CS4001 Report

Fuzzy Wakeup System

Aran Sena

Group project, in collaboration with:

Fabian Miiro
Sebastian Ruder

Trinity College
University of Dublin

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Contents

1 Introduction

This report details a Fuzzy Logic Controller we have designed to provide users with a more intelligent alarm.This was done as a proof of concept to show how the future of highly connected devices and increasingly connected sensors (phones etc.) could contribute to more personal, useful technology - in this case by helping the user wake up feeling more ready for their day whether they've had a 10-hour sleep-in, or have been working all night and only got 3 hours sleep.

To an extent the fuzzy system implemented has worked - in our test cases the fuzzy system adjusted the user's wakeup times in ways which intuitively made sense. One issue encountered was that in an attempt to limit the number of rules implemented, we limited the number of fuzzy subsets implemented for each linguistic primary term; which in some cases resulted in un-smooth responses, or overcompensation for changes in the input.

I believe it was worth using fuzzy logic for this problem, as it is a vastly complex process with many, many factors (we greatly limited the inputs from the original set of possible inputs). Sleep is a process which can be affected by many things, and which can affect people in many ways - in order to capture the heuristic knowledge of what constitutes "a good night's sleep", I believe fuzzy logic is perfect. In addition to capturing heuristic knowledge, from the point of view of integrating the system with a future internet-of-things framework, I believe fuzzy logic would be very useful from the point of view of it allowing for the integration of new technologies to the control system as they become available (e.g. if we wanted to integrate a new smart-thermostat, we could integrate it's control outputs via crossproducts).

The theory behind the methods applied are mainly sourced from CS4001's course notes [1], and supplemented by [2].

2 Background

Sleep is a complex and very necessary activity undertaken by everyone, but is far from being fully understood analyitically - it's not clear why we need to spend about a third of our lives unconcious; however as anyone who has had a bad night's sleep will know, the effects of a bad night's sleep are clear.

Knowing the importance of sleep, and the effect it can have on our ability to function throughout the day, we have attempted to create a fuzzy logic system which can help people better manage the hardest part of sleeping - waking up - while also improving how rested they feel from their rest.

I believe a fuzzy logic controller (FLC) is well suited to this task, given the complex nature of sleep and what exactly defines "a good night's rest". We have approached this from the point of view of capturing expert knowledge by utilizing our own heuristic knowledge of what we feel contributes to a good or poor night's sleep, rather than taking a more scientific approach. As the application could conceivably be set up and run without user interaction, does not need to respond in a tight control time period, and requires an accurate response for small changes in inputs, I believe the selected Mamdani approach was also appropriate.

While it may seem that some of the inputs may be unusual or impratical to ask a user of this wakeup system to provide, my personal view on this system would be that it could act as the decision system working in a highly connected internet-of-things style system; where your coffee machine could be as aware of your next meeting as your phone's calender. With increasing connectivity in our everyday devices, a wealth of personal data and tools is becoming available to developers to help create highly intelligent systems which are deeply rooted into our daily activities, such as the intelligent wakeup system proposed here.

3 Simulation / Model

When we first set out to develop our model, we spent time considering as many potential factors which could influence sleep, and the types of inputs which would contribute to them.

This step resulted in 25 factors, each with their own term set, which could influence the sleeping process. Analysing these further, it could be seen that these factors could be grouped into 3 catagories - Factors external to the user (e.g. the time of their first meeting the next day, or their commute time) - Factors internal to the user (e.g. the time since their last meal before bed or the amount of exercise they had that day) - and then factors which influence the ease of waking up (e.g. the amount of light that's in the room, or the user's current sleep cycle).

We determined 25 factors was far too many to attempt to model for this project, and acknolwedged it was unlikely to even be an exhaustive list of factors which contribute to sleep, so instead agreed to develop a proof-of-concept by selecting some key factors from the 3 catagories of factors and make reasonable assumptions where required.

These 3 categories defined the fuzzy subsystems implemented, with a fuzzy subsystem being made for determining how easy it is for the user to fall asleep, a fuzzy subsystem being made for determining how long the user should sleep for, and finally a fuzzy subsystem for determing how the user should be woken up by the alarm system.

System Architecture

In Figure 1, 3 fuzzy subsystems can be seen. As mentioned, these subsystems operate in a somewhat chronological order, with the 1st subsystem determining the user's ease of falling asleep, the 2nd subsystem determing how long the user is able to sleep for, and the 3rd subsystem determining how the user should be woken up.

The output from the 1st subsystem is used as an input for the 2nd subsystem, and the 2nd subsystem's output is used as an input for the 3rd subsystem.

Each subsystem is a fuzzy logic system with 3 inputs. The 1st and 2nd subsystem produce one output. The 3rd subsystem produces 2 outputs.

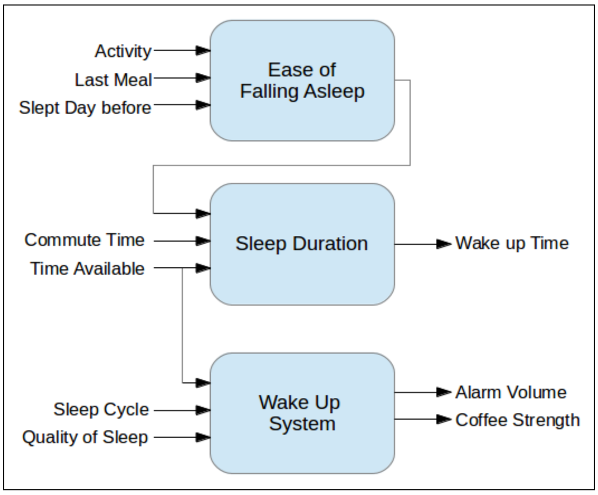

Figure 1: Fuzzy Wakeup System Architecture

Subsystems

Below are lists of the subsystems' inputs, with their term set and the reasoning behind the input.

Images of these subsystem's membership functions can be found in the appendix.

Subsystem 1

Inputs

- Activity during the day
  - *Little, Normal, A lot*
  - Scale: 0 - 3000 calories, based on average guidelines.
  - Assumption: A person who has had a lot of physical activity throughout the day will find it easier to fall asleep.
  - There are many tools available with today's technology to estimate this, so we feel this is reasonable information to assume we can access.
- Last meal or drink
  - *Just Now, Some Time Ago, Long Time Ago*
  - Scale: 0 - 360 minutes, based on Joy Bauer's article "How Food Affects Your Sleep"

- Slept day before
  - *Little, Normal, A Lot*
  - Scale: 0 - 720 minutes, based on heuristic estimate.
  - Assumption: Someone who has slept little the night before will find it easier to fall asleep the following night.

Output

- Easiness of Falling Asleep
  - *Easy, Normal, Hard*
  - Scale: Unit Interval [0, 1]
  - Assumption: This output attempts to quantify the user's easy of falling asleep as a percentage, for use in other systems.
  - This output is a highly complex concept, for which we could imagine many other factors contributing, such as the user's mental or physical health.

Subsystem 2

Inputs

- Ease of Sleep
  - *Easy, Normal, Hard*
  - Scale: 0 - 1
  - Assumption: If it is likely the user will find it difficult to fall asleep, then less of the available time will actually be used for sleeping.
- Commute Time
  - *Very Short, Short, Average, Long, Very Long*
  - Scale: 0 - 120 minutes, based heuristic estimate
  - Assumption: The longer the commute time, the less sleep the user will be able to have. Additional terms were used here to provide more intuitive responses that better matched the non-linearity which we wished to capture.
- Time to Sleep
  - *Very Little, Little, Average, More, Lots*
  - Scale: 0 - 600 minutes, based on heuristic estimate.
  - Assumption: This input is the amount of time the user has available from when they go to bed, up to when their first meeting/appointment must happen (i.e it includes the time for getting dressed and commuting).
  - It is also assumed that the time the user went to bed can be inferred from a sufficiently intelligent connected device
  - This is a **key input** for determining how long the user will be able to sleep and acts as a theoretical maximum - the other factors act to reduce the time available.

Output

- Sleep Duration
  - *Very Little, Little, Less Normal, Normal, More Normal, Lots*
  - Scale: Unit Interval [0, 1]
  - Assumption: This output is used to determine what percentage of the Time to Sleep can actually be used for sleep (i.e. an application would multiply this output by the Time to Sleep input to get a final value).
  - It is intended that the output from this stage would set the time of alarm to allow the user time to get dressed, and time to commute to their first meeting.

Subsystem 3

Inputs

- Time Available to Sleep
  - *Little, Normal, A Lot*
  - Scale: 0 - 720 minutes

- Assumption: If the user does not have a lot of time to sleep, they may need a strong coffee to make them feel alert in the morning.

- Current Sleep Cycle
  - *Awake, Lightly Asleep, Fast Asleep*
  - Scale: Unit interval [0,1], heuristic estimate
  - Assumption: Stages of Sleep can be broken into these roughly 3 stages, and it is assumed that a person who is fast asleep will require a louder alarm to wake them up.
  - Many current technologies have implemented smart alarms which attempt to estimate the user's current sleep cycle by measuring how much they are moving (i.e. using a smart phone's accelerometer), so we feel it is not unfeasible to assume we could get access to this information.

- Quality of Sleep
  - *Bad, Normal, Good*
  - Scale: 0 - 1, heuristic estimate.
  - Assumption: This input is the vaguest of all inputs to our system, and estimation of it's value would ideally require a fuzzy subsystem of it's own; however we have chosen to use an assumed input for this to constrain the complexity of our project.
  - In an ideal system, this would indicate the user believing they did (or didn't) have "a good night's sleep", and help us craft actions to help them when they wake up (e.g. adjustment of lighting in the room)

Outputs

- Volume of Alarm
  - *Low, Medium, High*
  - Scale: 0 - 100, arbitrary scale as found on radios with 0 being no sound and 100 being maximum volume.
  - Assumption: This output's goal is to ensure the user is woken by the alarm, without causing excessive distress (i.e. someone in a deep sleep may require a loud alarm, but someoneon in a light state of sleep would not).

- Strength of Coffee
  - *Weak, Regular, Strong*
  - Scale: 0 - 3 shots of espresso
  - Assumption: This output's goal is to help ensure the user is awake and alert at their first meeting - someone who has had a poor night of sleep may require an additional "boost" in the morning compared to someone who is well rested.

Fuzzy Rulebase

The general effects of each input was described in the previous section; however selected key rules are provided in the appendix.

The rules for subsystems 1 and 2 were constructed by determinging the appropriate output for each permutation of the 3 inputs, resulting in 27 rules each.

The rules for subsystem 2 were constructed by determining the appropriate output when pairs of inputs were consider, i.e. what would the appropriate output of Input 1 + Input 2 be, and what would be the appropriate output of Input 1 + Input 3 be? This approach, combined with the additional terms in some of the inputs' term sets resulted in 3 fuzzy patched relationships, with 54 rules. Tables which detail these rules are shown in the appendix. It was found that some rules relating to the commute time needed weighting to reduce the consequent effects on the subsystems outputs, as small changes were having large effects. It is believed that further system tuning could reduce this effect.

Defuzzification for each subsystem was achieved with the Centroid method. No defuzzification was required for the overall output of the system, as the subsystems interacted by providing inputs to other subsystems, rather than aggregating to an overall output.

The resulting Fuzzy surfaces can be found in the appendix.

4 ResultsAnalysis

Testing involved the creation of some imaginary test users, each with a particular type of persona.

The 3 users lifestyles could be described as: An average student (AS), A "work-hard-play-hard" (WHPH) buisnessperson, and finally a sedate commuter (SC).

The full results table is shown in the appendix, but let us discuss the Work-Hard-Play-Hard lifestyle case for an example of the results.

This case attempts to simulate the type of user who could be described as a workaholic, centering their lives around their job by living close to the office and working late into the night before an early start the next day.

For subsystem one, our inputs are:

- Last meal: 15 minutes - a late snack after work.
- Slept day before: 4 hours
- Activity during day: 3000 calories - a lot of walking around

This results in an output "easiness of falling asleep" of 0.166 (the lower, the easier). This intuitively makes sense, it is easy to imagine how working at this pace could result in falling asleep very quickly when you eventually made it to bed.

For substem two, our inputs are:

- Commute time: 20 minutes - living close to work
- Ease of Sleep: This is input is the output of subsystem 1
- Time to Sleep: Assuming a 7AM start, and a bed time of 2AM, this person has a theoretical maximum of 5 hours (300 minutes) to sleep

This results in an output "Sleep Duration Modifier" of 0.867, meaning they can only sleep for about 87% of the theoretical maximum time available. This indicates they will get roughly 4 hrs 20 mins of sleep, leaving them with 20 mins to get ready before their 20 min commute. Intuitively this result appears to make sense.

For subsystem three, our inputs are:

- Current sleep cycle: 0.9 - Due to exhaustion, it is assumed the body will be in a deep sleep
- Time available to sleep: As before, we take the theoretical maximum of 300 minutes
- Quality of sleep: 0.4 - Somewhat normal; however not great due to lifestyle

This results in an output alarm volume of 83 (Medium-High), and a coffee strength of 2.34 shots of espresso. Again, this intuitively makes sense given their deep sleep state, and the short low quality rest they are getting.

5 Conclusions

Overall, our Fuzzy wake up system appears to be able to provide reasonable wake up times, as seen in the results table.

I believe that our results demonstrate the potential for fuzzy logic systems to be highly useful in the near-future technological landscape of highly-connected devices, where technology will be able to help us in our day-to-day lives in more ways.

The key advantage gained in using an application based on our fuzzy logic system, over a traditional alarm, is that it evolves from being a simple clock tool to being more like a personal assistant which attempts to understand the user's lifestyle, in order to appointments are kept (the user does not need to manually set alarm times and factor in things like commute times) and to try help the user feel alert when they wake (intelligent alarm functions like adaptive volume control, and household intelligence such as automated coffee).

Given the complexity and often vagueness of factors which affect the whole sleeping process, I believe that the approach of applying fuzzy logic was highly justified. Given the size of the problem being addressed, I believe it is also true to say that further expansion and improvement of this system is possible using fuzzy systems.

References

[1] Khurshid Ahmad. CS4001. *Trinity College Dublin*, 2014.

[2] Michael Negnevitsky. *Artificial Intelligence: A Guide to Intelligent Systems*. Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA, 1st edition, 2001.

6 Appendix

6.1 Membership Functions

Subsystem 1

Inputs

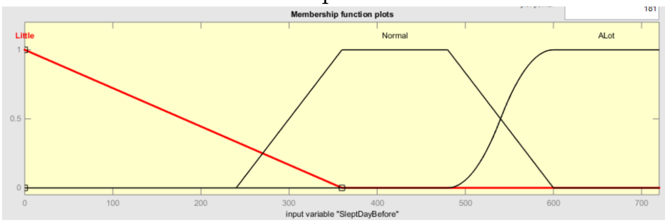

Figure 2: Time Slept Day Before

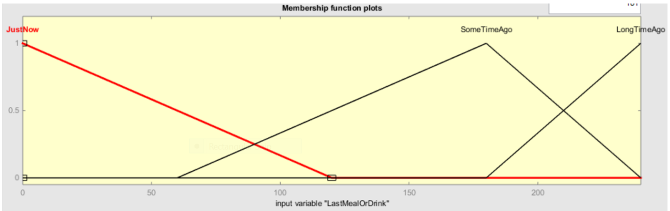

Figure 3: Time Since Last Meal

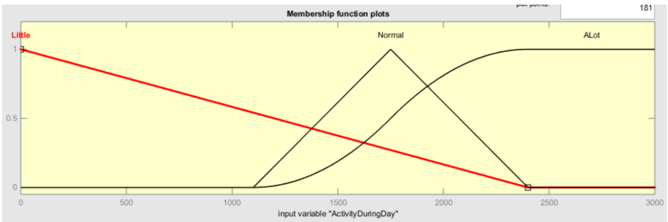

Figure 4: Amount of Activity During the Day

Output

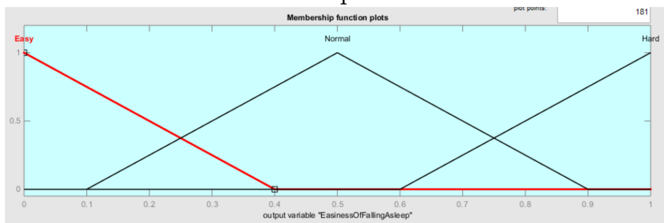

Figure 5: User's Ease of Falling Asleep

Subsystem 2

Input

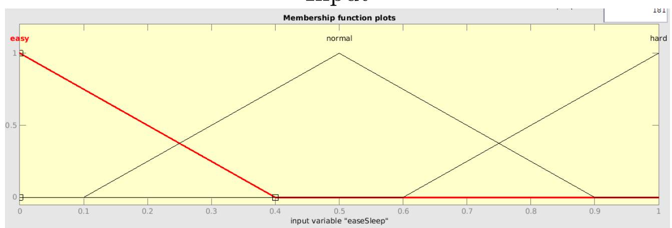

Figure 6: Ease of Sleep (output from Subsystem 1)

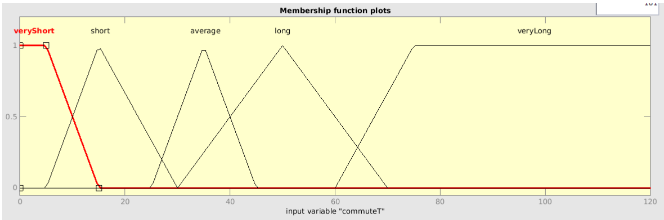

Figure 7: Expected Commute Time in the Morning

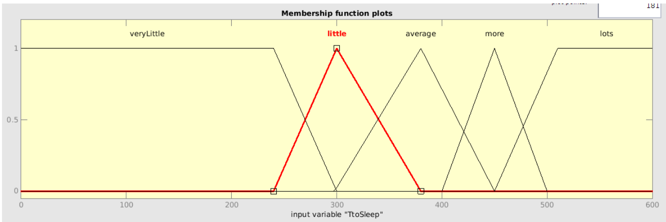

Figure 8: Theoretical Maximum Time Available to Sleep

Output

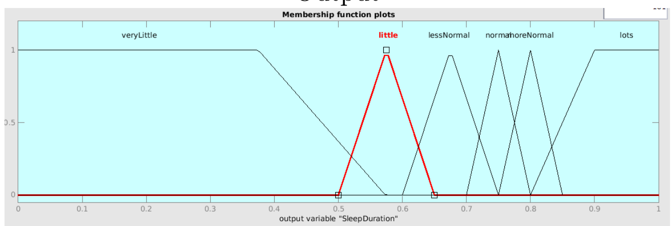

Figure 9: Sleep Duration (as a percentage of the theoretical maximum)

Subsystem 3

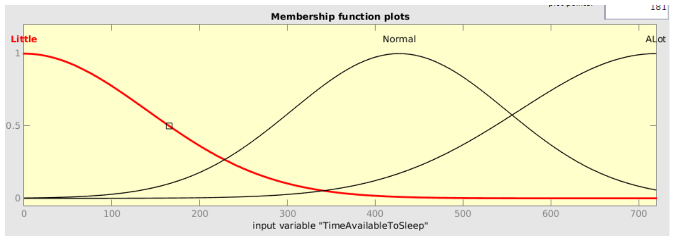

Figure 10: Theoretical maximum time available to sleep

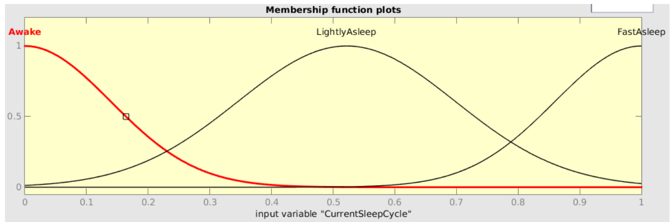

Figure 11: Current Sleep Cycle

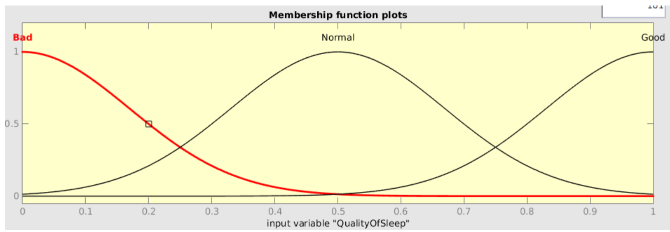

Figure 12: Quality of Sleep

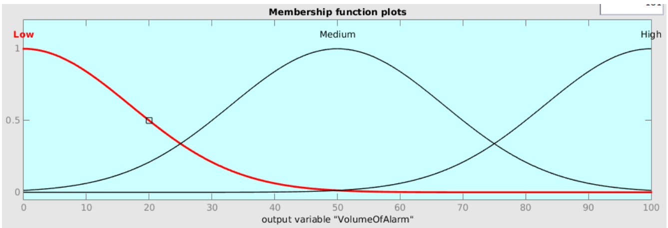

Figure 13: Alarm Volume

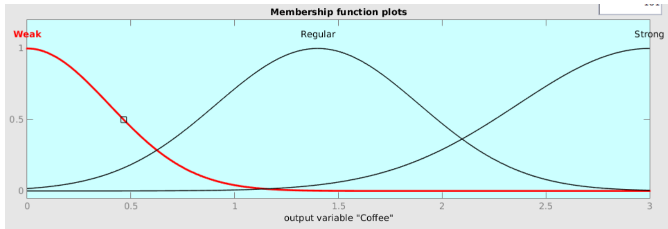

Figure 14: Strength of Coffee

6.2 Key Rules

Below is a selection of the key rules for each subsystem.

Subsystem 1

—Rules which heavily influence easiness of falling asleep—

Assumption: We will more easily fall asleep if we have slept little the day before (all rules except one that include slept little day before have easy as output).

If (LastMealOrDrink is SomeTimeAgo) and (SleptDayBefore is Little) and (ActivityDuringDay is ALot) then (EasinessOfFallingAsleep is Easy)
If (LastMealOrDrink is SomeTimeAgo) and (SleptDayBefore is Little) and (ActivityDuringDay is Normal) then (EasinessOfFallingAsleep is Easy)
If (LastMealOrDrink is SomeTimeAgo) and (SleptDayBefore is Little) and (ActivityDuringDay is Little) then (EasinessOfFallingAsleep is Easy)
If (LastMealOrDrink is JustNow) and (SleptDayBefore is Little) and (ActivityDuringDay is Little) then (EasinessOfFallingAsleep is Easy)
If (LastMealOrDrink is JustNow) and (SleptDayBefore is Little) and (ActivityDuringDay is Normal) then (EasinessOfFallingAsleep is Easy)
If (LastMealOrDrink is JustNow) and (SleptDayBefore is Little) and (ActivityDuringDay is ALot) then (EasinessOfFallingAsleep is Easy)
If (LastMealOrDrink is LongTimeAgo) and (SleptDayBefore is Little) and (ActivityDuringDay is ALot) then (EasinessOfFallingAsleep is Easy)
If (LastMealOrDrink is LongTimeAgo) and (SleptDayBefore is Little) and (ActivityDuringDay is Normal) then (EasinessOfFallingAsleep is Easy)

Normality also leads to easily falling asleep
If (LastMealOrDrink is SomeTimeAgo) and (SleptDayBefore is Normal) and (ActivityDuringDay is Normal) then (EasinessOfFallingAsleep is Easy)

—Rules that show it's hard to fall asleep —

Almost half of the rules (4/9) that results in it being hard to fall asleep includes that we have eaten a long time ago.

If (LastMealOrDrink is LongTimeAgo) and (SleptDayBefore is ALot) and (ActivityDuringDay is Little) then (EasinessOfFallingAsleep is Hard)
If (LastMealOrDrink is LongTimeAgo) and (SleptDayBefore is ALot) and (ActivityDuringDay is Normal) then (EasinessOfFallingAsleep is Hard)
If (LastMealOrDrink is LongTimeAgo) and (SleptDayBefore is Normal) and (ActivityDuringDay is Normal) then (EasinessOfFallingAsleep is Hard)
If (LastMealOrDrink is LongTimeAgo) and (SleptDayBefore is Normal) and (ActivityDuringDay is Little) then (EasinessOfFallingAsleep is Hard)

Off all the 'hard to fall asleep rules' 77% of them got at least two rules at their peakes (Little | ALot | LongTimeAgo | JustNow).
If (LastMealOrDrink is SomeTimeAgo) and (SleptDayBefore is ALot) and (ActivityDuringDay is Little) then (EasinessOfFallingAsleep is Hard)

If (LastMealOrDrink is JustNow) and (SleptDayBefore is ALot) and (ActivityDuringDay is Little) then (EasinessOfFallingAsleep is Hard)
If (LastMealOrDrink is JustNow) and (SleptDayBefore is ALot) and (ActivityDuringDay is Normal) then (EasinessOfFallingAsleep is Hard)
If (LastMealOrDrink is JustNow) and (SleptDayBefore is Normal) and (ActivityDuringDay is Little) then (EasinessOfFallingAsleep is Hard)
If (LastMealOrDrink is LongTimeAgo) and (SleptDayBefore is Normal) and (ActivityDuringDay is Little) then (EasinessOfFallingAsleep is Hard)
If (LastMealOrDrink is LongTimeAgo) and (SleptDayBefore is ALot) and (ActivityDuringDay is Normal) then (EasinessOfFallingAsleep is Hard)
If (LastMealOrDrink is LongTimeAgo) and (SleptDayBefore is ALot) and (ActivityDuringDay is Little) then (EasinessOfFallingAsleep is Hard)

Subsystem 2

—Rules which heavily influence more sleep—

Assumption: We can sleep longer if the commute will be short and we have a decent amount of time to sleep:

if (commuteT is veryShort) and (TtoSleep is average) then (SleepDuration is lots)
if (commuteT is short) and (TtoSleep is more/lots) then (SleepDuration is lots)
if (commuteT is average) and (TtoSleep is lots) then (SleepDuration is lots)

If we can fall asleep easily, and we have a decent amount of time to sleep, we can sleep more:
if (easeSleep is normal) and (TtoSleep is lots) then (SleepDuration is lots)
if (easeSleep is easy) and (TtoSleep is more/lots) then (SleepDuration is lots)

If the commute is short, and we can sleep easily, we can sleep for more of the time available:
if (commuteT is veryShort) and (easeSleep is normal/easy) then (SleepDuration is lots)
if (commuteT is short) and (easeSleep is easy) then (SleepDuration is lots)

—Rules which heavily influence less sleep—

Assumption: If we know we have long to travel, and little time to sleep, we can't use as much of the available time:

if (commuteT is average/long/verylong) and (TtoSleep is veryLittle) then (SleepDuration is veryLittle)
if (commuteT is verylong) and (TtoSleep is Little) then (SleepDuration is veryLittle)

If it is hard to sleep, and we have little time to sleep, then we can't sleep for as long:
if (easeSleep is *hard) and (TtoSleep is little/veryLittle) then (SleepDuration is veryLittle)

If the commute is long, and it's hard to fall asleep, then we can't sleep for as long:
if (commuteT is verylong) and (easeSleep is hard) then (SleepDuration is veryLittle)

Subsystem 3
Waiting on Seb...

Subsystem 2 Rulebase development

		Time Available to Sleep				
		veryLittle	little	average	more	lots
Commute Time	very short	lessNormal	normal	moreNormal	**lots**	**lots**
	short	little	normal	moreNormal	**lots**	**lots**
	average	**veryLittle**	lessNormal	normal	moreNormal	**lots**
	long	**veryLittle**	little	lessNormal	normal	morenormal
	very long	**veryLittle**	**veryLittle**	little	lessNormal	normal

		Time available to Sleep				
		veryLittle	little	average	more	lots
Ease of Falling Asleep	hard	veryLittle	veryLittle	little	lessNormal	Normal
	normal	little	lessNormal	Normal	moreNormal	lots
	easy	lessNormal	Normal	MoreNormal	lots	lots

		Commute Time				
		very short	short	average	long	very long
Ease of Falling Asleep	hard	moreNormal	normal	lessNormal	little	veryLittle
	normal	lots	moreNormal	normal	lessNormal	little
	easy	lots	lots	moreNormal	normal	lessNormal

Figure 15: Subsystem 2 Rulebase Tables

6.3 Surfaces

Subsystem 1

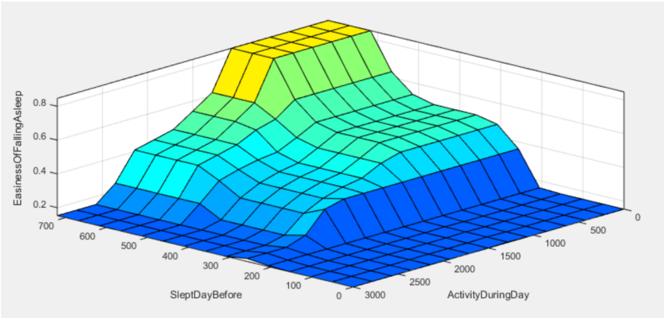

Figure 16: Activity During the Day v Time Slept Day Before v Ease of Falling Asleep

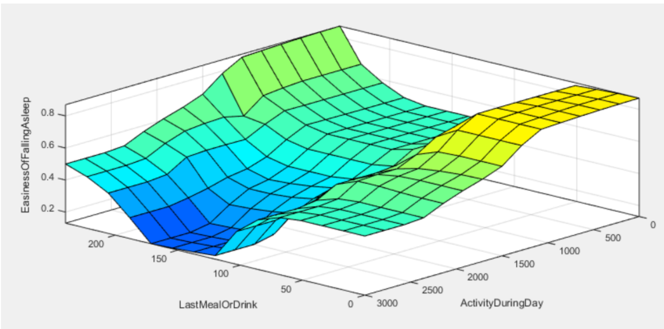

Figure 17: Last Meal Before Sleep v Activity During the Day v Ease of Falling Asleep

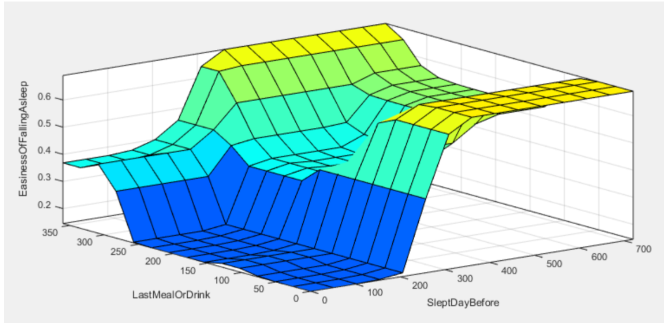

Figure 18: Last Meal Before Sleep v Time Slept Day Before v Ease of Falling Asleep

Subsystem 2

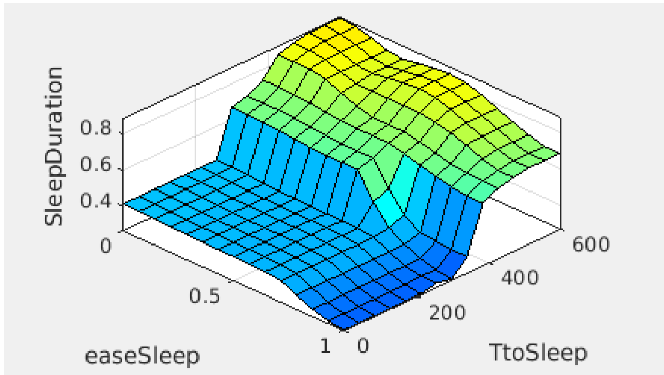

Figure 19: Ease of Sleep v Time Available to Sleep v Sleep Duration

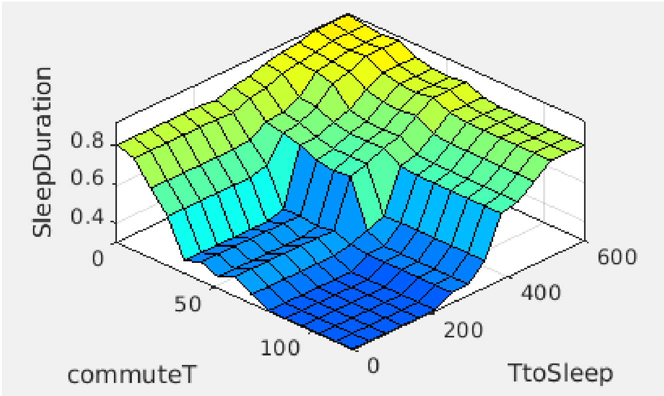

Figure 20: Commute Time v Time Available to Sleep v Sleep Duration

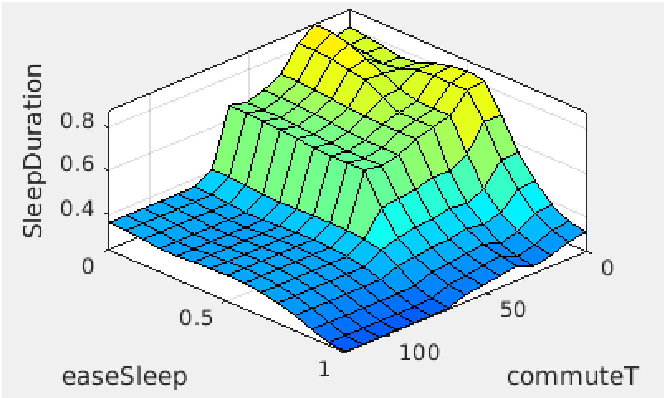

Figure 21: Commute Time v Time Available to Sleep v Sleep Duration

Subsystem 3

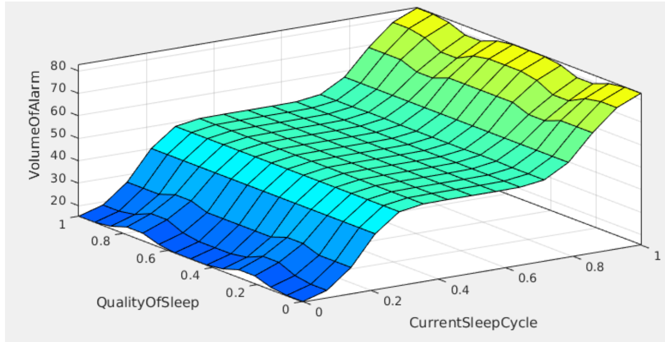

Figure 22: Current Sleep Cycle v Quality of Sleep v Strength of Coffee

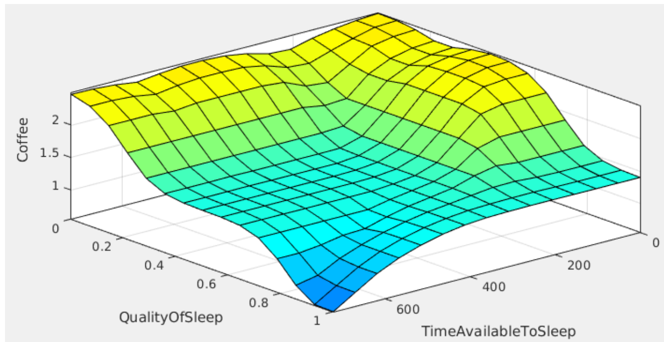

Figure 23: Current Sleep Cycle v Quality of Sleep v Strength of Coffee

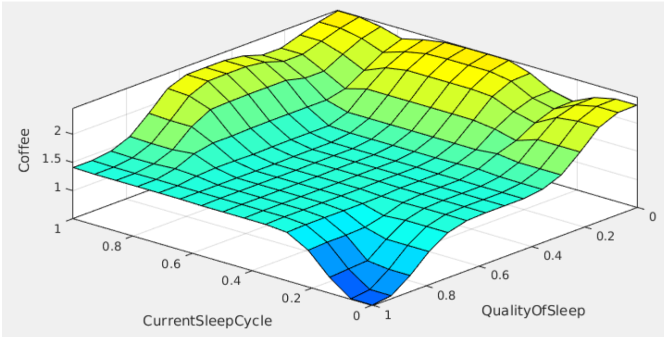

Figure 24: Time Available to Sleep v Quality of Sleep v Strength of Coffee

6.4 Results Tables

Results from 3 test cases: Average Student (AS), Work Hard Playhard Buisnessperson (WHPH), Sedate Commuter (SC)

Subsystem 1

User	Last Meal	Slept Day Before	Activity	**Ease of Sleep**
AS	60	360	2400	0.5
WHPH	15	240	3000	0.166
SC	120	540	1500	0.476

Subsystem 2

User	Commute Time	Ease of Sleep	Time Available to Sleep	**Sleep Duration**	**Time Sle*eping**
AS	60	0.5	480	0.848	6.784[1]
WHPH	20	0.166	300	0.867	4.335[2]
SC	90	0.476	600	0.82	8.2[3]

1: This would indicate a wake up time of about 7.30AM for a bed time of 1AM, with 30min to get ready, a commute of 60min and an appointment at 9AM.
2: Person wakes up at around 6.15AM, has 25 mins to get ready and then commutes 20min (i.e. assumes they live close to work, and they start work at 7AM).
3: Person wakes up around 6.58am, gets ready in 30 mins roughly, then has a long commute of 90mins for a 9AM start.

Subsystem 3

User	Current Sleep Cycle	Time Available to Sleep	Quality of Sleep	**Volume of Alarm**	**Coffee**
AS	0.8	480	0.6	78.6	1.99
WHPH	0.9	300	0.4	83	2.34
SC	0.6	600	0.9	50	1.03