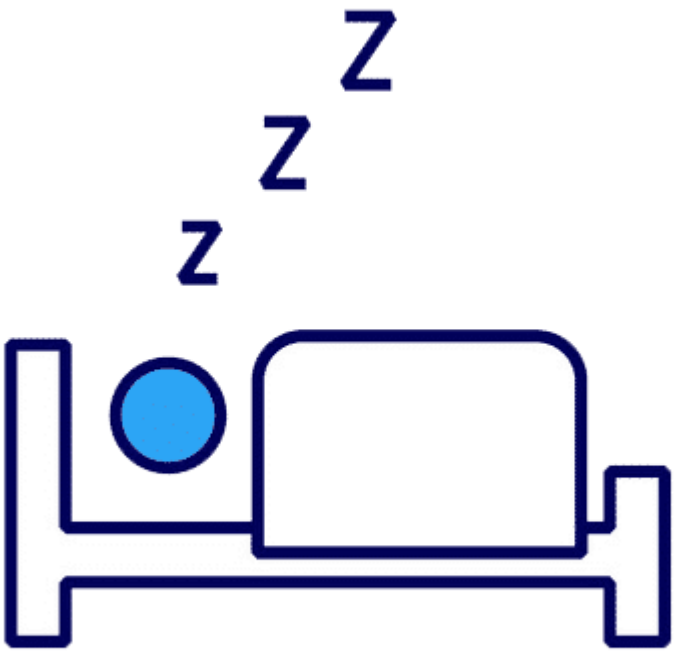
Thomas LEOPOLD & Baptiste VIERA

Assessment of sleep quality and diagnosis of sleep



Supervised by D.DESCHAMPS

Acknowledgements

We would like to sincerely thank Mr. ZALILA who was able to transmit his passion for fuzzy logic. We were pleasantly surprised by the versatility that fuzzy logic offers to solve complex real-life problems.

We do not regret having made the choice to follow SY10 this semester, because even if this UV requires an important personal investment in order to master all the new concepts, it proved to be an exciting and enriching UV. As Mr ZALILA had announced at the beginning of the semester, we now have all the necessary tools to set up projects based on fuzzy logic as shown in this report.

We would also like to thank Mr. DESCHAMPS for guiding and advising us throughout the semester in order to carry out our project which we are pleased to present to you.

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Introduction

The average person sleeps for eight hours a day, which means that he or she will sleep for approximately 229,961 hours, that is, for more than 26 years, or one third of his or her life. Nowadays, many scientific studies have shown that sleep is as important for our survival as eating and drinking.

Sleep can be defined as a succession of three to five cycles of about 90 minutes each. Within each cycle, there is an alternation of two different types of sleep that are associated with specific brain waves: REM sleep, slow wave sleep also called REM (Rapid Eye Movement) sleep, and non-REM sleep, which represent respectively about 25% and 75% of our sleep time.

Lack of sleep inevitably has negative repercussions on our health but also on our social life. For example, the brain is no longer able to activate the process of memory consolidation or a repeated lack of sleep can drastically increase the risk of developing cardiovascular diseases and cancers. Sleep is therefore crucial for multiple biological functions and this is why sleep disorders must be taken seriously in order to avoid any damage to health.

For example, we can look at sleep apnea which is now a global problem since more than 18 million Americans suffer from it daily. This disease is valid for both sexes but also for children since it is estimated that 2% to 3% are affected.

Sleep apnea is, as its name suggests, a sleep disorder that causes a brief interruption in the sleeper's breathing. A patient is considered to have sleep apnea when he or she experiences several interruptions of at least 10 seconds. From a medical point of view, sleep apnea occurs when the muscles of the throat are not able to keep the airway open and this causes a low level of oxygen in the blood and a poor quality of sleep.

Since we are interested in the quality of sleep as well as its diseases, it is necessary to define another common disease: insomnia. It is defined as a decrease in the quality and quantity of sleep. Even if the origins of insomnia are not clearly identified, there are a multitude of symptoms. Indeed, sleeping for short periods of time, waking up too early and feeling like you haven't slept all night are some of the key symptoms to identify.

The use of fuzzy mathematics is particularly interesting because we will deal with imprecise data. Moreover, given the complexity of sleep and the uncertainty of the data of the different variables involved, the use of binary logic would be inappropriate since it would oversimplify the solution of the problem which means that the results would not be consistent. The intelligibility of the system will also be of great help since it will allow the implementation of consultation advice which will contribute to the improvement of sleep quality.

The goal of our fuzzy model is, on the one hand, to evaluate the quality of sleep of an adult (man or woman) by giving him a score on 100 based on brain waves such as beta, sigma, delta and alpha; as well as to detect if he suffers from sleep diseases like insomnia or sleep apnea. In a second step, we will interpret the results obtained to refer the person to specialized doctors.

I - What is sleep?

As mentioned in the introduction, there are two different types of sleep, non-REM sleep and REM sleep.

The non-REM period (slow wave sleep) is divided into three stages.

The first stage is that of falling asleep, which lasts only a few minutes. At this stage, our body and muscles relax, our heart rate, breathing and eye movements decrease. We are at the border between wakefulness and sleep. The frequency of alpha waves (rhythms), which correspond to the state of calm wakefulness, decreases sharply to make way for the installation of sleep, which is reflected by an increase in the frequency of theta waves.

The second stage which represents 50% of the total sleep time is the light sleep phase. Our body and muscles relax even more, as well as our heart rate and breathing rate which continue to decrease. At this stage, eye movements have stopped and our body temperature has started to drop. Theta waves remain dominant but are interrupted by peaks of brain activity called spindles or sigma waves. These spindles, which play a key role in memory consolidation, are the expression of deepening sleep. Then, during this phase, we also distinguish non-systematic peaks of activity, even more intense than those produced by the sigma rhythms, which are called K-complexes. Even if their role is not totally determined, they seem to be elements leading to the deepening of sleep.

The third and most important stage is the deep sleep phase.
This is the period when the heart and breathing rates are lowest. Slow, high amplitude waves, called delta waves, which may begin to appear during stage 2, occupy more than 20% of brain activity during the deep sleep phase. This stage is the expression of a sleep that repairs and regenerates our body.

Following this stage, of deep slow wave sleep, there is a rapid electroencephalographic activity that is similar to that observed during the awake state. This is REM sleep, which generally occurs 90 minutes after falling asleep. Mixed brain wave frequencies of low amplitude are observed: theta rhythm is dominant compared to alpha and beta rhythms. In addition, there is an abolition of muscle tone, repeated eye movements and an irregularity of the cardiac and respiratory rhythms which have accelerated. It is important to know that it is during this REM period that our most intense dreams take place.

In our project, in order to evaluate the quality of sleep of a person, we will focus on the non-REM period which is the most decisive according to us by focusing essentially on the alpha, beta, sigma and delta waves.

II - Design of the fuzzy system

1 - List of input variables

1. Magnesium level
2. Sound intensity
3. Vitamin C levels
4. Meditation time
5. Alcohol content
6. Nicotine rate
7. Fat content
8. Carbohydrate levels
9. Fiber content
10. Time at which coffee is drunk
11. Quantity of coffee
12. Vitamin E level
13. Calcium level
14. Time of day when we are confronted with blue light
15. Vitamin B6 levels
16. Number of night wakings
17. Time to fall asleep
18. Snoring
19. Heart rate
20. Number of apneas longer than 10 seconds
21. Oxygen level in the blood

2 - Explanation of the choice of variables and subsystems

A- Subsystem n°1: Alpha waves

As we explained earlier, alpha waves are responsible for the calm wakefulness and relaxation and are therefore essential during the first stage of the non-REM (*non-rapid eye movement*) period. During this phase, which lasts only a few minutes, our body relaxes and gets ready to start the second stage of sleep: the light sleep phase. During this phase, the alpha waves will have strongly decreased.

It is therefore logical for such a sub-system to focus on two substances that act on the relaxation of the body in a significant way: alcohol and nicotine. Alcohol has a particular character since it allows patients to fall asleep quickly but the quality of sleep is low. During the first stage of the non-REM period, a high level of alcohol promotes the development of alpha waves and thus also relaxation. But, during the light sleep phase, which corresponds to the installation of sleep, we observe an abnormal increase of alpha waves which means that the non-REM sleep is finally disturbed and explains the frequent sleep interruptions. It is this phase that we will take into account in the continuation of our project.

The **alcohol** variable will represent the amount of alcohol in the blood in g/kg.

Concerning nicotine, most smokers claim that smoking allows them to relax. Indeed, this substance causes the same disturbances on the brain waves as alcohol and as we have seen in the previous paragraph, it decreases the quantity and the overall quality of sleep.

The variable **nicotine** represents the number of cigarettes smoked per day.

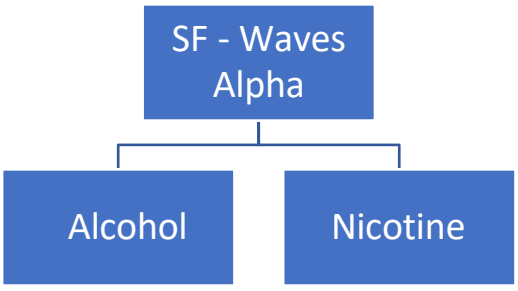

Figure 1: SF - Alpha Waves

B - Subsystem n°2: Beta waves

It is important to know that beta brain waves are mainly present during the day, when we are awake. Thus, we observe a very low electroencephalographic activity of beta rhythms during the different phases of sleep. However, stress can significantly increase the activity of this type of wave and consequently make it difficult for our body to enter the light sleep phase which is the second stage of non-REM sleep. The delay in falling asleep, and the possible interruptions of sleep will be responsible for a reduced quality of sleep. Indeed, the duration of the slow wave and deep sleep stages as well as REM sleep will be shorter than normal, so sleep will not be restful.

To assess the stress level of the person, we set up a fuzzy subsystem **Cortisol** which is a steroid hormone that secreted in excess can be called stress hormone. This fuzzy system consists of three variables that have a direct impact on the secretion of cortisol.

The variable **sound intensity** corresponds to the sound intensity in decibel measured when the person starts to fall asleep. If the surrounding noise is too high, it can significantly increase the amount of cortisol produced by the body and indirectly the activity of beta waves.

The **vitamin C** variable corresponds to the daily dose in milligrams taken by an adult (man or woman). Vitamin C (ascorbic acid), in addition to its antioxidant effects and its effects on the immune system, German researchers have shown that this vitamin, when taken in sufficient quantities, can reduce the level of cortisol in our bodies and indirectly reduce beta rhythms.

The variable **meditation** corresponds to the duration in minutes of this discipline. It is no longer necessary to prove its benefits on our body. Before falling asleep, the practice of meditation will allow us to relax our body, to release it, and especially to eliminate all stress, in other words to reduce the secretion of cortisol.

The **Cortisol** fuzzy system combines with the **magnesium** variable to form the **Beta Wave** fuzzy system.

The variable **magnesium** corresponds to the daily dose in milligrams taken by an adult (man or woman). Magnesium is a mineral salt that plays an important role in the regulation of stress and anxiety because it binds to GABA (gamma-aminobutyric acid) receptors, a neurotransmitter that decreases the electroencephalographic activity of mainly beta waves.

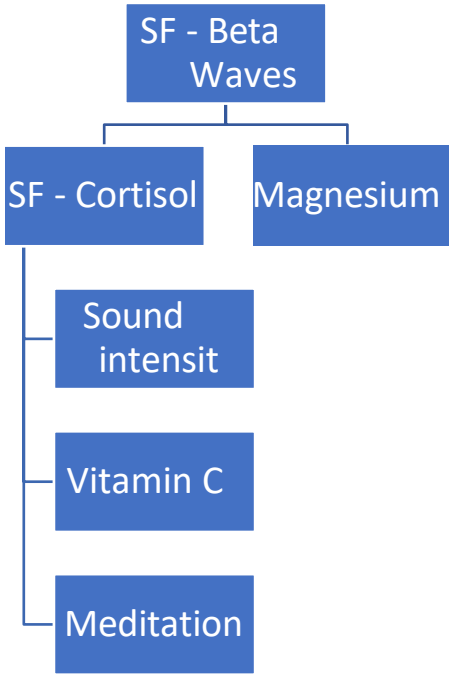

Figure 2: SF - Beta Waves

C - Subsystem n°3: Sigma waves

Sigma waves consist of a sudden increase in electroencephalographic activity over a period of 0.5 to 2 seconds. They are responsible for memory consolidation but also for sleep preservation. They are especially present during the second part of the night because they act on the hippocampus in order to prepare a new learning period.

To evaluate the concentration of **sigma waves**, we set up a fuzzy **melatonin** subsystem. This hormone, which is naturally produced in case of darkness, is also known as the "sleep hormone" and plays an important role in sleep. Its secretion peaks between 2 and 4 a.m., the time when sigma waves are most active to ensure restful sleep. This fuzzy subsystem is therefore made up of 3 variables that can influence melatonin levels.

The **calcium** variable is the number of mmol/L of calcium per liter of blood in a human.

The **blue light** variable corresponds to the time from which one is confronted with a screen. The wavelength of blue light (intermediary office) is 509 nm. It should be known that melatonin is very sensitive to light and it is for this reason that it is secreted in the dark. The light produced by our screens will therefore send a bad signal to our brain which will prevent the secretion of melatonin and therefore it will shift the sleep rhythm considerably.

The **vitamin B6** variable corresponds to the number of milligrams of vitamin per day. Vitamin B6 is beneficial for the body and for sleep since it will convert tryptophan (an amino acid) into serotonin, which is a neurotransmitter to regulate the amount of melatonin. It has actually been shown by the University of Adelaide (2018) that people who take a vitamin B6 supplement possess better quality sleep.

Then, the **melatonin** blur system combines with **vitamin E** to form the **Sigma Wave** blur system.

The **vitamin E** variable corresponds to the daily intake (IU) of vitamin to ensure the proper functioning of the human body. Vitamin E is a powerful antioxidant and has neuroprotective effects. Lack of sleep leads to problems with memory consolidation, and the consumption of vitamin E helps to prevent this thanks to its antioxidant role on the hippocampus.

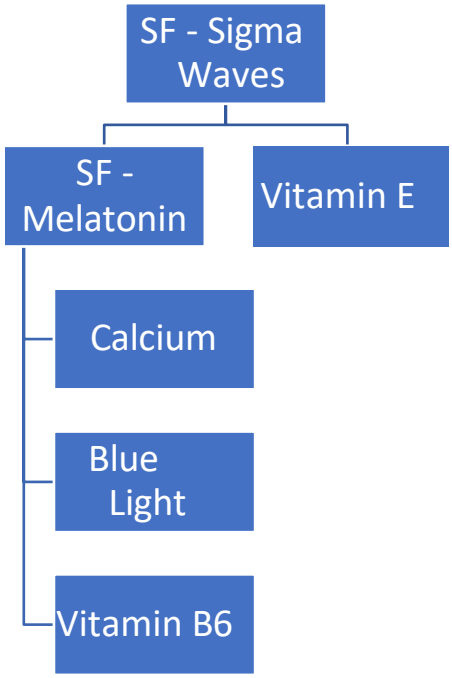

Figure 3: SF - Sigma Waves

D - Subsystem n°4: Delta waves

As mentioned in the introduction, delta brain waves are mainly triggered during the deep sleep phase of the non-REM period. This type of wave is directly related to a restful sleep. The higher the electroencephalographic activity of the delta rhythms, the better the quality of sleep.

We found that the amount of adenosine (a hypothesized neuromodulator of wakefulness) in our brain and the quality of food ingested before going to play an important role in delta wave activity.

That's why we decided to combine the **adenosine** blur system with the **food quality** blur system to form the **delta wave** blur system.

First, let's zoom in on the **adenosine** subsystem. It is important to know that it has been proven that a sufficient concentration of adenosine in the brain increases drowsiness and especially delta wave activity during the deep sleep phase.

The subsystem in question will be composed of the following variables: **coffee quantity** and **coffee hour**.

The variable **coffee quantity** represents the number of 52 ml cups of coffee containing 100 mg of caffeine.

The variable **coffee hour** represents the number of hours between taking a certain amount of coffee and going to sleep.

We were interested in coffee because caffeine has the ability to cross the blood-brain barrier that separates the bloodstream of the brain from the rest of the body. Since the caffeine molecule has a similar structure to the adenosine molecule, once in the brain, it can bind, without activating them, to the adenosine receptors on the surface of the cells. Caffeine can be said to be an adenosine receptor antagonist or competitive inhibitor because it blocks the reaction normally catalyzed by the enzyme cAMP phosphodiesterase. This leads to an increase in dopamine levels, which is responsible for low delta brain wave activity and therefore unrefreshing sleep.

The other fuzzy subsystem that, together with the **adenosine** system**,** forms the **beta wave** fuzzy system is **food quality**. This system consists of the following three variables: **carbohydrate**, **fat** and **fiber**.

The **carbohydrate** variable represents the daily dose of carbohydrate in grams. It has been shown that a very high dose of carbohydrate in the blood is associated with a lower quality of sleep. Indeed, during the slow wave sleep phase, the expression and duration of delta wave activity is much lower than normal.

The **fat** variable represents the daily dose of fat in grams. On the other hand, for healthy people, an additional intake of fat will help their body to produce more delta waves and to extend their activity duration during the slow and deep sleep phase.

Note: The average duration of delta wave activity for a person on the "high carbohydrate, low fat" diet is only 97 minutes, while the person on the "low carbohydrate, high fat" diet is 117 minutes and the control person is about 110 minutes.

The **fiber** variable represents the daily dose of fiber in grams. Just like fat, fiber will help extend the duration of slow wave and deep sleep and thus increase the duration of delta rhythm activity, which characterizes good quality and especially restorative sleep.

Note that for the construction of our classes we decided to separate the case of men and women since the values of our variables all depend on the caloric intake of the adult. The recommended caloric intake of an adult man is higher than that of a woman (about 2500 calories for the man against 2000 calories for the woman).

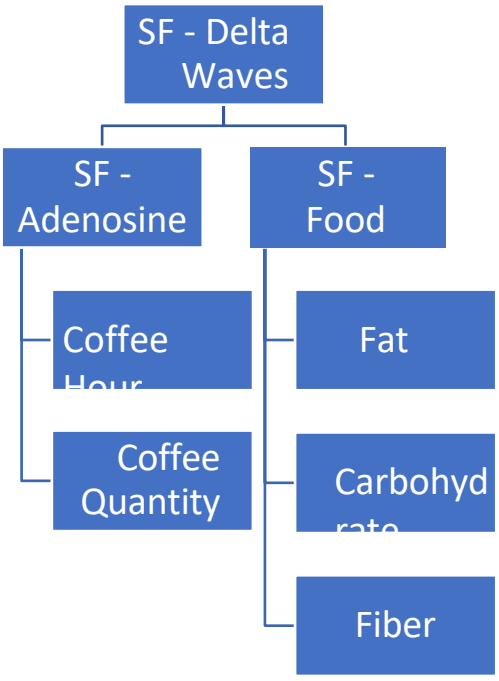

Figure 4: Delta waves

E - Subsystem n°5: Sleep apnea

In addition to assessing sleep quality, we also wanted to diagnose two sleep diseases: apnea and insomnia.

As previously explained, a patient has sleep apnea when he/she experiences several breathing interruptions of minimum 10 seconds. We have defined a fuzzy **sleep apnea** system consisting of three variables.

The **heart rate** variable corresponds to the number of beats per minute when the patient is sleeping. It is important to know that sleep apnea often results in a significant drop in heart rate because the brain is deprived of oxygen for its proper functioning. The lower the heart rate, the more likely the patient is to suffer from this disease.

The variable **number of apneas per hour longer than 10 seconds** simply refers to the definition of the disease. Indeed, the apnea period must be superior to 10 seconds and the more interruptions, the more likely the patient will be considered as a sleep apneic.

Finally, the **blood oxygen level** (SpO2) variable is the percentage of oxygen saturation in the blood. This is the percentage of oxygenated hemoglobin to the amount of hemoglobin in the blood. For example, if the patient has a percentage of 97%, this means that each red blood cell is composed of 97% oxygenated hemoglobin and 3% non-oxygenated hemoglobin. Normal SpO2 values are between 95 and 100% and if a patient's SpO2 is ever below 95% it means that he or she is suffering from poor oxygenation, also called hypoxia.

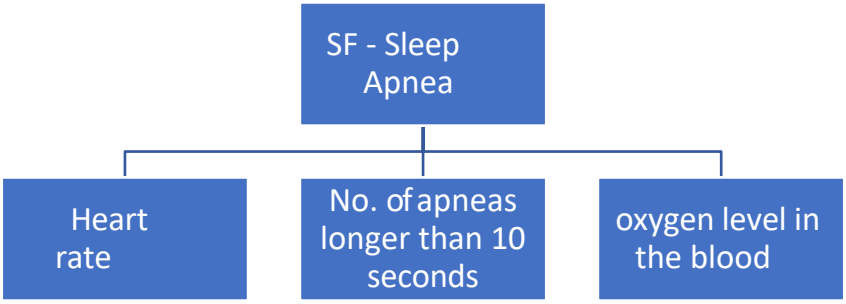

Figure 5: FS - Sleep Apnea

F - Subsystem #6: Insomnia

As we have seen previously, insomnia is a widespread sleep disorder that consists of a reduction in the quantity and quality of sleep. The **insomnia** fuzzy system is therefore composed of the following three variables:

We are therefore logically interested in the variable **number of nocturnal awakenings**. The more the patient wakes up during the night, the more likely he or she will suffer from insomnia.

The **time to sleep** variable is also important because a patient is considered to have insomnia when it takes more than 20 minutes to fall asleep.

And finally, the **snoring** variable is measured in decibels and corresponds to the noise of breathing during sleep. The higher the volume of sound, the more likely the patient has insomnia.

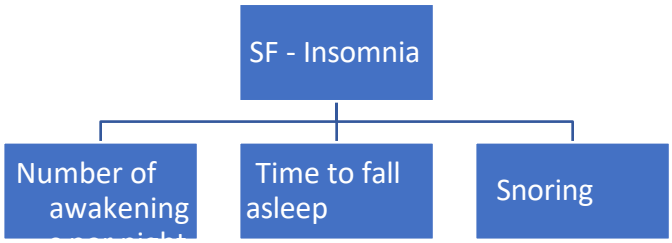

Figure 6: FS - Insomnia

G - Subsystem #7: Sleep quality

Now that we have defined the **alpha wave** and **beta wave** fuzzy subsystems, we can explain the **Q_Endorming** fuzzy system which combines the two previously mentioned subsystems.

Indeed, the output of the **alpha wave** subsystem tells us whether the alpha wave activity is high, medium or low depending on the patient's alcohol and nicotine levels. As previously pointed out, we are interested in the light sleep phase, in other words, the higher the amount of alpha waves the lower the quality of sleep.

The second fuzzy **beta wave** subsystem will also output the beta wave activity as a function of the patient's blood cortisol and magnesium levels. Beta waves are related to stress because the more a patient is stressed, the more the beta wave activity will be important. Beta waves are therefore harmful for the sleep phase: the lower the activity of these waves, the better the quality of sleep.

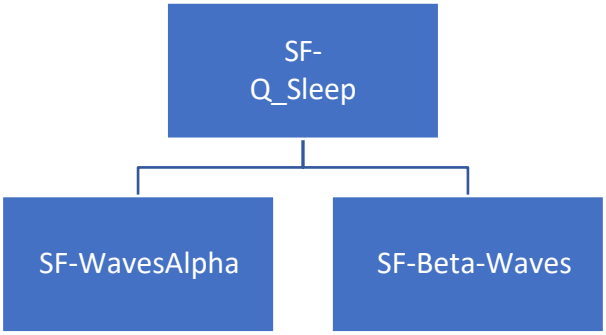

Figure 7: SF - Sleep Quality

H - Subsystem no. 8: Sleep quality

The fuzzy system **Q_Sleep** being defined as well as the subsystems **sigma waves** and **delta waves**, we can now explain one of the 3 main systems: the system **Q_Sleep**.

This system is composed of the **sigma wave** fuzzy subsystem which will indicate the sigma wave activity through the melatonin and vitamin E levels of the patient. As mentioned in the definition of the subsystem, sigma waves are essential during the second part of the night since they are responsible for memory consolidation and therefore allow the patient to have a restful sleep. Therefore, the higher the sigma wave activity, the better the sleep quality.

The second subsystem, **delta waves,** will allow us, like the **sigma wave** system, to know the activity of delta waves. These waves are triggered during the deep sleep phase of the non-REM period; they are therefore beneficial since they promote the development of deep and restful sleep. Thus, the higher the delta wave activity, the higher the quality of sleep.

Finally, the last fuzzy subsystem used is **Q_Sleep**. As its name indicates, it allows to evaluate the quality of the first part of the night, in other words the falling asleep of an individual. Therefore, the more easily the patient falls asleep, the more important the quality of sleep will be.

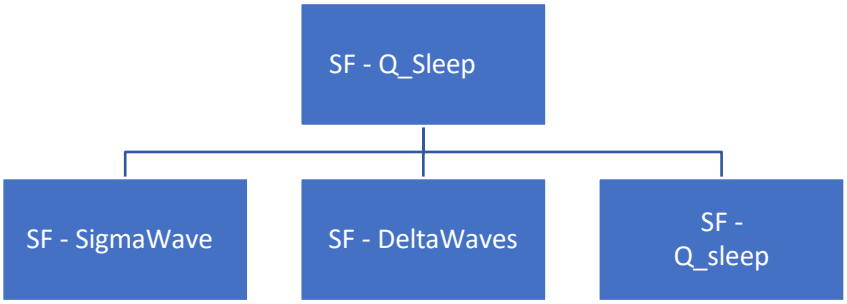

Figure 8: SF - Sleep Quality

I - Fuzzy system : Advice

Since we have just defined the fuzzy subsystem **Q_Sleep**, we can now have our complete fuzzy system which includes the subsystems **apnea** and **insomnia** as well as **Q_Sleep**.

The **apnea** subsystem will tell us if the patient has apnea to some degree (low, medium or high). The **insomnia** subsystem will also tell us if the patient has insomnia and to what degree. Finally, the **Q_Sleep** subsystem will give us a score on the individual's sleep quality. The correlation of these three data allows us to provide the patient with personalized advice for consultation with specialized doctors so that he can improve his sleep quality as effectively as possible.

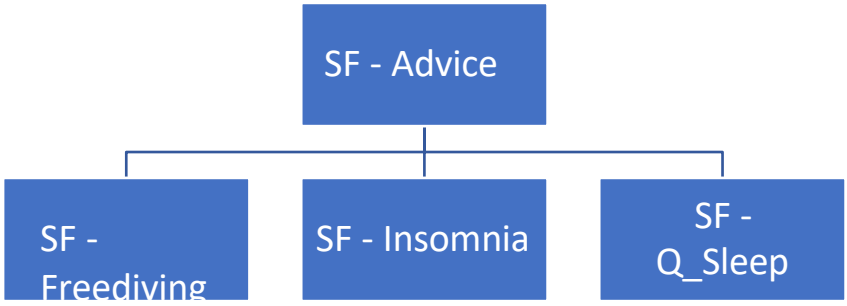

Figure 9: SF - Tips

III - Implementation with MATLAB

Note that we have chosen to use for our fuzzy model the Zalila classification algorithm which turns out to be interesting for the problem we have posed. Then, we decided to use only the MIN operator (a MIN B = the minimum between the two) which is the most optimistic operator, the most permissive of the T-norms. In our project, we do not seek to reduce the impact of an inference on the final output. This is why we did not use another T-norm such as the probabilistic T-norm which is more restrictive than the min.

1 - Creation of subsystems

A - Subsystem n°1: Alpha waves

Number of cigarettes per day	
[0 0 1 4]	Low
[1 4 5 9]	Medium
[5 9 14 14]	High

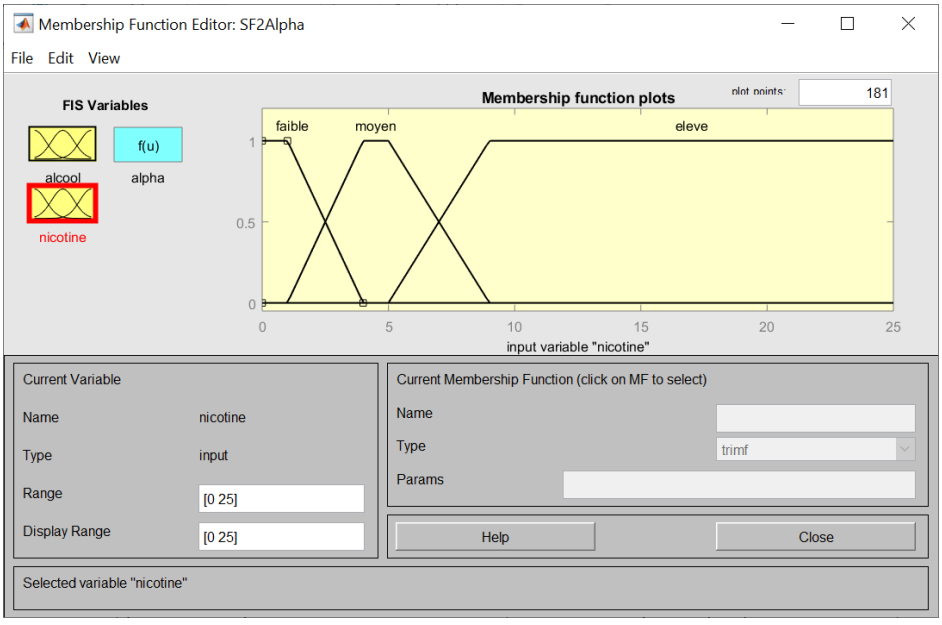

Figure 10: Nicotine Classes

Alcohol content (g alcohol/kg)	
[0 0 0.5 0.10]	Low
[0.05 0.10 0.32 0.64]	Medium
[0.32 0.64 1 1]	High

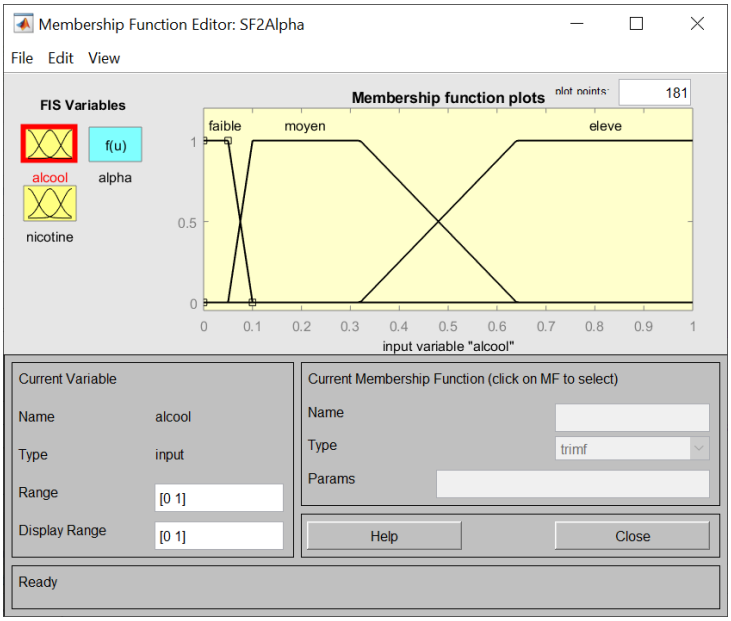

Figure 11: Alcohol Classes

Wave_Alpha system rules:

Alcoho / Nicotine	Low	Medium	High
Low	Low	Medium	High
Medium	Medium	High	High
High	High	High	High

The possible conclusions of the Wave_Alpha system rules are: Low, Medium, High

B - Subsystem n°2: Beta waves

Cortisol subsystem:

Sound intensity (in dB)	
[0 0 15 30]	Low
[15 30 40 55]	Medium
[40 55 infinity infinity]	High

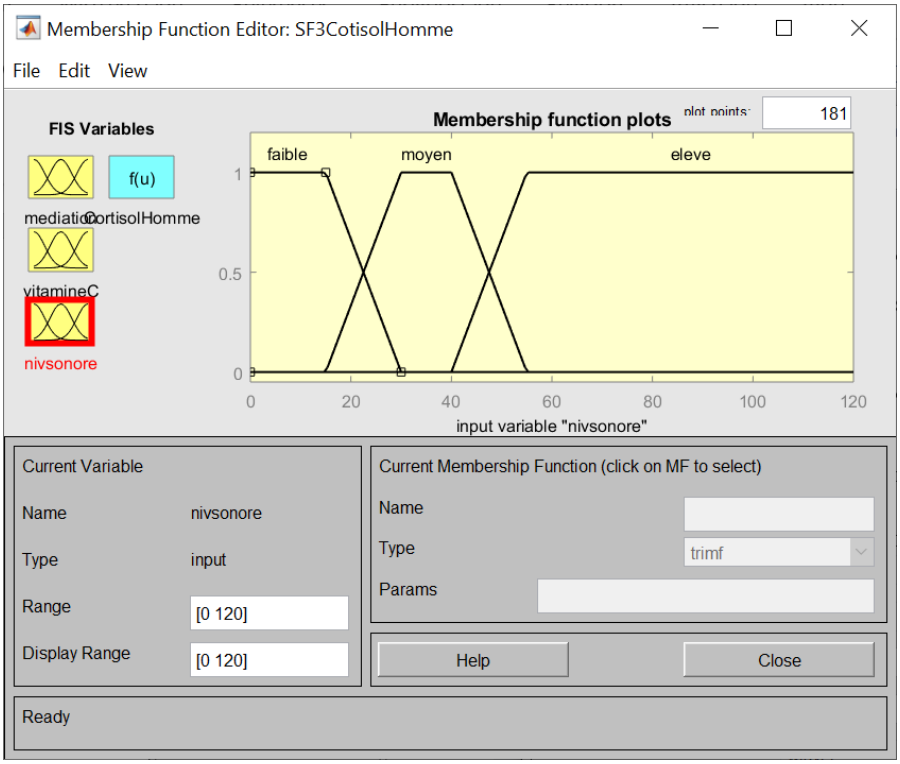

Figure 12: Sound Level Classes

Female Vitamin C level (mg/L)	
[5 5 20 50]	Low
[20 50 100 1500]	Medium
[100 1500 infinity infinity]	High

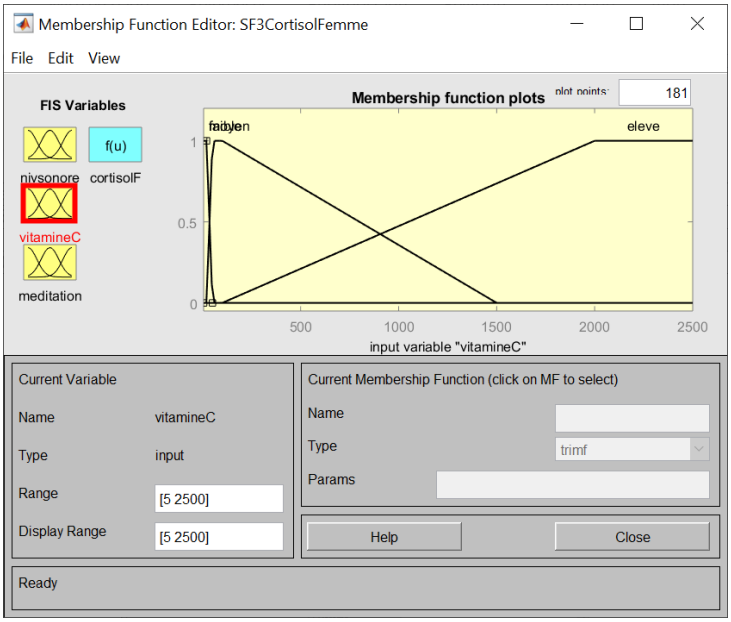

Figure 13: Vitamin C Classes Female

Vitamin C level for men (mg/L)	
[5 5 40 70]	Low
[40 70 110 2000]	Medium
[110 1500 infinity infinity]	High

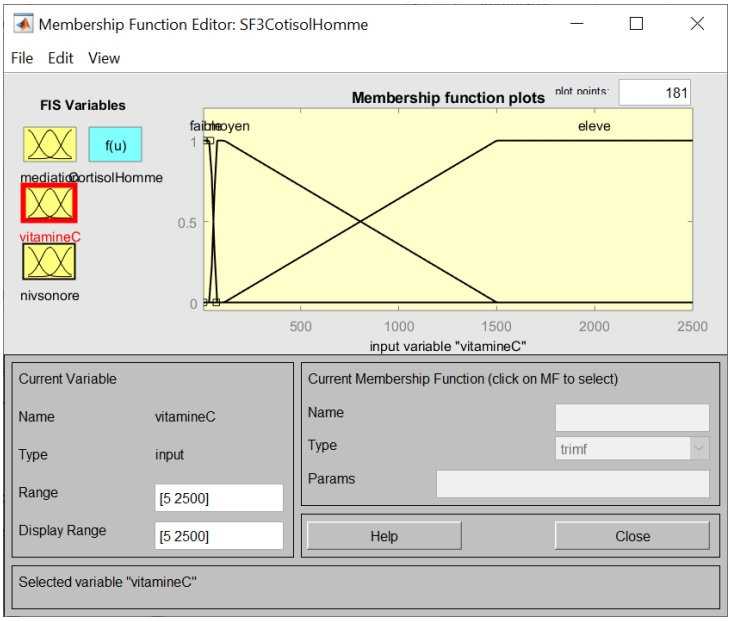

Figure 14: Vitamin C Classes Male

Mediation (in minutes)	
[0 0 2 5]	Low
[2 5 10 15]	Medium
[10 15 infinity infinity]	High

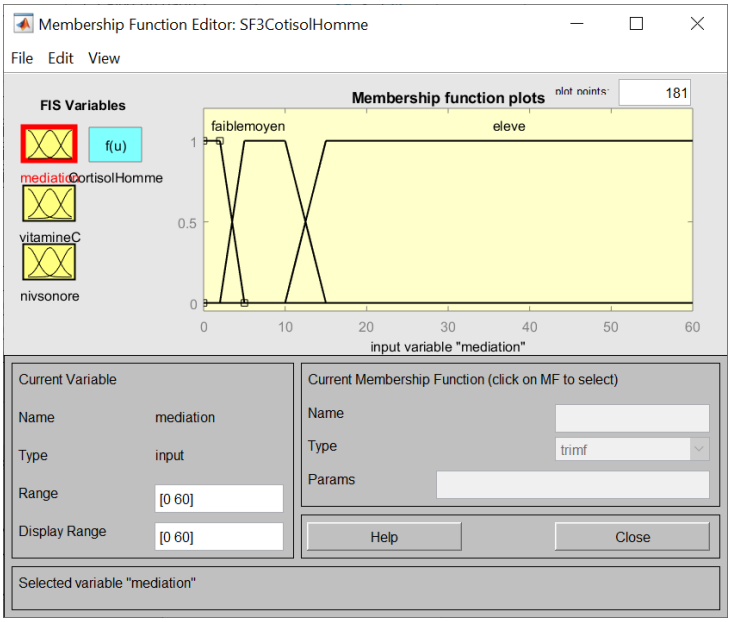

Figure 15: Meditation Classes

Cortisol rules:

Meditation Low

Intensity sound / Vitamin C	Low	Medium	High
Low	High	High	High
Medium	Low	Medium	High
High	Low	Low	High

Meditation Medium

Intensity sound / Vitamin C	Low	Medium	High
Low	Medium	High	High
Medium	Low	Medium	High
High	Low	Low	High

Meditation High

Intensity / sound / Vitamin C	Low	Medium	High
Low	Low	Medium	High
Medium	Low	Low	High
High	Low	Low	High

The possible conclusions of the Cortisol system rules are: Low, Medium, High

Beta Waves subsystem :

Magnesium level for men (mg/day)	
[100 100 200 300]	Low
[200 300 520 2500]	Medium
[520 2500 infinity infinity]	High

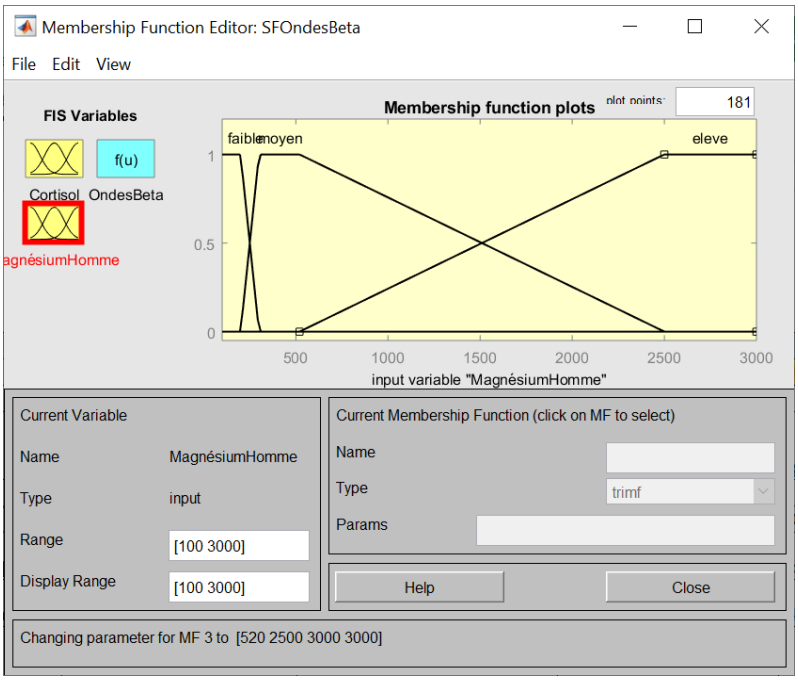

Figure 16: Magnesium classes for men

Magnesium rate Woman (mg/day)	
[100 100 200 250]	Low
[200 250 370 2500]	Medium
[370 2500 infinity infinity]	High

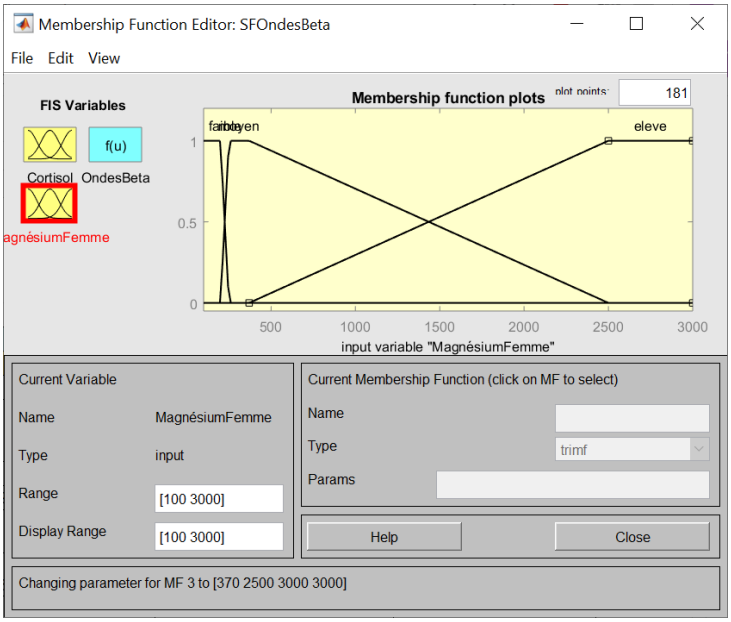

Figure 17: Magnesium classes for women

Beta Wave Rules:

Cortisol / Magnesium	Low	Medium	High
Low	Medium	High	High
Medium	Low	Medium	High
High	Low	Low	Medium

The possible conclusions of the Waves_Beta system rules are: Low, Medium, High

C - Subsystem n°3: Sigma waves

Melatonin subsystem:

Calcium level (mmol of calcium/L)	
[0 0 1.8 2]	Low
[18 2.2 2.6 2.7]	Medium
[2.7 2.9 3 3]	High

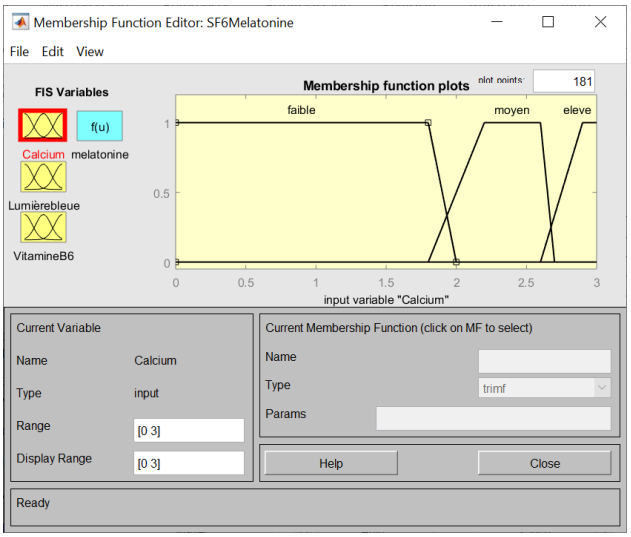

Figure 18: Calcium Classes

Time of day when we are confronted with blue light	
[0 0 1 2]	Medium
[1 2 4 6]	High
[4 6 22 23]	Low
[22 23 24 24]	Medium

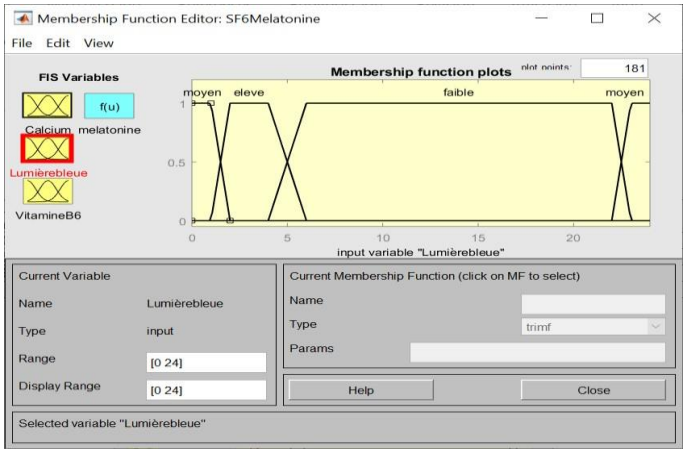

Figure 19: Blue Light Classes

Vitamin B6 level (in mg)	
[0 0 1 1.5]	Low
[1 1.5 1.8 2.4]	Medium
[1.8 2.4 100 207]	High

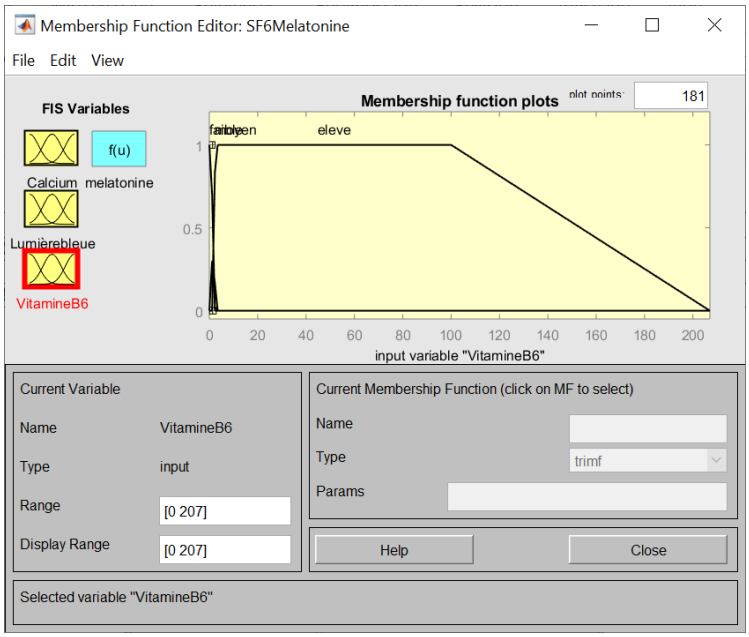

Figure 20: Vitamin B6 classes

Melatonin rules:

Low Calcium:

Light blue / Vitamin B6	Low	Medium	High
Low	Low	Low	Low
Medium	Medium	Low	Low
High	Medium	Low	Low

Average Calcium:

Light blue / Vitamin B6	Low	Medium	High
Low	Medium	Low	Low
Medium	High	Low	Low
High	High	Medium	Low

Calcium High :

Light blue / Vitamin B6	Low	Medium	High
Low	High	Medium	Low
Medium	High	High	Medium
High	High	High	Medium

The possible conclusions of the Melatonin system rules are: Low, Medium, High

Sigma Wave Subsystem:

Daily intake Vitamin E (IU)	
[0 0 10 15]	Low
[10 15 35 40]	Medium
[35 40 200 400]	High

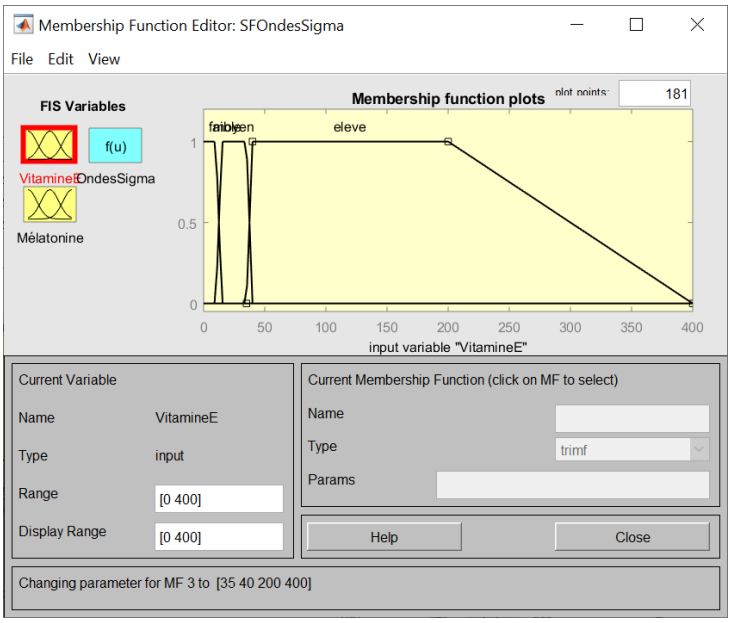

Figure 21: Vitamin E classes

Sigma Wave Rule:

Melatonin / Vitamin E	Low	Medium	High
Low	Low	Low	Medium
Medium	Low	Medium	High
High	Low	High	High

The possible conclusions of the Wave_Sigma rules are: Low, Medium, High

D - Subsystem n°4: Delta waves

Adenosine subsystem:

Time in hours of coffee intake before going to sleep	
[0 0 3 6]	Low
[3 6 12 16]	Medium
[12 16 20 20]	High

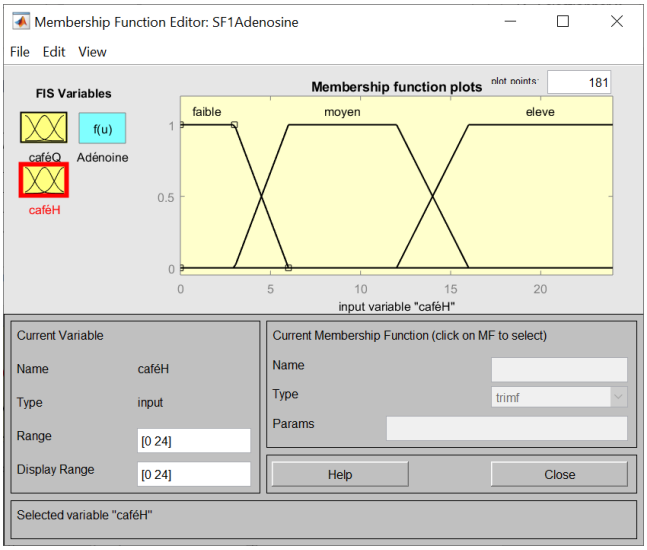

Figure 22: Coffee Hour Classes

Number of 52 mL coffee cups	
[1 1 1 2]	Low
[1 2 3 4]	Medium
[3 4 5 5]	High

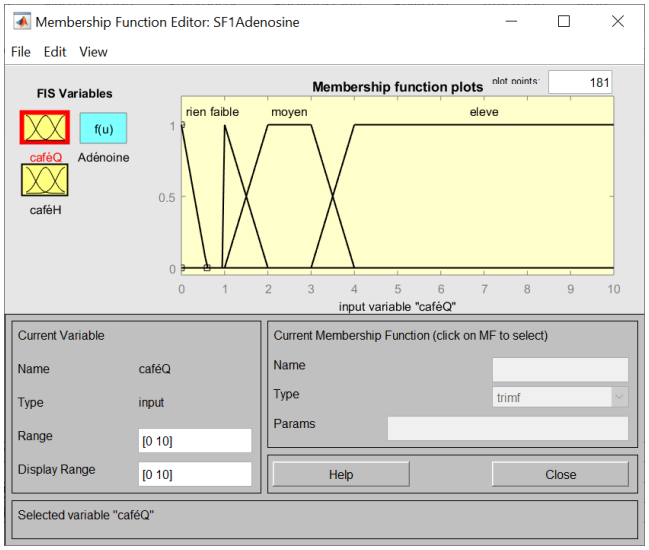

Figure 23: Coffee Quantity Classes

Adenosine rules:

Coffee Time / Coffee Quantity	Low	Medium	High
Nothing	High	High	High
Low	Medium	High	High
Medium	Low	Medium	High
High	Low	Low	Medium

The possible conclusions of the Adenosine system rules are: Low, Medium, High

Food subsystem:

Number of grams of fat Male	
[33 33 50 70]	Low
[50 70 140 225]	Medium
[140 225 infinity infinity]	High

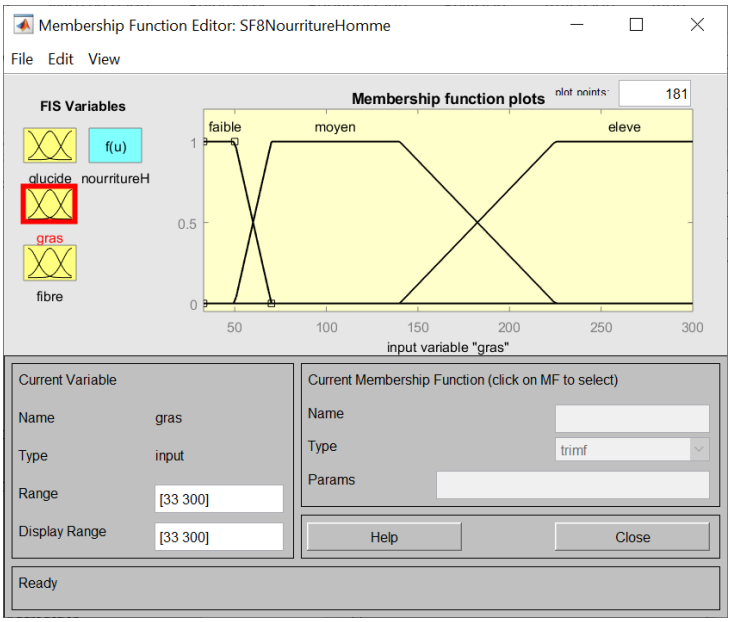

Figure 24: Male Fat Classes

Number of grams of fat Female	
[33 33 40 50]	Low
[40 50 90 170]	Medium
[90 170 infinity infinity]	High

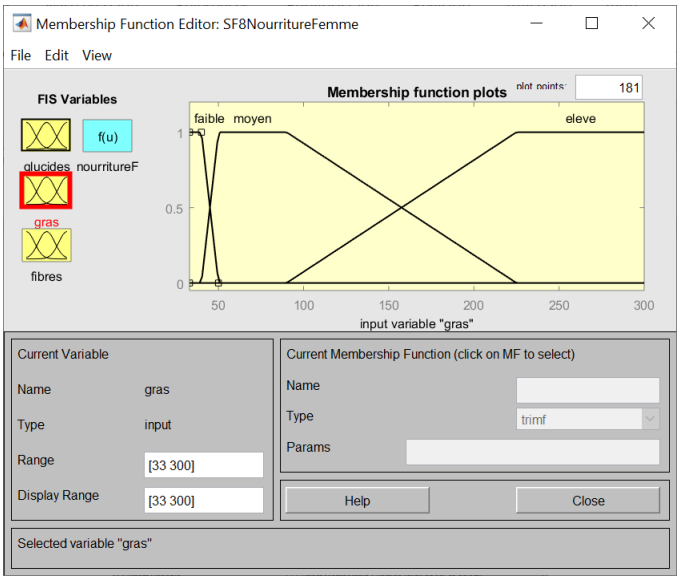

Figure 25: Female Fat Class

Number of grams of carbohydrates Man	
[50 50 150 200]	Low
[150 200 500 600]	Medium
[500 600 infinity infinity]	High

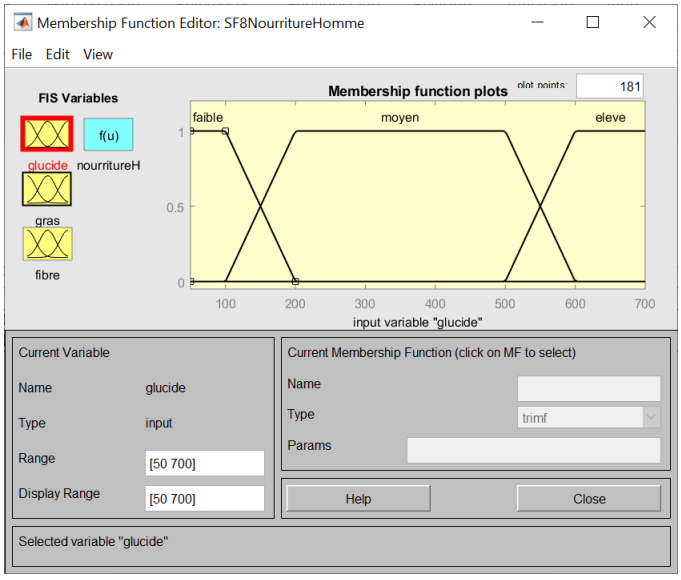

Figure 26: Carbohydrate classes for men

Number of Grams of carbohydrates Female	
[50 50 100 150]	Low
[100 150 350 450]	Medium
[350 450 infinity infinity]	High

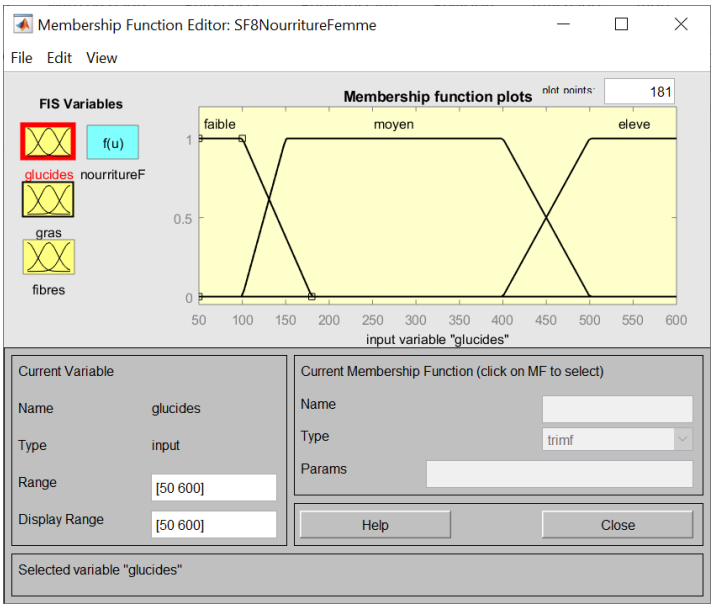

Figure 27: Female Carbohydrate Classes

Number of Grams of Fiber Male	
[5 5 15 30]	Low
[15 30 40 70]	Medium
[40 70 infinity infinity]	High

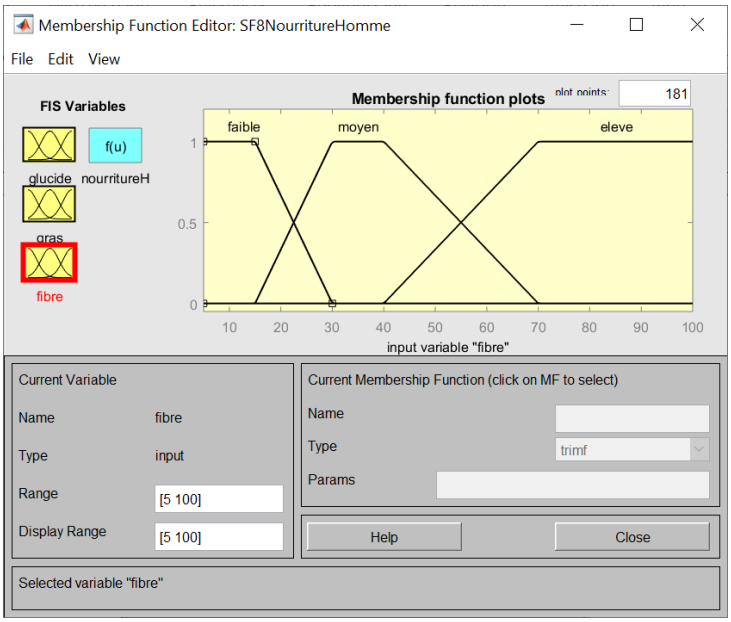

Figure 28: Fiber Classes for Men

Number of Grams of Fiber Female	
[5 5 10 20]	Low
[10 20 25 50]	Medium
[25 50 infinity infinity]	High

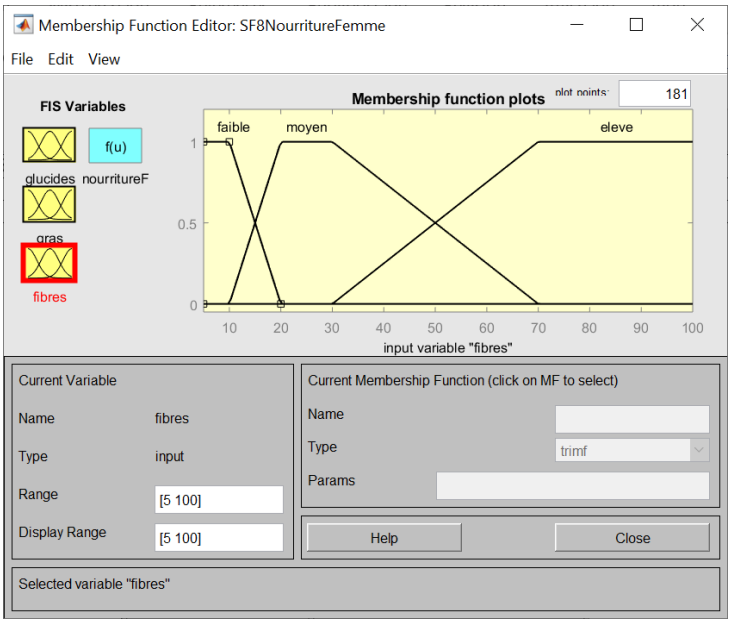

Figure 29: Fiber Classes for Women

Rules Food:

Low fiber :

Fat / Carbohydrates	Low	Medium	High
Low	Low	Average	High
Medium	Low	Low	Average
High	Low	Low	Low

Medium fiber :

Fat / Carbohydrates	Low	Medium	High
Low	Low	High	High
Medium	Low	Average	High
High	Low	Low	Low

High fiber:

Fat / Carbohydrates	Low	Medium	High
Low	Average	High	High
Medium	Low	High	High
High	Low	Low	Low

The possible conclusions of the Food system rules are: Low, Medium, High

Delta Wave Rules:

Adenosine / Food	Low	Medium	High
Low	Low	Low	Medium
Medium	Low	Medium	High
High	Low	High	High

The possible conclusions of the Wave_Delta system rules are: Low, Medium, High

E - Subsystem n°6: Sleep apnea

Number of beats per minute	
[10 10 15 20]	Low
[20 40 80 90]	Medium
[90 100 130 173]	High

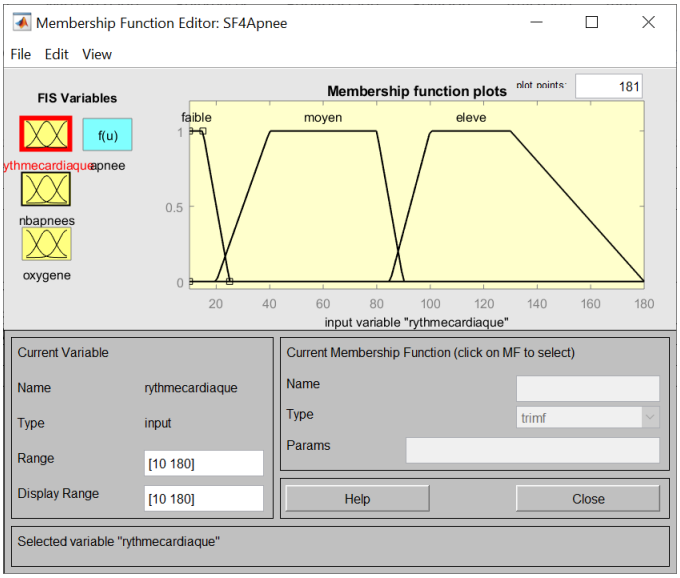

Figure 30: Heart Rate Classes

Number of apneas per hour longer than 10 seconds	
[0 0 5 15]	Low
[5 15 16 30]	Medium
[16 30 infinity infinity]	High

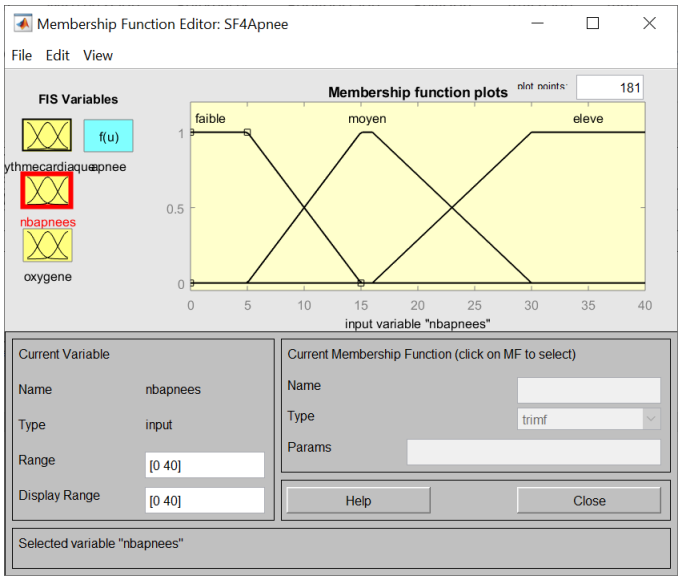

Figure 31: Classes Apnea Numbers

Blood oxygen level (%)	
[70 70 77.8 83.8]	Low
[77.8 83.8 88 91.5]	Medium
[88 91.5 100 100]	High

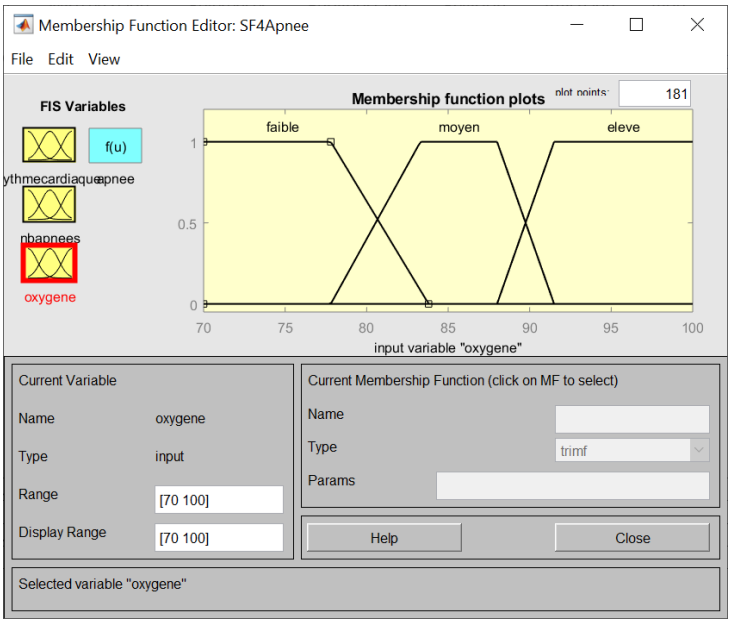

Figure 32: Oxygen Rate Classes

Sleep Apnea Rules:

Low heart rate:

Nb of apneas / Oxygen	Low	Medium	High
Low	Medium	High	High
Medium	Low	Medium	High
High	Low	Low	High

Average heart rate:

Nb of apneas / Oxygen	Low	Medium	High
Low	Medium	High	High
Medium	Low	Medium	Medium
High	Low	Medium	Medium

High heart rate:

Nb of apneas / Oxygen	Low	Medium	High
Low	Low	Medium	High
Medium	Low	Low	Medium
High	Low	Low	Low

The possible conclusions of the Apnea system rules are: Low, Medium, High

F - Subsystem #6: Insomnia

Number of awakenings per night	
[0 0 1 2]	Low
[2 3 4 5]	Medium
[4 5 8 10]	High

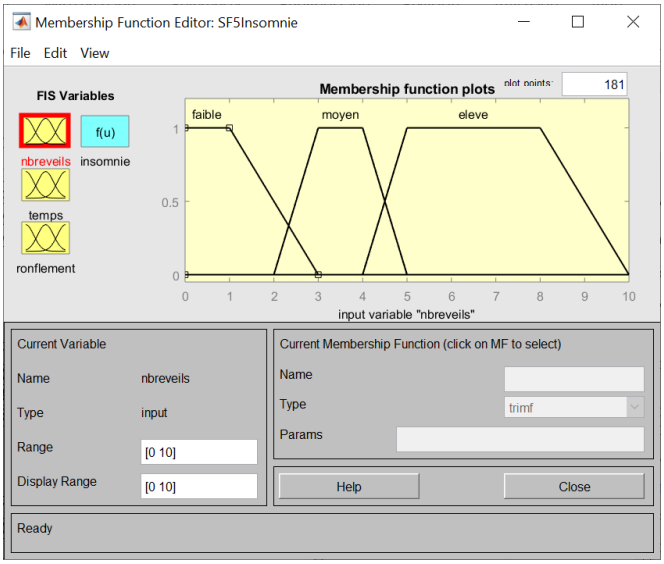

Figure 33: Number of Waking Classes

Time to fall asleep	
[0 0 5 10]	Low
[5 10 20 30]	Medium
[20 30 40 40]	High

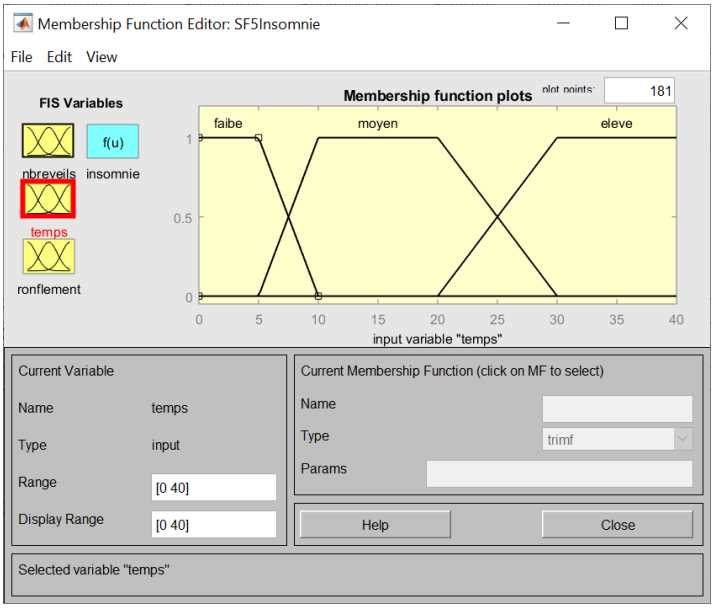

Figure 34: Time to Sleep Classes

Snoring (db)	
[0 0 15 30]	Low
[30 45 60 70]	Medium
[70 80 95 100]	High

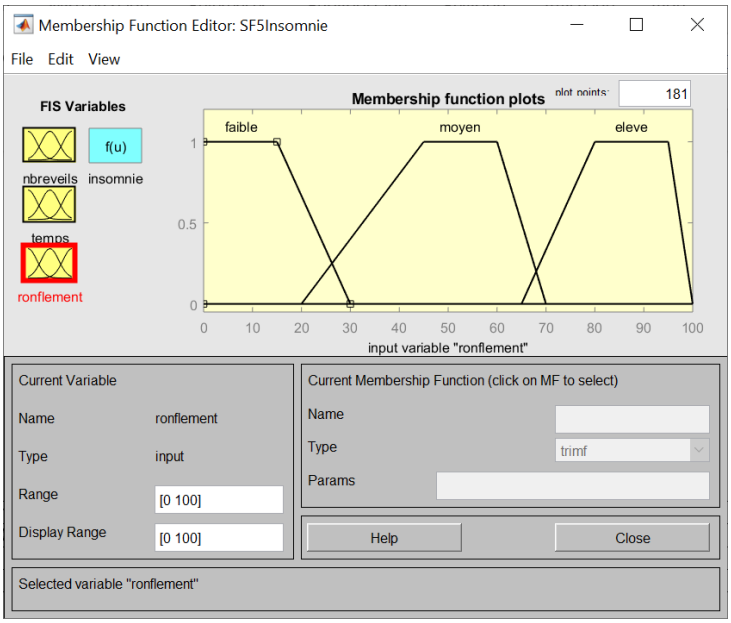

Figure 35: Snoring classes

Rules Insomnia:

Low number of awakenings :

Time / Snoring	Low	Medium	High
Low	Low	Low	Medium
Medium	Low	Medium	Medium
High	Low	Medium	High

Average number of awakenings :

Time / Snoring	Low	Medium	High
Low	Low	Medium	Medium
Medium	Medium	Medium	High
High	Medium	High	High

High number of awakenings :

Snoring \ Time	Low	Medium	High
Low	Medium	Medium	High
Medium	Medium	High	High
High	High	High	High

The possible conclusions of the Insomnia system rules are: Low, Medium, High

G - Subsystems n°7: Quality Sleep

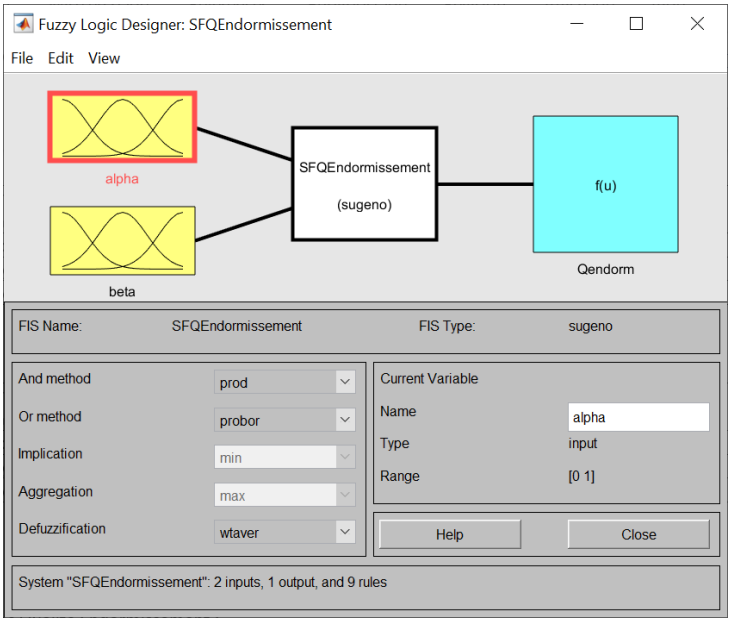

Figure 36: Sleep quality

Quality rules Sleep :

Alpha waves / Beta waves	Low	Medium	High
Low	High	Average	Low
Medium	Average	Average	Low
High	Low	Low	Low

The possible conclusions of the Quality_Endorsement rules are: Low, Medium, High

H - Subsystem no. 8: Sleep quality

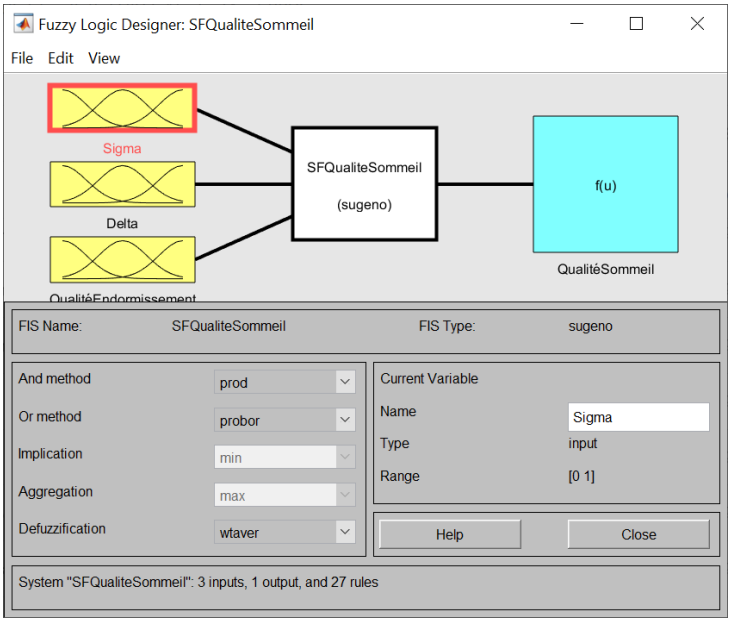

Figure 37: Sleep Quality

Sleep Quality Rules:

Low sleep quality :

Sigma waves / Delta waves	Low	Medium	High
Low	Low	Low	Medium
Medium	Low	Medium	Medium
High	Medium	Medium	High

Quality Average sleep :

Sigma waves / Delta waves	Low	Medium	High
Low	Low	Low	Medium
Medium	Medium	Medium	High
High	Medium	High	High

Quality High Sleep :

Sigma waves / Delta waves	Low	Medium	High
Low	Low	Medium	High
Medium	Medium	Medium	High
High	Medium	High	High

The possible conclusions of the Sleep_Quality system rules are: Low, Medium, High

I - Fuzzy system : Advice

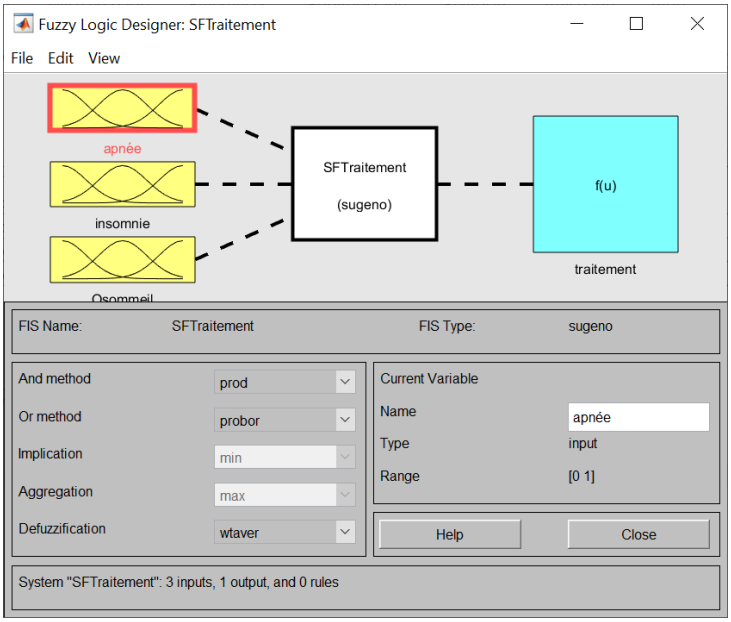

Figure 38: Tips

Rules Tips:

Low Sleep Quality:

Apnea / Insomnia	Low	Medium	High
Low	C1	C4	C5
Medium	C2	C6	C7
High	C3	C8	C9

Quality Average Sleep :

Apnea / Insomnia	Low	Medium	High
Low	C10	C13	Impossible case
Medium	C11	C14	Impossible case
High	Impossible case	Impossible case	Impossible case

High Sleep Quality:

Apnea / Insomnia	Low	Medium	High
Low	C19	Impossible case	Impossible case
Medium	Impossible case	Impossible case	Impossible case
High	Impossible case	Impossible case	Impossible case

The possible conclusions of the Advice system rules are: Low,

Medium, High

Dictionary :

C1 = "Your sleep quality is poor! However, you are not insomniac or apneic! Please consult a general practitioner and if you can a neurologist to help you improve your lifestyle.

C2 = "Your sleep quality is poor! You have some insomnia but you are not apneic! Please consult a general practitioner and if you can a neurologist to help you improve your lifestyle and find a solution to limit insomnia.

C3 = "Your sleep quality is poor! You are very insomniac but you are not apneic! Please consult urgently a general practitioner and if you can a neurologist so that he can help you to improve your lifestyle and find a solution to limit severe insomnia ".

C4 = "Your sleep quality is poor! You are not insomniac but you are a little apneic! Please consult a general practitioner and if you can a neurologist to help you improve your lifestyle. It is advisable to see a pneumologist to limit sleep apnea "

C5 = "Your sleep quality is poor! You are not an insomniac but you are very apneic! Please consult a general practitioner and if you can a neurologist to help you improve your lifestyle. It is very strongly advised to see a pulmonologist to limit sleep apnea which is severe!"

C6 = "Your sleep quality is poor! You have some insomnia and you have some apnea! Please see a general practitioner and if you can a neurologist to help you improve your lifestyle and limit insomnia. It is advisable to see a pneumologist to limit sleep apnea "

C7 = "Your sleep quality is poor! You have a little insomnia but you are very apneic! Please consult a general practitioner and if you can a neurologist so that he can help you improve your lifestyle and find a solution to limit insomnia. It is very strongly advised to see a pneumologist to limit sleep apnea which is severe.

C8 = "Your sleep quality is poor! You are very insomniac but you are a bit apneic! Please consult a general practitioner urgently and if you can a neurologist so that he can help you improve your lifestyle and find a solution to limit severe insomnia. It is advisable to see a pneumologist to limit sleep apnea.

C9 = "Your sleep quality is poor! You are very insomniac and you are very apneic! Please urgently consult a general practitioner and if you can a neurologist so that he can help you improve your lifestyle and find a solution to limit severe insomnia. It is strongly advised to see a pneumologist to limit sleep apnea which is severe.

C10 = "Your sleep quality is normal without being excellent! You are neither insomniac nor apneic! It could be useful to consult a general practitioner or even a neurologist to help you improve your lifestyle.

C11 = "Your sleep quality is normal without being excellent! You are a bit insomniac but you are not apneic! It would be interesting to consult a general practitioner and if you can a neurologist so that he can help you improve your lifestyle and find a solution to limit your little insomnia.

C13 = "Your sleep quality is normal without being excellent! You are not an insomniac but you are a bit apneic! It could be useful to consult a general practitioner or even a neurologist to help you improve your lifestyle. It could also be interesting to consult a pneumologist to limit the small sleep apneas.

C14 = "Your sleep quality is normal but it is borderline poor! You are a little insomniac and a little apneic! Please consult a general practitioner and if you can a neurologist so that he can help you to improve your lifestyle and find a solution to limit the small insomnia. It is also advisable to see a pneumologist to limit the small sleep apneas.

C15 = "The quality of your sleep is remarkable! Your lifestyle is excellent! You sleep like a baby! Keep it up!"

2 - Method for distinguishing between men and women

We set up a dialog box that asks the user to enter 1 if it is a man and 0 if it is a woman. We save this value in a variable.

```
%Chosir son sexe

prompt ={'Tape 1 si homme, tape 0 si femme :'};

def ={'0'};
dlgtitle='Genre';
lineNo=1;
answer=inputdlg(prompt, dlgtitle, lineNo, def);
if isempty(answer),
    disp('Action annulée');
    return;
end;

reponse = str2num(answer{1});
```

Figure 39: Sex Selection Code 1

Then using an "if", we select the fuzzy partitions according to the gender of the person.

```
%La personne qui fait le test est un homme
if reponse == 1
```

Figure 40: Sex Selection Code 2

3 - Method for testing over several nights

To do this, we set up a dialog box that asks the user how many nights he wants to run the test on. We then save this value in a variable.

```
% Choisir le nombre de nuits pour faire le test

prompt ={'Sur cb de nuits voulez-vous faire le test'};
def ={'1'};
dlgtitle='Nbr nuits';
lineNo=1;
answer=inputdlg(prompt, dlgtitle, lineNo, def);
if isempty(answer),
    disp('Action annulée');
    return;
end;
nb_nuits = str2num(answer{1});
```

Figure 41: Multi-Night Code 1

Then for each of our 21 input variables, we set up a "for" loop that requests and records the values for "n" nights. Then, we do an average in order to exploit the result obtained.

```
%Initialisation des entrées à 0, utile pour faire une moyenne ensuite
taux_alcool=0;
taux_nicotine=0;

%Boucle pour faire le test sur plusieurs nuits
for i=1: nb_nuits,
```

Figure 42: Multi-Night Code 2

Between these two pieces of code, we find the code of the Zalila algorithm. For the sake of clarity we have decided not to put it here.

```
%Si plusieurs nuits sont sélectionnées ont fait la moyenne
taux_alcool = str2num(answer{1})+ taux_alcool;
taux_nicotine = str2num(answer{2}) + taux_nicotine;
end;

taux_nicotine=taux_nicotine/nb_nuits;
taux_alcool=taux_alcool/nb_nuits;
```

Figure 43: Multi-Night Code 3

4 - Defuzzification method

In order to obtain a score out of 100 that gives an indication of the quality of sleep, we decided to defuzzify the output of the fuzzy system "Quality of sleep" by the barycentre method. We took as values Low = 0 Average = 50
Elevee = 100 to have a score between 0 and 100.

Here is the method we applied: If we put d1, d2, d3 the degrees of membership between 0 and 1 corresponding to each fuzzy class using the following formula (d1*0+d2*50+d3*100) / (d1+d2+d3), we obtain the sleep quality score out of 100.

```
%Deffuzzification de la qualité du sommeil par méthode du barycentre

ccl_sommeil=[ccl_sommeil(1) ccl_sommeil(2) ccl_sommeil(3)];
ccl_som = [0 50 100];
disp('La qualité sur 100 de votre sommeil est de :');
disp(sum(ccl_som.*ccl_sommeil)/sum(ccl_sommeil));
```

Figure 44: Defuzzification code

5 - Method for counseling the person at the end of the test

We decided to create about 15 outputs for our fuzzy **advice** system that correspond to the advice of a specialized doctor given by our program to improve sleep.

For the sake of clarity we have not written the tips directly at the level of "classes" of the fuzzy **tips** system. For this reason we have set up a kind of dictionary.
We have built a dictionary so that our program will display the most suitable advice for the person taking the test.
To do this, we decided to look for the degree of membership of our "classes" that was the highest and having associated with this "class" a specific board, we display on the screen the board in question.

```
%On cherche le plus élevé degré d'appartenance associé à nos conséquences
maxi=0;
for i = 1:nb_ccl_conseils,
   if ccl_conseils(i)> maxi
       maxi=ccl_conseils(i);
   end;
end;

if maxi==ccl_conseils(15)
   disp('La qualité de votre sommeil est remarquable ! Votre train de vie est excellent ! Vous dormez comme un bébé ! Continuez ainsi !');
 end;
```

Figure 45: Code for finding the best advice

IV - Case study

1 - Case 1: Marc

Marc is a man who does not have a very good lifestyle, however to test our fuzzy system over 2 days, he decided to decrease the amount of drugs he was taking. His alcohol level went from 0.7 g/kg to 0.2 g/kg. He also decreased the number of cigarettes he smoked from 10 cigarettes to 5 cigarettes per day. Coffee being too important for his day, he stayed at 3 coffees per day but he had taken his last coffee 3 hours before going to sleep on the first day whereas he took it 10 hours on the second. Regarding his diet, Marc eats rather sweet since he has 400 grams of carbohydrates in his blood. On the other hand, his fat and fiber levels are respectively 60 and 35 grams, which represents an average level.
Fortunately for him, a high level of sugar does not significantly affect the most important vitamins. His vitamin C, B6 and E levels are 70 mg/L, 1.8 mg/day, 22 IU respectively. Marc has always placed importance on the consumption of dairy products, which is why he has a satisfactory calcium level of 2.4 mmol/L. And finally, following the recommendations of a friend, Marc regularly takes magnesium to reduce his fatigue and stress, which explains his high level of 1000 mg/day.
Not liking to live in the country, Marc has chosen to live in the middle of the city, which makes the noise intensity rise to 35 decibels. He usually starts each day with 10 minutes of meditation to relax. However, Marc has trouble getting away from the screens and is exposed to blue light until 2 a.m. He is also exposed to a lot of noise. Although he fell asleep in 10 minutes, his first night was particularly agitated as he woke up 4 times and his snoring was measured at 15 decibels. His heart rate will remain average: 52 beats per minute and his oxygen level will be 95%. Without realizing it, he also had 2 apneas of more than 10 seconds. The next day, Marc took twice as long to fall asleep, but he only woke up once during the night.

The snoring volume is still 15 decibels and his oxygen level, as well as his heart rate, will be identical. Like the night before, he will have two apneas of more than 10 seconds.

Variables	Day 1	Day 2	Comments
Sound Intensity (dB)	35	35	
Vitamin C level (mg/L)	70	70	
Meditation (minutes)	10	10	
Magnesium level (mg/day)	1000	1000	
Calcium level (mmol/L)	2.4	2.4	
Blue Light (hours)	2	2	
Vitamin B6 level (mg/day)	1.8	1.8	
Vitamin E level (IU)	22	22	
Coffee Time (hour)	3	10	
Coffee Quantity (no. of cups)	3	3	
Carbohydrate content (g)	400	400	
Fat content (g)	60	60	
Fiber content (g)	35	35	
Nicotine (Nb of cigarettes/day)	10	5	
Alcohol (g/kg)	0.7	0.2	
Number of night wakings	4	1	
Time to fall asleep (minutes)	10	20	
Snoring (dB)	15	15	
Heart rate (beats/minutes)	50	50	
Number of apneas longer than 10 seconds	2	2	
Oxygen content (%)	95	95	

Table 1: Case Study Marc

Consequence of the fuzzy system:

Score : 0/100

Tip: "Your sleep quality is poor! You have some insomnia but you are not apneic! Please consult a general practitioner and if you can a neurologist so that they can help you improve your lifestyle and find a solution to limit insomnia."

2 - Case 2: Charlotte

At the age of 30, Charlotte decided to change her lifestyle to take care of her body and her health. For almost 15 years now, Charlotte has been living an exemplary lifestyle and tries every day to put all her chances on her side to have a remarkable or even irreproachable quality of sleep. First of all, living in Paris, in the center of the city where the noise level outside can be high, she started by bringing in the best experts in acoustics so that they could isolate her room as much as possible. The results were quite conclusive because by completing our program on a single night test, Charlotte reported that the sound intensity was 0 decibel. Then, always in the optics to decrease a possible stress which could disturb her sleep, she consumes many citrus fruits, but also a lot of guava and blackcurrant in order to have a high rate of vitamin C which is according to her seizure on our program of 1000 mg (for the night of test).

At the age of 28, while traveling in India, she discovered the scientifically proven benefits of meditation on stress management. Charlotte fell in love with this practice and informs us that she meditates for 50 minutes every day. In addition, she consumes a lot of green vegetables and whole grains so that her magnesium intake is high! It is 700 mg/day.

Since she was a child, Charlotte has loved cheese such as Gruyere or Parmesan, but also seafood such as sardines or salmon. And recently, after watching a documentary, she also started eating seaweed such as seaweed. Cheese and seafood are very good sources of calcium and seaweed is an excellent source of calcium. Note that she consumes these foods in moderation. This explains her blood calcium level of 2.6 mmol/L. Knowing the dangers of blue light and its very harmful consequences on sleep, she decided to stop watching screens at 8:00 p.m., that is, at the end of the regional news broadcast on France 3.
Charlotte, who has an exemplary behaviour, had informed herself 15 years ago about the benefits of vitamins B6 and E and fixed her vitamin B6 quantity at 150 mg/day and her vitamin E quantity at 300 IU.

Before she turned 30, Charlotte considered herself a coffee addict and drank a lot of coffee, sometimes even before going to sleep. She has long since stopped doing that. In fact, she only consumes one coffee in the morning, 17 hours before going to sleep. Her nutritionist told her the best diet for a good night's sleep: low carb, high fat and high fiber. His carbohydrate intake is 75 g/d, fat intake is 170 g/d and fiber intake is 70 g/d. Not wishing to disturb her sleep or even endanger her life, she does not smoke or drink, which explains the quantities of 0 cigarettes/d and 0 g of alcohol per kg that she entered in our program over one night.

Then Charlotte informs us that she doesn't wake up at night, that she takes only 10 minutes to fall asleep and her companion Paul assures us that she never snores either! Finally, the last information she has entered in our program is her heart rate which is 50 beats/min, the number of apneas per hour of more than 10 seconds which is 0 and her blood oxygen level which is 98%. It should be noted that these three numerical values are excellent and will result in a very good quality of sleep.

Variables	Day 1	Comments
Sound Intensity (dB)	0	
Vitamin C level (mg/L)	1000	
Meditation (minutes)	50	
Magnesium level (mg/day)	700	
Calcium level (mmol/L)	2.8	
Blue Light (hours)	20	
Vitamin B6 level (mg/day)	150	
Vitamin E level (IU)	300	
Coffee Time (hour)	16	
Coffee Quantity (no. of cups)	1	
Carbohydrate content (g)	75	
Fat content (g)	170	
Fiber content (g)	70	
Nicotine (Nb of cigarettes/day)	0	
Alcohol (g/kg)	0	
Number of night wakings	0	
Time to fall asleep (minutes)	10	
Snoring (dB)	0	
Heart rate (beats/minutes)	50	
No. of apneas longer than 10 seconds	0	
Oxygen content (%)	98	

Table 2: Charlotte case study

Consequence of the fuzzy system:

Score : 100/100

Tip: "The quality of your sleep is remarkable! Your lifestyle is excellent! You sleep like a baby! Keep it up!"

3 - Case 3: John

John is a man in his fifties who lives in the city (30 decibels) and suffers severely from sleep apnea. His diet is extremely sweet but low in fat, which explains his carbohydrate level of 600 grams and his fat level of 80 grams. His fiber content is about average at 20 grams. John does not drink alcohol and is also a non-smoker. However, he drinks an average of 5 coffees a day and the last one 8 hours before going to sleep. He does not have time to meditate either because he has a high hourly volume and is therefore confronted with blue light until 4am. His vitamin C, vitamin B6 and vitamin E levels are 150 mg/L, 1.5 mg/day and 20 IU respectively. However, because of his poor diet, his calcium level is relatively low: 2 mmol/L. His magnesium level remains very correct with a concentration of 300 mg/day. John falls asleep in only 15 minutes but will suffer from his illness. Indeed, because of his 26 apneas, his heart rate drops to 24 beats per minute and his oxygen level even drops to 78%. He will wake up 3 times during the night and the sound volume of his snoring will be evaluated at 60 decibels.

Variables	Values	Comments
Sound Intensity (dB)	30	
Vitamin C level (mg/L)	150	
Meditation (minutes)	0	
Magnesium level (mg/day)	300	
Calcium level (mmol/L)	2	
Blue Light (hours)	4	
Vitamin B6 level (mg/day)	1.5	
Vitamin E level (IU)	20	
Coffee Time (hour)	8	
Coffee Quantity (no. of cups)	5	
Carbohydrate content (g)	600	
Fat content (g)	80	
Fiber content (g)	20	
Nicotine (Nb of cigarettes/day)	0	
Alcohol (g/kg)	0	
Number of night wakings	3	
Time to fall asleep (minutes)	15	
Snoring (dB)	60	
Heart rate (beats/minutes)	24	
Number of apneas longer than 10 seconds	26	
Oxygen content (%)	78	

Table 3: Jean Case Study

Consequence fuzzy system :

Score : 0/100

Tip: "Your sleep quality is poor! You have a little insomnia but you are very apneic! Please consult a general practitioner and if you can a neurologist so that he/she can help you improve your lifestyle and find a solution to limit insomnia. It is very strongly advised to see a pulmonologist to limit sleep apnea which is severe."

4 - Case 4: Justine

Justine is 28 years old and has decided to go back to school for further education. She is a student at the Technological University of Compiègne, more commonly called UTC. She is currently following the MARS course (Mechatronics, Actuators, Robotisation & Systems) of the mechanical engineering branch.
Having learned about the existence of our sleep quality evaluation program and the prescription of advice for consulting specialized doctors in a report broadcast on the 8 o'clock news on France 2, she decided to contact us to do a test over 3 nights. The first night will correspond to the night before the day of revision for the exam, the second night will correspond to the night before the dreaded exam and the third night will correspond to the night before the rest day.

Night 1: Night before the e x a m preparation day

The day of preparation is for Justine a rather stressful day and she does not necessarily take care of her health.

Night 2: Night before the exam day

Justine is overwhelmed by stress and makes the mistake of completely neglecting her health. This will inevitably have an impact on the quality of his sleep.

Night 3: Night before the rest day (the exam is passed)

Even though Justine did not excel in her exam, she felt relaxed and decided to take back control of her life by taking care of herself and her health in order to improve mainly her quality of sleep.
However, to celebrate the end of the exam, she chooses to go to the PIC (beer bar of the UTC) the evening she is going to take our test. Is this really a good idea ?

Summary table of the information entered by Justine over 3 nights:

Variables	Day 1	Day 2	Day 3	Comments
Sound Intensity (dB)	20	20	20	This variable remains constant over the 3 days
Vitamin C level (mg/L)	35	20	70	
Meditation (minutes)	5	5	5	During the 3 days, she does the effort to maintain his morning meditation ritual
Magnesium level (mg/day)	225	175	370	
Calcium level (mmol/L)	1.8	1.5	2.4	
Blue Light (hours)	2	23	20	
Vitamin B6 level (mg/day)	1.5	1.3	1.8	
Vitamin E level (IU)	15	10	20	
Coffee Time (hour)	2	10	17	
Coffee Quantity (no. of cups)	3	5	1	
Carbohydrate content (g)	400	500	150	Because of her stress, she tends to eat very sweet foods
Fat content (g)	80	60	160	
Fiber content (g)	30	30	30	
Nicotine (Nb of cigarettes/day)	3	5	0	
Alcohol (g/kg)	0	0	0.3	The value 0.3 is explained by a switch to PIC (bar of the UTC)
Number of night wakings	3	5	0	
Time to fall asleep (minutes)	35	40	20	
Snoring (dB)	60	80	30	
Heart rate (beats/minutes)	80	90	50	
Number of apneas longer than 10 seconds	0	0	0	
Oxygen content (%)	95	97	96	

Table 4: Justine Case Study

Consequence blurred system :

Score : 38.46/100

Tip: "Your sleep quality is poor! You are very insomniac but you are not apneic! Please consult urgently a general practitioner and if you can a neurologist so that he/she can help you improve your lifestyle and find a solution to limit severe insomnia."

5 - Case 5: Emma

Emma is a woman in her forties who lives without excess but without defiance. She does not drink alcohol and is satisfied with 2 cigarettes a day. She lives in the countryside, unfortunately close to an airport, which means that she is confronted with a noise level of 50 decibels. To start her day, Emma spends about 7 minutes meditating to relax. Paying attention to her diet in general, Emma's carbohydrate, fat and fiber levels are quite respectable: 250 grams, 90 grams, 20 grams. Aware of the harmful effects of over-consumption of coffee, she only drinks 2 cups a day and the last one only 7 hours before going to sleep. She adopts the same behavior looking at the screens what makes that she stops all digital use as of 10 pm. Her calcium and magnesium levels are within the normal range and are respectively 2.4 mmol/L and 300 mg/day.
The consumption of citrus fruits also allows him to have a level of vitamin C satisfactory: 75 mg/L. And finally its levels of vitamin B6 and vitamin E are respectively 1.65 mg/day and 22 mg/day. Emma takes only 15 minutes to fall asleep and she does not snore all night. However, because of airplane take-offs and/or landings, she wakes up 3 times. She is not apneic, so she will not have had any apnea during the night and she will have a heart rate of 50 beats per minute and an excellent oxygen level of 95%.

Variables	Values	Comments
Sound Intensity (dB)	50	
Vitamin C level (mg/L)	75	
Meditation (minutes)	7	
Magnesium level (mg/day)	300	
Calcium level (mmol/L)	2.4	
Blue Light (hours)	22	
Vitamin B6 level (mg/day)	1.65	
Vitamin E level (IU)	22	
Coffee Time (hour)	7	
Coffee Quantity (no. of cups)	2	
Carbohydrate content (g)	250	
Fat content (g)	90	
Fiber content (g)	20	
Nicotine (Nb of cigarettes/day)	2	
Alcohol (g/kg)	0	
Number of night wakings	3	
Time to fall asleep (minutes)	15	
Snoring (dB)	0	

Heart rate (beats/minutes)	50	
Number of apneas longer than 10 seconds	0	
Oxygen content (%)	95	

Table 5: Emma Case Study

Consequence fuzzy system :

Score : 50/100

Tip: "Your sleep quality is normal but not excellent! You are a bit insomniac but you are not apneic! It would be interesting to consult a general practitioner and if you can a neurologist so that he can help you to improve your life style and find a solution to limit your small insomnia.

V - Limitations and prospects for improvement

To illustrate our fuzzy system, we had to take fictitious cases because we needed personal data to run our program. But as the majority of the population has no interest in disclosing their information, it was very complicated for us to find consistent data on the internet and that is why we turned to fictitious cases.

By opting for a hierarchical system we were forced to neglect certain links between different variables in order to limit the complexity of the fuzzy system.

Research could also have been conducted to determine the variables that most affect sleep quality in order to provide real, accurate and personalized treatment instead of just referring the patient in question to a medical specialist. This would also have improved the comprehensibility of the system as the most important variables would have been identified and these results could have raised patient awareness and significantly improved their sleep quality.

Then, in order to simplify the complexity of the project, we decided to assign only 3 different classes to evaluate the quality of sleep: low, medium and high. The use of 4 or 5 different classes would have allowed us to have a more precise decision system and thus to give even more precise advice related to the different sleep problems of each individual. However, a large number of classes will harm the intelligibility of the system since the number of rules will increase extremely significantly, exponentially.

During our project we decided to focus only on the non-REM phase of sleep because it was extremely rich in terms of brain wave types. However, it would have been interesting to also focus on the second phase (REM sleep), which is a phase more related to deep sleep and dream/nightmare development, in order to have a diagnosis on the whole night.

Finally, we could also have used more "social" variables, such as feelings, which influence behavior in order to have a maximum of different variables to make the most complete diagnosis possible that takes into account the maximum of parameters.

VI - Annexes

1 - Organizational chart

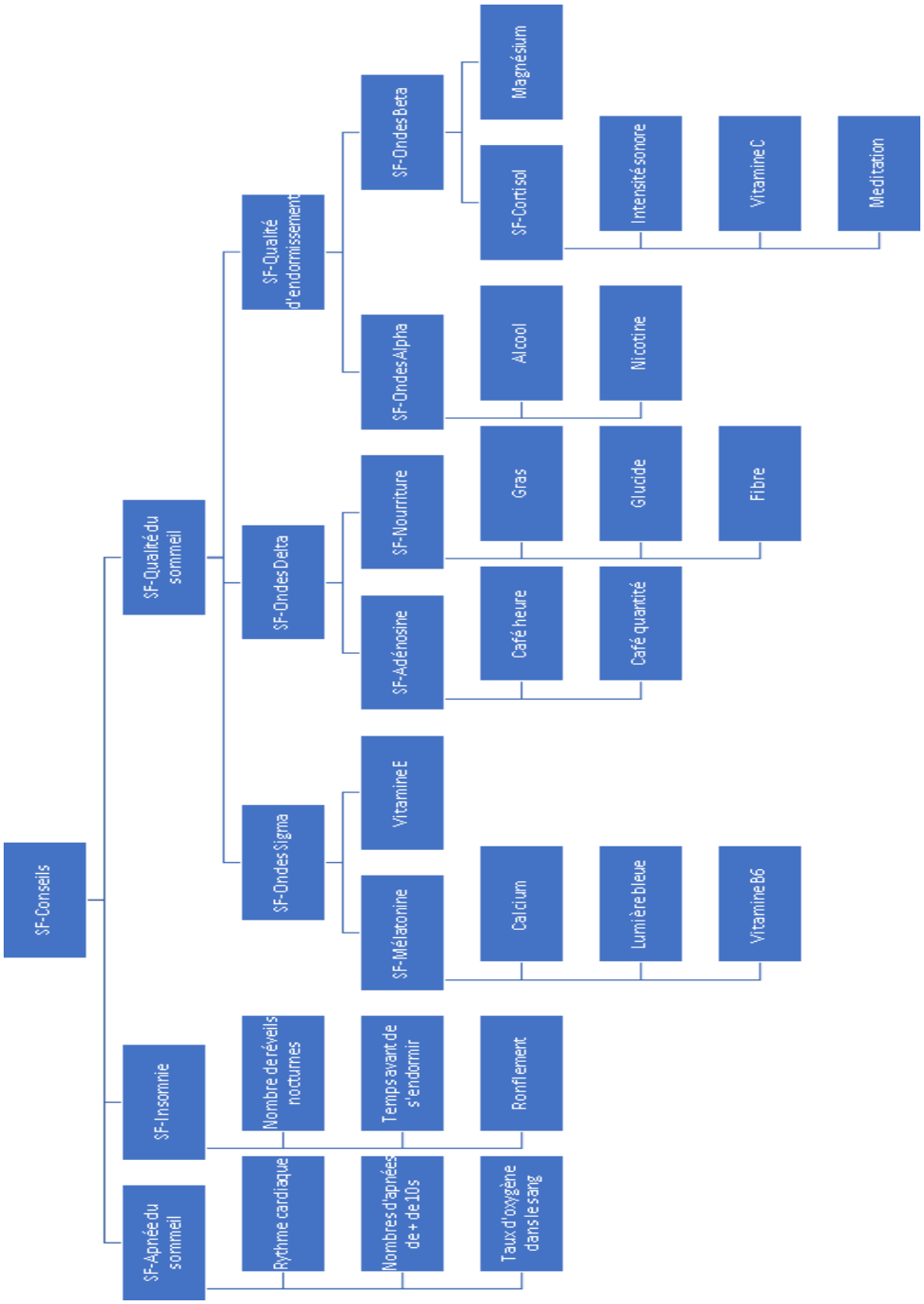

Figure 46: Global Organization Chart

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