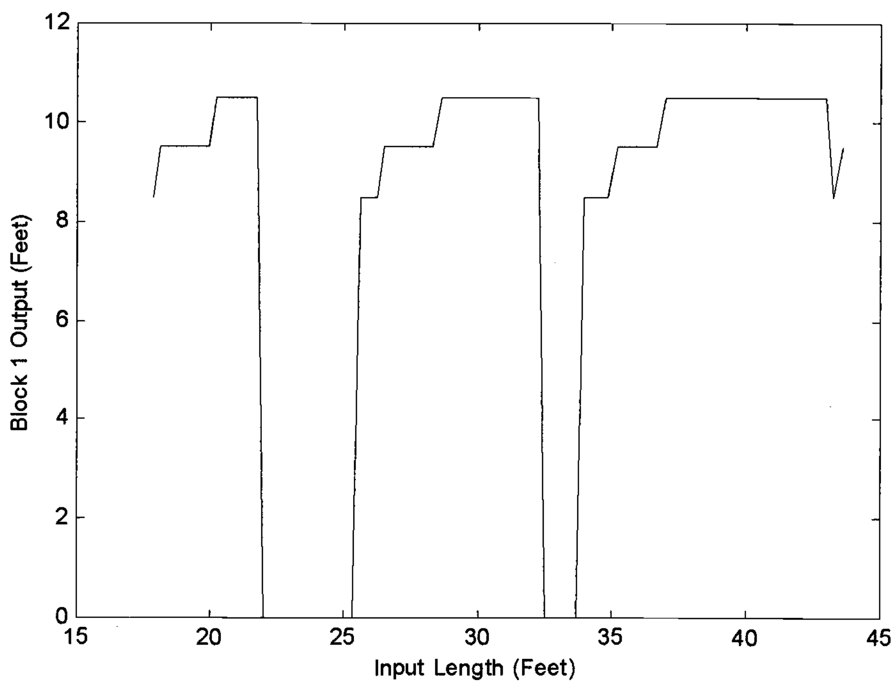
(e) Block 5

Figure 5.6. Mill "B" Fuzzy Logic Controller Solutions for Stems with LED and 1" Lily Pad on the East (Negative Taper). (a) Block 1, (b) Block 2, (c) Block 3, (d) Block 4, and (e) Block 5.

Simulation results are presented in tabular form in appendices I and J. The simulation time that took the Fuzzy Logic Controller to provide a new output in response to an input change was less than 100 milliseconds.

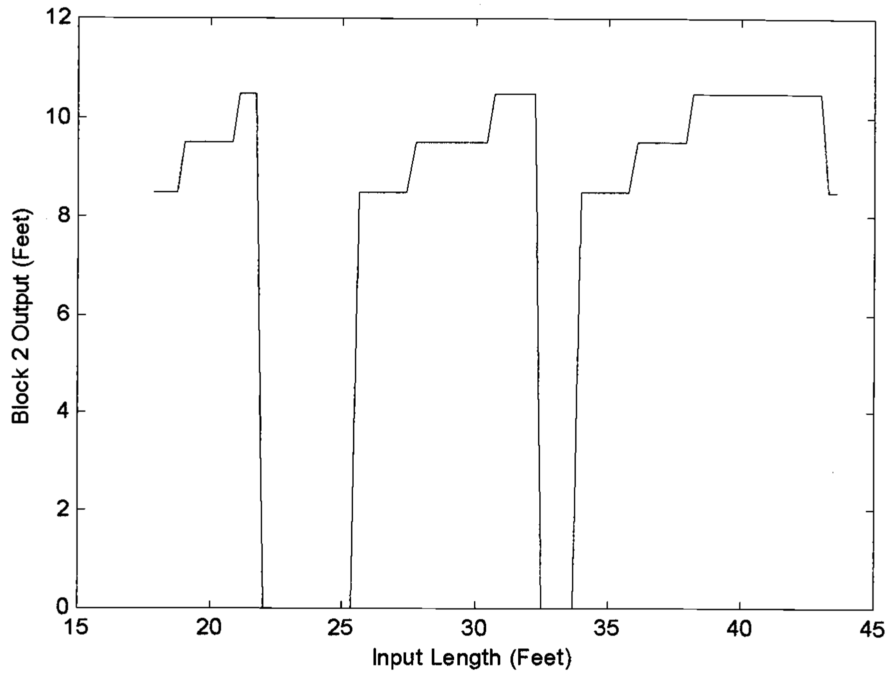
From the results of section 5.4 we can conclude as for Mill "A" and Veneer Mill that the LED location (West or East) inverts the bucking block solutions. In blocks one and two solutions we can note the there are no dead zones (no block solutions) as indicated in the specifications table 3.4. We can also observe from appendices I and J that the block solutions have sharp changes from one block length to another as required in the specifications.

5.4 Results for Veneer Mill Fuzzy Logic Controller

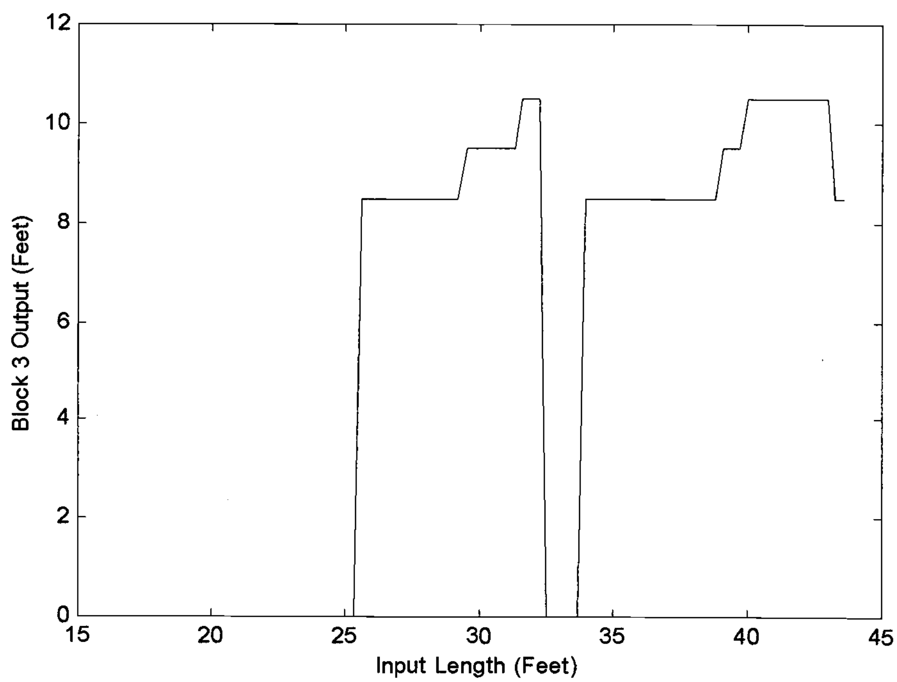


(a) Block 1

Continued

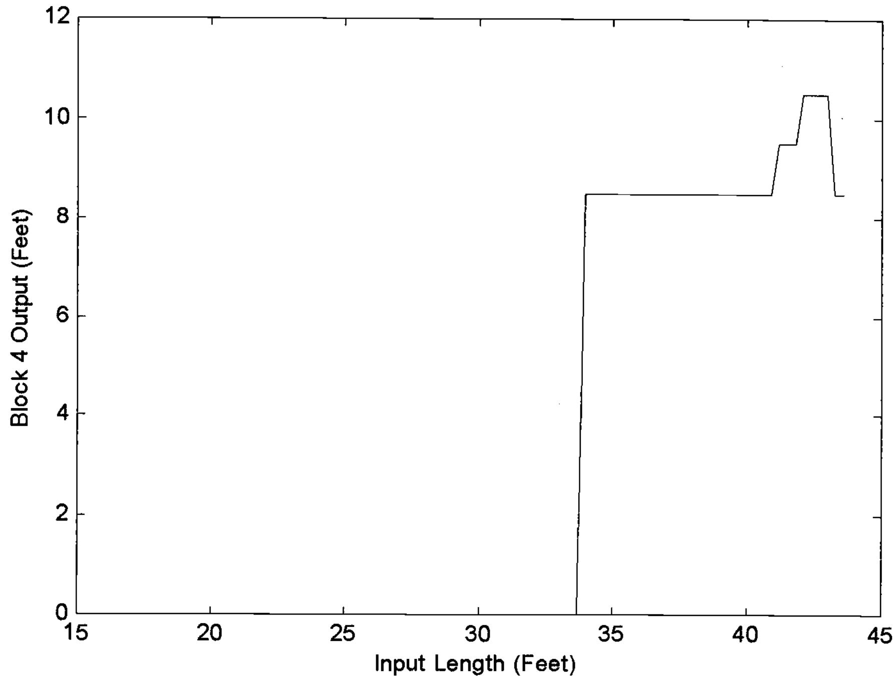


(b) Block 2



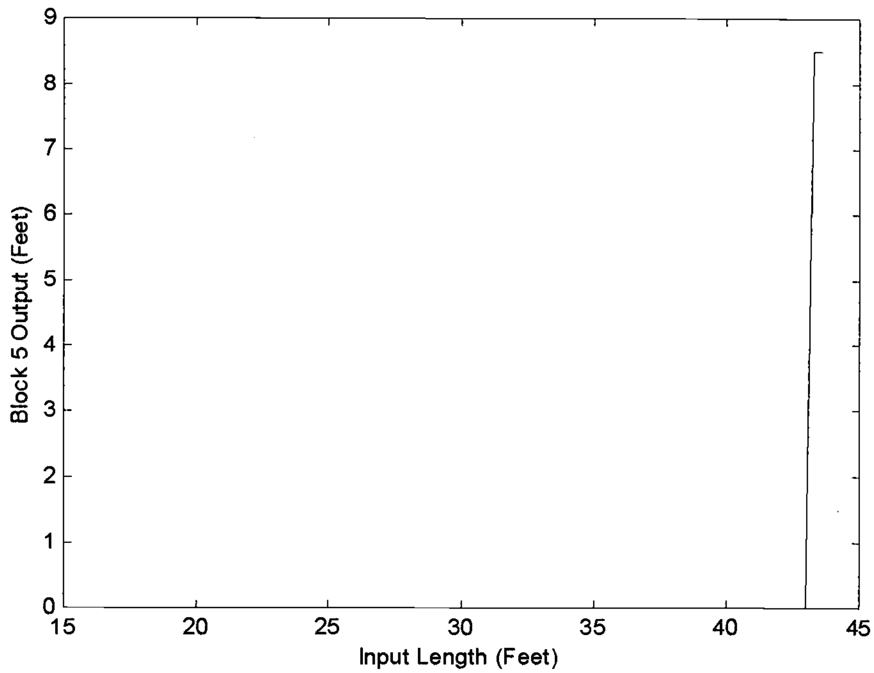
(c) Block 3

Continued



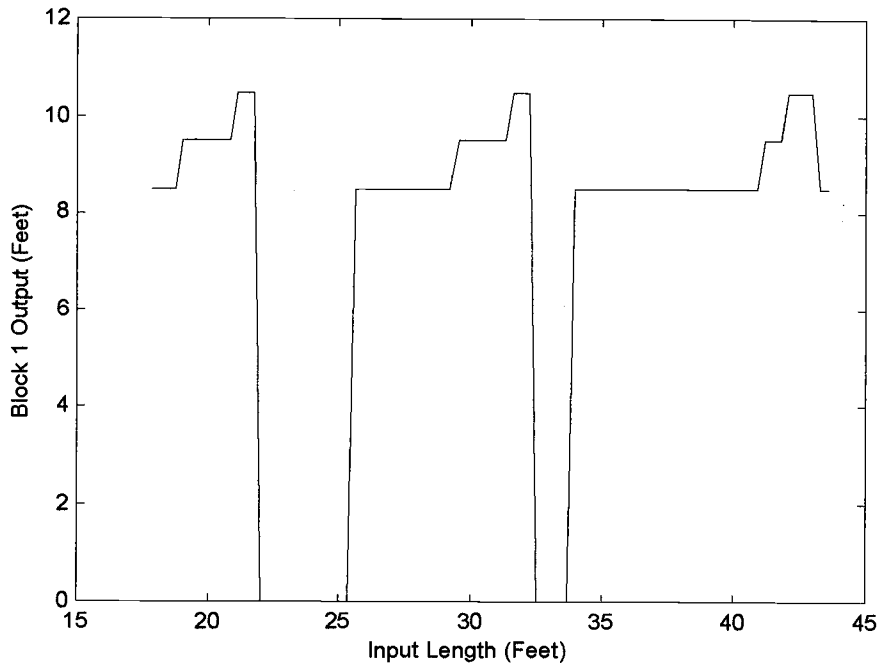
(d) Block 4

Continued

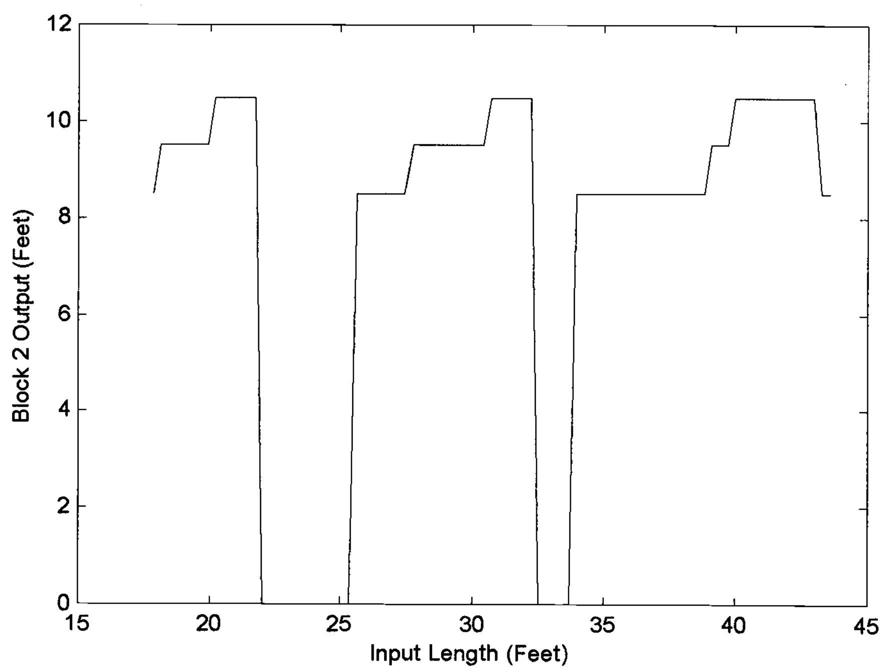


(e) Block 5

Figure 5.7. Veneer Fuzzy Logic Controller Solutions for Stems with LED and 1" Lily Pad on the West (Positive Taper). (a) Block 1, (b) Block 2, (c) Block 3, (d) Block 4, and (e) Block 5.

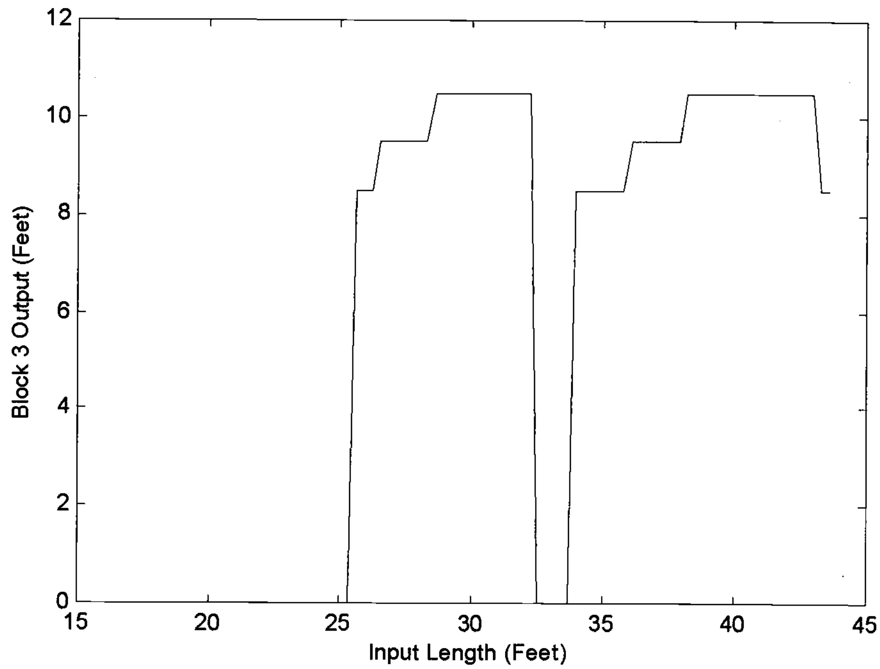


(a) Block 1

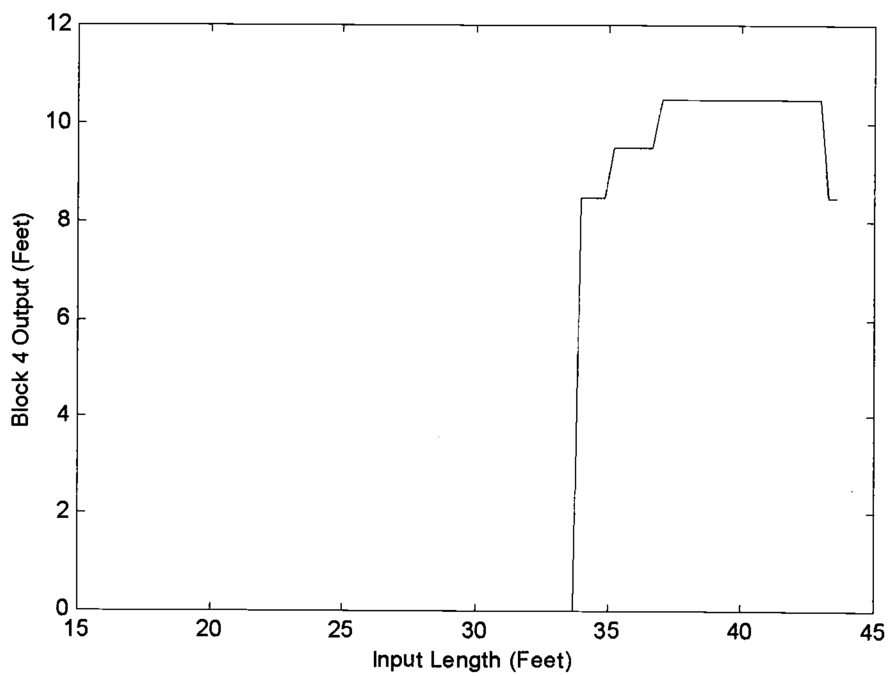


(b) Block 2

Continued

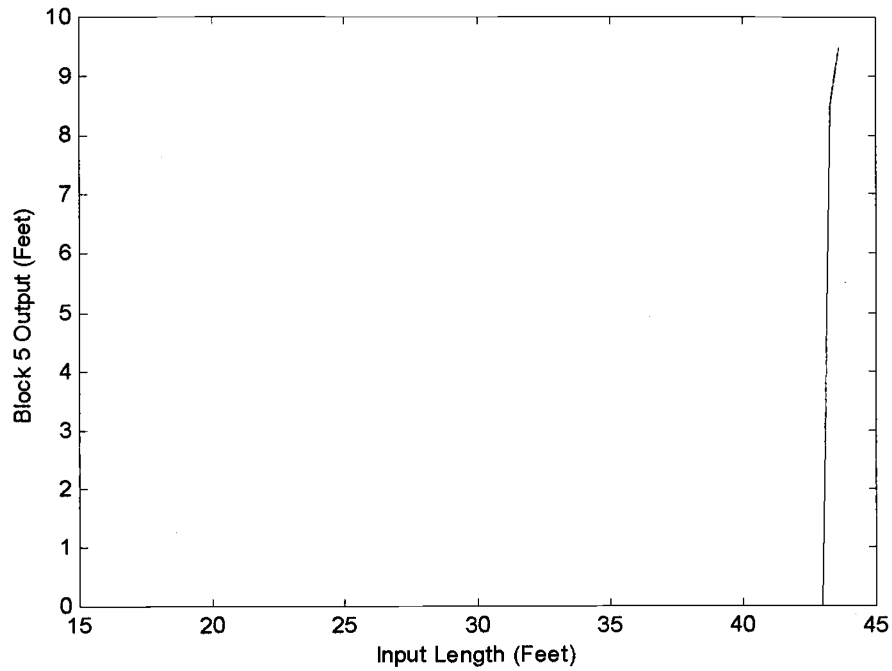


(c) Block 3



(d) Block 4

Continued



(e) Block 5

Figure 5.8. Veneer Fuzzy Logic Controller Solution for Stems with LED and 1" Lily Pad on the East (Negative Taper). (a) Block 1, (b) Block 2, (c) Block 3, (d) Block 4, and (e) Block 5.

Simulation results are presented in tabular form in appendix K and L. The simulation time that took the Fuzzy Logic Controller to provide a new output in response to an input change was less than 100 milliseconds.

From the results of section 5.3 we can conclude as for Mill "A" that the LED location (West or East) inverts the bucking block solutions. In blocks one and two solutions we can note the dead zones (no block solutions) as indicated in the specifications table 3.3. We can also observe from appendices K and L that the block solutions have sharp changes from one block length to another as require in the specifications.

6. CONCLUSIONS

6.1 Summary

The research work presented in this thesis can be summarized as follows:

1. The design of a Fuzzy Logic Controller to make Stems Bucking decisions was possible because of a well established set of expert rules that have been accumulated over the years and put them into practice by human operators.
2. Basic membership functions, trapezoidal, and bell type were utilized through the entire system design. These membership functions provided the expected block solutions for all three mills Bucking Controllers.
3. The division of the Bucking Controller into three independent controllers, one for each mill, made the design and simulation less complex, and the solution processing time faster.
4. The two Mill "A" Controllers, continuous and discrete, provided two different bucking philosophies. However, the discrete controller turned out to be the best because it recovers more wood and it takes care of inaccuracies generated in the scanning system, or on the chain due to stem slippage when the conveyor stops and starts.
5. Veneer plant and Mill "B" controllers were more complicated to implement because they both have five outputs and a more complex set of expert rules.
6. For all mills, the block solutions are inverted for stems with the large end diameter on the West or on the East, respectively.

7. The simulation provided invaluable test information vital for the realization of the controllers. Problems were found and solved, different type of membership functions, and inference systems were tested, and required filters at the input and output of the controllers were design to obtain the expected results.

6.2 Future Development

The investigation of a bucking merchandizer based on fuzzy logic provides a challenge for future development. A merchandizer is a bucking optimizer or controller that fits blocks of different mills in a stem based on cost.

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APPENDICES

Appendix A. Rules for Mill "A" Continuous Type Fuzzy Logic Controller

1. If (Length is In020) and (Taper is PosTaper) then (MillABlock1 is NoCut)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
2. If (Length is In20) and (Taper is PosTaper) then (MillABlock1 is L20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
3. If (Length is In2123) and (Taper is PosTaper) then (MillABlock1 is L20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
4. If (Length is InShort24) and (Taper is PosTaper) then (MillABlock1 is SS12)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
5. If (Length is InShort24) and (Taper is PosTaper) then (MillABlock1 is S12)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
6. If (Length is InLong24) and (Taper is PosTaper) then (MillABlock1 is S12)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
7. If (Length is InLong24) and (Taper is PosTaper) then (MillABlock1 is L12)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
8. If (Length is In2426) and (Taper is PosTaper) then (MillABlock1 is SS12)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
9. If (Length is In2426) and (Taper is PosTaper) then (MillABlock1 is S12)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
10. If (Length is InShort26) and (Taper is PosTaper) then (MillABlock1 is L12)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
11. If (Length is InShort26) and (Taper is PosTaper) then (MillABlock1 is S14)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
12. If (Length is InLong26) and (Taper is PosTaper) then (MillABlock1 is S14)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
13. If (Length is InLong26) and (Taper is PosTaper) then (MillABlock1 is L14)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
14. If (Length is In2628) and (Taper is PosTaper) then (MillABlock1 is L12)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
15. If (Length is In2628) and (Taper is PosTaper) then (MillABlock1 is S14)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
16. If (Length is InShort28) and (Taper is PosTaper) then (MillABlock1 is L14)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
17. If (Length is InShort28) and (Taper is PosTaper) then (MillABlock1 is S16)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
18. If (Length is InLong28) and (Taper is PosTaper) then (MillABlock1 is S16)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
19. If (Length is InLong28) and (Taper is PosTaper) then (MillABlock1 is L16)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
20. If (Length is In2830) and (Taper is PosTaper) then (MillABlock1 is L14)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)

21. If (Length is In2830) and (Taper is PosTaper) then (MillABlock1 is S16)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
22. If (Length is InShort30) and (Taper is PosTaper) then (MillABlock1 is L16)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
23. If (Length is InShort30) and (Taper is PosTaper) then (MillABlock1 is S18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
24. If (Length is InLong30) and (Taper is PosTaper) then (MillABlock1 is S18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
25. If (Length is InLong30) and (Taper is PosTaper) then (MillABlock1 is L18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
26. If (Length is In3032) and (Taper is PosTaper) then (MillABlock1 is L16)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
27. If (Length is In3032) and (Taper is PosTaper) then (MillABlock1 is S18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
28. If (Length is InShort32) and (Taper is PosTaper) then (MillABlock1 is L18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
29. If (Length is InShort32) and (Taper is PosTaper) then (MillABlock1 is S20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
30. If (Length is InLong32) and (Taper is PosTaper) then (MillABlock1 is S20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
31. If (Length is InLong32) and (Taper is PosTaper) then (MillABlock1 is L20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
32. If (Length is In3234) and (Taper is PosTaper) then (MillABlock1 is S18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
33. If (Length is InShort34) and (Taper is PosTaper) then (MillABlock1 is L18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
34. If (Length is InShort34) and (Taper is PosTaper) then (MillABlock1 is S20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
35. If (Length is InLong34) and (Taper is PosTaper) then (MillABlock1 is S20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
36. If (Length is InLong34) and (Taper is PosTaper) then (MillABlock1 is L20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
37. If (Length is In3436) and (Taper is PosTaper) then (MillABlock1 is S18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
38. If (Length is InShort36) and (Taper is PosTaper) then (MillABlock1 is L18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
39. If (Length is InShort36) and (Taper is PosTaper) then (MillABlock1 is S20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
40. If (Length is InLong36) and (Taper is PosTaper) then (MillABlock1 is S20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
41. If (Length is InLong36) and (Taper is PosTaper) then (MillABlock1 is L20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
42. If (Length is In3638) and (Taper is PosTaper) then (MillABlock1 is S18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)

43. If (Length is InShort38) and (Taper is PosTaper) then (MillABlock1 is L18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
44. If (Length is InShort38) and (Taper is PosTaper) then (MillABlock1 is S20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
45. If (Length is InLong38) and (Taper is PosTaper) then (MillABlock1 is S20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
46. If (Length is InLong38) and (Taper is PosTaper) then (MillABlock1 is L20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
47. If (Length is In3840) and (Taper is PosTaper) then (MillABlock1 is S18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
48. If (Length is InShort40) and (Taper is PosTaper) then (MillABlock1 is L18)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
49. If (Length is InShort40) and (Taper is PosTaper) then (MillABlock1 is S20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
50. If (Length is InLong40) and (Taper is PosTaper) then (MillABlock1 is S20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
51. If (Length is InLong40) and (Taper is PosTaper) then (MillABlock1 is L20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
52. If (Length is In4042) and (Taper is PosTaper) then (MillABlock1 is L20)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
53. If (Length is InGrt42) and (Taper is PosTaper) then (MillABlock1 is NoCut)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
54. If (Length is In020) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)
55. If (Length is In20) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L20)(MillABlock3 is NoCut) (1)
56. If (Length is In2123) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L20)(MillABlock3 is NoCut) (1)
57. If (Length is InShort24) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is SS12)(MillABlock3 is NoCut) (1)
58. If (Length is InShort24) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S12)(MillABlock3 is NoCut) (1)
59. If (Length is InLong24) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S12)(MillABlock3 is NoCut) (1)
60. If (Length is InLong24) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L12)(MillABlock3 is NoCut) (1)
61. If (Length is In2426) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is SS12)(MillABlock3 is NoCut) (1)
62. If (Length is In2426) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S12)(MillABlock3 is NoCut) (1)
63. If (Length is InShort26) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L12)(MillABlock3 is NoCut) (1)
64. If (Length is InShort26) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S14)(MillABlock3 is NoCut) (1)

65. If (Length is InLong26) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S14)(MillABlock3 is NoCut) (1)
66. If (Length is InLong26) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L14)(MillABlock3 is NoCut) (1)
67. If (Length is In2628) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L12)(MillABlock3 is NoCut) (1)
68. If (Length is In2628) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S14)(MillABlock3 is NoCut) (1)
69. If (Length is InShort28) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L14)(MillABlock3 is NoCut) (1)
70. If (Length is InShort28) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S16)(MillABlock3 is NoCut) (1)
71. If (Length is InLong28) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S16)(MillABlock3 is NoCut) (1)
72. If (Length is InLong28) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L16)(MillABlock3 is NoCut) (1)
73. If (Length is In2830) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L14)(MillABlock3 is NoCut) (1)
74. If (Length is In2830) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S16)(MillABlock3 is NoCut) (1)
75. If (Length is InShort30) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L16)(MillABlock3 is NoCut) (1)
76. If (Length is InShort30) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S18)(MillABlock3 is NoCut) (1)
77. If (Length is InLong30) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S18)(MillABlock3 is NoCut) (1)
78. If (Length is InLong30) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L18)(MillABlock3 is NoCut) (1)
79. If (Length is In3032) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L16)(MillABlock3 is NoCut) (1)
80. If (Length is In3032) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S18)(MillABlock3 is NoCut) (1)
81. If (Length is InShort32) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L18)(MillABlock3 is NoCut) (1)
82. If (Length is InShort32) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S20)(MillABlock3 is NoCut) (1)
83. If (Length is InLong32) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S20)(MillABlock3 is NoCut) (1)
84. If (Length is InLong32) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L20)(MillABlock3 is NoCut) (1)
85. If (Length is In3234) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S18)(MillABlock3 is NoCut) (1)
86. If (Length is InShort34) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L18)(MillABlock3 is NoCut) (1)

87. If (Length is InShort34) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S20)(MillABlock3 is NoCut) (1)
88. If (Length is InLong34) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S20)(MillABlock3 is NoCut) (1)
89. If (Length is InLong34) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L20)(MillABlock3 is NoCut) (1)
90. If (Length is In3436) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S18)(MillABlock3 is NoCut) (1)
91. If (Length is InShort36) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L18)(MillABlock3 is NoCut) (1)
92. If (Length is InShort36) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S20)(MillABlock3 is NoCut) (1)
93. If (Length is InLong36) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S20)(MillABlock3 is NoCut) (1)
94. If (Length is InLong36) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L20)(MillABlock3 is NoCut) (1)
95. If (Length is In3638) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S18)(MillABlock3 is NoCut) (1)
96. If (Length is InShort38) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L18)(MillABlock3 is NoCut) (1)
97. If (Length is InShort38) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S20)(MillABlock3 is NoCut) (1)
98. If (Length is InLong38) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S20)(MillABlock3 is NoCut) (1)
99. If (Length is InLong38) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L20)(MillABlock3 is NoCut) (1)
100. If (Length is In3840) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S18)(MillABlock3 is NoCut) (1)
101. If (Length is InShort40) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L18)(MillABlock3 is NoCut) (1)
102. If (Length is InShort40) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S20)(MillABlock3 is NoCut) (1)
103. If (Length is InLong40) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is S20)(MillABlock3 is NoCut) (1)
104. If (Length is InLong40) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L20)(MillABlock3 is NoCut) (1)
105. If (Length is In4042) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is L20)(MillABlock3 is NoCut) (1)
106. If (Length is InGrt42) and (Taper is NegTaper) then (MillABlock1 is NoCut)(MillABlock2 is NoCut)(MillABlock3 is NoCut) (1)

Appendix B. Rules for Mill "A" Discrete Type Fuzzy Logic Controller

1. If (AlnLength is Aln012) and (Taper is PosTaper) then (ABlock1 is ANocut)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
2. If (AlnLength is Aln12) and (Taper is PosTaper) then (ABlock1 is ANocut)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
3. If (AlnLength is Aln14) and (Taper is PosTaper) then (ABlock1 is ANocut)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
4. If (AlnLength is Aln16) and (Taper is PosTaper) then (ABlock1 is ANocut)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
5. If (AlnLength is Aln18) and (Taper is PosTaper) then (ABlock1 is ANocut)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
6. If (AlnLength is Aln20) and (Taper is PosTaper) then (ABlock1 is A203)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
7. If (AlnLength is Aln24) and (Taper is PosTaper) then (ABlock1 is A12)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
8. If (AlnLength is Aln26) and (Taper is PosTaper) then (ABlock1 is A14)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
9. If (AlnLength is Aln28) and (Taper is PosTaper) then (ABlock1 is A16)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
10. If (AlnLength is Aln30) and (Taper is PosTaper) then (ABlock1 is A18)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
11. If (AlnLength is Aln32) and (Taper is PosTaper) then (ABlock1 is A20)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
12. If (AlnLength is Aln34) and (Taper is PosTaper) then (ABlock1 is A20)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
13. If (AlnLength is Aln36) and (Taper is PosTaper) then (ABlock1 is A20)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
14. If (AlnLength is Aln38) and (Taper is PosTaper) then (ABlock1 is A20)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
15. If (AlnLength is Aln40) and (Taper is PosTaper) then (ABlock1 is A20)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
16. If (AlnLength is Aln407) and (Taper is PosTaper) then (ABlock1 is A203)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
17. If (AlnLength is Aln012) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
18. If (AlnLength is Aln12) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
19. If (AlnLength is Aln14) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
20. If (AlnLength is Aln16) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)

21. If (AlnLength is Aln18) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is ANoCut)(ABlock3 is ANoCut)(1)
22. If (AlnLength is Aln20) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is A203)(ABlock3 is ANoCut)(1)
23. If (AlnLength is Aln24) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is A12)(ABlock3 is ANoCut)(1)
24. If (AlnLength is Aln26) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is A14)(ABlock3 is ANoCut)(1)
25. If (AlnLength is Aln28) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is A16)(ABlock3 is ANoCut)(1)
26. If (AlnLength is Aln30) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is A18)(ABlock3 is ANoCut)(1)
27. If (AlnLength is Aln32) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is A20)(ABlock3 is ANoCut)(1)
28. If (AlnLength is Aln34) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is A20)(ABlock3 is ANoCut)(1)
29. If (AlnLength is Aln36) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is A20)(ABlock3 is ANoCut)(1)
30. If (AlnLength is Aln38) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is A20)(ABlock3 is ANoCut)(1)
31. If (AlnLength is Aln40) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is A20)(ABlock3 is ANoCut)(1)
32. If (AlnLength is Aln407) and (Taper is NegTaper) then (ABlock1 is ANocut)(ABlock2 is A203)(ABlock3 is ANoCut)(1)

Appendix C. Rules for Mill "B" Fuzzy Logic Controller

1. If (MBnLength is MBln36) and (Taper is PosTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOut9.08)(MBOutBlock4 is MBOut9.08)(MBOutBlock5 is MBOutNoCut)(1)If (MBnLength is MBln016) and (Taper is PosTaper) then (MBOutBlock1 is MBOutNocut)(MBOutBlock2 is MBOutNoCut)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
2. If (MBnLength is MBln16) and (Taper is PosTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
3. If (MBnLength is MBln17) and (Taper is PosTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
4. If (MBnLength is MBln18) and (Taper is PosTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
5. If (MBnLength is MBln19) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
6. If (MBnLength is MBln20) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
7. If (MBnLength is MBln21) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
8. If (MBnLength is MBln22) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
9. If (MBnLength is MBln23) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
10. If (MBnLength is MBln24) and (Taper is PosTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is

11. MBOut8.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
12. If (MBnLength is MBln25) and (Taper is PosTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOut8.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
13. If (MBnLength is MBln26) and (Taper is PosTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOut8.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
14. If (MBnLength is MBln27) and (Taper is PosTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOut9.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
15. If (MBnLength is MBln28) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut8.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
16. If (MBnLength is MBln29) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut9.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
17. If (MBnLength is MBln30) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut10.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
18. If (MBnLength is MBln31) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut10.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
19. If (MBnLength is MBln32) and (Taper is PosTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOut8.08)(MBOutBlock4 is MBOut8.08)(MBOutBlock5 is MBOutNoCut)(1)
20. If (MBnLength is MBln33) and (Taper is PosTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOut8.08)(MBOutBlock4 is MBOut8.08)(MBOutBlock5 is MBOutNoCut)(1)
21. If (MBnLength is MBln34) and (Taper is PosTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is
22. MBOut8.08)(MBOutBlock4 is MBOut8.08)(MBOutBlock5 is MBOutNoCut)(1)

23. If (MBnLength is MBln35) and (Taper is PosTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOut9.08)(MBOutBlock4 is MBOut8.08)(MBOutBlock5 is MBOutNoCut)(1)
24. If (MBnLength is MBln36) and (Taper is PosTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOut9.08)(MBOutBlock4 is MBOut9.08)(MBOutBlock5 is MBOutNoCut)(1)
25. If (MBnLength is MBln37) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOut9.08)(MBOutBlock4 is MBOut9.08)(MBOutBlock5 is MBOutNoCut)(1)
26. If (MBnLength is MBln38) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut9.08)(MBOutBlock4 is MBOut9.08)(MBOutBlock5 is MBOutNoCut)(1)
27. If (MBnLength is MBln39) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut10.08)(MBOutBlock4 is MBOut9.08)(MBOutBlock5 is MBOutNoCut)(1)
28. If (MBnLength is MBln40) and (Taper is PosTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut10.08)(MBOutBlock4 is MBOut10.08)(MBOutBlock5 is MBOutNoCut)(1)
29. If (MBnLength is MBln41) and (Taper is PosTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOut8.08)(MBOutBlock4 is MBOut8.08)(MBOutBlock5 is MBOut8.08)(1)
30. If (MBnLength is MBln42) and (Taper is PosTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOut8.08)(MBOutBlock4 is MBOut8.08)(MBOutBlock5 is MBOut8.08)(1)
31. If (MBnLength is MBln30GEQ43) and (Taper is PosTaper) then (MBOutBlock1 is MBOutNoCut)(MBOutBlock2 is MBOutNoCut)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
32. If (MBnLength is MBln016) and (Taper is NegTaper) then (MBOutBlock1 is MBOutNoCut)(MBOutBlock2 is MBOutNoCut)(MNOutBlock3 is
33. MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
34. If (MBnLength is MBln16) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)

35. If (MBnLength is MBln17) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
36. If (MBnLength is MBln18) and (Taper is NegTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
37. If (MBnLength is MBln19) and (Taper is NegTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
38. If (MBnLength is MBln20) and (Taper is NegTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
39. If (MBnLength is MBln21) and (Taper is NegTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
40. If (MBnLength is MBln22) and (Taper is NegTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
41. If (MBnLength is MBln23) and (Taper is NegTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
42. If (MBnLength is MBln24) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOut8.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
43. If (MBnLength is MBln25) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is
44. MBOut9.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
45. If (MBnLength is MBln26) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOut9.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
46. If (MBnLength is MBln27) and (Taper is NegTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOut9.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)

47. If (MBnLength is MBln28) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut10.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
48. If (MBnLength is MBln29) and (Taper is NegTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut10.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
49. If (MBnLength is MBln30) and (Taper is NegTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut10.08)(MBOutBlock4 is MBOutNoCut)(MBOutBlock5 is MBOutNoCut)(1)
50. If (MBnLength is MBln31) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut10.08)(MBOutBlock4 is MBOut10.08)(MBOutBlock5 is MBOutNoCut)(1)
51. If (MBnLength is MBln32) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOut8.08)(MBOutBlock4 is MBOut8.08)(MBOutBlock5 is MBOutNoCut)(1)
52. If (MBnLength is MBln33) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOut8.08)(MBOutBlock4 is MBOut9.08)(MBOutBlock5 is MBOutNoCut)(1)
53. If (MBnLength is MBln34) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOut9.08)(MBOutBlock4 is MBOut9.08)(MBOutBlock5 is MBOutNoCut)(1)
54. If (MBnLength is MBln35) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOutNoCut)(1)
55. MBOut9.08)(MBOutBlock4 is MBOu9.08)(MBOutBlock5 is MBOutNoCut)(1)
56. If (MBnLength is MBln36) and (Taper is NegTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOut9.08)(MBOutBlock4 is MBOut9.08)(MBOutBlock5 is MBOutNoCut)(1)
57. If (MBnLength is MBln37) and (Taper is NegTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOut9.08)(MBOutBlock4 is MBOut9.08)(MBOutBlock5 is MBOutNoCut)(1)

58. If (MBnLength is MBln38) and (Taper is NegTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut9.08)(MNOutBlock3 is MBOut10.08)(MBOutBlock4 is MBOut10.08)(MBOutBlock5 is MBOutNoCut)(1)
59. If (MBnLength is MBln39) and (Taper is NegTaper) then (MBOutBlock1 is MBOut9.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut10.08)(MBOutBlock4 is MBOut10.08)(MBOutBlock5 is MBOutNoCut)(1)
60. If (MBnLength is MBln40) and (Taper is NegTaper) then (MBOutBlock1 is MBOut10.08)(MBOutBlock2 is MBOut10.08)(MNOutBlock3 is MBOut10.08)(MBOutBlock4 is MBOut10.08)(MBOutBlock5 is MBOutNoCut)(1)
61. If (MBnLength is MBln41) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOut8.08)(MBOutBlock4 is MBOut8.08)(MBOutBlock5 is MBOut8.08)(1)
62. If (MBnLength is MBln42) and (Taper is NegTaper) then (MBOutBlock1 is MBOut8.08)(MBOutBlock2 is MBOut8.08)(MNOutBlock3 is MBOut8.08)(MBOutBlock4 is MBOut9.08)(MBOutBlock5 is MBOut9.08)(1)
63. If (MBnLength is MBlnGEQ43) and (Taper is NegTaper) then (MBOutBlock1 is MBOutNoCut)(MBOutBlock2 is MBOutNoCut)(MNOutBlock3 is MBOutNoCut)(MBOutBlock4 is MBOut NoCut)(MBOutBlock5 is MBOutNoCut)(1)

Appendix D. Rules for Veneer Mill Fuzzy Logic Controller

1. If (VlnLength is Vln017) and (Taper is PosTaper) then (VBlock1 is VNocut)(VBlock2 is VNoCut)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
2. If (VlnLength is Vln17) and (Taper is PosTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
3. If (VlnLength is Vln18) and (Taper is PosTaper) then (VBlock1 is V9.5)(VBlock2 is V8.5)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
4. If (VlnLength is Vln19) and (Taper is PosTaper) then (VBlock1 is V9.5)(VBlock2 is V9.5)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
5. If (VlnLength is Vln20) and (Taper is PosTaper) then (VBlock1 is V10.5)(VBlock2 is V9.5)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
6. If (VlnLength is Vln21) and (Taper is PosTaper) then (VBlock1 is V10.5)(VBlock2 is V10.5)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
7. If (VlnLength is Vln2225) and (Taper is PosTaper) then (VBlock1 is VNocut)(VBlock2 is VNoCut)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
8. If (VlnLength is Vln25.5) and (Taper is PosTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V8.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
9. If (VlnLength is lnV26.5) and (Taper is PosTaper) then (VBlock1 is V9.5)(VBlock2 is V8.5)(VBlock3 is V8.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
10. If (VlnLength is lnV27.5) and (Taper is PosTaper) then (VBlock1 is V9.5)(VBlock2 is V9.5)(VBlock3 is V8.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
11. If (VlnLength is lnV28.5) and (Taper is PosTaper) then (VBlock1 is V10.5)(VBlock2 is V9.5)(VBlock3 is V8.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
12. If (VlnLength is lnV29.5) and (Taper is PosTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V9.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
13. If (VlnLength is lnV30.5) and (Taper is PosTaper) then (VBlock1 is V10.5)(VBlock2 is V10.5)(VBlock3 is V8.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)

14. If (VlnLength is lnV31.5) and (Taper is PosTaper) then (VBlock1 is V10.5)(VBlock2 is V10.5)(VBlock3 is V10.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
15. If (VlnLength is lnV32.5) and (Taper is PosTaper) then (VBlock1 is VNocut)(VBlock2 is VNoCut)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
16. If (VlnLength is lnV33.5) and (Taper is PosTaper) then (VBlock1 is VNocut)(VBlock2 is VNoCut)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
17. If (VlnLength is lnV34) and (Taper is PosTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V8.5)(VBlock4 is V8.5)(VBlock5 is VNoCut)(1)
18. If (VlnLength is lnV35) and (Taper is PosTaper) then (VBlock1 is V9.5)(VBlock2 is V8.5)(VBlock3 is V8.5)(VBlock4 is V8.5)(VBlock5 is VNoCut)(1)
19. If (VlnLength is lnV36) and (Taper is PosTaper) then (VBlock1 is V9.5)(VBlock2 is V9.5)(VBlock3 is V8.5)(VBlock4 is V8.5)(VBlock5 is VNoCut)(1)
20. If (VlnLength is lnV37) and (Taper is PosTaper) then (VBlock1 is V10.5)(VBlock2 is V9.5)(VBlock3 is V8.5)(VBlock4 is V8.5)(VBlock5 is VNoCut)(1)
21. If (VlnLength is lnV38) and (Taper is PosTaper) then (VBlock1 is V10.5)(VBlock2 is V10.5)(VBlock3 is V8.5)(VBlock4 is V8.5)(VBlock5 is VNoCut)(1)
22. If (VlnLength is lnV39) and (Taper is PosTaper) then (VBlock1 is V10.5)(VBlock2 is V10.5)(VBlock3 is V9.5)(VBlock4 is V8.5)(VBlock5 is VNoCut)(1)
23. If (VlnLength is lnV40) and (Taper is PosTaper) then (VBlock1 is V10.5)(VBlock2 is V10.5)(VBlock3 is V10.5)(VBlock4 is V8.5)(VBlock5 is VNoCut)(1)
24. If (VlnLength is lnV41) and (Taper is PosTaper) then (VBlock1 is V10.5)(VBlock2 is V10.5)(VBlock3 is V10.5)(VBlock4 is V9.5)(VBlock5 is VNoCut)(1)
25. If (VlnLength is lnV42) and (Taper is PosTaper) then (VBlock1 is V9.5)(VBlock2 is V9.5)(VBlock3 is V8.5)(VBlock4 is V10.5)(VBlock5 is VNoCut)(1)
26. If (VlnLength is lnV43) and (Taper is PosTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V8.5)(VBlock4 is V8.5)(VBlock5 is V8.5)(1)
27. If (VlnLength is lnV43.5) and (Taper is PosTaper) then (VBlock1 is V9.5)(VBlock2 is V8.5)(VBlock3 is V8.5)(VBlock4 is V8.5)(VBlock5 is V8.5)(1)

28. If (VlnLength is lnVGEQ44) and (Taper is PosTaper) then (VBlock1 is VNocut)(VBlock2 is VNoCut)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
29. If (VlnLength is Vln017) and (Taper is NegTaper) then (VBlock1 is VNocut)(VBlock2 is VNoCut)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
30. If (VlnLength is Vln17) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
31. If (VlnLength is Vln18) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V9.5)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
32. If (VlnLength is Vln19) and (Taper is NegTaper) then (VBlock1 is V9.5)(VBlock2 is V9.5)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
33. If (VlnLength is Vln20) and (Taper is NegTaper) then (VBlock1 is V9.5)(VBlock2 is V10.5)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
34. If (VlnLength is Vln21) and (Taper is NegTaper) then (VBlock1 is V10.5)(VBlock2 is V10.5)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
35. If (VlnLength is Vln2225) and (Taper is NegTaper) then (VBlock1 is VNocut)(VBlock2 is VNoCut)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
36. If (VlnLength is Vln25.5) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V8.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
37. If (VlnLength is lnV26.5) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V9.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
38. If (VlnLength is lnV27.5) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V9.5)(VBlock3 is V9.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
39. If (VlnLength is lnV28.5) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V9.5)(VBlock3 is V10.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
40. If (VlnLength is lnV29.5) and (Taper is NegTaper) then (VBlock1 is V9.5)(VBlock2 is V9.5)(VBlock3 is V10.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
41. If (VlnLength is lnV30.5) and (Taper is NegTaper) then (VBlock1 is V9.5)(VBlock2 is V10.5)(VBlock3 is V10.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)

42. If (VlnLength is lnV31.5) and (Taper is NegTaper) then (VBlock1 is V10.5)(VBlock2 is V10.5)(VBlock3 is V10.5)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
43. If (VlnLength is lnV32.5) and (Taper is NegTaper) then (VBlock1 is VNocut)(VBlock2 is VNoCut)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
44. If (VlnLength is lnV33.5) and (Taper is NegTaper) then (VBlock1 is VNocut)(VBlock2 is VNoCut)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)
45. If (VlnLength is lnV34) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V8.5)(VBlock4 is V8.5)(VBlock5 is VNoCut)(1)
46. If (VlnLength is lnV35) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V8.5)(VBlock4 is V9.5)(VBlock5 is VNoCut)(1)
47. If (VlnLength is lnV36) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V9.5)(VBlock4 is V9.5)(VBlock5 is VNoCut)(1)
48. If (VlnLength is lnV37) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V9.5)(VBlock4 is V10.5)(VBlock5 is VNoCut)(1)
49. If (VlnLength is lnV38) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V10.5)(VBlock4 is V10.5)(VBlock5 is VNoCut)(1)
50. If (VlnLength is lnV39) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V9.5)(VBlock3 is V10.5)(VBlock4 is V10.5)(VBlock5 is vVNoCut)(1)
51. If (VlnLength is lnV40) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V10.5)(VBlock3 is V10.5)(VBlock4 is V10.5)(VBlock5 is VNoCut)(1)
52. If (VlnLength is lnV41) and (Taper is NegTaper) then (VBlock1 is V9.5)(VBlock2 is V10.5)(VBlock3 is V10.5)(VBlock4 is V10.5)(VBlock5 is VNoCut)(1)
53. If (VlnLength is lnV42) and (Taper is NegTaper) then (VBlock1 is V10.5)(VBlock2 is V10.5)(VBlock3 is V10.5)(VBlock4 is V10.5)(VBlock5 is VNoCut)(1)
54. If (VlnLength is lnV43) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V8.5)(VBlock4 is V8.5)(VBlock5 is V8.5)(1)
55. If (VlnLength is lnV43.5) and (Taper is NegTaper) then (VBlock1 is V8.5)(VBlock2 is V8.5)(VBlock3 is V8.5)(VBlock4 is V8.5)(VBlock5 is V9.5)(1)

56. If (VlnLength is lnVGEQ44) and (Taper is NegTaper) then (VBlock1 is VNocut)(VBlock2 is VNoCut)(VBlock3 is VNoCut)(VBlock4 is VNoCut)(VBlock5 is VNoCut)(1)

Appendix E. Mill "A" Continuous Type Fuzzy Logic Controller Results For Input Stems with the Large End Diameter and 1 inch Lily Pad on the West.

Nominal Input Length (Feet)	Taper West/East (Pos/Neg)	Block 1 (Feet)	Block 2 (Feet)	West Lily Pad (Inches)	East Lily Pad (Inches)
21	1	20.6	0	0.6875	0
21.3	1	20.6	0	0.6875	0
21.6	1	20.6	0	0.6875	0
21.9	1	20.6	0	0.6875	0
22.2	1	20.6	0	0.6875	0
22.5	1	20.6	0	0.6875	0
22.8	1	20.6	0	0.6875	0
23.1	1	20.6	0	0.6875	0
23.4	1	20.6	0	0.6875	0
23.7	1	20.6	0	0.6875	0
24	1	20.6	0	0.6875	0
24.3	1	20.6	0	0.6875	0
24.6	1	12.1709	12.0593	0.6875	0
24.9	1	12.2989	12.2313	0.6875	0
25.2	1	12.394	12.4362	0.6875	0
25.5	1	12.5008	12.6294	0.6875	0
25.8	1	12.6433	12.7869	0.6875	0
26.1	1	12.8121	12.9182	0.6875	0
26.4	1	13.0147	13.0155	0.6875	0
26.7	1	14.1979	12.1323	0.6875	0
27	1	14.3648	12.2654	0.6875	0
27.3	1	14.4793	12.4509	0.6875	0
27.6	1	14.5925	12.6377	0.6875	0
27.9	1	14.7044	12.8258	0.6875	0
28.2	1	14.8381	12.9921	0.6875	0
28.5	1	16.0413	12.0889	0.6875	0
28.8	1	16.2315	12.1987	0.6875	0
29.1	1	16.3959	12.3343	0.6875	0
29.4	1	16.5291	12.5011	0.6875	0

29.7	1	16.6365	12.6937	0.6875	0
30	1	16.7521	12.8781	0.6875	0
30.3	1	16.922	13.0082	0.6875	0
30.6	1	18.1521	12.0781	0.6875	0
30.9	1	18.2925	12.2377	0.6875	0
31.2	1	18.3896	12.4406	0.6875	0
31.5	1	18.4982	12.632	0.6875	0
31.8	1	18.6421	12.7881	0.6875	0
32.1	1	18.8117	12.9185	0.6875	0
32.4	1	19.0147	13.0155	0.6875	0
32.7	1	20.1287	12.2016	0.6875	0
33	1	20.236	12.3942	0.6875	0
33.3	1	20.3164	12.6138	0.6875	0
33.6	1	20.3863	12.8439	0.6875	0
33.9	1	20.4542	13.076	0.6875	0
34.2	1	20.5428	13.2875	0.6875	0
34.5	1	20.0344	14.0958	0.6875	0
34.8	1	20.1693	14.2609	0.6875	0
35.1	1	20.2682	14.462	0.6875	0
35.4	1	20.3398	14.6904	0.6875	0
35.7	1	20.4094	14.9208	0.6875	0
36	1	20.476	15.1542	0.6875	0
36.3	1	20.5928	15.3374	0.6875	0
36.6	1	20.0844	16.1458	0.6875	0
36.9	1	20.2031	16.3271	0.6875	0
37.2	1	20.293	16.5372	0.6875	0
37.5	1	20.3631	16.7671	0.6875	0
37.8	1	20.4324	16.9978	0.6875	0
38.1	1	20.5046	17.2256	0.6875	0
38.4	1	19.9592	18.071	0.6875	0
38.7	1	20.1287	18.2016	0.6875	0
39	1	20.236	18.3942	0.6875	0
39.3	1	20.3164	18.6138	0.6875	0
39.6	1	20.3863	18.8439	0.6875	0
39.9	1	20.4542	19.076	0.6875	0
40.2	1	20.5428	19.2875	0.6875	0
40.5	1	20.0344	20.0958	0.6875	0

40.8	1	20.1693	20.2609	0.6875	0
41.1	1	20.2682	20.462	0.6875	0
41.4	1	20.3398	20.6	0.6875	0
41.7	1	20.4094	20.6	0.6875	0
42	1	20.476	20.6	0.6875	0
42.3	1	20.5928	20.6	0.6875	0
42.6	1	0	0	0.6875	0
42.9	1	0	0	0.6875	0
43.2	1	0	0	0.6875	0
43.5	1	0	0	0.6875	0

Appendix F. Mill "A" Continuous Type Fuzzy Logic Controller Results for Input Stems with the Large End Diameter and 1 inch Lily Pad on the East.

Nominal Input Length (Feet)	Taper West/East (Pos/Neg)	Block 1 (Feet)	Block 2 (Feet)	West Lily Pad (Inches)	East Lily Pad (Inches)
21	-1	0	20.6	0	0.6875
21.3	-1	0	20.6	0	0.6875
21.6	-1	0	20.6	0	0.6875
21.9	-1	0	20.6	0	0.6875
22.2	-1	0	20.6	0	0.6875
22.5	-1	0	20.6	0	0.6875
22.8	-1	0	20.6	0	0.6875
23.1	-1	0	20.6	0	0.6875
23.4	-1	0	20.6	0	0.6875
23.7	-1	0	20.6	0	0.6875
24	-1	0	20.6	0	0.6875
24.3	-1	0	20.6	0	0.6875
24.6	-1	12.0593	12.1709	0	0.6875
24.9	-1	12.2313	12.2989	0	0.6875
25.2	-1	12.4362	12.394	0	0.6875
25.5	-1	12.6294	12.5008	0	0.6875
25.8	-1	12.7869	12.6433	0	0.6875
26.1	-1	12.9182	12.8121	0	0.6875
26.4	-1	13.0155	13.0147	0	0.6875
26.7	-1	12.1323	14.1979	0	0.6875
27	-1	12.2654	14.3648	0	0.6875
27.3	-1	12.4509	14.4793	0	0.6875
27.6	-1	12.6377	14.5925	0	0.6875
27.9	-1	12.8258	14.7044	0	0.6875
28.2	-1	12.9921	14.8381	0	0.6875
28.5	-1	12.0889	16.0413	0	0.6875
28.8	-1	12.1987	16.2315	0	0.6875
29.1	-1	12.3343	16.3959	0	0.6875
29.4	-1	12.5011	16.5291	0	0.6875

29.7	-1	12.6937	16.6365	0	0.6875
30	-1	12.8781	16.7521	0	0.6875
30.3	-1	13.0082	16.922	0	0.6875
30.6	-1	12.0781	18.1521	0	0.6875
30.9	-1	12.2377	18.2925	0	0.6875
31.2	-1	12.4406	18.3896	0	0.6875
31.5	-1	12.632	18.4982	0	0.6875
31.8	-1	12.7881	18.6421	0	0.6875
32.1	-1	12.9185	18.8117	0	0.6875
32.4	-1	13.0155	19.0147	0	0.6875
32.7	-1	12.2016	20.1287	0	0.6875
33	-1	12.3942	20.236	0	0.6875
33.3	-1	12.6138	20.3164	0	0.6875
33.6	-1	12.8439	20.3863	0	0.6875
33.9	-1	13.076	20.4542	0	0.6875
34.2	-1	13.2875	20.5428	0	0.6875
34.5	-1	14.0958	20.0344	0	0.6875
34.8	-1	14.2609	20.1693	0	0.6875
35.1	-1	14.462	20.2682	0	0.6875
35.4	-1	14.6904	20.3398	0	0.6875
35.7	-1	14.9208	20.4094	0	0.6875
36	-1	15.1542	20.476	0	0.6875
36.3	-1	15.3374	20.5928	0	0.6875
36.6	-1	16.1458	20.0844	0	0.6875
36.9	-1	16.3271	20.2031	0	0.6875
37.2	-1	16.5372	20.293	0	0.6875
37.5	-1	16.7671	20.3631	0	0.6875
37.8	-1	16.9978	20.4324	0	0.6875
38.1	-1	17.2256	20.5046	0	0.6875
38.4	-1	18.071	19.9592	0	0.6875
38.7	-1	18.2016	20.1287	0	0.6875
39	-1	18.3942	20.236	0	0.6875
39.3	-1	18.6138	20.3164	0	0.6875
39.6	-1	18.8439	20.3863	0	0.6875
39.9	-1	19.076	20.4542	0	0.6875
40.2	-1	19.2875	20.5428	0	0.6875
40.5	-1	20.0958	20.0344	0	0.6875

40.8	-1	20.2609	20.1693	0	0.6875
41.1	-1	20.462	20.2682	0	0.6875
41.4	-1	20.6	20.3398	0	0.6875
41.7	-1	20.6	20.4094	0	0.6875
42	-1	20.6	20.476	0	0.6875
42.3	-1	20.6	20.5928	0	0.6875
42.6	-1	0	0	0	0.6875
42.9	-1	0	0	0	0.6875
43.2	-1	0	0	0	0.6875
43.5	-1	0	0	0	0.6875

Appendix G. Mill "A" Discrete Type Fuzzy Logic Controller Results For Input Stems with the Large End Diameter and 1 inch Lily Pad on the West.

Nominal Input Length (Feet)	Taper West/East (Pos/Neg)	Block 1 (Feet)	Block 2 (Feet)	West Lily Pad (Inches)	East Lily Pad (Inches)
20.6	1	20.5063	0	0.6875	0
20.9	1	20.5063	0	0.6875	0
21.2	1	20.5063	0	0.6875	0
21.5	1	20.5063	0	0.6875	0
21.8	1	20.5063	0	0.6875	0
22.1	1	20.5063	0	0.6875	0
22.4	1	20.5063	0	0.6875	0
22.7	1	20.5063	0	0.6875	0
23	1	20.5063	0	0.6875	0
23.3	1	20.5063	0	0.6875	0
23.6	1	20.5063	0	0.6875	0
23.9	1	20.5063	0	0.6875	0
24.2	1	20.5063	0	0.6875	0
24.5	1	20.5063	0	0.6875	0
24.8	1	12.1	12.3302	0.6875	0
25.1	1	12.1	12.6302	0.6875	0
25.4	1	12.1	12.9302	0.6875	0
25.7	1	12.1	13.2302	0.6875	0
26	1	12.1	13.5302	0.6875	0
26.3	1	12.1	13.8302	0.6875	0
26.6	1	14.1028	12.1274	0.6875	0
26.9	1	14.1028	12.4274	0.6875	0
27.2	1	14.1028	12.7274	0.6875	0
27.5	1	14.1028	13.0274	0.6875	0
27.8	1	14.1028	13.3274	0.6875	0
28.1	1	14.1028	13.6274	0.6875	0
28.4	1	14.1028	13.9274	0.6875	0
28.7	1	16.1063	12.2239	0.6875	0
29	1	16.1063	12.5239	0.6875	0

29.3	1	16.1063	12.8239	0.6875	0
29.6	1	16.1063	13.1239	0.6875	0
29.9	1	16.1063	13.4239	0.6875	0
30.2	1	16.1063	13.7239	0.6875	0
30.5	1	16.1063	14.0239	0.6875	0
30.8	1	18.1107	12.3195	0.6875	0
31.1	1	18.1107	12.6195	0.6875	0
31.4	1	18.1107	12.9195	0.6875	0
31.7	1	18.1107	13.2195	0.6875	0
32	1	18.1107	13.5195	0.6875	0
32.3	1	18.1107	13.8195	0.6875	0
32.6	1	20.1064	12.1238	0.6875	0
32.9	1	20.1064	12.4238	0.6875	0
33.2	1	20.1064	12.7238	0.6875	0
33.5	1	20.1064	13.0238	0.6875	0
33.8	1	20.1064	13.3238	0.6875	0
34.1	1	20.1064	13.6238	0.6875	0
34.4	1	20.1064	13.9238	0.6875	0
34.7	1	20.1064	14.2238	0.6875	0
35	1	20.1064	14.5238	0.6875	0
35.3	1	20.1064	14.8238	0.6875	0
35.6	1	20.1064	15.1238	0.6875	0
35.9	1	20.1064	15.4238	0.6875	0
36.2	1	20.1064	15.7238	0.6875	0
36.5	1	20.1064	16.0238	0.6875	0
36.8	1	20.1064	16.3238	0.6875	0
37.1	1	20.1064	16.6238	0.6875	0
37.4	1	20.1064	16.9238	0.6875	0
37.7	1	20.1064	17.2238	0.6875	0
38	1	20.1064	17.5238	0.6875	0
38.3	1	20.1064	17.8238	0.6875	0
38.6	1	20.1064	18.1238	0.6875	0
38.9	1	20.1064	18.4238	0.6875	0
39.2	1	20.1064	18.7238	0.6875	0
39.5	1	20.1064	19.0238	0.6875	0
39.8	1	20.1064	19.3238	0.6875	0
40.1	1	20.1064	19.6238	0.6875	0

40.4	1	20.1064	19.9238	0.6875	0
40.7	1	20.1064	20.2238	0.6875	0
41	1	20.1064	20.5238	0.6875	0
41.3	1	20.5063	20.4239	0.6875	0
41.6	1	20.5063	20.6	0.6875	0
41.9	1	20.5063	20.6	0.6875	0
42.2	1	20.5063	20.6	0.6875	0
42.5	1	0	0	0.6875	0
42.8	1	0	0	0.6875	0
43.1	1	0	0	0.6875	0

Appendix H. Mill "A" Discrete Type Fuzzy Logic Controller Results For Input Stems with the Large End Diameter and 1 inch Lily Pad on the East.

Nominal Input Length (Feet)	Taper West/East (Pos/Neg)	Block 1 (Feet)	Block 2 (Feet)	West Lily Pad (Inches)	East Lily Pad (Inches)
20.6	-1	0	20.5063	0	0.6875
20.9	-1	0	20.5063	0	0.6875
21.2	-1	0	20.5063	0	0.6875
21.5	-1	0	20.5063	0	0.6875
21.8	-1	0	20.5063	0	0.6875
22.1	-1	0	20.5063	0	0.6875
22.4	-1	0	20.5063	0	0.6875
22.7	-1	0	20.5063	0	0.6875
23	-1	0	20.5063	0	0.6875
23.3	-1	0	20.5063	0	0.6875
23.6	-1	0	20.5063	0	0.6875
23.9	-1	0	20.5063	0	0.6875
24.2	-1	0	20.5063	0	0.6875
24.5	-1	0	20.5063	0	0.6875
24.8	-1	12.3302	12.1	0	0.6875
25.1	-1	12.6302	12.1	0	0.6875
25.4	-1	12.9302	12.1	0	0.6875
25.7	-1	13.2302	12.1	0	0.6875
26	-1	13.5302	12.1	0	0.6875
26.3	-1	13.8302	12.1	0	0.6875
26.6	-1	12.1274	14.1028	0	0.6875
26.9	-1	12.4274	14.1028	0	0.6875
27.2	-1	12.7274	14.1028	0	0.6875
27.5	-1	13.0274	14.1028	0	0.6875
27.8	-1	13.3274	14.1028	0	0.6875
28.1	-1	13.6274	14.1028	0	0.6875
28.4	-1	13.9274	14.1028	0	0.6875
28.7	-1	12.2239	16.1063	0	0.6875
29	-1	12.5239	16.1063	0	0.6875

29.3	-1	12.8239	16.1063	0	0.6875
29.6	-1	13.1239	16.1063	0	0.6875
29.9	-1	13.4239	16.1063	0	0.6875
30.2	-1	13.7239	16.1063	0	0.6875
30.5	-1	14.0239	16.1063	0	0.6875
30.8	-1	12.3195	18.1107	0	0.6875
31.1	-1	12.6195	18.1107	0	0.6875
31.4	-1	12.9195	18.1107	0	0.6875
31.7	-1	13.2195	18.1107	0	0.6875
32	-1	13.5195	18.1107	0	0.6875
32.3	-1	13.8195	18.1107	0	0.6875
32.6	-1	12.1238	20.1064	0	0.6875
32.9	-1	12.4238	20.1064	0	0.6875
33.2	-1	12.7238	20.1064	0	0.6875
33.5	-1	13.0238	20.1064	0	0.6875
33.8	-1	13.3238	20.1064	0	0.6875
34.1	-1	13.6238	20.1064	0	0.6875
34.4	-1	13.9238	20.1064	0	0.6875
34.7	-1	14.2238	20.1064	0	0.6875
35	-1	14.5238	20.1064	0	0.6875
35.3	-1	14.8238	20.1064	0	0.6875
35.6	-1	15.1238	20.1064	0	0.6875
35.9	-1	15.4238	20.1064	0	0.6875
36.2	-1	15.7238	20.1064	0	0.6875
36.5	-1	16.0238	20.1064	0	0.6875
36.8	-1	16.3238	20.1064	0	0.6875
37.1	-1	16.6238	20.1064	0	0.6875
37.4	-1	16.9238	20.1064	0	0.6875
37.7	-1	17.2238	20.1064	0	0.6875
38	-1	17.5238	20.1064	0	0.6875
38.3	-1	17.8238	20.1064	0	0.6875
38.6	-1	18.1238	20.1064	0	0.6875
38.9	-1	18.4238	20.1064	0	0.6875
39.2	-1	18.7238	20.1064	0	0.6875
39.5	-1	19.0238	20.1064	0	0.6875
39.8	-1	19.3238	20.1064	0	0.6875
40.1	-1	19.6238	20.1064	0	0.6875

40.4	-1	19.9238	20.1064	0	0.6875
40.7	-1	20.2238	20.1064	0	0.6875
41	-1	20.5238	20.1064	0	0.6875
41.3	-1	20.4239	20.5063	0	0.6875
41.6	-1	20.6	20.5063	0	0.6875
41.9	-1	20.6	20.5063	0	0.6875
42.2	-1	20.6	20.5063	0	0.6875
42.5	-1	0	0	0	0.6875
42.8	-1	0	0	0	0.6875
43.1	-1	0	0	0	0.6875

Appendix I. Mill "B" Fuzzy Logic Controller Results For Input Stems with the Large End Diameter and 1 inch Lily Pad on the West.

Nominal Input Length (Feet)	Taper West/ East (Pos/ Neg)	Block 1 (Feet)	Block 2 (Feet)	Block 3 (Feet)	Block 4 (Feet)	Block 5 (Feet)	West Lily Pad (Inches)	East Lily Pad (Inches)
17.8302	1	9.0771	8.076	0	0	0	0.6875	0
18.1302	1	9.0771	9.0771	0	0	0	0.6875	0
18.4302	1	9.0771	9.0771	0	0	0	0.6875	0
18.7302	1	9.0771	9.0771	0	0	0	0.6875	0
19.0302	1	10.08	9.0771	0	0	0	0.6875	0
19.3302	1	10.08	9.0771	0	0	0	0.6875	0
19.6302	1	10.08	9.0771	0	0	0	0.6875	0
19.9302	1	10.08	9.0771	0	0	0	0.6875	0
20.2302	1	10.08	10.08	0	0	0	0.6875	0
20.5302	1	10.08	10.08	0	0	0	0.6875	0
20.8302	1	10.08	10.08	0	0	0	0.6875	0
21.1302	1	10.08	10.08	0	0	0	0.6875	0
21.4302	1	10.08	10.08	0	0	0	0.6875	0
21.7302	1	10.08	10.08	0	0	0	0.6875	0
22.0302	1	10.08	10.08	0	0	0	0.6875	0
22.3302	1	10.08	10.08	0	0	0	0.6875	0
22.6302	1	10.08	10.08	0	0	0	0.6875	0
22.9302	1	10.08	10.08	0	0	0	0.6875	0
23.2302	1	10.08	10.08	0	0	0	0.6875	0
23.5302	1	10.08	10.08	0	0	0	0.6875	0
23.5177	1	10.08	10.08	0	0	0	0.6875	0
23.8177	1	10.08	10.08	0	0	0	0.6875	0
24.1177	1	8.076	8.076	8.076	0	0	0.6875	0
24.4177	1	8.076	8.076	8.076	0	0	0.6875	0
24.7177	1	8.076	8.076	8.076	0	0	0.6875	0
25.0177	1	9.0771	8.076	8.076	0	0	0.6875	0
25.3177	1	9.0771	8.076	8.076	0	0	0.6875	0
25.6177	1	9.0771	8.076	8.076	0	0	0.6875	0

25.9177	1	9.0771	8.076	8.076	0	0	0.6875	0
26.2177	1	9.0771	9.0771	8.076	0	0	0.6875	0
26.5177	1	9.0771	9.0771	8.076	0	0	0.6875	0
26.8177	1	9.0771	9.0771	8.076	0	0	0.6875	0
27.1177	1	9.0771	9.0771	9.0771	0	0	0.6875	0
27.4177	1	9.0771	9.0771	9.0771	0	0	0.6875	0
27.7177	1	9.0771	9.0771	9.0771	0	0	0.6875	0
28.0177	1	10.08	10.08	8.076	0	0	0.6875	0
28.3177	1	10.08	10.08	8.076	0	0	0.6875	0
28.6177	1	10.08	10.08	8.076	0	0	0.6875	0
28.9177	1	10.08	10.08	8.076	0	0	0.6875	0
29.2177	1	10.08	10.08	9.0771	0	0	0.6875	0
29.5177	1	10.08	10.08	9.0771	0	0	0.6875	0
29.8177	1	10.08	10.08	9.0771	0	0	0.6875	0
30.1177	1	10.08	10.08	10.08	0	0	0.6875	0
30.4177	1	10.08	10.08	10.08	0	0	0.6875	0
30.7177	1	10.08	10.08	10.08	0	0	0.6875	0
31.0177	1	10.08	10.08	10.08	0	0	0.6875	0
31.3177	1	10.08	10.08	10.08	0	0	0.6875	0
31.3052	1	10.08	10.08	10.08	0	0	0.6875	0
31.6052	1	10.08	10.08	10.08	0	0	0.6875	0
31.9052	1	10.08	10.08	10.08	0	0	0.6875	0
32.2052	1	8.076	8.076	8.076	8.076	0	0.6875	0
32.5052	1	8.076	8.076	8.076	8.076	0	0.6875	0
32.8052	1	8.076	8.076	8.076	8.076	0	0.6875	0
33.1052	1	9.0771	8.076	8.076	8.076	0	0.6875	0
33.4052	1	9.0771	8.076	8.076	8.076	0	0.6875	0
33.7052	1	9.0771	8.076	8.076	8.076	0	0.6875	0
34.0052	1	9.0771	9.0771	8.076	8.076	0	0.6875	0
34.3052	1	9.0771	9.0771	8.076	8.076	0	0.6875	0
34.6052	1	9.0771	9.0771	8.076	8.076	0	0.6875	0
34.9052	1	9.0771	9.0771	8.076	8.076	0	0.6875	0
35.2052	1	9.0771	9.0771	9.0771	8.076	0	0.6875	0
35.5052	1	9.0771	9.0771	9.0771	8.076	0	0.6875	0
35.8052	1	9.0771	9.0771	9.0771	8.076	0	0.6875	0
36.1052	1	9.0771	9.0771	9.0771	9.0771	0	0.6875	0
36.4052	1	9.0771	9.0771	9.0771	9.0771	0	0.6875	0

36.7052	1	9.0771	9.0771	9.0771	9.0771	0	0.6875	0
37.0052	1	10.08	9.0771	9.0771	9.0771	0	0.6875	0
37.3052	1	10.08	9.0771	9.0771	9.0771	0	0.6875	0
37.6052	1	10.08	9.0771	9.0771	9.0771	0	0.6875	0
37.9052	1	10.08	9.0771	9.0771	9.0771	0	0.6875	0
38.2052	1	10.08	10.08	9.0771	9.0771	0	0.6875	0
38.5052	1	10.08	10.08	9.0771	9.0771	0	0.6875	0
38.8052	1	10.08	10.08	9.0771	9.0771	0	0.6875	0
39.1052	1	10.08	10.08	10.08	9.0771	0	0.6875	0
39.4052	1	10.08	10.08	10.08	9.0771	0	0.6875	0
39.7052	1	10.08	10.08	10.08	9.0771	0	0.6875	0
40.0052	1	10.08	10.08	10.08	10.08	0	0.6875	0
39.9927	1	10.08	10.08	10.08	9.0771	0	0.6875	0
40.2927	1	10.08	10.08	10.08	10.08	0	0.6875	0
40.5927	1	10.08	10.08	10.08	10.08	0	0.6875	0
40.8927	1	10.08	10.08	10.08	10.08	0	0.6875	0
41.1927	1	10.08	10.08	10.08	10.08	0	0.6875	0
41.4927	1	10.08	10.08	10.08	10.08	0	0.6875	0
41.7927	1	8.076	8.076	8.076	8.076	8.076	0.6875	0
42.0927	1	8.076	8.076	8.076	8.076	8.076	0.6875	0
42.3927	1	8.076	8.076	8.076	8.076	8.076	0.6875	0
42.6927	1	9.0771	9.0771	8.076	8.076	8.076	0.6875	0
42.9927	1	9.0771	9.0771	8.076	8.076	8.076	0.6875	0
43.2927	1	0	0	0	0	0	0.6875	0
43.5927	1	0	0	0	0	0	0.6875	0

Appendix J. Mill "B" Fuzzy Logic Controller Results For Input Stems with the Large End Diameter and 1 inch Lily Pad on the East.

Nominal Input Length (Feet)	Taper West/ East (Pos/Neg)	Block 1 (Feet)	Block 2 (Feet)	Block 3 (Feet)	Block 4 (Feet)	Block 5 (Feet)	West Lily Pad (Inches)	East Lily Pad (Inches)
17.8302	-1	8.076	9.0771	0	0	0	0	0.6875
18.1302	-1	9.0771	9.0771	0	0	0	0	0.6875
18.4302	-1	9.0771	9.0771	0	0	0	0	0.6875
18.7302	-1	9.0771	9.0771	0	0	0	0	0.6875
19.0302	-1	9.0771	10.08	0	0	0	0	0.6875
19.3302	-1	9.0771	10.08	0	0	0	0	0.6875
19.6302	-1	9.0771	10.08	0	0	0	0	0.6875
19.9302	-1	9.0771	10.08	0	0	0	0	0.6875
20.2302	-1	10.08	10.08	0	0	0	0	0.6875
20.5302	-1	10.08	10.08	0	0	0	0	0.6875
20.8302	-1	10.08	10.08	0	0	0	0	0.6875
21.1302	-1	10.08	10.08	0	0	0	0	0.6875
21.4302	-1	10.08	10.08	0	0	0	0	0.6875
21.7302	-1	10.08	10.08	0	0	0	0	0.6875
22.0302	-1	10.08	10.08	0	0	0	0	0.6875
22.3302	-1	10.08	10.08	0	0	0	0	0.6875
22.6302	-1	10.08	10.08	0	0	0	0	0.6875
22.9302	-1	10.08	10.08	0	0	0	0	0.6875
23.2302	-1	10.08	10.08	0	0	0	0	0.6875
23.5302	-1	10.08	10.08	0	0	0	0	0.6875
23.5177	-1	10.08	10.08	0	0	0	0	0.6875
23.8177	-1	10.08	10.08	0	0	0	0	0.6875
24.1177	-1	8.076	8.076	8.076	0	0	0	0.6875
24.4177	-1	8.076	8.076	8.076	0	0	0	0.6875
24.7177	-1	8.076	8.076	8.076	0	0	0	0.6875
25.0177	-1	8.076	8.076	9.0771	0	0	0	0.6875
25.3177	-1	8.076	8.076	9.0771	0	0	0	0.6875
25.6177	-1	8.076	8.076	9.0771	0	0	0	0.6875
25.9177	-1	8.076	8.076	9.0771	0	0	0	0.6875

26.2177	-1	8.076	9.0771	9.0771	0	0	0	0.6875
26.5177	-1	8.076	9.0771	9.0771	0	0	0	0.6875
26.8177	-1	8.076	9.0771	9.0771	0	0	0	0.6875
27.1177	-1	9.0771	9.0771	9.0771	0	0	0	0.6875
27.4177	-1	9.0771	9.0771	9.0771	0	0	0	0.6875
27.7177	-1	9.0771	9.0771	9.0771	0	0	0	0.6875
28.0177	-1	8.076	10.08	10.08	0	0	0	0.6875
28.3177	-1	8.076	10.08	10.08	0	0	0	0.6875
28.6177	-1	8.076	10.08	10.08	0	0	0	0.6875
28.9177	-1	8.076	10.08	10.08	0	0	0	0.6875
29.2177	-1	9.0771	10.08	10.08	0	0	0	0.6875
29.5177	-1	9.0771	10.08	10.08	0	0	0	0.6875
29.8177	-1	9.0771	10.08	10.08	0	0	0	0.6875
30.1177	-1	10.08	10.08	10.08	0	0	0	0.6875
30.4177	-1	10.08	10.08	10.08	0	0	0	0.6875
30.7177	-1	10.08	10.08	10.08	0	0	0	0.6875
31.0177	-1	8.076	10.08	10.08	10.08	0	0	0.6875
31.3177	-1	8.076	10.08	10.08	10.08	0	0	0.6875
31.3052	-1	8.076	10.08	10.08	10.08	0	0	0.6875
31.6052	-1	8.076	10.08	10.08	10.08	0	0	0.6875
31.9052	-1	8.076	10.08	10.08	10.08	0	0	0.6875
32.2052	-1	8.076	8.076	8.076	8.076	0	0	0.6875
32.5052	-1	8.076	8.076	8.076	8.076	0	0	0.6875
32.8052	-1	8.076	8.076	8.076	8.076	0	0	0.6875
33.1052	-1	8.076	8.076	8.076	9.0771	0	0	0.6875
33.4052	-1	8.076	8.076	8.076	9.0771	0	0	0.6875
33.7052	-1	8.076	8.076	8.076	9.0771	0	0	0.6875
34.0052	-1	8.076	8.076	9.0771	9.0771	0	0	0.6875
34.3052	-1	8.076	8.076	9.0771	9.0771	0	0	0.6875
34.6052	-1	8.076	8.076	9.0771	9.0771	0	0	0.6875
34.9052	-1	8.076	8.076	9.0771	9.0771	0	0	0.6875
35.2052	-1	8.076	9.0771	9.0771	9.0771	0	0	0.6875
35.5052	-1	8.076	9.0771	9.0771	9.0771	0	0	0.6875
35.8052	-1	8.076	9.0771	9.0771	9.0771	0	0	0.6875
36.1052	-1	9.0771	9.0771	9.0771	9.0771	0	0	0.6875
36.4052	-1	9.0771	9.0771	9.0771	9.0771	0	0	0.6875
36.7052	-1	9.0771	9.0771	9.0771	9.0771	0	0	0.6875

37.0052	-1	9.0771	9.0771	9.0771	10.08	0	0	0.6875
37.3052	-1	9.0771	9.0771	9.0771	10.08	0	0	0.6875
37.6052	-1	9.0771	9.0771	9.0771	10.08	0	0	0.6875
37.9052	-1	9.0771	9.0771	9.0771	10.08	0	0	0.6875
38.2052	-1	9.0771	9.0771	10.08	10.08	0	0	0.6875
38.5052	-1	9.0771	9.0771	10.08	10.08	0	0	0.6875
38.8052	-1	9.0771	9.0771	10.08	10.08	0	0	0.6875
39.1052	-1	9.0771	10.08	10.08	10.08	0	0	0.6875
39.4052	-1	9.0771	10.08	10.08	10.08	0	0	0.6875
39.7052	-1	9.0771	10.08	10.08	10.08	0	0	0.6875
40.0052	-1	10.08	10.08	10.08	10.08	0	0	0.6875
39.9927	-1	9.0771	10.08	10.08	10.08	0	0	0.6875
40.2927	-1	10.08	10.08	10.08	10.08	0	0	0.6875
40.5927	-1	10.08	10.08	10.08	10.08	0	0	0.6875
40.8927	-1	10.08	10.08	10.08	10.08	0	0	0.6875
41.1927	-1	10.08	10.08	10.08	10.08	0	0	0.6875
41.4927	-1	10.08	10.08	10.08	10.08	0	0	0.6875
41.7927	-1	8.076	8.076	8.076	8.076	8.076	0	0.6875
42.0927	-1	8.076	8.076	8.076	8.076	8.076	0	0.6875
42.3927	-1	8.076	8.076	8.076	8.076	8.076	0	0.6875
42.6927	-1	8.076	8.076	8.076	9.0771	9.0771	0	0.6875
42.9927	-1	8.076	8.076	8.076	9.0771	9.0771	0	0.6875
43.2927	-1	0	0	0	0	0	0	0.6875
43.5927	-1	0	0	0	0	0	0	0.6875

Appendix K. Veneer Fuzzy Logic Controller Results For Input Stems with the Large End Diameter and 1 inch Lily Pad on the West.

Nominal Input Length (Feet)	Taper West/ East (Pos/Neg)	Block 1 (Feet)	Block 2 (Feet)	Block 3 (Feet)	Block 4 (Feet)	Block 5 (Feet)	West Lily Pad (Inches)	East Lily Pad (Inches)
17.8302	1	8.4969	8.4969	0	0	0	0.6875	0
18.1302	1	9.5031	8.4969	0	0	0	0.6875	0
18.4302	1	9.5031	8.4969	0	0	0	0.6875	0
18.7302	1	9.5031	8.4969	0	0	0	0.6875	0
19.0302	1	9.5031	9.5031	0	0	0	0.6875	0
19.3302	1	9.5031	9.5031	0	0	0	0.6875	0
19.6302	1	9.5031	9.5031	0	0	0	0.6875	0
19.9302	1	9.5031	9.5031	0	0	0	0.6875	0
20.2302	1	10.5	9.5031	0	0	0	0.6875	0
20.5302	1	10.5	9.5031	0	0	0	0.6875	0
20.8302	1	10.5	9.5031	0	0	0	0.6875	0
21.1302	1	10.5	10.5	0	0	0	0.6875	0
21.4302	1	10.5	10.5	0	0	0	0.6875	0
21.7302	1	10.5	10.5	0	0	0	0.6875	0
22.0302	1	0	0	0	0	0	0.6875	0
22.3302	1	0	0	0	0	0	0.6875	0
22.6302	1	0	0	0	0	0	0.6875	0
22.9302	1	0	0	0	0	0	0.6875	0
23.2302	1	0	0	0	0	0	0.6875	0
23.5302	1	0	0	0	0	0	0.6875	0
23.8302	1	0	0	0	0	0	0.6875	0
24.1302	1	0	0	0	0	0	0.6875	0
24.4302	1	0	0	0	0	0	0.6875	0
24.7302	1	0	0	0	0	0	0.6875	0
25.0302	1	0	0	0	0	0	0.6875	0
25.0177	1	0	0	0	0	0	0.6875	0
25.3177	1	0	0	0	0	0	0.6875	0
25.6177	1	8.4969	8.4969	8.4969	0	0	0.6875	0

25.9177	1	8.4969	8.4969	8.4969	0	0	0.6875	0
26.2177	1	8.4969	8.4969	8.4969	0	0	0.6875	0
26.5177	1	9.5031	8.4969	8.4969	0	0	0.6875	0
26.8177	1	9.5031	8.4969	8.4969	0	0	0.6875	0
27.1177	1	9.5031	8.4969	8.4969	0	0	0.6875	0
27.4177	1	9.5031	8.4969	8.4969	0	0	0.6875	0
27.7177	1	9.5031	9.5031	8.4969	0	0	0.6875	0
28.0177	1	9.5031	9.5031	8.4969	0	0	0.6875	0
28.3177	1	9.5031	9.5031	8.4969	0	0	0.6875	0
28.6177	1	10.5	9.5031	8.4969	0	0	0.6875	0
28.9177	1	10.5	9.5031	8.4969	0	0	0.6875	0
29.2177	1	10.5	9.5031	8.4969	0	0	0.6875	0
29.5177	1	10.5	9.5031	9.5031	0	0	0.6875	0
29.8177	1	10.5	9.5031	9.5031	0	0	0.6875	0
30.1177	1	10.5	9.5031	9.5031	0	0	0.6875	0
30.4177	1	10.5	9.5031	9.5031	0	0	0.6875	0
30.7177	1	10.5	10.5	9.5031	0	0	0.6875	0
31.0177	1	10.5	10.5	9.5031	0	0	0.6875	0
31.3177	1	10.5	10.5	9.5031	0	0	0.6875	0
31.6177	1	10.5	10.5	10.5	0	0	0.6875	0
31.9177	1	10.5	10.5	10.5	0	0	0.6875	0
32.2177	1	10.5	10.5	10.5	0	0	0.6875	0
32.5177	1	0	0	0	0	0	0.6875	0
32.8177	1	0	0	0	0	0	0.6875	0
33.1177	1	0	0	0	0	0	0.6875	0
33.1052	1	0	0	0	0	0	0.6875	0
33.4052	1	0	0	0	0	0	0.6875	0
33.7052	1	0	0	0	0	0	0.6875	0
34.0052	1	8.4969	8.4969	8.4969	8.4969	0	0.6875	0
34.3052	1	8.4969	8.4969	8.4969	8.4969	0	0.6875	0
34.6052	1	8.4969	8.4969	8.4969	8.4969	0	0.6875	0
34.9052	1	8.4969	8.4969	8.4969	8.4969	0	0.6875	0
35.2052	1	9.5031	8.4969	8.4969	8.4969	0	0.6875	0
35.5052	1	9.5031	8.4969	8.4969	8.4969	0	0.6875	0
35.8052	1	9.5031	8.4969	8.4969	8.4969	0	0.6875	0
36.1052	1	9.5031	9.5031	8.4969	8.4969	0	0.6875	0
36.4052	1	9.5031	9.5031	8.4969	8.4969	0	0.6875	0

36.7052	1	9.5031	9.5031	8.4969	8.4969	0	0.6875	0
37.0052	1	10.5	9.5031	8.4969	8.4969	0	0.6875	0
37.3052	1	10.5	9.5031	8.4969	8.4969	0	0.6875	0
37.6052	1	10.5	9.5031	8.4969	8.4969	0	0.6875	0
37.9052	1	10.5	9.5031	8.4969	8.4969	0	0.6875	0
38.2052	1	10.5	10.5	8.4969	8.4969	0	0.6875	0
38.5052	1	10.5	10.5	8.4969	8.4969	0	0.6875	0
38.8052	1	10.5	10.5	8.4969	8.4969	0	0.6875	0
39.1052	1	10.5	10.5	9.5031	8.4969	0	0.6875	0
39.4052	1	10.5	10.5	9.5031	8.4969	0	0.6875	0
39.7052	1	10.5	10.5	9.5031	8.4969	0	0.6875	0
40.0052	1	10.5	10.5	10.5	8.4969	0	0.6875	0
40.3052	1	10.5	10.5	10.5	8.4969	0	0.6875	0
40.6052	1	10.5	10.5	10.5	8.4969	0	0.6875	0
40.9052	1	10.5	10.5	10.5	8.4969	0	0.6875	0
41.2052	1	10.5	10.5	10.5	9.5031	0	0.6875	0
41.5052	1	10.5	10.5	10.5	9.5031	0	0.6875	0
41.8052	1	10.5	10.5	10.5	9.5031	0	0.6875	0
41.7927	1	10.5	10.5	10.5	9.5031	0	0.6875	0
42.0927	1	10.5	10.5	10.5	10.5	0	0.6875	0
42.3927	1	10.5	10.5	10.5	10.5	0	0.6875	0
42.6927	1	10.5	10.5	10.5	10.5	0	0.6875	0
42.9927	1	10.5	10.5	10.5	10.5	0	0.6875	0
43.2927	1	8.4969	8.4969	8.4969	8.4969	8.4969	0.6875	0
43.5927	1	9.5031	8.4969	8.4969	8.4969	8.4969	0.6875	0

Appendix L. Veneer Fuzzy Logic Controller Results For Input Stems with the Large End Diameter and 1 inch Lily Pad on the East.

Nominal Input Length (Feet)	Taper West/ East (Pos/Neg)	Block 1 (Feet)	Block 2 (Feet)	Block 3 (Feet)	Block 4 (Feet)	Block 5 (Feet)	West Lily Pad (Inches)	East Lily Pad (Inches)
17.8302	-1	8.4969	8.4969	0	0	0	0	0.6875
18.1302	-1	8.4969	9.5031	0	0	0	0	0.6875
18.4302	-1	8.4969	9.5031	0	0	0	0	0.6875
18.7302	-1	8.4969	9.5031	0	0	0	0	0.6875
19.0302	-1	9.5031	9.5031	0	0	0	0	0.6875
19.3302	-1	9.5031	9.5031	0	0	0	0	0.6875
19.6302	-1	9.5031	9.5031	0	0	0	0	0.6875
19.9302	-1	9.5031	9.5031	0	0	0	0	0.6875
20.2302	-1	9.5031	10.5	0	0	0	0	0.6875
20.5302	-1	9.5031	10.5	0	0	0	0	0.6875
20.8302	-1	9.5031	10.5	0	0	0	0	0.6875
21.1302	-1	10.5	10.5	0	0	0	0	0.6875
21.4302	-1	10.5	10.5	0	0	0	0	0.6875
21.7302	-1	10.5	10.5	0	0	0	0	0.6875
22.0302	-1	0	0	0	0	0	0	0.6875
22.3302	-1	0	0	0	0	0	0	0.6875
22.6302	-1	0	0	0	0	0	0	0.6875
22.9302	-1	0	0	0	0	0	0	0.6875
23.2302	-1	0	0	0	0	0	0	0.6875
23.5302	-1	0	0	0	0	0	0	0.6875
23.8302	-1	0	0	0	0	0	0	0.6875
24.1302	-1	0	0	0	0	0	0	0.6875
24.4302	-1	0	0	0	0	0	0	0.6875
24.7302	-1	0	0	0	0	0	0	0.6875
25.0302	-1	0	0	0	0	0	0	0.6875
25.0177	-1	0	0	0	0	0	0	0.6875
25.3177	-1	0	0	0	0	0	0	0.6875
25.6177	-1	8.4969	8.4969	8.4969	0	0	0	0.6875

25.9177	-1	8.4969	8.4969	8.4969	0	0	0	0.6875
26.2177	-1	8.4969	8.4969	8.4969	0	0	0	0.6875
26.5177	-1	8.4969	8.4969	9.5031	0	0	0	0.6875
26.8177	-1	8.4969	8.4969	9.5031	0	0	0	0.6875
27.1177	-1	8.4969	8.4969	9.5031	0	0	0	0.6875
27.4177	-1	8.4969	8.4969	9.5031	0	0	0	0.6875
27.7177	-1	8.4969	9.5031	9.5031	0	0	0	0.6875
28.0177	-1	8.4969	9.5031	9.5031	0	0	0	0.6875
28.3177	-1	8.4969	9.5031	9.5031	0	0	0	0.6875
28.6177	-1	8.4969	9.5031	10.5	0	0	0	0.6875
28.9177	-1	8.4969	9.5031	10.5	0	0	0	0.6875
29.2177	-1	8.4969	9.5031	10.5	0	0	0	0.6875
29.5177	-1	9.5031	9.5031	10.5	0	0	0	0.6875
29.8177	-1	9.5031	9.5031	10.5	0	0	0	0.6875
30.1177	-1	9.5031	9.5031	10.5	0	0	0	0.6875
30.4177	-1	9.5031	9.5031	10.5	0	0	0	0.6875
30.7177	-1	9.5031	10.5	10.5	0	0	0	0.6875
31.0177	-1	9.5031	10.5	10.5	0	0	0	0.6875
31.3177	-1	9.5031	10.5	10.5	0	0	0	0.6875
31.6177	-1	10.5	10.5	10.5	0	0	0	0.6875
31.9177	-1	10.5	10.5	10.5	0	0	0	0.6875
32.2177	-1	10.5	10.5	10.5	0	0	0	0.6875
32.5177	-1	0	0	0	0	0	0	0.6875
32.8177	-1	0	0	0	0	0	0	0.6875
33.1177	-1	0	0	0	0	0	0	0.6875
33.1052	-1	0	0	0	0	0	0	0.6875
33.4052	-1	0	0	0	0	0	0	0.6875
33.7052	-1	0	0	0	0	0	0	0.6875
34.0052	-1	8.4969	8.4969	8.4969	8.4969	0	0	0.6875
34.3052	-1	8.4969	8.4969	8.4969	8.4969	0	0	0.6875
34.6052	-1	8.4969	8.4969	8.4969	8.4969	0	0	0.6875
34.9052	-1	8.4969	8.4969	8.4969	8.4969	0	0	0.6875
35.2052	-1	8.4969	8.4969	8.4969	9.5031	0	0	0.6875
35.5052	-1	8.4969	8.4969	8.4969	9.5031	0	0	0.6875
35.8052	-1	8.4969	8.4969	8.4969	9.5031	0	0	0.6875
36.1052	-1	8.4969	8.4969	9.5031	9.5031	0	0	0.6875
36.4052	-1	8.4969	8.4969	9.5031	9.5031	0	0	0.6875

36.7052	-1	8.4969	8.4969	9.5031	9.5031	0	0	0.6875
37.0052	-1	8.4969	8.4969	9.5031	10.5	0	0	0.6875
37.3052	-1	8.4969	8.4969	9.5031	10.5	0	0	0.6875
37.6052	-1	8.4969	8.4969	9.5031	10.5	0	0	0.6875
37.9052	-1	8.4969	8.4969	9.5031	10.5	0	0	0.6875
38.2052	-1	8.4969	8.4969	10.5	10.5	0	0	0.6875
38.5052	-1	8.4969	8.4969	10.5	10.5	0	0	0.6875
38.8052	-1	8.4969	8.4969	10.5	10.5	0	0	0.6875
39.1052	-1	8.4969	9.5031	10.5	10.5	0	0	0.6875
39.4052	-1	8.4969	9.5031	10.5	10.5	0	0	0.6875
39.7052	-1	8.4969	9.5031	10.5	10.5	0	0	0.6875
40.0052	-1	8.4969	10.5	10.5	10.5	0	0	0.6875
40.3052	-1	8.4969	10.5	10.5	10.5	0	0	0.6875
40.6052	-1	8.4969	10.5	10.5	10.5	0	0	0.6875
40.9052	-1	8.4969	10.5	10.5	10.5	0	0	0.6875
41.2052	-1	9.5031	10.5	10.5	10.5	0	0	0.6875
41.5052	-1	9.5031	10.5	10.5	10.5	0	0	0.6875
41.8052	-1	9.5031	10.5	10.5	10.5	0	0	0.6875
41.7927	-1	9.5031	10.5	10.5	10.5	0	0	0.6875
42.0927	-1	10.5	10.5	10.5	10.5	0	0	0.6875
42.3927	-1	10.5	10.5	10.5	10.5	0	0	0.6875
42.6927	-1	10.5	10.5	10.5	10.5	0	0	0.6875
42.9927	-1	10.5	10.5	10.5	10.5	0	0	0.6875
43.2927	-1	8.4969	8.4969	8.4969	8.4969	8.4969	0	0.6875
43.5927	-1	8.4969	8.4969	8.4969	8.4969	9.5031	0	0.6875