MEDICO RESEARCH CHRONICLES
ISSN NO. 2394-3971
DOI No. 10.26838/MEDRECH.2021.8.2.479

OPEN ACCESS

Contents available at www.medrech.com

APPLICATION OF DATA ENVELOPMENT ANALYSIS (DEA) IN CHOOSING THE PROPER MAGNETIC RESONANCE IMAGING (MRI) MACHINE

Pooneh Dehghan[1], Alireza Rajaei[2], Reza Zandi[3], Seyyed Hasan Langari[4], Shahin Mehdipour[5], Salar Taki[6], Homayoun Hadizadeh Kharazi[7]

1. *Associate Professor of Radiology, Imaging department, Taleghani Hospital, Shahid Beheshti University of Medical Sciences, Iran*
2. *Associate Professor of Rheumatology, Head of Education Development Center, Shahid Beheshti University of Medical Sciences, Iran*
3. *Assistant Professor of Orthopaedics, Department of Orthopedics, Taleghani Hospital, Shahid Beheshti University of Medical Sciences, Iran*
4. *Radiologist, Imaging department, Taleghani Hospital, Shahid Beheshti University of Medical Sciences, Iran*
5. *MRI product manager, Fanavari Azmayeshgahi Company; Advanced partner of Siemens Healthineers in Iran.*
6. *MRI product manager, Fanavari Azmayeshgahi Company; Advanced partner of Siemens Healthineers in Iran.*
7. *Chief radiologist and CEO of Babak Imaging Center, Iran*

ARTICLE INFO

Article History
Received: March 2021
Accepted: April 2021
Keywords: Cost-benefit analysis; Data envelopment analysis; MRI machines; MRI

ABSTRACT

ORIGINAL RESEARCH ARTICLE

This study is aimed to apply one of the decision-making tools, Data Envelopment Analysis (DEA) in the field of imaging in health care for choosing the most efficient model of Siemens MRI machines for clinical purposes. A list of Siemens MRI machines with their corresponding details such as price and technical characteristics were collected as mentioned in the machine booklets and through consultation with Siemens representative in the country. Variables were defined and categorized as input and output and the linear mathematical model for each machine was written and calculated using the super-efficiency model to find the most efficient Siemens MRI machine and rank the available models using DEA. The results showed that the most efficient model of Siemens MRI is Prisma (Super-efficiency score = 2.009302) followed by Skyra (Super-efficiency score = 1.697531) and Sola (Super-efficiency score = 1.683571).

Data Envelopment Analysis (DEA) is recommended as the decision-making tool for selecting advanced technologies in healthcare since it can handle a substantial number of variables as input and output and unlike other decision-making tools such as Analytic Hierarchy Process (AHP) which is widely used in this industry, the weight of each variable

Corresponding author*
Seyyed Hasan Langari

is determined by the linear mathematical model which makes it reproducible and reliable.

1. INTRODUCTION:

In modern imaging departments with educational responsibilities such as university-based or university-affiliated hospitals, Magnetic Resonance Imaging (MRI) is considered a necessity for training medical students and radiology trainees as well as conducting proper patient care. It is also an advanced diagnostic tool, but due to its prohibitive cost (minimum half a million euros), sometimes it does not fulfil the criteria for becoming the first purchasing priority of the hospitals.

This study aims to apply one of the decision-making tools, Data Envelopment Analysis (DEA) in the field of imaging in health care and contribute to a deeper understanding of the application of this tool, namely choosing the most efficient model of MRI as its objective of study.

This project has the unique characteristic of bringing different sciences together to achieve a common goal. It involves Radiology, which is the only subspecialty of medicine that is strongly associated with physics; Mathematics for linear programming, and business administration for applying decision-making tools.

To the best of our knowledge, it is the first time that quantitative variables in MRI machines are extracted to formulate a basic Charnes, Cooper, and Rhodes (CCR) model of DEA to select the most efficient MR technology.

2. GENERAL OBJECTIVE AND LITERATURE REVIEW

Decision-making tools are being increasingly used with promising results in the management of imaging departments[1]. However, these tools have not been used in selecting medical technologies.

In healthcare, the decision-making process is more complicated than most businesses since many disciplines are involved and many concerns regarding patient safety should be kept in mind once modern technology is introduced. Due to cultural and organizational differences, a recommendation for technology adoption in one local setting may not be appropriate in another, even when the scientific evidence, such as that supplied by HTA reports, is the same. Resources should also be taken into consideration: small rural and community hospitals or health authorities with fewer resources may be poorly positioned and different adaptation processes should be suggested for this cases[2].

Unlike commercial businesses, in the health industry profitability is not the top priority. Patient safety and clinical effectiveness play far more prominent roles. Thus, variables related to image quality that directly affect the diagnostic performance of the MRI machine in addition to the physical characteristics of the machine which are directly related to patient comfort are taken into consideration. However, there is no argument that cost-effectiveness is also crucial and is always taken into consideration in any investment.

Technological assessment in health care is done through Health Technology Assessment (HTA core model), which is a registered trademark[3], and it is essentially a methodological approach for producing and sharing this information. However, this framework is not regularly used as mentioned in a study conducted in Portugal with a similar objective as ours to investigate the decision-making process regarding the purchase of MRI machines. It has been shown that of the 150 MRI machines in this country [4] patients are not taken into consideration even though these technologies are aimed at providing them the possible care. It was concluded that neither guidelines nor the HTA approach are used as an evidence-based information source for assisting decision-makers in their purchase decision[5].

Decision-making tools, specifically DEA, are regularly utilized in many industries, mainly other than the healthcare industry. At the University of North Carolina, a two-phase process for decision-making was proposed for technology selection such as machine tools, industrial robots, and manufacturing systems[6]. In the first phase, technologies' the provided the best combinations of vendor specifications on performance were selected, and in the second phase, a Multi-Attribute Decision-Making (MADM) model was used to make the final decision. It was tested on a robot data set and appeared to be promising.

Modifications of the DEA model developed later to accommodate the specific demands of the managers and decision-makers. A study in Spain proposed a new DEA model in which the different modes of functioning in manufacturing systems are considered[7]. It was concluded that the model resulted in cost savings and lead time reductions.

However, the decision-making process in health care appears to be different from other specialties. In a study published in 2015, Multiple Criteria Decision Making (MCDM) was not used in any of the research articles in this field from 2000 to 2014[8]. In this study, MCDM is a generic term for all methods used for helping people make decisions according to their preferences when there are inconsistent criteria.

Taking into consideration that hospitals and healthcare systems are data-rich and information-poor a rising interest to use business-oriented approaches appeared from 2016. Business Analytics (BA) software tools combined with custom-made software applications are shown to be efficient in providing relevant and reliable data to make accurate and evidence-based decisions in a timely fashion. The evolution of medical informatics has changed the management approach to the medical field, particularly imaging departments. Decision-making tools are being increasingly used with promising results in the management of imaging departments[1]. However, these tools have not been used in selecting medical technologies.

MRI appears to be the most promising and expensive technology in medical imaging. The Decision-making Process of purchasing expensive technologies such as MRI should be clear, efficient, crisp, and concise. In attempting to find out what others do in this regard, numerous examples and shortcomings were encountered. Once an MRI machine is purchased, a long-term business relationship develops between the imaging department and the hospital with the supplier. Supplier selection also involves various criteria such as delivery performance, price, quality, and reliability. To provide an efficient and feasible solution to the supplier selection problem, different MCDM techniques such as Analytical Hierarchy Process (AHP), and DEA could be used. The single criterion approach of the lowest cost supplier is no longer acceptable in our challenging and competitive environment: price and quality are in close competition regarding their importance in evaluating the suppliers. In a study designed to specifically address this problem, it has been stated that although DEA appears to be the most commonly used method, AHP is used to evaluate suppliers according to different categories to provide consistency in supplier selection[9].

Most of the studies for selecting medical devices apply AHP as the decision-making tool like the study in Portugal [10] which has utilized AHP for selecting Computed Tomography (CT) and another study in Turkey for selecting MRI machines[11]. Both studies have heavily relied on subjective criteria. Due to their similarity with our project, a detailed analysis of these studies is presented in the research methodology section.

A review article on the employment of DEA in the healthcare sector grouped the utilization of this decision-making tool into four different areas:

(1) Efficiency analysis of hospital data regarding their financial and human resources.
(2) Application of new methodologies on hospital data management.
(3) Answering specific management questions.
(4) Investigating the impact of policymaking, such as reforms of health systems, on hospital efficiency[12].

The Chinese healthcare system uses the traditional DEA model to measure the technical efficiency of public hospitals. However, in this model bias correction of the scores is an important issue to deal with. In a study of public hospitals in Tianjin, they introduced the Boostrap-DEA approach from international literature to overcome the shortcoming of the traditional DEA approach and found it to be quite effective in this regard and suggested its wide application to measure relative efficiency and productivity of Chinese hospitals. The number of open beds and the number of staff were selected as input, whereas the number of diagnostic visits and the number of discharged inpatients as output indicators[13].

Another study in the Slovak Republic applied DEA for healthcare efficiency assessment[14]. The number of beds and medical staff was considered as inputs, and the number of all medical equipment, magnetic resonance (MR) devices, computed tomography (CT) devices, also use of beds, and average nursing time as outputs. An output-oriented four-year window DEA model in eight regions was employed. The results of the analysis showed that the increasing number of MRI, CT, and medical devices in the four-year interval, did not have a significant impact on the overall efficiency of healthcare facilities.

In Eastern Ethiopia, a six-year panel data from 2007/8 to 2012/13 was used to examine technical efficiency, total factor productivity, and determinants of the technical inefficiency of hospitals with DEA[15]. It showed that teaching hospitals were less efficient, suggesting policy interventions such as increasing the doctor/staff ratio and decreasing the number of inpatient visits per doctor to improve the technical efficiency of hospitals.

Similar studies have been executed in Busher[16], and Lorestan [17] both southern provinces of Iran, also in Lebanon [18] but they all used this method to evaluate the healthcare service system.

As healthcare is mainly a service-based system, most studies evaluating its efficiency focus on the quality and efficiency of service received by the patients and the community. Much less attention has been paid to evaluating medical technology per se, without considering the end-users.

Technical efficiency measurement in healthcare literature concentrates mainly on hospitals and medical centers, considering financial and human resource indices such as financial expenditure, number of beds, number of staff, number of diagnostic visits, bed occupancy rate, hospitalization days, hospital revenue, and related quantitative data as input and output indicators.

To the best of our knowledge, DEA has not been used for equipment selection (both diagnostic and therapeutic) in the healthcare system.

3. RESEARCH STRATEGY AND METHODS

The political situation in Iran has eliminated GE (General Electrics) from the market and remarkably diminished the presence of other companies: Canon (previously known as Toshiba) and Hitachi are Japanese companies with major American shareholders who pulled out of the market quickly. Philips has also limited its activity in the country, so we were forced to restrict our study to Siemens MRI machines.

Siemens representative in Iran (Fanavari Azmayeshgahi Co. advanced partner of Siemens Healthineers in Iran) was approached for data collection. A list of MRI machines with their corresponding details regarding their price and introduction booklets of each of the machines were collected.

Through consultation with colleagues (radiologists and radiology technicians) and the MRI product manager of Siemens in Iran, a list of quantitative technical characteristics was extracted for comparison between different MRI machines.

These characteristics were categorized as inputs and outputs, keeping in mind that in the basic DEA model lower inputs and higher outputs are preferable, so variables that were to be kept low were considered as input and those that were to be augmented as outputs.

A few technical characteristics such as maximum turbo factor, maximum b-value, and whole-body scan time were considered at first, however, after data collection, they were eliminated since all MRI machines had the same value.

The finalized list of pertinent technical characteristics is shown below:

- ✓ **Magnet strength** (Tesla)
- ✓ **Magnet bore size** (Cm)
- ✓ **Magnet length** (Cm)
- ✓ **Field of view (FoV) in the Z-axis**
- ✓ **Gradient Strength**
- ✓ **Gradient Slew Rate**
- ✓ **Maximum number of RF receiving channels**
- ✓ **Maximum number of independent RF receiving channels used simultaneously in a single scan and single FoV**
- ✓ **Energy Saving**
- ✓ **Price** (Euro)
- ✓ **Maintenance fee** (Euro)
- ✓ **Site preparation** (m^2)
- ✓ **Minimum TR[1] (SE[2] and GRE[3])** (msec)
- ✓ **Minimum TE[4] (SE and GRE)** (msec)

□□□Time of Repetition; 2 Spin Echo; 3 Gradient Recalled Echo; 4 Time of Echo)

4. DATA COLLECTION AND ANALYSIS

Data collection was mainly done through email, interviews over the phone, and in-person from Fanavari Azmayeshgahi Co. Advanced partner of Siemens Healthineers in Iran (figure 1).

Data were analyzed using DEA, which is one of the decision-making tools used to evaluate the performance of organizations. It measures efficiency by using the following ratio:

Output/ Input

We used CCR, one of the basic DEA models which were introduced by Charnes, Cooper, and Rhodes, 1978. For each DMU (Decision Making Unit), here an MRI machine, the virtual input and output by weights are formed[19]:

$$\text{Virtual input} = V_1X_1 + \ldots. + V_mX_m$$
$$\text{Virtual output} = U_1Y_1 + \ldots. + U_mY_m$$

where (V_i) and (U_i) are weights that are yet unknown[20]. The efficiency of each DMU is measured once but needs *n* optimizations. The following linear programming problem is utilized to obtain values for the *weight* of inputs (v_i) (i = 1, …, m) and outputs (u_r) (r = 1, … , s) as variables.

$$\max_{\mu,v} \theta = \mu_1 y_{1o} + \ldots + \mu_s y_{so}$$
$$\text{subject to} \quad v_1 x_{1o} + \ldots + v_m x_{mo} = 1$$
$$\mu_1 y_{1o} + \ldots + \mu_s y_{so} \leq v_1 x_{1o} + \ldots + v_m x_{mo} \quad (j= 1, \ldots , n)$$
$$v_1 , v_2 , \ldots , v_m \geq 0$$
$$\mu_1 , \mu_2 , \ldots , \mu_m \geq 0$$

The CCR model did not make any distinction between the MRI machines and found a global optimal solution for all models with an objective value of 1.

In order to select the best MRI machine, super-efficiency model which was initially proposed by (Andersen & Petersen, 1993) and later further developed by (Cooper, Seiford, & Tone, 2007) was utilized. The super-efficiency of DMU is defined as the optimal objective function value θ* of the following program (Andersen & Petersen, 1993):

$$\max \theta^* = \mu_1 y_{1o} + \dots + \mu_s y_{so}$$
$$\text{subject to} \quad v_1 x_{1o} + \dots + v_m x_{mo} = 1$$
$$\mu_1 y_{1o} + \dots + \mu_s y_{so} \leq v_1 x_{1o} + \dots + v_m x_{mo} \qquad (j = 1, \dots, n,\ j \neq o)$$
$$v_1, v_2, \dots, v_m \geq 0$$
$$\mu_1, \mu_2, \dots, \mu_m \geq 0$$

5. RESULTS

Variables determining input and output in different models of MRI machines are presented in table 1 and table 2 [21].

The super-efficiency scores in the global optimal report for each of the MRI machines are presented in table 3:

6. DISCUSSION

Many factors that were not in our control influenced the design of our study. As mentioned previously, the political situation in Iran significantly influenced the design of our study. Leading companies importing MRI machines such as GE, Hitachi, Canon (formerly known as Toshiba) pulled out of our market quickly. Philips has also limited its activity in the country, so we were forced to restrict our study to Siemens MRI machines.

Siemens has also been proven to overcome market crises on several occasions both in our country and internationally in the past few decades and appears to be the feasible choice to rely on in the current situation.

A summary of DEA's advantages over other decision-making tools are listed below[20]:

- ✓ It can handle large numbers of variables which makes it easier to deal with complex problems that are more likely to be encountered in the real world.
- ✓ Using the "efficient frontier" which is the most efficient unit under audit while the "regression line" divides the units into two relatively equal sections: excellent and unsatisfactory by crossing through the middle of data.
- ✓ Measuring "total factor productivity": all inputs and all outputs in the Decision-Making Unit (DMU) under review are considered and explicitly attributed to each other to avoid attributing one output to other inputs that are not directly correlated.
- ✓ Handling large numbers of variables and relations, making it easier to deal with complex issues.
- ✓ Choosing between different inputs and outputs without any restriction facilitates collaboration between analysts and decision-makers: potential competitors could be identified and new scenarios with benchmarks could also be defined.
- ✓ The optimal weights for inputs and outputs and not determined in advance but derived from the data.

Generically a DMU is an entity that converts inputs to outputs, and its performance is evaluated. DMUs in this project are MRI machines.

General principles in this model are listed below:

- Positive numerical data should be available for each input and output in all DMUs.
- Inputs and outputs reflect the variables that determine the relative efficiency of the DMUs.
- Lower inputs and higher outputs are preferable.
- Measurement units of inputs and outputs need not be similar.

This study suggests that Prisma is the most efficient model of Siemens MRI machine. Reviewing the inputs and outputs of this model and comparing them with those of other models, indicate that apart from Magnet bore size and energy-saving, the other outputs of this machine are in the top models, and the gradient strength of this machine is significantly higher than all other MRIs in our study.

7. RECOMMENDATIONS FOR FURTHER INVESTIGATION

Suggestions for future investigation in this field are summarized below:

- The result of this study needs to be compared with a similar study of other companies providing the same technology (MRI machines) such as GE, Philips, Hitachi, and other less well-known brands.
- There is also room for improvement in the technical variables determining inputs and outputs to calculate efficiency ratios of different DMUs. It is self-evident that more number of inputs and outputs results in a much more consistent study.

In this study, we have assumed that the dataset is crisp. Therefore, there is a need to apply fuzzy DEA in the presence of fuzzy data.

8. LIMITATIONS

The major limitation we encountered was imposed restrictions from the economic and political situation, which caused many prominent MRI companies to leave or significantly reduced their activity in the Iranian market. Thus, limited options of MRI machines were available to study, Siemens MRIs to be specific.

Technical data regarding the input and output variables of MRIs had to be filled by the Siemens company representative in Iran and data regarding one model (Terra) which is the most sophisticated model with the very limited clinical application were not available, so it was excluded from our study.

9. CONCLUSION

Data Envelopment Analysis (DEA) is recommended as the decision-making tool for selecting advanced technologies in healthcare since it can handle large numbers of variables as input and output and unlike other decision-making tools such as Analytic Hierarchy Process which is widely used in this industry, the weight of each input or output is determined by the linear mathematical model which makes it reproducible and reliable.

Using this method, Prisma is the most efficient Siemens MRI machine for clinical purposes. However, the result of this study needs to be compared with similar studies of other companies providing the same technology (MRI machines) such as GE, Philips, Hitachi, and other less well-known brands.

10. REFERENCES

1. Jones S, Cournane S, Sheehy N, Hederman L. A Business Analytics Software Tool for Monitoring and Predicting Radiology Throughput Performance. *Journal of Digital Imaging*. 2016;29(6):645-653.
2. Poulin P, Austin L, Scott C, et al. Introduction of new technologies and decision-making processes: a framework to adapt a local health technology Decision Support Program for other local settings. *Medical Devices: Evidence and Research.* 2013;6:185-193.
3. eunethta. In. *EUnetHTA network*2016.
4. Ribeiro MM, O'Neil JG, Mauricio JC. Caraterização da Tecnologia Por

Ressonância Magnética Em Portugal. Lisboa. In. *ISBN:978-989-96573-1-1*. Lisbon, Lisbone, Portugal2013.

5. Maia MJo. Decision-making process in radiology: the magnetic resonance example in the TA context. *Enterprise and Work Innovation Studies*. 2011;7(7):75-101.
6. Khouja M. The Use of Data Envelopment Analysis for Technology Selection. *Computers and Industrial Engineering*. 1995;28(1):123-131.
7. Lozano S, Villa G, Eguia I. Data Envelopment Analysis with multiple modes of functioning: Application to reconfigurable manufacturing systems. *International Journal of Production Research*. 2017;51(10).
8. Mardania A, Jusohb A, Nora KM, Khalifaha Z, Valipour A, Norhayati Z. Multiple criteria decision-making techniques and their applications – a review of the literature from 2000 to 2014. *Economic Research*. 2015;28(1):516-571.
9. Agarwal P, Sahai M, Mishra V, Bag M, Singh V. A review of multi-criteria decision-making techniques for supplier evaluation and selection. *International Journal of Industrial Engineering Computations*. 2011;2:801-811.
10. Oliviera V, Sobral J, Riveiro MM. Development of a Tool for Selection and Acquisition of Medical Devices based on the Analytic Hierarchy Process. Paper presented at 2019 IEEE 6th Portuguese Meeting2019; Lisbon.
11. Koksalmis GH, Calisir C, Durucu M, Calisir F. Selecting an MRI System: A Multi-Criteria Decision Making Model for MRI Technicians. *International Journal of Business Analytics*. 2018;5(3):22-30.
12. Kohl S, Schoenfelder J, Fugener A, Brunner JO. The use of Data Envelopment Analysis (DEA) in healthcare with a focus on hospitals. *Health Care Management Science*. 2018;22(2):245-286.
13. Li H, Dong S. Measuring and Benchmarking Technical Efficiency of Public Hospitals in Tianjin, China: A Bootstrap–Data Envelopment Analysis Approach. *Inquiry*. 2015;52.
14. Stefko R, Gavurova B, Kocisova K. Healthcare Efficiency Assessment using DEA analysis in the Slovak Republic. *Health Economic Review*. 2018;8(6).
15. Ali M, Debela M, Bamud T. Technical efficiency of selected hospitals in Eastern Ethiopia. *Health Economics Review*. 2017;7(24).
16. Kiani MM, Khanjankhani K, Mosavi Rigi SA, et al. Efficiency Evaluation of University Hospitals in Bushehr Province before and after the implementation of the Health System Development Plan. *Evidence-Based Health Policy, Management, and Economics*. 2018;2(1):1-11.
17. Nouraei Motlagh S, Ghasempour S, Yusefzadeh H, Lotfi F, Astaraki P, Saki K. Evaluation of the Productivity of Hospitals Affiliated to Lorestan University of Medical Sciences Using the Malmquist and the Kendrick-Creamer Indices. *Shiraz E-Medical Journal*. 2019;20(7).
18. Ebrahim MD, Daneshvar S. Efficiency Analysis of Healthcare System in Lebanon Using Modified Data Envelopment Analysis. *Journal of Healthcare Engineering*. 2018.
19. Charnes A, Cooper WW, Rhodes E. Measuring the efficiency of decision-making units. *European Journal of Operational Research*. 1978:429-444.
20. Cooper WW, Seiford LM, Tone K. *Data Envelopment Analysis: A Comprehensive Text with Models. Application, References, and DEA-*

Solver Software. New York: Springer; 2000.

21. Siemens Internal Data Sheet. In. *Siemens MRI Internal Data Sheet*. Tehran, Iran: Siemens company; 2019.

Table 1- Variables determining input in different models of MRI machines

MRI (DMU)	Length (cm)	Price (*1000) (Euro)	Site Prep. (m^2)	Maintenance (*1000 Euro)	Min TR SE (msec)	Min TR GRE (msec)	Min TE SE (msec)	Min TE GRE (msec)
Essenza	147	873	4*2.5	611	6.9	0.96	1.9	0.32
Sempra	171	900	4*2.5	630	6.9	0.92	1.9	0.31
Avanto	170	1100	4*2.5	770	6.2	0.69	3.2	0.22
Amira	171	1150	4*2.5	805	5.9	0.91	1.7	0.28
Aera	145	1350	4*2.5	945	6.5	0.92	1.8	0.28
Avanto fit	170	1650	4*2.5	1155	4.8	0.68	1.6	0.22
Altea	157	1400	4*2.5	980	6.5	0.92	1.8	0.28
Sola	157	1850	4*2.5	1295	5	0.7	1.5	0.22
Spectra	173	1850	4.6*2.6	1295	8.6	0.97	3.5	0.26
Skyra	173	2300	4.6*2.6	1610	5	0.7	1.5	0.22
Prisma	198	3800	6*3.5	2660	4.3	0.7	1.5	0.22
Lumina	186	2300	4.6*2.6	1610	5	0.69	1.5	0.22
Vida	186	3000	4.6*2.6	2100	5	0.69	1.5	0.22

Table 2- Variables determining output in different models of MRI machines

MRI (DMU)	Strength (Tesla)	Bore (cm)	FOV (Z axis)	Gradient Strength	Gradient Slew Rate	Max No. RF channel	Max No Rec channel Used	Energy saving
Essenza	1.5	60	35	30	100	46	16	0
Sempra	1.5	60	45	30	100	96	16	30%
Avanto	1.5	60	50	33 45	125 200	76	32	0
Amira	1.5	60	45	33	125	96	24	30%
Aera	1.5	70	45	33 45	125 200	204	64	0
Avanto fit	1.5	60	50	45	200	204	48	0
Altea	1.5	70	50	33	125	180	32	30%
Sola	1.5	70	50	45	200	204	64	30%
Spectra	3	60	45	33	125	96	24	0
Skyra	3	70	45	45	200	204	128	0
Prisma	3	60	50	80	200	228	128	0
Lumina	3	70	50	36	200	180	32	30%
Vida	3	70	50	60	200	228	128	30%

Table 3-Super-efficiency scores of MRI machines

MRI machine (DMU)	Super-efficiency Score	Rank
Prisma	2.009302	1
Skyra	1.697531	2
Sola	1.683571	3
Vida	1.521739	4
Aera	1.349320	5
Avanto	1.338326	6
Sempra	1.277778	7
Lumina	1.209268	8
Spectra	1.181143	9
Altea	1.136665	10
Essenza	1.108763	11
Avanto-fit	1.091563	12
Amira	1.060976	13

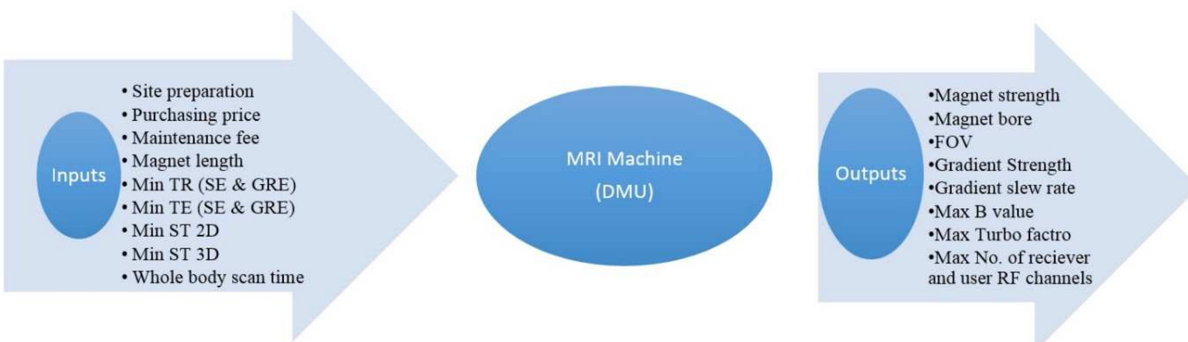

Figure 1- Inputs and outputs for evaluating MRI machines