CHAPTER 5

IDENTIFICATION OF VARIOUS DIABETIC COMPLICATIONS USING FUZZY RELATIONAL EQUATION

5.1 INTRODUCTION

Fuzzy Relational Equation (FRE) has been utilized in several different approaches for modeling the diagnostic process. In this chapter the fuzzy relation between symptoms and risk factors for diabetic patient, based on the expert’s medical knowledge and clinical research opinion are taken to identify various complications that cause due to diabetes. The prediction of diabetes using neural network has been already dealt in Chapter 4 of this thesis which helps medical experts in decision making. The detailed description of diabetes mellitus and its complications which are discussed in Chapter 3 are used for constructing FRE max-min matrix. This proposed method is an effort to closely imitate a physician's insight of symptom-disease relations and his approximate reasoning for conclusion.

5.2 FUZZY RELATIONAL EQUATION

A fuzzy relational equation plays a vital role in medical diagnosis. The well organized data acquirement and illustration are one of the essential challenges for constructing and subsequent use of medical examiner and knowledge based system in clinical observation. Fuzzy relationships can be framed based on the prevalence of symptoms that occur in the disease. The physician’s medical knowledge is represented as fuzzy relation between symptoms and diseases (Sanchez 1979) and it was further continued by Czogala et al (1982). An algebraic method for calculating all minimal solution was introduced by Lichun et al (1988) and an analytical method was
provided by De Baets et al (2000). The matrix pattern to compute graphically the minimal solutions was proposed by Louh et al (2002).

Fuzzy Relation Equation (FRE) is associated with the concept of composition of binary relations. Consider three fuzzy binary relations \( P(X,Y) \), \( Q(Y,Z) \) and \( R(X,Z) \), which are defined on the sets.

\[
X \equiv \{ x_i / i \in I \}, \quad Y \equiv \{ y_j / j \in J \}, \quad Z \equiv \{ z_k / k \in K \},
\]

where it is assumed that \( I = N_n \), \( J = N_m \) and \( K = N_s \). Let the membership matrices of \( P, Q \) and \( R \) be denoted by \( P = [p_{ij}] \), \( Q = [q_{jk}] \), \( R = [r_{ik}] \), respectively, where

\[
p_{ij} = P(x_i, y_j), \quad q_{jk} = Q(y_j, z_k), \quad r_{ik} = R(x_i, z_k)
\]

for all \( i \in I(=N_n) \), \( j \in J(=N_m) \) and \( k \in K(=N_s) \). This means that all entries in the matrices \( P, Q \) and \( R \) are real numbers in the unit interval \([0, 1]\). The three relations constraints has been assumed between each other in such a way that

\[
P \circ Q = R \quad \ldots (5.1)
\]

where \( \circ \) denotes the max-min composition (Zadeh et al 1965). This means that

\[
\max_{j \in J} \min_{k \in K} \left( r_{ik} = \eta_k \right)
\]

\[
\ldots (5.2)
\]

for all \( i \in I \) and \( k \in K \), where \( \lor \) and \( \land \) represents min and max respectively. When \( P \) and \( Q \) are expressed as relation matrices, the calculation \( p \circ q \) is almost the same as matrix multiplication, except that \( \times \) and \( + \) are replaced by \( \lor \) and \( \land \), respectively. For this reason, the max-min composition is also called the max-min product. Matrix equation \( (P \circ Q) = R \) encompasses \( n \times s \) simultaneous equation. When two of the components in each of the equations are given and one is unknown, these equations are called as fuzzy relation equations.
When matrices P and Q are given and matrix R is to be determined from Equation (5.1), the problem becomes trivial. It can be solved by performing max-min multiplication operation on P and Q, as defined by Equation (5.2). The solution in this case exists and is unique. The problem becomes far from trivial when one of the two matrices on the left hand side of Equation (5.1) is unknown. In this case the solution is guaranteed neither to exist nor to be unique. Since R in Equation (5.1) is obtained by composing P and Q, it is suggestive to view the problem of determining P (or, alternatively, Q) from R and Q (or, alternatively, R and P) as a decomposition of R with respect to Q (or, alternatively, with respect to P) as problems in various contexts can be formulated as problems of decompositions, the utility of any method for solving the Equation (5.1) is quite high. A method is assumed for solving Equation (5.1) only for the first decomposition problem (given Q and R). Then, this method can be indirectly utilized for solving second decomposition of problem as well. The Equation (5.1) can be rewritten in the form as

\[ Q^{-1} \cdot P^{-1} = R^{-1}, \]  \hspace{1cm} \text{... (5.3)}

employing transposed matrices, the Equation (5.3) for \( Q^{-1} \) is solved by the above method and, then, obtain the solution of Equation (5.1) by

\[ \left( Q^{-1} \right)^{-1} = Q \cdot \]  \hspace{1cm} \text{... (5.4)}

5.3 DATA PREPARATION

The expert’s and the clinical research opinion are collected from SRC Diabetes Care Center, Erode through questionnaire method which is given in Appendix 1. While collecting the database of the patients, Questionnaire/Interview methods are followed to speed up the process of diagnosis. With the expert opinion, the first stage dataset for
Interviewing/Questionnaire was prepared in the local regional language for the convenience of the patients. Initial trial was made for analyzing the non crisp way of answering of patients like frequently, very rarely etc. Care was taken not to miss any response as it is the preliminary stage of diagnosis. The database of 1050 patients was collected for the implementation.

5.4 FUZZY RELATIONAL EQUATION FOR CARDIOVASCULAR DIABETIC MELLITUS

Coronary Heart disease is defined as an impaired of heart functions due to inadequate blood supply to the heart. The wall of the heart gets blood supply from the aorta through a pair of small coronary arteries. Due to some risk factors there may be blockage or narrowing of the coronary arteries which results in inadequate blood supply to the heart muscles. The risk factors causing coronary heart disease are classified into non-modifiable and modifiable risk factors. The non-modifiable risk factors are the age, male sex and family history. The modifiable risk factors are smoking, hypertension, cholesterol, diabetes mellitus, sedentary life style (physical inactivity), obesity, deficiency of vitamins, alcoholism, mental stress etc.

The major risk factors taken as the attributes are:

H₁: High blood pressure
H₂: Smoking/Other Tobacco use
H₃: Overweight and obesity people
H₄: Abnormal blood fats
H₅: Inactive life style
H₆: Old Age
The main attributes/head $S_1$, $S_2$, ..., $S_5$ related to the symptoms are:

- $S_1$: Swelling of legs and ankles
- $S_2$: Chest pain
- $S_3$: Dyspnoea (shortness of breath)
- $S_4$: Dizziness
- $S_5$: Less blood flow

The five symptoms heads $S_1$, $S_2$, ..., $S_5$ used above are related to the risk factors ($H_1$, $H_2$, ..., $H_6$) of heart disease as the row of fuzzy relational matrix. Using these related symptoms of heart disease along columns the fuzzy relational equations are formed using expert’s opinion. Certain limits set by the expert’s opinion are as follows:

- $H_1 \geq 0.5$ High blood pressure
- $H_2 \geq 0.5$ Smoking/Other Tobacco use
- $H_3 \geq 0.5$ Overweight and obesity people
- $H_4 \geq 0.5$ Abnormal blood fats
- $H_5 \geq 0.4$ Inactive life style
- $H_6 \geq 0.4$ Old Age

**Expert’s Opinion**

The expert’s opinion of cardiovascular diabetic mellitus are transformed into the fuzzy relation equation $P$ which is given by

$$
\begin{bmatrix}
S_1 & S_2 & S_3 & S_4 & S_5 \\
H_1 & 0.7 & 0.6 & 0.4 & 0.4 & 0.5 \\
H_2 & 0.4 & 0.5 & 0.7 & 0.4 & 0.4 \\
H_3 & 0.5 & 0.7 & 0.6 & 0.5 & 0.4 \\
H_4 & 0.4 & 0.9 & 0.6 & 0.3 & 0.3 \\
H_5 & 0.5 & 0.4 & 0.6 & 0.3 & 0.3 \\
H_6 & 0.5 & 0.5 & 0.5 & 0.4 & 0.4 \\
\end{bmatrix}
$$

$$Q^T = [0.6 \quad 0.8 \quad 0.7 \quad 0.4 \quad 0.3]$$ and $R^T = [0.48 \quad 0.49 \quad 0.56 \quad 0.72 \quad 0.42 \quad 0.40]$
By considering the diabetic patient having the symptoms and given values for \( Q \), where \( Q^T = [0.6 \ 0.8 \ 0.7 \ 0.4 \ 0.3] \). Now \( P \) and \( Q \) are known in the fuzzy relation equation \( P \circ Q = R \). Using the max-min principle in the equation \( P \circ Q = R \), \( R^T = [0.48 \ 0.49 \ 0.56 \ 0.72 \ 0.42 \ 0.40] \) is obtained.

In the fuzzy relational equation \( P \circ Q = R \), \( P \) is considered as weightages of the expert’s, \( Q \) is the symptoms of the heart disease and \( R \) is the computed resultant for risk factors. It is also assumed that the diabetic condition of patient is badly affected by risk factors, when the patient crosses the adult age. According to the expert’s opinion the heart attack risk in diabetic patient is more when fat content is more in blood. Overweight and obesity is in the second risk, followed by smoking, due to increase in blood pressure.

**Clinical Research Opinion**

The clinical research opinion of cardiovascular diabetic mellitus are transformed into the fuzzy relation equation \( P \) which is given by

\[
P = \begin{bmatrix}
S_1 & S_2 & S_3 & S_4 & S_5 \\
H_1 & 0.7 & 0.6 & 0.4 & 0.4 & 0.5 \\
H_2 & 0.4 & 0.5 & 0.7 & 0.4 & 0.4 \\
H_3 & 0.5 & 0.7 & 0.6 & 0.5 & 0.4 \\
H_4 & 0.4 & 0.9 & 0.6 & 0.3 & 0.3 \\
H_5 & 0.5 & 0.4 & 0.6 & 0.3 & 0.3 \\
H_6 & 0.5 & 0.5 & 0.5 & 0.4 & 0.4 \\
\end{bmatrix}
\]

\[Q^T = [0.6 \ 0.9 \ 0.8 \ 0.4 \ 0.5 \ 0.4] \] and \( R^T = [0.54 \ 0.56 \ 0.63 \ 0.81 \ 0.48 \ 0.45] \).

These symptoms are given based on the risk factors for diabetic patients. According to expert’s opinion \( Q^T = [0.6 \ 0.8 \ 0.7 \ 0.4 \ 0.3] \). Hence \( P \) and \( Q \) are in the fuzzy relation equation, then \( R \) is calculated as \( P \circ Q^T = R \). Using the
max-min principle in the equation \( P \circ Q^T = R, \quad R = [0.48 \ 0.49 \ 0.56 \ 0.72 \ 0.42 \ 0.40]^T \) is obtained. According to the clinical research opinion the heart attack risk in diabetic patient is more when fat content is more in blood. Overweight and obesity is in the second risk, followed by smoking, due to increase in blood pressure.

According to the expert’s and clinical research opinion, the cardiovascular diabetic mellitus can be controlled by regular check-up of blood sugar and proper control with medicine and by monitoring regular blood pressure and regular tests of heart function. Prevention on weight gain by promoting salt restricted fat-free diet and regular exercise. A special test of fat content “Lipid Profile” if available may be done. It indicates the magnitude developing heart disease. By controlling smoking and drinking of alcohol the risk factor of heart disease could be reduced.

### 5.5 FUZZY RELATIONAL EQUATION FOR DIABETIC NEPHROPATHY

As in the case of heart, long-standing diabetes can also lead to complications in the kidneys. Patients with Type 1 Diabetes have 30-40% chance of developing kidney disorders after 20 years while it is 15-20% in Type 2, but since Diabetes Type 2 is more prevalent, kidney disease is more prevalent in Type 2 than Type 1. In India 11% of deaths in diabetics are due to kidney disorders.

The mechanism of development of these disorders is same as that of the heart. There is deposition of fat on the walls of small and large blood vessels (arteries) of the kidney leading to narrowing of blood vessels and blood flow obstruction. Due to this defect, the blood pressure increases and
waste products of the blood accumulate. The danger signals of kidney disorders in diabetes are increased lassitude, breathlessness on exertion, increased urination at night, swelling of the ankle, unstable control of blood sugar (reduced insulin requirements), and increased blood pressure. People with diabetes have a higher risk than normal for kidney disease. The tiny blood vessels in the kidneys that filter out waste products from the blood can get blocked and leaky. Also, cigarette smoking can lead to reduced blood flow to the kidney.

**Diagnosis**

- When kidneys are functionally normal, the urine contains no protein, while in diseased kidneys, urine contains protein which may rise up to 5 gm in 24 hours or even more.
- When the disease is in advanced stage, blood levels of urea and creatinine are very high.
- Due to diseased kidneys, urinary infection may develop as evidenced by pus cells and bacteria in urine.

**Treatment**

- Proper control of sugar by regular blood sugar monitoring and medicines.
- Treatment of high blood pressure if present.
- Treatment of urinary infection if present.
- In advanced disease of kidney, dialysis (removal of waste products from blood and recirculation of purified blood) or kidney transplant may be required.
Prevention

Following measures in diabetics can prevent this disease:

- Regular monitoring of blood pressure and control whenever necessary.
- Regular monitoring of blood sugar and controlling it.
- Avoid medicines (e.g. painkillers, dyes for x-rays) which affect kidney function.
- Regular 24 hours urinary protein levels and blood tests for kidney function (blood urea and creatinine).

Kidney Function Tests

A number of tests measure kidney function. The microalbumin determines the presence of amounts of albumin (a type of protein) in urine. Even a small amount of albumin may be a sign of early kidney damage. If the test results are positive, medicine is used to protect kidney. A serum creatinine test measures how well the kidney works to clear a muscle waste product called creatinine from blood. Expert’s recommended both a microalbumin and serum creatinine test once a year.

Risk Factors of Kidney Disorder Disease

The risk factors causing kidney disorder are classified into non-modifiable and modifiable risk factors. The non-modifiable diabetic risk factors are the age, sex and family history. The modifiable risk factors are smoking, hypertension, cholesterol, diabetes mellitus, damage of blood vessel, less blood supply to legs and feet etc.
The major risk factors taken as the attributes are:

$H_1$: High Blood Glucose

$H_2$: High Blood Pressure

$H_3$: Smoking

$H_4$: High Protein Content in Urine

$H_5$: High Blood Levels of Urea and Creatinine

The main attributes/heads $S_1, S_2, ..., S_5$ related to the symptoms are:

$S_1$: Increase in Lassitude

$S_2$: Breathless on Exertion

$S_3$: Increased Urination at night

$S_4$: Swelling of Ankle

$S_5$: Unstable control of blood sugar (Reduced Insulin Requirements)

The five symptoms heads $S_1, S_2, ..., S_5$ used above are related to the risk factors ($H_1, H_2, ..., H_5$) of kidney disorder as the row of fuzzy relational matrix. Using these heads related symptoms to kidney disorder along columns the fuzzy relational equations are formed using expert’s opinion. Certain limits set by the expert’s opinion are as follows:

$H_1 \geq 0.5$ High Blood Glucose

$H_2 \geq 0.5$ High Blood Pressure

$H_3 \geq 0.5$ Smoking

$H_4 \geq 0.5$ High Protein Content in Urine

$H_5 \geq 0.5$ High Blood Levels of Urea and Creatinine
Expert’s Opinion

The expert’s opinion of diabetic nephropathy is transformed into the fuzzy relation equation $P$ which is given by

$$
\begin{bmatrix}
S_1 & S_2 & S_3 & S_4 & S_5 \\
H_1 & 0.7 & 0.5 & 0.4 & 0.5 & 0.4 \\
H_2 & 0.6 & 0.7 & 0.5 & 0.6 & 0.4 \\
H_3 & 0.4 & 0.5 & 0.6 & 0.5 & 0.3 \\
H_4 & 0.5 & 0.6 & 0.5 & 0.4 & 0.6 \\
H_5 & 0.5 & 0.8 & 0.7 & 0.5 & 0.6
\end{bmatrix}
$$

$Q^T = [0.6 \ 0.8 \ 0.7 \ 0.6 \ 0.6]$ and $R^T = [0.42 \ 0.56 \ 0.42 \ 0.48 \ 0.64]$

By considering the diabetic patient having the symptoms and given values for $Q$, where $Q^T = [0.6 \ 0.8 \ 0.7 \ 0.6 \ 0.6]$. Now $P$ and $Q$ are known in the fuzzy relation equation $P \circ Q = R$. Using the max-min principle in the equation $P \circ Q = R$, $R^T = [0.42 \ 0.56 \ 0.42 \ 0.48 \ 0.64]$ is obtained.

In the fuzzy relation, $P$ is considered as weightages of the expert’s, $Q$ is the symptoms of kidney disorder and $R$ is the computed resultant for risk factors. According to the expert’s opinion the kidney disorder risk in diabetic patient is more when fat content is more in blood. Blood pressure is the first risk factor, the second risk followed by smoking, due to increase in blood pressure.

Clinical Research Opinion

The clinical research opinion of diabetic nephropathy is transformed into the fuzzy relation equation $P$ which is given by

$Q^T = [0.6 \ 0.8 \ 0.7 \ 0.6 \ 0.6]$ and $R^T = [0.42 \ 0.56 \ 0.42 \ 0.48 \ 0.64]$
These symptoms are given based on the risk factors for diabetic patients. According to expert’s opinion $Q^T = [.6 .8 .6 .5 .6]$. Hence P and Q are in the fuzzy relation equation, then R is calculated as $P \circ Q^T = R$. Using the max-min principle in the equation $P \circ Q^T = R$. i.e., $R = [.42 .60 .40 .48 .64]^T$ is obtained. According to the clinical research opinion the diabetic patient is badly affected by kidney disorder due to high blood levels of urea and creatinine, high blood pressure is the second risk factor, followed by high protein content in urine, smoking habit, high blood glucose level.

According to the clinical research opinion and expert’s opinion kidney can be protected by keeping the blood glucose levels at or near normal, controlling the blood pressure and not by smoking, which leads to reduce blood flow to the kidney. An early sign of kidney problems is protein in the urine. Every year urine test must be done to check the protein level by conducting microalbumin test because kidney can become damaged long before affected by any other symptoms. A serum creatinine blood test is also recommended annually, high creatinine levels are a sign of kidney problems that need medical attention.
5.6 FUZZY RELATIONAL EQUATION FOR DIABETIC NEUROPATHY

Diabetic neuropathy is the collective name for damages to nerves from diabetes. Diabetic neuropathy occurs in approximately 50% of individuals with long-standing diabetes.

Nerves Affected with Diabetic Neuropathy

Somatic nerves (nerves to the body wall, and limbs) as well as Autonomic nerves (nerves to internal organs like heart and stomach) are affected with diabetic neuropathy. But the most common entity is distal symmetric polyneuropathy. A decrease in sensations from the legs is the common and earlier symptom of this; but later on hands are also involved with this symptom. Patients with this symptom used to feel as if they have worn an aesthetic socks and gloves. Hyperesthesia (increased sensation), parathesia (a sensation of numbness, tingling, sharpness, or burning) and pain also occur later on. Loss of sensation in the foot acts as a tricky risk factor for provoking ulceration and its complications, very often. Inability to feel the pain of heart attack (silent myocardial infarction) and sense hypoglycemia (i.e. hypoglycemia unawareness), orthostatic hypotension (fainting on standing due to sudden drop in normal blood pressure) is some of the manifestations of autonomic neuropathy.

Treatment for Diabetic Neuropathy

Better blood sugar control with avoidance of alcohol, supplementation of vitamins like B12', B6' folate and symptomatic treatment are the mainstays of management. On disappearance of the pain of acute diabetic neuropathy over the first year, analgesics may be discontinued. Chronic, painful diabetic neuropathy is difficult to treat but may respond to
‘tricyclic antidepressants’ (e.g. amitriptyline, desipramine, nortriptyline),
gabapentin, and other agents (mexitilene, phenytoin, carbamazepine, capsaicin
cream). But the nonsteroidal anti-inflammatory drugs (diclofenac, ibuprofen)
should be avoided in persons with kidney damage.

Orthostatic hypotension secondary to autonomic neuropathy is
difficult to treat. Still a variety of agents have limited success
(fludrocortisone, midodrine, clonidine, octreotide, and yohimbine) but with
significant side effects. Nonpharmacologic maneuvers like adequate salt
intake, avoidance of dehydration and diuretics, and support to lower extremity
etc, may provide some relief from pain due to diabetic neuropathy.

Preventive Measures of Diabetic Neuropathy

Maintenance of better blood sugar control, regular exercises, diet
rich in minerals and vitamins (especially those with enough B12', B6' folate)
and abstinence from alcohol and tobacco form the mainstays of neuropathy
prevention in diabetes mellitus.

Precautions to be Taken While Going for Exercise

It will be better to abstain for persons with neurologic
complications of diabetes-especially if having peripheral neuropathy, from
traumatic and weight-bearing exercises such as running, since such activities
may easily lead to foot ulcers and stress fractures.

Complications of the Nerves in Diabetes

Majority of patients with diabetes develop complications of the
nerves. About 60% patients with about 25 years duration of diabetes are
found to develop these complications though the number may increase upto
90% in many cases. These complications are detected in both Type 1 and Type 2 Diabetes and mainly in middle-aged are elderly individuals. Invariably they are seen in uncontrolled mild diabetes of long duration. The nerves involved may be nerves of the hands and feet are these of the brain and spinal cord. Diagnosis is made by nerves conduction studies (velocities) on affected nerves and Electromyography (functioning of nerves in the arms and legs). Treatment varies according to the features presented. Vitamins have no role in treatment.

**Prevention**

Diabetic neuropathy can be prevented by proper evaluation of symptoms and testing of nerve and muscle functions. Treatment involves control of blood sugar levels and proper antibiotics.

**Infections**

It is universally known that diabetes is very prone to develop infections of different types. About 8.5% of diabetic patients are known to die due to infections inspite of availability of various antibiotics.

The 3 major causes of infections are

- Poor control of diabetes.
- Reduced immunity or resistance to fight diseases.
- Defects in the blood vessels and nerves.

**Types of Infections**

- Urinary infections are commonest and increase during pregnancy.
- Chest infections like tuberculosis and pneumonia.
• Skin infection-Boils, carbuncles, fungal infections especially in the genital area in female.
• Rarely infections of bones and gall bladder.

**The major risk factors taken as the attributes are:**

H₁: Direct damage due to lack of carbohydrate metabolism
H₂: Due to reduced blood supply to the nerves
H₃: Due to deposition of fat in large and small arteries supplying the nerves of hands and feet or brain

**The main attributes/head S₁, S₂,.....S₁₄ related to the symptoms are:**

The spectrum of symptoms reported by patients with nerves complication is given below:

S₁: Burning, cramp-like, piercing are dull aching pain in the feet and legs rarely in hand especially at night
S₂: Tingling, numbness and chillness in feet and legs followed by pain in muscles and insensitivity to hot, cold and pain sensations
S₃: Inability to maintain balance of body and strength and direction of movements of hands and feet
S₄: Deformities of toes and nails, thickened skin and ulcers and sole (due to insensitivity of feet and due to repeated injuries)
S₅: Pain, weakness and thinning of muscles of thigh
S₆: Inability to control passing of urine
S₇: Repeated diarrhoea or constipation
S₈: Abdominal cramps
S₉: Inability to sweat
S₁₀: Intolerance to extreme temperatures
S₁₁: Impotence
S\textsubscript{12}: Fall in blood pressure on suddenly standing up from lying down position
S\textsubscript{13}: Sudden attacks of weakness or paralysis usually on one side of body
(Stroke)
S\textsubscript{14}: Infections of the brain

The fourteen symptom heads S\textsubscript{1}, S\textsubscript{2}......S\textsubscript{14} used above are related to
the risk factors (H\textsubscript{1}...H\textsubscript{3}) of neuropathy as the row of fuzzy relational matrix.
Using these heads related symptoms to neuropathy along columns the fuzzy
relational equations are formed using expert’s opinion. Certain limits set by
the expert’s opinion are as follows:
H\textsubscript{1}≥0.5 Direct damage due to lack of carbohydrate metabolism.
H\textsubscript{2}≥0.5 Due to reduced blood supply to the nerves.
H\textsubscript{3}≥0.5 Due to deposition of fat in large and small arteries supplying the
nerves of hands and feet or brain.

**Expert’s Opinion**

The expert’s opinion of diabetic neuropathy is transformed into the
fuzzy relational equation P which is given by

\[
P = \begin{bmatrix}
S_1 & S_2 & S_3 & S_4 & S_5 & S_6 & S_7 & S_8 & S_9 & S_{10} & S_{11} & S_{12} & S_{13} & S_{14} \\
H_1 & 0.5 & 0.4 & 0.6 & 0.3 & 0.2 & 0.3 & 0.5 & 0.1 & 0.2 & 0.1 & 0.3 & 0.4 & 0.4 & 0.3 \\
H_2 & 0.5 & 0.3 & 0.2 & 0.1 & 0.3 & 0.4 & 0.5 & 0.2 & 0.1 & 0.3 & 0.4 & 0.6 & 0.7 & 0.2 \\
H_3 & 0.2 & 0.3 & 0.1 & 0.4 & 0.5 & 0.6 & 0.4 & 0.5 & 0.3 & 0.5 & 0.4 & 0.5 & 0.6 & 0.6 
\end{bmatrix}
\]

\[
Q^T = [0.5 \ 0.4 \ 0.6 \ 0.5 \ 0.6 \ 0.5 \ 0.3 \ 0.5 \ 0.4 \ 0.6 \ 0.7 \ 0.7] \text{ and } R^T = [0.40 \ 0.50 \ 0.40]
\]

By considering the diabetic patient having the symptoms and given
values for Q, where \( Q^T = [0.5 \ 0.4 \ 0.6 \ 0.5 \ 0.6 \ 0.5 \ 0.3 \ 0.5 \ 0.4 \ 0.6 \ 0.7 \ 0.7]. \) Hence
P and Q are in the fuzzy relation equation \( P \circ Q = R. \) Using the max-min
principle in the equation \( P \circ Q = R, \text{ } R^T = [0.40 \ 0.50 \ 0.40] \) is obtained.
In the fuzzy relation $P$ is considered as weightages of the expert’s, $Q$ is the symptoms of nerve disorder and $R$ is the computed resultant for risk factors. It is also assumed that the nerves of the patient are badly affected by risk factors when the blood supply is reduced to the nerves. According to the expert’s opinion the nerve disorder risk in diabetic patient is more when blood supply reduces. Lack of carbohydrate metabolism is in the second risk, followed by deposit of fat in small and large arteries.

**Clinical Research Opinion**

The clinical research opinion of diabetic neuropathy is transformed into the fuzzy relation equation $P$ which is given by

\[
\begin{bmatrix}
S_1 & S_2 & S_3 & S_4 & S_5 & S_6 & S_7 & S_8 & S_9 & S_{10} & S_{11} & S_{12} & S_{13} & S_{14} \\
H_1 & 0.5 & 0.4 & 0.6 & 0.3 & 0.2 & 0.3 & 0.5 & 0.1 & 0.2 & 0.1 & 0.3 & 0.4 & 0.4 & 0.3 \\
H_2 & 0.5 & 0.3 & 0.2 & 0.1 & 0.3 & 0.4 & 0.5 & 0.2 & 0.1 & 0.3 & 0.4 & 0.6 & 0.7 & 0.2 \\
H_3 & 0.2 & 0.3 & 0.1 & 0.4 & 0.5 & 0.6 & 0.4 & 0.5 & 0.3 & 0.5 & 0.4 & 0.5 & 0.6 & 0.6
\end{bmatrix}
\]

\[
Q^T = [0.4 \quad 0.5 \quad 0.6 \quad 0.3 \quad 0.4 \quad 0.5 \quad 0.6 \quad 0.4 \quad 0.3 \quad 0.5 \quad 0.6 \quad 0.6] \quad \text{and} \quad R^T = [0.36 \quad 0.42 \quad 0.36].
\]

These symptoms are given based on the risk factors for diabetic patients. According to expert’s opinion $Q^T = [0.4 \quad 0.5 \quad 0.6 \quad 0.3 \quad 0.4 \quad 0.5 \quad 0.6 \quad 0.4 \quad 0.3 \quad 0.5 \quad 0.6 \quad 0.6].$ Hence $P$ and $Q$ are in the fuzzy relation equation, then $R$ is calculated as $P \circ Q^T = R.$ Using the max-min principle in the equation $P \circ Q^T = R,$ i.e., $R = [0.36 \quad 0.42 \quad 0.36]^T$ is obtained. According to the clinical research opinion the diabetic patient is badly affected by nerve disorder due to the risk factor of reduced blood supply to the nerves, the second risk followed due to the lack of carbohydrate metabolism and finally due to deposition of fat in large and small arteries supplying the nerves of hands and feet or brain.
According to the expert’s and clinical opinion, the diabetic neuropathy can be controlled by regular check-up of blood sugar and proper usage of antibiotic by physician advice controlling various skin, chest, urinary infections. If the diabetes is controlled properly in a diabetic patient automatically immunity or resistance to fight disease increases. Monitoring regular nerve function can be checked by Electromyography.

5.7 FUZZY RELATIONAL EQUATION FOR DIABETIC GANGRENE OF FOOT

Gangrene of Foot is a chronic complication of diabetes mellitus developing over years, due to gradual damage to blood vessels and nerves of leg, resulting in foot ulcers and death of certain parts of foot (diabetic gangrene). Nerves that carry sensation (i.e. sensory nerves) from the foot are more involved in diabetes, than those that move on their foot. The chronic complications of diabetes mellitus develop over years, in both types of diabetes. These are due to gradual reduction in blood flow, resulting from slow destruction of blood vessel walls and hence generally known as vascular complications (vascular=vessel related). In Neuropathy (disease of the nerves) also, the blood vessel damage plays a significant role.

Preventive Measure of Foot Problems in Diabetes Mellitus

In addition to the combined approach of regular medical care, screening, monitoring, and daily adherence to doctor’s guidelines to maintain normal blood sugar levels, the following things are also to be done.

- **Self examination of Foot:** A diabetic person should examine his feet for changes every day. Feet examination should be the last routine of a diabetic person, before going into bed. A diabetic person should examine his feet, as keen as his face. The eyes should reach every inch below knee
portions of both legs, with special attention to the area between the toes. A hand mirror should be used, to see the sole conveniently. If it becomes difficult to reach the feet or to see them properly, even with the help of a mirror, someone else should be asked (such as spouse) to look at them.

If the patient washes feet with soap and water before going to bed, drying also should be done, gently with soft cloth. Even special and soft foot wares should not be worn for a long time, initially (new one). Patient must check for any broken skin, ulcers, bunions, blisters, or increased callus formation and notify the doctors if any changes are found. Patients must routinely check their feet.

- **Clinical Examination by a Doctor:** Type 1 diabetic person, should begin annual foot examinations, five years after the diagnosis. In persons with type 2 diabetes, annual foot examination should begun at the time of diagnosis itself. On routine medical visits, doctors usually check the blood flow and sensation in the feet, in both types of patients. The other changes to be noted are signs of current or previous ulcer, cold feet, thin skin, bluish skin colour, skin breaks associated with athlete’s foot (a sort of fungal infection), and bunions.

**Gangrene of Foot**

Gangrene refers to death or decay of a part of body. Gangrene of the foot is very common in diabetes and has necessitated amputation (removal) of toes or even the whole foot in many cases. Causes of gangrene destruction of nerves of the foot or lower limb are reduction in blood supply to the foot and skin infection of the foot or sole.
Foot Problems

15% of patients with diabetes will develop foot ulcers due to nerve damage and reduced blood flow. If foot ulcers develop the patients must see the doctor immediately.

Treatment

- Controlling blood sugar is of utmost importance.
- Soft pad on the sole.
- Rest to the legs or complete bed rest.
- Treatment of infection with antibiotics.
- Treatment of pain with pain-killers.
- Amputation (removal) of affected toes or whole foot when disease is spreading or pain not controlled.

Prevention

- Regular monitoring of blood sugar.
- Examination of the feet yearly or twice a year.
- Washing feet daily and using lubricating creams, oils.
- Not to walk barefoot.
- Avoid extremes of temperature.
- Wear appropriately fitting shoes.
- Cut toe nails regularly.
- Never to cut corn or calluses.
- Treatment for skin diseases.
Treatment of foot is always done in the hospital with regular monitoring of feet and laboratory parameters. The foot must be kept clean, warm and dry. Patient must change daily clean soft socks and with well fitting shoes. Examine shoes every day for cracks, pebbles, nails and other irregularities. Patient affected by gangrene foot must not use alcohol based solutions, as it makes the feet dry. Patient must never walk barefoot, never apply heat of any kind to feet and must not cut corns or calluses on self.

**Risk Factors**

The risk factors causing Gangrene of Foot are classified into non-modifiable and modifiable risk factors. The non-modifiable risk factors are the age, male sex and family history. The modifiable risk factors are damage of blood vessel, less blood supply to legs and feet etc.

**The major risk factors taken as the attributes are:**

- **H₁**: Poor Control of Blood Glucose
- **H₂**: High Blood Pressure
- **H₃**: High Cholesterol
- **H₄**: Less Blood Supply of Blood to Legs and Foot
- **H₅**: Damage of Blood Vessels (Smoking)

**The main attributes/heads S₁, S₂,..... S₅ related to the symptoms are:**

- **S₁**: Pain in the foot
- **S₂**: Loss of sensation in foot
- **S₃**: Changes in colour and texture
- **S₄**: Chillness in ankle and foot
- **S₅**: Skin infection of foot
The five symptoms heads $S_1$, $S_2$, …, $S_5$ used above are related to the risk factors ($H_1$, $H_2$, …, $H_5$) of gangrene of foot as the row of fuzzy relational matrix. Using these related symptoms to gangrene of foot along columns the fuzzy relational equations are formed using expert’s opinion. Certain limits set by the expert’s opinion are as follows:

$H_1 \geq 0.6$ Poor Control of Blood Glucose

$H_2 \geq 0.5$ Blood Pressure

$H_3 \geq 0.5$ Cholesterol

$H_4 \geq 0.5$ Blood Supply of Blood to Legs and Foot

$H_5 \geq 0.5$ Damage of Blood Vessels (Smoking)

**Expert’s Opinion**

The expert’s opinion of diabetic gangrene of foot is transformed into the fuzzy relation equation $P$ which is given by

$$P = \begin{bmatrix}
H_1 & S_1 & S_2 & S_3 & S_4 & S_5 \\
0.6 & 0.5 & 0.4 & 0.3 & 0.5 \\
0.5 & 0.4 & 0.2 & 0.4 & 0.3 \\
0.5 & 0.3 & 0.4 & 0.2 & 0.3 \\
0.6 & 0.7 & 0.5 & 0.4 & 0.6 \\
0.4 & 0.3 & 0.3 & 0.5 & 0.5 
\end{bmatrix}$$

$Q^T = [0.6 \ 0.7 \ 0.5 \ 0.4 \ 0.3]$ and $R^T = [0.36 \ 0.30 \ 0.30 \ 0.49 \ 0.24]$

By considering the diabetic patient having the symptoms and given values for $Q$, where $Q^T = [0.6 \ 0.7 \ 0.5 \ 0.4 \ 0.3]$. Hence $P$ and $Q$ are in the fuzzy relation equation $P \circ Q = R$. Using the max-min principle in the equation $P \circ Q = R$, $R^T = [0.36 \ 0.30 \ 0.30 \ 0.49 \ 0.24]$ is obtained.
In the fuzzy relation $P$ is considered as weightages of the expert’s, $Q$ is the symptoms of gangrene of foot and $R$ is the computed resultant for risk factors. According to the expert’s opinion the gangrene of foot risk in diabetic patient is more when the blood supply to legs and foots are poor. Due to smoking blood pressure, cholesterol increases which damages blood vessels is the second risk, followed by smoking, due to increase in blood pressure.

**Clinical Research Opinion**

The clinical research opinion of gangrene of foot are transformed into the fuzzy relational equation $P$ which is given by

\[
P = \begin{bmatrix}
S_1 & S_2 & S_3 & S_4 & S_5 \\
H_1 & 0.6 & 0.5 & 0.4 & 0.3 & 0.5 \\
H_2 & 0.5 & 0.4 & 0.2 & 0.4 & 0.3 \\
H_3 & 0.5 & 0.3 & 0.4 & 0.2 & 0.3 \\
H_4 & 0.6 & 0.7 & 0.5 & 0.4 & 0.6 \\
H_5 & 0.4 & 0.3 & 0.3 & 0.5 & 0.5
\end{bmatrix}
\]

$Q^T = [0.6, 0.8, 0.7, 0.4, 0.5]$ and $R^T = [0.36, 0.32, 0.30, 0.56, 0.25]$

These symptoms are given based on the risk factors for diabetic patients. According to expert’s opinion $Q^T = [0.6, 0.8, 0.7, 0.4, 0.5]$. Hence $P$ and $Q$ are in the fuzzy relation equation, then $R$ is calculated as $P \circ Q^T = R$. Using the max-min principle in the equation $P \circ Q^T = R$. i.e., $R = [0.36, 0.30, 0.49, 0.29]^T$ is obtained. According to the clinical research opinion the diabetic patient is badly affected by gangrene of foot due to poor blood supply to legs and foots, poor control of blood glucose is in the second risk, followed by blood pressure, cholesterol, damage of blood vessels due to smoking.
According to the expert’s and clinical opinion, diabetic gangrene of foot can be outlawed by regular check-up of control of blood sugar. Use of soft pad on sole, preventing foot ulcer by wearing proper foot wears instead of tight foot wear. Giving rest to leg, treating the infection by using antibiotics and pain killer. Amputation or Removal of affected toes or whole foot when disease spread or if pain is uncontrolled. Controlling smoking and drinking of alcohol.

5.8 FUZZY RELATIONAL EQUATION FOR DIABETIC RETINOPATHY

Diabetic retinopathy is one of the most common eye disease linked with diabetes. It is the leading cause of blindness among working age people and adults. It is diabetic complication but with early treatment and detection, vision loss is preventable.

- **Diabetic Retinopathy**: damage to the blood vessels in the retina.
- **Cataract**: clouding of the eye's lens. Cataracts develop at an earlier age in people with diabetes.
- **Glaucoma**: increase in fluid pressure inside the eye that leads to optic nerve damage and loss of vision. A person with diabetes is nearly twice as likely to get glaucoma as other adults.

Diabetic retinopathy is the most common diabetic eye disease and a leading cause of blindness in adults. It is caused by changes in the blood vessels of the retina. In some people with diabetic retinopathy, blood vessels may swell and leak fluid. In other people, abnormal new blood vessels grow on the surface of the retina. The retina is the light-sensitive tissue at the back of the eye. A healthy retina is necessary for good vision. If a patient has diabetic retinopathy, at first the patient may not notice changes to the vision.
But over time, diabetic retinopathy can get worse and cause vision loss. Diabetic retinopathy usually affects both eyes.

**Treatment**

To prevent the development of this eye disease, diabetic patients should maintain

- Blood cholesterol
- Blood sugar and Blood pressure

**The major risk factors taken as the attributes are:**

H\(_1\) : Smoking
H\(_2\) : High cholesterol level
H\(_3\) : High blood pressure
H\(_4\) : Failure to control diabetes
H\(_5\) : Increased Glucose level for long period
H\(_6\) : Pregnant women with diabetes

**The main attributes/heads S\(_1\), S\(_2\),…, S\(_3\) related to the symptoms are:**

S\(_1\) : Red film or dark streaks that obstruct the vision
S\(_2\) : Missing or shadow areas of vision
S\(_3\) : Spots floating
S\(_4\) : Poor night vision
S\(_5\) : Blurred vision
S\(_6\) : Vision loss

The six symptoms heads S\(_1\), S\(_2\),…, S\(_6\) used above are related to the risk factors (H\(_1\), H\(_2\),…H\(_6\)) of eye disease as the row of fuzzy relational matrix. Using these related symptoms of eye disease along columns the fuzzy
relational equations are formed using expert’s opinion. Certain limits set by the expert’s opinion are as follows:

\[ H_1 \geq 0.5 \text{ Smoking} \]
\[ H_2 \geq 0.5 \text{ Blood Pressure} \]
\[ H_3 \geq 0.5 \text{ Cholesterol} \]
\[ H_4 \geq 0.5 \text{ Blood Supply of Blood to Legs and Foot} \]
\[ H_5 \geq 0.5 \text{ Damage of Blood Vessels (Smoking)} \]

**Expert’s Opinion**

The expert’s opinion of eye diseases are transformed into the fuzzy relation equation \( P \) given by

\[
P = \begin{bmatrix}
S_1 & S_2 & S_3 & S_4 & S_5 & S_6 \\
H_1 & 0.5 & 0.4 & 0.7 & 0.5 & 0.4 & 0.4 \\
H_2 & 0.7 & 0.6 & 0.6 & 0.4 & 0.5 & 0.3 \\
H_3 & 0.3 & 0.9 & 0.3 & 0.6 & 0.6 & 0.6 \\
H_4 & 0.4 & 0.3 & 0.4 & 0.7 & 0.3 & 0.5 \\
H_5 & 0.8 & 0.5 & 0.7 & 0.5 & 0.4 & 0.3 \\
H_6 & 0.6 & 0.5 & 0.5 & 0.3 & 0.5 & 0.7
\end{bmatrix}
\]

\[ Q^T = [.8 \ .6 \ .8 \ .7 \ .6 \ .7] \text{ and } R^T = [.64 \ .54 \ .56 \ .49 \ .36 \ .49]. \]

By considering the diabetic patient having the symptoms and given values for \( Q \), where \( Q^T = [.8 \ .6 \ .8 \ .7 \ .6 \ .7] \). Hence \( P \) and \( Q \) are in the fuzzy relation equation \( P \circ Q = R \). Using the max-min principle in the equation \( P \circ Q = R \), where \( R^T = [.64 \ .54 \ .56 \ .49 \ .36 \ .49] \) is obtained.

In the fuzzy relation \( P \) is considered as weightages of the expert’s, \( Q \) is the symptoms of eye disease and \( R \) is the computed resultant for risk factors. According to the expert’s opinion the eye is badly affected by the risk factors like increase in glucose level followed by high cholesterol level then
due to smoking then high blood pressure and finally if a pregnant women is affected by diabetic The symptoms could be missing of vision or shadowing, red film on vision, spot floating, poor night vision, vision loss or blurred vision.

**Clinical Research Opinion**

The clinical research opinion of eye disease are transformed into the fuzzy relational equation $P$ which is given by

$$
P = \begin{bmatrix}
S_1 & S_2 & S_3 & S_4 & S_5 & S_6 \\
H_1 & 0.4 & 0.4 & 0.7 & 0.5 & 0.4 & 0.4 \\
H_2 & 0.6 & 0.6 & 0.6 & 0.5 & 0.5 \\
H_3 & 0.3 & 0.8 & 0.3 & 0.5 & 0.3 \\
H_4 & 0.4 & 0.3 & 0.4 & 0.7 & 0.4 & 0.4 \\
H_5 & 0.7 & 0.5 & 0.6 & 0.5 & 0.2 & 0.6 \\
H_6 & 0.6 & 0.5 & 0.5 & 0.3 & 0.3 & 0.7
\end{bmatrix}
$$

$Q^T = [0.7, 0.8, 0.6, 0.5, 0.4, 0.3]$ and $R^T = [0.49, 0.64, 0.42, 0.35, 0.20, 0.21]$.

These symptoms are given based on the risk factors for diabetic patients. According to expert’s opinion $Q^T = [0.7, 0.8, 0.6, 0.5, 0.4, 0.3]$. Hence $P$ and $Q$ are in the fuzzy relation equation $P \circ Q^T = R$. Using the max-min principle in the equation $P \circ Q^T = R$, $R^T = [0.49, 0.64, 0.42, 0.35, 0.20, 0.21]$ is obtained. According to the clinical research opinion the eye is badly affected by the risk factors like increase in glucose level followed by high cholesterol level then due to smoking then high blood pressure and finally if a pregnant women is affected by diabetic The symptoms could be missing of vision or shadowing, red film on vision, spot floating, poor night vision, vision loss or blurred vision.
According to the expert’s and clinical opinion, the eye disease can lead to the risk of serious vision, precautions can be made by controlling blood pressure, regular eye check up, keeping blood glucose under control, sudden check up has to be done if blurry vision or little speck floating before eye. Pregnant women must get examined in first three months of pregnancy

5.9 SUMMARY

This chapter has presented the fuzzy relations for various complications of diabetes. Fuzzy relations are developed by allowing the relationship between elements of two or more sets which is based on an infinite number of degrees of relationship between the extremes of completely related or not related symptoms and risk factors. It is observed that the results obtained by expert’s opinion and the clinical research opinion are found to be similar which satisfies the fuzzy relations.