

MRI UPGRADES AT RADIOLOGY ASSOCIATES

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## ABSTRACT

### Problem Statement

The MRI machines at Radiology Associates are limiting the company's ability to expand and compete within the local market.

After discussing with technicians and managers at Radiology Associates, we decided to focus on hardware and software upgrades for the MRI machines. With 2 of the 3 locations purchasing new machines in the near future, our focus was on upgrades at the Santa Maria facility. The two machines at this location needed hardware and/or software upgrades to remain on par competitively both within the company and with local scanning options.

Flexible coils are beneficial in terms of size, weight, and both patient/technician experience. They are significantly lighter and smaller than their traditional, out-of-box counterparts. The flexible nature also allows for increased patient comfort and, potentially, image quality. Rejection rates may decrease as well. Several economic models were created to give decision makers of Radiology Associates options: rent, purchase, rent + purchase, etc. Based on this, we recommend renting the set of flexible coils for 1 year, then purchasing. This option provides the highest rate of returns taking into account learning curve and adjustment periods.

The software upgrades that are proposed include cardiac imaging and blood sensitive imaging of the brain. Cardiac imaging would be a new exam type since this type of imaging is not currently offered. Both machines in Santa Maria are capable of cardiac imaging with the proposed upgrades. The blood sensitive imaging is available for the Hitachi Oasis and would help diagnose PTSD, brain hemorrhaging and strokes.

## ACKNOWLEDGMENTS

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# I. Introduction

The subject of this report is the proposed upgrades to the magnetic resonance imaging machines at Radiology Associates.

The current state of the four MRI's at Radiology Associates is currently limiting the company's ability to expand and compete within the local market. The idea for this project originated when Radiology Associates decided to purchase a fifth MRI machine to better serve their clients. With one new machine, was necessary to focus on how the remaining could be upgraded. How does having only 20% of their machines up-to-date affect Radiology Associates' ability to compete within the industry and local market? Further research was needed in order to decide what potential upgrades were possible on each of the four machines, which are all at different stages of their lifecycle.

The following are objectives in this study:

- Understand the technology behind Magnetic Resonance Imaging and the new innovations involving this field. Present compiled findings to Radiology Associates.
- Perform an analysis on the current state of the four MRI machines in order to compare and contrast with each other and with outside competition. The full analysis of each MRI machine will include the following criteria:
  - Manual post processing - analyzing images and communication with other sources
  - Scan time per patient - strength of magnets
  - Quick and safe changeover process (coils) - human factors
  - Image quality
- Perform an economic analysis in order to create a justification for proposed upgrades. These proposed upgrades will include individual hardware and software component upgrades. If the proposal is not economically feasible, machine should not be upgraded and a plan to purchase a new machine should be put in place.
- The methodology taken to solve and present the solution to this problem is Plan, Do, Check, Act. The key tasks that are going to be taken to solve the problem are as follows:
  - Plan: Perform an initial analysis on the four MRI machines and the processes involving the machines.
  - Do: Perform an analysis on the machines and generate recommendations for machine improvements based on the technical analysis. Compare and contrast machines based on data and background research in order to add value to each machine with potential improvements.
  - Check: Perform an economic analysis to justify potential improvements.

- Act: Deliver findings in report/presentation form and propose plans if found to be economically feasible.

At the conclusion of this project, a proposal will be generated containing recommendations for Radiology Associates on how they should upgrade their MRI machines, if economically feasible.

#### Problem Statement

The MRI machines at Radiology Associates are limiting the company's ability to expand and compete within the local market.

## II. Background

Radiology Associates is a medical imaging company located on the central coast of California with three locations: Templeton, Pismo Beach, and Santa Maria. They offer many types of imaging for all parts of the human body including CT scans, ultrasounds, and MRI imaging. The doctors and radiologists at Radiology Associates work together to produce images of the human body, interpret the results, and communicate to the appropriate sources on the next steps.

### How a MRI Machine Works

A magnetic resonance imaging machine, or an MRI, is a noninvasive procedure that produces 2D or 3D imagery of the inside of the human body. The machine "uses the body's natural magnetic properties to produce detailed images from any part of the body" (Berger). The first successful MRI scan was performed on July 3, 1977 by Dr. Raymond Damadian. Although the scan took almost five hours to complete and produced an unclear image, it was the beginning of an important aspect of medical technology. An MRI machine provides a look into the human body using magnets and pulses of energy in the form of radio waves. "When the body is placed in a strong magnetic field, such as an MRI scanner, the protons' axes all line up" and then radio waves are added to the magnetic field (Berger). After the waves are turned off the protons return to their normal rotation and this process is what creates the signal that is received. This is what creates the images. Different types of tissues in the body have different rates of returning back to a normal axis which makes them identifiable. The scans can pinpoint specific areas of the body that have irregular tissue as well as monitor blood flow throughout the body. The main component of an MRI is the magnet, which is measured in tesla units. MRI's can be used to detect: multiple sclerosis, brain tumors, torn ligaments, tendonitis, cancer and strokes. Those with pacemakers and other metal implants have the potential to be harmed in an MRI because of the movement that can come from the strong magnetic attraction. Otherwise, there are "no known biological hazards of MRI because, unlike x ray and computed tomography, MRI uses radiation in the radiofrequency range which is found all around us and does not damage tissue as it passes through" (Berger).

### True North vs. Magnetic North

There are two types of "north" defined by scientists and geographers. True North is the point on earth where all longitudinal lines meet at top. Magnetic north is the direction the needle on a compass will point (Curtis 72). The earth is a giant magnet and the needle on a compass tends to align with that magnetic field. The angle between the two points can vary depending where on earth you are located.



## Open vs. Closed

Historically, there have been many downsides to MRI imaging, specifically relating to the size of bore. Some patients would either experience claustrophobia or simply not fit. New technologies include open MRI machines, which employ two magnetic plates moving up and down. Some benefits include accepting a wider variety of patient sizes and accommodation of specialty cases such as children or those with disabilities (Hailey 1). Some current downsides include cost and magnetic field strength ranging from 1.0T to 1.5T; max strength is only half that of max closed machine strength. Image quality is the compromise.

## PDCA

The PDCA cycle is a method of problem solving and project management popularized by W. Edwards Deming, one of the fathers of modern quality improvement (Moen 7). It is a method designed to not only implement, but also to control and sustain the proposed changes should they be effective. The steps are as follows: Plan, Do, Check, and Act. The Plan phase involves organizing thoughts, ideas, and creating a framework to collect data and determine root causes to the problem. The Do phase is where all the brainstorming is put in to action. Data is collected and analyzed. Check and Act involve measuring how the implemented changes have affected the system; compare the before and after state and, if necessary, make appropriate changes. PDCA is effective since it is adaptable. The method allows for change during the process by encouraging deductive and inductive learning (Moen 10). PDCA is effective due to its continuous improvement style, encouraging different ideas to be implemented and tested constantly (Johnson 1).

## Cost-Benefit Analysis

One method to determine the economic viability of a project is with a cost-benefit analysis. This is a tool designed to check the monetary values of inputs and outputs (Robinson 1). This way, an analyst can determine the worth of a project or service based on the return on investment from everything put in to it to everything that will come out. All cash flows over a certain time frame are generated and calculated to present values for a fair comparison.

### Net Present Value

$$NPV(i, N) = \sum_{t=0}^N \frac{R_t}{(1+i)^t}$$

*Figure 1: NPW*

The net present worth formula is the present value of income projected over the next n number of years. The projected amount of revenue per year as well as the expected rate of return if the money was invested in another area. A calculated NPV that is greater than the initial investment is seen as a good investment, and those that are less will not be profitable.

## Coils

Receiver coils are used to transfer radiofrequency waves in to the patient's body. There are different coils all with shapes designed to be placed on various parts of the body. Two major types are widely available: volume coils and surface coils. Volume coils are used for larger scans – sometimes whole body and have specific shapes for extremities such as the head or feet. Surface coils are for very small regions of interest that and can have poor field of view.

## Image Quality

Image quality in MRI can be broadly broken into two categories, physics and clinical, in order to be quantitatively measured. For the purposes of this upgrade proposal, only the clinical study will need to be defined. Image quality can be defined as acceptable if the analysis is performed correctly and the issue is identified. Using a receiver-operator characteristic curve (ROC) with false negative plotted versus false positive results, the area under the curve should be unity, or 1. If that is true, that means the accuracy of the machine matches up with the accuracy of the observer, or technician in this case, and the diagnosis is correct (Rutt 3).

## Magnets

### Overview

There are different strengths of magnets that are used in MRI's. A tesla is the unit of measure for the strength of the magnets in the machines. There are three main types of magnets in a MRI machine. A resistive magnet is made from many coils wrapping around a cylinder that passes electrical current through to generate a magnetic field. Although cheaper to manufacture, the amount of electricity needed to power the magnet is very high causing it to be extremely expensive. A permanent magnet is always on and at full strength. One problem with permanent magnets is that due to the strong field, the magnets are extremely heavy (over two tons) and are difficult to manufacture and place. The most popular magnet by far is a superconducting magnet. Like a resistive magnet, a superconducting magnet is coils of wire that pass through a magnetic field. In order to lower electricity bills and make the process less expensive, the magnet is continuously cooled with liquid helium in the cryostat in order to drop the temperature of the

wires to 450 degrees below zero. The extremely low temperature decreases the amount of energy required to run the system.

## Magnet Strength

Magnetic field strength has been a topic of interest for MRI machines. More specifically, how strong should the magnets in a company's machine be. This study classifies high intensity to be 1.5T and above and low intensity to be .5T - 1.49T. High intensity magnets will have faster imaging speeds and higher resolution images but, of course, at a premium. Depending on application of the MRI, what disease to identify and what area of the body, image quality may not matter if the correct diagnosis is made (Rutt 6). The results of this study show that .5T and 1.5T magnets have a diagnostic equivalence for two major disease types. However, that information cannot yet be applied to other categories because more studies must be done.

Currently, 1.5 Tesla magnets have the majority of the market share in the MRI industry (Kraff). However, there is increasing popularity towards an increasing amount of tesla for magnet strengths. In a scan performed in 2014, there are obvious differences between a 1.5 T and a 7 T MRI machine. In the 7T machine, "20% more microhemorrhages were found in brain metastases" (Kraff). Enlarged vessels and necrosis were also more clearly visible. However, a 7T machine is not economically feasible in environments other than in the research capacity.

## Current Magnets in Use

The majority of MRI's used in the medical field today have a 1.5 Tesla strength magnet. Radiology Associates currently has one 1.2T magnet, three 1.5T magnets and a future 3T magnet. A study was conducted in order to determine if any significant differences were present in the final images from a 1.5T MRI and a 3T MRI. "Thirteen patients with non-locally advanced rectal cancer underwent imaging with both 1.5T and 3T-MRI" (Maas). One of the units used is the same model as one of the MRI's located in the Five Cities location of Radiology Associates, the Philips Medical Systems' "Intera" unit. When comparing the different magnet types, although "there is a better visibility of the rectal wall at 3T, it does not aid in the distinction between T2 tumors with desmoplasia and borderline T3 tumors" (Maas).

## Ergonomics

### NIOSH Lifting Guidelines

This equation is to calculate the guidelines for the acceptable amount of weight that can be lifted by individuals in the workplace over the course of a shift. This formula is as follows:

Recommended Weight Limit =  $LC * HM * VM * DM * AM * FM * CM$  with the following definitions:

- LC is the weight of the object

- HM is the horizontal distance of hands from the midpoint of the object
- VM is the vertical distance of hands from floor
- DM is vertical distance traveled
- AM is angle of displacement of load
- FM is frequency of lifting in lifts/minute
- CM is the lifting frequency and vertical displacement

Each value is in the factors table that will be used to calculate the different aspects of the lift. If the lifting index (Lifted object weight / Recommended weight limit), is less than one then the lift is deemed unsafe. This is important because some of the coils used at Radiology Associates have been deemed too heavy and there are lighter, more flexible coils available on the market.

## MCDA

A MCDA is a methodology that is used when there are different alternatives available and it is necessary to rank the solutions. It takes the preferences that are desired by the user and gives them a rating in regards to importance. Then it gives each alternative a rating for each category. The final ranking is determined by weighting each alternative based on the importance of the respective category. This ranking method makes it possible to make decisions based on different criteria.

### III. Design (or Theory)

#### Current State

#### Machines

##### Santa Maria site, Digital Medical Imaging (DMI)

This location has two MRI machines. The first is a closed 1.5 Tesla GE HDXT at the Software Level 16.0. The magnet for this machine was upgraded in January 2015 with a D-Stream Interface, which included higher coil configurations and a software upgrade. The other machine is an open design 1.25 Tesla Hitachi Oasis currently at software level 4. The Hitachi Oasis is the only "open" MRI machine currently in use in the Central Coast. Due to the open nature of the machine the magnet is the weakest of those in use at Radiology Associates but the appeal of the machine is that is considered less claustrophobic and more accessible to a range of body types.

##### Pismo Beach site, Five Cities Medical Imaging (FCMI)

This site has one MRI machine, a closed 1.5 Tesla Philips "Intera" at the 3.2 Software Level. Due to the age of the machine it will no longer be serviced by Philips beginning in 2017. Because of this, a 3.0T machine will be purchased soon for this location as a replacement and the Intera will be removed. No upgrades will be recommended for this machine.

##### Templeton site, Radiology Diagnostic Center (RDC)

Currently this site has one MRI machine, a closed 1.5T Philips "Achieva" at the 1.8 Software level. In the upcoming months RDC will be purchasing another MRI machine, a closed 3.0 T GE MR 750W 70cm Bore. This machine will be added as an addition to RDC and two machines will be in use at that facility.

MAGNETIC RESONANCE IMAGING		
<input type="checkbox"/> Brain	<input type="checkbox"/> Pelvis	MR ANGIOGRAPHY
<input type="checkbox"/> Posterior Fossa	<input type="checkbox"/> Female Pelvis	
<input type="checkbox"/> IAC	<input type="checkbox"/> Prostate	<input type="checkbox"/> Brain
<input type="checkbox"/> 5 <sup>th</sup> CN	<input type="checkbox"/> Bony Pelvis	<input type="checkbox"/> Carotid/Vertebral
<input type="checkbox"/> Pituitary	<input type="checkbox"/> Neuropelvis	(Chest/ Neck/ Brain)
<input type="checkbox"/> Orbits	<input type="checkbox"/> C Spine	<input type="checkbox"/> Renal Hypertension
<input type="checkbox"/> Sinus/ Facial	<input type="checkbox"/> T Spine	Protocol (MRI/ MRA)
<input type="checkbox"/> TMJ Bilateral	<input type="checkbox"/> L Spine	<input type="checkbox"/> Abdomen (Aorta)
<input type="checkbox"/> Soft Tissue Neck	<input type="checkbox"/> Shoulder L R	<input type="checkbox"/> Aortogram and
<input type="checkbox"/> Brachial Plexus (Neck/Chest)	<input type="checkbox"/> Elbow L R	Bilat Lwr Extrem
<input type="checkbox"/> Chest	<input type="checkbox"/> Wrist L R	<input type="checkbox"/> Soft Tissue Mass
<input type="checkbox"/> Breast - Bilat	<input type="checkbox"/> Hand/ Finger L R	Protocol
<input type="checkbox"/> MRCP	<input type="checkbox"/> Hip L R	<input type="checkbox"/> Lower Ext Non-
<input type="checkbox"/> Liver	<input type="checkbox"/> Knee L R	Joint _____
<input type="checkbox"/> Abdomen	<input type="checkbox"/> Ankle/ Hindfoot L R	<input type="checkbox"/> Upper Ext Non-
<input type="checkbox"/> Enterography (Abd/Pel)	<input type="checkbox"/> Forefoot L R	Joint _____

Figure 2: Current Exam Offerings at Radiology Associates

There are currently 39 different types of exams performed at Radiology Associates. Different coils are needed for each type of scan. Each machine has its own set of coils that are not compatible with another.

## Exams Not Currently Offered

### Cardiac MRI Imaging

Currently “conventional cardiac MRI exams represent less than 1% of all MR studies performed”. This is due to the complicated nature of a CMR exam and the length being over an hour to have an accurate depiction of the heart. However, with new technology the benefit to offering cardiac imaging is becoming more apparent. Cardiac imaging can help monitor cardiac disease by giving a view of the heart chamber, valves and also blood flow.

### Key Performance Indicators

In order to meet the goals of Radiology Associates there were three metrics used in order to gage the proposals—quality and flow.

## Quality

In regards to quality, the focus was on the quality of the patient and technician experience as well as the scan quality. For patients, an MRI exam can be an unsettling experience. It is an enclosed space that can make patients feel claustrophobic. For technicians the coils can be heavy and there is a lot of setup involved. Finally, scan quality between a 1.5T and 3T can be obvious, with the latter having a stronger magnet and clearer imaging.

### Customer Satisfaction Survey Results

	Jan 2016	Feb 2016	Mar 2016	Apr 2016	May 2016	June 2016	July 2016	August 2016	September 2016
Compliments	97	54	55	47	1465	1661	1502	1645	1103
Complaints	25	32	27	26	142	189	112	89	63
Percentage of Complaints	20%	37%	33%	36%	9%	10%	7%	5.13%	5.40%
Feedback Received	122	86	82	73	1607	1850	1614	1734	1166
Patients Seen	5526	5994	6506	6161	6129	6175	5757	6364	5797

Percentage of Feedback	2%	1%	1%	1%	26%	30%	28%	27%	20%
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The Quality True North Metric can be measured through customer feedback in the form of surveys. The numbers above are collected through the following methods:

- DoctorConnect (Survey & Comments)
- HappyOrNot (Daily Positive and Negative)
- Quality Feedback Phone Line
- Emails from Jessica (from website)
- Emails from RASLO Website

Our upgrade recommendations will also seek to improve the quality of patients and technicians through this metric.

## Flow

Flow corresponds to the length of stay of the patient. One of the key performance metrics at Radiology Associates is patient length of stay. In this project, the focus is going to be in lowering the scan time. Radiology Associates performed 148 types of MRI exams at their three sites for a total of 8,409 exams from January-June 2016. Many of the coils at the sites are considered out of date, and there have been many technological advances that have not been explored in regards to new equipment. Due to the massive cost associated with MRI machines the upgrade efforts will need to be focused on the parts that are used the most. In order to analyze this, all of the exam data from January-June 2016 was collected and

the top exams performed were identified.

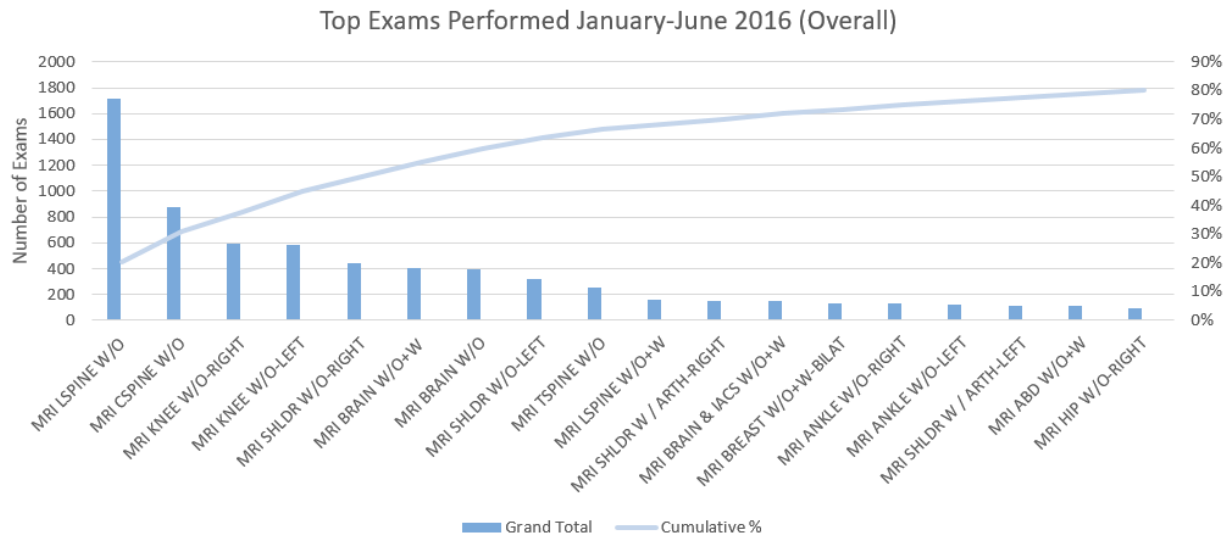


Figure 3: Pareto

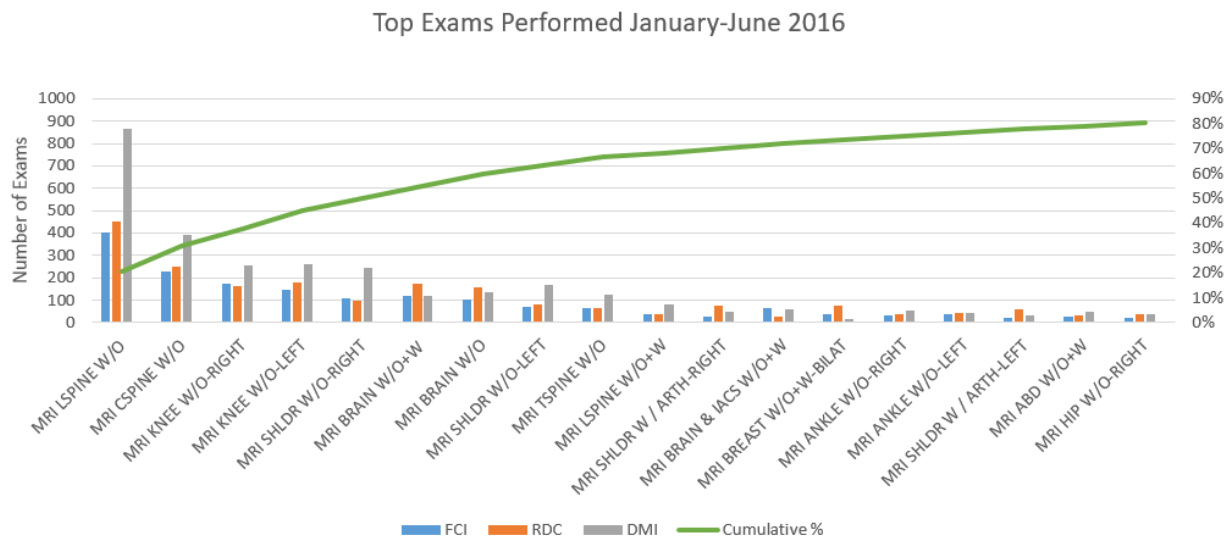


Figure 4: Pareto w/ Location Breakdown

According to this analysis, 18 of the 148 exams are 80.2% of the total exams performed on the 4 MRI machines. These exams are where the focus will be placed because a reduction in scan time for these scans will make the most impact.

After focusing the attention on the top 18 exam types, the next step is to investigate the length of patient stay and find room for improvement.



## Upgrade Proposal

### Hardware Upgrades

After analyzing the Pareto and conducting interviews with both managers and technicians at Radiology Associates, we have decided to focus on the Santa Maria location for hardware upgrades. This is due, in part, to the high volume nature of this location. More patients are referred to this location due to the Open MRI, an upgrade that aims to reduce anxiety during exams. Santa Maria has higher numbers overall – however, that is not simply due to having two machines. After looking at the data, there is actually more patient scans per machine compared to the other locations in Templeton and Pismo.

From the aforementioned interviews, we also discovered a needs for both patient and technician experience. Technicians dreaded moving coils back and forth from shelving to machine between exams. The coils are bulky and can weigh up to 30 lbs at the high range. This problem can affect the Quality True North Metric since the experience for technicians is not positive. Continued monitoring of this during and post-implementation is needed to quantify results. For patients, large and heavy coils can also make the experience negative; many already do not want to be in the machine and now there is another piece of equipment attached to their bodies. Lowering the size and weight of the coils has the potential to increase patient and technician experience.

There are more benefits with using third party coils as well. Traditionally, coils are specific to anatomy. For example, a shoulder coil is used for shoulders or a knee coil is available for knees. Since flex coils are not specific to anatomy, one set can replace many types of scans. For the Santa Maria location, this is calculated to be 15 types; that is a 41% decrease in number of coils on the shelves.

Third Party flexible coils tend to be less prevalent than their OEM counterparts but also less expensive. For that reason, we chose to look at third party options. Our research led us to a company called MRInstruments, currently the only FDA-approved manufacturer in the states. The following are benefits of their DuoFlex system:

- Compatible with Santa Maria GE 1.5T MRI Machine
- 2 Sizes available in package: 10cm + 24cm
  - mix and match
- Low Weight
- Currently only player in market with FDA approval

- We did not look at flex coils from OEMs
- # Exam types replaced by single coil suite – 15 out of total 37.

With all these benefits, the next step is to quantify them. What are the metrics that align with Radiology Associates' True North Metrics? Out of the two mentioned, the hardware side focuses on quality. Flow must be measured post-implementation. Size will be measured with tape measure as volume in in<sup>3</sup>. Weight will be measured with a normal body scale in pounds (lb).

### Weight Comparison

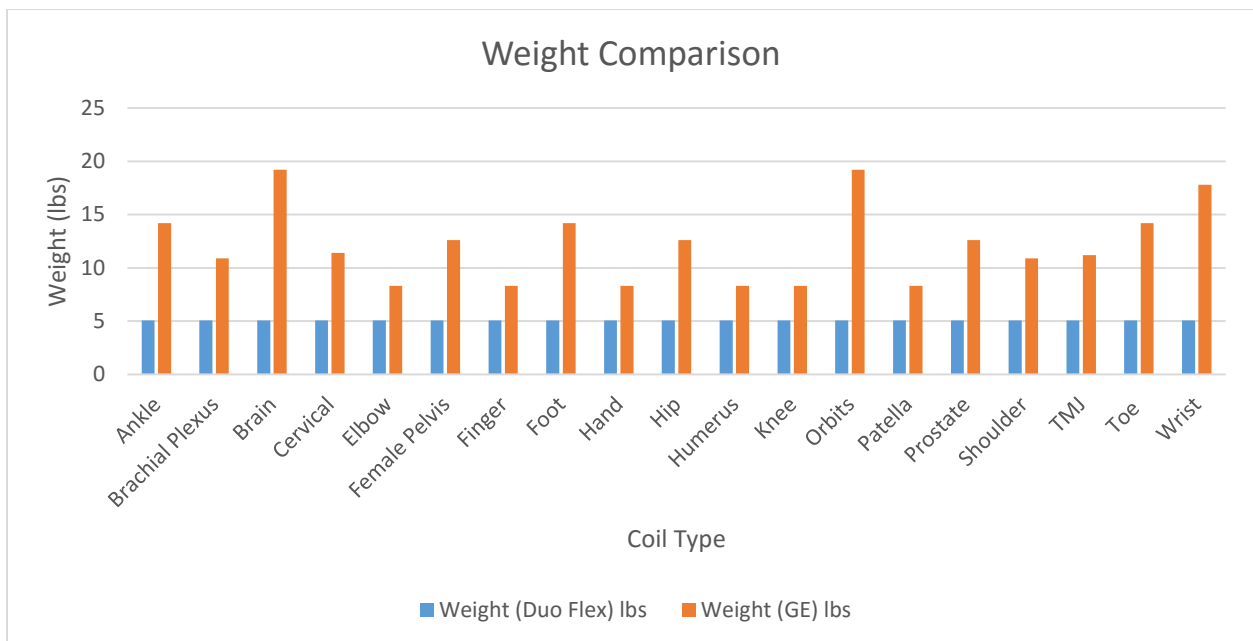


Figure 4: Weight Comparison

This graph shows the current weight of each type of coil found at the Santa Maria location. These are compared to the weight of a set of flexible coils from MR Instruments – 5.1 lbs. Technicians at Radiology Associates can benefit from this since they are the ones moving these coils back and forth from the patient bed to storage area every day, every exam. Quality of technician experience can potentially increase due to reduced frustration with equipment – this should be measured post implementation.

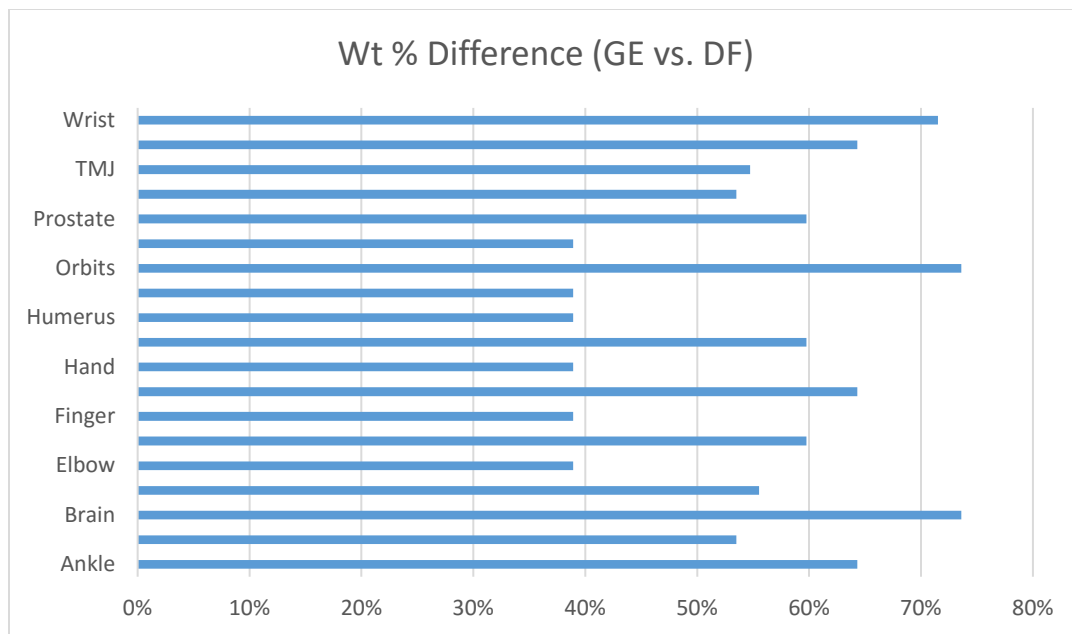


Figure 5: Percentage Weight Difference

With a weight difference of about 80-90% across the coil types, the case is strong to try this flexible coil set. Ergonomics of using these coils with patients see a potential improvement as well since the coils now blend in with the other equipment.

## Size Comparison

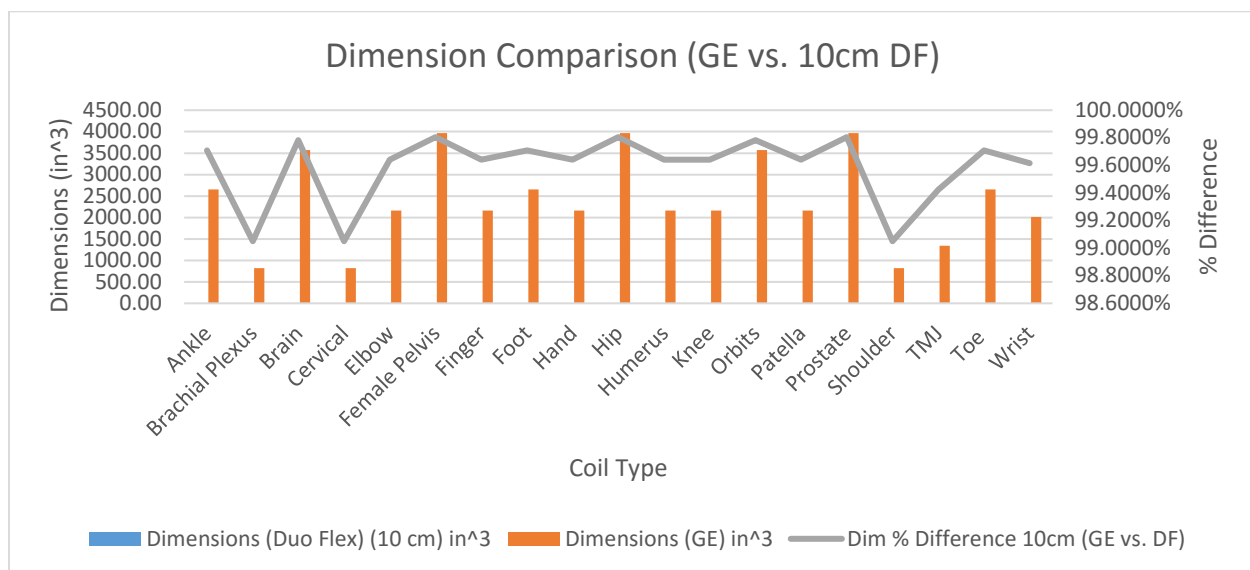


Figure 6: Dimension Comparison 10cm

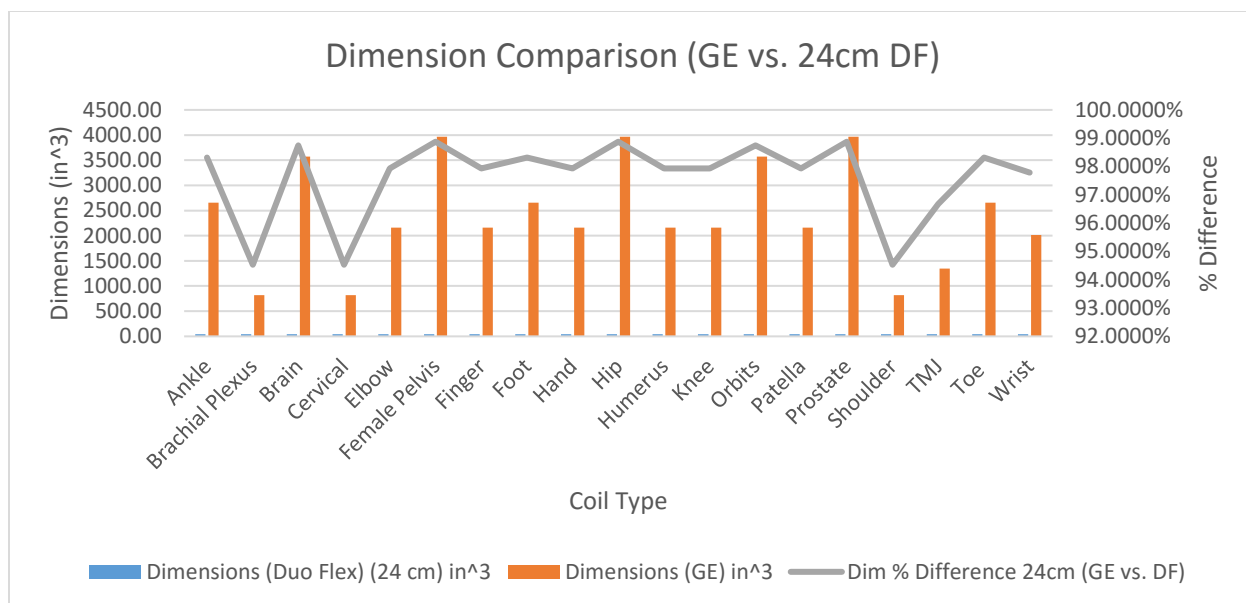


Figure 7: Dimension Comparison 24cm

Figure 5 and 6 show a measure of size differences in the current state of coils vs. the flexible coils. Volume (in³) is used to depict this measure with the two sizes of flexible coils produced by the company. Across the board the difference is even more dramatic than weight. It is now greater than 90% overall; the patient will notice very little during scans.

Quality of patients see a potential increase with these coils. Having an MRI scan is not the most comfortable experience with large, clunky coils in addition to small machine bores. Claustrophobic patients, in particular, do not enjoy the confined area for long time periods. Even with the open MRI machine, claustrophobia can be an issue. Having this set of coils will reduce one part of the issue. Patient satisfaction can then be measured through surveys and technician feedback post implementation.

## Package

So now that the benefits are clear, what is included in the package?

The price for the DuoFLEX suite – which includes 2 -24cm coils, 2 -10cm coils, which can be used together or interchangeable (10 with 24cm). There are 8 channels total, on par with the current state.

- List Price is 45,000
- 1 Year Warranty
- 2 Days Applications – training and installation

A rental program is also available with different pricing options. Rental will be discussed later on in the economic analysis.

Currently this system is compatible with 1.5T GE systems. Development for 1.5T Siemens and 3.0T versions underway.

## Software Upgrades

The software upgrades are focusing on the two MRI machines that are in the need of an update—both in Santa Maria. Every MRI machine owned by Radiology Associates has a different software level and operating system, making each potential upgrade individualized to the specific machine.

### 1.5T GE HDxT

The 1.5T GE HDXT is currently at a software level of 16.0. This magnet was upgraded January 2015 with a D-Stream Interface, including higher coil configurations and a software upgrade.

### ViosWorks

Currently Radiology Associates does not have cardiac imaging capabilities for their MRI machines. GE has recently presented their newest innovations—a cardiac scanning software that is compatible with current MRI models. The scan will be 10-15 minutes in length and will create a 7-dimension view of the heart (3 in space, 1 in time and 3 in velocity). This scan length is not only extremely short but shows blood flow as a moving image which will help doctors determine cardiac issues much faster. One of the main issues with cardiac MRI software is that the heart is a rapidly moving organ and it is difficult to get a clear depiction unless the patient undergoes a lengthy 60 minute plus exam. During MRI Exams patients are asked to hold their breath for clearer pictures to be taken. In the case of patients undergoing cardiac treatment, prolonged amounts of time without breathing are not ideal and in some cases impossible. A major upside of this exam is that it is free breathing and leaves patients more comfortable.

Due to the large size of the imagery produced this software will be cloud based in regards to processing. This will ensure Radiology Associates has enough processing power to undergo these exams.

### HD23

HD23 is a new software package available for the 1.5T HDxT.

- Cost of Training: \$3,300. Participants should already be qualified to operate the existing software for the HDxT.

- New areas in HD23
  - New Coil Database
  - “Ready Brain” which is a fully automated exam, even for non-expert users.

## Hitachi Oasis

### *Evolution 5 - Hitachi*

Currently the Hitachi Oasis is at a software level 4.0C. Evolution 5 is the latest software upgrade with the basic package available at no cost to existing Hitachi Oasis users. It will be implemented sometime in 2017.

The “Option” upgrade package has five additional features and applications that are available for Radiology Associates to add onto the upcoming software upgrade.

- T2\* (T2-Star) RelaxMap
  - \$15,000

Assessment of where there are concentrated iron levels in the body by calculating the T2\* values via an algorithm. The output is a display of the liver with a color gradient clearly depicting the concentrated areas of iron. Currently Radiology Associates is using RCDP Protocol, which is using T2 values during abdomen/liver scans. T2\* values are able to display a gradient, which will help create better imaging.

- BSI (Blood Sensitive Imaging)
  - \$16,000

Blood Sensitive imaging uses “deoxygenated blood as a natural contrast agent to aid in the diagnosis of brain hemorrhage and stroke” (Hitachi). In a case study done by Hitachi, a patient with an internal brain bleed was scanned using BSI methodology and a more traditional MRI scan. It was not evident in the older scans that there was a brain bleed; however, using BSI it was much clearer. Currently, Radiology Associates has issues with some patients having an allergic reaction to the contrast used in exams. Also, patients that have kidney issues are not able to process the contrast injections properly. Having the contrast be deoxygenated blood will open up the offerings to more patients. Other benefits include being able to detect micro bleeds in the brain. One of the applications for this imaging is an enhanced detection of tumors.

#### Benefits:

- Non-contrast
- Detects micro bleeds
- High resolution and thin slices

BSI Imaging can also be used for patients with PTSD. With a larger military presence in California it would be beneficial to continue to explore this option to see if there is definite need in this market.

- CardioSuite Enhancements

- \$32,000

Radiology Associates does not currently have capabilities for cardiac imaging. With this software upgrade, the company will be able to offer cardiac imaging and even more importantly, would be able to use existing coils for the procedures. This upgrade will only involve the software purchase. One of the issues with cardiac imaging is the length of time that it takes to complete a proper scan. This would need to be taken into consideration when looking into the final purchase decisions.

- FatSep Enhancements

- \$14,400

Fat suppression over a large field of view and when metallic implants are in the patient. This can create fat and water only images.

- isoFSE Enhancements

- \$22,500

This enhancement is a 3D volume sequence that creates high quality images through Multi-Planar Reconstruction. Some issues with current imaging include feathering and a lack of clear imaging in some regards. This reconstruction involves reimaging of the planes and improving the level of detail.

## Economic Analysis

### Hardware

Cost is always the ultimate factor in deciding whether or not a new project should be pursued, much less implemented. With that in mind, we decided to conduct an economic analysis using net present worth, or NPW, values. NPW is useful when taking into consideration the time value of money. As explained in our literature review, all the costs and benefits associated with a project across a certain time period create an equivalent value and compare options.

To produce these numbers, we made the following assumptions:

- Average Reimbursement per scan = \$406
- Number Scans per day\* = 10
- Average Number Work Days per year = 261

- Revenue per year per machine\* = \$1,059,660.00
- Additional Monthly Revenue\*\* = \$2,100.00

\*Number calculated with the 6 months of historical data from January to June 2016. Without knowing what other projects are in progress at Radiology Associates, we assumed these numbers would hold for the remainder of this year.

\*\*Number based off MRI Instruments studies with their previous clients and revenue figures. Range of values was given; we took the lower number to be conservative in our analysis.

#### Rental

n	Positive	Negative	Net	P/F Factor	Equivalence	
0	\$6,300.00	\$20,340.00	-\$14,040.00	1	-\$14,040.00	
1	\$25,200.00	\$23,940.00	\$1,260.00	0.956937799	\$1,205.74	
2	\$25,200.00	\$23,940.00	\$1,260.00	0.915729951	\$1,153.82	
3	\$25,200.00	\$23,940.00	\$1,260.00	0.876296604	\$1,104.13	
4	\$25,200.00	\$23,940.00	\$1,260.00	0.838561344	\$1,056.59	
5	\$25,200.00	\$23,940.00	\$1,260.00	0.802451047	\$1,011.09	
					-\$8,508.63	<-- NPW value

Figure 8: Rental NPW

Rental does not appear to be a viable alternative due to the negative net present worth value. Renting will simply cost more and more each year with the same benefit.

#### Purchase

n	Positive	Negative	Net	P/F Factor	Equivalence	
0	\$6,300.00	\$45,000.00	-\$38,700.00	1	-\$38,700.00	
1	\$25,200.00	\$0.00	\$25,200.00	1	\$25,200.00	
2	\$25,200.00	\$0.00	\$25,200.00	1	\$25,200.00	
3	\$25,200.00	\$0.00	\$25,200.00	1	\$25,200.00	
4	\$25,200.00	\$0.00	\$25,200.00	1	\$25,200.00	
5	\$25,200.00	\$0.00	\$25,200.00	1	\$25,200.00	
					\$87,300.00	<-- NPW value

Figure 9: Purchase NPW



### Rental 1 Year + Purchase

n	Positive	Negative	Net	P/F Factor	Equivalence	
0	\$6,300.00	\$20,340.00	-\$14,040.00	1	-\$14,040.00	
1	\$25,200.00	\$24,660.00	\$540.00	0.956937799	\$516.75	
2	\$25,200.00	\$0.00	\$25,200.00	0.915729951	\$23,076.39	
3	\$25,200.00	\$0.00	\$25,200.00	0.876296604	\$22,082.67	
4	\$25,200.00	\$0.00	\$25,200.00	0.838561344	\$21,131.75	
5	\$25,200.00	\$0.00	\$25,200.00	0.802451047	\$20,221.77	
					\$72,989.33	<-- NPW value

Figure 10: Rent 1 year + Purchase

### Rental 2 Years + Purchase

n	Positive	Negative	Net	P/F Factor	Equivalence	
0	\$6,300.00	\$20,340.00	-\$14,040.00	1	-\$14,040.00	
1	\$25,200.00	\$23,940.00	\$1,260.00	0.956937799	\$1,205.74	
2	\$25,200.00	\$24,660.00	\$540.00	0.915729951	\$494.49	
3	\$25,200.00	\$0.00	\$25,200.00	0.876296604	\$22,082.67	
4	\$25,200.00	\$0.00	\$25,200.00	0.838561344	\$21,131.75	
5	\$25,200.00	\$0.00	\$25,200.00	0.802451047	\$20,221.77	
					\$51,096.42	<-- NPW value

Figure 11: Rent 2 years + Purchase

### Summary

Rent vs. Buy	NPW Values
Rent	\$ (8,508.63)
Purchase	\$ 87,300.00
Rent 1 year + purchase	\$ 72,989.33
Rent 2 years + purchase	\$ 51,096.42
Rent 3 years + purchase	\$ 39,870.00

Figure 12: Economic Analysis Summary

Looking at the numbers, it makes sense to simply purchase the flexible coil set since it has the most positive net present worth value. We do not recommend that. Although there are numerous benefits to this, further analysis is needed for affirmation. The current state of coils works well and changing that could result in slower scan times or other errors. We do not yet know how the technicians will adapt to the new hardware; how will the learning curve look? Due to these uncertainties, we recommend the second highest value option: Rent for 1 year then purchase. The first year will be used to conduct the following:

- Technician surveys
- Patient surveys
- Learning Curve Analysis

At the end of the year, another meeting is necessary to determine if purchasing is good for the company. That decision must be determined based on the aforementioned surveys and analysis. Note: the rental price paid will be applied towards purchase price (up to 1 year).

## Software

For the 1.5T HDxT it is recommended to explore the pricing of the ViosWorks software when it is officially released.

One of the methods used in determining the software choices for the Hitachi Oasis included a MCDA chart, which prioritized the different criteria.

The following criterion was used in order to best compare the software:

- Minimizing Cost
  - While this project did not have a budget, it was very important to keep in mind the cost. Radiology Associates is already undergoing a lot of change involving the purchase of new MRI machines.
- Exam Enhancements
  - This was a main focus from the initial meeting at Radiology Associates to go over the project. The importance of increasing the variety of exams to compete with other local businesses was deemed very important. Since Cardiac and full body imaging were not currently offered, it would open up the potential for new patients.
- Image Quality
  - With the 3T machine being purchased for the Templeton location the image quality for those patient scans are going to be of a higher quality. With many exams, the increase of the magnet strength is a correlation to image quality. It is important for the new machine's images to not overshadow those of the existing machines.
- Satisfaction
  - These criteria encompass patient and doctor satisfaction. For patients it is improving the quality of the experience whether it involves a shorter processing time, less strenuous breath holds or general quality of experience. The image quality is also important because doctors value clear images to work with and there will be a reduction in rescans.

Criteria	Minimize Cost	Exam Enhancements	Image Quality	Satisfaction	Total
Weights	5	5	4	4	
<b>T2* RelaxMap</b>	\$12,000	More Capabilities	Gradient view of liver	Clearer for Doctors	64
	5	3	4	2	
<b>BSI (Blood Sensitive Imaging)</b>	\$12,800	Enhancing Current	Detection of microbleeds clearer	No Contrast Necessary	80
	5	3	5	5	
<b>CardioSuite</b>	\$32,000	New Offering	Clear depiction of heart	Free Breathing	71
	2	5	4	5	
<b>FatSep Enhancements</b>	\$14,400	Enhancing Current	Contrast over large FOV	Increase Patient Usability	67
	5	2	4	4	
<b>isoFSE Enhancements</b>	\$22,500	Enhancing Current	Clearer 3D images	Clearer for Doctors	53
	3	2	5	2	

Figure 13: MCDA

Given the criteria, the recommended software upgrades for the Hitachi Oasis are the Blood Sensitive Imaging and the CardioSuite additions. However, there is no set budget for this project at Radiology Associates and these are recommendations. Given the results, Radiology Associates can make their decisions based on current budget needs as well as from software needs determined in the future.

## V. Results and Discussion

Radiology Associates does not have a set budget or plans for this project, therefore making concrete recommendations was not in the scope of this project.

For the future and before any further action, it will be important to explore the market share and need in Central California for the software upgrades. Unfortunately, during this project the software that provides insight to the most referred exams was unavailable for data. In the future, Radiology Associates should use this data as another set of criteria for the upgrades. With more information regarding how many doctor referrals per treatment it will help drive the need for upgrades in certain directions. Cardiac imaging would be a main focus in this analysis. If there are large amounts of patients being referred for cardiac imaging it will be in the best interest of Radiology Associates to pursue that upgrade.

### Post-Implementation Plan

- Monitor Customer Satisfaction Survey
- Survey Technicians
- Monitor key metrics
  - Flow - #scans/machine

### Possible Sources of Error

Although each coil was specific to patient anatomy, it was not always the case in practical, real-world usage. Technicians have more experience with the MRI machine compared to anyone else in the company and, over the years, they have found ways to accommodate and adapt to situations such as patient size. Shoulder coils are used for knees, wrist coils are used for ankles, and so forth. It is a way to continue the scan instead of sending the patients back. This helps with the rejection rate at Radiology Associates.

### Ethical Implications

Some of the coil types we are looking at are multi-use, which means they can be applied to several types of body scans. What happens if the scheduled scan of the chest, for example, leads to discovery of an abnormality in the neck or upper abdomen? Does the technician have an obligation to report this or tell the patient? Not all abnormalities are fatal and sometimes when alerted panic arises. With this panic is a patient that will spend much more money than expected for scans and treatments that could potentially just be false alarms. Another issue with our proposal may include the image quality. The types of coils we will recommend must help produce higher quality images; it makes sense from a business sense and logical perspective. This new information could potentially show more detailed abnormalities within, for

example, the brain. What should be done if the outcome looks poor for the patient? Some believe that medical imaging is not the ultimate say, and that miracles can happen for patients. If doctors dismiss cases or call patients untreatable due to imaging, it can cause ethical issues to arise. Finally, the lead radiologist mentioned how future MRI technology would be able to measure pain. How would this new information be used? Would this be an ethical way to sort patient treatment? Pain is measured and felt by humans in different ways. This way of prioritization would not be normalized among the human population and could potentially be an unethical way to treat patients.

#### Social Impact

Many of the current coil designs invoke very negative, claustrophobic responses from patients. Our proposed coil types may affect the way patients view MRI scanning in a positive way. They may be less hesitant when the doctor recommends this type of imaging. From a technician standpoint, they face uncomfortable situations everyday where patients are rejected from the scheduled imaging due to size. The proposed coil design can reduce the number of situations where a technician is forced to reject a patient due to their size and body shape.

#### Environmental Effects

There are little to no effects on the environment from our proposal to upgrade software and hardware at Radiology Associates. The effects would come from the way these coils are manufactured or installed.

## VI. Conclusions

The goal of this project was to balance machine quality across the three locations of Radiology Associates. Some locations were receiving new 3.0T machines. What about the other ones? The existing machines needed upgrades to keep their respective locations competitive with not only each other, but also the local competition.

This project was broken down into software and hardware with the following recommendations listed below.

## Final Recommendations

Hardware	Software
1. Purchase MRInstruments DuoFlex Coil Set for GE 1.5T @ Santa Maria	3. CardioSuite for Hitachi Oasis
2. Rent 1 year, then Purchase	4. Blood Sensitive Imaging for Hitachi Oasis
	5. ViosWorks for 1.5T GE HDxT when available

### Benefits of DuoFlex Third Party coils

- Replace multiple coils
  - 40% decrease in # coils
- Reduce claustrophobia w/ patients (size)
  - > 90% decrease in volume
  - 80-90% decrease in weight
- Image quality – moves w/ patients
- Increase referrals – new technology

### Benefits of Software Updates

#### Hitachi Oasis

- CardioSuite
  - New type of imaging
  - Can be used with existing coils
- Blood Sensitive Imaging
  - Clearer imaging
  - Contrast not necessary

- Can be used to diagnose patients with PTSD, strokes and brain hemorrhaging

#### 1.5T GE HDxT

- ViosWorks
  - New type of imaging
  - Fast scan time
  - Needs to be re-examined when the software is officially released and pricing is available

#### Looking Back

If we were to do the project again, a couple changes would be made:

- Look into comparisons between OEMs and Third Party Flex Coils
- Broaden upgrades to other machines at all locations

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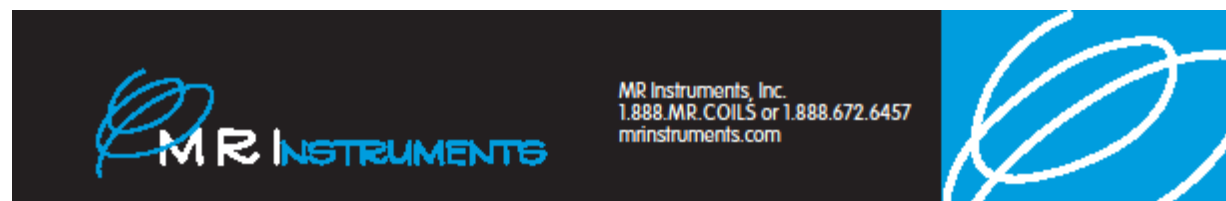
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### **DuoFLEX® X-factor Rental Overview**

The DuoFLEX Rental Program can accommodate immediate utilization of DuoFLEX and its benefits without, or prior to, capital budget approval.



DuoFLEX® is compatible with most GE  
1.5T MRI systems

1. We will quote the DuoFLEX® Suite as a purchase. However, the timing and/or approval of your capital budget may cause a delay in the acquisition.
2. As an alternative, you can rent DuoFLEX® for \$1,695/month in year 1 and \$1,995 thereafter, plus applicable sales tax.
3. We will visit your site for a full demonstration of DuoFLEX® and conduct our normal applications training for your lead MRI technologists. There is no commitment required to rent or purchase DuoFLEX®. If you are not satisfied for any reason, we will simply take the DuoFLEX suite with us when we leave on Day 2.
4. If you like DuoFLEX®, we can leave the suite with you and begin the rental for \$1,695/month.
5. If, during the first 12 months of the rental, you purchase the DuoFLEX® we will credit 100% of the rental payments toward your purchase price. If you purchase the DuoFLEX after the first 12 months, we will still apply 12 months of rental payments toward the purchase price.
6. You may stop the rental at any time with no further commitment except to ship the coil suite back. Once we receive the DuoFLEX® Suite, we stop the monthly billing.
7. Since this is a rental program, all service/replacement requirements are covered/included.



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## DuoFLEX® X-factor

What is your X-percent ?

How many additional studies might you be able to perform monthly ?



DuoFLEX® is compatible with most GE 1.5T MR systems

	DuoFLEX® X%	Average Range, Per Month	Your Institution
A	Studies from existing patient base which are currently not acceptable or cannot be completed	1 - 2	
B	New referrals from the general market based upon the X-panded capabilities of DuoFLEX	1 - 2	
C	Additional referrals from specialty practices who own their own MRI and cannot scan X%	4 - 6	
D	Total X% Per Month	6 - 10	
E	Net Technical Reimbursement Per Exam	\$350-\$625	
F	X-tra Monthly Revenue (DxE)	\$2,100-\$6,250	
	X-tra Annual Revenue (Fx12)		
G	Monthly DuoFLEX® Rental (not including sales tax, if applicable)	\$1,695*	\$1,695*
H	Immediate X-tra Margin via Rental (F-G)	\$405-\$4,555	
	X-tra Annual Margin (Hx12)		
	*Rental increases to \$1,995 per month in year 2.		

DMAIC A3 CHARTER: MRI in the 21st Century				
Executive Sponsor	Problem Statement			DMAIC Project Timeline
	Radiology Associates' aging MRI technology is limiting our ability to compete within the local market and compromising our ability to obtain our True North Metrics.			Kickoff Meeting
Process Owner	Aim			Define/Measure Review
Heather Fisher	Expand services offered Eliminate manual post processing Decrease scan time per patient Implement quick and safe changeover process (simplify coils) Improve image quality			Analyze Review
Team Lead	Scope			Improve Review
	All MRI scanners currently in service			Control Review
Team Members	Key Metric	Current State	Goal	Financial Impact
1/3 Content Expert(s):				
1/3 Up/Down Stream:				
1/3 Outside Eyes:				
Radiologist(s):				