PROMETHEE ANALYSIS OF BREAST CANCER IMAGING DEVICES

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
HASAN ERDAĞLI

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Biomedical Engineering

NICOSIA, 2019

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Approval of Director of Graduate School of

Applied Sciences

Prof. Dr. Nadire ÇAVUŞ

We certify this thesis is satisfactory for the award of the degree of Master of Sciences in Biomedical Engineering

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To all women…

ABSTRACT

Breast cancer is the most common type of cancer seen in women. The incidence of the breast cancer increases with age. The most important thing in the breast cancer is the diagnosis of cancer before spreading to other organs by the blood or lymph circulation. When cancer is diagnosed at an early stage, the success rate of the breast cancer treatment is over 90%. For this reason, breast cancer imaging devices should be used for early diagnosis of the breast cancer.

The main aim of this study is to shed more information on the parameters that affect the different imaging devices alternatives for breast cancer and how these parameters affect the preference ranking of each imaging device. In this study, the most common used imaging devices for breast cancer are analysed (Screen Film Mammography, Digital Mammography, Digital Breast Tomosynthesis, Ultrasound, Magnetic Resonance Imaging, Positron Emission Tomography, Positron Emission Tomography – Computed Tomography (PET/CT), Positron Emission Tomography – Magnetic Resonance Imaging (PET/MRI), Breast Computed Tomography, Positron Emission Mammography, Breast Specific Gamma Imaging and Single Photon Emission Computed Tomography) based on some parameters that are likely to affect the outcome of the imaging methods. These parameters are; cost of per scan, cost of device, radiation dose, specificity, sensitivity, total scan time, spatial resolution, comparison of natural radiation exposure, real 3D, compression and claustrophobia. This analysis and ranking was evaluated and compared using fuzzy PROMETHEE, a multi-criteria decision making technique.

Keywords: Cancer; breast cancer; imaging devices; multi-criteria decision making; fuzzy PROMETHEE

ÖZET

Meme kanseri, kadınlarda en sık görülen kanser türüdür. Meme kanseri görülme oranı yaşla birlikte artmaktadır. Meme kanserinde en önemli şey, kanserin diğer organlara kan veya lenf dolaşımı ile yayılmadan önce teşhis edilmesidir. Kanser erken bir aşamada teşhis edilirse, meme kanseri tedavisinin başarı oranı %90'ın üzerindedir. Bu nedenle meme kanseri görüntüleme cihazları, meme kanserinin erken teşhisi için kullanılmalıdır.

Bu çalışmanın amacı, meme kanseri için kullanılan görüntüleme cihaz alternatiflerini etkileyen parametreler ve bu parametrelerin her bir görüntüleme cihazının tercih sıralamasını nasıl etkilediği ile ilgili daha fazla bilgi vermektir. Bu çalışmada, meme kanseri için en yaygın kullanılan görüntüleme cihazları (Ekran-Film Mamografi,Dijital Mamografi, Dijital Meme Tomosentezi, Ultrason, Manyetik Resonans Görüntüleme, Pozitron Emisyon Tomografisi, Pozitron Emisyon Tomografisi - Bilgisayarlı Tomografi (PET/BT), Pozitron Emisyon Tomografisi - Manyetik Resonans Görüntüleme (PET/MR), Bilgisayarlı Meme Tomografisi, Pozitron Emisyon Mamografi, Memeye Özel Gama Görüntüleme, Tek Foton Emisyon Bilgisayarlı Tomografi), görüntüleme yöntemlerinin sonucunu etkileyebilecek bazı parametrelere dayanarak analiz edilmiştir. Bu parametreler; tarama başına maliyeti, cihazın maliyeti, radyasyon dozu, özgüllük, duyarlılık, toplam tarama süresi, uzamsal çözünürlük, doğal radyasyon dozuyla karşılaştırma, üç boyut, sıkıştırma ve klostrofobidir. Bu analiz ve sıralama, çok kriterli bir karar verme tekniği olan bulanık PROMETHEE kullanılarak değerlendirildi ve karşılaştırıldı.

Anahtar kelimeler: Kanser; meme kanseri; görüntüleme cihazları; çok kriterli karar verme; bulanık PROMETHEE

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LIST OF ABBREVIATIONS

SFM:	Screen Film Mammography
DM:	Digital Mammography
DBT:	Digital Breast Tomosynthesis
U/S:	Ultrasound
MRI:	Magnetic Resonance Imaging
PET:	Positron Emission Tomography
PET/CT:	Positron Emission Tomography – Computed Tomography
PET/MRI:	Positron Emission Tomography – Magnetic Resonance Imaging
BCT:	Breast Computed Tomography
PEM:	Positron Emission Mammography
BSGI:	Breast Specific Gamma Imaging
SPECT:	Single Photon Emission Computed Tomography
mSv:	Millisievert
lp/mm:	Line pairs per millimeter
3D:	Three Dimensional
sec:	Second
fuzzy PROMETHEE:	Preference Ranking Organization Method for Enrichment Evaluations

CHAPTER 1
INTRODUCTION

Cancer is the growth and proliferation of the cells in an uncontrolled or abnormal manner due to the DNA damage in cells.

All cancers develop from our cells, which are the basic life unit of the body. Healthy cells in our bodies have skill to divide. Cells use these skills to reproduce dead cells and repair injured tissues but each cell has a certain number of divisiveness throughout its life. They can’t be divided indefinitely. In order to human body work healthy and properly, the cells must grow, divide and produce more cells. Sometimes this process deviates from its normal path and the cells continue to divide without need for new cells. Even if the cell has DNA damage in its normal life, the cell will either repair it or die. In cancerous cells, damaged DNA become irreparable and starts proliferation uncontrollably. The DNA can be damaged by environmental factors (such as chemicals, radiation, air pollutions, viruses, excessive sunlight, tobacco products, etc.). The cancerous cells form tumour by accumulation. The tumour may be benign or malignant. Cells don't spread to other parts of the body which they are in benign tumours. In necessary situations, they are taken from the body and often do not repeat. The malignant tumours are cancer. Cells in the malignant tumour are abnormal and divide uncontrollably and irregularly. These tumours can be compress, destroy or penetrate to the normal tissues. If the cancerous cells leave the tumour that they formed, they can be able to spread to the other parts of the body through the lymph circulation or blood circulation. Where they go, they continue to divide and grow, with this way form new tumour colonies.

The incidence of cancer types varies between men and women. The most common kind of cancer seen in women worldwide is the breast cancer. One in every 4 women with cancer in the world is the breast cancer (Breast Cancer Research Foundation, 2018). Mostly, it seen in menopausal women but it may be seen at any age.

The breast cancer incidence and the mortality are lower in developing countries than in developed countries.

The breast cancer is the result of uncontrolled proliferation of the cells that form milk and milk channel in the breast tissue.

The most prominent symptom of the breast cancer is the mass in breast or the region close to the breast (armpit). If the mass is enlarged, the nipple can be turning inward and the breast can be enlarged. Bloody or bloodless discharge from the nipple might also be a sign of breast cancer, which are very rare situations.

The most important thing in the breast cancer is the diagnosis of cancer before spreading to other organs by the blood or lymph circulation. For this reason, breast cancer imaging devices should be used for early diagnosis of the breast cancer.

That imaging devices are;

- Screen Film Mammography
- Digital Mammography
- Digital Breast Tomosynthesis
- Ultrasound
- Magnetic Resonance Imaging
- Positron Emission Tomography
- Positron Emission Tomography – Computed Tomography
- Positron Emission Tomography – Magnetic Resonance Imaging
- Breast Computed Tomography
- Positron Emission Mammography
- Breast Specific Gamma Imaging
- Single Photon Emission Computed Tomography

In this thesis study, the most common imaging devices for breast cancer are considered and analysed in order to obtain a ranking of the parameters in relation to cost of per scan, cost of device, radiation dose, comparison of natural radiation exposure, specificity, sensitivity, energy resolution, total scan time, spatial resolution, real 3D, compression and claustrophobia of the imaging devices. The analysis and ranking is done using fuzzy PROMETHEE.

1.1 Thesis Problem

- Breast cancer is the most common type of cancer seen in women worldwide (American Institute for Cancer Research, 2018).
- There were over 2 million new breast cancer cases in 2018 (World Health Organization/ Global Cancer Statistics, 2018).
- In 2018, approximately 627,000 women died due to breast cancer worldwide (World Health Organization, WHO 2018).
- Breast cancer survival rates vary greatly worldwide, ranging from 80% or over in high-income countries, around 60% in middle-income countries and below 40% in low-income countries (World Health Organization, WHO 2014).
- The reason of seen too much of breast cancer and the low survival rates can be explained by the lack of adequate diagnosis facilities or lack of their parameter qualities.

1.2 Aim of the Study

- To analyse and rank the most common imaging devices for Breast Cancer using fuzzy-PROMETHEE.
- To determine the most desirable imaging devices based on some contributing parameters that determine the quality of diagnosis of the breast cancer.
- To help related people by presenting the best result according to the needed attributes of the breast cancer imaging devices.

1.3 Significance of the Study

- The result of this study will add the most comprehensive information and comparison about the breast cancer imaging devices' parameters to literature.

- The results of this study will provide comparability with alternative devices on the breast cancer imaging options and detailed information about the parameters of the devices, to manufacturers, patients and hospitals.
- The results of this study will help patients to find the most effective way to increase their breast cancer diagnosis rate.
- The results of this study will make it easier to select best imaging option for the breast cancer.

1.4 Limitations of the Study

- Although there are different types of parameters other than the used parameters, this information are not available for each device. Because of this, they are not added to this study.
- Some companies didn't publish their information about manufactured devices. Because of this, there are lacks of source to find the information.

CHAPTER 2
CLINICAL BACKGROUND

2.1 Anatomy of the Breast

The main components of the female breast (Cooper, A. P. ,1840);

- **Lymph Node:** The lymph nodes are located in the breast tissue and armpit to carry lymph fluid to remove foreign substances.
- **Lymphatic Vessel:** The function of the lymphatic vessels in the breast is to drain excess amount of fluid.
- **Blood Vessel:** The blood vessels in the breast also carry fluid called lymph.
- **Lobes:** The lobes are bunches of the lobules which are the structures that have the ability to produce milk.
- **Ducts:** The ducts are the milk channels and their function is to transport milk to the nipple from the lobules.
- **Fat, Ligaments, and Connective tissue:** Fatty tissue is the effective factor in the breast's size and the size of the breast depends on the amount of the fatty tissue. In addition to this, ligaments and connective tissue give the breast its shape by supporting it.

2.2 Breast Cancer

The Breast Cancer is the growth and proliferation of the cells in an uncontrolled or abnormal manner due to the DNA damage in ducts and lobes cells in the breast tissue.

All cancers develop from our cells of the body. The cells in our bodies have ability to produce new cells to reproduce dead cells and repair injured tissues. The breast cancer occurs when the abnormal cells grow and divide without their normal control and continue to divide and multiply in the breast because of the DNA damage.

Between 50 and 75 percent of the breast cancers are invasive ductal carcinoma and 10 to 15 percent of it is invasive lobular carcinoma. The invasive ductal carcinoma is the occurrence of the breast cancer in milk channels (duct), the invasive lobular carcinoma is the occurrence in milk glands (lobes) and the few of the breast cancer can be seen in other breast tissues (Dillon, D. A., Guidi, A. J., & Schnitt, S. J. , 2010).

Breast cancer, can spread to the region close to the breast via the cancerous tissue itself. Also it is possible to spread other parts of the body through the lymph system and the bloodstream.

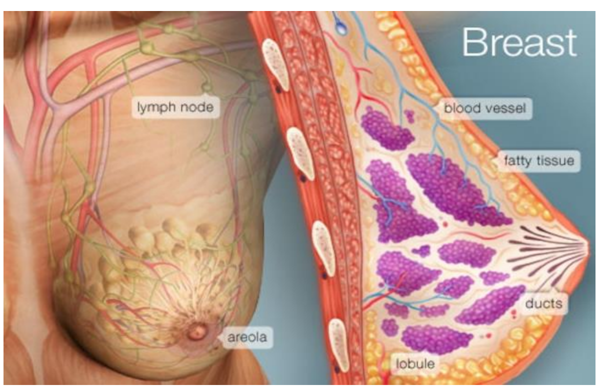

Figure 2.1: Anatomy of the Breast (WebMD, LLC. , 2014)

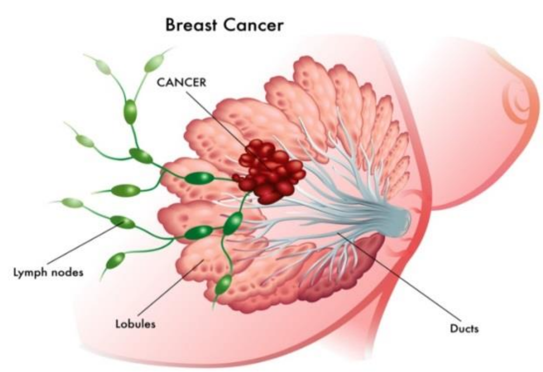

Figure 2.2: Breast Cancer (saglikbilimlerifakultesi.com, 2019)

CHAPTER 3
BREAST CANCER IMAGING DEVICES

3.1 Screen Film Mammography

Screen-Film Mammography is a device, which is used for imaging breast cancer. The Screen-film mammography includes three main components which are; small x-ray tube, compression plate and x-ray cassette. Patients' breast placed between compression plate and grid where the compression plate provides compression to the breast to decrease the thickness of the breast. By this way, breast tissue expands and the image quality increases. The x- ray tube sends narrow beams through the patients' breast. While the x-rays leave the breast, they are collected up by the x-ray cassette which is located at the opposite side of the x-ray tube. The collected information can be printed from the cassette as an image.

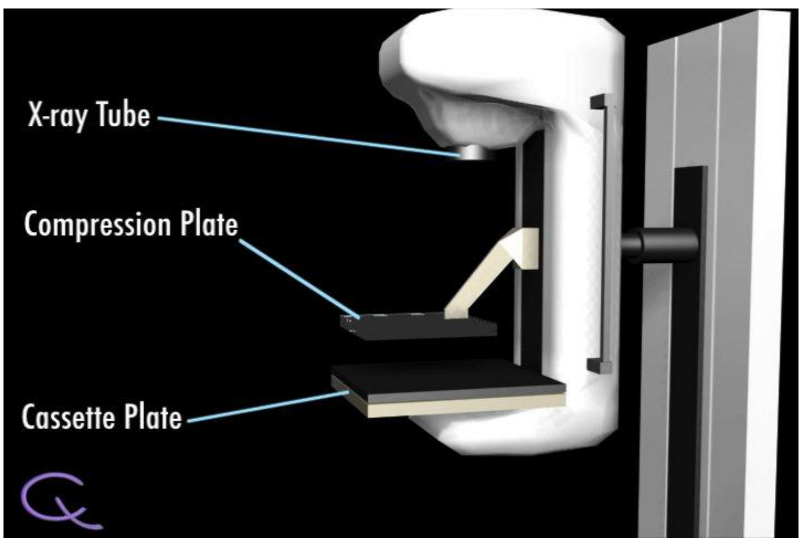

Figure 3.1: Screen-Film Mammography (EMORY WINSHIP CANCER INSTITUTE)

3.2 Digital Mammography

Digital Mammography is a device, which is used for imaging breast cancer by using special detector to collect and convert x-ray into a digital image. The digital mammography includes three main components which are; x-ray tube, compression plate and x-ray detector. Patients' breast placed between compression plate and grid to provide compression to the breast to decrease the thickness of the breast. By this way, breast tissue expands and the image quality increases. The x- ray tube sends narrow beams through the breast. While x-rays leave the breast, they are collected by the x-ray detector which is located at the opposite side of the x-ray tube. The collected information from the detector can be seen in a digital platform like monitor of the digital mammography.

Figure3.2: Digital Mammography (Hologic Selenia)

3.3 Digital Breast Tomosynthesis

Digital Breast Tomosynthesis is a device, which is used for imaging breast cancer by using special type of x-ray source and computer reconstructions to create 3D (three dimensional) images. Because of these abilities, the digital breast tomosynthesis, also called 3D mammography. In Digital Breast Tomosynthesis examination, patients' breast placed between compression plate and detector, to provide compression to the breast to decrease the thickness of the breast like similar mammographic applications. The special type of x-ray tube makes an arc and sends many of narrow beams through the breast from different angles. Information which are taken from the breast are collected by the detector and these information are the series images of the breast from the different angle and they are reconstructed by the computer. By this way, the series images transform into detailed three dimensional images.

Figure 3.3: Digital Breast Tomosynthesis (Hologic 3D Mammography)

3.4 Ultrasound

Ultrasound is a device, which is used for imaging breast cancer by using high-frequency sound waves. Ultrasound examination does not include any radiation. The imaging process starts with placing a sound-emitting probe of the device on the patients' breast. The applied sound waves from the probe pass through the breast and when these sound waves strikes any mass inside the breast, it bounce back or echo and the same probe receives these echo waves. The collected echo waves from the probe, analysed by the devices' computer and transformed into an image. By this way, it is possible to measure the distance, size and shape of the mass inside the breast.

Figure 3.4: Ultrasound (Lange Productions)

3.5 Magnetic Resonance Imaging

An MRI scan is an imaging technique that uses magnetism and radio waves to produce images of patient's body. The human body contains of average % 60 water (in adult) and the water molecules consist of two hydrogen and an oxygen atoms. The working principle of the MRI device is associated with these hydrogen atoms. The MRI magnet creates a strong magnetic field that arrange the protons of hydrogen atoms, then the hydrogen atoms exposed to a beam of radio waves. The protons which are aligned absorb the energy from the magnetic field and flip their spins. When the magnetic field is turned off from the MRI scanner, the hydrogen protons return to their normal spin. The return process of the hydrogen protons produces a radio signal and the images created by measuring this radio signal. This scan type gives us the molecular detailed information from the body.

Figure 3.5: Breast MRI (GE Healthcare)

3.6 Positron Emission Tomography

Positron Emission Tomography (PET) is an imaging technique that uses a special kind of camera and a radioactive substance, to observe the organs inside the patients' body for detecting cancer. The radioactive substances include glucose. When radioactive substances injected the body it goes to the tissues that use glucose for energy and annihilation occurs when the electron (e−) reacts with the positron (e+). PET images are generated with detection of the 511 Kev photons that arise during positron annihilation. The PET device, consist of the circular gamma radiation detector sequent, which has a scintillation crystal and each scintillation crystal connects to the photomultiplier tube of the device. The two 511 Kev photons interact with the crystals in PET detector ring and the photomultiplier tubes transform and amplify the photons to electrical signals and the electrical signal transform to the images. In the result of the detected images, three dimensional images created.

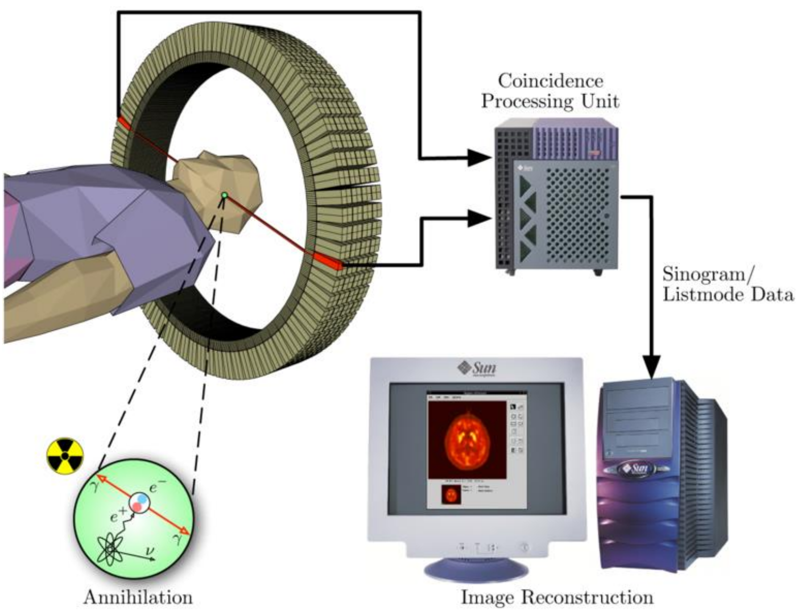

Figure 3.6: PET Scanner (Wikimedia Commons)

3.7 Positron Emission Tomography – Computed Tomography

PET/CT is the combination of the positron emission tomography and computed tomography in a single gantry system of device. This system gives us both anatomical and functional information from the patient. For the anatomical information, Computed Tomography (CT) and for the functional information, Positron Emission Tomography (PET) is used. During PET/CT scan, radioactive substances injected to the patient. The patient lies on a bed which moves towards the gantry system slowly. PET detect photons by circular gamma ray detector sequent, which has a scintillation crystal and photomultiplier tubes transform and amplify the photons to electrical signals. A CT scan has an x-ray tube that rotates around the patient for shooting narrow beams of x-rays through the patients' body. During the x-rays leave the patient, x-rays are collected by the detectors which are located at the opposite side of the x-ray tube. The collected information transmit to a computer and detailed images created.

A CT scan shows the locations of the body's organs and PET scan shows abnormal cell activity of the body's organs. In this way the exact location of the cancer can be shown.

Figure 3.7: PET/CT (GE Healthcare, Discovery IQ)

3.8 Positron Emission Tomography – Magnetic Resonance Imaging

PET/MRI is the combination of the positron emission tomography and magnetic resonance imaging in a single gantry system of device. This system gives us both molecular and functional information from the patient. For the molecular information Magnetic Resonance Imaging (MRI) and for the functional information Positron Emission Tomography (PET) is used. During PET/MRI scan, radioactive substances injected to the patients. The patient lies on a bed which moves towards the gantry system slowly. PET detect photons by circular gamma ray detector array, which has a series of scintillation crystal and photomultiplier tubes converts and amplify the photons to electrical signals. An MRI scan use magnetism and radio waves to produce images of body. The MRI magnet creates a strong magnetic field that arrange the protons of hydrogen atoms, then the hydrogen atoms exposed to a beam of radio waves. The protons which are aligned absorb the energy from the magnetic field and flip their spins. When the magnetic field is turned off from the MRI scanner, the hydrogen protons return to their normal spin. The return process of the hydrogen protons produces a radio signal and the images created by measuring this radio signal. The collected information transmit to a computer and detailed images created.

Figure 3.8: PET/MRI (GE Healthcare, Signa)

3.9. Breast Computed Tomography

Breast Computed Tomography is a device, which is used for imaging breast cancer by using x-ray tube and digital detector. This device includes a hole where patients' breast placed inside it without any compression to the breast. The imaging process starts with placing patients' breast into this hole, lying face down on the device. When patients' breast placed inside the hole, it is surrounded by the x-ray tube and the digital detector. The x-ray tube and the digital detector are positioned parallel to each other and they have ability to rotate 360 degree around the breast. The special type of x-ray tube sends many of narrow beams through the breast from different angles. Information which is taken from the breast is collected by the digital detector. This information is the series images of the breast from the different angle. These series images are combined by the device' reconstruction system and they transform into detailed three dimensional images.

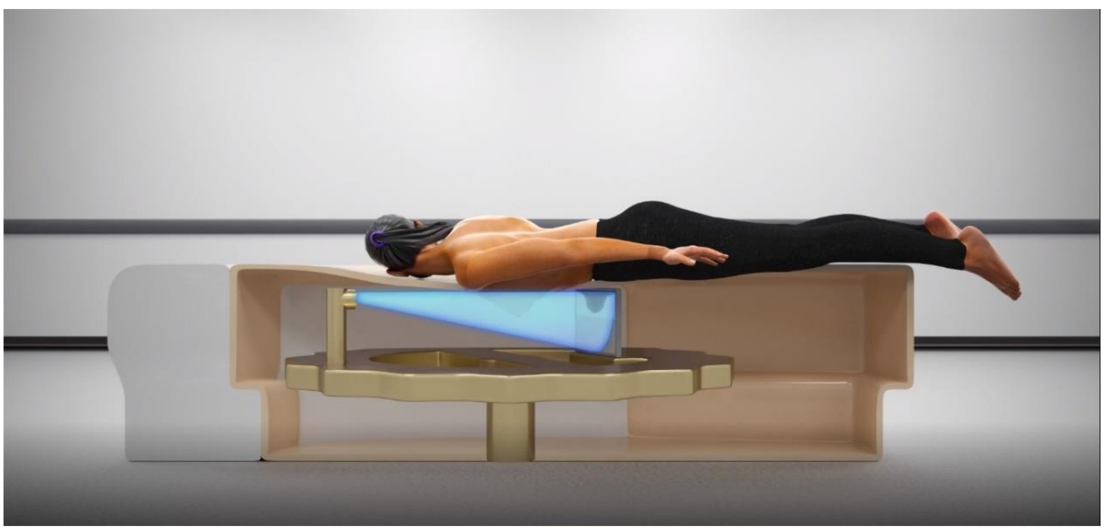

Figure 3.9: Breast Computed Tomography (Koning Breast CT)

3.10. Positron Emission Mammography

Positron emission mammography (PEM) is a nuclear imaging device, which is used for imaging breast cancer by using special type of camera and a radioactive substance. In PEM examination, patients' breast placed between two gamma ray detectors, which have a series of scintillation crystal and each scintillation crystal connected to a photomultiplier tube. The imaging process starts with injection of the radioactive substances to the patients'. The radioactive substance includes glucose. The radioactive substances are collected by the cancerous tissue in the breast, because cancerous tissue needs glucose to growth and annihilation occurs when the electron (e−) reacts with the positron (e+). PEM images are generated with detection of the 511 Kev photons that arise during positron annihilation. The two 511 Kev photons interact with the crystals in PEM detectors and the photomultiplier tubes transform and amplify the photons to electrical signals and the electrical signal transform to the images. In the result of the detected images, three dimensional images created.

Figure 3.10: Positron Emission Mammography (CMR Naviscan, EYMSA)

3.11. Breast Specific Gamma Imaging

Breast Specific Gamma Imaging (BSGI) is a nuclear imaging device, which is used for imaging breast cancer by using special type of camera (gamma-camera) and a radioactive substance. In BSGI examination, patients' breast placed between gamma camera, which is optimized for breast imaging and compression plate to decrease thickness and immobilize the breast during imaging process. The radioactive substance includes glucose. The radioactive substances are collected by the cancerous tissue in the breast, because cancerous tissue needs glucose to growth. The gamma rays detect by the gamma camera. In order to detect the gamma photons, the large crystal of sodium iodide is used. Only the gamma photons hits to the crystal, other photons are absorbed by the collimator. A crystal gives a tiny flash when a gamma photon hits it. The flash is picked up by photomultiplier tubes and converts it to an electrical signal and the electrical signal transform to the images by the computer of the device.

Figure 3.11: Breast Specific Gamma Imaging (The Dilon 6800 Gamma Camera, Dilon Technologies)

3.12 Single Photon Emission Computed Tomography

SPECT scan is a type of nuclear imaging test and it shows how blood flows to tissues and organs. A radioactive tracer is injected into the patient for taking information. Unlike PET, there is rotating camera or cameras and SPECT emits gamma radiation. A sinogram is generated by rotating detectors around a patient. The gamma rays detected by the detectors which are placed around the patient. In order to detect the gamma photons, the large crystal of sodium iodide is used. Only the gamma photons hits to the crystal, other photons are absorbed by the collimator. A crystal gives a tiny flash when a gamma photon hits it. The flash is picked up by photomultiplier tubes and converts it to an electrical signal. The electrical signals transform to the images by the computer.

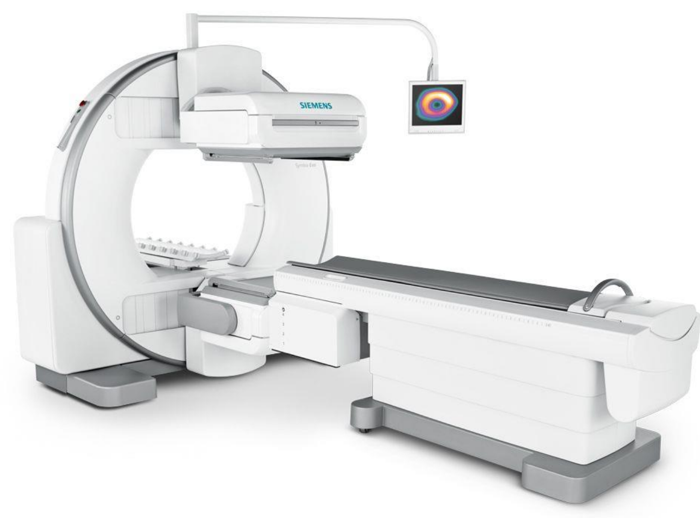

Figure 3.12: SPECT Scanner (SIEMENS, Symbia Evo)

CHAPTER 4
PARAMETERS

Table 4.1: Breast Cancer Imaging Devices and Their Detailed Parameters

Device / Parameter	SFM	DM	DBT	U/S	MRI	PET	PET/ CT	PET/MRI	BCT	PEM	BSGI	SPECT
Cost of Per Scan	$45	$155.76	$215.94	$155	$2,611	$4,500	$5,000	$3,500	$1,500	$1,100	$450	$3,950
Cost of Device	$240,000	$273,940	$462,010	$45,000	$400,000	$1,900,000	$2,000,000	$4,500,000	$1,000,000	$700,000	$500,000	$500,000
Radiation Dose (mSv: millisievert)	0.56 mSv	0.44 mSv	1.0 mSv	No Radiation	No Radiation	6.7 mSv	17.6 mSv	9.3 mSv	1.39 mSv	6.65 mSv	9.15 mSv	6 mSv
Specificity	%98.5	%96.9	%80.7	%88.5	%89.7	%85	%89	%71.4	%87	%96	% 59.5	%71
Sensitivity	% 66.1	%69.1	%92	%72.6	%82	%90	%95	%100	%91	%95	% 96.4	%87
Total Scan Time	5sec.	6 sec.	4 sec.	15 min.	30 min.	25 min.	30 min.	30 min.	10 sec.	5 min.	10 min.	30 min.
Spatial Resolution (lp/mm: line pairs per millimeter)	16 lp/mm	5.0 lp/mm	2.65 lp/mm	2.0 lp/mm	1.5 lp/mm	1.5 lp/mm	1.1 lp/mm	0.3 lp/mm	0.32 lp/mm	1.5 lp/mm	1.6 lp/mm	2.0 lp/mm
Comparison of Natural Radiation Exposure (3 mSv)	10 weeks	8 weeks	4 months	No Radiation	No Radiation	2.3 years	5.8 years	3.1 years	5.5 months	2.2 years	3 years	2 years
Real 3D	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓
No Compression	✗	✗	✗	✗	✓	✓	✓	✓	✓	✗	✗	✓
Not Claustrophobic	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓	✗

4.1 Cost of Per Scan

Cost of per breast cancer imaging devices scan vary between $ 45 (SFM) and $ 5,000 (PET/CT) according to difference of applied technology, cost of the devices, used radioactive substance and working principles of devices.

4.2 Cost of Device

Cost of breast cancer imaging devices vary between $ 45,000 (Ultrasound) and $ 4,500,000 (PET/MRI). The used technology in breast cancer imaging devices, such as; x-ray tube, gamma ray detector, high performance magnets are increased the cost of the devices.

4.3 Radiation Dose

The applied radiation dose units in medical imaging are generally called as a millisieverts (mSv). The radiation dose of breast cancer imaging devices varies between 0 (No Radiation) mSv and 17.6 mSv. The ultrasound and the MRI devices are not including any x- ray source. On the other hand in PET/CT application, patients are exposed average 17.6 mSv because of it is include both X-ray source and radioactive substance.

4.4 Specificity

Specificity values are showing the true negative rate of the patient. It means it indicates the rate of correct diagnosis to a non-cancerous patient. The specificity value should be high in order to prevent the wrong positive cancer diagnosis even if there is no cancerous tissue in the patients. The specificity of breast cancer imaging devices vary between and % 59.5 (BSGI) and % 98.5 (SFM).

4.5 Sensitivity

Sensitivity values are showing the true positive rate of the patient. It means it indicates the rate of correct diagnosis to a cancerous patient. The sensitivity value should be high in order to prevent the wrong negative cancer diagnosis even if there is a cancerous tissue in the patients. The sensitivity of breast cancer imaging devices vary between and % 66.1 (SFM) and % 100 (PET/MRI).

4.6 Total Scan Time

Total scan time is the time of spent in each breast cancer imaging operation. The total scan time shows differences for each imaging devices according to differences in imaging process. The total scan time of breast cancer imaging devices vary between and 4 seconds (DBT) and 30 minutes (MRI – PET/CT – PET/MRI).

4.7 Spatial Resolution

Spatial resolution is the amount of pixels used in creation of a digital image. The images which have higher spatial resolution have more detailed information than lower spatial resolution images. Because of this reason it has important role to serve detailed examination of the breast cancer images.

4.8 Comparison of Natural Radiation Exposure

We are continuously exposed to natural sources of radiation. Natural radiation is also called background radiation. They occurs from, cosmic radiation from outer space, radon gas in the house and environmental radiation sources. The average natural radiation doses which are exposed in year are 3 mSv.

4.9 Real 3D

3D (three dimensional) imaging ability is the important property for breast cancer imaging devices to improve diagnostic confidence, decrease exploratory surgery and decrease damage in healthy tissue by specifying the treatment area.

4.10 Compression

Compression is a disadvantage for the breast cancer imaging devices. Some of the breast cancers imaging devices are include compression unit to decrease the thickness of the breast. By this way, breast tissue expands and the image quality increases. Although it is a useful process and not major disadvantage, most of time the compression gives pain to the patient and it may cause some patients not to choose like that devices.

4.11 Claustrophobia

Claustrophobia is one of the most common phobias in worldwide (15 to 37 present of people) (Claustrophobia: Fear of confined spaces - Causes, Symptoms and Treatment / Healthtopia, 2018) for both men and women and it seen more likely to be claustrophobic in women than men.

Because of this reason, claustrophobia is the major disadvantage for the breast cancer imaging devices. Claustrophobic devices are; MRI, PET, PET/CT, PET/MRI and SPECT.

CHAPTER 5
LITERATURE REVIEW

Ozsahin et al. (2017) with using a Multi Criteria Decision Making (MCDM) technique carried out a study to analyze and compare the most common used nuclear medicine imaging devices (Positron Emission Tomography (PET), Positron Emission Tomography/Computed Tomography (PET/CT), Single Positron Emission Computed Tomography (SPECT), Single Positron Emission Computed Tomography/Computed Tomography (SPECT/CT) and Positron Emission Tomography/Magnetic Resonance Imaging (PET/MRI)) based on some parameters that are likely to affect the outcome of the imaging methods. These parameters are; cost of treatment, average scan time, spatial resolution, specificity of the device, sensitivity of the device, energy resolution and average radiation dose. In their analysis, to define the magnitude of the triangular fuzzy numbers, they used Yager Index and they used Visual PROMETHEE method to arrive at their results. Their research analysis finalized that PET with a net-flow of 0.0005 is a more advantageous and suitable imaging device according to the used parameters.

Ozsahin et al. (2018) with using a Multi Criteria Decision Making (MCDM) technique carried out a study to analyze and compare the x-ray based imaging devices (Radiography machine, Angiography, Computed Tomography (CT), Fluoroscopy and Mammography) based on some parameters that are likely to portray the efficiency, negativity and potentiality and of each imaging device. These parameters are; cost of treatment, cost of device, sensitivity, specificity and radiation dose. In their analysis, to define the magnitude of the triangular fuzzy numbers, they used Yager Index and they used Visual PROMETHEE method to arrive at their results. Their results rank shows, when the cost of machine is not added into consideration, with the net flow of 0.0017 the conventional x-ray device as a suitable imaging device. On the other hand, when the cost of device is added into consideration, mammography outranked the other x-ray based medical imaging devices with a net flow of 0.0015.

CHAPTER 6
METHOD

6.1 Fuzzy Logic

In standard explanation, an element is a member of the set or not. When mathematically expressed, the element takes the value of '1' when it is the member of the set and it takes the value of '0' when it is not the member of the set. Fuzzy logic is the expansion of the standard set representation. The membership degree of the elements can be any value between '0' and '1' in the fuzzy logic. If specific two degrees are hot or cold, what does it mean of value of between of these two degrees? Fuzzy logic is a method that provides the degree of membership to these intermediate values. For example, according to the fuzzy logic, purely red and purely green apples are top points, the boundaries are indicate and labels for the ones between the top points are possible. Because of green apple is a start, bit redden green apples are 30%, if they are more redden 40%, if they are little green (mostly red) it means they are in 70% fried apples categories. Thus, a method that enriches the truth values of classical logic emerges.

Fuzzy logic can be defined as design of decision mechanism and it is essential to the development of humanoid capabilities for artificial intelligence (Zadeh, L. A., Klir, G. J., & Yuan, B. , 1996).

6.2 Multi Criteria Decision Making

Multipi Criteria Decision Making (MCDM) is a method to evaluate various available options, according to decision criteria and also to assign importance weightings (Very High, Important, Medium, Low, Very Low) to the criteria. Upon this, according to the assigned importance weightings, the best option can be determined and makes the parameter a favorable (maximal advantage) or unfavorable (minimal concession) choice for a specific application.

6.3 Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE)

PROMETHEE is a technique of the multi-criteria decision making tool to analyze and rank available options based on the parameter of each options for researcher. It is developed by Brans et al. (Brans, Vincke & Mareschal, 1986). The PROMETHEE technique is one of the easy to use and most effective methods both planning and application when it is compared to other Multi-Criteria Decision Making methods.

The reason of the PROMETHEE being most favorable technique of multi criteria decision methods are (Ulengin et al., 2001);

- PROMETHEE can be applied in real life decision making problems.
- PROMETHEE works on fuzzy logic and uncertainty.
- PROMETHEE can provide control mechanism to researcher to check him or her fictitious and real data to observe their potential.
- PROMETHEE can give both partial and complete ranking of the options respectively.

Only two kinds of information are required for the PROMETHEE method from the researcher (decision maker): the information on the weights of the defined criteria and the the researcher's preference function to compare the contribution of alternatives in terms of each criterion. (Macharis, Springael, De Brucker & Verbeke, 2004).

In the PROMETHEE method, different preference functions (P_j) are available for the purpose of describe to different criteria. The preference function (P_j) describes the difference between the rating with two alternatives (a and a_t) in terms of each criterion and a preference degree ranking between '0' and '1'. There are different types of the preference functions which can be used to apply the PROMETHEE method. They are; linear, usual, level, Gaussian, U-shape and V-shape functions.

6.3.1 Steps of the PROMETHEE Method (Brans, Vincke & Mareschal, 1986)

1. Determine a specific preference function p_j (d) for each parameter j.

2. Determine the weight of each parameter $w_t = (w_1, w_2, w_3 \ldots, w_k)$. Each weights of the parameter can be defined equally if only their importance is equal according to the discretion of the decision maker. $\sum_{k=1}^{K} w_k = 1$.

3. Determine the outranking relation π for all alternative a_t, $a_{t'} \in A$.

$$\pi(a_t, a_{t'}) = \sum_{k=1}^{K} w_k.\left[p_k\big(f_k(a_t) - f_k(a_{t'})\big)\right], \qquad AXA \rightarrow [0,1]$$

4. Determine the negative (entering) and positive (leaving) outranking flows;

- Negative (entering) outranking flow for a_t: $\Phi^-(a_t) = \frac{1}{n-1}\sum_{\substack{t'=1 \\ t' \neq t}}^{n} \pi(a_{t'}, a_t)$

- Positive (leaving) outranking flow for a_t: $\Phi^+(a_t) = \frac{1}{n-1}\sum_{\substack{t'=1 \\ t' \neq t}}^{n} \pi(a_t, a_{t'})$

n is the meaning of the number of alternatives. Each alternative is compared with (n-1) number of another alternative.

The positive (leaving) outranking flow $\Phi^{+}(a_t)$ refers to the strength of alternative $(a_t) \in A$, while the negative (entering) outranking flow $\Phi^{-}(a_t)$ refers to the weakness of the alternatives, $(a_t) \in A$.

5. Determine the partial preorder on the alternatives of A. In PROMETHEE I alternative a_t is decided to alternative $a_{t'}$ $(a_t P a_{t'})$ if it supplies the one of the following conditions: $(a_t P a_{t'})\ if;$

$$\begin{cases} \Phi^{+}(a_t) > \Phi^{+}(a_{t'})\ and\ \Phi^{-}(a_t) < \Phi^{-}(a_{t'}) \\ \Phi^{+}(a_t) > \Phi^{+}(a_{t'})\ and\ \Phi^{-}(a_t) = \Phi^{-}(a_{t'}) \\ \Phi^{+}(a_t) = \Phi^{+}(a_{t'})\ and\ \Phi^{-}(a_t) < \Phi^{-}(a_{t,}a_{t'}) \end{cases}$$

If there are two alternatives (a_t and $a_{t'}$), with similar or equal positive (leaving) and negative (entering) flows, a_t is indifferent to $a_{t'}$ ($a_t I a_{t'}$):

$$(\ a_t I a_{t'})\ \text{if: } \Phi^{+}(a_t) = \Phi^{+}(a_{t'})\ \ and\ \ \Phi^{-}(a_t) = \Phi^{-}(a_{t'}).$$

a_t is unique to $a_{t'}$ $(a_t R a_{t'}$) if;

$$\begin{cases} \Phi^{+}(a_t) > \Phi^{+}(a_{t'})\ and\ \Phi^{-}(a_t) > \Phi^{-}(a_{t'}) \\ \Phi^{+}(a_t) < \Phi^{+}(a_{t'})\ \ \ and\ \Phi^{-}(a_t) < \Phi^{-}(a_{t'}) \end{cases}$$

6. Determine the net outranking flow for each alternative:

$$\Phi^{net}(a_t) = \Phi^{+}(a_t) - \Phi^{-}(a_t)$$

(The net outranking flow = The positive outranking flow − the negative outranking flow)

With usage PROMETHEE II, the complete pre order can be obtained by the net flow and determined by:

a_t is preferred to $a_{t'}$ $(a_t P a_{t'})$ if $\Phi^{net}(a_t) > \Phi^{net}(a_{t'})$

a is indifferent to $a_{t'}$ ($a_t I a_{t'}$) if $\Phi^{net}(a_t) = \Phi^{net}(a_{t'})$.

As a result, the better alternative is the one having the higher $\Phi^{net}(a_t)$ (the net outranking flow) value.

6.4 Application of PROMETHEE to the Project

To determine the weight of each parameters of the breast cancer imaging device, Yager index was used to find the triangular fuzzy numbers.

Table 6.1 shows detailed information about the parameters of breast cancer imaging devices.

Table 6.1: Parameter Values of Breast Cancer Imaging Devices

Device / Parameter	SFM	DM	DBT	U/S	MRI	PET	PET/ CT	PET/MRI	BCT	PEM	BSGI	SPECT
Cost of Per Scan	$45	$155.76	$215.94	$155	$2,611	$4,500	$5,000	$3,500	$1,500	$1,100	$450	$3,950
Cost of Device	$240,000	$273,940	$462,010	$45,000	$400,000	$1,900,000	$2,000,000	$4,500,000	,$1,000,000	$700,000	$500,000	$500,000
Radiation Dose (mSv: millisievert)	0.56 mSv	0.44 mSv	1.0 mSv	No Radiation	No Radiation	6.7 mSv	17.6 mSv	9.3 mSv	1.39 mSv	6.65 mSv	9.15 mSv	6 mSv
Specificity	%98.5	%96.9	%80.7	%88.5	%89.7	%85	%89	%71.4	%87	%96	% 59.5	%71
Sensitivity	% 66.1	%69.1	%92	%72.6	%82	%90	%95	%100	%91	%95	% 96.4	%87
Total Scan Time	5sec.	6 sec.	4 sec.	15 min.	30 min.	25 min.	30 min.	30 min.	10 sec.	5 min.	10 min.	30 min.
Spatial Resolution (lp/mm: line pairs per millimeter)	16 lp/mm	5.0 lp/mm	2.65 lp/mm	2.0 lp/mm	1.5 lp/mm	1.5 lp/mm	1.1 lp/mm	0.3 lp/mm	0.32 lp/mm	1.5 lp/mm	1.6 lp/mm	2.0 lp/mm
Comparison of Natural Radiation Exposure (3 mSv)	10 weeks	8 weeks	4 months	No Radiation	No Radiation	2.3 years	5.8 years	3.1 years	5.5 months	2.2 years	3 years	2 years
Real 3D	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓
No Compression	✗	✗	✗	✗	✓	✓	✓	✓	✓	✗	✗	✓
Not Claustrophobic	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓	✗

Table 6.2 shows the linguistic scale of importance for patients, using a triangular fuzzy numbers. Each parameters of breast cancer imaging devices, classified according to their importance level for patients.

Table 6.2: Linguistic scale of importance for Patients

Linguistic scale for evaluation	**Triangular fuzzy scale**	**Importance ratings of criteria**
Very High (VH)	(0.75, 1, 1)	Specificity, Sensitivity, Spatial Resolution, Real3D
Important (H)	(0.50, 0.75, 1)	-
Medium (M)	(0.25, 0.50, 0.75)	Cost of Per Scan, Radiation Dose, Total Scan Time, No Compression, Claustrophobia
Low (L)	(0, 0.25, 0.50)	Comparison of Natural Radiation Exposure
Very Low (VL)	(0, 0, 0.25)	-

Table 6.3: Visual PROMETHEE Application of Breast Cancer Imaging Devices for Patients

Parameter	**Min/Max**	**Weight**	**Preference Function**
Cost of Per Scan	min	0,50	Gaussian
Radiation Dose	min	0,50	Gaussian
Specificity	max	0,92	Gaussian
Sensitivity	max	0,92	Gaussian
Total Scan Time	min	0,50	Gaussian
Spatial Resolution	max	0,92	Gaussian
Comparison of Natural Radiation Exposure	min	0,25	Gaussian
Real 3D	max	0,92	Gaussian
No Compression	max	0,50	Gaussian
Claustrophobia	min	0,50	Gaussian

Table 6.4: Visual PROMETHEE Statistics of Breast Cancer Imaging Devices for Patients

Parameter	**Unit**	**Minimum**	**Maximum**	**Average**
Cost of Per Scan	$	45	5000	1932
Radiation Dose	mSv	0,0	17,60	4,90
Specificity	%	59,5	98,5	84,4
Sensitivity	%	66,1	100,0	86,3
Total Scan Time	sec	4,00	1800,0	877,08
Spatial Resolution	lp/mm	0,30	16,00	2,96
Comparison of Natural Radiation Exposure	weeks	0,0	305,0	84,89
Real 3D	yes/no	0,0	1,0	0,75
No Compression	yes/no	0,0	1,0	0,50
Claustrophobia	yes/no	0,0	1,0	0,42

Table 6.5 shows the linguistic scale of importance for hospitals, using a triangular fuzzy numbers. Each parameters of breast cancer imaging devices, classified according to their importance level for hospitals.

Table 6.5: Linguistic scale of importance for Hospitals

Linguistic scale for evaluation	Triangular fuzzy scale	Importance ratings of criteria
Very High (VH)	(0.75, 1, 1)	Cost of Per Scan, Specificity, Sensitivity, Spatial Resolution, Real 3D
Important (H)	(0.50, 0.75, 1)	Cost of Device
Medium (M)	(0.25, 0.50, 0.75)	Radiation Dose, Total Scan Time
Low (L)	(0, 0.25, 0.50)	Comparison of Natural Radiation Exposure, No Compression, Claustrophobia
Very Low (VL)	(0, 0, 0.25)	-

Table 6.6: Visual PROMETHEE Application of Breast Cancer Imaging Devices for Hospitals

Parameter	Min/Max	Weight	Preference Function
Cost of Per Scan	max	0,92	Gaussian
Cost of Device	min	0,75	Gaussian
Radiation Dose	min	0,50	Gaussian
Specificity	max	0,92	Gaussian
Sensitivity	max	0,92	Gaussian
Total Scan Time	min	0,50	Gaussian
Spatial Resolution	max	0,92	Gaussian
Comparison of Natural Radiation Exposure	min	0,25	Gaussian
Real 3D	max	0,92	Gaussian
No Compression	max	0,25	Gaussian
Claustrophobia	min	0,25	Gaussian

Table 6.7: Visual PROMETHEE Statistics of Breast Cancer Imaging Devices for Hospitals

Parameter	**Unit**	**Minimum**	**Maximum**	**Average**
Cost of Per Scan	$	45	5000	1932
Cost of Device	$	45000	4500000	1043413
Radiation Dose	mSv	0,0	17,60	4,90
Specificity	%	59,5	98,5	84,4
Sensitivity	%	66,1	100,0	86,3
Total Scan Time	sec	4,00	1800,0	877,08
Spatial Resolution	lp/mm	0,30	16,00	2,96
Comparison of Natural Radiation Exposure	weeks	0,0	305,0	84,89
Real 3D	yes/no	0,0	1,0	0,75
No Compression	yes/no	0,0	1,0	0,50
Claustrophobia	yes/no	0,0	1,0	0,42

CHAPTER 7
RESULTS

The results of the analysis show that with the set cost of per scan, cost of device, radiation dose, specificity, sensitivity, total scan time, spatial resolution, comparison of natural radiation exposure, real 3D , compression and claustrophobia, PEM (1^{st}) and BCT (2^{nd}) are two most favourite imaging devices for breast cancer both the patients and the hospitals.

Table 7.1: Complete Ranking of Breast Cancer Imaging Devices for Patients

Complete Ranking	Device	Positive outranking flow	Negative outranking flow	Net flow
1	PEM	0,3400	0,1451	0,1949
2	BCT	0,3034	0,1641	0,1394
3	DBT	0,3078	0,1796	0,1283
4	DM	0,3293	0,2149	0,1145
5	U/S	0,2761	0,2131	0,0630
6	SFM	0,3317	0,2940	0,0377
7	MRI	0,2357	0,2477	-0,0120
8	BSGI	0,2239	0,3050	-0,0811
9	PET/MRI	0,2130	0,3151	-0,1021
10	PET	0,1865	0,2992	-0,1128
11	PET/CT	0,1775	0,3033	-0,1258
12	SPECT	0,1300	0,3739	-0,2438

Figure 7.1 shows an action profile of the weak points and strong points about Positron Emission Mammography (PEM) for patients , having a positive ranking in cost of per scan, specificity, sensitivity, total scan time, spatial resolution, real 3D and claustrophobia but showing a low ranking in breast compression, radiation dose and comparison of natural radiation exposure.

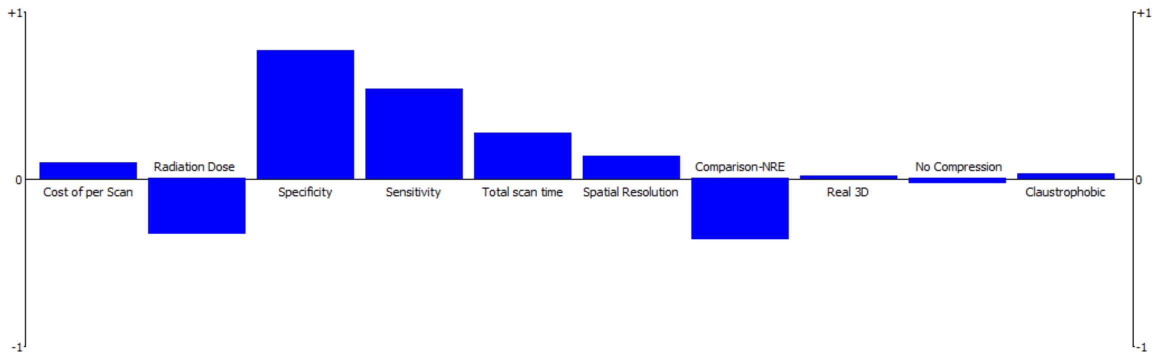

Figure 7.1: Action Profile of PEM for Patients

Figure 7.2 shows an action profile of the weak points and strong points about Breast Computed Tomography (BCT) for patients , having a positive ranking in radiation dose, specificity, sensitivity, total scan time, spatial resolution, comparison of natural radiation exposure, real 3D, breast compression and claustrophobia but showing a low ranking in cost of per scan.

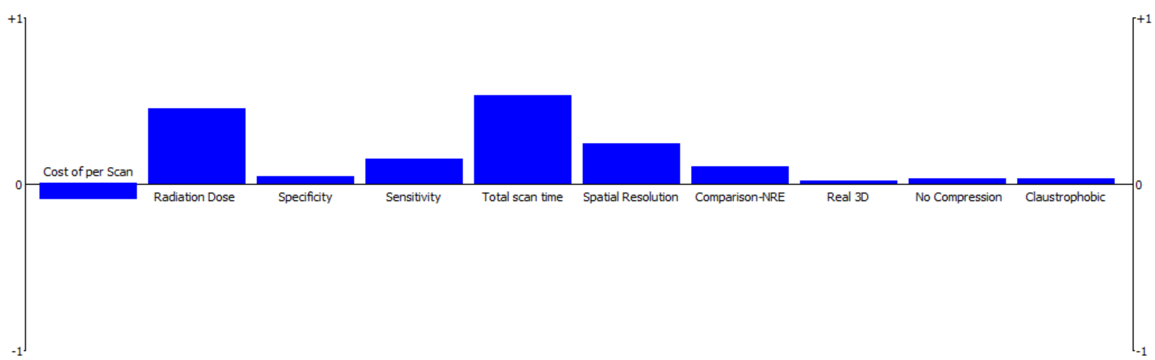

Figure 7.2: Action Profile of BCT for Patients

Figure 7.3 shows an action profile of the weak points and strong points about Digital Breast Tomosynthesis (DBT) for patients , having a positive ranking in cost of per scan, radiation dose, sensitivity, total scan time, spatial resolution, comparison of natural radiation exposure, real 3D and claustrophobia but showing a low ranking in specificity and breast compression.

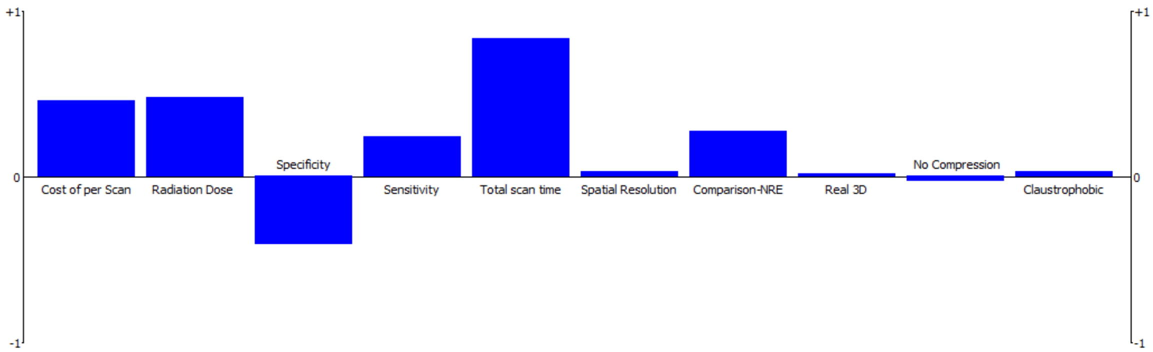

Figure 7.3: Action Profile of DBT for Patients

Figure 7.4 shows an action profile of the weak points and strong points about Digital Mammography (DM) for patients, having a positive ranking in cost of per scan, radiation dose, specificity, total scan time, comparison of natural radiation exposure and claustrophobia but showing a low ranking in sensitivity, spatial resolution, real 3D and breast compression.

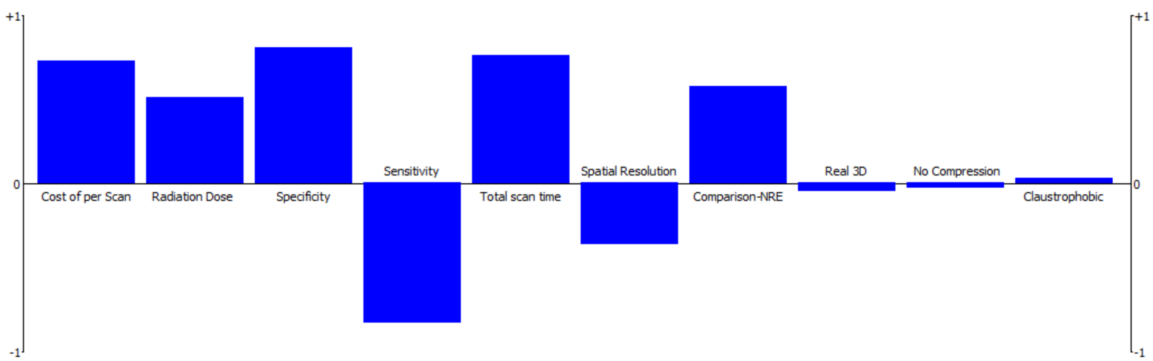

Figure 7.4: Action Profile of DM for Patients

Figure 7.5 shows an action profile of the weak points and strong points about Ultrasound (U/S) for patients, having a positive ranking in cost of per scan, radiation dose, specificity, spatial resolution, comparison of natural radiation exposure, real 3D and claustrophobia but showing a low ranking in sensitivity, total scan time and breast compression.

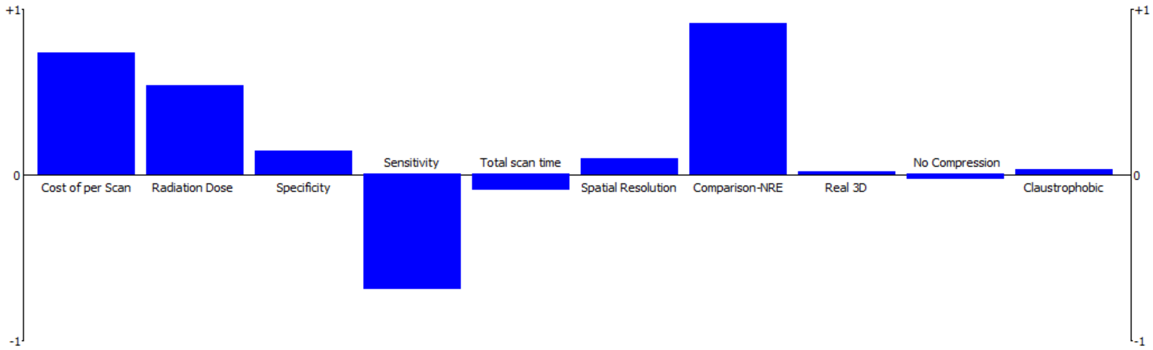

Figure 7.5: Action Profile of U/S for Patients

Figure 7.6 shows an action profile of the weak points and strong points about Screen-Film Mammography (SFM) for patients, having a positive ranking in cost of per scan, radiation dose, specificity, total scan time, comparison of natural radiation exposure and claustrophobia but showing a low ranking in sensitivity, spatial resolution, real 3D and breast compression.

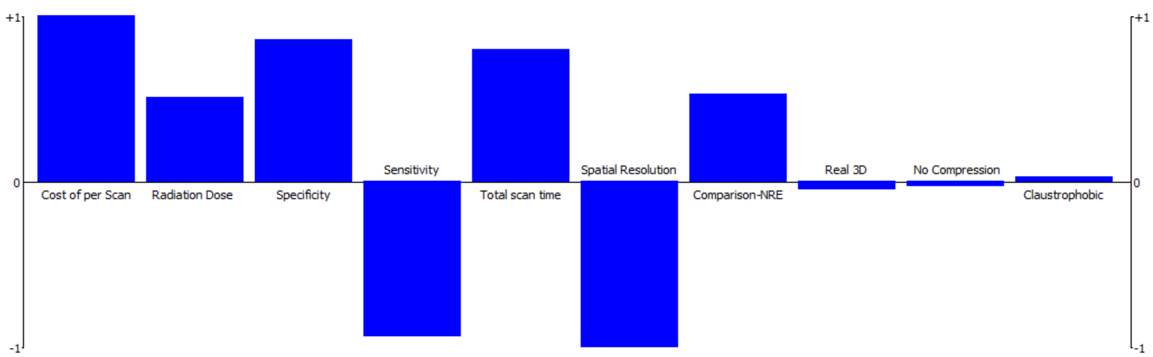

Figure 7.6: Action Profile of SFM for Patients

Figure 7.7 shows an action profile of the weak points and strong points about Magnetic Resonance Imaging (MRI) for patients, having a positive ranking in radiation dose, specificity, spatial resolution, comparison of natural radiation exposure, real 3D and breast compression but showing a low ranking in cost of per scan, sensitivity, total scan time and claustrophobia.

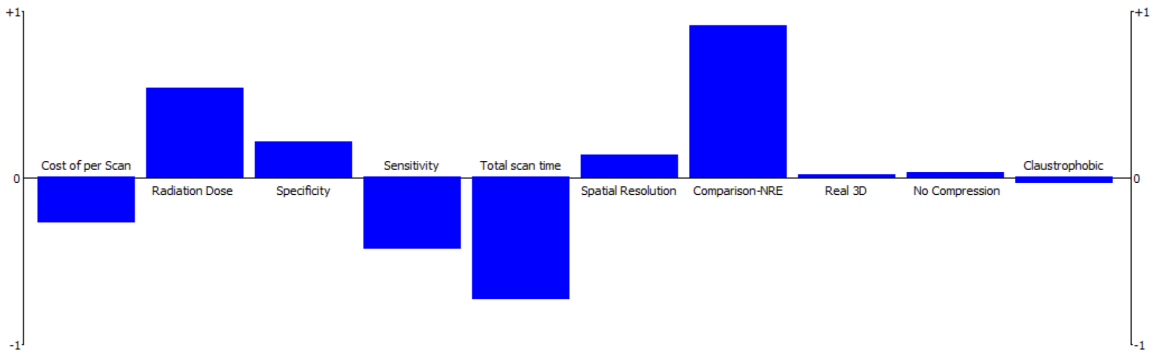

Figure 7.7: Action Profile of MRI for Patients

Figure 7.8 shows an action profile of the weak points and strong points about Breast Specific Gamma Imaging (BSGI) for patients, having a positive ranking in cost of per scan, sensitivity, total scan time, spatial resolution and claustrophobia but showing a low ranking in radiation dose, specificity, comparison of natural radiation exposure, real 3D and breast compression.

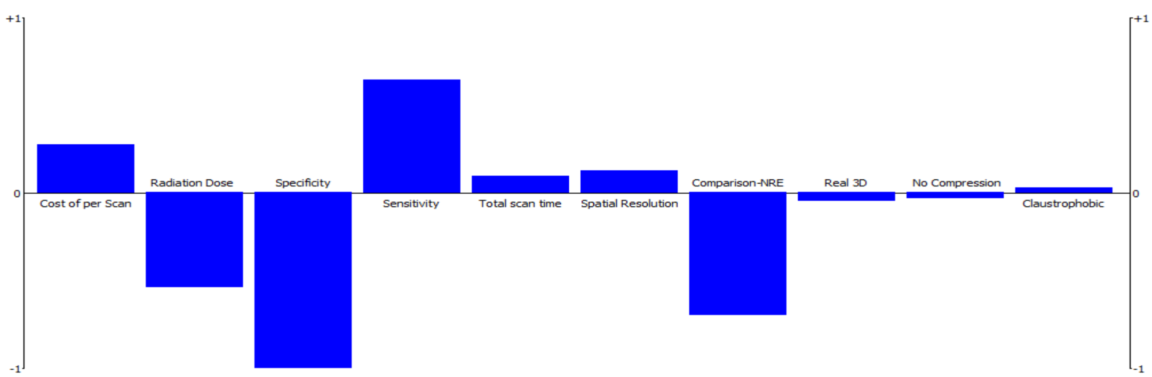

Figure 7.8: Action Profile of BSGI for Patients

Figure 7.9 shows an action profile of the weak points and strong points about Positron Emission Tomography- Magnetic Resonance Imaging (PET/MRI) for patients, having a positive ranking in sensitivity, spatial resolution, real 3D and breast compression but showing a low ranking in cost of per scan, radiation dose, specificity, total scan time, comparison of natural radiation exposure and claustrophobia.

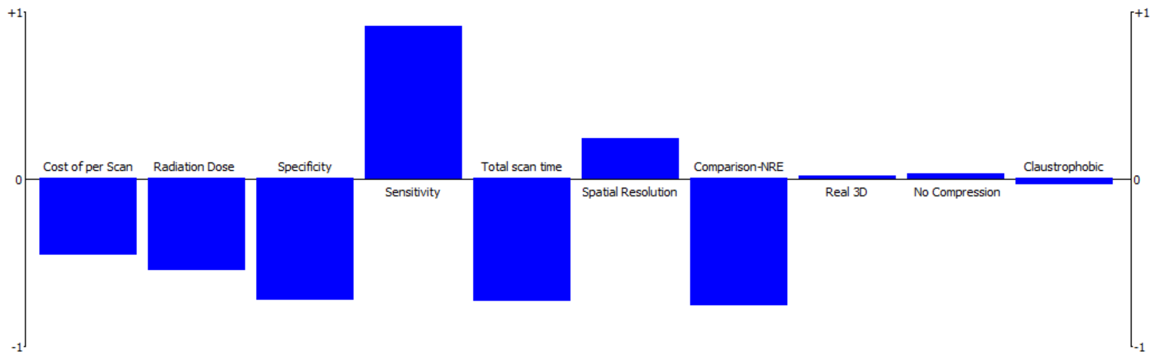

Figure 7.9: Action Profile of PET/MRI for Patients

Figure 7.10 shows an action profile of the weak points and strong points about Positron Emission Tomography (PET) for patients, having a positive ranking in sensitivity, spatial resolution, real 3D and breast compression but showing a low ranking in cost of per scan, radiation dose, specificity, total scan time, comparison of natural radiation exposure and claustrophobia.

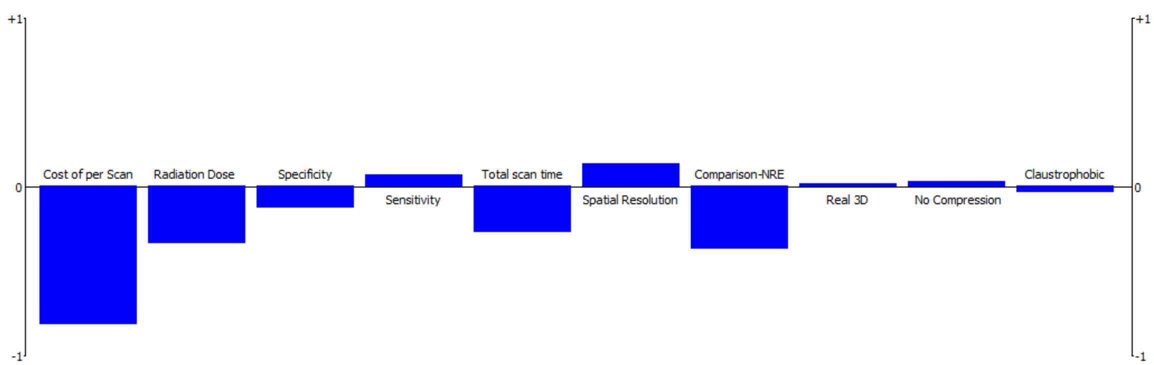

Figure 7.10: Action Profile of PET for Patients

Figure 7.11 shows an action profile of the weak points and strong points about Positron Emission Tomography – Computed Tomography (PET/CT) for patients, having a positive ranking in specificity, sensitivity, spatial resolution, real 3D and breast compression but showing a low ranking in cost of per scan, radiation dose, total scan time, comparison of natural radiation exposure and claustrophobia.

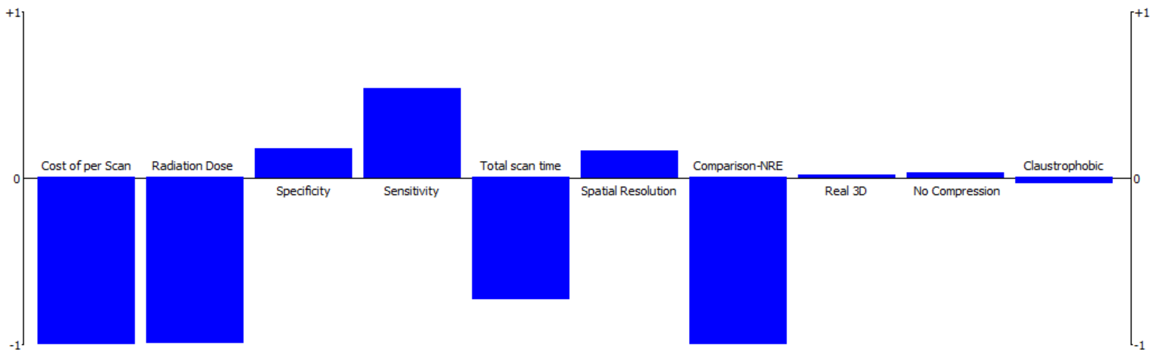

Figure 7.11: Action Profile of PET/CT for Patients

Figure 7.12 shows an action profile of the weak points and strong points about Single Photon Emission Computed Tomography (SPECT) for patients, having a positive ranking in spatial resolution, real 3D and breast compression but showing a low ranking in cost of per scan, radiation dose, specificity, sensitivity, total scan time, comparison of natural radiation exposure and claustrophobia.

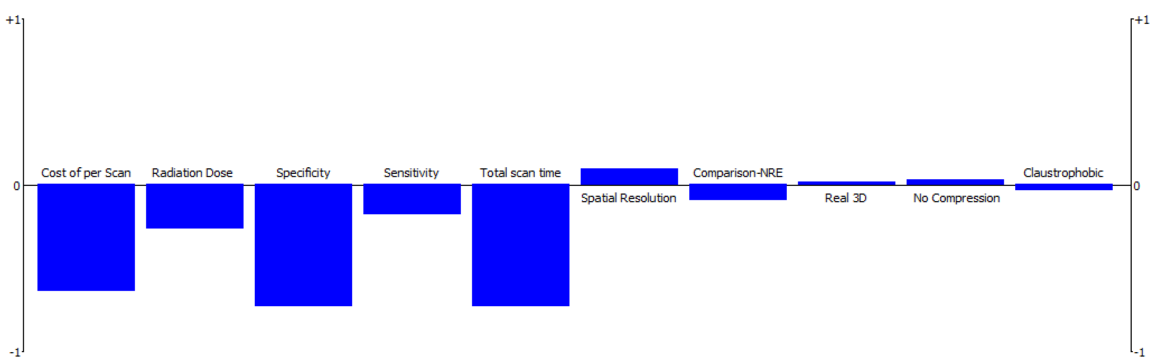

Figure 7.12: Action Profile of SPECT for Patients

Figure 7.13 shows a detailed rainbow ranking of the breast cancer imaging devices and their identified parameters that make a device favourable or unfavourable for patients.

Devices from the best to the worst respectively;

PEM > BCT > DBT > DM> US > SFM > MRI > BSGI > PET/MRI > PET > PET/CT > SPECT

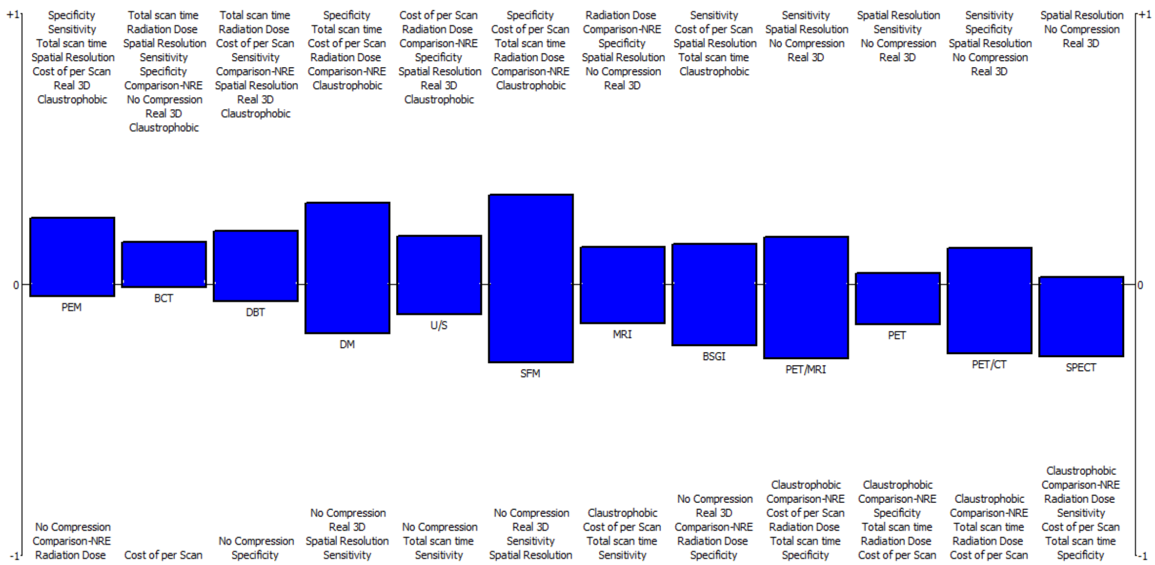

Figure 7.13: Positive and Negative Ranking of Breast Cancer Imaging Devices for Patients

Table 7.2: Complete Ranking of Breast Cancer Imaging Devices for Hospitals

Complete Ranking	Device	Positive outranking flow	Negative outranking flow	Net flow
1	PEM	0,3660	0,2363	0,1297
2	BCT	0,3404	0,2459	0,0945
3	MRI	0,3461	0,2542	0,0919
4	DBT	0,3293	0,2750	0,0542
5	DM	0,3386	0,3120	0,0266
6	U/S	0,3087	0,2922	0,0165
7	PET/CT	0,2989	0,2991	-0,0002
8	PET	0,2985	0,3040	-0,0055
9	SFM	0,3252	0,4044	-0,0793
10	SPECT	0,2580	0,3513	-0,0934
11	PET/MRI	0,2669	0,3739	-0,1070
12	BSGI	0,2522	0,3800	-0,1278

Figure 7.14 shows an action profile of the weak points and strong points about Positron Emission Mammography (PEM) for hospitals, having a positive ranking in specificity, sensitivity, total scan time, spatial resolution, real 3D and claustrophobia but showing a low ranking in cost of per scan, cost of device, radiation dose, comparison of natural radiation exposure and breast compression.

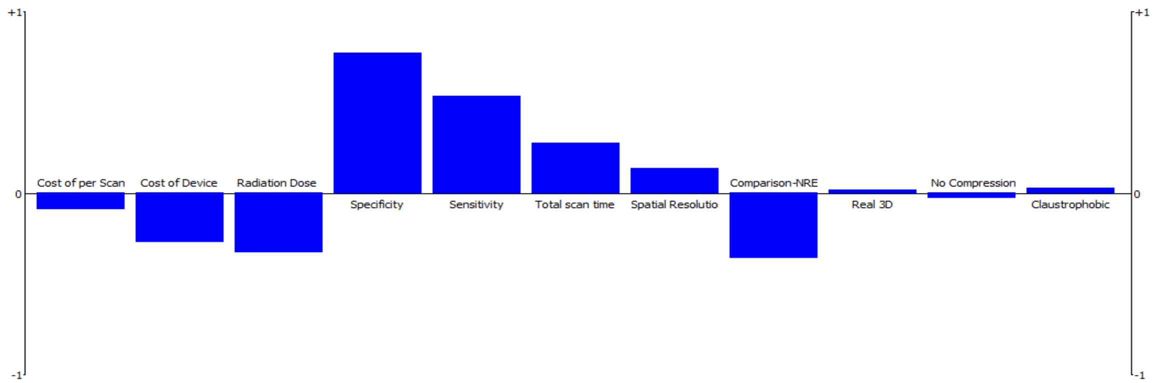

Figure 7.14: Action Profile of PEM for Hospitals

Figure 7.15 shows an action profile of the weak points and strong points about Breast Computed Tomography (BCT) for hospitals , having a positive ranking in cost of per scan, radiation dose, specificity, sensitivity, total scan time, spatial resolution, comparison of natural radiation exposure, real 3D, breast compression and claustrophobia but showing a low ranking in cost of device.

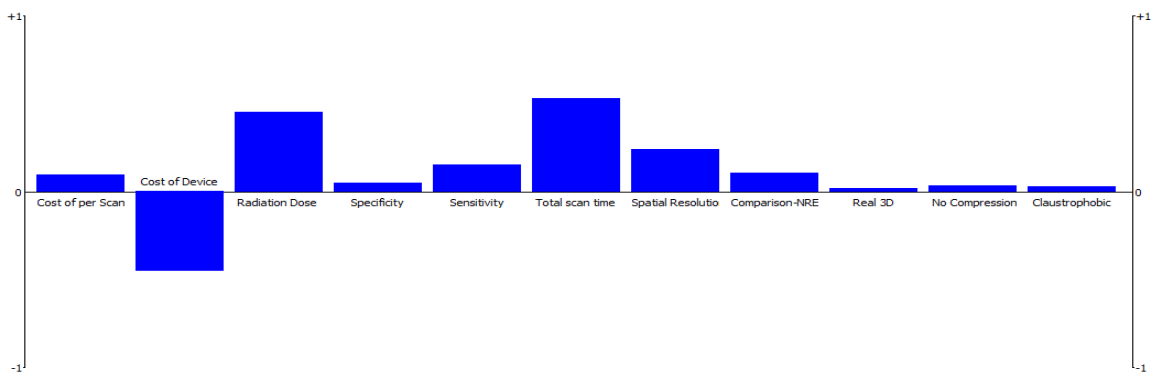

Figure 7.15: Action Profile of BCT for Hospitals

Figure 7.16 shows an action profile of the weak points and strong points about Magnetic Resonance Imaging (MRI) for hospitals, having a positive ranking in cost of per scan, cost of device, radiation dose, specificity, spatial resolution, comparison of natural radiation exposure, real 3D and breast compression but showing a low ranking in sensitivity, total scan time and claustrophobia.

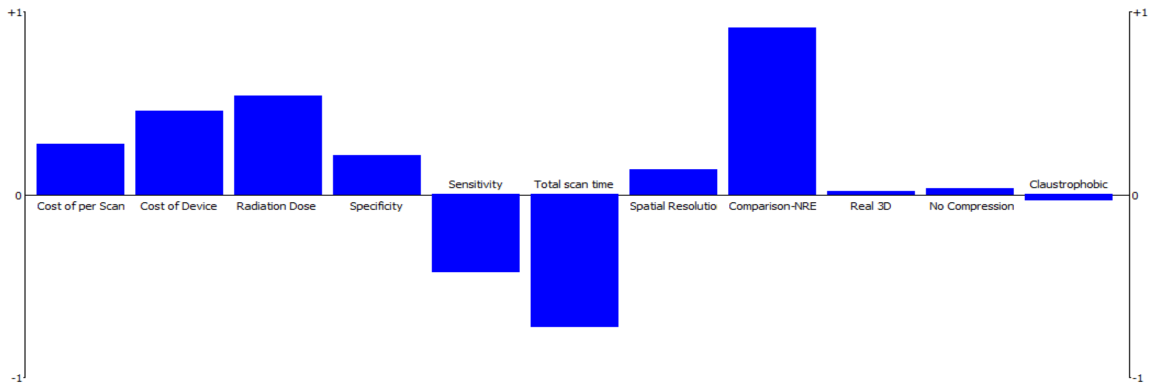

Figure 7.16: Action Profile of MRI for Hospitals

Figure 7.17 shows an action profile of the weak points and strong points about Digital Breast Tomosynthesis (DBT) for hospitals , having a positive ranking in cost of device, radiation dose, sensitivity, total scan time, spatial resolution, comparison of natural radiation exposure, real 3D and claustrophobia but showing a low ranking in cost of per scan, specificity and breast compression.

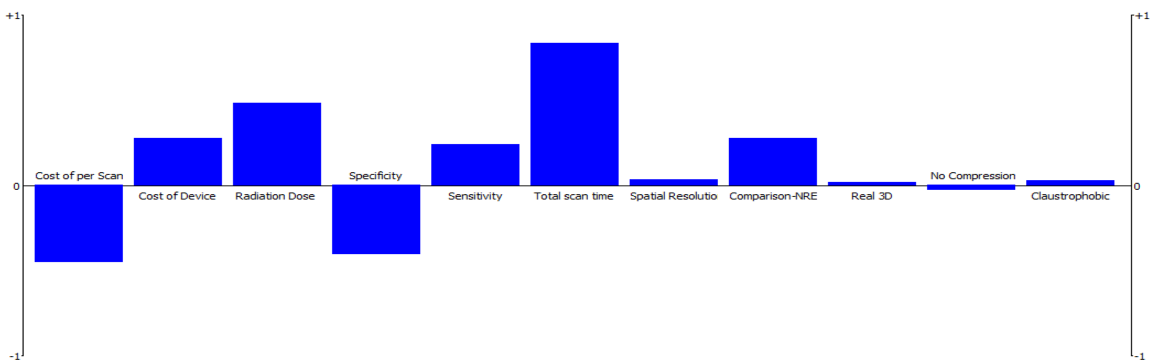

Figure 7.17: Action Profile of DBT for Hospitals

Figure 7.18 shows an action profile of the weak points and strong points about Digital Mammography (DM) for hospitals, having a positive ranking in cost of device, radiation dose, specificity, total scan time, comparison of natural radiation exposure and claustrophobia but showing a low ranking in cost of per scan, sensitivity, spatial resolution, real 3D and breast compression.

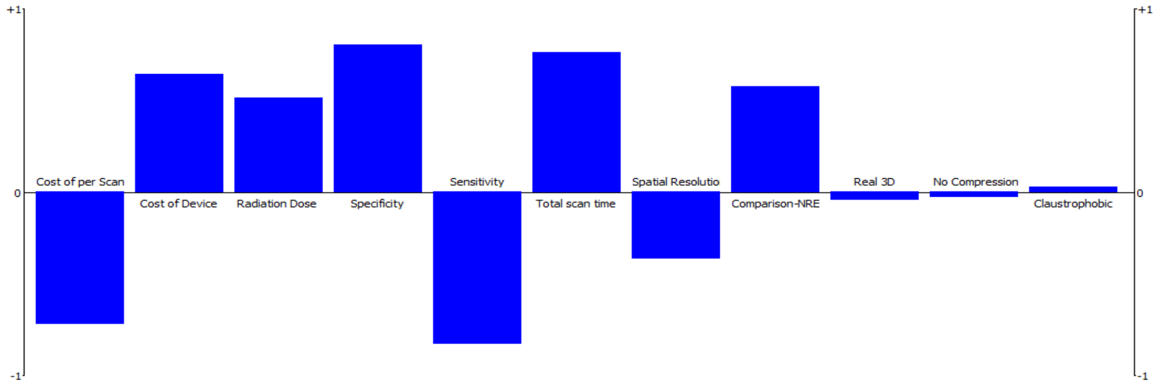

Figure 7.18: Action Profile of DM for Hospitals

Figure 7.19 shows an action profile of the weak points and strong points about Ultrasound (U/S) for hospitals, having a positive ranking in cost of device, radiation dose, specificity, spatial resolution, comparison of natural radiation exposure, real 3D and claustrophobia but showing a low ranking in cost of per scan, sensitivity, total scan time and breast compression.

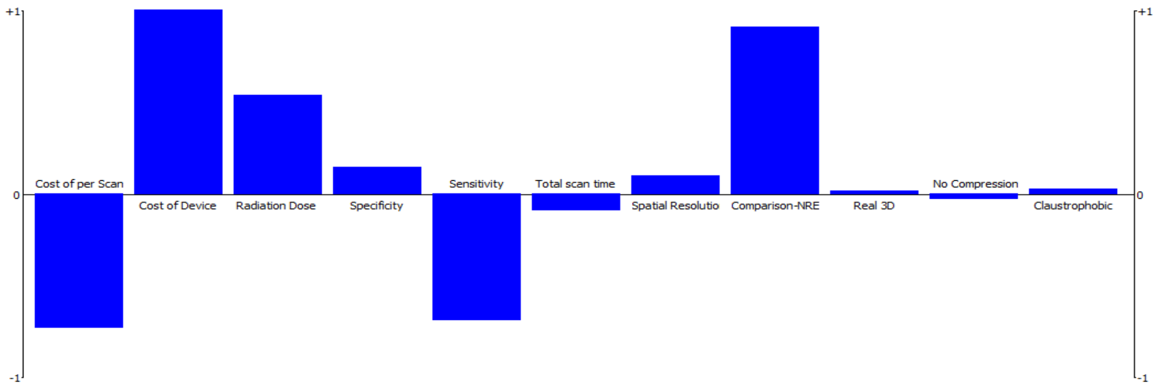

Figure 7.19: Action Profile of U/S for Hospitals

Figure 7.20 shows an action profile of the weak points and strong points about Positron Emission Tomography – Computed Tomography (PET/CT) for hospitals, having a positive ranking in cost of per scan, specificity, sensitivity, spatial resolution, real 3D and breast compression but showing a low ranking in cost of device, radiation dose, total scan time, comparison of natural radiation exposure and claustrophobia.

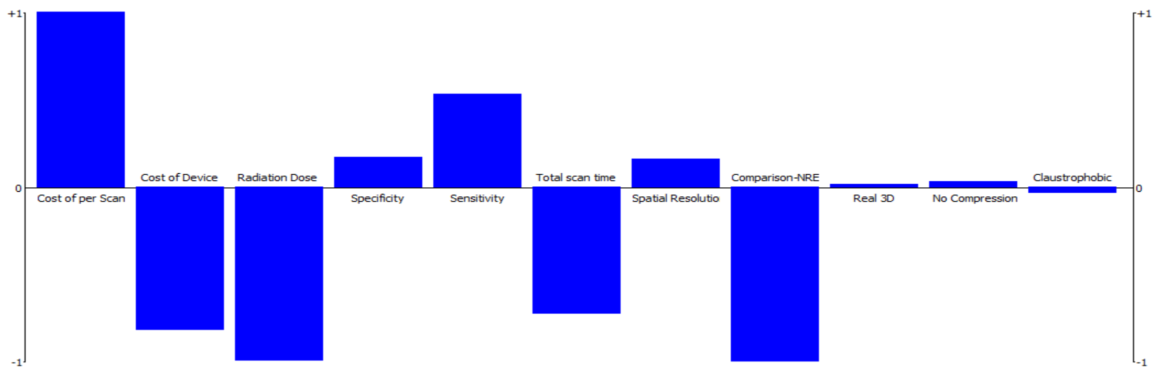

Figure 7.20: Action Profile of PET/CT for Hospitals

Figure 7.21 shows an action profile of the weak points and strong points about Positron Emission Tomography (PET) for hospitals, having a positive ranking in cost of per scan, sensitivity, spatial resolution, real 3D and breast compression but showing a low ranking in cost of device, radiation dose, specificity, total scan time, comparison of natural radiation exposure and claustrophobia.

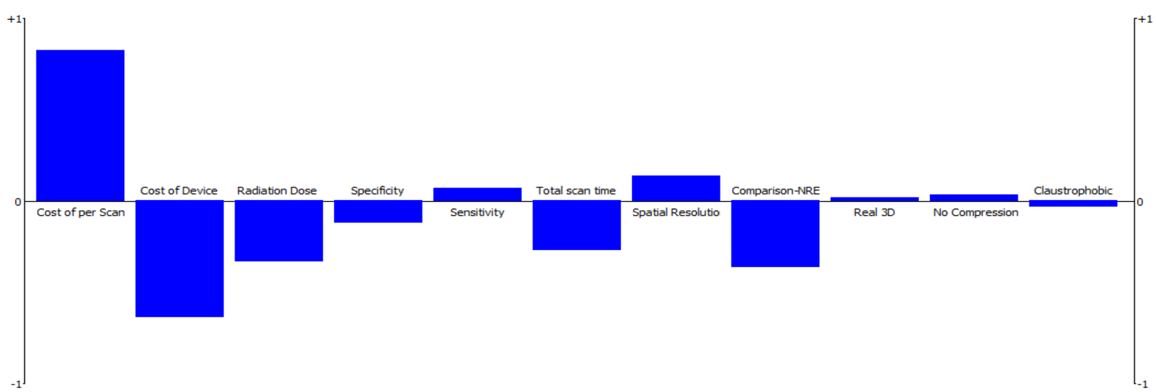

Figure 7.21: Action Profile of PET for Hospitals

Figure 7.22 shows an action profile of the weak points and strong points about Screen-Film Mammography (SFM) for patients, having a positive ranking in cost of device, radiation dose, specificity, total scan time, comparison of natural radiation exposure and claustrophobia but showing a low ranking in cost of per scan, sensitivity, spatial resolution, real 3D and breast compression.

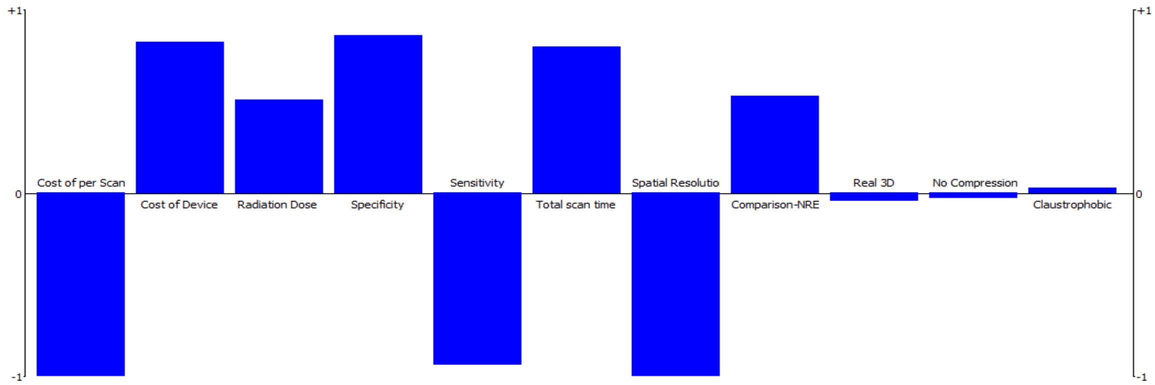

Figure 7.22: Action Profile of SFM for Hospitals

Figure 7.23 shows an action profile of the weak points and strong points about Single Photon Emission Computed Tomography (SPECT) for hospitals, having a positive ranking in cost of per scan, spatial resolution, real 3D and breast compression but showing a neutral ranking in cost of device and low ranking in radiation dose, specificity, sensitivity, total scan time, comparison of natural radiation exposure and claustrophobia.

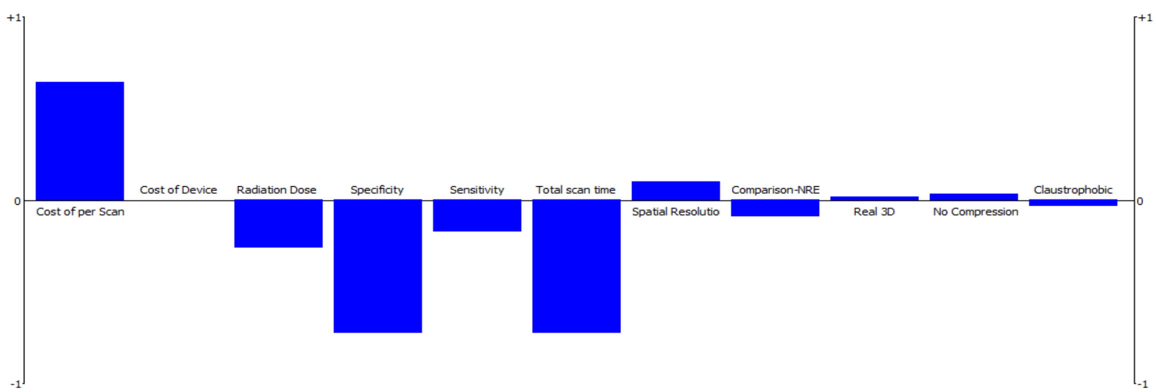

Figure 7.23: Action Profile of SPECT for Hospitals

Figure 7.24 shows an action profile of the weak points and strong points about Positron Emission Tomography- Magnetic Resonance Imaging (PET/MRI) for hospitals, having a positive ranking in cost of per scan, sensitivity, spatial resolution, real 3D and breast compression but showing a low ranking in cost of device, radiation dose, specificity, total scan time, comparison of natural radiation exposure and claustrophobia.

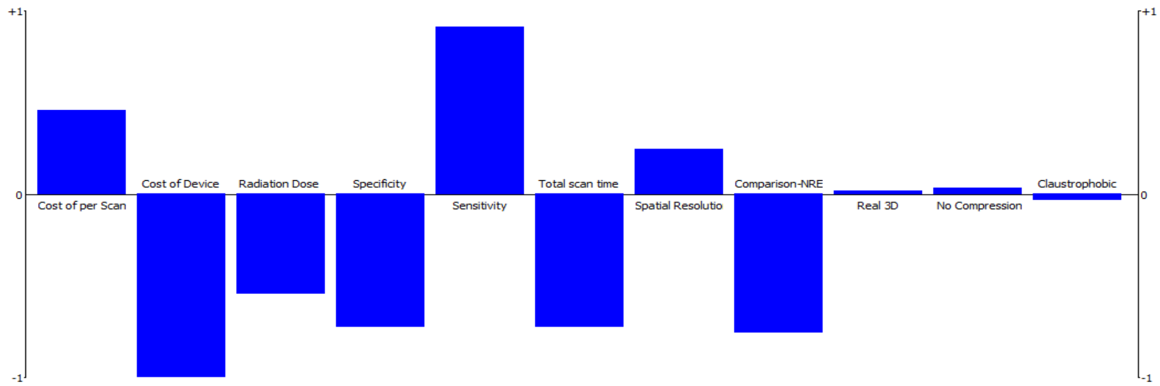

Figure 7.24: Action Profile of PET/MRI for Hospitals

Figure 7.25 shows an action profile of the weak points and strong points about Breast Specific Gamma Imaging (BSGI) for hospitals, having a positive ranking in sensitivity, total scan time, spatial resolution and claustrophobia but showing a neutral ranking in cost of device and low ranking in cost of per scan, radiation dose, specificity, comparison of natural radiation exposure, real 3D and breast compression.

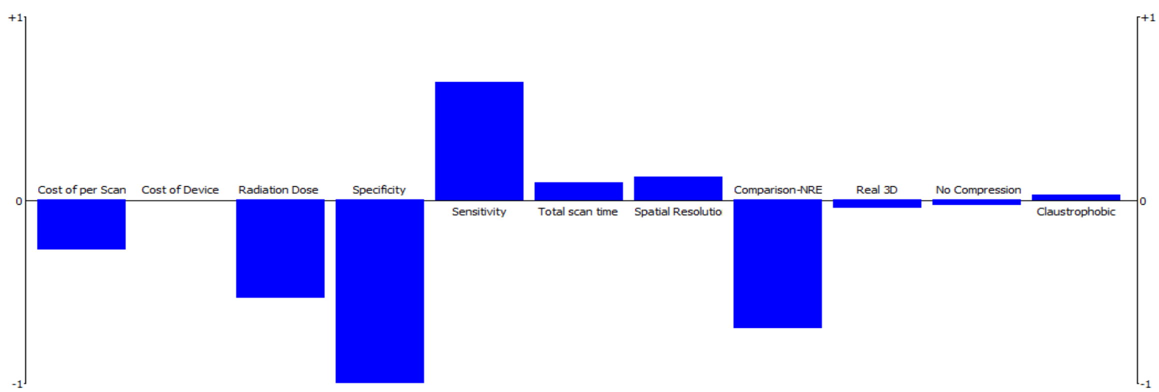

Figure 7.25: Action Profile of BSGI for Hosiptals

Figure 7.26 shows a detailed rainbow ranking of the breast cancer imaging devices and their identified parameters that make a device favourable or unfavourable for hospitals.

Devices from the best to the worst respectively;

PEM > BCT > MRI > DBT > DM >U/S > PET/CT > PET > SFM > SPECT > PET/MRI > BSGI

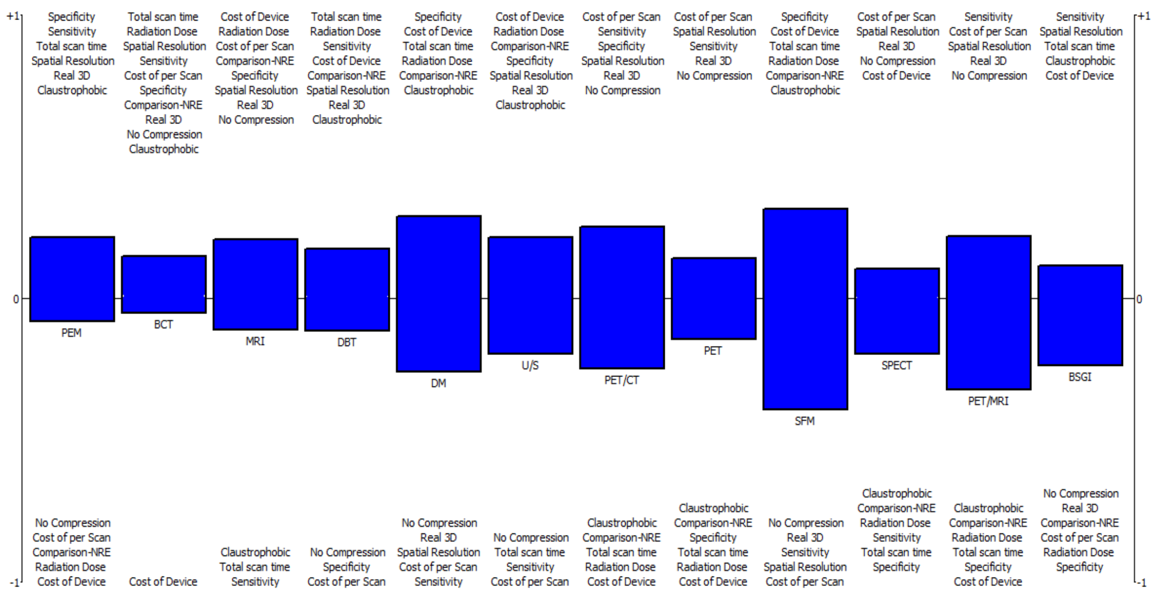

Figure 7.26: Positive and Negative Ranking of Breast Cancer Imaging Devices for Hospitals

CHAPTER 8
CONCLUSION AND DISCUSSION

8.1 Conclusion

The analysis of these study shows that Positron Emission Mammography (PEM) clearly outclassing other imaging devices of Breast Cancer for both patients and hospitals. In consequence of its high values in scale of importance like; high sensitivity (the rate of correct diagnosis to a cancerous patient), high specificity (the rate of correct diagnosis to a non-cancerous patient), high spatial resolution (the number of pixels used in creation of a digital image) and Real 3D ability. PEM also has low total scan time and cost of scan below average. It has a radiation dose slightly above the average but in addition to all of these, PEM is suitable for claustrophobic patients. Patients and hospitals which are sensitive to radiation dose can choose the second best breast cancer imaging device, Breast Computed Tomography (BCT). On the other hand, the worst option for the patients is Single Photon Emission Computed Tomography (SPECT) and the worst option for the hospitals is Breast Specific Gamma Imaging (BSGI), due to their less value in scale of importance.

Fuzzy PROMETHEE, provide control mechanism to researcher to check him or her fictitious or real data to observe their potential with comparing, according to importance scale of fuzzy PROMETHEE weighs. As a result, a detailed ranking can be made from the best option to the worst.

8.2 Discussion

The result of this study provides guidance on the devices used in the imaging of breast cancer for both patients and hospitals. It increases the diagnostic reliability, which is of great importance for the patient, by presenting the most suitable breast cancer imaging device according to their detailed parameters.

Patients, who want to have a breast cancer examination, can use this study to determine the most suitable device for themselves. In this way, the process of early diagnosis, which is of great importance, is speed up. In addition to this, hospitals can compare the parameters of the breast cancer imaging devices and they can determine the best options for themself before buying. As this study is prepared according to the present data, the results can be change with the developing device technologies.

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