CHAPTER 2: LITERATURE REVIEW

2.1. INTRODUCTION

Many organizations have published literature that details the successes and methods of their P2 programs. To analyze the benefits of the P3 program, a review of this existing P2 information and applicable analysis techniques is necessary. This chapter presents a review of literature discussing the P3 program's history and logistics; summarizes research performed by other P2 programs, and outlines methods used to determine time savings and reduced future liabilities from P2 suggestions.

2.2. UNL P3 PROGRAM

Nebraska is primarily an agricultural state with low population density. Consequently, there are few governmental resources available to provide professional P2 technical assistance to most communities in the state. The state's solution was to support the Partners in Pollution Prevention program at the University of Nebraska-Lincoln (Dvorak et al., 2003). The benefits of this approach are that engineering student interns can be taught P2 concepts. Also, knowledge can be diffused to companies throughout the state at a lower cost than employing a staff of professionals. To achieve a statewide presence, the P3 program is funded and supported (through training and resources) by many organizations throughout Nebraska. In addition to the UNL Civil Engineering department, the various partners (e.g., Nebraska Materials Exchange, USEPA Region VII) who participate in the program and roles in the internship are listed in Table 2.1.

Table 2.1. Project Partners in P3 Program (Dvorak et al., 2003a).

Partner	Form of Partnership[a]
Nebraska Department of Environmental Quality	T,R,A
University of Northern Iowa Waste Reduction Center	T,R
US EPA Region VII	T,R
UNL Cooperative Extension	T,R,A
UNL Environmental Health and Safety	T
Nebraska Safety Council	T,A
Nebraska Material Exchange	T,R
Lincoln Lancaster County Health Department	T,A
Nebraska Industrial Competitiveness Service (NICS)/ Nebraska Business Development Center (NBDC) & Pollution & Prevention Regional Information Center (P2RIC)	T,R,A
Nebraska Energy Office	T,R
Waste Cap	T,A
Brulin Corporation	T,A
Numerous Vendors	R

[a]Form of Partnership: T = Provides training session(s) for interns,
R = Serves as resource to answer interns' questions during technical assistance,
A = Partially supervises an intern in providing technical assistance during the summer

The P3 program has four goals. First, the program provides an intensive educational experience (and academic credit) for engineering interns. Second, the program provides technical assistance to small business and industry clients throughout Nebraska. The program's third goal is to provide education on general P2 concepts to civic groups in Nebraska. Finally, the program performs research pertaining to complex P2 problems (Dvorak et al., 2003).

2.2.1. P3 Intern Training

Interns participate in an intensive two-week training program before working on their specific projects. The training helps reduce the amount of day-to-day supervision required for each intern. It also helps increase the uniformity and quality of the final technical assistance reports (Dvorak et al., 2003).

Typically, the training involves five hours per day of structured activities. The remainder of the day is spent completing homework and client-specific research. Interns are expected to spend an average a total of ten hours a day performing P2 work during the two-week training session (Dvorak et al., 2003).

The course curriculum is designed to give interns a broad understanding of P2 concepts and applications. Verbal and written communication skills are emphasized during the training, being that they are crucial for successful summer assistance projects. In addition, interns are trained in applied research skills. They are exposed to a variety of P2 service providers who may be of assistance during the summer assistance. During the assistance mode groups (Table 2.2) interns are provided with specific resources to help overcome unique challenges that may arise during the summer assistance. Finally, coursework encourages interns to work in teams to provide each other with technical and moral support during the summer. Table 2.2. lists topics typically covered during the training (Dvorak et al., 2003). The table presents the amount of time spent on each activity and the partner responsible for the training.

2.2.2. Intern Placement with Clients

After the two-week training session is complete, interns work on assigned technical assistance projects for approximately nine weeks. The program assists clients of various sizes and existing understanding of P2. To meet clients' varied needs, the program offers three modes of assistance: small business, industrial assistance and industrial placement (Dvorak et al., 2003).

Each summer six to nine interns are assigned to the small business assistance mode. Each small business intern provides assistance to four to eight smaller (less than 200 employees) companies in the state. Small business students work from a community's Cooperative Extension office. Daily supervision is provided by extension staff and UNL faculty supervision is available via telephone.

Table 2.2. Topics Typically Covered in Two-Week Intern Training Course (Dvorak et al., 2003).

Day	Hours of Instruction	Topic	Instructor
1	4	Welcome & Overview of Project	Faculty & Staff
1	1	Sustainability & Benefits of P2	UNL Faculty
2	2	Legislative & Historical Development of P2/Overview of Regulation	UNL Faculty
2	2	Focus Group Training	UNL Faculty
2	1	How to Obtain Answers to Regulatory Questions	NDEQ
2	1	Group Building Exercises	NDEQ
2	1	Review of Past Summer's Reports	UNL Faculty
3	4	Waste Assessment Approaches	UNL Faculty
3	1	Technical Assistance Report Format	UNL Faculty
3	2	P2 Service Providers	Partners
4	6	Practice P2 Assessment Project	Faculty & Staff
4	2	P2 Approaches & Methods	UNL Faculty
5	2	Health & Safety Training	Health & Safety Staff
5	2	General Economics of Pollution Prevention	UNL Faculty
5	1	Energy Efficiency	Partners
6	1	Total Cost Assessment/Life Cycle Assessment	UNL Faculty
6	7	Practice P2 Assessment Project	Faculty & Staff
7	2	Applied Research Skills UNL Staff	UNL Staff
7	2	Library & Internet Research Skills Partners	P2 Librarian
8	3	Assistance Mode Groups	Faculty & Staff
8	2	Overview of P2, E2, Philosophy	EPA
8	1	Nebraska Material Exchange Partners	Partners
8	2	Environmental Management Systems	Partners
9	4	Assistance Mode Groups	Faculty & Staff
9	1	Interacting with & Finding Vendor Information	Partners
10	N/A	Out-of-Town Field Trip	N/A

Each small business project typically involves one or two weeks to research suggestions and complete a report. Clients participating in the small business assistance mode are not required to pay for the technical assistance (Dvorak et al., 2003).

The industrial assistance mode employs three to five interns each summer who are assigned to offer assistance to industries in the state. These interns are based out of UNL engineering college offices. Interns participating in this mode are supervised by UNL faculty and P2 graduate students. Industrial assessment interns typically work with one or two clients each summer. Interns in this mode perform in-depth research on their clients' manufacturing processes. As a result, the industrial assessment mode requires more applied research than the small business assistance modes. Clients participating in an industrial assistance assessment are not required to pay for the technical assistance (Dvorak et al., 2003).

Industrial placement mode interns provide technical assistance to only one client and work on-site in their client's office. Supervision is given by the client's staff, while UNL faculty provides guidance over the telephone. Industrial placement tends to be the most thorough of the three modes due to the intern's increased exposure and resulting familiarity with the client's operations. In exchange for receiving the dedicated assistance from an intern, clients participating in the industrial placement mode are required to pay approximately $2,000 of the intern's stipend (Dvorak et al., 2003; Partners in Pollution Prevention, 2003).

2.3. SURVEY DEFINITIONS AND CONCEPTS

Questionnaires are widely used for large-scale assessments of a P2 program's impact (Goldberg et al., 1998; Martin, 1999; Spektor and Roy, 2003). Although this assessment approach is relatively simple to conduct, one must be careful to design a questionnaire to avoid bias and to collect a sufficient number of responses to have valid results.

Questionnaires are an excellent survey approach when the research sample is widely distributed geographically, the research budget is modest, the respondents need some time to think about their answers, questions are written in a closed-ended style, the respondents need some privacy while responding and there is limited person-power to conduct the survey (Mangione, 1995).

There are many definitions used in the literature to describe surveys. Terms that are relevant to the P3 survey are defined below. Questionnaires that consist of yes/no responses and have no room for the respondent to write their opinions are considered closed-ended surveys. When the survey offers a selection of responses ranging from a strongly negative to zero to strongly positive response, it is considered bi-modal. A Likert scaled survey is a subset of bi-modal scaled survey that measures respondent attitudes towards an issue.

Those developing a survey must be careful to avoid encouraging bias when designing the survey questions. When composing bi-modal scaled surveys it is useful to develop an even number of opinion-related responses that appear to be an equal psychological (respondent perceived) distance from each other. An even selection helps minimize the occurrence of central tendency bias (Mangione, 1995).

The literature on surveys differs as to what is required for a reasonable response rate. One resource suggests that a response rate of 50% to 60% is acceptable (Goyder, 1985). The strictest range found was between 60% and 70%. A response rate below 50% is universally considered not statistically acceptable (Goyser, 1985; Mangione, 1995).

2.4. TRENDS FROM P2 PROGRAMS

Many organizations have published reports on the success of their P2 programs. These programs vary in scope, from multi-national to state-run technical assistance programs. The most informational reports attempt to aggregate results from multiple programs and make conclusions about P2 on a regional or national scale. Other programs published reports that do not discuss national scale results, but instead present research that has yielded interesting insights on factors influencing the success of waste minimization projects. Six published studies of technical assistance programs are discussed in the following sections. The sections are organized from the earliest published study to most recent.

2.4.1. Northeast Waste Management Officials' Association

The Northeast Waste Management Official's Association (NWMOA) compiled P2 information from eight states; Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont, to gain a better idea of the region's progress. Data was gathered by a questionnaire filled out by the P2 assistance providers (Goldberg et al., 1998a).

The study concluded that programs in Northeastern states averaged three P2 suggestions per site visit. There was some inconsistency among respondents as to how one defines a site visit. During these site visits, it was reported that minor regulatory compliance issues were discussed 44% of the time (Goldberg et al., 1998a).

Massachusetts identified a strong link between P2 and safety improvements at a company. They reported that 66% of the participating clients saw a health or safety improvement as a result of the assistance. Massachusetts' research was preliminary but the link between health and waste minimization appears to be one major conclusion of their study (Goldberg et al., 1998a).

The NWMOA reported an average implementation rate of 44% for any given suggestion; although they admit methods and definitions vary as to how each state determines savings and implementation. The NWMOA was one of the first programs to report on the need for a uniform method and set of definitions when reporting P2 success metrics. Some common problems found while compiling data for the NWMOA report included inconsistent units when reporting metrics, differing definitions of a site visit and differing methods to calculate cost savings. To manage the inconsistencies, the NWMOA proposed developing a task force to create common definitions and to develop software that can help programs account for their successes (Goldberg et al., 1998a; Goldberg et al., 1998b; Goldberg et al., 2004).

2.4.2. U.S Department of Energy Industrial Assessment Centers

The Oak Ridge National Laboratory's (ORNL) report on the Industrial Assessment Center Program's impact details lessons learned from a large-scale energy conservation assistance program; the ORNL study and assistance program were funded by the U.S. Department of Energy (DOE). This program offered energy, waste and productivity assessments to small and medium-sized businesses. Assessments were prepared by teams of engineering students and faculty from 30 colleges across the country. The ORNL reevaluated the program's success by collecting data from previous clients via mail questionnaires (Martin et al., 1999).

Upon critically reviewing the report, one may question the validity of the program's questionnaire responses. The survey's validity depends on how one considers response rate. One-hundred and two companies out of 2,954 participants were randomly selected to receive the questionnaire (3.5% of the total participants). Of those 102 surveyed, 42 agreed to participate, in 37 instances the primary contact at the business was not available and 23 refused to participate. The study cites the response rate as 65%; 42

agreed to participate out of the 65 contacted (those who agreed plus those who refused). If the rate calculation included the 37 previous clients who's primary contact was unavailable, then the response rate is actually 41%; a rate which is considered not scientifically acceptable (Mangione, 1995; Martin et al. 1999). Either way the response rate was considered, only 1.4% of the total assisted population responded to the survey. Low sample size adds doubt to the positive savings quantities and implementation rates presented.

Sample size issues aside, the ORNL published thoroughly researched insights as to how businesses make energy efficiency decisions. The ORNL's research confirmed and explained how P2 programs conclude that suggestions will see a profitable persistence of between 4 to 7 years before the suggestion is replaced. This study proposes that the theory of evolutionary economics dictates the primary mechanism of P2 suggestion replacement. Evolutionary economics is a theory that states economic development is most reliant on creative destruction; an idea where new technologies overwhelm and replace the old (Martin et al., 1999).

2.4.3. National Pollution Prevention Roundtable

The National Pollution Prevention Roundtable (NPPR) conducted an even larger-scale assessment on the state of P2 in the country. They surveyed 60 P2 programs nation-wide and collected case studies to evaluate and report state and local achievements from 1990 to 2000. The report told much about P2 assistance programs in EPA Region VII; the region Nebraska is located in. Most programs in EPA Region VII cite a lack of funds as the largest barrier to success. While the national average number of P2 staff members in the country is 11, Nebraska only has one. To counteract the lack of funds all states in EPA Region VII, except Kansas, have service providers who administer student internship technical assistance programs. Nationally, 37% of the states have some type of P2 student internship program available (Spektor and Roy, 2003).

The NPPR reports positive savings from P2 programs nationwide. It was estimated that 167 billion pounds of pollution were prevented from 1990 to 2000. In 1998 alone, savings from P2 projects totaled $256 million nationwide (Spektor and Roy, 2003). It was roughly estimated that from 1998 to 2000 every dollar spent on state or local programs yielded $6 of savings by the regulated community (National Pollution Prevention Roundtable Press Release, 2003).

Difficulties similar to those faced by the NWMOA were noted when attempting to aggregate P2 savings from multiple programs. The NPPR stated that the biggest obstacle of accurately gauging successes is a common system of measurement. Units must be common to aggregate savings and terminology must be consistent between programs (Spektor and Roy, 2003).

The idea that standardized methods are needed to account for environmental improvements is not limited to only P2 program analyses such as Goldberg et al. (1998a) and Spektor and Roy (2003). Organizations attempting to compare and rank the environmental health and safety performance of large companies have stated they noticed similar quantification and validity difficulties (Yang, 2004).

2.4.4. Pennsylvania DEP and Iowa DNR

Both Pennsylvania and Iowa published reports discussing their state's waste minimization efforts. The Pennsylvania Department of Environmental Protection's (DEP) P2 program reported that for every dollar invested in P2, a company will see $9.00

in savings. This cost/benefit ratio includes savings from fewer raw materials being purchased and less time spent reporting and permitting (Commonwealth of Pennsylvania Department of Environmental Protection, 1996). It is difficult to compare this cost/benefit ratio to other programs' because it is unclear what other assumptions were used. Regardless of assumptions, the Pennsylvania DEP's figure is higher than the NPPR's figure of $6.00 saved. A higher than average ratio indicates that Pennsylvania has more successful P2 projects or accounts for different savings, such as time spent on reporting, in their cost/benefit ratios (National Pollution Prevention Roundtable Press Release, 2004).

Iowa conducted telephone surveys of 300 businesses to determine state-wide impressions of P2. Much like Nebraska, Iowa primarily has an agricultural economy with a few larger cities spread throughout the state. Consequently, results may be applicable to Nebraska P2 perceptions.

The Iowa survey asked respondents to define P2. Only 5% were able to give the generally accepted federal and state definition while the majority did not have a common definition. Businesses gave their opinions on factors that effectively influence P2 change. Iowa's survey reported that 45% to 66% of the surveyed businesses list their employees and research as the top motivators for P2 changes. This indicates that businesses in Iowa value relationships and the credibility of a presenter when being exposed to P2 suggestions (Bell; 2001).

2.4.5. Environmental Pollution Prevention Project

The Environmental Pollution Prevention Project (EP3) is a program sponsored by the United States Agency for International Development (USAID) which helps establish sustainable P2 programs to developing countries. Eighteen countries were assisted, with nine of the eighteen establishing multi-year programs. Countries with sustainable, multi-year programs are Bolivia, Chile, Ecuador, Egypt, Indonesia, Jamaica, Mexico, Paraguay and Tunisia. Over 300 facilities were assisted worldwide. The EP3 program's goals are of a larger scale than the other P2 programs discussed in this literature review; however, many of its' objectives are identical to assistance providers in the United States. The EP3 provides P2 technical assistance, offers training and outreach and helps establish P2 policies in businesses (Gallup and Marcotte, 2004).

Projects were more successful when the EP3 partnered with reputable local organizations with ties to industries and key governmental institutions. The credibility of the partnered organizations was identified as a factor that increased implementation rates of suggestions. Suggestions were implemented at a rate of 25% to 50%, depending on the industry sector. Most implemented suggestions were classified as good housekeeping, proper management and better process control. These implemented suggestions were often no to low cost improvements that brought immediate, substantial and visible benefits (Gallup and Marcotte, 2004).

2.5. INDIRECT BENEFITS OF P2

P2 projects have many benefits beyond the cost savings associated with reduced purchasing and disposal of waste. A more comprehensive method of assessing assistance projects is needed to quantify all benefits.

Different technical literature sources refer to the difficult to quantify benefits of P2 by different names. The below-cited sources are useful to identify all indirect benefits one can reasonably account for in a project analysis. The weakness of literature describing P2 benefits is inconsistent definitions of important terms. To avoid confusion between terminologies, note that Chapter 5 defines all difficult to quantify benefits as indirect benefits. Other literature sources may refer to these indirect savings as 'hidden', 'less tangible' or 'submerged' savings.

2.5.1. Life-Cycle Analysis

Life-cycle analysis (LCA) is a concept and methodology for auditing the performance of industrial products, processes or activities. When applied to P2, LCA compares resource consumption, energy use and environmental burdens of an existing system to a proposed system over the entire life of the systems. LCA allows for the selection of operations associated with the most efficient output (Freeman, 1995; Frankl and Rubik, 2000; Sonnemann et al., 2004).

There are three general components of a LCA. First, an inventory is taken of the system. In the case of P2, a waste assessment is conducted to quantify system inputs and outputs. Next an impact assessment is conducted. Finally, an assessment is conducted to improve the system (Freeman, 1995).

One type of LCA most relevant to P2 impact assessments is life-cycle impact assessments (LCIA). A LCIA analyzes a product system's (i.e., P2 suggestion) life cycle to better understand its' environmental significance. There are three steps to a LCIAs. The first step is to select impact categories, indicators and models. The second step is to classify the environmental loads you will be assessing. The third step is to characterize (i.e., quantify) environmental loads by means of a reference pollutant typical to each environmental impact category (Sonnemann et al., 2000).

2.5.2. Total Cost Assessments

Total Cost Assessment (TCA) is a method for auditing and evaluating the environmental performance of a process or activity. There are three main steps to a TCA. First, one needs to perform an inventory analysis of the process. Next, an assessment must be performed on the project's impact. Finally, an assessment should be performed that identifies potential improvements to the project (Freeman, 1995).

Organizations should attempt to be thorough during the second step (assessment of impact) of a TCA. There are three types of impacts that may be difficult to quantify; hidden costs, liability and less tangible costs. A hidden benefit would be savings associated with compliance, permitting, reporting, monitoring, manifesting, insurance, on-site waste management, operations of on site pollution control and revenue from sale of pollution credit. Liability benefits result from fewer penalties and fines, personal injuries, property damage, and natural resource damage. Less tangible benefits are benefits resulting from increased revenue from enhanced product quality, increased revenue from enhanced company and product image, savings from decreased health maintenance costs and increased productivity from improved employee relations (Freeman, 1995). It is; however, difficult to account for less tangible benefits such as public image, customer satisfaction and worker productivity (Behrens, 2000).

A project must be active for many years to fully capture all benefits in a TCA. It is estimated that a project must be in effect for more than five years to realize all indirect benefits (Curran, 1996). More time is also required to benefit from preventative suggestions. Most preventative benefits can be measured when a suggestion is in place for five to ten years (Freeman, 1995).

2.5.3. Safety and Prevention Benefits

Projects that improve safety and promote hazard prevention can reduce costs at a company. Safety improvements have the direct benefit of reducing costs associated with personnel injury. If safety is improved or hazards are prevented then indirect cost savings will occur (referred to as hidden costs by Freeman, 1995). For example, administrative expenses can be reduced, insurance can be reduced, morale can be improved, lost time can be minimized and investigation time can be avoided.

Fewer occurrences of property damage can generate other indirect (referred to as submerged costs in Burgees, 1981). Some indirect savings from less property damage are less production delays, less investigations of accidents and disposal of debris. Product damage occurring less often also generates indirect cost savings. Common indirect cost savings from less product damage are less production delays, less shipment delays, less replacement and less disposal of debris. Finally, indirect savings can result from less undue maintenance. Some indirect savings from undue maintenance are reduced cleanup, repair, renovation and debris disposal (Burgees, 1981).

Indirect savings can be difficult to quantify. One could instead conduct a qualitative analysis on safety impacts by considering the hazard prevention hierarchy presented by Roger Brauer. According to Brauer, the least desirable result of a safety or P2 project is that no safety benefits are realized. Next, the hazard could be controlled but not reduced in severity. Even better, a project could reduce the hazard's level of severity. The most favorable result of a safety or preventative project is when the hazard is eliminated entirely (Brauer, 1993).

2.5.4. Methods to Estimate Indirect P2 Benefits

It is useful for an organization to account for hidden savings resulting from P2 projects. For example, environmental costs can be offset by money saved from projects or revenues generated through the sale of by-products. Fully accounting for hidden savings can help an organization make a better informed decision to implement waste reduction projects.

Organizations use various methods to account for indirect benefits. Many methods involve applying formulas developed within an organization (Lave, 1980; Hawkey, 2004) or using computer methods to determine the returns on health and safety investments (Junker, 2000; Hawkey, 2004; Hughes et al., 2004). Both methods often employ mathematical models such as multi-attribute utility models, option pricing theory and the knowledge capital approach. These models provide a means to address situations involving mixtures of economic and non-economic (indirect) attributes (Rouse and Boff, 1999). Both methods, however, are limited when used by P2 assistance providers because P2 providers must quantify savings from multiple clients with varying amounts of corporate interest in benefit tracking.

Less project-specific methods have been developed to allow P2 programs to be consistent when quantifying benefits from multiple projects. These methods use actuarial techniques, professional judgment, decision analysis techniques such as probability analysis or engineering cost estimation to determine monetary savings. In 1989 the USEPA developed a method relying on engineering cost estimation, specifically, empirically developed equations to account for P2 benefits. This method is advantageous because it is simple to use, accounts for many liabilities, is widely applicable, is highly standardized and is not site-specific (USEPA, 1996).

The USEPA's method involves using a set of equations to account for various costs of a project. Equations are given for the cost of inspections, preparedness, medical surveillance, notification, reporting, monitoring, testing, planning, training, manifesting and labeling. In general, these costs are the monetary value of saved time. The eleven time saving equations are given in the general form shown in Equation 2.1.

$$C = f \times [n + (t \times w)] \qquad \text{Eq. (2.1)}$$

where C is the cost per year, f is the frequency of event occurring per year, n is the non-labor cost per event, t is the time required per event and w is the loaded wage rate per hour of the employees involved. If one can not determine the variables in Equation 2.1 for their specific situations, the USEPA guidance provides tables listing typical values (USEPA, 1989).

The USEPA also developed equations that could help determine future liability savings such as personal injury, economic loss, real property damage, surface sealing, soil and waste removal and treatment, natural resource damage and ground water removal and treatment. These equations multiply national averaged values and empirically determined constants to calculate yearly cost savings. The equations addressing remediation costs require different variables depending on the origin of contamination. Results vary if the contamination resulted from leaking tanks, transportation accidents or landfill disposals (USEPA, 1989).

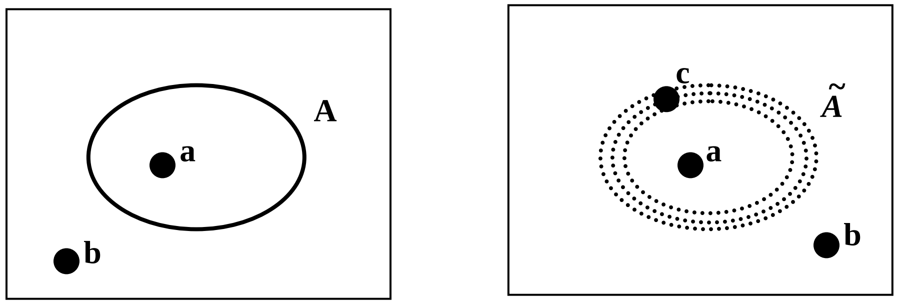
2.6. FUZZY SET THEORY

Problems in the real world are often complicated by the presence of uncertainty in the form of ambiguity. Dr. Lotfi Zadeh developed fuzzy logic, a mathematical tool to address ambiguity of data sets, in 1965. For systems that have little complexity, closed-form mathematics on unambiguous data sets is sufficient. If the system is much more complex; perhaps the data is intrinsically imprecise or the real value falls within an ambiguous range, then one may need to consider fuzzy logic to solve the system (Ross, 1995). The following section will first explain the concept of fuzzy set theory by comparing it to classical set theory then it will conclude by discussing methods to transform fuzzy sets into unambiguous values.

2.6.1. Fuzzy Set Theory Concepts

A classical set has no uncertainty in the location of boundaries. When there is no uncertainty associated with a set it is said to have crisp boundaries. On the other hand, a set with ambiguity to its boundaries is said to be a fuzzy set. Figure 2.1. depicts the differences between a classical and fuzzy set (Ross, 1995).

In Figure 2.1(a). point ‘a’ is a member of the crisp set ‘A’ while point ‘b’ is not; there is no ambiguity to these two points’ membership. Figure 2.1(b) shows that point ‘a’ is a full member of set $\tilde{A}$ while point ‘b’ is clearly not a member. Point ‘c’; however, is on the boundary of set $\tilde{A}$ and its membership within the set is ambiguous (Ross, 1995). In other words, consider membership within a set, such as point ‘a’ in Figure 2.1(b), as being represented by the integer 1. Non-membership in the set, such as point ‘b’ in Figure 2.1(b), is represented by the integer 0. Point ‘c’ in Figure 2.1(b) has some value of membership on the interval [0,1].



(a) **(b)**

Figure 2.1. Diagrams for (a) Crisp Set Boundary and (b) Fuzzy Set Boundary (After Ross, 1995).

If point ‘c’ has a membership value approaching 1 then it is moving closer to the inside of the fuzzy boundary. Conversely, if its membership is approaching 0 then point ‘c’ is moving away from the inside of the boundary (Ross, 1995).

A less abstract example of fuzzy numbers would be to consider the question: Is a person *nearly* 6 feet tall? A classical set would have to set specific criteria for being nearly 6 feet tall. Suppose the criterion of nearly 6 feet tall is a height between 5 and 7 feet. Figure 2.2(a). graphically depicts the classical set of membership of a set that is nearly 6 feet tall. Figure 2.2(b); conversely, is a fuzzy description of the situation. In the classical set situation a person who is 5’10’’ would be considered as nearly 6 feet tall as a person who is exactly 6’0”. A person 4’11.999” would not be considered nearly 6 feet tall. The fuzzy set situation creates a triangular fuzzy number that considers ambiguity and shows that the varying heights may all be nearly 6 feet tall but have different membership values in the set (Ross, 1995).

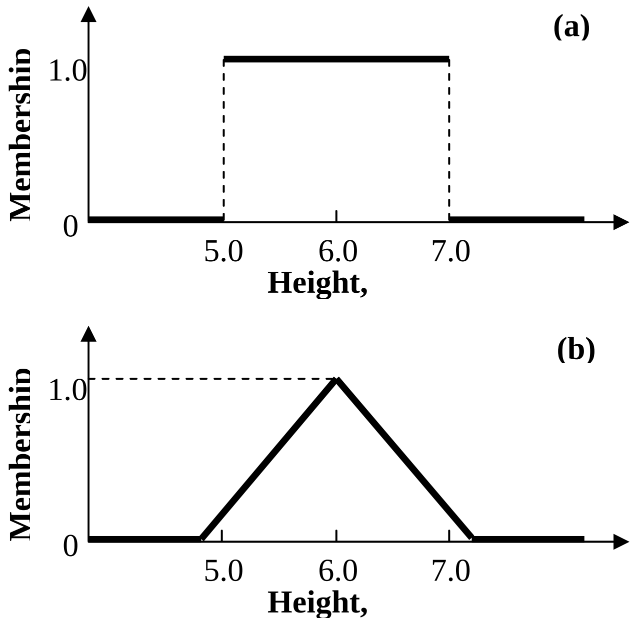


Figure 2.2 Classical (a) and Fuzzy (b) Sets Describing Height (After Ross, 1995).

2.6.2 Defining Membership Functions from Linguistic Data

Fuzzy numbers are often provided in a linguistic format. There normative view is the most common view when considering converting linguistic data to membership functions. The normative view considers the imprecision conveyed by linguistic variables is subjective and thus, needs to be defined directly by their users as a function. Two methods are commonly used to help determine the shape of such a function. The first method, binary direct, requires users to answer ‘yes’ or ‘no’ to questions describing an element. The fraction of ‘yes’ responses over all responses define the membership value for that element in the imprecise concept that is being represented. The second method, continuous direct, requires users to rate elements on a continuous scale from ‘definitely in the concept’ (membership of 1) to ‘definitely not in the concept’ (membership of 0) to define the vertices of fuzzy shapes (Karwowski and Mital, 1986; Behrens et al., 2000).

2.6.2 Defuzzification

After a data set is modeled as a fuzzy number it is often useful to convert the number into a single scalar quantity. Defuzzification is the conversion of a fuzzy number to a single scalar (or crisp) quantity. There are seven popular methods of defuzzifying fuzzy numbers (Ross, 1995). One conversion method, the centroid method, will be used in this thesis.

1. *Maximum membership principle*

   This method, also known as the height method, is concerned with the peak value of a fuzzy membership function. It can only be used if a single maximum point is given. The peak value, or value with a membership of 1, is the defuzzified number (Ross, 1995).

2. *Weighted average method*

   The weighted average method is only valid for symmetrical membership functions. The method weights the various symmetrical shapes in the function according to their membership values and combines them into a single number (Ross, 1995).

3. *Mean-maximum membership*

   The mean-maximum membership method is similar to the maximum-membership principle but a single maximum point is not needed. This method can defuzzify fuzzy membership functions that have a maximum plateau, such as a trapezoid shaped function. The method takes the average value on the plateau as the crisp number (Ross, 1995).

4. *Center of sums*

This method involves the algebraic sum of individual output fuzzy sets instead of their union. The disadvantage of this method is that intersecting areas are added twice. This method is similar to the weighted average method but instead of individual membership values being weighted, the weights are the areas of membership functions (Ross, 1995).

5. *Center of largest area*

The center of largest area is applicable if a shape has at least two convex sub-regions. In this case, the center of gravity of the larger sub-region is used as the defuzzified value. In cases where the sub-region is convex then the center of gravity is determined by the centroid method, discussed below (Ross, 1995).

6. *First (or last) of maxima*

This method uses the overall output or union of all individual output fuzzy sets to determine the smallest value of the domain with maximized memberships. One could also use an alternate formula that calculates the last of maxima (Ross, 1995).

7. *Centroid Method*

This method is also commonly known as the center of area and center of gravity method. The centroid method is the most prevalent and physically appealing of all defuzzification methods presented above (Ross, 1995). To determine defuzzified values of fuzzy membership functions one must determine the centroid of the fuzzy membership function. A function’s centroid can be found from Equation 2.2.

$$z^* = \frac{\int \mu_c(z) \cdot z \partial z}{\int \mu_c(z) \partial z} \qquad \text{Eq. (2.2)}$$

where *z* is a fuzzy number of a given parameter. Figure 2.3. graphically illustrates the centroid method (Ross, 1995).

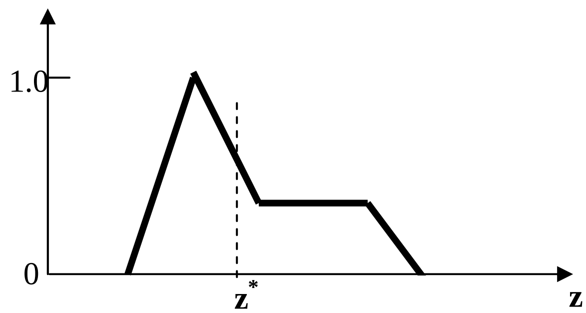


Figure 2.3. Centroid Defuzzification Method (After Ross, 1995).

If the fuzzy membership function is a triangle, as it often is in this study, the integral to determine the centroid, z^*, can be simplified to Equation 2.3 (Housner and Hudson, 1950).

$$z^* = A + \frac{[(B - A) + (C - A)]}{3} \qquad \text{Eq. (2.3)}$$

where *A* is the absolute minimum value, *B* is the most credible value and *C* is the absolute maximum value. Figure 2.4. illustrates the variable locations found in Equation 2.3.

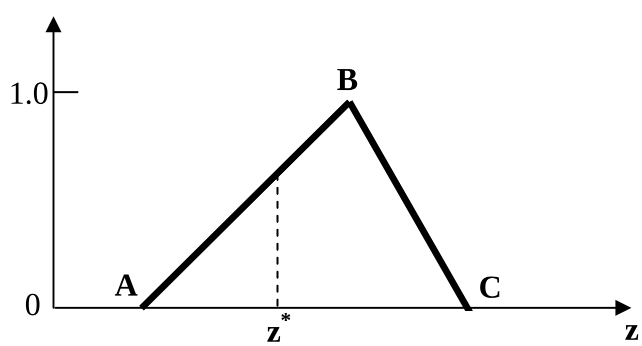


Figure 2.4. Centroid of a Triangle.

2.7. CONSTRUCTION COST INDEX

In some cases, it may be necessary for organizations quantifying P2 monetary savings to translate values from a past estimate into a current quantity that includes inflation. The R.S. Means guide to cost estimation recommends one uses the construction cost index (CCI) calculated by the Engineering NewsRecord (ENR) (R.S. Means Co., 2002). The CCI determines a twenty city average cost of 200 hours common labor, 25 hundredweight of standard structural steel, 1.128 tons of Portland cement and 1,088 board-feet of 2 x 4 lumber every month. The ENR makes current CCI values available in their weekly publication (Engineering News Record, 2004c).

It is more appropriate to use the twenty city average CCI values instead of an index closest to a project's home city. The average value has a smoother trend which is less susceptible to localized price spikes. It is also important to realize that the monthly CCI values are not adjusted for seasonal fluctuations in construction costs. It follows that when performing a price projection one may consider using a yearly average instead of the most current monthly index value (Engineering News Record, 2004c).

The CCI is applied by determining a ratio of the current year's CCI to the original year's CCI. For example, suppose an organization must determine the value of a P2 suggestion that was estimated in 1989. To project the current value, the 1989 cost must be multiplied by the ratio of the current CCI over the CCI of 1989. The monthly averaged value of the CCI in 1989 was 4615 (Engineering New Record, 2004a). The average value of the CCI from July 2003 to July 2004 is 6899 (Engineering News Record, 2004a; Engineering New Record, 2004b). The multiplier one must use to project the 1989 value of a P2 suggestion into 2004 inflation adjusted money is $\frac{6{,}899}{4{,}615}$, or 1.49.

2.8. SUMMARY

The P3 program has been training interns and providing technical assistance for eight years. The well-established program is in a prime position for a systematic analysis of its impact in Nebraska, similar to those conducted by other well-established programs in the country. A properly designed mail survey can effectively determine whether clients have different experiences with the program depending on their location in the state and relationship with P2 service providers. Reassessments of projects can determine how the program's implementation and savings compares to other programs throughout the country. When accounting for program impact; however, it is difficult to determine precise savings from many indirect or future liability reduction benefits. To address difficult to quantify benefits an analysis of clients that makes use of empirical equations and fuzzy set theory is required.