California Pipe Pressure

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Project 1 - EXPERT SYSTEMS / FUZZY LOGIC

**Introduction and Background**

Burst pipes are a dangerous problem that should be avoided at all costs, and it is for this reason that calculating a Maximum Allowable Operating Pressure (MAOP) is crucial so as to avoid such occurrences. Unfortunately, it is not so simple as determining one pressure and applying it throughout the entire state of California. Different areas have different needs as well as different pipes based on when, how, and by whom they were built. For example, a one square mile area in Los Angeles would require significantly higher pressure than that same area in Bakersfield, and an area that was built up after its pipe system was installed may not be equipped to handle its capacity. Calculating what the pipes are physically able to handle is not terribly difficult, but once you factor in area needs, things get a bit more complicated, and this program aims to address that difficulty and calculate the MAOP automatically.

**Knowledge Engineering**

Our expert was Jason McMillan, a Civil Engineer with the state of California (and Brad's brother-in-law). He works out of the Natomas office when he is not travelling the state to audit various pipe systems. We sat down with him to pick his brain and he scribbled out drawings and explained the issues he encounters regularly, even linking us to official government documentation explaining everything from classification to the equations used to determine MAOP. After the first stage of knowledge engineering, we began rules engineering and then revisited Jason to make sure we were on the right track before moving forward with the program.

Three simplifications were made for the sake of completability and ease of use of the program. First, when considering the equation for the crisp measurements in the first part of the system, we decided to assume that type choice (ie a welded pipe) would automatically give us a yield strength and thickness of the pipes. Normally, these things could change depending on condition of pipe or how the pipe was built (for example, you could have a steel pipe that is .5 inches thick and one that is 1 inch thick), but they would just introduce an unnecessary amount of inputs for minimal change in accuracy, so they were cut for the sake of reducing the scope of the project slightly. Yield strength in particular gives us a set answer based on type, and is handled more by exception than by design, so it seemed unnecessary to keep it as a separately determined value.

Secondly, we opted to make the "longitudinal joint factor" in the equation described below a constant of 1.00. The reason for this is that out of 20 types of welds, 17 of them use 1 as the multiplier. The three exceptions to the rule use 0.60, 0.60, and 0.80, which may make a relatively significant difference, but such instances are so rare that it seemed trivial and unimportant for this exercise.

Thirdly, we are assuming offshore pipelines are treated the same as onshore pipelines. There are some minor differences in reality, however given that there are not any cities floating on the water, we have made the assumption that the difference between a lower classification area and an offshore area are negligible, again for the sake of scope. This also reduces complexity for sections like Orange County or the Bay Area as there may be sections of pipe that are offshore, but are servicing onshore areas.

The last simplification is that we have removed a couple of exceptions. For example, pipes running below unfinished roadways or railways may be treated differently than freshly installed pipes under a newly renovated area. There are a handful of these types of rule exceptions that increase the scope of the program to an unreasonable program, and so it is assumed that the rules are standard across different types of areas and the engineer must make the final call after the program runs and calculates classification and MAOP.

**Expert System Design**

The easiest part in designing our expert system was creating the crisp determinations. This is in large part due to the existence of an equation that does most of the work for us:

```
P = (2 St/D) x F x E x T
```

```
Where

P = Design pressure
S = Yield strength
D = Diameter of pipe
t = Thickness of pipe
F = Design Factor
E = Longitudinal joint factor
T = Temperature
```

In following this equation, we did make a couple of assumptions and simplifications as mentioned above, so “E” is automatically set equal to 1 while “S” and “t” are determined by an input of type. Because of the determination of yield strength and thickness, we calculated “2St” all in one go and finished the equation off in our last step. We made diameter and temperature additional inputs taken from the use to generate values for “D” and “T” leaving only the Design Factor.

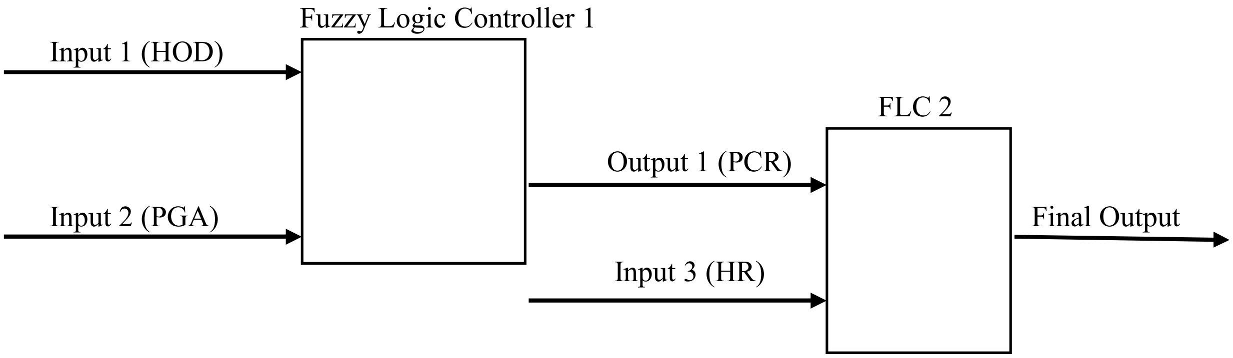
Here are a couple examples of the rules we used to turn inputs into usable values:

```
(defrule crispRule4

      (temp-input ?x)

      (test (>= ?x 400))

      (test (< ?x 450))

      =>

      (assert (temp-factor 0.900)))

(defrule crispRule8

      (type carbon)

      =>

      (assert (pipe-factor 8875)))

(defrule crispRule13

      (pipe-factor ?x)

      (diameter-factor ?y)

      (temp-factor ?z)

      (class-factor ?w)
```

```
=>
(assert (results (*(* (/ ?x ?y) ?z)?w))))
```

These rules give examples of determining temperature multiplier, pipe type multiplier, and the results when using only the crisp determinates.

The Design Factor is actually fairly tricky. In fact, it is where the fuzzy logic comes in. We went through several different iterations of this section before settling on something that actually seemed to work. The reason for the complexity is that there are three separate fuzzy inputs, one of which can drastically change the outcome, almost as a binary determination. In order to tackle this, we decided on a two pronged approach: first calculate the two simple fuzzy inputs, then use their fuzzy output as the input for a second fuzzy system. The approach looks something like this:




The ultimate goal for this section is to determine a classification for the zone in question. These classifications are ranked 1-4 and have their own multipliers in the above equation. The reasoning behind it is that if an area experiences a higher service load, whether through more people or taller buildings, the overall maximum pressure must be reduced to avoid going above the actual capacity of the pipes.

There are three factors in determining classification:

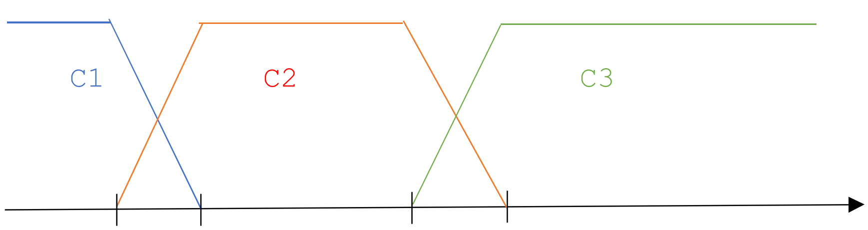
1 – How many Human Occupancy Dwellings are in the zone? Note that you must count an apartment building with 30 units as you would count 30 separate houses, hence the verbage.

2 – How many people are serviced by Public Gathering Areas or other buildings in the zone? For example, a park or campground or office building: if they are occupied by a certain number of people for a certain amount of the year, the classification may increase in spite of a lack of homes.

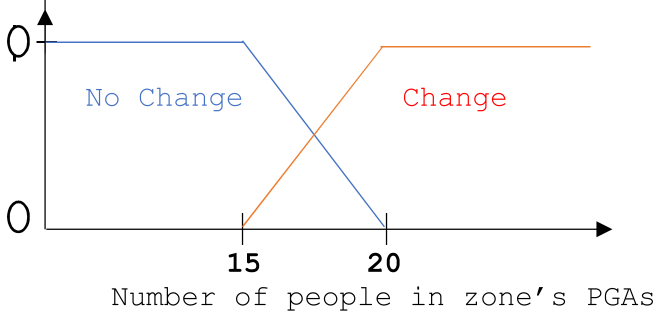
3 – How prevalent are High Rises in the zone? If the zone is marked as one where high rises are "prevalent" then the classification automatically jumps to 4, but "prevalent" is not a crisp determination. Interestingly, this is the only way to reach a classification of 4, which is part of what made designing the system so complex.

In accordance with this, we used the first two determinations as the first two fuzzy inputs, as seen here:

Input 1 (Human Occupancy Dwellings - HOD)




Input 2 (Public Gathering Areas/Other Buildings – PGA)




These two inputs are used for the following FAM (Fuzzy Associative Matrix) and output, which will be reused as the input to our second fuzzy system.

FAM 1

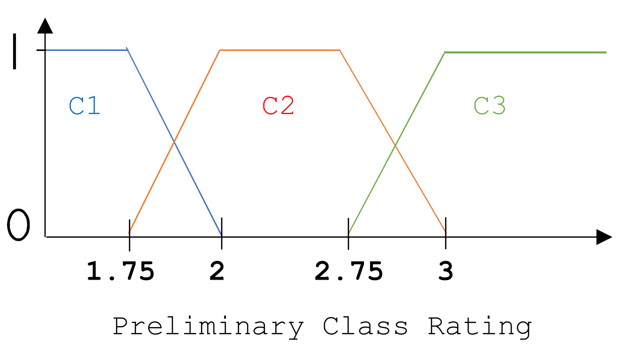
| PGAs \ HODs | CLASS 1 | CLASS 2 | CLASS 3 |
|---|---|---|---|
| NO CHANGE | **CLASS 1** | **CLASS 2** | **CLASS 3** |
| CHANGE | **CLASS 2** | **CLASS 3** | **CLASS 3** |

The logic here amounts to the following statements:

```
IF HOD = 1 AND PGA = NC THEN PCR = 1
IF HOD = 1 AND PGA =  C THEN PCR = 2
IF HOD = 2 AND PGA = NC THEN PCR = 2
IF HOD = 2 AND PGA =  C THEN PCR = 3
IF HOD = 3 AND PGA = NC THEN PCR = 3
IF HOD = 3 AND PGA =  C THEN PCR = 3
```

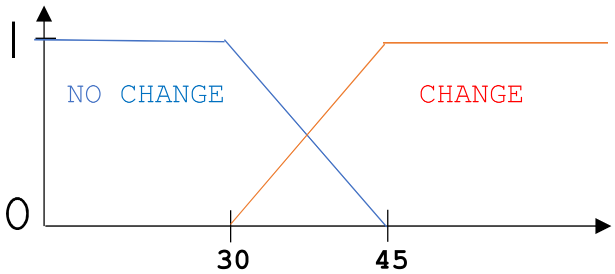
Which, in turn, brings us to the preliminary output:

Output 1 (Preliminary Class Rating - PCR)



This output is then used in conjunction with Input 3 (HR) in order to make a final determination of class.

Input 3 (High Rises - HR)




Number of HRs in zone

The below is the final FAM and output determining the classification of the zone and thereby the Design Factor in the above equation.

FAM 2

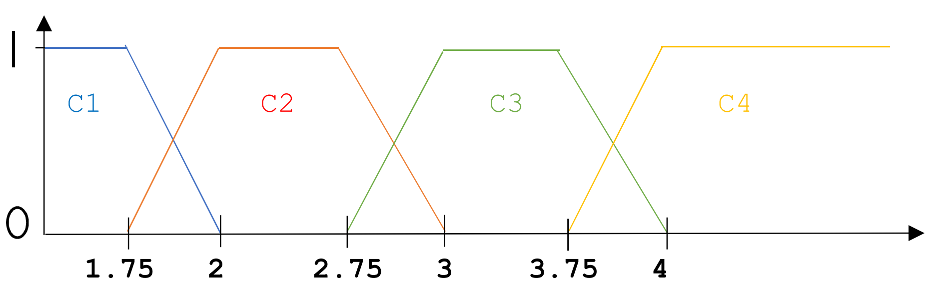
| HRs \ PCR | CLASS 1 | CLASS 2 | CLASS 3 |
|---|---|---|---|
| NO CHANGE | **CLASS 1** | **CLASS 2** | **CLASS 3** |
| CHANGE | **CLASS 4** | **CLASS 4** | **CLASS 4** |

The logic here amounts to the following statements:

```
IF PCR = 1 AND HR = NC THEN CLASS = 1
IF PCR = 1 AND HR =  C THEN CLASS = 4
IF PCR = 2 AND HR = NC THEN CLASS = 2
IF PCR = 2 AND HR =  C THEN CLASS = 4
IF PCR = 3 AND HR = NC THEN CLASS = 3
IF PCR = 3 AND HR =  C THEN CLASS = 4
```

Leaving us with a final fuzzy output shown below that will be rounded to the nearest class for a crisp determination that can then be used in the equation in order to get our final MAOP.

Final Fuzzy Output (Class)




Class

A couple examples of the coded ruleset used in order to achieve this can be seen below:

```
;; Fuzzy Inputs
(deftemplate HOD
0 50 dwellings
((Class1 (8 1) (10 0))
 (Class2 (8 0) (10 1) (36 1) (46 0))
 (Class3 (36 0) (46 1))))

(deftemplate PGA
0 30 people
((NC1 (15 1) (20 0))
 (Change1 (15 0) (20 1))))

(deftemplate HR
0 75 high-rises
((NC2 (30 1) (45 0))
 (Change2 (30 0) (45 1))))

;; Fuzzy Outputs
(deftemplate PCR
0 4 classification1
((PCR1 (1.75 1) (2 0))
 (PCR2 (1.75 0) (2 1) (2.75 1) (3 0))
 (PCR3 (2.75 0) (3 1))))

(deftemplate Final
0 5 classification2
((Final1 (1.75 1) (2 0))
 (Final2 (1.75 0) (2 1) (2.75 1) (3 0))
 (Final3 (2.75 0) (3 1) (3.75 1) (4 0))
 (Final4 (3.75 0) (4 1))))
```

Below are the two FAMs:

```
;; FAM 1 rules
(defrule F1NC1
(HOD Class1)
(PGA NC1)
=>
(assert (PCR PCR1)))

(defrule F1NC2
(HOD Class2)
(PGA NC1)
=>
(assert (PCR PCR2)))

(defrule F1NC3
(HOD Class3)
(PGA NC1)
=>
(assert (PCR PCR3)))

(defrule F1C1
(HOD Class1)
(PGA Change1)
=>
(assert (PCR PCR2)))

(defrule F1C2
(HOD Class2)
(PGA Change1)
=>
(assert (PCR PCR3)))
```

```
(defrule F1C3
(HOD Class3)
(PGA Change1)
=>
(assert (PCR PCR3)))

;; FAM 2 rules
(defrule F2NC1
(PCR PCR1)
(HR NC2)
=>
(assert (Final Final1)))

(defrule F2NC2
(PCR PCR2)
(HR NC2)
=>
(assert (Final Final2)))

(defrule F2NC3
(PCR PCR3)
(HR NC2)
=>
(assert (Final Final3)))

(defrule F2C1
(PCR PCR1)
(HR Change2)
=>
(assert (Final Final4)))

(defrule F2C2
```

```
(PCR PCR2)

(HR Change2)

=>

(assert (Final Final4)))


(defrule F2C3

(PCR PCR3)

(HR Change2)

=>

(assert (Final Final4)))
```

Some sample inputs and outputs are shown below to illustrate the effectiveness of the program once all logic has been implemented.

```
What type of pipe is it
carbon

What is the diameter of the pipe?
5

What is the temperature of the gas?
100

Enter the number of Human Occupency Dwellings
(Note: Count apartments as individual dwellings):
5

Enter the number of people regularly occupying nearby Public Gathering Areas:
10

Enter the number of high rises in the zone:
0

Classification is 1
MAOP is 1278.0
```

```
What type of pipe is it
electric-fusion-welded

What is the diameter of the pipe?
3

What is the temperature of the gas?
376

Enter the number of Human Occupency Dwellings
(Note: Count apartments as individual dwellings):
15

Enter the number of people regularly occupying nearby Public Gathering Areas:
10

Enter the number of high rises in the zone:
50

Classification is 4
MAOP is 1545.67
```

```
What type of pipe is it
carbon and alloy

What is the diameter of the pipe?
30

What is the temperature of the gas?
200

Enter the number of Human Occupency Dwellings
(Note: Count apartments as individual dwellings):
25

Enter the number of people regularly occupying nearby Public Gathering Areas:
20

Enter the number of high rises in the zone:
3

Classification is 3
MAOP is 147.9166666666667
```

**Conclusion**

After much trial and error, our approach seems to have worked successfully. While a bit limited in scope (ie no error checking), the outputs generated match what is to be expected, both in terms of Classification and final MAOP. When first loading the program into CLIPs it gives a couple errors, but it does not do so consistently nor does it appear to affect the outcome, so eventually we determined they needed to be disregarded. As for limitations and reliability, so long as inputs are entered correctly (see user guide) and assumptions discussed earlier in the document are made, the program should be perfectly reliable. Of course, the aforementioned assumptions indicate that there are a few exceptions that we did not account for, but beyond that there do not appear to be any real limitations.

## Appendix A – Installation Guide

Installing and running the program is simple:

- Unzip the files into the folder of your choosing
- Press the Windows key and type "fzclipswin.exe" and run it
- Press "Ctrl + L" to load a file into CLIPS
- Navigate to the folder where you unzipped the contents in step one and select "pressure.clp" (alternatively, select "clothes.clp" to run the sample program from part 1)
- Press "Ctrl + U" to reset the inputs
- Press "Ctrl + R" to run the program

If you wish to run the program again after completion, simply repeat the above two steps as many times as desired.

## Appendix B – User Guide

Error checking has not been implemented into this program. As a result, please follow below input directions exactly:

When asked for "pipe type" you can enter:

- Line
- Zinc-coated
- Carbon
- Welded
- Metal-arc-welded
- Carbon and alloy

When asked for "diameter" enter any positive number.

When asked for "temperature" enter any positive number 450 or below. (If the temperature is above 450, the Temperature factor remains unchanged, so just enter 450.)

When asked for "Human Occupancy Dwellings" enter any positive integer 50 or below. (If more than 50, classification does not change, so enter 50.)

When asked for "people in Public Gathering Areas" enter any positive integer 30 or below. (If more than 30, classification does not change, so enter 30.)

When asked for "High Rises" enter any positive integer 75 or below. (If more than 75, classification does not change, so enter 75.)

If you are reading the outputs, you should see a Classification 1, 2, 3, or 4 as well as a Maximum Allowable Operating Pressure. The Classification is useful in determining if calculations must be altered based on any exceptions as listed above, but for the purpose of this program it mostly serves to make sure the Fuzzy Control Units are working properly. The MAOP is the final answer that solves the problem this program set out to solve.

## References

McMillan, Jason. Personal Interview. 1 February 2019 & 12 February 2019