STRATEGIC ANALYSIS OF THE COMMERCIALIZATION POTENTIAL OF A NOVEL ALGORITHM

by

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Bachelor of Science, University of British Columbia, 2004

PROJECT SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF BUSINESS ADMINISTRATION

In the
Faculty
of
Business Administration

Management of Technology Program

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SIMON FRASER UNIVERSITY

Summer 2008

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ABSTRACT

An evaluation of the commercialization potential of a novel algorithm with applications in many industries was conducted. The results of the evaluation indicate that the medical imaging industry offers the best opportunity for the algorithm based on the algorithm's performance attributes and the needs of the medical imaging market. The Computed Tomography (CT) and the hybrid Computed Tomography-Positron Emission Tomography (CT-PET) market segments are the optimal market alternatives for pursuing commercialization. A partnership with a major medical imaging equipment OEM is the most attractive commercialization path available to the algorithm as it offers an opportunity for long-term success.

Keywords: Algorithm, Commercialization, Medical Imaging

EXECUTIVE SUMMARY

A novel algorithm, recently formulated by a university professor, provides a unique solution to a well known mathematical problem – the multi-terminal, k-way graph cut problem. This mathematical problem is relatively generic, corresponding to many diverse real-world problems. Such problems include optimizing computing costs when assigning modules to processors, partitioning files in a network, assigning users to a computer, image de-noising and image segmentation. Accordingly, the algorithm solution to the problem has a large number of applications in many industries, indicating that it has commercial potential. At the same time, the general nature of both the mathematical problem and the algorithm solution greatly complicates the assessment of the algorithm's overall commercial ability. Consequently, this analysis was conducted to investigate the algorithm's commercialization potential and evaluate the market and commercialization route alternatives available to it.

Four of the most promising industries for the algorithm's commercialization were evaluated based on the market opportunity they offer. The synergies between the performance attributes of the algorithm and the market needs of the four industries indicate that the medical imaging industry provides the most favourable commercialization opportunity for the algorithm. A more detailed evaluation of the medical imaging industry suggests that growth is largely influenced by technological advancements in imaging devices, changes in population demographics and the increasing cost of healthcare. These market growth drivers, in addition to technological

barriers signify that both the CT and CT-PET market segments are ideal for the algorithm's commercialization.

A Porter's five-forces evaluation of the medical imaging industry suggests that with mild rivalry, relatively limited buyer bargaining power, extremely low supplier bargaining power, no substitutes, and little threat from new entrants, the industry is an attractive and profitable one for incumbents. For potential entrants, the industry presents significant barriers, as the medical equipment OEMs are integrated into all segments of the value chain including software development. Although selling or licensing the algorithm to a medical OEM could provide a near term return, a partnership agreement with one of the three major medical imaging equipment OEMs is the only commercialization route that can provide long-term success for both the algorithm and the developer.

DEDICATION

To my family who has encouraged and supported me throughout my life.

ACKNOWLEDGEMENTS

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GLOSSARY

Blog   A website regularly updated with commentary, news and events.

Computer vision The technology that enables machines to automatically extract information from images. Typical tasks performed by computer vision systems include recognition, motion, scene reconstruction and image restoration

CT   Computed tomography (CT) is a medical imaging method that generates two-dimensional and three-dimensional images of the inside of a human from a series of x-rays.

Extranet   A private network using internet protocols that allows an organization to securely share information with vendors, suppliers, customers and other businesses.

Intranet   A private computer network using internet protocols to that allows an organization to securely share company information with employees.

LAN   Local Area Network (LAN) is a computer network that covers users within a small geographical area.

Machine Vision   See Computer Vision.

Mammography   Mammography is a process that uses x-rays to examine human breast tissue for abnormalities. It is primarily used for the early detection of breast cancer.

MRI   Magnetic Resonance Imaging (MRI) is a technique that uses radio waves and a strong magnetic field to two-dimensional and three-dimensional images of the internal structure and function of the human body.

OEM   An Original Equipment Manufacturer (OEM) manufactures and sells equipment that is resold under another brand or in another product.

PACS   Picture Archiving and Communication Systems (PACS) is a computer network system that allows for the quick retrieval and exchange of digital medical images between healthcare providers.

PET   Positron Emission Tomography (PET) is a nuclear medicine scan that generates a three-dimensional image of the functional processes of the human body through the detection of gamma rays emitted by a positron-emitting tracer that is administered to the patient before the scan

Radiography   Radiography refers to the use of x-rays to view the internal structure of the human body such as bones.

RFID   Radio-frequency identification (RFID) is technique that uses radio-frequency to automatically identify and retrieve information stored on tags. RFID is currently being used in supply chain management to track and manage inventory.

Ultrasound   Ultrasound is a medical imaging technique that uses sound waves to create images of the internal body organs. It is routinely used to view fetal development.

Wiki   A wiki is a set of web pages with content that can be modified by any of its users. Wikis are a collaborative tool that is becoming popular in many organizations.

WAN   Wide Area Network (WAN) is a computer network that covers users in a wide geographic area.

X-ray   A medical imaging device that uses x-rays to for the purpose of viewing the inside of the human body.

1 INTRODUCTION

1.1 Background

A university professor has formulated a novel solution to a problem that has long intrigued mathematicians – the multi-terminal, k-way graph cut problem. The solution is in the form of a computer algorithm that has applications in diverse areas. Some of these areas include networking and visual computing. Examples of networking applications include optimizing computing costs when assigning modules to processors, partitioning files in a network and assigning users to a computer (Dalhaus et al., 1992; Stone, 1997). The visual computing applications encompass image de-noising (Boykov et al., 1998), correspondence of stereo images (Birchfield & Tomasi, 1999), and image segmentation (Boykov et al., 2001).

This algorithm has applications in many other areas as well, where the general problem of assigning "labels" to "sites" exists. The actual "labels" and "sites" depend on the specific nature of the problem. For example, in visual computing, the site corresponds to a pixel in an image and the label corresponds to a specific part of the image such as a face in a photograph of a person. Because of the diverse and exhaustive number of applications for this algorithm, its commercial potential is not obvious. This paper will therefore investigate the algorithm's potential applications, and its commercial ability in specific promising markets and market segments. Moreover, a strategic analysis will be conducted to determine the optimal market and commercialization path for the algorithm.

1.1.1 Multi-terminal k-way graph cut problems

In general terms, the multi-terminal k-way graph cut problem describes the problem of assigning one of a number of possible "labels" to a number of "sites". In mathematical terms, the problem describes a graph made up of vertices and edges, where a number (k) of these vertices, are fixed 'terminal' vertices. The problem is to find a method of cutting the graph such that each fixed terminal vertex is separated from all other terminal vertices. This type of sectioning is known as a k-way cut. Figure 1.1 illustrates a k-way cut of a graph with three groups of terminal vertices.
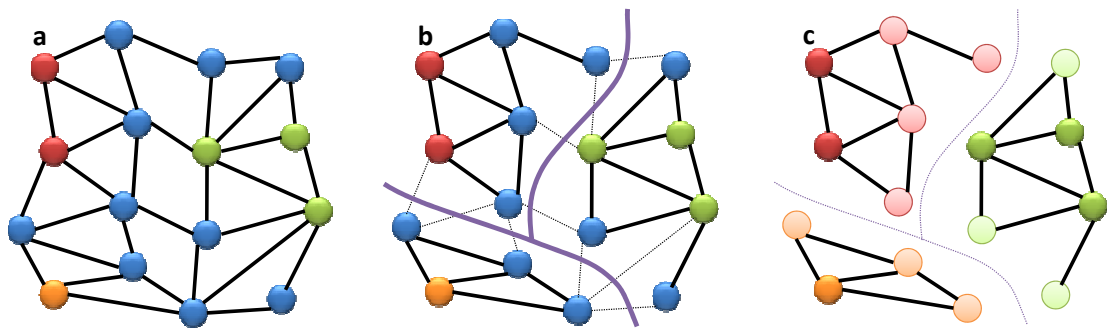
Figure 1.1: A k-way cut.

(a) A graph with vertices (blue), terminal vertices (red, green, and orange) and edges (black line segments connecting the vertices). (b) A cut (purple line) severing the edges. (c) Vertices labelled according to the cut (lighter red, green and orange). *Note*. From Hamarneh, G, 2008. Reprinted with permission.

When there are only two groups of terminal vertices ($k=2$), the problem is solvable and the solution can be found in polynomial time by using Ford-Fulkerson algorithm (Ford & Fulkerson, 1956), the Edmonds-Karp algorithm (Edmonds & Karp, 1972) or the Goldberg-Tarjan algorithm (Goldberg & Tarjan, 1988). However, the problem becomes much more complicated when $k{\geq}3$.

The solutions to these multi-way problems come in the form of algorithms because no single solution exists for a particular problem. Thus, mathematicians and computer scientists have developed these computationally intensive algorithms. Currently, research in this field is focused on minimizing cut costs and creating computationally efficient algorithms. Developments in these areas will in general equate to faster processing times and better quality of outputs in applications. The specific benefits will depend on the application itself and the nature of the problem being solved.

1.1.2   Current applications

Networking continues to be a strong application area for multi-way algorithms as the number of computers and users in organizations increase. As the number of users increases, tasks such as assigning users to work stations, folders, servers, and assigning modules to processors are becoming more complicated as well as more costly. Multi-way algorithms have been successful in these applications as they can efficiently complete these assignment tasks.

However, the algorithms that are currently available are not operating at optimal efficiency. A more efficient algorithm will translate into time and cost savings for an organization. For large organizations (those with many computers and users), small improvements in the efficiency of the algorithm can result in tremendous savings in operational costs. As more and more organizations seek ways to reduce costs to remain competitive in today's business world, multi-way applications in networking remain strong.

Visual computing programs are also a popular use of multi-way algorithms. In visual computing, multi-way algorithms are used for image de-noising, correspondence of stereo images, and image segmentation. Specific application areas include and are not limited to medical imaging, satellite imagery and face recognition software. Improvements to multi-way algorithms in this application area can improve image quality, which includes resolution, colour, clarity, intensity etc. Multi-way algorithms are important in these applications as images are created by non-traditional means (i.e. photograph vs. magnetic resonance imaging (MRI), computer tomography (CT) or ultrasound). The data used to create these types of images can be processed by multi-way algorithms to improve image quality.

1.1.3   Potential applications

As well as new applications within industries currently served by k-way algorithms, entirely new industries are prime candidates for this algorithm. The goods transportation industry represents one of these prime candidates. Companies within this industry can use the algorithm in conjunction with their current technology to determine the quickest and most cost effective route to ship a package. Currently, courier companies such as FedEx use the hub-and-spoke model for shipping packages. A multi-way solution can help improve the efficiency of this model or create an altogether new business process model that is more efficient than the current hub-and-spoke model.

Although networking is an old application of k-way algorithms, new opportunities for the algorithm exist within the industry. Websites such as Yahoo!, Google, MSN and Facebook have millions of users worldwide and the task of assigning accounts and servers to users can utilize multi-way algorithms. It is unclear what types of algorithms

are currently in use for this type of problem, but even incremental improvements in such assignment tasks can equate to substantial cost savings solely due to the sheer volume of tasks being performed.

Furthermore, there is an increasing trend towards web applications such as Google Apps, which means that data that was traditionally being stored on in-house servers is now being stored on servers housed by the application provider. Again, assigning storage space to users as efficiently as possible is of particular importance for these types of organizations to keep their costs down and quality attributes, such as speed, at a level that is acceptable to users.

1.2   Benefits of the algorithm

The algorithm formulated by the university professor differs from existing algorithms in many respects. First of all, the algorithm is a much simpler, more elegant and general solution to the k-way problem than existing algorithm. Algorithms that are currently available are mathematically complex, making them rigid in terms their applicability to real-world k-way problems and their implementation into the existing IT infrastructure of specific applications. Besides, the complexity makes it difficult to make improvements to the algorithm itself, which again limits their applicability to industry specific problems.

The newly formulated algorithm, on the other hand, is a generic solution that can be modified according to the specific nature of the problem without difficulty. Additionally, its simplicity allows for the effortless integration of other algorithms, processes and methods. This attribute is very important when the solution requires modifications to inputs (sites and labels) or requires inputs from more than one source,

and when the solution or the output requires further processing to achieve the results required by the particular application. Overall, these properties contribute to the algorithm's flexibility and thus, overall utility in industry.

Aside from its flexibility, the algorithm also provides benefits on key performance attributes. Accuracy and precision are the two dimensions on which the algorithm reigns superior to the other k-way algorithms. The exact attributes of an application that are benefited by superior accuracy and precision depends on the specific nature of the problem. For example, in imaging applications greater accuracy and precision translates into higher resolution and the better colour, clarity and intensity of images. For courier applications, this could imply finding a more cost effective route to ship a package, and for the networking industry this could mean finding a quicker way to assign modules to processors.

1.3   Structure of the analysis

This analysis first investigates potential industries for the algorithm. Industries that are currently using a similar type of algorithm and industries that could potentially have uses for the algorithm are investigated. The results of this preliminary market research are then used to select the industry for further analysis. The selection criteria are based on the attributes of the algorithm and how well they correspond to the market needs.

Once the industry for further investigation has been selected, a more in-depth analysis of the most promising market is conducted. This analysis identifies the key market segments, the market potential, growth drivers and trends in the industry. Subsequently, the commercialization barriers are examined. These include any

technology challenges and market challenges that might be encountered in the pursuit of commercialization. In addition, the competitive forces in the selected industry are analyzed.

The final part of the analysis includes a comparison and evaluation of the strategic alternatives based on the market and commercialization alternatives identified. This analysis takes a scorecard approach in evaluating and comparing the factors that are critical for the successful commercialization of the algorithm amongst the alternatives identified. Lastly, recommendations are made based on the results of the analysis.

2 MARKET POTENTIAL AND SELECTION

The algorithm's commercial ability is evaluated in the three most promising industries. These industries are the computer networking industry, the visual computing industry and the goods transportation industry. Each industry represents a unique commercialization opportunity for the algorithm and is therefore each evaluated on the market opportunity they signify based on the market needs and the algorithm's ability to fulfill these needs.

2.1 Overview of Potential Industries

2.1.1 Computer Networking Industry

The computer networking industry encompasses organizations that design, develop, manufacture and support the equipment and software that is necessary to create and maintain computer networks. These computer networks include local-area networks (LANs), wide-area networks (WANs), intranets and extranets. World-wide, there are about 1,000 companies that manufacture and sell networking equipment and software (First Research, 2008). The combined annual revenue for these companies is estimated to be $60 billion (First Research, 2008).

This industry is characterized as being highly concentrated, with the 10 largest companies accounting for 50 percent of the market (First Research, 2008). In the U.S., the major competitors in this industry include Cisco Systems, Juniper Networks, Extreme Networks and Foundry Networks. Major foreign competitors include Nortel, Fujitsu, NEC, Alcatel-Lucent and Siemens (First Research, 2008). Cisco Systems is currently

dubbed as the worldwide leader in networking for the internet (Cisco Factsheet, 2008) with its 2007 fiscal year revenue totalling $34.9 billion (Cisco Corporate Timeline, 2008). Cisco's revenue accounted for over half of the industry's combined annual revenue. Cisco systems sell over 150 networking products, but, as the dominant player in the IP-based networking market segment, the company's key products are routers and switches (Hoover's, 2008). Cisco's other products include remote access servers, IP telephony equipment, optical networking equipment, conferencing systems, network service systems and security systems (Hoover's, 2008). The bulk of Cisco's customers are large enterprises and telecommunications service providers. (Hoover's, 2008) Cisco, however, does market products aimed at small and medium enterprises (Hoover's, 2008).

Competition in the computer networking industry is largely based on performance. Demand for networking equipment, software and support is driven by economic growth (First Research, 2008). As enterprises grow, user needs increase and the demand for higher performance equipment grows proportionately. As such, enterprises are continually seeking better ways to meet the operational needs of their growing companies. Profitability for companies competing in this industry is based on their ability to meet the volume demands of their large customers in a timely manner (First Research, 2008). Yet, companies that produce products that meet specialized demands are also profitable in this industry.

Companies that utilize networking equipment and software are seeking products that will allow them to meet the ever-increasing demands on their current networks and resources. They seek to reduce the complexity of their networks and minimize bottlenecks while providing a level of performance that is acceptable to their end-users.

This need creates an opportunity for network providers to increase their market share by developing high-performance and robust products that allow the network system to process and execute user requests with minimal processing time costs to the user.

2.1.2   Visual Computing Industry

The visual computing industry includes the areas of computer/machine vision and image processing. Computer vision refers to the technology that enables machines to automatically extract information from images. Typical tasks performed by computer vision systems include recognition, motion, scene reconstruction and image restoration. Image processing, on the other hand, refers to the technology that uses an image as an input to produce another image or a set of parameters related to the inputted image. Typical tasks performed by image processing systems include geometric transformations such as sizing and orientation, colour correction, compositing, editing, differencing, registration, stabilization and segmentation.

The general visual computing industry is relatively broad as it encompasses a number of diverse applications. Some of these application areas are medical imaging, manufacturing quality control, military applications, autonomous vehicles, visual effects and surveillance. Because of the broad range of applications there are a large number of organizations competing in this industry. Organizations in this industry typically specialize in a small number of related application areas and produce products for various sectors of the visual computing industry. The most prominent sectors within visual computing are medical imaging and machine vision.

2.1.2.1 Medical Imaging Industry

The medical imaging sector includes all organizations that are involved in the development and use of medical imaging technologies. Medical imaging technologies traditionally included only products and systems that capture and display human body images for diagnostic and therapeutic purposes (Industry Canada, 1999). However, medical imaging now broadly includes other imaging systems unrelated to the capture of human body images such as picture and archiving communications systems (PACS). Currently, the medical imaging industry includes image based medical diagnostic equipment as well as other healthcare related emerging imaging technologies. The main products produced by this industry are X-ray and radiography, mammography, medical resonance imaging (MRI), ultrasound, computed tomography (CT) scans, position emission tomography (PET) scans, picture archiving and communications systems (PACS), cardiology imaging and three-dimensional (3D) imaging (Trimark Publications, 2007).

The 2005 US medical imaging products industry generated revenues of $16 billion. Seventy-two percent of the sales in 2005 were due to medical imaging equipment and 28% were due to medical imaging consumables such as X-ray film (Freedonia, 2006). The Freedonia Group (2006) has forecasted the demand for medical imaging products to grow by 6% each year to $21.4 billion in 2010. This growth is expected to be driven primarily by a combination of three factors: advances in technology, an aging population and changes in healthcare approaches (Freedonia, 2006). Technological advances in scanners and consumables allow hospitals and other healthcare facilities to improve the quality and efficiency of medical care (Freedonia, 2006). The aging U.S.

population will increase the demand for medical imaging services (Freedonia, 2006). Finally, the economical constraints on the U.S. healthcare system are likely to lead to the development and subsequent use of medical approaches that facilitate the early detection of diseases and disorders, as early detection will not only allow for more effective treatment but also for more economical treatment approaches (Freedonia, 2006). This trend towards early detection methods will lead to an increase in demand for diagnostic equipment such as medical imaging scanners and related consumables.

The medical imaging equipment segment is dominated by a few well known players. The five market leaders in medical imaging products are GE Healthcare, Toshiba, Siemens, Philips and Picker International (Industry Canada, 1999). These companies produce popular medical imaging devices such as MRI, ultrasound, X-ray and CT scanners. The medical imaging equipment segment is expected to reach $16 billion in 2010, an increase of 6.8% annually from 2006 (Freedonia, 2006). The market leaders in the imaging consumables segment are Agfa and Kodak (Industry Canada, 1999). These companies produce products such as film, cassettes, contrast, image plates and imaging software. Freedonia (2006) forecasts the demand of medical imaging consumables to reach $5.3 billion in 2010.

But, with the shift towards digital imaging from analog imaging, film manufacturers such as Agfa, Kodak and Fuji are quickly losing their position in the consumables segment. Consequently, these companies are moving towards digital imaging technologies, as film will ultimately only represent a small fraction of the medical imaging consumables sold. These companies have already begun to make progress in the Picture Archiving and Communications Systems (PACS) segment. PACS

allows for the quick and efficient exchange of digital images between healthcare professionals. PACS systems will permit multiple clinicians to view images of patients simultaneously, leading to faster and more reliable diagnoses. The value provided to healthcare providers by PACS systems has led to its rapid penetration of the market place. In 2000, 25% of U.S. healthcare providers had implemented the PACS systems (Heieb et al., 2004). This figure had quickly increased to 51% by 2004 (Heieb et al., 2004). Gartner predicts that by 2008, 90% of healthcare providers will have adopted the PACS systems (Heieb et al., 2004).

IT vendors and software application companies are also taking advantage of the shift towards digital imaging in the healthcare industry. IT vendors such as IBM and Hewlett Packard have core capabilities in storage systems, network and IT-integration solutions. As a result, they are able to provide healthcare facilities with the IT-based aspects of adapting digital imaging technologies such as the PACS system. IBM is currently a leading IT vendor for the healthcare industry, and will continue to be so in the upcoming years as they position themselves as leaders in information-based medicine (Beaudoin, 2004). In 2004, IBM announced a $250 million investment over three years into its healthcare business with a portion of the funds set for information-based medicine initiatives (Electronic Healthcare, 2004). IT vendors like IBM have recognized that advances in imaging require the interoperability of the medical imaging devices, storage and database systems and software applications. Accordingly, IT vendors are collaborating with software application development companies to provide an end-to-end solution for healthcare facilities.

Software application companies also produce other complementary products required by the shift towards digital imaging. Leading healthcare software application providers such as Cerner, Accelrys and McKesson are providing software applications to the medical imaging industry and are increasingly partnering with IT-vendors such as IBM and Hewlett Packard. However, many small application providers are making gains in this space. These smaller software companies provide niche applications for the purposes diagnostics and image guided surgery for example. As the movement towards integration continues, opportunities for partnerships with the large players in the medical imaging industry will be created for the small software companies.

Overall, the medical imaging industry is experiencing growth in both the equipment and consumables segment. This growth has created opportunities for not only traditional imaging equipment developers but also for IT-vendors and software developers as the industry continues its shift towards fully integrated solutions. Competition in the industry is based on quality rather than price. Thus, successful competitors are those that are able to provide greater value to its customers. This can translate into wide variety of features and add-ons to existing equipment as well as the creation of altogether of new types of technologically advanced imaging equipment and systems. Some features of these new systems expected by healthcare facilities include and are not limited to higher image resolution, better storage/retrieval systems and diagnostic software.

2.1.2.2 Machine Vision

In the automated manufacturing and assembly sector, visual computing applications are known as machine vision. Machine vision systems, as defined by the

Automated Vision Association are the "devices used for optical non-contact sensing to receive and interpret automatically an image of a real scene in order to obtain information and/or to control machines or processes" (Matz, 1992). This type of automated technology which allows for images to be automatically captured and interpreted has a number of applications in the manufacturing sector such as process control, quality control, machine control and robot control (BCC, 2008).

Some of the industrial segments that are currently using machine vision in the manufacturing and assembly process are the automotive, consumer products, electronics, food & beverage, medical & pharmaceutical, packaging and robotics industries. Machine vision applications in the industrial production sector include detecting defects, monitoring production, and tracking, sorting and identifying parts (Cognex Overview, 2008). Machine vision systems can help production/manufacturing companies realize cost savings by eliminating production errors, lowering manufacturing costs and improving product quality (Cognex Overview, 2008). The benefits provided to companies with respect to speed, accuracy and cost have increased the popularity of machine vision systems amongst manufacturing and assembly firms. Machine vision systems also have a number of non-industrial applications. Some non-industrial applications include biometrics, security and surveillance, banking and postal, transportation, traffic management and road safety, medical lab automation, leisure and entertainment, and environment (BCC, 2008). In a highly competitive global market place, many companies are adopting such systems, as evidenced by the rapid market penetration of machine vision systems over the last decade in both industrial and non-industrial segments.

In 1996, the total market penetration for machine vision systems in the non-industrial segment was estimated to be between 6% and 8% (BCC, 2008). The market penetration had grown to 20% in 2006 and is projected to reach between 35% and 37% by 2012 (BCC, 2008). The non-industrial segment is expected to experience the greatest growth with its growth rate forecasted at 17% annually, translating to a market segment worth over $5.7 billion in 2012 (BCC, 2008). In 2006, the global market for machine vision systems was worth $8.1 billion and is expected to grow 10.9% annually to over $25 billion by 2012 (BCC, 2008). The industrial applications accounted for over two-thirds of the $9 billion 2007 global market (BCC, 2008). By 2012, the industrial segment is forecasted to reach $9.3 billion, which is more than 62% of the expected total global market.

The machine vision products that have seen the greatest growth between 2005 and 2006 were vision sensors (+144%), interfaces and cables (+74%) and software (+30%) (Schwarzkopf, 2007). Application-specific vision systems experienced a 0.5% decline in sales, possibly indicating a shift towards "off-the shelf" products as opposed to custom vision systems (Schwarzkopf, 2007). The manufacturing industry remains the largest consumer of vision products representing 84% of the turnover of vision products in 2006 (Schwarzkopf, 2007). Within manufacturing, the automotive industry accounts for the greatest share of the turnover of vision products with 29% (Schwarzkopf, 2007). While the manufacturing industry is the largest consumer of vision products, there are several significant non-manufacturing applications. For example, the non-manufacturing application of microscopy and life sciences accounted for 7% of overall machine vision revenue in 2006, just behind the printing industry (8%) and ahead of the

electrical/electronics industry (6%) (Schwarzkopf, 2007). The non-manufacturing applications segment is expected to experience the most rapid growth in the near future.

There are a large number of competitors in this industry, with a high concentration of competitors located in the European countries. The vast majority of vision companies are small and medium sized in terms of the number of employees. In fact, in 2006 the European Machine Vision Association (EMVA) reported that 42% of European machine vision companies had 10 or less employees and 35% had between 11 and 50 employees (Schwarzkopf, 2007). But, there are also a number of large-sized machine vision companies. EMVA reported that 7% of European machine vision companies had more than 100 employees (Schwarzkopf, 2007). And, the world's leading provider of vision systems, Congnex, headquartered in Boston, MA, currently has over 800 employees worldwide and generated 2007 revenues of $226 million. Congnex's key products include applications for error-proofing assembly and manufacturing tasks, detecting defects, identifying and tracking parts, robot guidance, and detecting surface defects in steel, paper and plastics (Cognex Key Facts, 2008). The growth seen in machine vision may well have been driven by a number of acquisitions (Meyer, 2008) such as Cognex's acquisition of Isys Controls in 1996 (Business Wire, 1996) and Electro Scientific Industries' acquisition of Applied Intelligent Systems Inc in 1997 (Fasca, 1997). Also, the industry has seen the entrance of a number of potentially strong competitors, the most notable firms being Microsoft and Intel (Computer Vision at MSRC, 2008) and (Machine Learning at Intel, 2008).

Despite the attractive market forecasts for growth in this industry, the first quarter of 2008 had other indications. According to the Automated Imaging Association's (AIA)

expanded machine vision index, which is composed of the 28 leading North American and European machine vision companies, the machine vision industry has been experiencing declining share prices since its peak in July 2007 (AIA, 2008). Paul Kellett (2008), an AIA Director, points out that year-to-year market fluctuations in sales volumes are basically due to economic conditions, as machine vision products are geared towards the type of companies whose performance is correlated with the performance of the economy. Based on the slowing U.S. economy and the possibility of a recession, 2008 market results are forecasted to be much weaker than 2007 (Kellett, 2008). Although economists predict weak GDP growth in the first two quarters of 2008, they also predict a slow recovery beginning in the third quarter of 2008 and stronger growth in 2009 (Kellett, 2008).

In addition to economic indicators, there are other drivers of change in this market. The long-term drivers of growth in the machine vision industry are highly dependent upon the technological advances made in machine vision products (Kellett, 2008). In other words, technological improvements that can provide greater utility for customers than existing products or previous versions can stimulate demand. For example, advancements in speed and accuracy of machine vision systems can provide cost savings for manufacturing firms. Also, long-term demand is created by the tendency to move towards stricter quality control, greater productivity and lower operational costs (Kellett, 2008). Finally, growth in this industry is also driven by the expansion of machine vision products to other application areas.

2.1.3 Goods Transportation Industry

The goods transportation industry is comprised of four key segments: express delivery, freight forwarding, logistics services and trucking, and includes both the ground and air transport of goods. The key customers of the goods transportation business come from the high-tech, pharmaceutical, textile, engineering, automotive & transport equipment, manufacturing, and financial services sectors. The manufacturing sector is expected to increase its usage of air and freight delivery services over the next few years. In fact, McKinsey estimates that 80% of manufactured goods will cross borders by 2020, up from the current 20% font ?(**Schreindorfer, 2006**). Likewise, the increase in e-commerce transactions and the development of the global economy will contribute to further growth in the goods transportation industry over the next decade.

The performance of the air delivery portion of the industry is closely related to world economic conditions. Therefore, a decline is expected in the growth rate of the air cargo business in 2008 as the U.S. GDP growth is likely to decrease to 1.9% in 2008 from 2.2% in 2007 (Orszag, 2008). Nonetheless, the GDP growth rate is forecasted to pick up in 2009 to 2.3% (Orszag, 2008). Another factor affecting the profitability of this business is the price of fuel. With fuel prices at a record high, the industry's competitors are seeking ways to cuts costs or to allocate some of the increase in operating costs to their customers. However, the industry's price elasticity of demand (-1.57) indicates that firms can only pass on the increase in costs to the consumer to a limited extent.

Some other drivers of growth in this industry include the mergers and acquisition of transportation companies in the international market space, diversification into other areas related to shipping such as supply chain management services and business

services, and technological enhancements. The technological enhancements enable delivery companies to provide better service to customers on key attributes such as speed and reliability. These enhancements include updating existing infrastructure to allow the delivery companies to meet customer expectations, provide value-added services to customers or reduce operational costs through modification of business processes. Some examples of technological enhancements over the last decade in the goods transportation industry include FedEx's parcel tracking functionality that permits customers to monitor the progress of their delivery and UPS's introduction of RFID (radio-frequency identification) systems to improve its customers' business processes.

The industry is characterized by a small number of dominant players. World-wide there are 19 key-competitors in the goods transportation industry, the top four being FedEx, DHL, UPS and TNT. In 2004, UPS dominated the U.S. domestic market with 48% of the market share, FedEx held 28% of the market, the second largest share (Schreindorfer, 2006). Although the U.S. domestic market is dominated by UPS, FedEx is the market leader internationally with 30% market share; DHL and UPS follow with 14% each (Schreindorfer, 2006). Together, these four competitors accounted for 95% of the 2004 domestic market and 70% of the international market (Schreindorfer, 2006). The total size of the domestic and international market in 2004 was $54.26 billion and $4.6 billion respectively (Schreindorfer, 2006).

The saturated domestic market and highly competitive international market has yielded intense rivalry in the world goods transportation industry. Some of the key attributes of this rivalry are customer focus, price, information technology and value-added services. The industry leaders have selected key attributes to differentiate their

products. For instance, FedEx has positioned itself as a premium delivery company as it provides superior service such as package tracking and the fastest express delivery service, allowing FedEx to charge its customers a premium price. UPS, on the other hand, has positioned itself as a leading provider of business solutions such as logistics, distribution and supply-chain management services, thus focusing on companies that have high volume shipping service needs.

Regardless of these companies' strategic positions in the market, an area that all four of these leaders have focused on is reducing operational costs. These companies incur enormous operating expenses each year, thus proportionally small reductions in operating costs can yield savings in the millions. These companies are therefore seeking ways to reduce operating costs through the improvement of business processes. This equates to enhancements of the internal IT infrastructure, and improvements to existing business models.

2.2   Market Opportunity

The opportunity that a specific market represents for the commercialization potential of the algorithm is a based on the key characteristics of both the market and the algorithm, and the synergies between them. The market opportunity is assessed through the evaluation of the market needs and the algorithm's ability to satisfy these needs, as well as the overall market potential of the algorithm.

2.2.1   Market Needs and Algorithm Fit

The algorithm provides a generic solution to the multi-way problem which has potential applications in a number of industries. The two fundamental aspects of the algorithm that

allows it to provide more utility than other multi-way solutions is its high level of precision and accuracy. Its performance on other dimensions, such as computer processing time, is not known at this point, but initial results suggest that it is comparable to existing algorithms.

The computer networking industry would use the algorithm to perform such tasks as assigning users to work stations, folders, servers, and assigning modules to processors. As the number of users and tasks increases, current networks are becoming congested, and are in turn affecting productivity and adding to operational expenses because of the need to constantly upgrade equipment such as servers to keep up with the ever increasing demands on the network. There is a clear need for a more efficient means of performing such tasks. The algorithm is a possible solution to the problem; it can optimize the performance of the existing network by efficiently completing these tasks. For example, the algorithm can be used to assign storage space to users while minimizing cost variables such as time and processing power. The increase in operational efficiency that is created by the algorithm can equate to savings in the millions for large corporations that heavily rely on networks to carry out day-to-day business processes.

A recent trend in network technology, however, has other implications in regards to the value provided by the algorithm. Cisco has noticed the importance of IT tools in the workplace; many employers are encouraging staff, partners and vendors to utilize IT tools to work together, as these types of interactions allow users to be more effective in their positions, which ultimately has a positive effect on the company's objectives (Carless, 2006). Such IT tools include blogs, wikis, social networks and collaborative applications (Carless, 2006). It is estimated that 15 million devices will be connected to

the internet by 2010 mostly due to the increase in the number of tasks being handled online, such as phone calls, searches, and downloads (Carless, 2006). Cisco Systems' CEO, John Chambers, points out that "More and more, we're using a network based, intelligent storage model in which resources are added to and deleted from the network independent of the applications they support. Instead of allocating storage to particular processor task, we just put it up on the network, make it available and the network can intelligently map which resources go with which application resources" (Carless, 2006). This change towards the network as a platform can result in a 20 to 30 percent increase in storage usage which leads to a large opportunity for an algorithm which can increase operational efficiency.

One key aspect of the trend towards the network as the platform is that the intelligence used to map which resources go with which application resources must be fast enough, because these types of internet applications must to be able to provide services in real-time to remain useful to the user. In other words, the intelligence used must maintain an acceptable level of speed, regardless of the number of tasks being performed at any given point in time. This condition has implications for the usability of the algorithm. Currently, it is not known exactly how fast the algorithm performs, although initial results suggest that the processing speed is similar to that of other algorithms. But, given the substantially larger volume of applications and applications resources being used at any given time, the algorithm must be able to allocate storage at an above average speed meaning that the algorithm must perform comparably well for one user using one application as for 1000 users using ten applications each. It is not known how well the algorithm performs in this respect, but it is known that, as the

number of sites and labels increases, the computation time also increases. This critical performance condition suggests that the algorithm is not the optimal product for the networking industry.

The medical imaging industry is another potential market for the algorithm. Growth in this industry is driven by advancements in technology that allow clinicians to better diagnose diseases and medical conditions so that treatment therapy can commence at an early stage when it is more effective and economical. The key feature of diagnostic medical imaging equipment that will allow clinicians to make more accurate diagnoses is image quality. Image quality is comprised of a number of features which include resolution, clarity, intensity, colour and texture.

For medical imaging applications, the algorithm will be able to, for example, determine which pixel in an image of internal organs belongs to either the kidney or the bladder. In other words, the algorithm can assign labels, in this case the particular organ, to sites (a specific pixel in the image) with a greater degree of precision and accuracy than any other algorithm. In addition, it can differentiate abnormalities such as diseased tissue or tumours within the organ. This increased accuracy and precision in labelling will produce images that exhibit a greater level of detail than images produced by other algorithms.

Better image quality is highly desired not just by the medical community and patients but also by the federal governments of countries where publicly-funded healthcare exists, such as the Medicare program in Canada and the Medicare and Medicaid programs for seniors and low-income individuals respectively in the U.S. As the baby-boomer population ages, the demands for medical procedures and care

increases, which creates substantially higher costs for running such government-funded healthcare programs. For example, in the U.S. it is estimated that 44 million seniors are covered by Medicare, and that running both the Medicare and Medicaid programs will cost the U.S. government $800 billion in 2008 alone (Reuters, 2008). A significant increase in the number of medical imaging diagnostic procedures will add to the already high costs of running such programs. Therefore, innovations that can potentially reduce the overall cost of the healthcare programs are in many cases supported by the country's government.

The images produced by the algorithm will allow medical professionals and clinicians to detect diseases and conditions at a much earlier stage, which will allow for early treatment and an overall better prognosis for the patient. It will also reduce the rate of misdiagnosis due to the difficulties encountered in interpreting images of poor quality. Early detection will result in considerable cost savings for private and publicly-funded healthcare facilities and clinics and can alleviate some of the key strains of an overburdened healthcare system. Savings will be realized from the reduction in expensive emergency care and treatment due to late detection. As well, issues such as hospital over-crowding for emergency care will, to some extent, be reduced. Additionally, waitlists for the diagnostic procedures themselves will be reduced, as better images will minimize the rate of misdiagnoses, retests and the use of multiple diagnostic tools.

The combination of an aging population, increasing healthcare costs, the stressed condition of healthcare programs in many countries and the current state of the quality of medical diagnostic images provide a clear market need for the algorithm. The algorithm satisfies the requirement for higher quality medical images through its performance on

the attributes that are critical in producing high quality images. The algorithm performs better than other algorithms on accuracy and precision, which allows it to produce superior images and hence makes it a good fit for the market.

The machine vision industry is another industry where the algorithm can be utilized. The machine vision industry is similar to the medical imaging industry in terms of its market needs. It also requires a high level of accuracy and precision in the images captured. However, the key difference between the two industries is that, in the medical imaging industry, images are captured and then viewed and interpreted by humans; whereas, in the machine vision industry, images are captured, analyzed and interpreted through artificial intelligence. Therefore, for machine vision systems, it is the quality of the data captured from the image rather than the image itself that is of importance.

The algorithm actually produces data in terms of the sites and labels before it is converted into an image, as in the medical imaging industry. So, the information collected on the sites and labels can then be inputted into another system that can analyze and interpret the data based on the task being performed. For instance, in a quality control setting, an image of the item being inspected will be captured; the algorithm will then produce data on this image which then will then be inputted into another system/process that will determine whether the item is defective or not based on the data produced by the algorithm and the specific quality attributes required of the item. Therefore, in order for the second step of data analysis and interpretation to be successful, the data inputted must be accurate and precise and be overall of high quality. The algorithm's flexibility will allow for the second data analysis and interpretation step to be easily integrated into to the algorithm.

Growth in this industry is driven by the expansion of machine vision systems into new applications areas or industries. The fastest growing machine vision segments are the non-manufacturing application segments. These segments include microscopy and life sciences, intelligent traffic systems, logistics and postal sorting, and security & surveillance. An industry that is increasingly moving towards machine vision systems for inspection processes is the pharmaceutical industry. The pharmaceutical industry has implemented machine vision systems to detect abnormalities in pills such as cracks and texture deformities. One feature that all of these segments have in common is that the image to be interpreted is either small or highly detailed, or both small and highly detailed. This trend towards detail implies that the data used for the analysis and interpretation process must capture highly detailed data. The algorithm satisfies these needs as it performs very well on the both the accuracy and precision dimensions.

The final industry short-listed as a potential candidate for the algorithm is the goods transportation industry. The goods transportation industry can best be described as being saturated and highly competitive. There are a small number of key players in this industry that co-exist because of the differentiated strategy implemented. However, the rising costs of everyday operations are effectively reducing margins and cutting into the profits of all of these firms. As such, companies are seeking ways to reduce operating costs through the improvement of business processes. One process that can utilize the algorithm is the determination of the shipping route for a package. The algorithm can be used to determine the most cost effective route and method (air, ground or both) to ship a package given a number of constraints such as maximum delivery time, distance, flight

schedule, hub location etc. The algorithm's ability to apply many constraints to an assignment task makes it a prime candidate for the application.

However, given the large number of constraints, it is difficult to determine whether the algorithm will be able to come up with a shipping route that is any different than what the company's current system would produce. For example, if a package were to be express delivered to a certain location within 24 hours, it is likely that there is only one route available that will satisfy not only the time constraint, but also the constraints of the hub location, and the flight schedule. So, in this case, the algorithm will not be able to generate any cost savings for the company because the route produced by the algorithm will be exactly the same as what the current system would produce, as there is only one possible solution to the problem.

The algorithm could potentially produce a solution that will yield cost savings in situations where there are fewer constraints or the constraints are relaxed. It is not exactly known what kind of algorithm or process courier companies use to determine shipping routes, thus making it difficult to determine exactly what kinds on improvements or saving the algorithm could provide. However, because of the limited number of routes a package can actually be shipped due to the constraints, it is believed that the algorithm will be at best an incremental improvement to the current method. This signifies that such a sophisticated, high performance algorithm is not necessary to assign shipping routes. However, because of the large volume of packages being shipped each and every day, even an incremental improvement in the process could yield enormous savings annually.

There is a clear need in this industry to minimize costs in order to remain competitive. However, there are many ways to achieve savings by optimizing operational

processes. The algorithm is a candidate for only one of these processes, shipping route determination, and can only provide an incremental improvement in this process. Yet there are many other business processes that can be improved upon and that can provide potentially larger savings for the company. Taking all these factors into account, the algorithm does not provide a good fit in terms its performance attributes and the market needs.

Out of the four industries considered, both the medical imaging industry and the machine vision industry appear to provide promising opportunities for the algorithm's commercialization. For both of these industries the key characteristics of the algorithm, which are high performance on accuracy and precision dimensions, satisfy the market needs. The goods transportation and computer networking industries on the other hand, do not present a good commercialization opportunity for the algorithm, as the algorithm does not provide a good fit to the needs of the markets.

2.2.2 Market Potential

Each of the four industries represents an opportunity for the commercialization of the algorithm. The computer networking, medical imaging, machine vision and goods transportation industries are all expected to see growth over the next couple of decades. However, the short-term outlook for all of these industries, with the exception of medical imaging, is not as favourable as their long-term potential. The reason being that growth in these particular industries corresponds closely to world economic conditions. Currently, U.S. GDP growth is expected to decrease to 1.9% in 2008 from 2.2% in 2007 (Orszag, 2008). Despite the unfavourable short-term economic conditions, substantial longer-term

growth is expected in all of these industries, thereby by creating a potential market for the algorithm.

Of the four industries, computer networking is by far the largest in terms of annual revenue. The 2007 total computer networking industry was estimated to be $60 billion (First Research, 2008). This revenue estimate is based on the sales of networking equipment such as switches, routers and network control equipment, network design, software development, installation, monitoring and maintenance, and other hardware and software products (First Research, 2008). The algorithm is in the form of computer code, so its implementation will occur through networking software computer programs.

Cisco Systems 2007 annual report (2007) reveals that products that do not include routers, switches and advanced technology accounted for 6.8% of Cisco's net sales for 2007 which is approximately $2 billion. Applying the very conservative estimate that 5% of the $2 billion in net sales were due to networking software, the net sales for networking software is estimated to be $100 million or 0.3% of Cisco's annual net sales of $30 billion. Applying this 0.3% to the annual industry sales of $60 billion, there is about a $180 million market for networking software, of which a proportion can be captured by the algorithm. These figures reveal that a large market potential exists for the algorithm in the computer networking industry.

The medical imaging industry is expecting growth over the coming years. The imaging equipment segment is expected to reach $16 billion by 2010 and the consumables segment, which includes film, cassettes, contrast, image plates and imaging software, is expected to reach $5.3 billion by 2010. Depending on the segment within medical imaging (scanners, x-ray etc.), the algorithm can either be incorporated directly

into the equipment or it can be sold separately as imaging software. Standard images are almost always produced by the equipment itself. Given that the algorithm is best used to create images rather than process them afterwards, the medical imaging equipment segment is most relevant for the algorithm. The exact size of the market for the algorithm is highly dependent on the type of commercialization plan such as licensing, or partnership etc. employed. Applying a conservative 4% royalty if the licensing route was chosen for commercialization, the total market size is approximately $800 million.

Growth in the machine vision industry is highly dependent upon economic factors; as such, its short-term growth is not favourable. The 2006 global market for machine vision systems was worth $8.1 billion. This figure reflects the sales of all machine vision products including sensors, interfaces and cables, software, cameras, lighting, and other accessories. The algorithm would be incorporated into machine vision software, thus software sales most accurately reflect the market potential for the algorithm. No exact figures were available specifically for machine vision software, so the conservative estimate of 5% applied to the 2006 machine vision global market gives an estimate of $405 million, which is approximately half of the medical imaging industry's total market potential.

In the goods transportation industry, the algorithm would be incorporated into the company's existing IT systems. This implies that the market potential for the algorithm in this industry will likely be based on some kind of partnership with the company that supplies the IT systems, a licensing agreement, or the sale of the algorithm to a single company competing in the industry. A computer networking company like Cisco is the most likely company to provide such IT services to goods transportation companies.

Therefore, based on a licensing agreement with such a networking company, applying a conservative estimate that 2% of the $180 million of computer networking software sales is due to the good transportation industry, and applying a further 4% for royalties, the total market potential equates to about $1.4 million, which is only a small fraction of the market potential for each of the other three industries.

2.3 Market Selection

The market most suitable for the commercialization of the algorithm is selected based on the total market opportunity it represents. Therefore, the key characteristics of both the market and the algorithm and the synergies between them are assessed. More specifically, the market needs and the algorithm's ability to satisfy theses needs, as well as the overall market potential are evaluated to determine the market most suitable for the algorithm's commercialization. The following section provides an evaluation of the market opportunity of each of the four candidate industries.

First, the synergies between the key characteristics of the algorithm and market needs are evaluated. There are four basic attributes, which, in combination, make the algorithm unique when compared to other algorithm solutions of the k-way problem. The first is its flexibility. The algorithm is designed in such a way that allows it to be implemented into virtually any type of application with little difficulty. The other key attribute of the algorithm is its superior performance on both accuracy and precision dimensions. The final attribute of the algorithm is its processing speed which is comparable to that of other k-way algorithms, but not exceptional by any means. Table 2.1 summarizes the major attributes of the algorithm and its corresponding level of performance.

Table 2.1: **Summary of algorithm's performance on key attributes**

Attribute	Performance Level
Flexibility	High
Accuracy	High
Precision	High
Processing Speed	Medium

Each of the four industries examined have particular needs which include a combination of a specific level of flexibility, precision, accuracy and processing speed. Table 2.2 summarizes the market needs for each of the four industries examined. These needs can then be matched against the attributes provided by the novel algorithm. Careful examination of the algorithm's performance on key attributes and the market needs reveals that both the medical imaging industry and the machine vision industry are good candidates for the algorithm's commercialization. The algorithm's performance attributes meets the needs of both of these industries. The computer networking industry on the other hand is not a good candidate, as the algorithm fails to meet its requirement for a high level of performance on the processing speed dimension. High processing speed is a critical performance requirement for this industry, as sub par performance on this attribute can essentially void any gains made on the other attributes. Finally, the algorithm's performance exceeds the requirements on all attributes for the goods transportation industry. This indicates that such an algorithm is not actually needed by the industry. A summary of the algorithms fit to the market needs is shown in Table 2.3.

Table 2.2:   Summary of minimum market requirements

Attribute	Industry			
	Computer Networking	Medical Imaging	Machine Vision	Goods Transportation
Flexibility	High	High	High	Medium
Accuracy	High	High	High	Medium
Precision	High	High	High	Medium
Processing Speed	High	Med	Med	Low

This evaluation of the market needs and algorithms ability to fulfill these needs has effectively eliminated two of the candidate industries. Evaluation of the market potential of the two remaining industries, machine vision and medical imaging, can determine the market most suitable for the algorithm's initial commercialization.

Both the machine vision and medical imaging industry are expecting growth. However, the performance of the machine vision industry is volatile, as it corresponds very closely to GDP growth. Hence, the short-term forecast for this market is not as favourable as its long-term outlook. The total size of the machine vision market for the algorithm is estimated to be $405 million, approximately half of the medical imaging market size for the algorithm. The medical imaging market is expected to see substantial growth over the next decade primarily due to the demand for better medical diagnostic

Table 2.3:   **Summary of algorithm's fit to market needs**

Attribute	Industry			
	Computer Networking	**Medical Imaging**	**Machine Vision**	**Goods Transportation**
Flexibility	✔	✔	✔	❯
Accuracy	✔	✔	✔	❯
Precision	✔	✔	✔	❯
Processing Speed	✖	✔	✔	❯

✔   performance meets market needs
✖   performance fails to meet market needs
❯   performance exceeds market needs

tools created by the aging baby boomer population. Unlike the machine vision market, the medical imaging market's performance is not as strongly influenced by economic factors, making forecasts more reliable. Moreover, both long-term and short-term performance projections are favourable and the total size of the market for the algorithm is estimated to be $800 million. Given that the market size in the medical imaging industry is twice that of the machine vision industry and that the performance of the machine vision industry is much more volatile, the medical imaging industry is selected as the market for the algorithm. Table 2.4 provides a summary of the algorithm's market potential in the machine vision and medical imaging industries.

Table 2.4:   Algorithm's market potential in the Machine Vision and Medical Imaging industry.

Industry	Market Size	Growth Rate (per annum)	Growth	Market Selection
Machine Vision	$405 million	10.9%	Volatile	✖
Medical Imaging	$800 million	6.8%	Stable	✔

✔   selected
✖   not selected

3 IN-DEPTH INDUSTRY ANALYSIS OF THE GLOBAL MEDICAL IMAGING MARKET

The analysis in the previous section revealed that the medical imaging industry presents the best opportunity for the algorithm's commercialization. The following section takes an in-depth look at the global medical imaging industry and examines specific market segments within the industry. Based on the results of the in-depth analysis, the segments that represent the best opportunity for the algorithm are identified.

3.1 Market Size and Segmentation

The medical imaging equipment industry is comprised of six main segments defined by product type: x-ray, magnetic resonance imaging (MRI), computed tomography (CT), ultrasound, nuclear medicine, which includes positron emission tomography (PET), and picture archiving and communication systems (PACS). The 2005 U.S. market size for medical imaging equipment totalled $11.5 billion and is projected to grow 6.8% each year to reach over $16 billion by 2010 (Freedonia, 2006). This growth is be driven by technological advances in equipment capabilities that enable healthcare facilities to provide more efficient and effective care (Freedonia, 2006). As well, the demand for medical imaging equipment will be partially driven by the expected increase in the volume of diagnostic tests due to the aging population (Freedonia, 2006). Finally, growth is also be driven by healthcare cost containment strategies, as the governments of countries with publicly funded healthcare programs seeks tools that allow for the early detection of diseases and conditions so that they can be treated more cost effectively.

The CT scanner segment is expected to see the strongest growth as medical facilities replace older scanners with newer models (Freedonia, 2006). The MRI and PET segments are also expected to experience strong growth driven mainly be the demand for advancements in technical capabilities (Freedonia, 2006). New generation MRI equipment advancements include shorter testing duration and better image resolution. Together these two features will satisfy the healthcare provider's objectives to provide better care and to contain costs. Enhanced images will allow clinicians to make more accurate diagnoses leading to prompt treatment therapy in the early stages of a disease or disorder, increasing the overall chance for patient recovery while cutting costs of expensive emergency treatment. The shorter testing time will enable healthcare facilities to shorten wait times for such diagnostic procedures; again improving the facilities overall ability to provide effective care to patients. The growth in the PET segment will largely be the result of the emergence of new hybrid PET/CT models which have advanced scanning capabilities and higher resolution images (Freedonia, 2006). Similar to the advancements in MRI, the new PET/CT hybrid scanners will allow facilities to improve patient care and reduce costs.

The X-ray market segment is expected to experience modest growth mainly due to the replacement of analog X-ray equipment with digital models (Freedonia, 2006). The nuclear medicine and ultrasound equipment market segments are also expected to grow modestly. However, growth will be driven both technological advancements in images and advancements in equipment design. New four-dimensional (4D) systems with advanced imaging capabilities have entered the market place; as well, the point of care

(POC) testing market will stimulate demand for hand-held devices and laptops in the ultrasound equipment market.

The world market for medical imaging equipment in 2002 (Table 3.1) indicates that the X-ray market segment held the biggest share of the medical imaging equipment market with 30%. The ultrasound, MRI and CT segments followed with 22%, 21% and 19% market share respectively. Nuclear medicine equipment held the smallest share of the market with just 8%. Other segments such as the non-medical application of picture archiving and communication systems (PACS) did not represent a significant segment in the world market. However, Gartner predicts that by 2008, 90% of U.S. healthcare providers will have adopted PACS (Heieb et al., 2004).

Table 3.1:   **The 2002 world market for medical imaging equipment**

Market Segment	2002 World Market (USD)	Market Share
X-ray	$4.5 billion	30%
Ultrasound	$3.4 billion	22%
MRI	$3.2 billion	21%
CT	$3.0 billion	19%
Nuclear Medicine	$1.3 billion	8%
TOTAL	$15.5 billion	100%

Source: Husing, Jäncke, & Tag, 2006

3.2 Market Segment Drivers and Trends

Growth is expected in the X-ray market segment as digital systems continue to replace analog systems. The analogue segment is still experiencing growth, but at a much lower rate than the digital segment (Monegain, 2008). One of the key trends driving growth in the X-ray market segment is the increasing rates of obesity and heart-disease. In fact Frost & Sullivan reports that the North American cardiac and vascular X-ray segment earned revenues of $756 million in 2006, and is expected to earn $894 million in 2013 (HIS, 2008). Technological advancements in digital image quality have supported the continued use of cardio X-ray machines (HIS, 2008). However, there is an increasing tendency for clinicians to utilize CT diagnostics over X-ray machines (HIS, 2008). This trend is expected to suppress the long-term prospects of the X-ray market segment.

The worldwide ultrasound market posted revenues of $3.97 billion in 2006, and is expected to surpass $4.5 billion in 2010 (Preleap, 2006). Growth in this market is driven in part by a new type of portable hand-carried ultrasound (HCU) device (Frost & Sullivan, 2004). These devices have made gains in specialty areas such as cardiology, radiology and OB/GYN essentially because of the high-performance, convenience and affordability these units offer (Frost & Sullivan, 2004). Growth can also be attributed to technological advancements in the area of image quality which has increased usage amongst surgeons, anaesthesiologist and emergency physicians (Frost & Sullivan, 2004).

The 2006 world market for MRI systems reached $3.5 billion and is expected to surpass $4 billion by 2010 (Health Imaging News, 2006). The preference of MRI systems for imaging organs and other structures such as the brain, spine, bones and joints have added to the growth seen in this market (Health Imaging News, 2006). Growth leading up

to 2010 will largely be the result of the expanded use of MRI systems to diagnose strokes and other brain injuries (Health Imaging News, 2006). Other application areas that are moving towards MRI systems for diagnostics include breast MR, body imaging and vascular imaging (Harvey, 2004). The types of MRI machines that are making the greatest market gains are higher field systems which produce higher quality images and require shorter testing times (Harvey, 2004).

The CT scanner segment is expected to lead the growth in the medical imaging equipment market (Freedonia, 2006). This growth is primarily the result of replacing older scanners with new advanced versions as innovation cycles for CT scanners become shorter (B Divya, 2007). The technical innovations for CT scanners are primarily increases in slice capacity. Multi-source and dual-source scanners have entered the market over the last decade, and the 256 slice scanner is expected to be launched in 2009 (B Divya, 2007). The benefits of increased slice count are application dependent, but in general, a higher slice count translates into higher quality images and faster testing time. The new 256 slice scanner is expected to be able to able to scan the entire heart in just one beat which will produce images superior to current scanners that take many more beats to produce a scan(B Divya, 2007). Application areas that CT scanners show preference over other diagnostic testing systems include oncology, pulmonology and liver imaging (B Divya, 2007). However, despite the advancements in image quality and testing speed, the high levels of radiation that are produced by CT scanners have made MRI the preferred tool for certain uses such as whole body scanning (B Divya, 2007).

The PET scanner market is also forecasted to grow at a strong pace mainly due to the introduction of hybrid PET-CT systems. In 2003 the total size of the U.S. PET and

CT-PET market was $505 million, of which 78% was accounted for by the hybrid CT-PET model (Husing et al., 2006) reflecting the trend towards the hybrid system. These hybrid systems allow healthcare facilities to cut costs as both radiology and nuclear medicine departments can make use of them (Frost & Sullivan, 2004). Hybrid models also provide superior image quality that allow for better diagnosis of cancer which due to its localized nature has previously been difficult to detect (Frost & Sullivan, 2004). These enhancements in image quality have enabled healthcare facilities to not only provide better care to patients but also provide more cost-effective treatment.

3.3 Market Segment Selection

All of the medical imaging market segments represent an opportunity for the algorithm's commercialization. However, based on the market segment trends and key drivers of growth, some segments present a better opportunity than others. The following section compares the six segments and provides a short list of the market segments that offer the most promising opportunity for the algorithm's commercialization.

Each of the six market segments represents a substantial market potential for the algorithm. In comparison to the other segments, nuclear medicine systems (PET scanners, PET-CT hybrid scanners) (Table 3.1) is the least significant, with only 8% of the 2002 world medical imaging equipment market; but even this is a billion dollar market (Table 3.1). All market segments are expected to exhibit growth in the short term. The three underlying drivers of growth that all six segments have in common are the aging population, technological advancements in systems and healthcare cost-containment strategies.

The X-ray market segment held the biggest share of the 2002 world medical imaging market with 30%. However, growth in this market has substantially decreased over the years despite its increased use in cardiac and vascular applications. One of the key drivers behind the observed trend is the preference for other diagnostic imaging tools such as CT scanners. CT scans provide higher resolution images providing medical professionals with the level of detail necessary to make a diagnosis. Although it is unlikely that X-ray technology will become obsolete in the next couple of decades as it does provide a quick method to diagnose certain types of injuries such as broken bones and fractures, the technology will be used far less for cardiac and vascular applications.

This market segment provides only a limited opportunity for the algorithm not only because of the decreasing demand for X-rays, but also because of the technical limitations of X-ray technology itself. X-ray technology provides a single two dimensional image of a three-dimensional entity. This type of image gives medical professionals a limited view of the human anatomy making it an inadequate tool for diagnosing many types of diseases and disorders. In other words, a higher quality image, or even amore detailed image will have its limitations in terms of diagnosing conditions, hence the reason for its limited use. Taking these facts into consideration, the X-ray segment does not present a good commercialization opportunity for the algorithm

The ultrasound market segment is expected to continue to grow; the key drivers behind its growth include design enhancements, increased affordability, and better image quality. The new portable ultrasound devices have become popular in certain specialties and amongst particular user groups. Ultrasound devices are attractive for certain uses because they offer convenience and real-time imaging without sacrificing too much on

image quality. Also, the test time for ultrasound procedures is five to ten minutes on average, far less then other imaging tools such as MRI and CT scans. The use of ultrasound devices are expected to further penetrate these groups as well as expand into other areas and user groups. The ultrasound market segment presents a good commercialization opportunity for the algorithm as improvements in image quality is at the forefront of growth in this market segment.

MRI usage has been increasing over the last decade due to increased image quality and shorter testing times. Although image quality has increased substantially, and in some application areas very high resolution images are being produced, there is still a demand for higher resolution in specific areas such as brain scans. This demand for better image quality offers an opportunity for the algorithm's commercialization. Furthermore, the advances made in actual test time and processing time provide support for the expanded use of MRI to other areas.

The sale of CT scanners is forecasted to lead growth in the medical imaging industry. Faster scanning times have not only increased the efficiency of running such tests, but have also lead to the improvements made to CT images themselves by minimizing the effects of motion on image quality. CT scans are also the preferred diagnostic testing tool for applications such as oncology. CT images provide enough detail that allows clinicians to detect small dense masses within and surrounding organs, a typical characteristic of tumours. The algorithm can create more detailed images as it can further enhance organs and tissues from tumours. With the increasing incident and prevalence rates of cancer, CT scanner usage and demand will continue to rise, effectively providing an opportunity for the algorithm's commercialization.

The nuclear medicine market segment is the final segment in the medical imaging industry. This segment is primarily composed of PET type of machines. Hybrid PET-CT machines have accounted for the vast majority of sales in this segment. Hence similar market drivers in the CT market segment lead growth in this market. The PET market segment therefore, offers an opportunity for the algorithm's commercialization that is similar to the CT market segment. Table 3.2 summarizes the uses of the different medical imaging devices, the growth drivers, and the algorithm's commercialization potential.

Table 3.2: Summary of market segment characteristics and commercialization potential.

Market Segment	Application Areas	Growth	Market Needs & Growth Drivers	Commercialization Potential
X-ray	- Human anatomy - Cardiac and vascular applications	↓	- Quick and easy test that provides adequate detail for an initial diagnosis	✘
Ultrasound	- Cardiology - Radiology - OB/GYN	↑	- Convenience - Real time diagnostics - Quality images - Affordability	✔
MRI	- Brain/spine - Bones/joints - Body - Vascular	↑	- Shorter test time - Quality images	✔
CT	- Oncology - Pulmonology - Liver	↑	- Shorter scan time - Quality and detailed imaging	✔
Nuclear Medicine (PET/PET-CT)	- Oncology	↑	- Quality images with emphasis on small details - Cost effectiveness	✔

4   BARRIERS TO COMMERCIALIZATION

The market analysis revealed that the algorithm does have commercial potential in the medical imaging market. However, as with the commercialization of any product, there are a number of factors that can impact the product's ability to capture the market. The following section identifies the technology and market barriers the algorithm could encounter in its path to commercialization. The overall attractiveness of the medical imaging industry is also evaluated.

4.1   Factors Impacting Commercialization

4.1.1   Technology Challenges

The algorithm is currently available in the form of computer code and thus represents relatively few technology challenges. However, there are some challenges that must be considered when determining the optimal commercialization route for the algorithm. The algorithm can be incorporated either directly into the medical imaging system's software or can be an add-on to the system as a separate piece of software.

The challenge with the first option of incorporating the code directly into the system software is ensuring that it can be integrated with all aspects of the system without creating bugs in other areas or modules. However, upgrading system software with new modules or functionality is a natural process in software development life cycle, and thus does not represent a significant challenge to the algorithm's commercialization.

As well the algorithm is flexible in that it can easily be integrated with other system processes.

The challenge that faces the second option of creating a separate add-on to the existing imaging system is compatibility. The new software must be compatible with the existing system. However, creating applications add-ons for specific systems or software is also a normal occurrence in software development and thus does not pose a huge challenge for the algorithm. As long as the specifications of the medical imaging systems are available, software developers can create compatible software.

Perhaps the biggest challenge will be ensuring the medical imaging system's hardware possesses the necessary processing speed that allow for images to be created in a reasonable amount of time. In many of the market segments identified, huge advancements in the speed of test acquisition and image processing have been made, which have allowed for the quality images that are produced today. In most market segments, the hardware's ability to iterate through the algorithm's complex calculations does not create a problem because the images are formed after the data is acquired by the medical imaging device. But, in segments such as ultrasound where the images are in real time, the hardware's processing speed might become an issue. Even a small lag in the time between acquiring the image and displaying the image can completely eliminate the utility of the device. This hardware issue presents a significant barrier to commercialization in the ultrasound segment. Thus, there is a need to evaluate whether the current specifications of such devices are adequate for the algorithm or whether further improvements to the devices' hardware systems are necessary for the algorithm to be useful.

4.1.2 Market Challenges

The market itself does not present a significant challenge for the algorithm as the devices that it will be incorporated into or be used in conjunction with have already been in use for decades. Furthermore, the market needs analysis reveals that image quality is of high importance and a distinct trend towards better image quality has been observed in the industry. Also, the governments of countries with publicly-funded healthcare programs have initiatives in place to further advance medical imaging technology. Hence, the algorithm can be tested and refined with support from the entire healthcare industry which includes healthcare facilities, clinicians and government agencies.

4.2 Competitive Forces in the Medical Imaging Industry

The following section evaluates the overall attractiveness of the medical imaging industry by analyzing the competitive forces at work within the industry. Porter's (1985) five-forces framework is the basis of this evaluation, which examines the rivalry of the competitors in the industry, the bargaining power of suppliers, the bargaining power of buyers, the threat of new entrants into the industry and the threat of substitutes. According to Porter's (1985) framework, an attractive industry refers to as one that is profitable now and likely to be so in the future.

4.2.1 State of Rivalry

The medical imaging industry is dominated by a small number of firms effectively creating an oligopoly. The key players in this industry include, GE Healthcare, Philips Medical and Siemens Healthcare. Together these companies account for the vast majority of the revenues earned in the medical imaging industry. These three market leaders

compete in a number of medical imaging segments. For example GE Healthcare offers a full range of medical imaging products including ultrasounds, CT scanners, MRI, PET and PET-CT. Philips and Siemens also offer a wide range of imaging products. However, the differentiation strategy employed by these firms is largely based on customization and services provided, rather than price.

One of the key characteristics of the medical imaging industry that creates a favourable environment for its competitors is the fact that there are a number of unique customer segments within the industry that demand a particular type of product. The key customer segments in this industry include large hospitals, small community hospitals, private clinics and physicians' offices. Clearly, the types of medical imaging devices required by large hospitals are quite different than the ones required by a small clinic. For instance, a small clinic would prefer a device that is affordable, of smaller size and portable, whereas a large hospital will require a device that is durable, of high image quality, and faster in terms of testing time.

For the most part, medical imaging equipment is customized for the purchasing institution. The complexity of medical imaging devices requires equipment to be sold in packages that include the medical device, external hardware components, software, and services. This complexity and customization enhance the opportunity for differentiation created by the customer segmentation observed. The required customization also creates an opportunity for the large number of small firms that are also competing in the industry by essentially creating small niche markets for imaging components and software. The combined characteristics of the medical imaging market create a mild state of rivalry, which enhances industry attractiveness.

4.2.2   Buyer Bargaining Power

Buyer bargaining power is relatively limited in this industry across all customer segments; however it does exist to a greater extent in the large institutional customer segment. Small institutions and clinics on the other hand, have little or no bargaining power as medical imaging equipment is essential for their daily business activities and there are only a small number of firms from which such equipment can be purchased. In addition, the small quantity of equipment and the relatively lower price of the equipment being purchased do not offer a basis for any sort of bargaining power for the purchasing firm.

On the contrary, the level of buyer bargaining power is significantly higher for large institutions such as hospitals. Large hospitals buy much more equipment (i.e. ultrasound, MRI, CT, and PET) and higher priced equipment than small institutions, and they can purchase the same range of equipment from any one of the other leading medical imaging firms. These combined factors contribute to the buyer bargaining power of large institutions. However, the major players in the industry have effectively minimized the extent of this buyer power by creating high switching costs for their customers.

The key players in this industry have invested in creating strong relationships with their customers. They understand their customers' needs and requirements which enable them to provide better service and minimize their customers' need to hire external consultants. Also, medical imaging equipment is complex and requires a great deal of training; thus, purchasing equipment from another firm would require a considerable investment to re-training staff. Finally, the major players not only sell the imaging equipment but they also sell complementary products such as components and software. This means that customers' would also have to purchase these complementary assets if they switch to another supplier which again translates into a significant capital investment. The high switching costs created

by the competing firms have effectively limited the buyer bargaining power in this industry which contributes to its attractiveness.

4.2.3 Supplier Bargaining Power

The supplier bargaining power in the medical imaging industry is almost nonexistent as the competitors in this industry manufacture their own products. Additionally, the components that are required as inputs to manufacture such devices are largely commodities which mean that they can be purchased from a large number of suppliers.

4.2.4 Threat of Substitute Products

Medical imaging devices allow clinicians to diagnose medical conditions and diseases that cannot be detected by any other method or by any reasonable means. For example, tumours can only be detected through the use of medical imaging equipment or surgically. What's more, conditions like fractures are solely diagnosed by medical imaging equipment. Although doctors could increase their reliance on their own judgement and physical examinations for a few conditions such as ligament injuries, for many diseases and conditions there are no substitutes for medical imaging devices. This contributes strongly to the attractiveness of the industry.

4.2.5 Threat of Entry

The threat of entry into this industry is relatively low as there are significant barriers for new entrants to overcome. Incumbents in this industry have made huge investments in creating relationships with customers, developing a strong sales force, creating a brand image, investing in R&D and establishing distribution channels, as well as developing other complementary assets. These complementary assets present a significant barrier to

new entrants as they have taken a long time and a huge capital investment to establish. These complementary assets have also enabled the market leaders to create high switching costs for customers, making it difficult for new entrants to compete in the market.

The major players in the medical imaging industry also offer a full range of other healthcare products and services. For example, GE Healthcare also offers surgical equipment, healthcare IT systems, clinical systems, medical accessories & supplies and lab equipment. This has made these major players a one-stop-shop for healthcare institutions, allowing them to offer a level of convenience and expertise that a new entrant simply cannot match. Still, there is a general trend in the healthcare industry towards integrated solutions, meaning that the major players now provide everything from diagnostic equipment to IT systems in an integrated solution, which has previously been unavailable. This move towards integrated solutions intensifies the switching costs observed, effectively creating huge barriers for new entrants specializing in any one of the product segments.

Previously, small firms providing niche devices and software applications were able to compete in the industry. But, the move towards providing end-to-end solutions for healthcare facilities has led the three market leaders to enter these types of product spaces. With the market leaders now providing essentially all types of products required for medical imaging and the healthcare industry in general, it has become increasingly more difficult for small firms specializing in a particular product area such as software applications to remain competitive. The strong complementary assets of the market

leaders and the high switching costs in the industry have effectively created substantial barriers to entry into any aspect of the industry.

4.2.6 Summary of Porter's Five-Forces Analysis

The competitive analysis reveals that the medical imaging is an attractive industry for incumbents. The industry is characterized as having mild rivalry, relatively limited buyer bargaining power, extremely low supplier bargaining power, no substitutes, and little threat from new entrants. There are a number of features in the medical imaging that contribute to its attractiveness.

First of all, the customer segmentation provides an opportunity for differentiation based on customization which has created only a mild state rivalry amongst the three major players in the industry. Secondly, the sophistication and complexity of medical imaging equipment has created high switching costs for customers which has minimized the extent of their buyer bargaining power. In addition, the inputs used to manufacture medical imaging equipment are largely commodities, eliminating supplier bargaining power. Finally, the threat of entry is low as the medical imaging industry is capital intensive and incumbents have made heavy investments in their complementary assets creating an environment in which it would be difficult for new entrants to compete. Together, these factors contribute to the overall attractiveness and profitability observed in this industry.

5 COMPARISON AND EVALUATION OF STRATEGIC ALTERNATIVES

The following section compares and evaluates the commercialization routes available for the algorithm. The market segments are evaluated based on the identified barriers to commercialization. The analysis of the competitive forces in the industry is the basis for the evaluation of the different commercialization routes available to the algorithm.

5.1 Evaluation of Market Alternatives

The following section identifies the key market characteristics that are necessary for the algorithm's successful commercialization. Using these characteristics as criteria, the four market segments are evaluated. This evaluation determines which market segments offer the best opportunity for commercialization.

One of the key barriers to commercialization that was identified for the ultrasound market was the technology challenge with which the algorithm would be faced. Therefore, an important criterion for evaluation would be the degree of technological challenges the market would present. Another factor that is important for determining which market segment represents the best opportunity is whether a specialized area within the market segment could benefit from the algorithm. For example, one of the areas that utilize CT scanners is oncology and improvements to image quality in this area will greatly increase the utility of CT scanners. Visible success in one area can significantly increase the chances of this algorithm being adopted into other application

areas within the segment and to other segments. Therefore, it is important that the market offers a unique opportunity for success.

Four market segments within the medical imaging industry have been identified as representing a commercialization opportunity for the algorithm. The four market segments are ultrasound, MRI, CT and nuclear medicine. These four market segments share a large number of characteristics; nevertheless key differences exist between these market segments with respect to the evaluation criteria identified.

Technological challenges pose a problem to the commercialization of the algorithm in the ultrasound market. It is unknown whether the current hardware specifications can capture and display images created by the algorithm in real time. The other three segments do not face this type of technological challenge as the images are created after the data is collected. In addition, unlike for ultrasounds, clinicians view the MRI, CT and PET images some time after the test has been administered.

The other criterion for success is the presence of a specialized or focused application area that can provide a means for measurable success. All of the medical imaging segments contain specific application areas where the algorithm can be initially introduced. However, unlike the other two segments, the CT and the nuclear medicine segments focus on oncology applications. Oncology diagnostics would provide the greatest benefits through improved images.

Table 5.1 provides a summary of market criteria and the relative ranking of the market segment for the specified criterion. The summary suggests that the CT and PET & PET-CT market segments present the best opportunity for the algorithm's commercialization. The technological challenges in these markets are at worst minimal,

and both segments service oncology application areas which would benefit the most from improvements in image quality.

Table 5.1:   Summary of the evaluation of market alternatives.

Evaluation Criteria	Ultrasound	MRI	CT	Nuclear Medicine (PET/PET-CT)
Technology Challenge	2	1	1	1
Specialized area requiring improvement	3	2	1	1
Rank	3	2	1	1

1=best choice, 5=worst choice

5.2   Evaluation of Commercialization Alternatives

The following section identifies the key characteristics of the commercialization alternatives that are necessary for the algorithm's successful commercialization. Using these characteristics as criteria, the three possible commercialization routes are evaluated. This evaluation determines which commercialization path offers the greatest opportunity for long-term success.

There are basically three criteria that will contribute to the algorithm's success. First of all, the commercialization alternative must be able to provide access to industry technology experts. Medical imaging equipment is very complex and access to

knowledge in this area is necessary to develop and refine the algorithm such that it meets

the requirements of the customers. Secondly, the commercialization alternative must be

able to provide access to medical imaging equipment so that the algorithm can be tested.

Finally, the alternative must be able to provide a means to distribute the algorithm to the

customers. There are basically four choices when it comes to the commercialization route

possibilities. They are to 1) enter the medical imaging market alone as a new business

entity, 2) form a partnership with an existing firm, 3) licence the algorithm to another

firm or 4) sell the algorithm to an interested organization. Each of these

commercialization paths presents challenges for successful commercialization.

Entering the medical imaging industry alone presents many challenges, the most

obvious being the barrier created by the industry characteristics. The industry is

dominated by three large players that have invested heavily in complementary assets such

as R&D, distribution channels, sales force, customer relationships and branding. These

characteristics represent a significant barrier for new entrants. However, the industry also

has a large number of small firms competing. These small firms provide niche products

to the industry such as specialized application software. Thus, it is possible to pursue

commercialization by entering the industry alone. However, the criteria identified must

be met to overcome some of the barriers created by the industry.

If commercialization is pursued by entering the industry alone the algorithm must be

sold as a separate add-on application software. This still requires access to industry

technology experts that can provide information on the hardware systems of the imaging

devices and the complexities of the processes that create the medical images. This

information is imperative to create a software application that is compatible with different

versions of the medical imaging equipment. Moreover, access to the medical imaging equipment to test and refine the software is unlikely when commercialization is pursued alone, because this equipment is very expensive. Finally, the industry characteristics make it difficult to capture customers once the software is available. Each of these factors greatly diminishes both the short-term and long-term prospects of the algorithm.

The second commercialization choice is to form a partnership with one of the major players in the industry. This alternative meets all the criteria that are necessary to successfully commercial the algorithm. A partnership will provide access to the technical expertise that is required to develop the algorithm for commercialization. The partner, which has developed the medical imaging equipment, can provide all the data and knowledge that is necessary to transform the algorithm into a commercial product, whether that is application software or an integrated piece of system software. Finally, a partnership will be able to offer the same distribution network and sales force to sell the product, which is very important given the barriers to entry in this market. This alternative creates an opportunity that not only provides a route to the long-term success of the commercial product, but also provides a faster route to commercialization, as the knowledge, expertise, equipment and customers are readily available and accessible.

The third option, which is licensing, will only provide short-term success. The licensing option does not require access to industry expertise, medical imaging equipment or distribution channels as the algorithm can be licensed in its current form. However, the licensing agreement is not likely to provide long-term success because the company licensing the algorithm can make changes to it in its second generation software or systems, which will not require royalties to be paid. In some instances, this situation can

be prevented through intellectual property rights and patents; however, this type of protection is also not adequate in many situations, particularly for software providers. Therefore, depending on the goal of the algorithm owner, a licensing agreement is a viable option.

The final option, which is selling the algorithm to an organization, will only produce short-term success. Much like the licensing option, it does not require access to industry expertise, medical imaging equipment or distribution channels as the organization that has bought the algorithm will be responsible for creating the commercial product and selling it. Thus, revenue will only be earned for the algorithm's owner from its initial sale regardless of the product's success. At the same time, it is possible for an organization to purchase the algorithm and not pursue its commercialization. Many companies collect intellectual property to eliminate the possibility of competition from new competitor products using the algorithm's technology in existing or upcoming products. In other words, this option of selling the algorithm may not even result in its commercialization. Consideration of all of these factors, as presented in table 5.2, the best commercialization route for the algorithm is forming a partnership with a major player in the industry.

Table 5.2:   **Summary of the evaluation of commercialization alternatives.**

Evaluation Criteria	Alone	Partnership	Licensing Agreement	Selling
Access to industry expertise	✘	✔	—	—
Access to medical imaging equipment	✘	✔	—	—
Access to distribution channels	✘	✔	—	—
Long-term success	✘	✔	✘	✘

5.3   Summary of Evaluation

The evaluation of the strategic alternatives reveals that both the CT and the nuclear medicine market segments present the best opportunity for the algorithm's commercialization. Both these segments provide a specific application area that can greatly benefit from the image quality improvements enabled by the algorithm. In both of these market segments there is a need in oncology to better detect small dense masses of tumours. The algorithm provides a means to enhance images with such features. In addition, these two markets present no technological barriers.

   The evaluation of the commercialization routes reveals that a partnership with a major medical imaging equipment OEM is the only alternative that can provide the long-

term success of the commercialized product. A partnership provides the industry expertise, access to equipment and access to customers that are necessary to develop the algorithm into a product to sell. The major players in the medical imaging market are GE Healthcare, Philips Medical and Siemens Medical.

6 OVERVIEW OF POTENTIAL PARTNERSHIP COMPANIES

The evaluation of the strategic alternatives in the previous section shows that entering into a partnership with one of the three major players in the industry presents the best opportunity for the algorithm's long-term success. Each of the three major players presents a unique opportunity for the algorithm's commercialization that must be taken into consideration when pursuing a partnership. The following section provides an overview of the three market leaders in the medical imaging industry: GE Healthcare, Philips Medical and Siemens Healthcare.

6.1 GE Healthcare

GE Healthcare is one of the six operating segments of General Electric Company (NYSE: GE). In 2007, GE Healthcare received nearly $17 billion in revenues, up 3% from the previous year, and earned $3.1 billion in profits in 2007, 3% lower than 2006 (GE, 2007). The increase in revenue observed in 2007 can be attributed to the higher volume of sales in the international diagnostic imaging, clinical systems and life sciences business divisions (GE, 2007)

Headquartered in the United Kingdom, and with over 46,000 employees worldwide, GE Healthcare provides healthcare products and services to over 100 countries (GE Healthcare , 2008). GE Healthcare's areas of expertise include medical imaging and information technologies, medical diagnostics, patient monitoring systems, performance improvement, drug discovery and biopharmaceutical manufacturing

technologies (GE Healthcare, 2008). The bulk of GE Healthcare products have applications in the diagnosis, treatment and monitoring of diseases and conditions emphasizing GE's vision of an "early health" model of care where the focus is on products that allow for the early detection of diseases so that patients have the greatest chance of recovery (GE Healthcare, 2008).

GE Healthcare is comprised of six business units, with each focusing on a specific aspect of the healthcare industry. The major products of these business units include diagnostic imaging systems (MRI, CT scanners, PET scanners, X-ray, nuclear imaging, and ultrasound), patient monitoring systems, diagnostic cardiology equipment, bone densitometry, aesthesia, oxygen therapy systems and neonatal and critical care devices (GE, 2007). Some of the key services that GE offers include equipment monitoring and repair, and IT solutions (, 2007). Other complementary products offered by GE Healthcare include imaging agents, biopharmaceutical purification products, protein and cellular analysis tools (GE, 2007). Appendix A summarizes the key products and services provided by each of GE Healthcare's business units. GE Healthcare's key customers are located worldwide and include hospitals, medical facilities, pharmaceutical, biotechnology and life sciences companies (GE, 2007).

6.2   Philips Medical

Philips Medical is one of the four divisions of Philips Electronics. In 2007, Philips medical grossed €6.5 billion in revenue and had earnings of €875 million (Philips, 2007). Philips experienced strong growth in the ultrasound, and the monitoring and customers services segments, but also experienced an overall decline in the sales of its imaging products largely due to the slowing U.S medical imaging market (Philips, 2007). Despite

the unfavourable performance of the imaging product segments, Philips did observe above average growth in a number of markets. In fact, much of Philips Medical's observed growth can be attributed to its focus on capturing key emerging geographic markets such as China, India and Latin America (Philips, 2007).

Philips Medical is headquartered in Andover, Massachusetts and Best, Netherlands with 33,000 employees worldwide and operations in 63 countries (Philips, 2008). Philips offers a wide variety of medical products including imaging systems, cardiac and monitoring systems, IT solutions and customer service (Philips, 2008). The focus of Philips healthcare products has been on providing a faster and more accurate means of diagnosing and treating diseases and conditions (Philips, 2008).

Philips Medical is composed of four divisions with each offering a particular set of products and services. The products offered by Philips Medical divisions include x-ray, ultrasound, MR, CT, nuclear medicine, PET, radiation oncology systems, patient monitoring, information management and resuscitation products (Philips, 2008). Philips also offers a number of services including training, education, business consultancy, financial services and e-care business services (Philips, 2008). Appendix B summarizes the key products and services provided by each of the four business divisions. To further enhance its product offering, Philips has invested in three affiliate companies, again with each focusing on a specific aspect of the healthcare industry (Philips, 2008) (Appendix B).

6.3   Siemens Healthcare

Siemens Healthcare is one of three sectors that comprise Siemens AG, Europe's largest engineering conglomerate and is composed of three business divisions which are imaging, laboratory diagnostics, and healthcare IT. In 2007, Siemens Healthcare grossed €9.8 billion in revenue up 6% from 2006 and earned €1.3 billion in profits, up 34% from 2006 (Siemens, 2007). These results can be attributed to Siemens' diagnostic imaging business, which yielded higher earnings and profits than the previous year, despite the slowing U.S. medical imaging market (Siemens, 2007).

Headquartered in Erlangen, Germany, with a team of over 8,000 researchers worldwide and operations in 138 countries, Siemens Healthcare offers a broad portfolio of healthcare products, services and solutions. Some of the key application areas that Siemens Healthcare provides products and services in include, diagnostics, therapeutics, clinical IT and audiology technologies (Siemens, 2007). This broad offering has allowed Siemens Healthcare to become one of the world's leading providers of products and services in the healthcare industry (Siemens, 2007). The recent acquisition of Dade Behring in 2007 has made Siemens Healthcare the first fully integrated diagnostic company in the world offering imaging and laboratory diagnostics as well as clinical IT (Siemens, 2007).

Siemens' strategy for growth over the next few decades is focused on patient-centric solutions as the demand for healthcare is forecasted to increase substantially due to the rapidly growing global population and the demographic shift in many countries (Siemens, 2007). Siemens expects to capitalize on the global population trend by focusing on increasing the efficiency of preventative care, early detection, diagnostics,

therapy and follow-up through innovative application technologies and healthcare IT solutions (Siemens, 2007).

In the short-term, Siemens Healthcare expects to continue to make improvements to their line of imaging devices such as CT scanners, MR and ultrasound systems (Siemens, 2007). As well, Siemens expects to develop new and innovative laboratory techniques and applications such as its MR/PET system which can detect diseases like Alzheimer's before the first symptoms ever appear. Finally Siemens, offers advanced IT networks that can link clinical data to eliminate communication barriers between hospitals, doctors' offices, pharmacies and insurers (Siemens, 2007). Currently, Siemens is focusing on integrating the innovations in each of its business units to provide fully personalized medical care – which is in line with its long-term growth strategy of patient-centric solutions (Siemens, 2007). Appendix C provides a summary of Siemens Healthcare's business divisions.

7 RECOMMENDATIONS

The analysis reveals that the algorithm definitely possesses market potential and that its commercialization should be pursued. The preliminary analysis of the potential industries for the algorithm indicates that the industry that offers the best opportunity for the algorithm is the medical imaging industry with respect to the industry's needs and the algorithm's ability to fulfill these needs. The in-depth analysis of market segments within the medical imaging industry showed that, in terms of equipment use, growth drivers and market trends, all medical imaging segments, except for the x-ray segment, provide an opportunity for the algorithm's commercialization. Finally, the barriers to commercialization were evaluated on the basis of the technological challenges and market challenges present, as well as the characteristics of the competitive forces in the medical imaging industry. The evaluation indicates that the medical imaging industry presented almost no market challenges and very few technological challenges to the algorithm's commercialization, with the exception of the ultrasound market segment. Further analysis was conducted to determine the best commercialization course for the algorithm which has yielded the following three recommendations for pursuing commercialization.

First of all, it is recommended that, for the initial attempt at commercialization, the CT market segment and the nuclear medicine market segment for PET and PET-CT hybrid imaging systems be pursued. Both of these market segments present almost no market challenges and very few technological challenges for the algorithm's

commercialization. Also, CT scanners and PET-CT hybrid systems are currently the fastest growing segments in the medical imaging industry and are forecasted to continue to grow over the next few decades, providing an opportunity for the algorithm's short-term and long-term success.

It is also recommended that oncology should be the specific application area that is initially pursued when attempting commercialization of the algorithm. Oncology is an area that requires substantial improvements with regards to the current state of the quality of images produced by CT and PET-CT hybrid scanners. The current issue with the image quality for oncology applications is that the images produced do not provide the necessary level of detail to detect small, localized dense masses of cells that are typical of tumours. These types of images are expected to show significant improvements via the application algorithm. Therefore, the oncology application area provides a platform for the algorithm to successfully demonstrate its ability while creating opportunities for expansion into other areas and market segments. This recommendation is further supported by the fact that cancer incidence and prevalence rates are at an all time high and are expected to increase significantly over the next few decades, adding to the demand for CT and PET-CT scanner systems.

The final recommendation for the commercialization of the algorithm is to form a partnership with one of the major medical imaging equipment OEMs in the industry. A Porter's five-forces analysis of the medical imaging industry indicates that there are considerable barriers to entering the industry irrespective of the type of product being introduced, in part due to the industry's highly integrated nature. The three major OEMs, GE Healthcare, Philips Medical and Siemens Healthcare offer products and services for

all aspects of the healthcare industry including, diagnostic equipment, laboratory tests, surgical equipment, health informatics, IT solutions and software. As well, these three major players have complementary assets that have been cultivated and refined over many years creating a barrier for new entrants that is extremely difficult to overcome. Therefore, due to the nature of the medical imaging industry, the algorithm's commercialization is highly dependent upon the formation of a partnership, preferably with an industry leader.

A partnership with one of the major OEMs minimizes the barriers to entering the medical imaging industry as the OEM will provide the algorithm with access to its complementary assets such as distribution channels, sales force, and customers, as well access to its technical expertise and industry knowledge. Although each of the industry leaders have sizable R&D departments that have made substantial progress in the realm of medical imaging devices and image quality in particular, the algorithm offers a unique opportunity for these companies to further enhance the ability of their products. Given the strong performance attributes of the algorithm, any one of the OEMs can benefit from incorporating it into their medical imaging products. In fact, because image quality is a major driver of sales in the medical imaging industry, an OEM can improve its revenues by having the algorithm integrated into its products.

The algorithm in its current state provides huge benefits for the partnering organization, but future generations of the algorithm are also expected to garner similar benefits. The algorithm's inventor continues to conduct research on the algorithm, and future generations of the algorithm will likely contain significant advancements in processing speed, interoperability and other characteristics, providing a further incentive

for a partnership agreement with an OEM. Therefore, the combination of the algorithm's

ability to improve sales figures and the indication of future advancements makes the

algorithm an opportunity worth pursing for OEMs, and thus a partnership agreement with

an OEM likely.

APPENDICES

Appendix A: GE Healthcare Business Units

Business Unit	Products	Application Areas
Diagnostic Imaging	- X-ray - Digital Mammography - Computed Tomography (CT) - Magnetic Resonance (MR) - Molecular Imaging	- Broken bones - Trauma - Heart conditions - Cancer - Brain disorders
Surgery	- Intra-operative and interventional imaging products	- General surgery - Orthopaedics' - Neurosurgery - Urology - Cardiology - GI - Pain management
Clinical Systems	- ECG - Bone Densitometry - Patient monitoring - Incubators - Infant warmers - Respiratory care - Anaesthesia management	- Patient care
Life Sciences	- Cellular technologies - Biopharmaceutical purification equipment and systems	- Drug discovery - Biopharmaceutical manufacturing
Medical Diagnostics	- Diagnostic imaging pharmaceuticals designed for use with x-ray, MR systems and nuclear cardiology	- Earlier detection and diagnosis of diseases - Disease management

Integrated IT Solutions	- Enterprise and departmental IT products - RIS/PACS and CVIS Systems - Revenue cycle management systems - Practice applications	- Clinical and financial systems

Source: GE Healthcare, 2008

Appendix B: Philips Medical

Philips Medical Business Divisions

Business Unit	Products	Application Areas
Imaging Systems	- X-ray - Computed Tomography (CT) - Magnetic Resonance (MR) - Nuclear medicine equipment	- Broken bones - Trauma - Cardio and vascular - Cancer - Brain disorders
Ultrasound & Monitoring Solutions	- Ultrasound - Diagnostic ECG - Patient monitors	- Patient care
Healthcare Informatics	- PACS - Clinical decision support - Cardiology IT - Document services	- Clinical Systems
Customer Services	- Consultancy - Clinical services - Education - Asset management - Equipment maintenance and care	- Optimization or workflow and maintenance

Source: Philips, 2007

Philips Medical Affiliates

Company (Philips' Share)	Description
MedQuist Inc. (72%)	Headquartered in Mount Laurel, New Jersey, MedQuist is a leading provider of medical transcription software technology services (MedQuist, 2008).
Philips Medical Capital (40%)	Philips Medical Capital is a joint venture with a subsidiary of De Rabobank. It provides financial solutions to healthcare facilities seeking to purchase Philips Healthcare products (Philips, 2008).
Trixell (24.5%)	Headquartered in Morains, France, Trixell is a joint venture between Philips Healthcare, Siemens Medical Engineering and Thales Electron Devices that is focuses of developing and producing X-ray flat panel digital detectors (Trixell, 2008).

Source: Philips, 2008

Appendix C: Siemens Healthcare's Business Divisions

Business Unit	Products	Application Areas
Imaging	- Angiography - Computed Tomography (CT) - Magnetic Resonance (MR) - Nuclear medicine/PET - Radiography - Surgery Systems - Ultrasound - Urology System	- Radiology - Cardiology - Oncology - Neurology
Laboratory Diagnostics	- Chemistry/Immunoassay Systems - Automation - Informatics - Haematology - Haemostasis - Microbiology - Molecular Diagnostics - Diabetes and Urinalysis - Blood Gas - Patient monitors	- Anaemia/Iron Metabolism - Autoimmune/Rheumatoid Disease - Bone Metabolism - Cardiovascular - Congenital & Infectious Disease - Diabetes - Toxicology/Electrolyte - Hepatic Diseases - Hepatitis & Retrovirus - Immunosuppressive disease - Liver fibrosis - Metabolic - Nephropathies - Pancreatic disease - Reproductive endocrinology - Thyroid functioning - Tumour markers
Healthcare IT	- IT Solution & Consulting - Integrated RIS/PACS - Computer-Aided Diagnosis (CAD) - eHealth Solutions - Document services	- Clinical Systems

Source: Siemens, 2007

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