Using the Analytical Hierarchy Process to Prioritize Medications for Treating Chronic Hypertension

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Abstract: Today, an increasing number of people are suffering from chronic hypertensive disease. In addition, there are more and more medications available to treat hypertension, which makes it difficult for doctors to choose the one that is most beneficial for the patient. This research is a good reference for beginner medical doctors, since it combines the opinions of six consultants in this field, based on their experience. The aim of this study was to prioritize the different medications available to treat chronic hypertension using a multi-criteria decision-making tool called the analytical hierarchy process (AHP). This tool was applied to two common cases of hypertension, with surveys being filled out by six expert medical consultants. This model used four different medications and six criteria. The averages of the survey results were determined so that all the expert doctors acted as one in this study. There were seven steps to the AHP, and the results prioritized each of the medications for the two cases. The result was a priority vector for each alternative in each case, showing the percentage for each alternative.

Keywords: Analytical Hierarchy Process, Chronic Hypertension

I. INTRODUCTION

The analytical hierarchy process (AHP) model is one of the most famous multi-criteria decision-making (MCDM) tools. It can mix both the qualitative and quantitative criteria, which makes this tool very suitable for use in this research. Applying the AHP in medicine is becoming more popular than ever because the continuous advances in medicine provide doctors with many different alternatives to choose from.

Chronic hypertensive disease is caused by the excess force of blood pushing against the blood vessel walls, creating abnormally high pressure in the arteries. Hypertension is a worldwide problem, and the number of people living with this disease has been increasing as the population increases. In 1980, approximately 600 million people 25 years old or older had hypertension, which increased to around 1 billion in 2008, representing 40% of that population. According to the World Health Organization (WHO), the percentage of individuals aged 25 and older with hypertension in the Kingdom of Saudi Arabia (KSA) was 40–44.9%. The rising number of people with hypertension presents a global health threat [1].

The exact cause of hypertension is not known and it cannot be corrected, but it can be controlled through a healthy lifestyle and medication. Ignoring hypertension can be very dangerous and could lead to stroke, angina, heart attack, heart failure, kidney failure, and peripheral artery disease [2].

Expert doctors have selected the four medications used most commonly to treat hypertension: amlodipine, hydrochlorothiazide, losartan, and lisinopril. Using the AHP in this research will help to prioritize these four different medicines for the two most common cases of chronic hypertensive disease based on the feedback from the expert medical doctors.

A doctor's choice of a medication for a specific patient involves the assessment of many criteria. With such many criteria and many alternatives, decision-making becomes complicated. Beginner doctors need to take advantage of expert consultants' medical opinions, and the AHP can provide them with

that. Establishing a database with many popular cases in medicine would be very helpful as guidance for doctors when they need to make decisions.

The aim of this study was to use the AHP to prioritize alternative medicines for two common cases of hypertension based on several criteria chosen by doctors who are experts in medicine. Prioritizing these alternatives could help beginner doctors to choose the best medication to prescribe for each of their hypertensive patients.

II. THE ANALYTICAL HIERARCHY PROCESS

Developed by Saaty [3 & 4], the AHP is one of several available MCDM analysis methods. This methodology has been applied to the structure, measures, and synthesis. The AHP allows the user to format problems in the form of a hierarchy or set of integrated levels, such as the goal, criteria, and alternatives. The main advantage of the AHP is its use of pairwise comparisons to obtain a ratio scale of measurement. Ratio scales are a natural method of comparing alternatives, and they allow the calculation of both tangible and intangible factors.

The AHP is composed of a set of axioms that define the scope of the problem setting [5]. The AHP is based on the clear mathematical structure of consistent matrices and the ability of their associated right eigenvectors to calculate exact or approximate weights [5–8]. The AHP compares criteria (or alternatives to a criterion) in a natural, pairwise fashion. In this process, the AHP uses a basic scale of absolute numbers, which has been proven in practice and validated by physical and decision-problem experiments. The basic scale captures individual preferences in terms of their quantitative and qualitative attributes [7 & 8]. It converts individual preferences into ratio scale weights that can be shared into a linear additive weight [w(a)] for each alternative. The result can be used to compare and rank the alternatives and assist the decision-maker in their task [9].

An important advantage of the AHP is that it allows for inconsistency in judgment. The other advantages and disadvantages of the AHP are described and debated extensively in the literature. For example, a series of articles in management science [10–14] compares the AHP with multi-attribute utility theory.

III. THE AHP IN MEDICINE

Many researchers have discussed the use of the AHP across a broad range of health and medical decision-making applications. For example, Hatcher [15] illustrated how the AHP can be included within a group decision support process and how the resulting system can be applied in several healthcare decision-making settings. In addition, Sloane et al. [16] discussed the applicability of the AHP for medical and hospital decision support. Liberatore and Nydick [17] evaluated 50 articles that addressed AHP applications in medicine. Most of the articles were related to project and technology evaluation and selection (14), followed by substantial activity in patient participation (9), therapy/treatment (8), and healthcare evaluation and policy (8).

The AHP has been used previously to evaluate and select medical treatments and therapies; however, this work did not involve the patient in the decision-making process. For example, Dolan [18] provided a detailed review of the theoretical foundations and methodologies of the AHP using the treatment of a dog bite wound as a motivating example. In addition, that researcher [18] applied the AHP to select an antibiotic regimen to treat a young woman hospitalized with acute pyelonephritis (kidney infection). The treatment alternatives included seven intravenous antibiotic regimens, and the criteria were maximizing the cure, minimizing the adverse effects (three categories), minimizing the cost, and minimizing resistance.

IV. DATA COLLECTION

For this research, a questionnaire was developed to collect the data, and six expert doctors completed the questionnaire. After filling out the questionnaire, the average of each result of all six consultants was calculated and input into the AHP model. Microsoft Excel was used to construct the AHP model and prioritize the different medications. Each of the two chosen cases had separate Excel AHP models, so each case was considered as a different study. The two most common chronic hypertension cases were chosen by the expert medical doctors as follows:

Case 1: An otherwise healthy 50-year-old male, not known to have any medical illnesses or to be taking any regular medications, presented to the clinic with repetitive high blood pressure. The rest of his vital signs and physical examination results were within normal limits.

Case 2: A 50-year-old male, known to have hypertension for the last 10 years, was not compliant with his medications. He presented to the clinic with repetitive high pressure, impaired renal function, and stage 2 kidney disease.

Each of the above cases had separate surveys and AHP models. In addition, the expert doctors chose six criteria as the most important criteria for these AHP model cases as follows:

1. Time to control blood pressure.
2. Frequency of taking the medication.
3. Patient compliance with the medication.
4. Minimum side effects.
5. Reduce complications of hypertension.
6. Cost of medication.

The four different medications chosen by the expert doctors were amlodipine, hydrochlorothiazide, losartan, and lisinopril.

Model application for Case 1

1. Develop a Pair-wise Comparison Matrix
    - Time to control blood pressure

    Table 3.1: 1st Case Time to control blood pressure Pair-wise comparison matrix

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril
Amlodipine	1.00	3.33	3.33	1.67
Hydrochlorothiazide	0.30	1.00	0.46	0.55
Losartan	0.30	2.17	1.00	2.00
Lisinopril	0.60	1.83	0.50	1.00
Sum	2.20	8.33	5.29	5.22

- Frequency of taking the medication

Table 3.2: 1st Case Frequency of Taking the Medication Pair-Wise Comparison Matrix

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril
Amlodipine	1.00	2.17	1.67	2.50
Hydrochlorothiazide	0.46	1.00	0.46	0.60
Losartan	0.60	2.17	1.00	2.33
Lisinopril	0.40	1.67	0.43	1.00
Sum	2.46	7.00	3.56	6.43

- Patient compliance

Table 3.3: 1st Case Patient Compliance Pair-wise comparison matrix

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril
Amlodipine	1.00	2.83	0.75	1.50
Hydrochlorothiazide	0.35	1.00	0.26	0.33
Losartan	1.33	3.83	1.00	2.33
Lisinopril	0.67	3.00	0.43	1.00
Sum	3.35	10.66	2.44	5.16

- Minimum side effect

Table 3.4: 1st Case Minimum side effect Pair-wise comparison matrix

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril
Amlodipine	1.00	3.67	0.60	1.30
Hydrochlorothiazide	0.27	1.00	0.24	0.25
Losartan	1.67	4.17	1.00	2.00
Lisinopril	0.77	4.00	0.50	1.00
Sum	3.71	12.84	2.34	4.55

- Reduce complication of hypertension

Table 3.5: 1st Case Reduce Complication of Hypertension Pair-Wise Comparison Matrix

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril
Amlodipine	1.00	2.00	0.24	0.24
Hydrochlorothiazide	0.50	1.00	0.30	0.30
Losartan	4.17	3.33	1.00	1.00
Lisinopril	4.17	3.33	1.00	1.00
Sum	9.83	9.66	2.54	2.54

- Cost

Table 3.6: 1st Case Cost Pair-Wise Comparison Matrix

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril
Amlodipine	1.00	0.23	1.69	2.66
Hydrochlorothiazide	4.27	1.00	7.22	11.35
Losartan	0.59	0.14	1.00	1.57
Lisinopril	0.38	0.09	0.64	1.00
Sum	6.24	1.46	10.54	16.58

- Criteria

Table 3.7: 1st Case Criteria Pair-Wise Comparison Matrix

	Time to control blood pressure	Frequency of taking the medication	Patient compliance	Minimum side effect	Reduce complication of hypertension	Cost
Time to control blood pressure	1.00	5.83	0.25	0.67	0.24	0.55
Frequency of taking the medication	0.17	1.00	0.19	0.37	0.16	0.32
Patient compliance	4.00	5.17	1.00	2.67	0.60	4.00
Minimum side effect	1.50	2.67	0.37	1.00	0.27	1.50
Reduce complication of hypertension	4.17	6.33	1.67	3.67	1.00	5.33
Cost	1.83	3.17	0.25	0.67	0.19	1.00
Sum	12.67	24.16	3.74	9.05	2.46	12.69

2. Develop A Normalized Matrix
3. Develop the Priority Vector

These Two Steps Will Be Merging In One Table As The Following.

- Time to control blood pressure

Table 3.8: 1st Case Time to control blood pressure Normalized Matrix and Priority Vector

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril	Priority Victor
Amlodipine	0.45	0.40	0.63	0.32	0.45
Hydrochlorothiazide	0.14	0.12	0.09	0.10	0.11
Losartan	0.14	0.26	0.19	0.38	0.24
Lisinopril	0.27	0.22	0.09	0.19	0.19

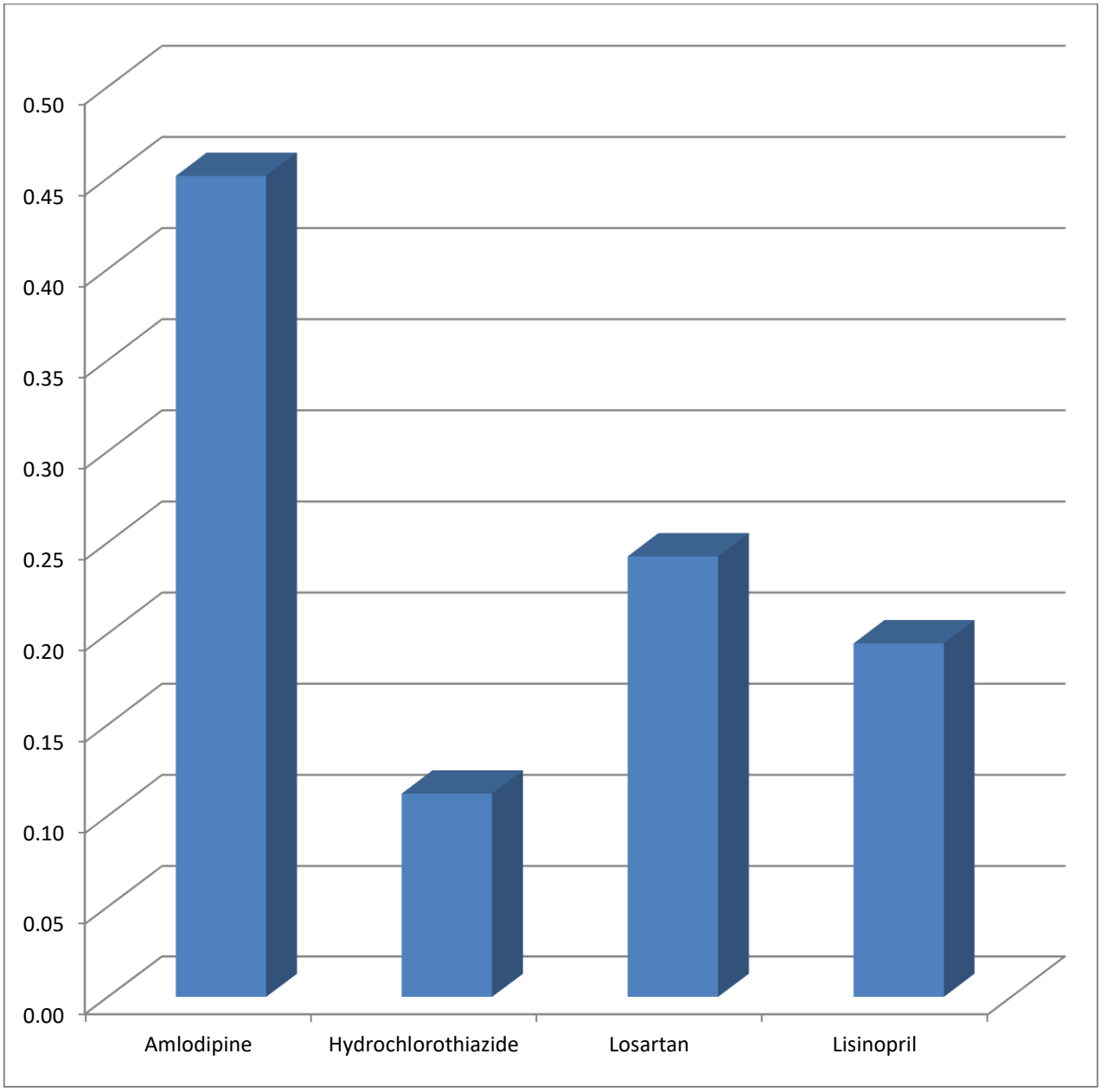

Figure 3.1: First Case Alternatives Priority Victor for Time to Control Blood Pressure Criterion

- Frequency of taking the medication

Table 3.9: 1st Case Frequency of taking the medication Normalized Matrix and Priority Vector

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril	Priority Victor
Amlodipine	0.41	0.31	0.47	0.39	0.39
Hydrochlorothiazide	0.19	0.14	0.13	0.09	0.14
Losartan	0.24	0.31	0.28	0.36	0.30
Lisinopril	0.16	0.24	0.12	0.16	0.17

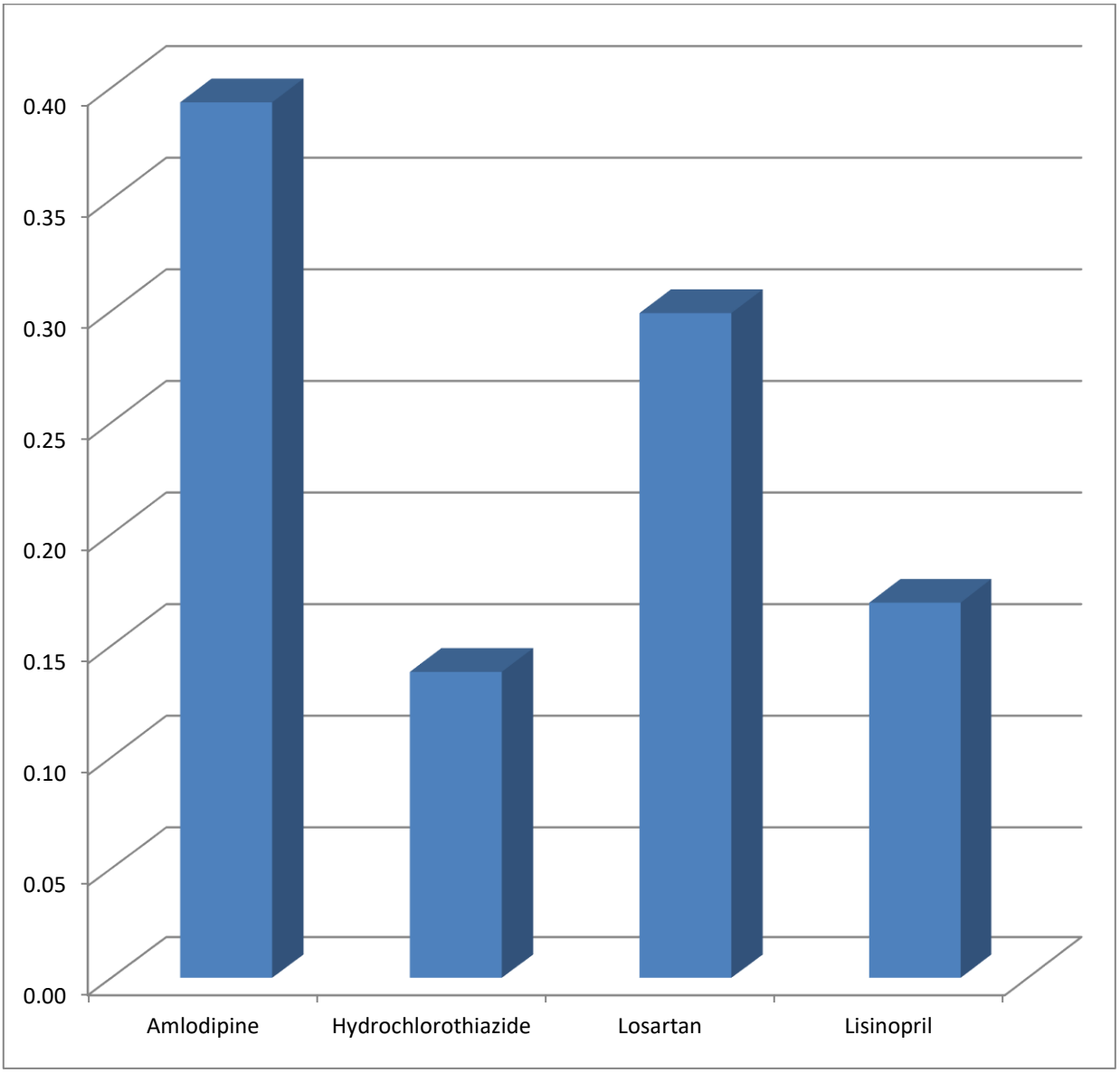

Figure 3.2: First Case Alternatives Priority Victor for Frequency of Taking the Medication Criterion

- Patient compliance

Table 3.10: 1st Case Patient Compliance Normalized Matrix and Priority Vector

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril	Priority Victor
Amlodipine	0.30	0.27	0.31	0.29	0.29
Hydrochlorothiazide	0.11	0.09	0.11	0.06	0.09
Losartan	0.40	0.36	0.41	0.45	0.40
Lisinopril	0.20	0.28	0.18	0.19	0.21

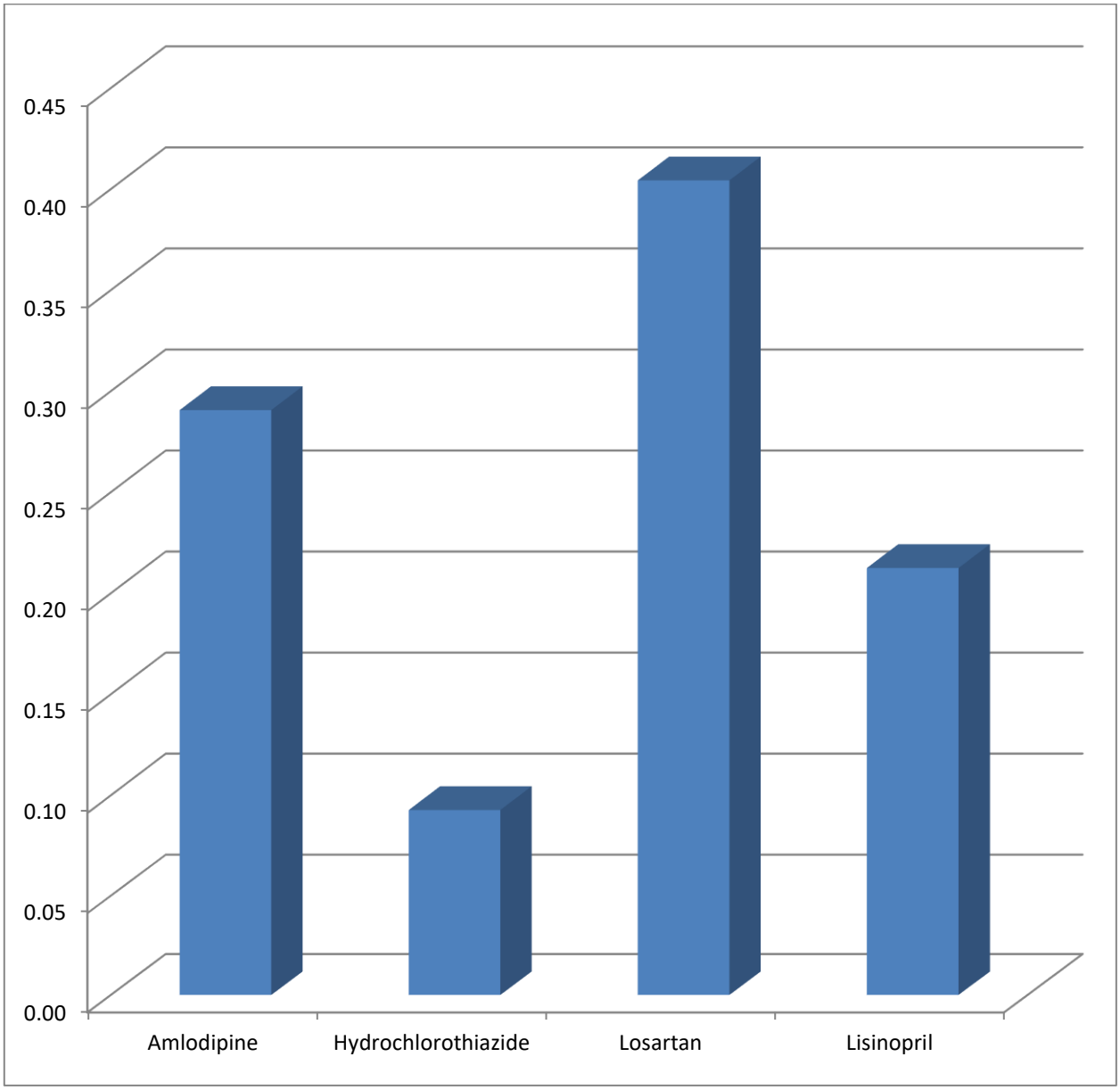

Figure 3.3: First Case Alternatives Priority Victor for Patient Compliance Criterion

- Minimum side effect

Table 3.11: 1st Case Minimum side effect Normalized Matrix and Priority Vector

	Amlodipine	Hydro-chlorothiazide	Losartan	Lisinopril	Priority Victor
Amlodipine	0.27	0.29	0.26	0.29	0.27
Hydrochlorothiazide	0.07	0.08	0.10	0.05	0.08
Losartan	0.45	0.32	0.43	0.44	0.41
Lisinopril	0.21	0.31	0.21	0.22	0.24

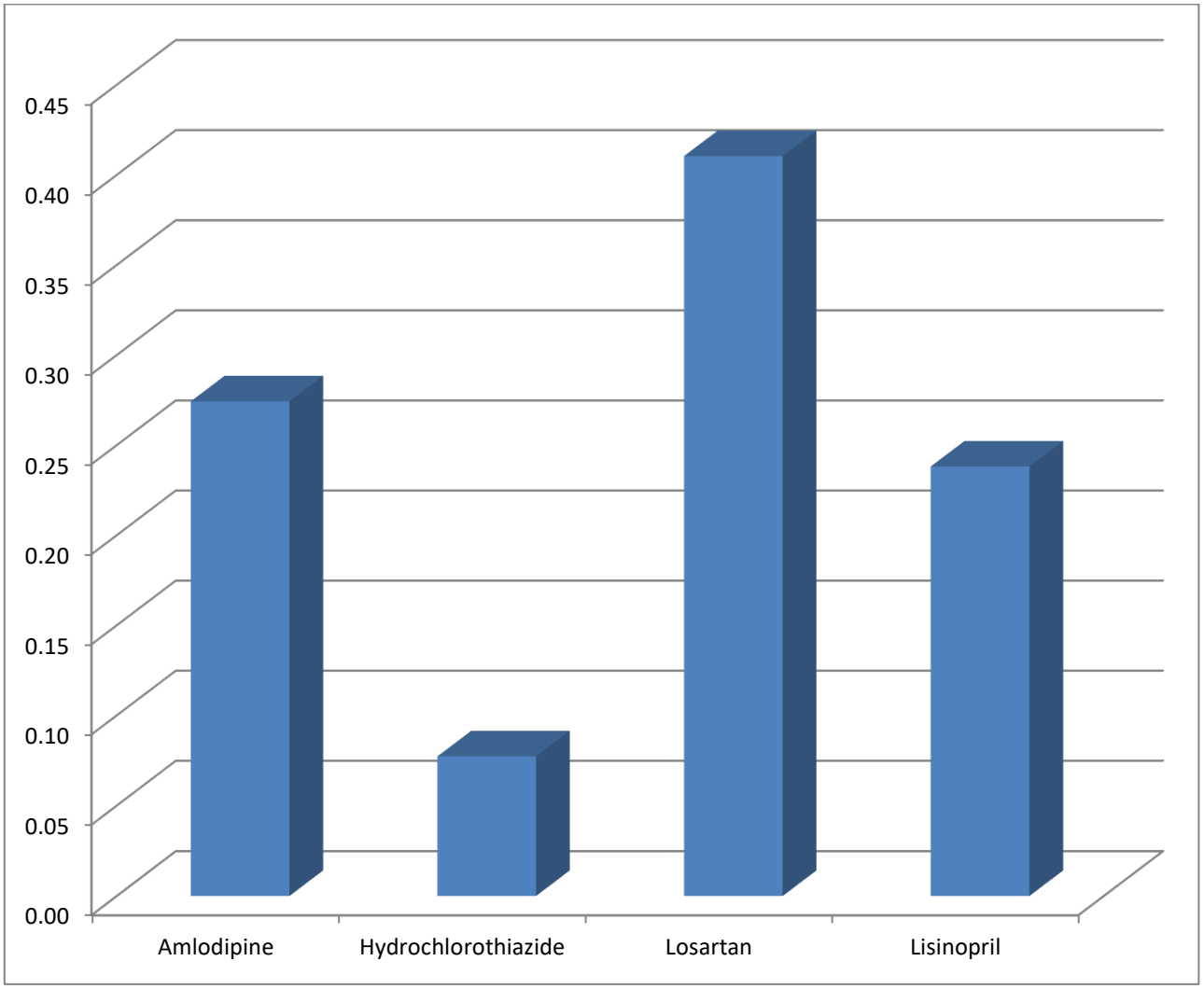

Figure 3.4: First Case Alternatives Priority Victor for Minimum Side Effect Criterion

- Reduce complication of hypertension

Table 3.12: 1st Case Reduce Complication of Hypertension Normalized Matrix and Priority Vector

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril	Priority Victor
Amlodipine	0.10	0.21	0.09	0.09	0.12
Hydrochlorothiazide	0.05	0.10	0.12	0.12	0.10
Losartan	0.42	0.34	0.39	0.39	0.39
Lisinopril	0.42	0.34	0.39	0.39	0.39

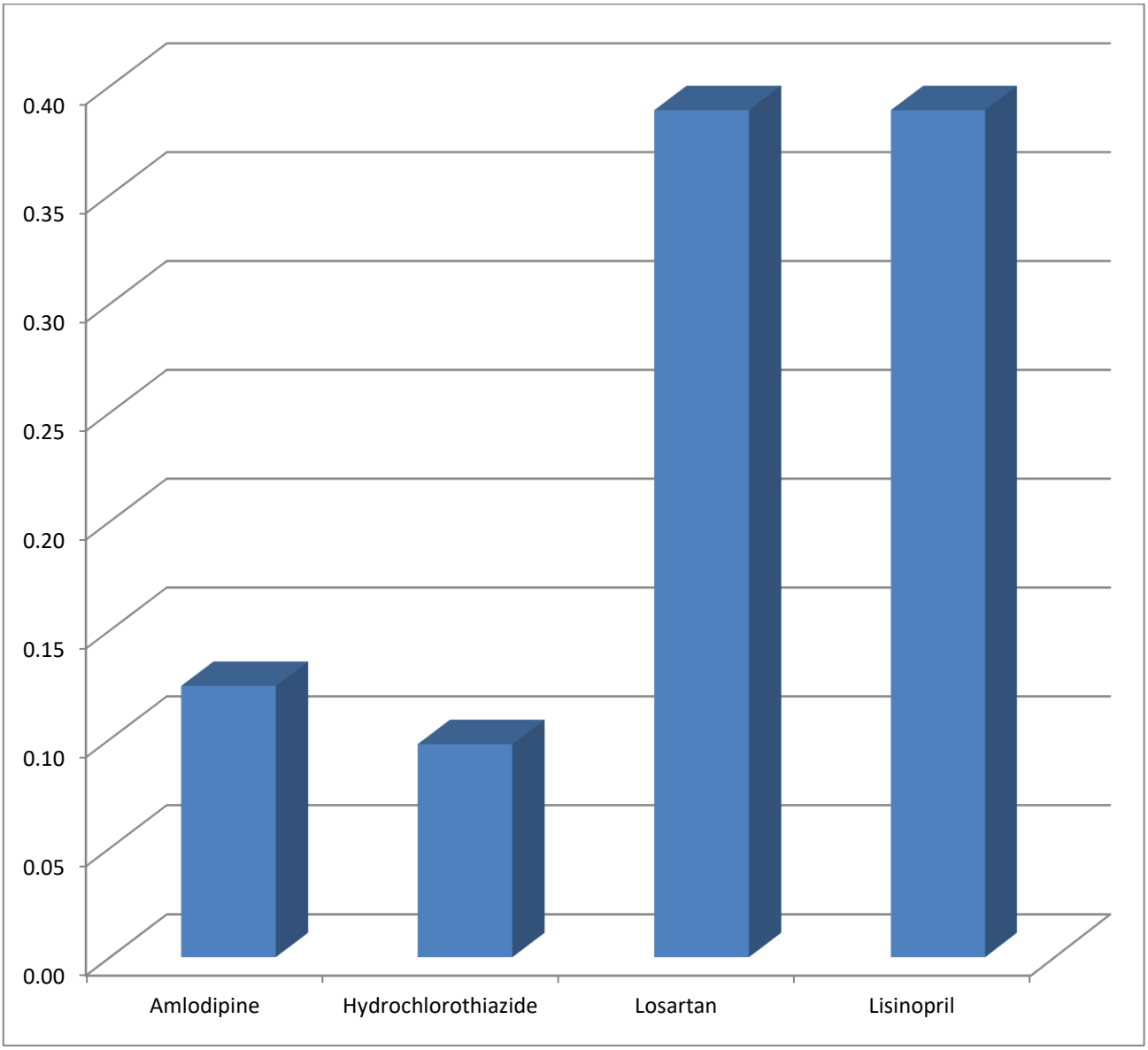

Figure 3.5: First Case Alternatives Priority Victor for Reduce Complication of Hypertension Criterion

- Cost

Table 3.12: 1st Case Cost Normalized Matrix and Priority Vector

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril	Priority Victor
Amlodipine	0.16	0.16	0.16	0.16	0.16
Hydrochlorothiazide	0.68	0.68	0.68	0.68	0.68
Losartan	0.09	0.09	0.09	0.09	0.09
Lisinopril	0.06	0.06	0.06	0.06	0.06

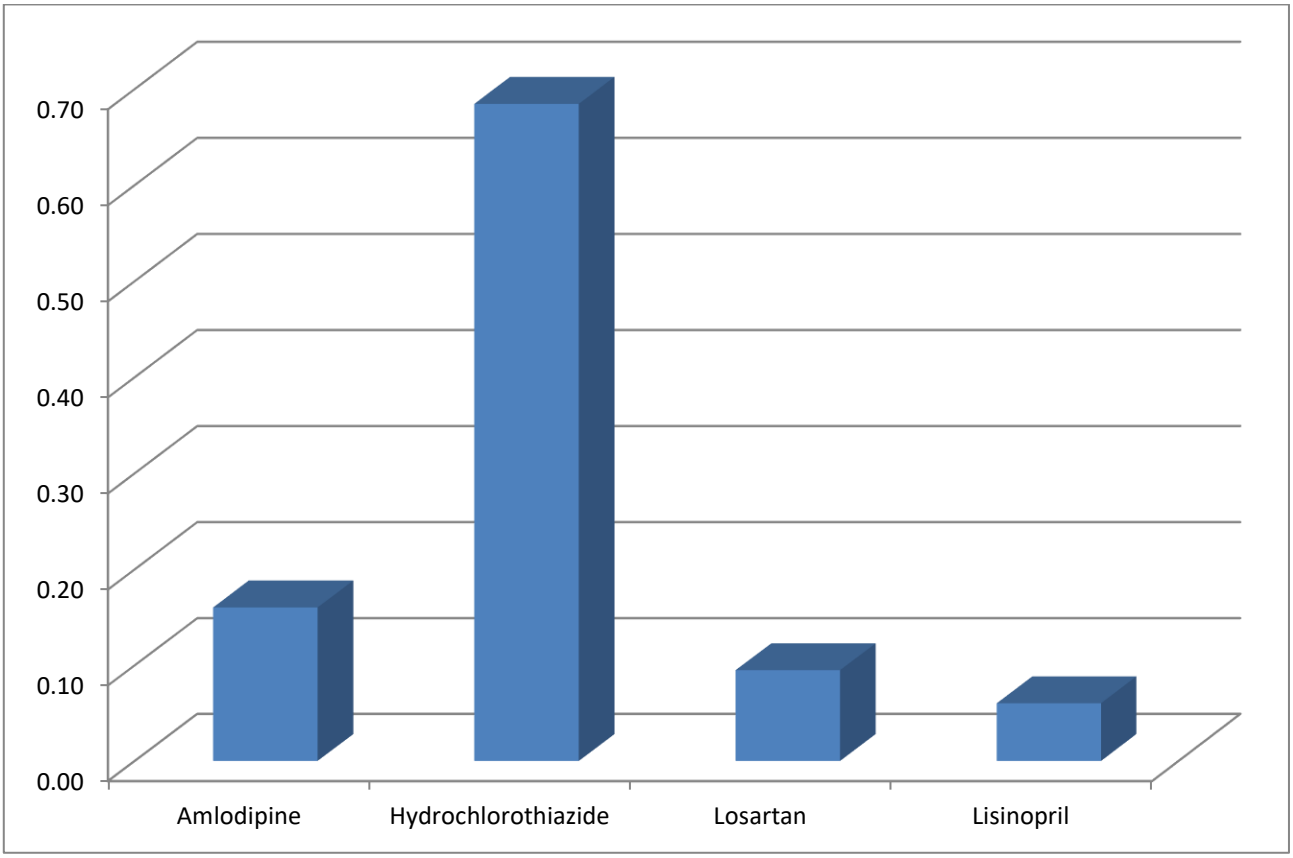

Figure 3.6: First Case Alternatives Priority Victor for Cost Criterion

- Criteria

Table 3.13: 1st Case Criteria Normalized Matrix and Priority Vector

Criteria	Time to control blood pressure	Frequency of taking the medication	Patient compliance	Mini. side effect	Reduce complication of hypertension	Cost	Priority Victor
Time to control blood pressure	0.08	0.24	0.07	0.07	0.10	0.04	0.10
Frequency of taking the medication	0.01	0.04	0.05	0.04	0.06	0.02	0.04
Patient compliance	0.32	0.21	0.27	0.30	0.24	0.32	0.28
Minimum side effect	0.12	0.11	0.10	0.11	0.11	0.12	0.11
Reduce complication of hypertension	0.33	0.26	0.45	0.41	0.41	0.42	0.38
Cost	0.14	0.13	0.07	0.07	0.08	0.08	0.10

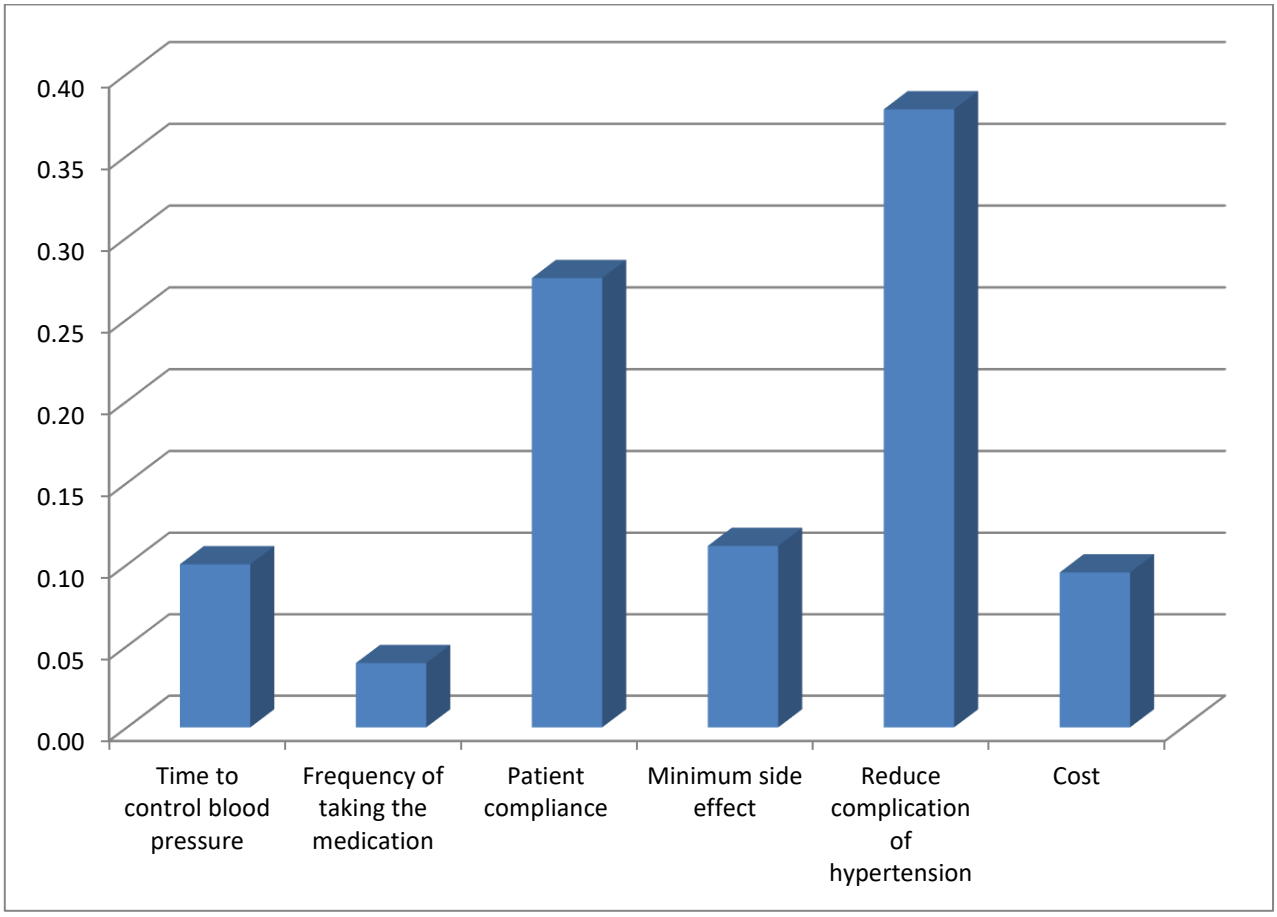

Figure 3.7: First Case Priority Victor for Criteria

4. Checking the consistency of the results

- Time to control blood pressure

Table 3.14: 1st Case Time to Control Blood Pressure Consistency Results

Column pair-wise*priority				Sum Vector	Sum vector/Priority vector	λmax
0.4510	0.3735	0.8068	0.3249	1.9562	4.3374	4.1809
0.1354	0.1121	0.1118	0.1063	0.4657	4.1526	
0.1354	0.2430	0.2423	0.3891	1.0099	4.1680	
0.2701	0.2052	0.1211	0.1946	0.7910	4.0657	

CI = (λmax-n)/(n-1) = 0.0603

RI = 0.90

CR=CI/RI

CR = 0.0603 / 0.90 = 0.0670

CR < 0.1 acceptable Range

- Frequency of taking the medication

Table 3.15: 1st Case Frequency of Taking the Medication Consistency Results

Column pair-wise*priority				Sum Vector	Sum vector/Priority vector	λmax
0.3934	0.2996	0.4994	0.4232	1.6156	4.1064	4.0779
0.1816	0.1383	0.1380	0.1014	0.5592	4.0440	
0.2356	0.2996	0.2990	0.3944	1.2287	4.1090	
0.1574	0.2309	0.1283	0.1693	0.6859	4.0519	

CI = (λmax-n)/(n-1) = 0.0260

RI = 0.90

CR=CI/RI

CR = 0.0260 / 0.90 = 0.02883

CR < 0.1 acceptable Range

- Patient compliance

Table 3.16: 1st Case Patient Compliance Consistency Results

Column pair-wise*priority				Sum Vector	Sum vector/Priority vector	λmax
0.2906	0.2623	0.3040	0.3187	1.1755	4.0454	4.0380
0.1027	0.0927	0.1056	0.0708	0.3717	4.0106	
0.3865	0.3550	0.4043	0.4950	1.6408	4.0587	
0.1937	0.2781	0.1735	0.2125	0.8578	4.0373	

CI = (λmax-n)/(n-1) = 0.0127

RI = 0.90

CR=CI/RI

CR = 0.0127 / 0.90 = 0.01407

CR < 0.1 acceptable Range

- Minimum side effect

Table 3.17: 1st Case Minimum Side Effect Consistency Results

Column pair-wise*priority				Sum Vector	Sum vector/Priority vector	λmax
0.2743	0.2834	0.2458	0.3095	1.1129	4.0579	4.0444
0.0747	0.0772	0.0985	0.0595	0.3100	4.0143	
0.4580	0.3218	0.4104	0.4762	1.6664	4.0603	
0.2110	0.3089	0.2052	0.2381	0.9631	4.0451	

CI = (λmax-n)/(n-1) = 0.0148

RI = 0.90

CR=CI/RI

CR = 0.0148 / 0.90 = 0.01643

CR < 0.1 acceptable Range

- Reduce complication of hypertension

Table 3.18: 1st Case Reduce Complication of Hypertension Consistency Results

Column pair-wise*priority				Sum Vector	Sum vector/Priority vector	λmax
0.1244	0.1954	0.0933	0.0933	0.5065	4.0709	4.1094
0.0622	0.0977	0.1168	0.1168	0.3935	4.0278	
0.5184	0.3253	0.3889	0.3889	1.6217	4.1694	
0.5184	0.3253	0.3889	0.3889	1.6217	4.1694	

CI = (λmax-n)/(n-1) = 0.0365

RI = 0.90

CR=CI/RI

CR = 0.0365 / 0.90 = 0.0405

CR < 0.1 acceptable Range

- Cost

Table 3.19: 1st Case Cost Consistency Results

Column pair-wise*priority				Sum Vector	Sum vector/Priority vector	λmax
0.1603	0.1603	0.1603	0.1603	0.6412	4.0000	4.0000
0.6846	0.6846	0.6846	0.6846	2.7382	4.0000	
0.0948	0.0948	0.0948	0.0948	0.3794	4.0000	
0.0603	0.0603	0.0603	0.0603	0.2412	4.0000	

CI = (λmax-n)/(n-1) = 0

RI = 0.90

CR=CI/RI

CR = 0 / 0.90 = 0

CR < 0.1 acceptable Range

- Criteria

Table 3.20: 1st Case Criteria Consistency Results

Column pair-wise*priority						Sum Vector	Sum vector/Priority vector	λmax
0.1002	0.2305	0.0688	0.0743	0.0908	0.0520	0.6166	6.1518	6.3454
0.0172	0.0395	0.0533	0.0417	0.0598	0.0301	0.2416	6.1090	
0.4009	0.2043	0.2752	0.2976	0.2266	0.3810	1.7855	6.4889	
0.1504	0.1056	0.1031	0.1114	0.1031	0.1429	0.7164	6.4282	
0.4177	0.2503	0.4595	0.4090	0.3784	0.5076	2.4225	6.4027	
0.1838	0.1252	0.0688	0.0743	0.0710	0.0952	0.6183	6.4920	

CI = (λmax-n)/(n-1) = 0.0691

RI = 1.240

CR=CI/RI

CR = 0.0691 / 1.24 = 0.05571

CR < 0.1 acceptable Range

5. Develop A Priority Matrix

Table 3.21: 1st Case Priority Matrix

Amlodipine	0.45	0.39	0.29	0.27	0.12	0.16
Hydrochlorothiazide	0.11	0.14	0.09	0.08	0.10	0.68
Losartan	0.24	0.30	0.40	0.41	0.39	0.09
Lisinopril	0.19	0.17	0.21	0.24	0.39	0.06

6. Develop A Criteria Pair-Wise Development Matrix

{0.10 0.04 0.28 0.11 0.38 0.10}

7. Develop an Overall Priority Vector

Table 3.22: 1st Case Overall Priority Vector

Criteria	0.10	0.04	0.28	0.11	0.38	0.10
Amlodipine	0.45	0.39	0.29	0.27	0.12	0.16
Hydrochlorothiazide	0.11	0.14	0.09	0.08	0.10	0.68
Losartan	0.24	0.30	0.40	0.41	0.39	0.09
Lisinopril	0.19	0.17	0.21	0.24	0.39	0.06

For Amlodipine:

(0.10*0.45) + (0.04*0.39) + (0.28*0.29) + (0.11*0.27) + (0.38*0.12) + (0.10*0.16) = 0.234

For Hydrochlorothiazide:

(0.10*0.11) + (0.04*0.14) + (0.28*0.09) + (0.11*0.08) + (0.38*0.10) + (0.10*0.68) = 0.153

For Losartan:

(0.10*0.24) + (0.04*0.30) + (0.28*0.40) + (0.11*0.41) + (0.38*0.39) + (0.10*0.09) = 0.349

For Lisinopril:

(0.10*0.19) + (0.04*0.17) + (0.28*0.21) + (0.11*0.24) + (0.38*0.39) + (0.10*0.06) = 0.264

So, The Final Results, After Applying AHP Tool, arranged from the Top Down are Shown in the Following Table:

Table 3.24: 1st Case Final Results

No.	***Medication***	***AHP Results***
1	Losartan	0.349
2	Lisinopril	0.264
3	Amlodipine	0.234
4	Hydrochlorothiazide	0.153

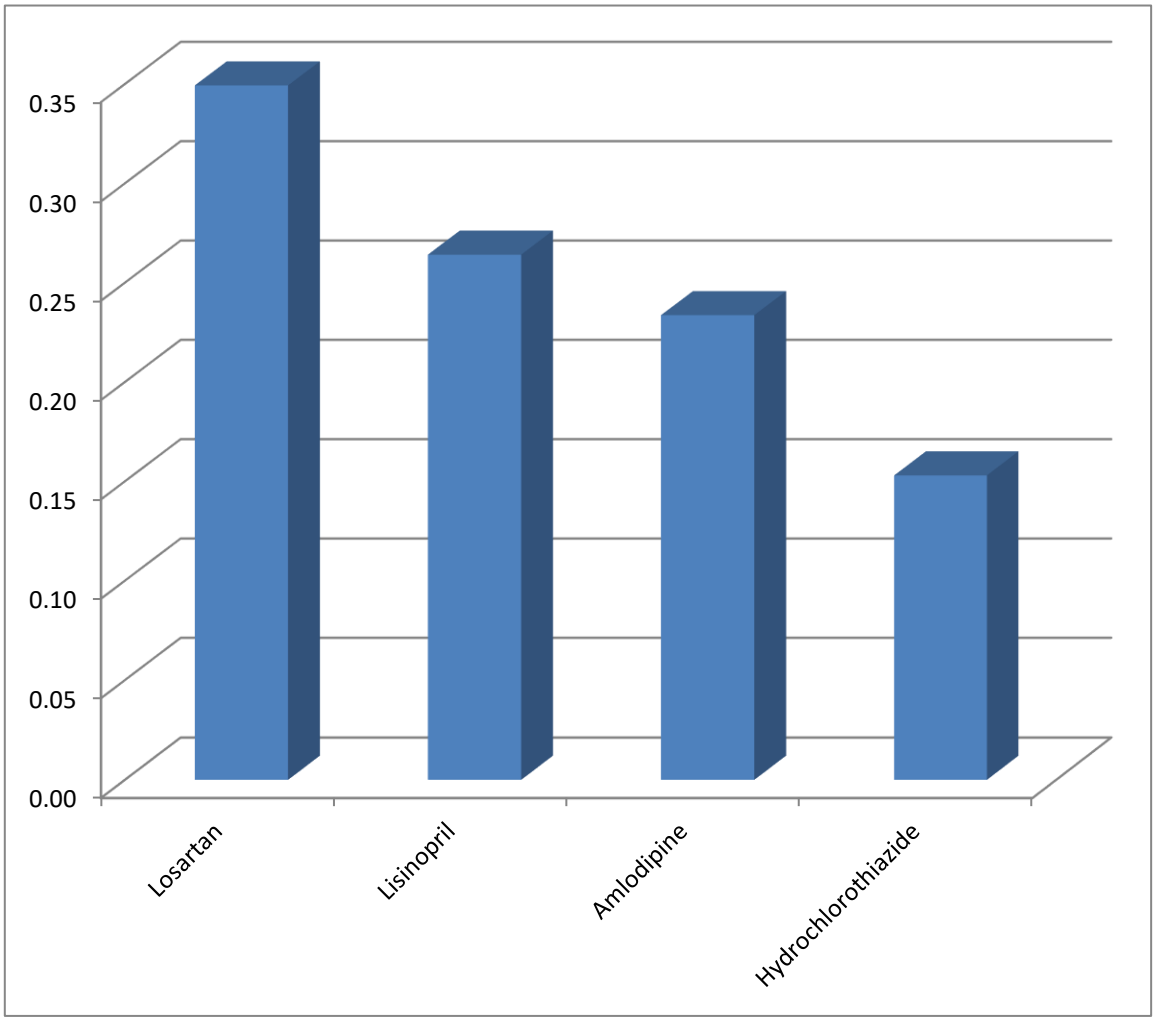

Figure 3.8: Prioritized Alternatives for the first case

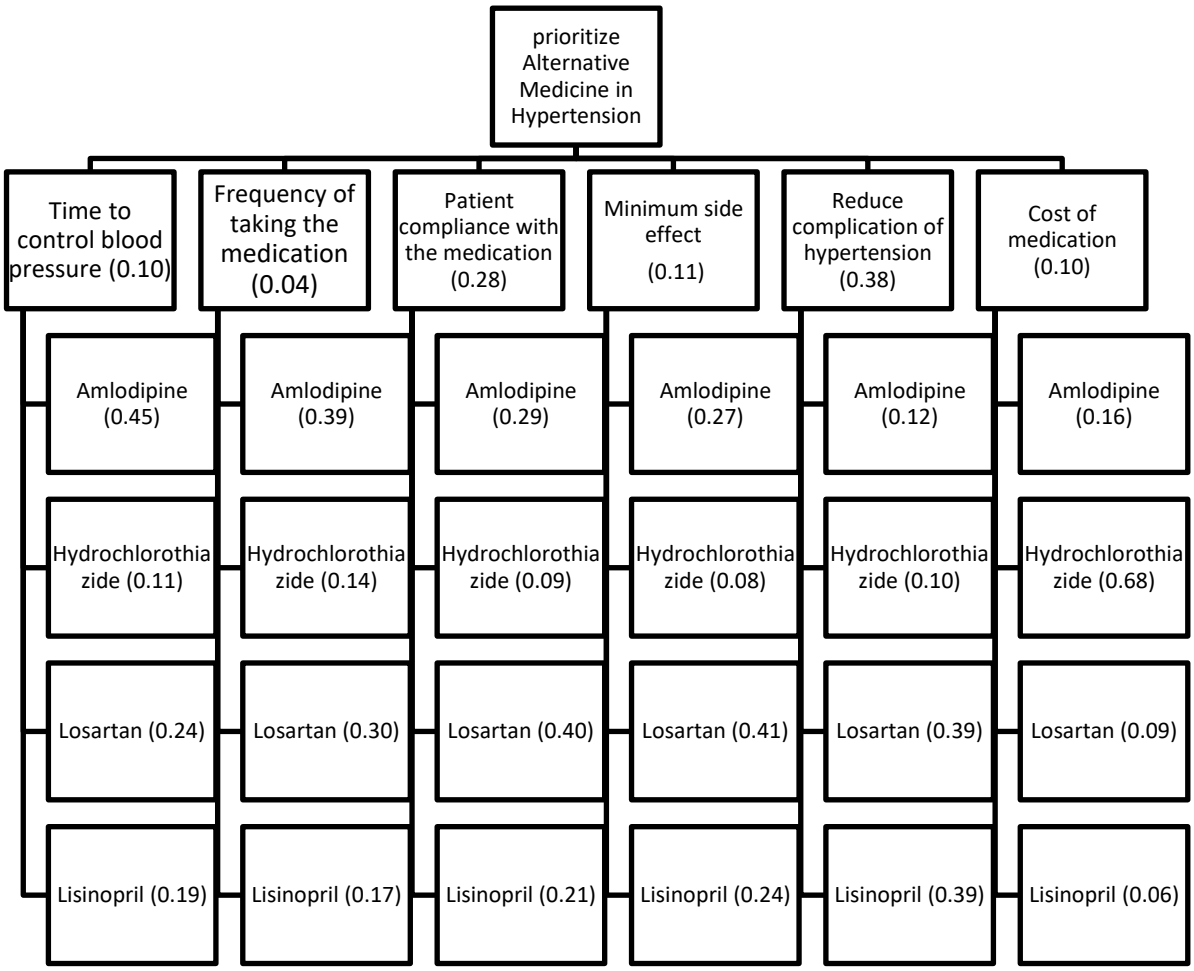

Figure 3.9: First Case Hierarchy with Priority victor

3.3 Second Popular Case Analysis

1. Develop a Pair-wise Comparison Matrix
   - Time to control blood pressure

Table 3.23: 2nd Case Time to Control Blood Pressure Pair-Wise Comparison Matrix

Time to control blood pressure	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril
Amlodipine	1.00	6.17	4.00	4.00
Hydrochlorothiazide	0.16	1.00	0.27	0.27
Losartan	0.25	3.67	1.00	1.67
Lisinopril	0.25	3.67	0.60	1.00
Sum	1.66	14.51	5.87	6.94

- Frequency of taking the medication

Table 3.24: 2nd Case Frequency of Taking the Medication Pair-Wise Comparison Matrix

Frequency of taking the medication	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril
Amlodipine	1.00	3.17	1.83	1.83
Hydrochlorothiazide	0.32	1.00	0.40	0.43
Losartan	0.55	2.50	1.00	1.00
Lisinopril	0.55	2.33	1.00	1.00
Sum	2.41	9.00	4.23	4.26

- Patient compliance

Table 3.25: 2nd Case Patient Compliance Pair-Wise Comparison Matrix

Patient compliance	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril
Amlodipine	1.00	3.17	2.33	3.00
Hydrochlorothiazide	0.32	1.00	0.37	0.37
Losartan	0.43	2.67	1.00	1.67
Lisinopril	0.33	2.67	0.60	1.00
Sum	2.08	9.51	4.30	6.04

- Minimum side effect

Table 3.26: 2nd Case Minimum Side Effect Pair-Wise Comparison Matrix

Minimum side effect	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril
Amlodipine	1.00	5.17	4.00	4.67
Hydrochlorothiazide	0.19	1.00	0.29	0.29
Losartan	0.25	3.50	1.00	1.33
Lisinopril	0.21	3.50	0.75	1.00
Sum	1.66	13.17	6.04	7.29

- Reduce complication of hypertension

Table 3.27: 2nd Case Reduce Complication of Hypertension Pair-Wise Comparison Matrix

Reduce complication of hypertension	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril
Amlodipine	1.00	5.17	1.67	1.67
Hydrochlorothiazide	0.19	1.00	0.27	0.27
Losartan	0.60	3.67	1.00	1.67
Lisinopril	0.60	3.67	0.60	1.00
Sum	2.39	13.51	3.54	4.61

- Cost

Table 3.28: 2nd Case Cost Pair-Wise Comparison Matrix

Cost	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril
Amlodipine	1.00	0.23	1.69	2.66
Hydrochlorothiazide	4.27	1.00	7.22	11.35
Losartan	0.59	0.14	1.00	1.57
Lisinopril	0.38	0.09	0.64	1.00
Sum	6.24	1.46	10.54	16.58

- Criteria

Table 3.29: 2nd Case Criteria Pair-Wise Comparison Matrix

Criteria	Time to control blood pressure	Frequency of taking the medication	Patient compliance	Minimum side effect	Reduce complication of hypertension	Cost
Time to control blood pressure	1.00	5.83	0.25	0.67	0.24	0.55
Frequency of taking the medication	0.17	1.00	0.19	0.37	0.16	0.32
Patient compliance	4.00	5.17	1.00	2.67	0.60	4.00
Minimum side effect	1.50	2.67	0.37	1.00	0.27	1.50
Reduce complication of hypertension	4.17	6.33	1.67	3.67	1.00	5.33
Cost	1.83	3.17	0.25	0.67	0.19	1.00
Sum	12.67	24.16	3.74	9.05	2.46	12.69

2. Develop A Normalized Matrix
3. Develop The Priority Vector

These Two Steps Will Be Merging In One Table As The Following.

- Time to control blood pressure

Table 3.30: 2nd Case Time to Control Blood Pressure Normalized Matrix and Priority Vector

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril	Priority Victor
Amlodipine	0.60	0.43	0.68	0.58	0.57
Hydrochlorothiazide	0.10	0.07	0.05	0.04	0.06
Losartan	0.15	0.25	0.17	0.24	0.20
Lisinopril	0.15	0.25	0.10	0.14	0.16

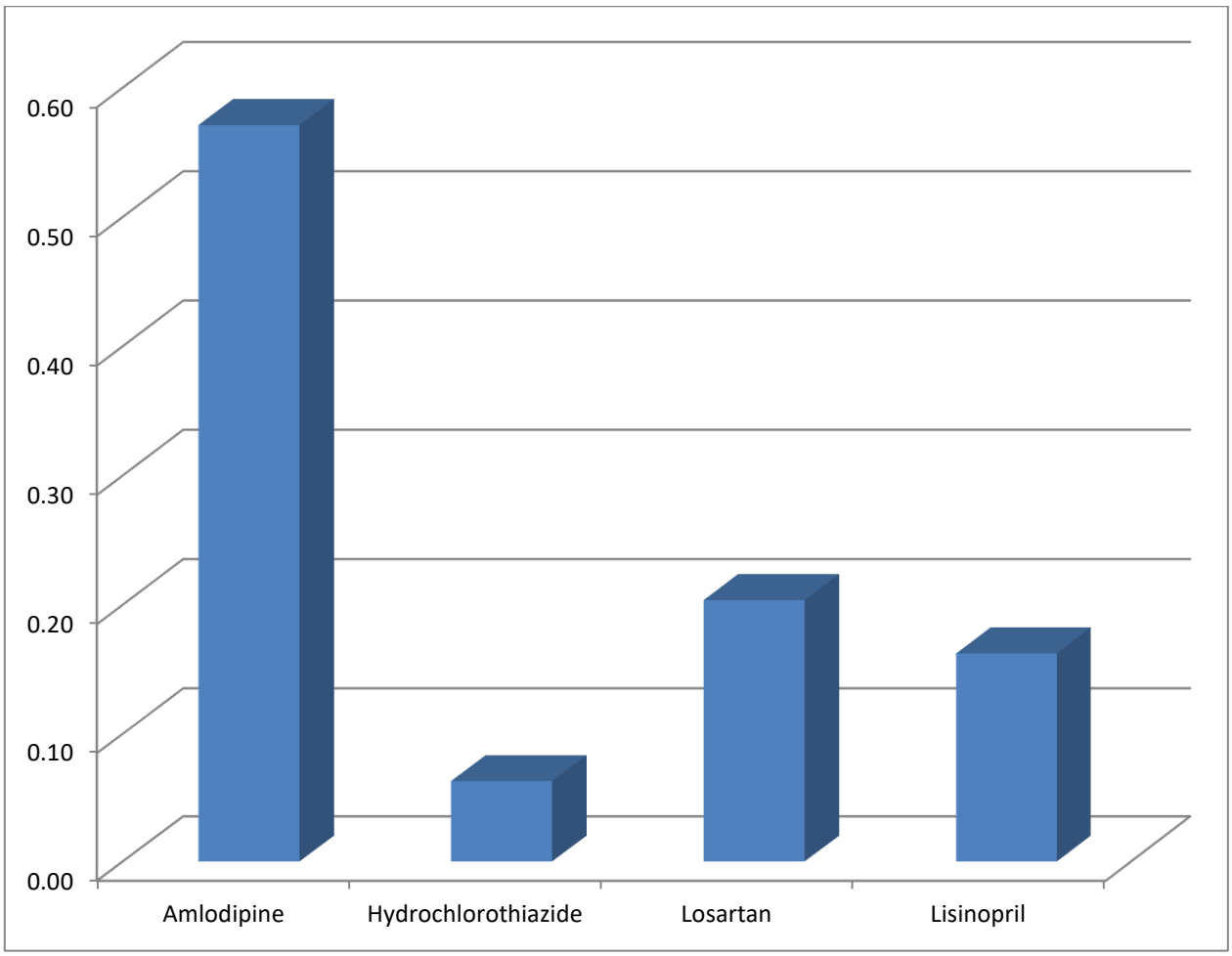

Figure 3.10: Second case Alternatives priority victor for time to control blood pressure criterion

- Frequency of taking the medication

Table 3.31: 2nd Case Frequency of Taking the Medication Normalized Matrix and Priority Vector

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril	Priority Victor
Amlodipine	0.42	0.35	0.43	0.43	0.41
Hydrochlorothiazide	0.13	0.11	0.09	0.10	0.11
Losartan	0.23	0.28	0.24	0.23	0.24
Lisinopril	0.23	0.26	0.24	0.23	0.24

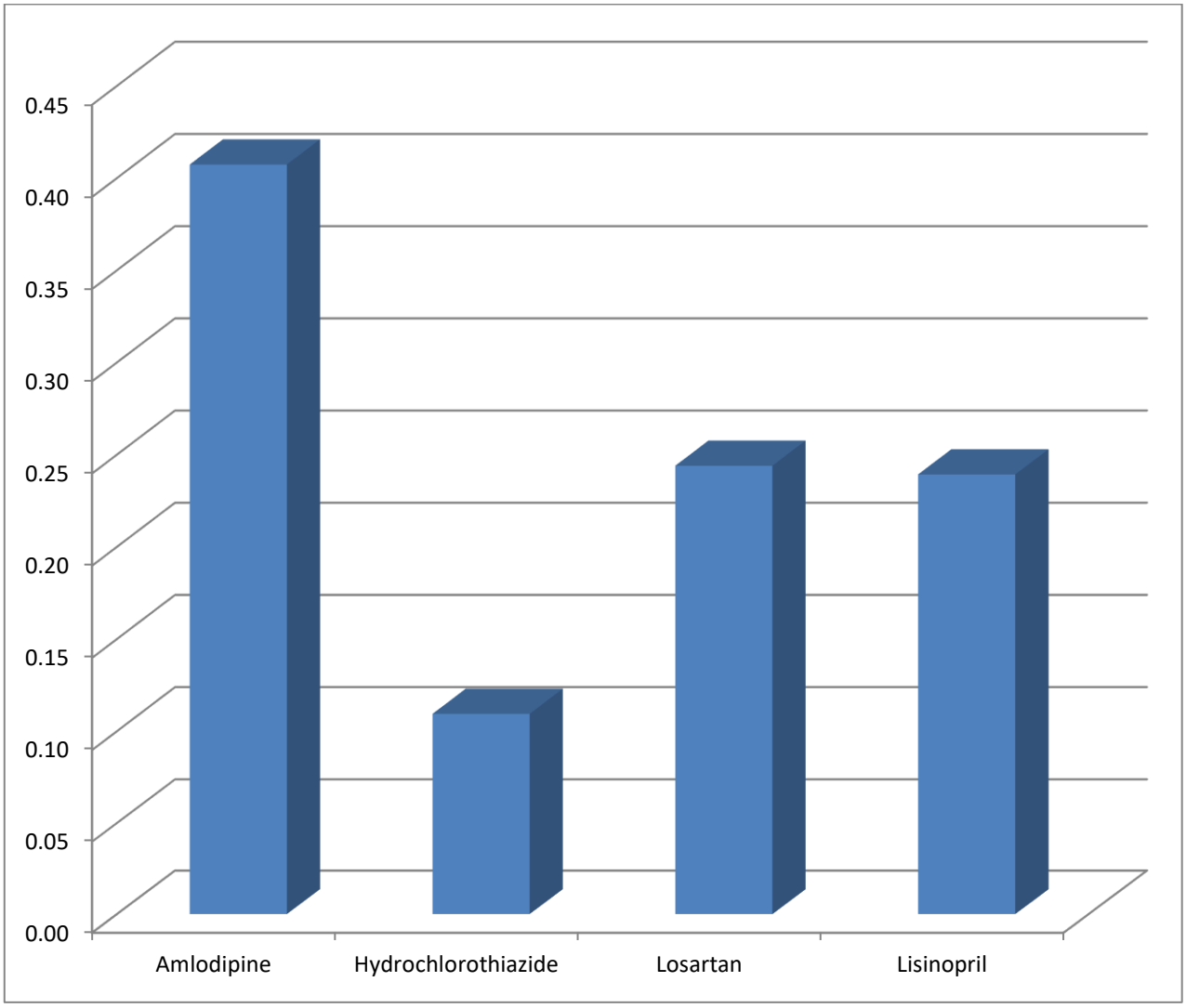

Figure 3.11: Second case Alternatives priority victor for frequency of taking the medication criterion

- Patient compliance

Table 3.32: 2nd Case Patient Compliance Normalized Matrix and Priority Vector

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril	Priority Victor
Amlodipine	0.48	0.33	0.54	0.50	0.46
Hydrochlorothiazide	0.15	0.11	0.09	0.06	0.10
Losartan	0.21	0.28	0.23	0.28	0.25
Lisinopril	0.16	0.28	0.14	0.17	0.19

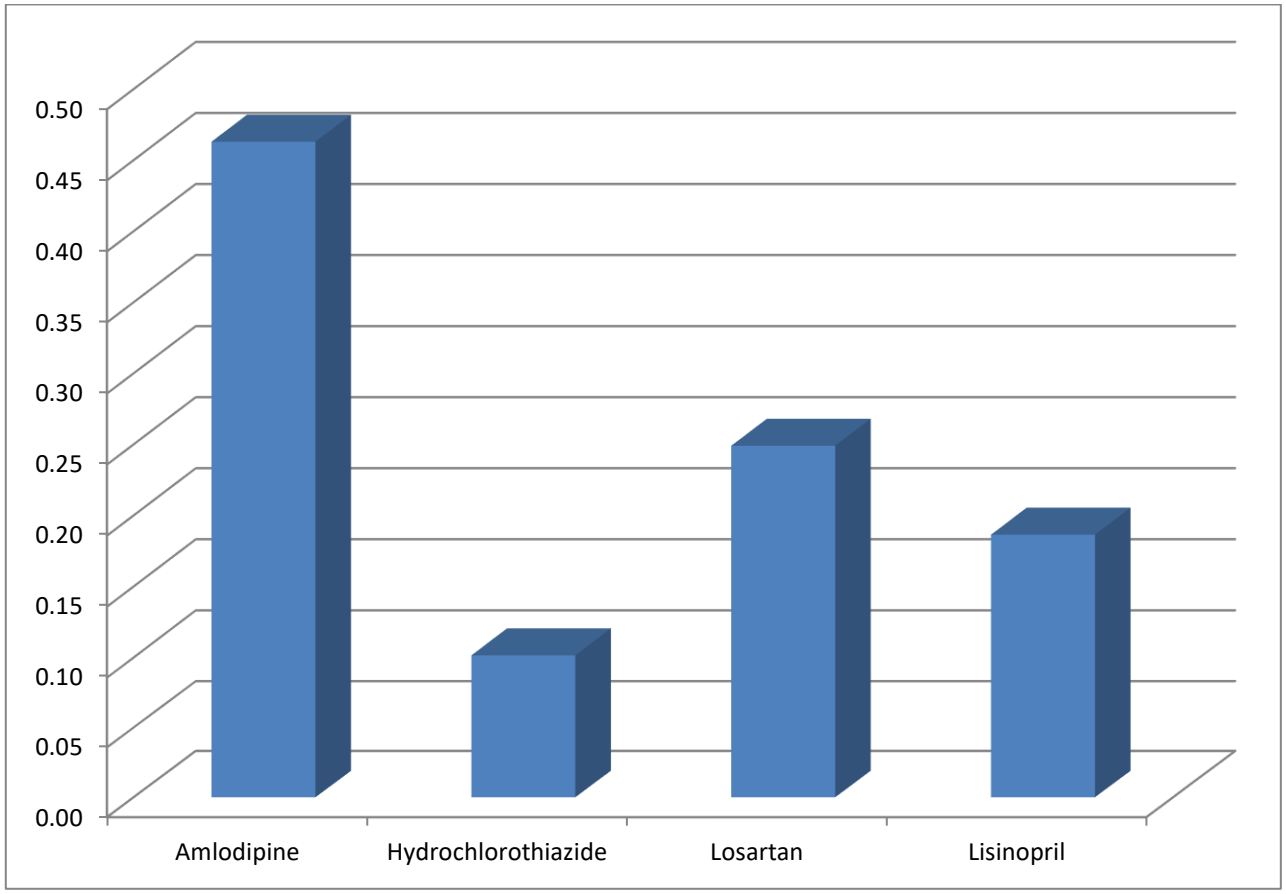

Figure 3.12: Second case Alternatives priority victor for Patient compliance criterion

- Minimum side effect

Table 3.33: 2nd Case Minimum Side Effect Normalized Matrix and Priority Vector

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril	Priority Victor
Amlodipine	0.60	0.39	0.66	0.64	0.57
Hydrochlorothiazide	0.12	0.08	0.05	0.04	0.07
Losartan	0.15	0.27	0.17	0.18	0.19
Lisinopril	0.13	0.27	0.12	0.14	0.16

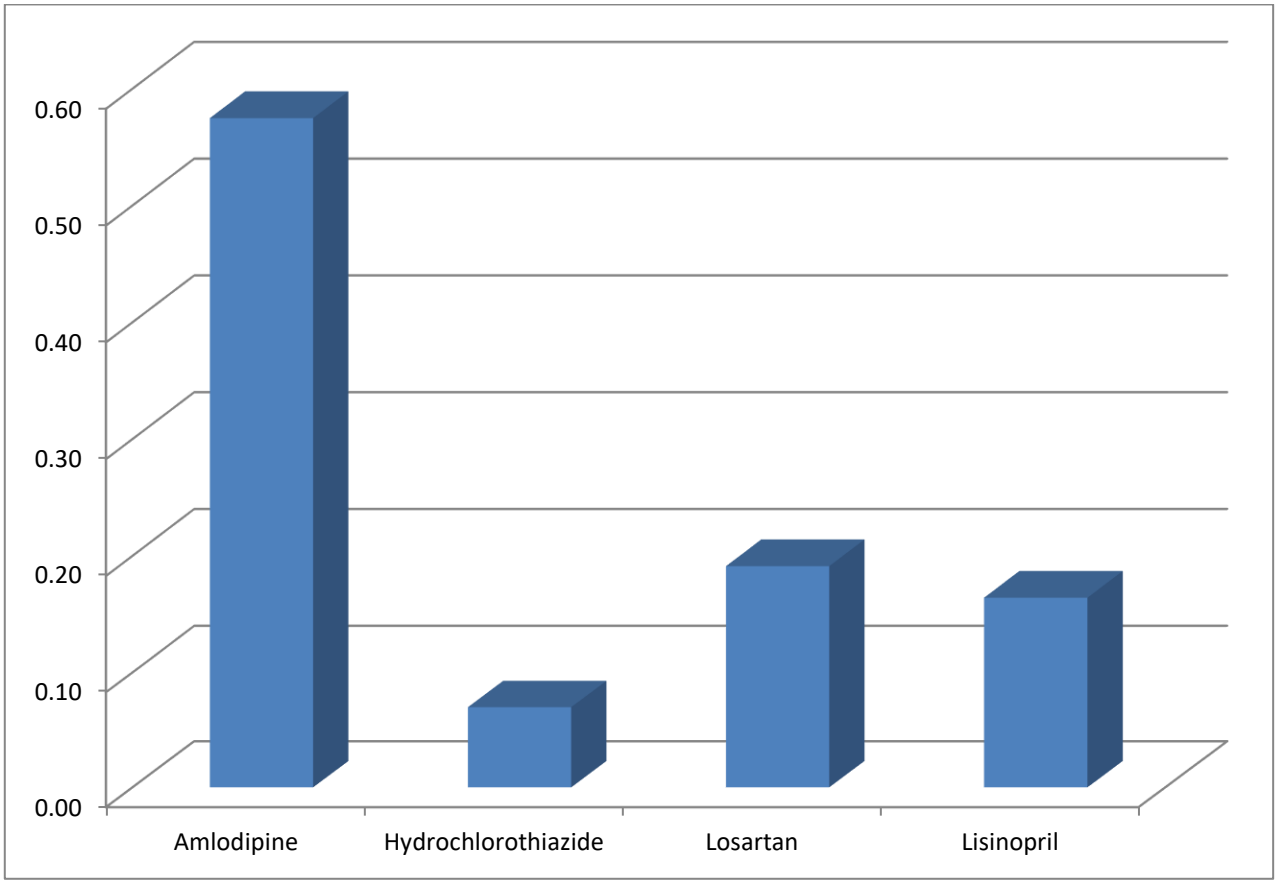

Figure 13: Second case Alternatives priority victor for minimum side effect criterion

- Reduce complication of hypertension

Table 3.34: 2nd Case Reduce Complication of Hypertension Normalized Matrix and Priority Vector

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril	Priority Victor
Amlodipine	0.42	0.38	0.47	0.36	0.41
Hydrochlorothiazide	0.08	0.07	0.08	0.06	0.07
Losartan	0.25	0.27	0.28	0.36	0.29
Lisinopril	0.25	0.27	0.17	0.22	0.23

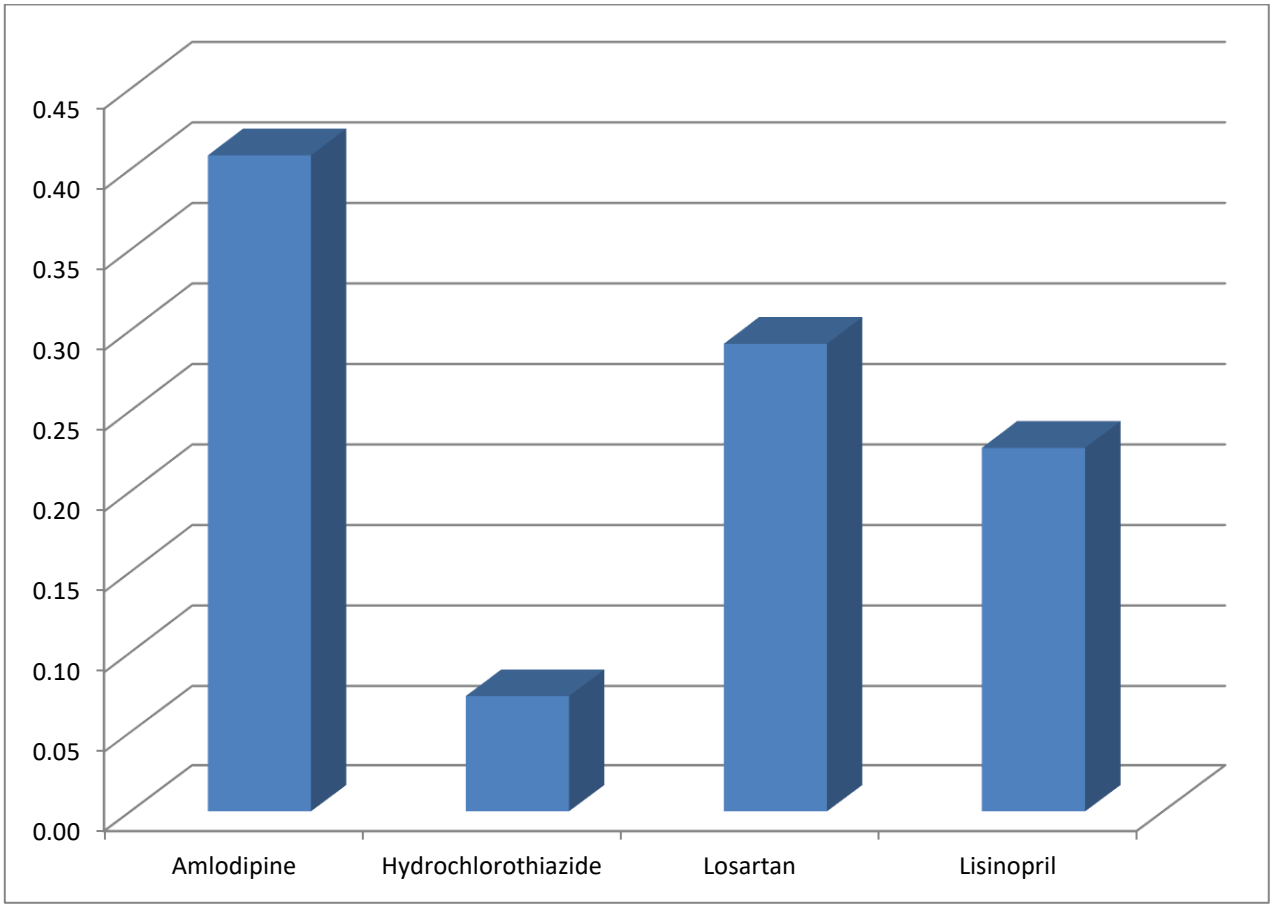

Figure 3.14: Second case Alternatives priority victor for reduce complication of hypertension criterion

- Cost

Table 3.35: 2nd Case Cost Normalized Matrix and Priority Vector

	Amlodipine	Hydrochlorothiazide	Losartan	Lisinopril	Priority Victor
Amlodipine	0.16	0.16	0.16	0.16	0.16
Hydrochlorothiazide	0.68	0.68	0.68	0.68	0.68
Losartan	0.09	0.09	0.09	0.09	0.09
Lisinopril	0.06	0.06	0.06	0.06	0.06

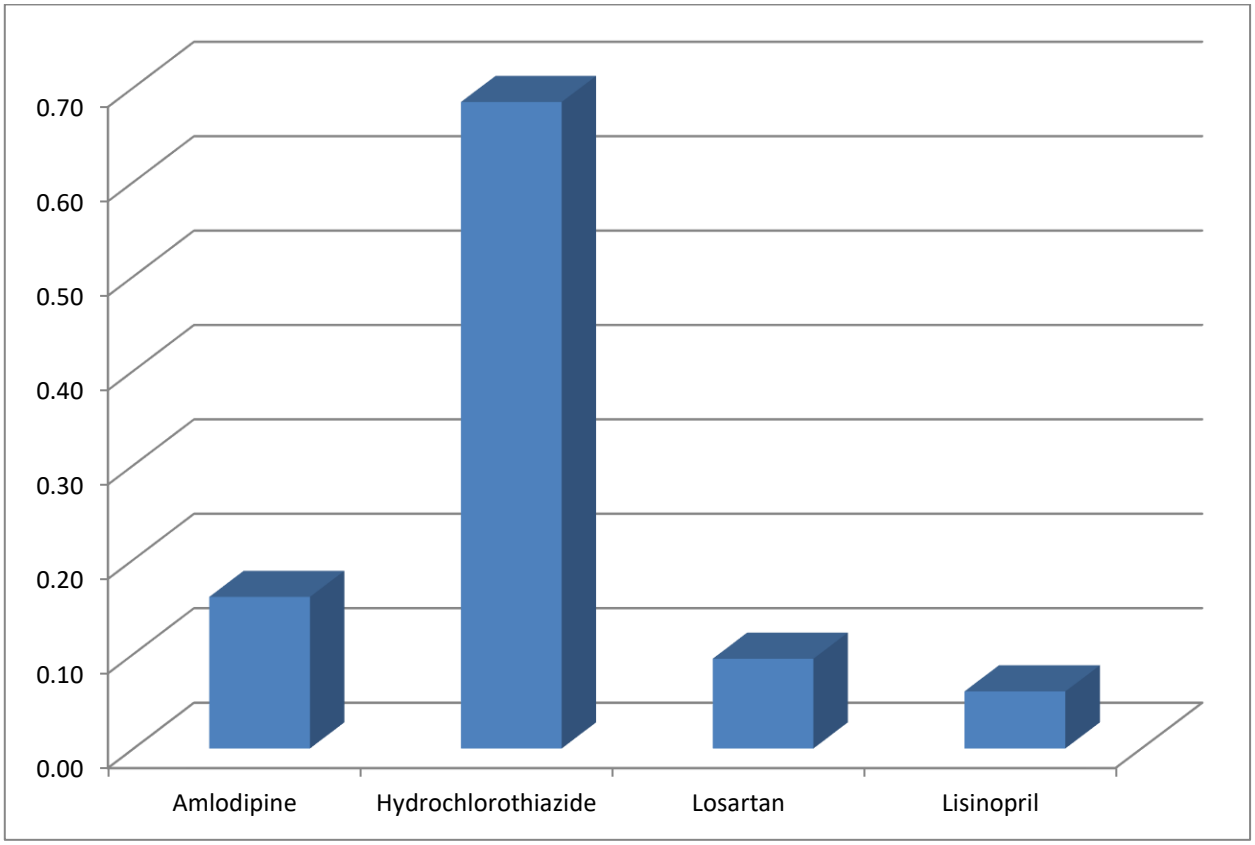

Figure 3.15: Second case Alternatives priority victor for cost criterion

- Criteria

Table 3.36: 2nd Case Criteria Normalized Matrix and Priority Vector

Criteria	Time to control blood pressure	Frequency of taking the medication	Patient compliance	Minimum side effect	Reduce complication of hypertension	Cost	Priority Victor
Time to control blood pressure	0.08	0.24	0.07	0.07	0.10	0.04	0.10
Frequency of taking the medication	0.01	0.04	0.05	0.04	0.06	0.02	0.04
Patient compliance	0.32	0.21	0.27	0.30	0.24	0.32	0.28
Minimum side effect	0.12	0.11	0.10	0.11	0.11	0.12	0.11
Reduce complication of hypertension	0.33	0.26	0.45	0.41	0.41	0.42	0.38
Cost	0.14	0.13	0.07	0.07	0.08	0.08	0.10

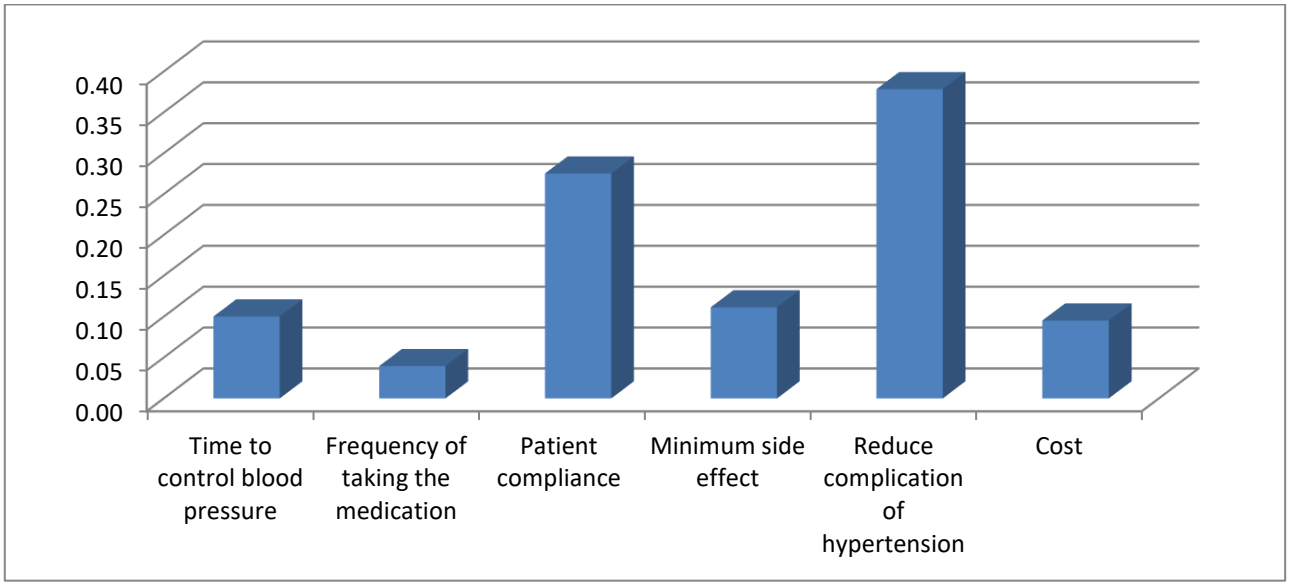

Figure 3.16: Second case priority victor for Criteria

4. Checking the consistency of the results

- Time to control blood pressure

Table 3.37: 2nd Case Time to Control Blood Pressure Consistency Results

Column pair-wise*priority				Sum Vector	Sum vector/Priority vector	λmax
0.5711	0.3888	0.8142	0.6494	2.4235	4.2437	4.1297
0.0926	0.0630	0.0555	0.0442	0.2553	4.0506	
0.1428	0.2313	0.2036	0.2711	0.8487	4.1696	
0.1428	0.2313	0.1219	0.1623	0.6583	4.0549	

CI = (λmax-n)/(n-1) = 0.0432

RI = 0.90

CR=CI/RI

CR = 0.0432 / 0.90 = 0.0480

CR < 0.1 acceptable Range

- Frequency of taking the medication

Table 3.38: 2nd Case Frequency of Taking the Medication Consistency Results

Column pair-wise*priority				Sum Vector	Sum vector/Priority vector	λmax
0.4074	0.3464	0.4465	0.4378	1.6381	4.0213	4.0143
0.1286	0.1094	0.0976	0.1027	0.4383	4.0067	
0.2226	0.2735	0.2440	0.2393	0.9793	4.0139	
0.2226	0.2549	0.2440	0.2393	0.9607	4.0154	

CI = (λmax-n)/(n-1) = 0.0048

RI = 0.90

CR=CI/RI

CR = 0.0048 / 0.90 = 0.0053

CR < 0.1 acceptable Range

- Patient compliance

Table 3.39: 2nd Case Patient Compliance Consistency Results

Column pair-wise*priority				Sum Vector	Sum vector/Priority vector	λmax
0.4630	0.3215	0.5802	0.5594	1.9241	4.1556	4.1051
0.1462	0.1015	0.0933	0.0698	0.4108	4.0464	
0.1987	0.2711	0.2490	0.3114	1.0302	4.1372	
0.1543	0.2711	0.1491	0.1865	0.7610	4.0813	

CI = (λmax-n)/(n-1) = 0.0350

RI = 0.90

CR=CI/RI

CR = 0.0350 / 0.90 = 0.0389

CR < 0.1 acceptable Range

- Minimum side effect

Table 3.40: 2nd Case Minimum Side Effect Consistency Results

Column pair-wise*priority				Sum Vector	Sum vector/Priority vector	λmax
0.5748	0.3608	0.7648	0.7667	2.4671	4.2919	4.1561
0.1112	0.0698	0.0546	0.0469	0.2825	4.0480	
0.1437	0.2443	0.1912	0.2184	0.7975	4.1714	
0.1231	0.2443	0.1438	0.1642	0.6753	4.1131	

CI = (λmax-n)/(n-1) = 0.0520

RI = 0.90

CR=CI/RI

CR = 0.0520 / 0.90 = 0.0578

CR < 0.1 acceptable Range

- Reduce complication of hypertension

Table 3.41: 2nd Case Reduce Complication of Hypertension Consistency Results

Column pair-wise*priority				Sum Vector	Sum vector/Priority vector	λmax
0.4086	0.3760	0.4870	0.3791	1.6508	4.0397	4.0367
0.0790	0.0727	0.0795	0.0619	0.2931	4.0296	
0.2447	0.2669	0.2916	0.3791	1.1823	4.0542	
0.2447	0.2669	0.1746	0.2270	0.9133	4.0232	

CI = (λmax-n)/(n-1) = 0.0122

RI = 0.90

CR=CI/RI

CR = 0.0122 / 0.90 = 0.0135

CR < 0.1 acceptable Range

- Cost

Table 3.42: 2nd Case Cost Consistency Results

Column pair-wise*priority				Sum Vector	Sum vector/Priority vector	λmax
0.1603	0.1603	0.1603	0.1603	0.6412	4.0000	4.0000
0.6846	0.6846	0.6846	0.6846	2.7382	4.0000	
0.0948	0.0948	0.0948	0.0948	0.3794	4.0000	
0.0603	0.0603	0.0603	0.0603	0.2412	4.0000	

CI = (λmax-n)/(n-1) = 0

RI = 0.90

CR=CI/RI

CR = 0 / 0.90 = 0

CR < 0.1 acceptable Range

- Criteria

Table 3.45: 2nd Case Criteria Consistency Results

Column pair-wise*priority						***Sum Vector***	***Sum vector/Priority vector***	***λmax***
0.1003	0.2306	0.0688	0.0743	0.0908	0.0523	0.6171	6.1518	6.3437
0.0172	0.0395	0.0533	0.0417	0.0598	0.0300	0.2416	6.1083	
0.4012	0.2043	0.2752	0.2976	0.2266	0.3803	1.7852	6.4868	
0.1505	0.1056	0.1031	0.1115	0.1031	0.1426	0.7163	6.4263	
0.4180	0.2503	0.4596	0.4091	0.3784	0.5067	2.4221	6.4008	
0.1824	0.1252	0.0688	0.0743	0.0710	0.0951	0.6168	6.4879	

CI = (λmax-n)/(n-1) = 0.0687

RI = 1.24

CR=CI/RI

CR = 0.0687 / 1.24 = 0.0554

CR < 0.1 acceptable Range

5. Develop A Priority Matrix

Table 3.43: 2nd Case Priority Matrix

Amlodipine	0.57	0.41	0.46	0.57	0.41	0.16
Hydrochlorothiazide	0.06	0.11	0.10	0.07	0.07	0.68
Losartan	0.20	0.24	0.25	0.19	0.29	0.09
Lisinopril	0.16	0.24	0.19	0.16	0.23	0.06

6. Develop A Criteria Pair-Wise Development Matrix

{0.10 0.04 0.28 0.11 0.38 0.10}

7. Develop An Overall Priority Vector

Table 3.44: 2nd Case Overall Priority Vector

Criteria	0.10	0.04	0.28	0.11	0.38	0.10
Amlodipine	0.57	0.41	0.46	0.57	0.41	0.16
Hydrochlorothiazide	0.06	0.11	0.10	0.07	0.07	0.68
Losartan	0.20	0.24	0.25	0.19	0.29	0.09
Lisinopril	0.16	0.24	0.19	0.16	0.23	0.06

For Amlodipine:

(0.10*0.57) + (0.04*0.41) + (0.28*0.46) + (0.11*0.57) + (0.38*0.41) + (0.10*0.16) = 0.435

For Hydrochlorothiazide:

(0.10*0.06) + (0.04*0.11) + (0.28*0.10) + (0.11*0.07) + (0.38*0.07) + (0.10*0.68) = 0.139

For Losartan:

(0.10*0.16) + (0.04*0.24) + (0.28*0.19) + (0.11*0.16) + (0.38*0.23) + (0.10*0.06) = 0.239

For Lisinopril:

(0.10*0.16) + (0.04*0.24) + (0.28*0.19) + (0.11*0.16) + (0.38*0.23) + (0.10*0.06) = 0.187

So, the final results, after applying AHP tool, arranged from the Top Down are shown in the Following Table:

Table 3.45: 2nd Case Final Results

No.	***Medication***	***AHP Results***
1	Amlodipine	0.435
2	Losartan	0.239
3	Lisinopril	0.187
4	Hydrochlorothiazide	0.139

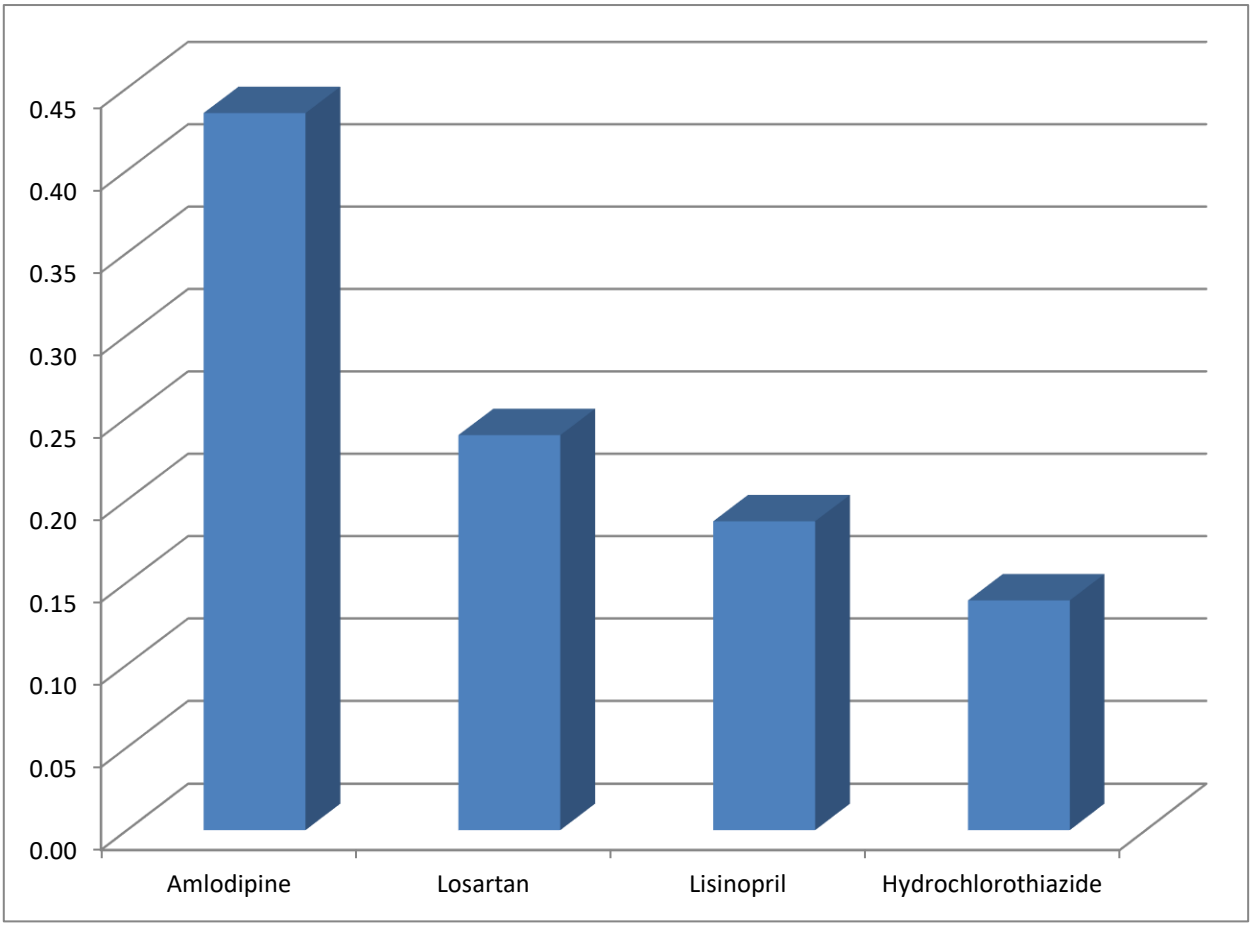

Figure 3.17: Prioritized Alternatives for the second case

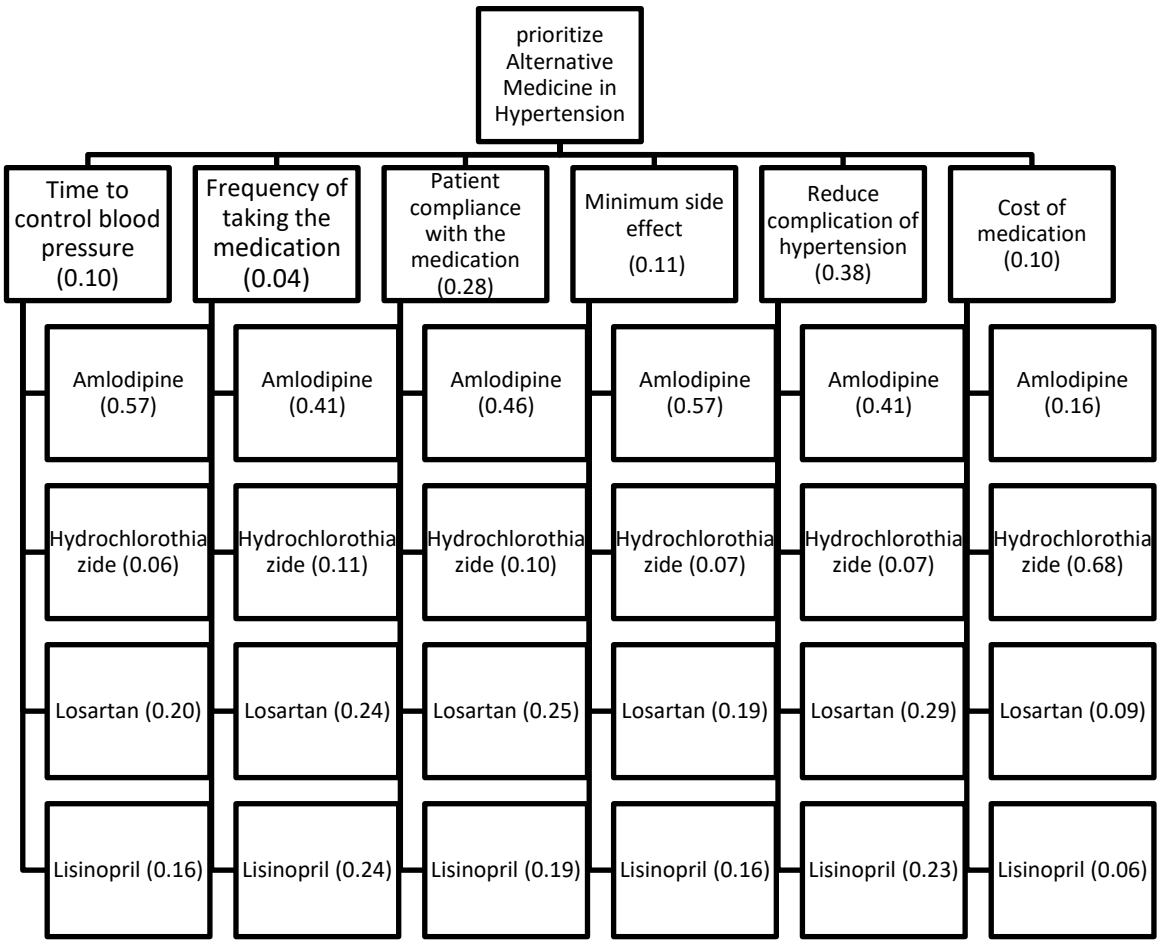

Figure 3.18: Second Case Hierarchy with Priority victor

V. CONCLUSION

The AHP is a great tool for MCDM since it can one make complicated decisions in all fields. Having such a powerful tool in the field of medicine could reduce the number of wrong decisions and save many lives.

Chronic hypertensive disease is very common in our area, and according to the WHO, the percentage individuals 25 years old or older with this disease in the KSA ranges from 40–44.9%, which is high in comparison to other countries (lower than 35%). Applying the AHP in cases of this potentially dangerous and common disease could be very helpful for doctors when making decisions and contribute to making people healthier.

For this research, the data was collected from six doctors who are experts in the field of medicine, and the average results were calculated incorporating all of the doctors' decisions into one opinion. The results of each case were inserted into separate AHP models, and seven steps were applied to each model to calculate the final results. We used the final results (priority vectors) to prioritize the different medications depending on the higher value. The consistency ratio for all of the criteria was below 0.10, which means that all of the results were very consistent and reliable.

Criteria Priority Vectors

The priority vectors for the criteria for the two common cases were as follows:

1. Reduce the complications of hypertension. This criterion received the highest ranking with a priority vector of 0.38, making it the most important criterion for the experts.
2. Patient compliance with the medication. This criterion got the second highest ranking with a priority vector of 0.28.
3. Minimum side effects. This criterion got the third highest ranking with a priority vector of 0.11.
4. Time to control blood pressure and cost of medication. These two criteria received the fourth highest ranking with a priority vector of 0.10.
5. Frequency of taking the medication. This criterion got the lowest ranking with a priority vector of 0.04.

Common Case 1

The priority vector results for this case prioritized the alternative medications as the following:

1- Losartan. The first best alternative with a priority vector of 0.349.

2- Lisinopril. The second-best alternative with a priority vector of 0.264.

3- Amlodipine. The third best alternative with a priority vector of 0.234.

4- Hydrochlorothiazide. The fourth best alternative with a priority vector of 153.

Common Case 2

The priority vector results for this case prioritized the different medications as follows:

1- Amlodipine. The first best alternative with a priority vector of 0.435.

2- Losartan. The second-best alternative with a priority vector of 0.239.

3- Lisinopril. The third best alternative with a priority vector of 0.187.

4- Hydrochlorothiazide. The fourth best alternative with a priority vector of 139.

VI. RECOMMENDATIONS

1. It is recommended that doctors prioritize the different medications in those cases similar to the above common cases based on the ranking above.
2. In the second case, amlodipine received a very high score when compared with other medications, so it is highly recommended for similar patients.
3. It is not recommended to prescribe hydrochlorothiazide in “regular” cases, since its priority vector was the lowest in both common study cases.
4. If the patient has financial difficulties, hydrochlorothiazide can be prescribed since it is very cheap when compared to the medications.

VII. SCOPE OF FURTHER RESEARCH

In this research, the AHP was used in two common cases of chronic hypertension. Future research should be conducted in other cases of hypertension, as well as other chronic diseases. Moreover, other decision-making tools should be used in future studies and compared to the results of this study.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical statement: The authors declare that they have followed ethical responsibilities.

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