Defining platforms for artificial intelligence algorithms in radiology

Increasing the transparency of the market for AI platforms for radiology

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Abstract

Introduction Deploying multiple AI products for radiology is unmanageable in practice. The clinical added value of AI products in radiology is not achieved by deploying AI products as stand-alone applications. To tackle this problem, AI platforms are introduced to the market. However, due to its infancy, a definition of an AI platform remains absent. Combined with the unknown availability of AI platforms for radiology and their offered features, it is challenging for radiology departments to procure a fitting AI platform

Goal The main goal of this thesis is to provide guide radiology departments in the procurement of a fitting AI platform. This goal is achieved by providing a definition for AI platforms and increase transparency on available AI platforms.

Methods A questionnaire is constructed and validated by a group of expert stakeholders using the DELPHI method. The questionnaire gathered data on features as offered AI products, deployment of AI products, output of AI products, workflow integration and support. An analysis of the AI platform features resulted in a definition of AI platforms to complement the literature. With the results, an online overview of all available AI platforms for radiology and their features is created on www.aiforradiology.com.

Results the overview included 35 AI platforms for radiology, offering the deployment of a wide selection of AI products. Out of the 10 responses from the questionnaire, all 10 AI platform vendors offer a solution for the processing of radiology images with third party AI products through the platform. All 10 platforms also offer an automatic orchestration of medical images to relevant AI products. Most platforms (8/10) offer the option for customers to develop and deploy AI algorithms on the platform and 9 out of 10 platforms offer the procurement of third party AI products through the platform.

Discussion an AI platform is defined as *a technical solution that enables the deployment and orchestration of third party AI products, consolidating all service and support.* One of the implications is that the group of experts to assess important features was not diverse enough. The thesis also did not focus enough on features that exclude AI platforms. It is recommended that similar research is conducted for AI platforms for pathology.

Preface

This report contains my master thesis for the Health Sciences master program at the University of Twente. I conducted my thesis from November 2021 until August 2022 with the aid of Radboud university medical center, providing me with all information and tools needed with regards to Artificial Intelligence in radiology and acting as external supervisors. My planning was divided in three phases. The first phase consisted of a lot of meetings with personnel from the Diagnostic Imaging Group and radiology department of Radboud university medical center. The second phase consisted of actually conducting my proposed research and the last phase consisted of presenting my findings in this thesis.

The methods for conducting this research and this field of research was unique for me and was experienced as enjoyable. I learned a lot about the complex IT systems and challenges that occur with the implementation of new technology. This curiosity has led me to broaden my knowledge in the IT and pursuing an IT traineeship, hopefully exploring more about IT systems in healthcare.

Although this thesis being an overall great experience, some challenges were experiences as well. Due to the Covid-19 pandemic, certain constrictions still remain. This not only made it difficult to visit the Radboud university medical center more frequently, but also had an impact on my personal and social life. Besides, with the passing of one of my dear friends, it was not always easy to focus on a hard working attitude. However, with the patience, support and guidance of my supervisors, I am satisfied with my work and my resulted thesis. Thanks to all my supervisors that made this possible, both internal and external, and a special thanks to Kicky, who has supported me way more than was asked from her.

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1. Introduction

Artificial intelligence (AI), which is the science of making machines capable of human-like decision-making, is becoming more and more popular in various sectors in healthcare (Muehlematter et al., 2021; Rice University, 2022). The leading medical specialty in AI is radiology, which accounts for more than half of the AI products in healthcare, both in Europe and USA (Muehlematter et al., 2021). Radiology is the medical specialty that uses imaging technology as computed tomography (CT) or magnetic resonance imaging (MRIs), that visualises certain body structures to diagnose and treat diseases (American College of Radiology, 2022). AI products for radiology are used to contribute to the imaging analysis process by performing detection, quantification, diagnostic, image enhancement, or prioritization tasks. Examples are an AI product for the volumetric quantification of brain structures, an AI product which is used to detect vessel occlusions in a patient's brain or an AI product that prioritizes suspected brain haemorrhage cases in the worklist of the radiologists (van Leeuwen, Schalekamp, et al., 2021). Preliminary studies show that with a proper integration into the workflow of radiologists, AI products may improve patient outcomes and eventually reduce costs (Hassan et al., 2020; van Leeuwen, de Rooij, et al., 2021). Additionally, a more recent study which surveyed radiologists with clinical experience with AI products, show that AI products used for the prioritisation of the worklist, are considered helpful in reducing the workload for medical staff by most radiologists (Becker et al., 2022). However, AI products used for diagnostic assistance are considered not proven to be helpful to reduce the workload by most radiologists (Becker et al., 2022).

AI for radiology is a field which is still in its early stages with limited clinical implementation. The substantial research and development around AI products make it a dynamic market with new products and suppliers appearing constantly. At the time of writing, around 200 CE certified AI products are commercially available (van Leeuwen, Schalekamp, et al., 2021). A CE certification is a European certification needed to commercially sell products in the European Union (EU) and indicates that the product meets the safety, health and environmental protection requirements. Since the offering of products has increased in such a short time, it is difficult for departments to get a good overview of the available products and therefore reduce the chance of making a well-considered choice for an AI product that fit their needs. In turn, this might negatively affect the clinical implementation success, since the AI solutions do not meet the expectations of the radiologist departments. Besides, it takes a lot of time for personnel to look for all available products and differentiate between the advantages and disadvantages of each available product separately.

To tackle this problem and keep track of AI products for radiology, all available products are listed on www.aiforradiology.com, which is continuously updated with new products that become commercially available in the EU (van Leeuwen, Schalekamp, et al., 2021). The website improves transparency of the AI market, offering radiology departments the opportunity to make a well-considered choice for an AI product that fits their needs. This will lead to more promising results, positively effecting the clinical implementation of AI in radiology. Besides, due to the fact that the website is updated with the newest CE certified AI products, the transparency of the most recent AI products is maintained over time and procurement guidance of AI products for radiology departments is guaranteed (van Leeuwen, de Rooij, et al., 2021; van Leeuwen, Schalekamp, et al., 2021). The website and this thesis are both academic endeavours of the medical imaging department of the Radboud university medical center in The Netherlands.

Despite the broad supply, the clinical benefits, and transparency of AI products for radiology, the clinical implementation for daily use remains limited. The main reason for this, is that each product works in different workflows, image viewing software and has its own characteristics and features which results in a difference in suitability per radiology department (Filice et al., 2020; He et al., 2019; Sanjay Parekh, 2019). In practice, this translates into different measures of integration into existing IT systems of hospitals, which makes it unscalable to deploy multiple AI products as stand-alone applications (Filice et al., 2020). Besides, because of the rising number of AI products, it takes more administrative workload for customers to select, negotiate, procure and deploy a single fitting AI product each time from different vendors (Filice et al., 2020; Sanjay Parekh, 2019; Tadavarthi et al., 2020).

The rising number of AI products for radiology has resulted in the development of AI platforms, offering the procurement and/or operation of multiple AI products through a single platform. One of the most important features of an AI platform is that only the platform needs to be integrated into the existing IT systems of a hospital and not each AI product individually; the offered AI solutions on the platform are integrated with the platform itself. For example, all offered AI solutions by a platform, operate on or are compatible with the same user interface or PACS (Picture Archiving and Communication System), which serves as a viewing software at the radiologist's workstation (Charles et al., 2018). This enables radiologists to view processed image results of multiple AI products on the same workstation or using the same software (Leiner et al., 2021), enabling an easier adoption of multiple AI products by the radiology department.

Logically, the upcoming AI platforms are an even younger solution than the AI products themselves, limiting the available literature and clinical experience. With the rising number of AI platforms, two main issues are recognized. The first issue is that, due to limited literature, a clear definition of an AI platform remains absent. This makes it complex to determine features that define an AI platform. If there are no predefined characteristics of an AI platform, hospitals cannot be completely aware of the possible added value of an AI platform. The second issue is that it is unknown for hospitals which AI platforms are available and what the differences between these platforms are. This makes it challenging to compare between benefits and detriments of AI platforms, negatively influencing decision-making for radiology departments to purchase a fitting platform for clinical implementation.

The goal of this thesis is to guide radiology departments with the procurement of a fitting AI platform. To achieve this goal, this thesis aims to tackle the two issues described above. The first issue is tackled by a descriptive study, which will attempt to formulate a definition of an AI platform with according exclusion criteria. With this definition, an AI platform can be recognized by its common features and radiology departments get a grasp of the potential added value of AI platforms, making the goal of this thesis more accessible. For the second issue, this thesis aims to develop a tool to increase the transparency of available AI platforms and their different features. An increase in transparency will aid radiology departments in the decision-making of purchasing a fitting AI platform. In order to fill the gap in the literature and achieve the study goals, this thesis, which is unique in this field, aims to answer the following research question:

"What defines an AI platform, what are the available AI platforms for AI products for radiology and which features do they offer?"

By answering this question, this thesis provides three contributions; namely a definition for AI platforms, an overview of all available AI platforms for radiology and an overview of all AI platform features. To guide in answering this question, this thesis is divided in three components, conform to the contributions (figure 1). The first component starts with providing a broad definition for AI platforms with adequate in- and exclusion criteria, to further guide the sampling process for the next components. The goal of the second component is to create an overview of all available AI platforms for AI products for radiology, using the broad definition from component 1. The third component aims to collect all features offered by the included platforms in a database. Finally, based on the analysis of the AI platforms' features and investigating commonness amongst them, a specified definition is formulated to supplement the broad definition from component 1. This answers the research question, contributing to the literature by providing a first definition for an AI platform and provide radiology departments an understanding of the potential added value of AI platforms.

To further guide radiology departments with the procurement of AI platforms, the database will be presented publicly online on www.aiforradiology.com (figure 1). A new page will be created, providing the overview of the AI platforms and their features, linked to the integrated AI products on the same website. This provides a tool for radiology departments to compare AI platforms, which is easily refreshed with the most recent AI platforms and updates on existing AI platforms. This increases transparency of all available AI platforms and aids decision making around AI platform purchasing.

To summarize, the ultimate goal of this thesis is to guide radiology departments with the procurement of fitting AI platforms, by defining an AI platform and increasing transparency. Some literature has been found discussing the need for AI platforms, indirectly defining necessary features and forming a broad definition (Filice et al., 2020; Leiner et al., 2021; Sanjay Parekh, 2019). The theoretical contribution of this thesis is providing a specified definition of an AI platform, combining current literature and an analysis of all available platforms and their features. The practical contribution of this thesis is part of a wider project to increasing transparency of AI for radiology. The website www.aiforradiology.com, which currently lists all AI products for radiology, will be expanded with the database of this thesis, listing all AI platforms for AI products for radiology. The remainder of this thesis will elaborate on the method and why the results of this thesis are essential to the success of implementation of AI in radiology.

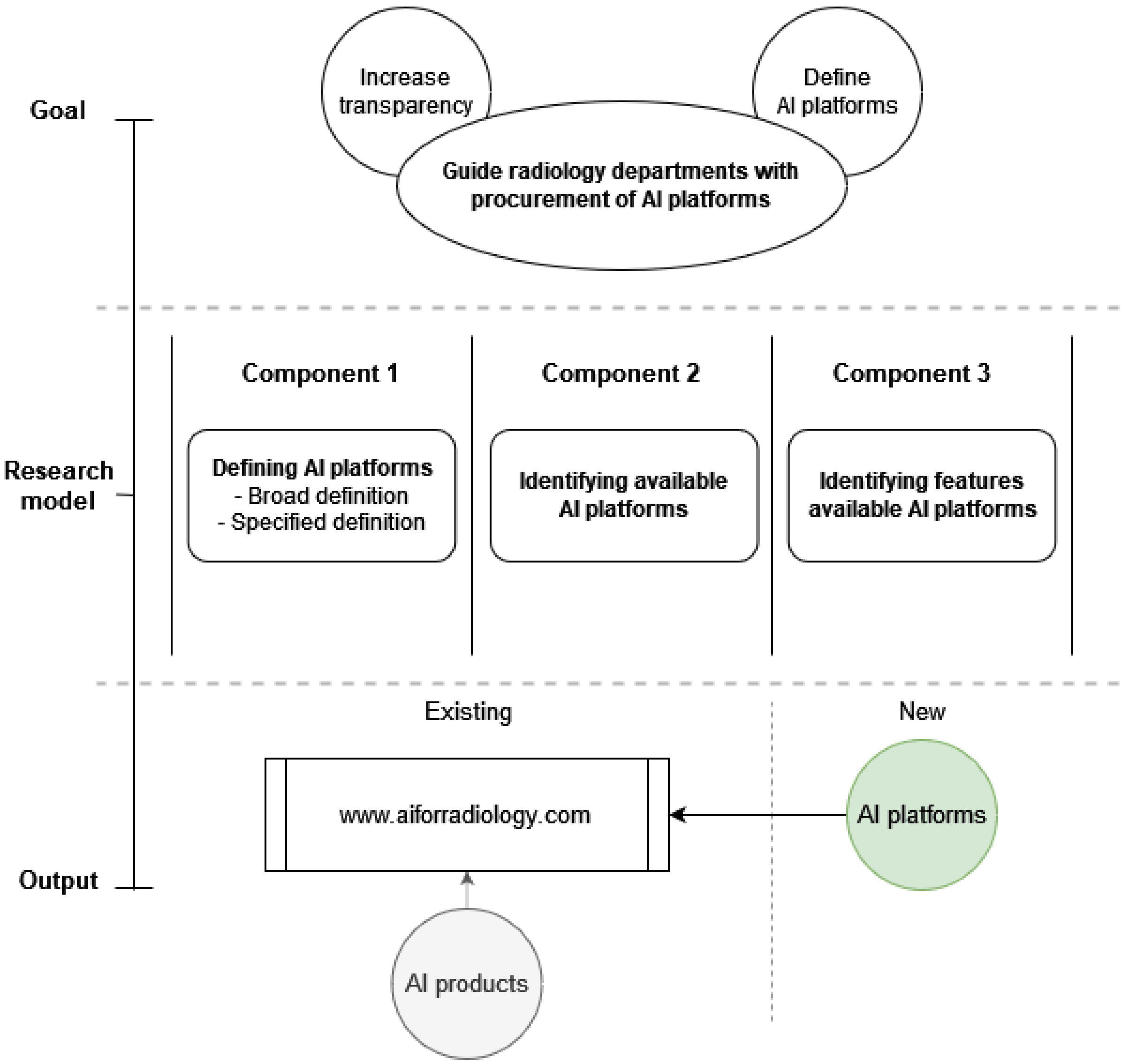

Figure 1: visualisation of the goal, research model and product of this thesis. The goal of this study, to guide radiology departments with the procurement of fitting AI platforms, is achieved by defining AI platforms and increasing transparency. This will be executed in 3 components, providing a definition for an AI platform and expanding www.aiforradiology.com with all AI platforms and their features, to further increase transparency.

2. Literature review

In order to comprehend the concept, use and issues of AI in radiology, a general understanding of radiology and its IT infrastructure is needed. Afterwards, AI is explained with clinical examples in radiology, and the deployment and procurement processes of an AI product. The impediments of AI product procurement and deployment are explained and compared to similar impediments in other industries. The next section investigates a solution for these issues, namely AI platforms. Similar studies are discussed and key stakeholders that are recognized in this chapter are reviewed, to guide in designing a research method for this thesis.

2.1. Radiology, workflow and IT infrastructure

As mentioned briefly in the introduction, radiology is the medical specialty that uses imaging technologies to diagnose and treat diseases (A.D.A.M., 2022; American College of Radiology, 2022). Radiology is divided in two specialty areas: diagnostic radiology and interventional radiology. Diagnostic radiologists use scanning technologies, also called modalities, such as mammography (for breast imaging), computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), or plain x-rays. These modalities scan a patient using electromagnetic radiation through the body, to visualize body structures (A.D.A.M., 2022). A diagnostic radiologist interprets the resulted images to assess a patient's condition, recognize certain abnormalities and diagnose diseases (American College of Radiology, 2022). Interventional radiologists mostly use CT, MRI, ultrasound or fluoroscopy modalities to guide with surgical procedures. The visualised body structures help the interventional radiologists with inserting catheters or small instruments in a patient's body, allowing for smaller incisions and guiding the radiologists through the body of the patient (A.D.A.M., 2022).

Radiologists usually have a high workload, due to the rising volume of examinations and complexity of scans and visualised body structures (Mauer, 2020). The key for optimization and increasing efficiency, lies in the workflow and IT systems that manage the workflow (Mauer, 2020). The workflow is the sequence of all tasks, whether physical or mental, performed within or between work environments (Digital Healthcare Research, 2022). The radiologist's workflow starts from the moment the radiologist receives an order to scan a patient. The patient is scanned, the resulted images are interpreted, and further actions are taken, concluding the workflow of a radiologist. The efficiency of the workflow is significantly influenced by the IT infrastructure and health care systems of the hospital and radiology department. To digitally manage healthcare data, hospitals use a variety of interconnected systems called Health Information Systems (HIS). This includes all systems for the collection, storage, management and transmission of patient data, systems for operations management, systems that influence and support clinicians decision-making and systems that support in healthcare policy-making (Brook, 2020).

One of the HISs that is essential for all clinical sectors, including radiology, is the organization wide Electronic Health Record (EHR), sometimes referred to as the Electronic Medical Record (EMR) (Cms.gov, 2021; Genereaux et al., 2021). The EHR is used to keep track of a patient's medical history and contains patient information and clinical data like demographics, vital signs, medications, laboratory results and radiology reports. The EHR grants easy access of data and reporting on outcomes, making the workflow of clinicians efficient. In the radiology department, a radiologist present at a workstation, has access to a patient's history of radiology reports. Besides, a radiologist is also able to store reports of medical images to the patient's EHR, which is then accessible on any radiologist's workstation at the hospital (Cms.gov, 2021; Genereaux et al., 2021). For the reporting of outcomes on medical images to the EHR or any other HIS used, most radiology departments, e.g., Radboud university medical center, use voice recognition software, to automatically convert speech to text. In some cases, like Radboud university medical center, the EHR is also used as the worklist of a radiologist, which shows the different studies or patients that need to be read (Mates et al., 2007). Other hospitals might use a different Radiology Information System (RIS) or HIS as the worklist of the radiologist (RCR, 2021).

When a patient is scanned on any modality, e.g. CT, PET or MRI, the image is sent to the Picture Archiving and Communication System (PACS) (Genereaux et al., 2021; Leiner et al., 2021; RCR, 2021). The PACS is a viewing software, which is one of the main working screens of a radiologist. Digital Imaging and Communications in Medicine (DICOM) is the standard image format for the storage, exchange and display of images between modalities and the PACS (Genereaux et al., 2021; Leiner et al., 2021). DICOM tags on medical images contain metainformation about the images. The DICOM tags can be used to influence the worklist of the radiologist, for example by ordering it by priority. The new worklist is viewed on a HIS on the radiologist's workstation, which could also be shown through the PACS (Genereaux et al., 2021; RCR, 2021). For the communication of radiology information from the PACS to the EHR or other HIS or RIS, Health Level 7 (HL7) is the most common messaging form (Genereaux et al., 2021; Leiner et al., 2021; RCR, 2021). All these systems and modalities have to be integrated together for an efficient workflow of the radiologist and minimize technical delays.

Figure 2 shows the radiology IT infrastructure at the Radboud university medical center from the moment a scan is made until retrieval of outcome reports of the scan (de Lange, 2022). First of all, a scan is made of a patient, regardless of the modality. Using DICOM tags through the PACS, the radiologist can influence the modality to adjust scans. The scan is then sent to the PACS with DICOM images, to be viewed for the radiologist. Information from the PACS is then sent to an external cloud, also called Vendor Neutral Archive (VNA), for storage of medical images. Due to the big data capacity of all their patients' medical images, Radboud university medical center uses an external storage cloud. The use of an external cloud storage varies per hospital, as some hospitals use on premise storage. Radiology information can then be sent from the cloud storage to the EHR, or from the EHR to the PACS using the HL7 messaging format. For a quicker access of medical images from the cloud, without downloading them to the EHR, a web viewer can also be used. In figure 3, a radiologist's workstation at Radboud university medical center is shown, which consists of the EHR on one monitor and the PACS on the other monitors (de Lange, 2022).

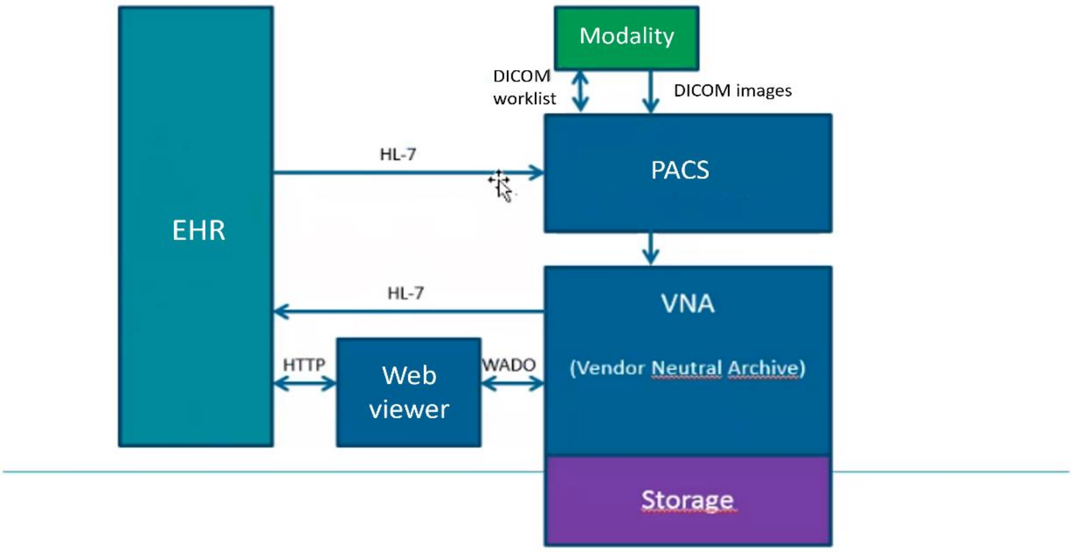

Figure 2: the radiology IT infrastructure at Radboud university medical center, The Netherlands (de Lange, 2022).

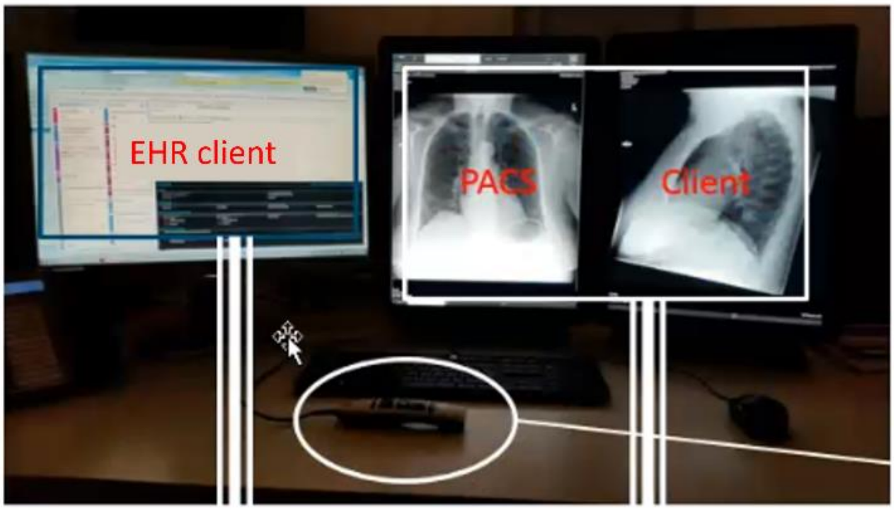

Figure 3: the workstation of a radiologist at Radboud university medical center, The Netherlands. On the left monitor, the EHR is viewed. On both the right monitors, the PACS is viewed (de Lange, 2022).

2.2. AI in radiology, AI product deployment and procurement process

Artificial Intelligence, or AI, is the science of making machines capable of human-like decision-making, using a technique called machine learning (Rice University, 2022). Machine learning is the art of developing self-running software that can learn autonomously or from other machines or humas. Machine learning is used on big databases to discover patterns and automate processes based on a data analysis, which is the basis of an AI software product (Rice University, 2022). The AI product adjusts to new input and automatically acts on the new data analysis to solve complex problems, learning from those solutions to improve (Rice University, 2022).

In a radiology setting, AI products are trained by providing big data sets with images and results of previous patients to recognize recurring features, body structures or abnormalities and diseases. An example is an AI product that identifies brain haemorrhages; the AI product is trained by providing a big number of CT scans of brains with and without haemorrhages (Tadavarthi et al., 2020). The algorithm of the AI product learns from the relevant image features in order to recognize the differences between a brain scan with a haemorrhage and a brain scan without a haemorrhage. The bigger the training data set is, the more accurate the AI product prediction is (Tadavarthi et al., 2020). The AI product can even learn and improve from every new patient image it processes in clinical setting (Tadavarthi et al., 2020).

As explained earlier, AI in radiology can have different uses, varying from image processing for detection, quantification, diagnostic, image enhancement or prioritization tasks (van Leeuwen, Schalekamp, et al., 2021). A recent study surveyed radiologists with clinical experience with AI, attending the European Society of Radiologists (ECR) (Becker et al., 2022). Most use cases of AI in clinical setting were related to diagnostic interpretation, image enhancement and prioritisation of workflow. 185 radiologists used AI products for diagnostic interpretation, of which 69.8% reported no reduction in workload with the help of AI products (Becker et al., 2022). However, out of the 111 radiologists that use AI products for the prioritisation of the workflow, 62.2% reported that the AI product is moderately helpful in the reduction of workload, while 23.4% reported the AI products very helpful (Becker et al., 2022). A more interesting finding is that only 17.8% of the radiologists experienced difficulties with the integration of AI products into their clinical workflow. Becker et al. argue that this might be due to radiologists not being involved in the integration and deployment process into existing radiology IT infrastructure (Becker et al., 2022).

In order to deploy a single AI product at a customer, it has to integrate with all necessary IT infrastructure as explained in previous chapter (Filice et al., 2020; Genereaux et al., 2021; Juluru et al., 2021; Leiner et al., 2021; RCR, 2021). The AI products have to be integrated in the existing radiology HISs, which is a complex challenge, to show the AI processed images to the radiologist for examination (RCR, 2021). The fundamental feature of an AI product is to process the medical image from the modality and send back the processed image to the PACS. At Radboud university medical center, the image is automatically sent from the modality to the PACS as usual (figure 4). Before the image is shown on the PACS, the image is automatically sent to the AI product via DICOM tags. The AI product then sends the processed image back to the PACS to be read by the radiologist (de Lange, 2022).

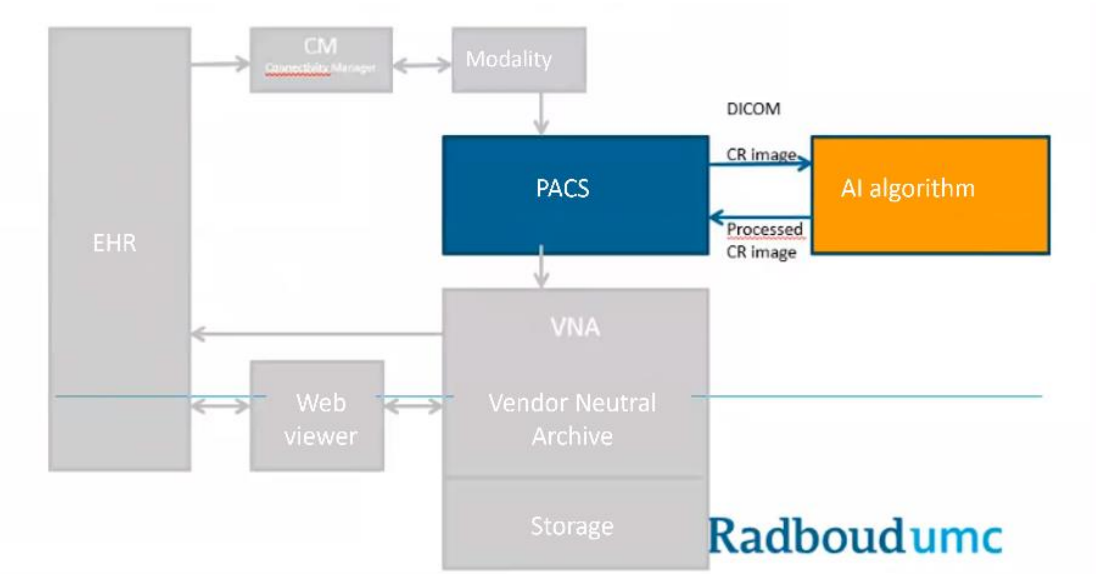

Figure 4: the IT infrastructure, with an integrated AI product, of the radiology department of Radboud university medical center (de Lange, 2022).

When a radiology department decides to procure and deploy an AI product for clinical use, they commence with a selection process (figure 4). The radiology department explores available options for AI products, compare options for AI products with the desired output and select a fitting AI product. To aid in the selection process, all CE certified AI products are listed on www.aiforradiology.com with their different features, like integration compatibility, intended clinical use and distribution channels for procurement. When a selection is made, the radiology department contacts the AI product vendor to negotiate available options regarding deployment and pricing of the AI product. When the contract is signed with the AI product vendor, the AI product is deployed at the radiology department and integrated with all HISs. Finally, the AI product is activated and implemented in the workflow of the radiologist for clinical use.

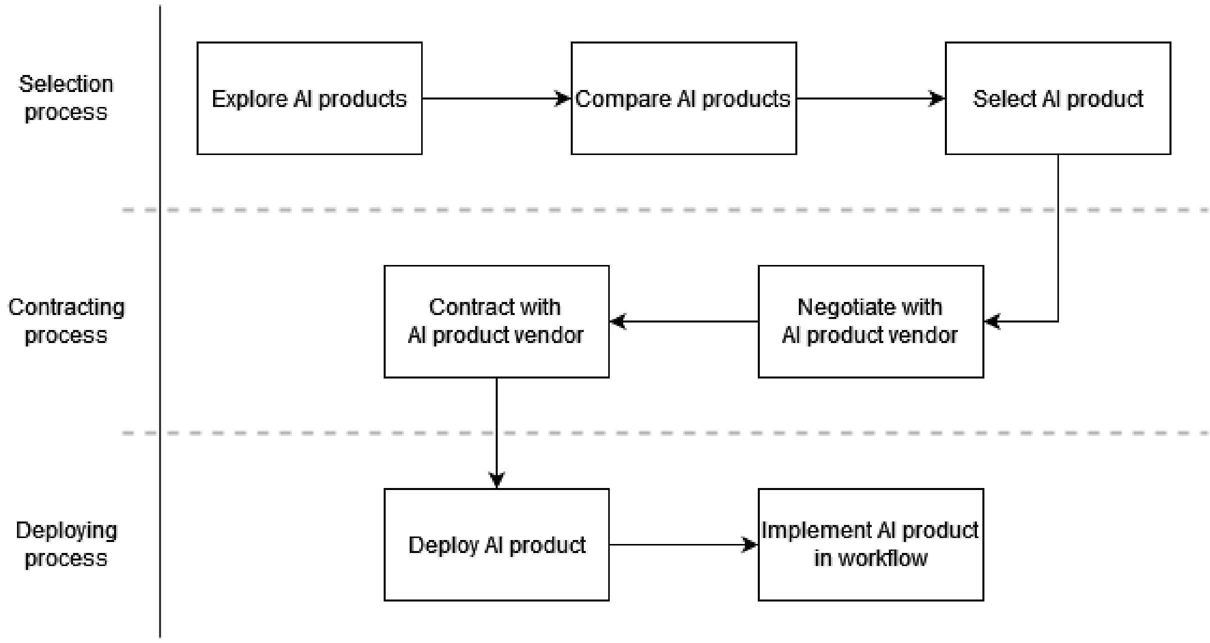

Figure 4: The procurement and deployment process of a single AI product. The selection process consists of exploring available AI products, comparing them and then selecting a fitting AI product. The contracting process consists of negotiating options with the AI product vendor and sign a contract. In the deploying process, the AI product is integrated with all IT infrastructure of the radiology department and implemented in the workflow of the radiologist.

The previous sections have clarified on radiology, AI in general, AI in radiology and the clinical implementation of AI in radiology using Radboud university medical center as an example. The next section will elaborate on the impediments of deploying and operating AI in a clinical setting, comparing these impediments with other industries to find a fitting solution.

2.3. Impediments multiple AI products and comparison with other industries

An AI product can be deployed in different ways, depending on the IT infrastructure of the hospital, the AI product's algorithm and HIS partnerships of the AI product vendor. All hospital IT systems as explained in the previous paragraph differ per hospital, making it challenging to deploy AI products. Leiner et al. describe that the main impediment for the clinical implementation of AI in radiology is the deployment. They state that "deploying and maintaining dozens or more individual (virtual) workstations or even software packages for all of these will be unmanageable." (Leiner et al., 2021). Figure 5 shows an illustration of multiple AI products deployed as stand-alone solutions with different integration with the hospital's IT infrastructure (Filice et al., 2020). The figure shows four AI products at the bottom and three essential radiology HISs at the top. Every single product is integrated separately and in a unique way with each HIS. This means that each time a radiology department purchases an AI product, the complex deployment issues recur and have to be solved separately every time.

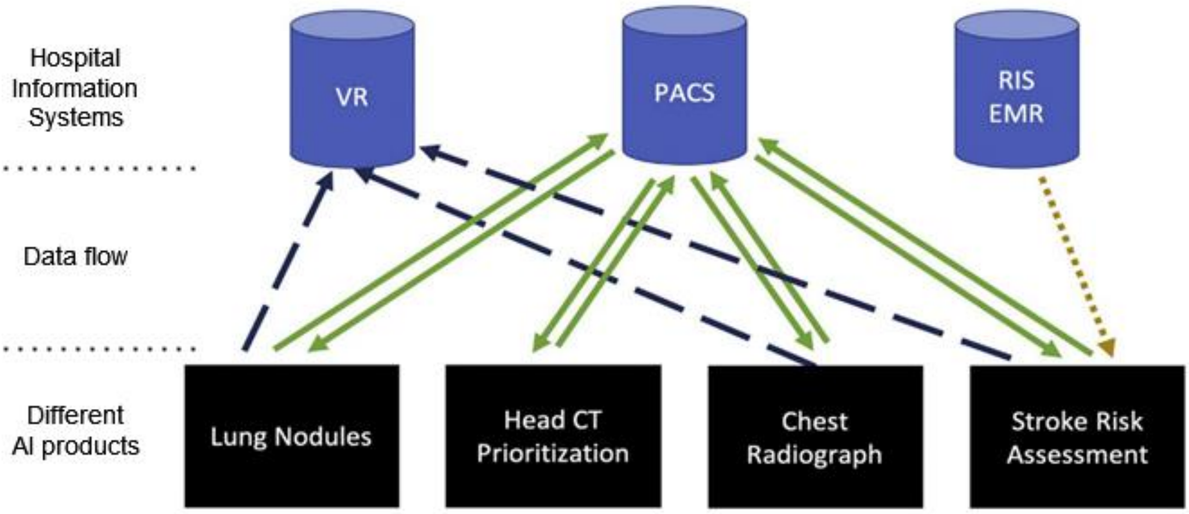

Figure 5: deployment of multiple stand-alone AI products into the radiologist's workflow *(Filice et al., 2020)*.*
**Every algorithm is integrated differently into the hospital's IT infrastructure. VR = Voice Recognition.*

Besides IT system integration, deploying AI products as stand-alone applications is not scalable, due to separate demand management, planning, security evaluation and heterogeneity in viewing and operating AI products (Filice et al., 2020). AI products operate and view the results differently, which interferes with the workflow of the radiologist. Some AI products are activated and show results through an online web viewer, which is an AI product vendor specific web viewer. Other AI products send the processed images directly to the PACS. Besides, some AI products are built in the modality (van Leeuwen, Schalekamp, et al., 2021). Due to differences in viewing, it will take more time for a radiologist to use an extra AI product. This suggests that the more AI products a radiologist uses, the more time it takes to examine an image. Another challenge is the difference in reporting and other HIS integration, e.g., EMR. Not all AI products have the same way of radiologist reporting on images or interoperability options with EMRs or other HISs of the customer. He et al. even suggest standardizing methods of retrieving and storing radiology AI data similar to the commonly standardized DICOM or PACS (He et al., 2019).

Developers and vendors of software in other industries might experience similar integration and procurement problems like AI products. For example, applications for your phone, which are all accessible through a single platform, e.g. Apple Store or Google Play Store. All applications offered on the App Store or Google Play Store are centrally procured through a single point of contact. This is an essential feature, since the offering is so immense, and it is nearly impossible to contract with all individual application developers when purchasing an application. In addition, all offered applications on the App Store and Google Play Store, regardless of the application vendor, are operatable on the same operating system, namely iOS and Android respectively. There are no integration or deployment issues, since all individual applications are integrated with the same operating system. Once your phone is integrated with a certain operating system, all individual applications offered on the app store are easily deployed and operatable through the operating system. A similar concept for AI products in radiology, should aim to enable the deployment and operation of multiple AI products on the same operating system, in order to gain considerable value for radiology departments and reduce workload for the IT staff due to integration and deployment complexity.

2.4. Component 1: broad definition AI platforms, advantages and disadvantages, and procurement and deployment process

As mentioned before, literature regarding such solutions for AI in radiology is very limited. In this literature review, almost all available relevant literature that could be identified is used. This suggests how little is known and how essential this thesis is for the world of AI in radiology. However, a similar comparison of such an AI solution with the App store is made by Leiner et al., who proposed a blueprint for a Vendor-Neutral AI infrastructure (VNAI), or an AI platform (Leiner et al., 2021). The AI platform can deploy multiple FDA approved or CE certified AI products in clinical practice. By programmable triggers, the AI platform can also automatically run certain AI products. Another feature the AI platform offers is the ability to test in house developed algorithms (Leiner et al., 2021). Figure 6 shows the basics of such an AI platform (Leiner et al., 2021). A medical image originating from any modality is sent to the PACS and then to the AI platform. The AI platform then either sends the image automatically to relevant AI products that are integrated with the AI platform with DICOM tags (1a) or manually by the radiologist at his workstation (1b). The AI platform returns the processed images to the PACS, the radiologist's workstation and any other hospital storage (Leiner et al., 2021). As can be seen in the figure, the AI platform is integrated with the customer's PACS and other relevant HISs, storages and radiologist's workstation. All individual AI products, in the figure indicated as 'app', are integrated with the AI platform. This means that the customer has complex deployment and integration issues once to deploy and integrate the AI platform. All extra AI products are integrated with the platform, and not individually with the radiology department's IT infrastructure (Leiner et al., 2021).

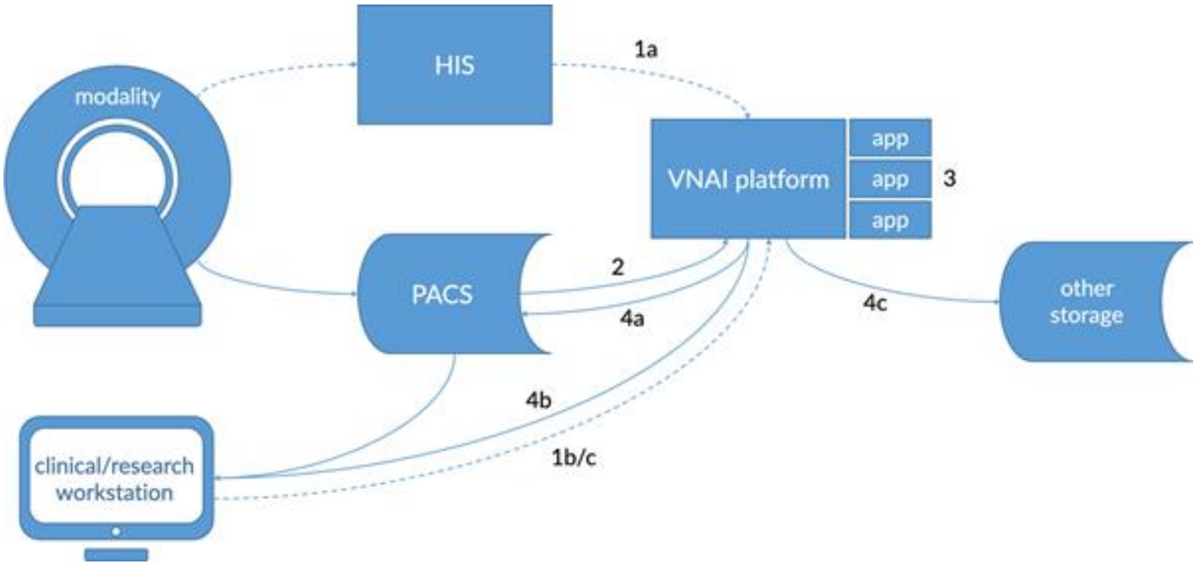

Figure 6: the flow of radiology information and medical radiology images through a VNAI platform (Leiner et al., 2021).

Filice et al. also discuss the option of an AI platform for additional AI product vendors to deploy their AI products (Filice et al., 2020). As seen in figure 7, the platform is integrated with all relevant HISs of the radiology department. The platform incorporates multiple AI products, so all AI products have to integrate with the IT infrastructure of the platform. The platform is the only system that has to integrate with the IT infrastructure of the hospital, i.e., the PACS, RIS, EHR/EMR and Voice Recognition software for reporting. This will considerably decrease planning, security review and technical deployment work for each AI product separately (Filice et al., 2020).

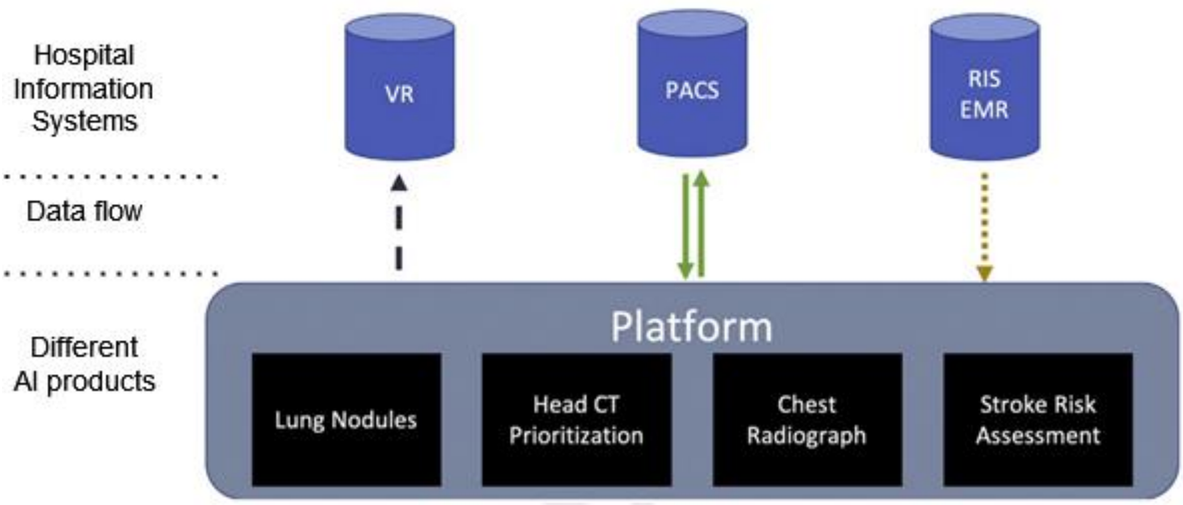

Figure 7: the deployment of multiple algorithms through an AI platform that integrates with the necessary hospital IT infrastructure (Filice et al., 2020).

Furthermore, a single similar market analysis to this thesis has been conducted in 2019 (Sanjay Parekh, 2019). Parekh has identified multiple advantages and disadvantages for AI platforms for radiology, as listed in table 1 ((Sanjay Parekh, 2019). The first two advantages listed in the table are access to a wide selection of AI products for multiple exam types and diversity of AI products (clinical, operational, and financial). Ideally, all AI products are possible to integrate with the AI platform. Due to the earlier explained integration issues, only a selection of AI products that are integrated with the AI platform, are available for the customer (Sanjay Parekh, 2019).

Table 1: The advantages and disadvantages of AI marketplaces for healthcare providers (Sanjay Parekh, 2019).

Advantages	Disadvantages
Access to a wide selection of algorithms for multiple exam types	Limited number of vendors with marketplace offerings
Diversity of algorithms, e.g. clinical, operational and financial	Limited (but increasing) choice of algorithms (vendors) for specific use-cases
May offer single point of contracting and invoicing	Harder to control unauthorised (maverick) spending
Algorithms may be validated by the marketplace	Unfamiliarity with marketplace concept for medical imaging
Some marketplaces offer a common user interface to access AI results	May not have direct access to the algorithm developer

Another benefit of AI platforms is that some platforms offer a single point of contracting and invoicing for different AI products (Sanjay Parekh, 2019). As discussed during a symposium organized by Sectra, an AI platform vendor, in late 2021, this will in turn decrease the initial activation energy of negotiating and contracting and will decrease the administrative overhead (Breimer et al., 2021). If every product has to be purchased directly from the vendor, a lot of time and energy is spent on administrative overhead (Sanjay Parekh, 2019). Besides, according to radiologists at the Sectra symposium, the ability to have some flexibility in choosing a suitable AI product is a benefit of AI platforms. The speakers envision, that the wider the AI adoption in radiology is, the larger the role and value for AI platforms (Breimer et al., 2021).

Another advantage of an AI platform is that the AI products may be validated by the marketplace (Sanjay Parekh, 2019). Validating an AI product means testing the product in a desired environment of the radiology department. In theory, these AI products might be valuable or improve outcomes and reporting. However, the AI product is tested in a certain environment and workflow which is different than the environment and workflow of the customer. This could lead to the AI products working as intended and have promising results in the setting where the product is tested but have different results in the customer's setting. The AI platform could apply certain curation methods to guarantee the quality for their customers. The last and most important advantage is described earlier by Leiner et al. and Filice et al. with the vendor neutral platform to operate all AI products on and could also be compared to the App Store or Google Play Store (Filice et al., 2020; Leiner et al., 2021; Sanjay Parekh, 2019).

The first two disadvantages described by Parekh are a limited number of AI platforms and a limited selection of AI products for specific cases (Sanjay Parekh, 2019). Due to the increasing offering of AI products, the number of AI platforms is also increased, and a lot of small AI product vendors have partnered to be able to take part in the vastly expanding demand for AI platforms. The limitation of algorithm choice on a specific platform remains, but this limitation might gradually dissolve. With more available literature and an increased understanding of AI platforms and AI product and an increasing demand in AI platforms, the selection of offered AI products on an AI platform will most likely increase.

Another disadvantage that Parekh mentions is the unfamiliarity with AI platforms (Sanjay Parekh, 2019), even though it is becoming more and more inevitable for radiology departments to implement an AI platform. Due to the rising numbers of AI products, it will become increasingly more unmanageable to operate and procure these products, as Leiner et al. describe. The last disadvantage states that there is no direct access to the AI product vendor.

The first component aimed to define an AI platform based on essential features. To briefly summarize the previous literature review, two criteria are identified that are assumed necessary to be defined as an AI platform. Firstly, the AI platform has to enable deployment of third party AI products through one platform. This is related to the second criterium, which states that a platform is excluded if it only offers procurement of third party AI products, without offering a platform for deployment of said AI products. If an AI platform does not offer deployment of third party AI products and the AI products are deployed individually, the deployment issues remain and there would be no difference from an individual AI product vendor.

When a radiology department decides to procure an AI product for clinical use through an AI platform, they first have to procure and deploy an AI platform (figure 8). The procurement and deployment process of an AI platform also starts with a selection process. The radiology department explores available AI platforms, compares suitable options and selects an AI platform. The selection process for an AI platform is challenging, since an AI platform is not defined in literature and the use of AI platforms and their features undergo a lot of change, due to its infancy. This thesis aims to fill this gap in the literature by defining an AI platform. All available AI platforms that fall under this definition will be listed on www.aiforradiology.com to increase transparency of available AI platforms and further guide radiology departments in the selection process. When a selection is made, the radiology

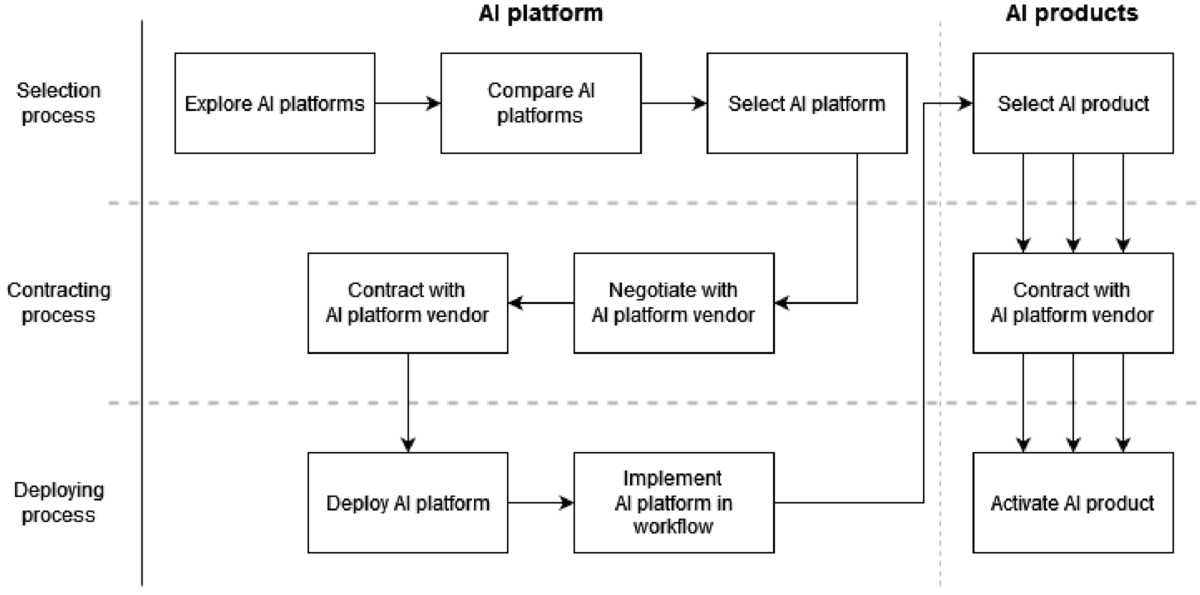

Figure 8: The procurement and deployment process of a single AI product, through an AI platform. Due to limited options, the selection process only consists of selecting an available, fitting AI product. The contracting process only consists of contacting the AI platform vendor and signing a contract. In the deploying process, the AI product only needs to be activated, to be implemented in the workflow of the radiologist.

department contacts the AI platform vendor to negotiate available options regarding deployment options and pricing of the AI platform. When the contract is signed with the AI platform vendor, the AI platform is deployed at the radiology department and integrated with all HISs. Finally, the AI platform is activated and implemented in the workflow of the radiologist for clinical use.

Theoretically, the AI platform still has no AI products integrated for implementation in the workflow. The radiology department now starts a selection process for AI products, from the available options of integrated AI products, offered on the AI platform. When a selection of AI product(s) is made, the radiology department contacts the AI platform vendor. If the radiology department decides to procure any additional AI products in the future, the AI platform is contacted. The contracting process is much faster and easier, since the deployment does not need to be discussed and the customer already has a relation with the AI platform. When the contract is signed with the AI platform vendor, the AI product activated through the AI platform without integration issues in the customers IT infrastructure. The new AI product is ready to use in clinical setting, without any changes in the radiologist's workflow. Compared to figure 4, the procurement process of an individual AI product, the main benefit of an AI platform is in the deployment process. Integration of all AI products is only with the IT infrastructure of the AI platform, without any new complex integration issues for each AI product. Besides, the customer has only one contacting point for the negotiation and contracting of new AI products. The downside is that not all AI products are available through the platform, but only a selection of AI products that are partnered with the AI platform for integration.

2.5.Component 2: identification available AI platforms

The second component aimed to list all available AI platforms for AI products for radiology. After reviewing available literature, the current situation regarding available AI platforms can be assessed. The literature mentioned six AI platforms in Parekh's market analysis, namely Blackford Analysis, TeraRecon, Nuance Healthcare, Siemens Healthineers, Incepto and Wingspan (Sanjay Parekh, 2019). Some literature mentioned AI product vendors that also offer an AI platform, but not by name (Filice et al., 2020; Leiner et al., 2021). No further AI platforms were mentioned in the found literature.

2.6. Component 3: feature identification of available AI platforms and stakeholder review

The third component focused on collecting data regarding offered features by the AI platforms. Parekh's selection guide for customers to choose an AI platform forms the basis of the data collection process for this thesis (Sanjay Parekh, 2019). The selection guide highlights certain criteria that customers should keep in mind when selecting an AI platform for radiology. Parekh divided the questions in eight topics: 1) partnerships, 2) applications, 3) regulatory clearance, 4) workflow, 5) functionality, 6) deployment, 7) contracting, and 8) support (Sanjay Parekh, 2019). Even though the market analysis of Parekh was performed three years ago, the market for AI platforms has changed a lot. A considerable amount of the limited literature on AI platforms has been published the past three years. Therefore, a selection is made of certain important topics, combining Parekh's topics and other reviewed literature. The topics are dissected with features to be assessed from relevant stakeholders, as can be seen in table 2.

The first topic is 'General information', which is divided in the number of partnered companies and the number of live customers. The number of live customers is not mentioned in literature, but is included to give a general idea of the size of the AI platform. The number of partnered companies is described as a disadvantage by Parekh, Leiner and Filice, as a possible vendor lock-in (Filice et al., 2020; Leiner et al., 2021; Sanjay Parekh, 2019). This is closely related to the number of first- and third party offered AI products, which is a feature of the next topic 'Offered solutions'. The second feature of this topic is the regulatory clearance. This is not mentioned in the literature, but in order to guide radiology department in the procurement process of an AI platform, it is essential to know which products are cleared for clinical use in their country.

The third topic is 'Technology' of the AI platform, which, after reviewing the literature, appears to be an important topic for the deployment of AI products and platforms. All features in this topic are described and elaborated on by both Filice and Leiner (Filice et al., 2020; Leiner et al., 2021). The first feature focuses on the integration with the workflow and the compatibility with all relevant Health Information Systems of the radiology department. This is necessary to asses, so radiology departments know whether their IT infrastructure is compliant for the deployment of a certain AI platform. The AI product output is useful to know for radiology departments, to select an AI platform that matches the workflow of their radiologists. The automatic activation of AI products is also essential to know, since this might be an essential feature that a radiology department bases their selection of an AI platform on. The fourth topic is ‘Economic factor’, which speaks for itself. Its first feature is the contracting point, which might be handled through one point (through the platform) or through the individual AI product vendors. This feature is discussed by both Parekh and Filice (Filice et al., 2020; Sanjay Parekh, 2019). The second feature is not mentioned by any literature, but is determinant for radiology departments. The last topic is ‘Service & support’, which feature looks whether the support offered by the platform is only for the platform, or also for their offering of AI products. This feature is only discussed by Parekh (Sanjay Parekh, 2019).

Table 2: The topics and features identified from the literature review. These topics form the basis for the data collection of features for the remainder of the thesis. *
*(1) = Sanjay Parekh, 2019; (2) = Filice et al., (3) = Leiner et al.,

Topic	Features
General information	- Number of live customers - Number of partnered companies [1, 2, 3]
Offered solutions	- First- and third party offered AI products [1, 2, 3] - Regulatory clearance AI products (CE, FDA or research)
Technology	- Workflow integration and compatibility with all HISs [2, 3] - AI product output [2, 3] - Automatic activation AI products [2, 3]
Economic factor	- Contracting point (through platform or individual AI product vendors) [1, 2] - Pricing of both platform and the offered AI products
Service & support	- Offered support by platform [1]

These topics and features will be assessed for relevancy by all relevant stakeholders. During the literature review, two types of stakeholders have been recognized in the procurement process of AI platforms and AI products through the AI platforms: vendors and customers. The vendors consist of two different stakeholders. The first stakeholder is the AI platform vendor, which offers an AI platform for the customer. The AI platform vendor plays an important role in offering a solution that meets the demands of the customers with a wide or specialized selection of AI products. The second stakeholder is the AI product vendor, which offers integration with the AI platform for clinical use for the customer. The AI product vendor plays an important role in offering a solution that clinically adds value to the workflow of the customer.

The customers, i.e., radiology departments, also consist of two stakeholders. The first stakeholder is the radiologist, who operates both the AI platform and AI products in a clinical setting. The radiologists play an important role in judging the clinical added value of AI products and AI platforms and an efficient workflow. The second stakeholder is the IT staff of the radiology department. The IT staff of the radiology department is heavily involved with integrating AI products and AI platforms with their existing IT infrastructure. The IT staff is familiar with the complexity of integration and deployment and play an important role in the procurement process.

2.7. Synthesis of literature review

To summarize this literature review, a synthesis of the literature for the three components is shown in figure 9. In conclusion, although AI products for radiology are a promising technology, implementation for clinical use of multiple AI products remains challenging due to deployment and managing issues. An auspicious solution is a vendor-neutral platform for procurement and integration of multiple AI products, often referred to as an AI platform. By performing this thesis, new insights regarding AI platforms and their offered features are obtained and a definition for an AI platform is provided. Besides, by constructing a website to update on new AI platforms and features, the transparency is maintained, and radiology departments are guided through the procurement process of AI platforms.

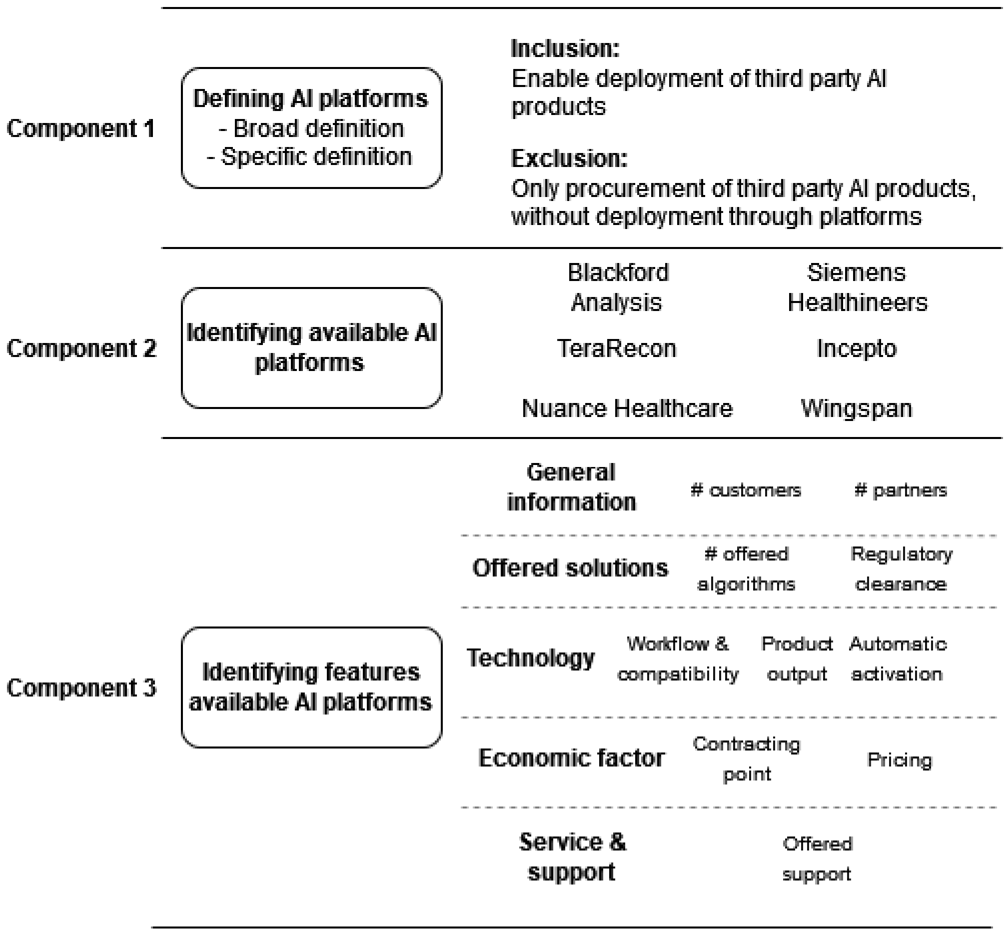

Figure 9: The research model based on the available literature, i.e. the scientific as-is situation.

3. Methods and materials

In this chapter, the methods and materials used for each component of the research model are elaborated on. An overview of all three components with accompanying methods, sampling and analysis is shown in figure 10, which serves as the leading design of this chapter. This chapter will elaborate on the methods and will thereby discuss how that contributes to according components. The methods will be explained in chronological order, as this thesis was actually executed.

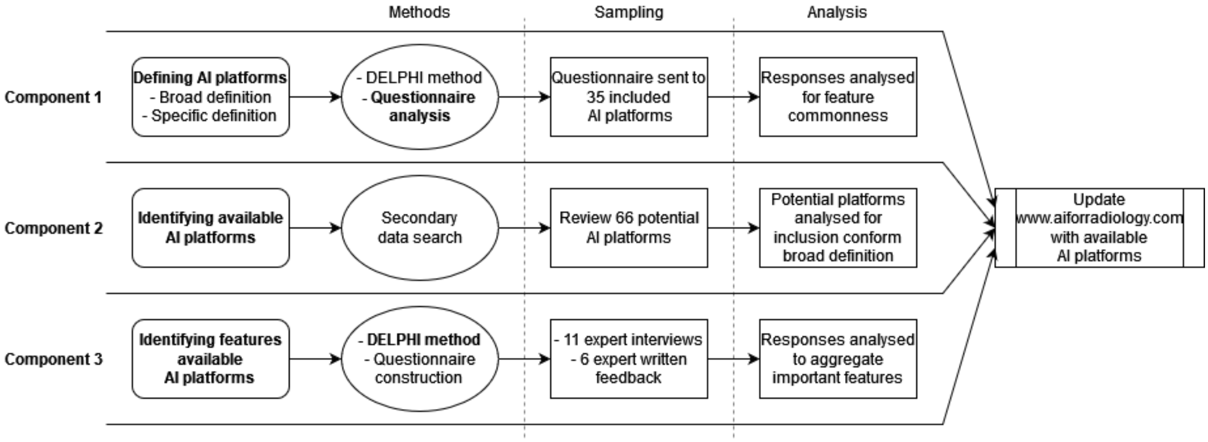

Figure 10: The research design with the three components and their methods, sampling and analysis. The methods achieve each components goals and the results are updated on www.aiforradiology.com.

3.1. Secondary data search for potential AI platforms

To establish a list of potential AI platforms to be included in this thesis, three sources have been used. The first and main resource is the website www.aiforradiology.com, which lists all available CE certified AI products for radiology. For each AI product, the distribution channels are listed, which can include AI platform vendors, AI product vendors and AI marketplaces, which do not offer a platform for deployment of AI products. Secondly, this list of distribution channels was supplemented with potential platforms found in radiology newsletters, press releases and social media. These were kept track of from the start of the thesis (1st of December 2021) up till two weeks before the result analysis, which is a total of 6 months. Thirdly, most distribution channels acknowledge their partner companies on their website. All partner companies are also added to the list of potential platforms, if not yet on the list. The list included 66 potential platforms and can be found in appendix 1.

The secondary data search contributes to component 2, which aims to identify available AI platforms. The websites were later on reviewed to analyse for inclusion conform the broad definition and exclusion criteria formulated for component 1. Vendors that were clearly not meeting the criteria were excluded. Vendors that were clearly meeting the criteria were included. Vendors that were not immediately clear whether they met the criteria or not, were contacted to determine whether they met the criteria. No responses were not included.

3.2. DELPHI method for questionnaire construction and broad definition

Now that a list of potential AI platforms is created, a broad definition needs to be formulated to filter and include actual AI platforms, contributing to component 1. The included AI platforms will be surveyed, asking for the features each AI platform offers, contributing to component 3.

3.2.1. Research approach and sampling

The selection of important topics and features identified from the literature in table 2, forms the basis of the questionnaire. Basic questions were formulated to assess each feature neatly. All topics, features and questions need to be validated by experts, since the concept of AI platforms is still young and not much is known about what an AI platform is or what is should offer. Therefore, qualitative data collection seems the most logical option to validate and construct the questionnaire. With qualitative data collection through interviews, a discussion on AI platforms can be opened, to investigate a definition and validate important features in the questionnaire. However, each expert has his own view, understanding, experience and expectation of AI platforms. Even two experts of the same stakeholder and the same institution will have differing views on AI platforms. Therefore, interviewing individual experts to construct a questionnaire does not seem like the ideal option. However, it seems logical to interview at least one expert from each stakeholder.

The best option is to open a discussion between experts from each stakeholder. Due to resource limitations, it was not possible to open a live discussion between experts from each stakeholder, which would be the best option to construct the questionnaire. To still open a discussion between experts from different stakeholders, the first draft of the questionnaire was validated using the DELPHI method (Twin, 2021). The Delphi method is a process that is used to come to a group consensus or opinion by multiple rounds of surveying a panel of experts (Twin, 2021). After every round, the results of the survey are aggregated into a new survey, which is sent to the same panel of experts. The experts can change their answer or opinion based on the group opinion in the new survey, which includes opinions of the other experts in the panel. This is repeated until new rounds do not result in new opinions and a consensus is achieved (Twin, 2021). The group consensus from the DELPHI method is based on the wisdom of crowds, which suggests that a group of experts collectively is smarter than individual experts (Halton, 2021).

The panel of experts in this thesis consisted of at least one expert representative from each stakeholder, namely: 2 representatives of AI platform vendors, each from a different vendor, 2 representatives of an AI product vendor, both from the same vendor, 1 IT expert in the radiology department of Radboud university medical center and a clinical physician in the radiology department of Radboud university medical center. The first draft of the questionnaire, which was based on the identified topics from the literature review, was discussed in an individual interview with each expert. The exact same draft was used for each interview.

3.2.2. Setup and analysis

First, each expert was asked how they defined an AI platform for radiology, to formulate in- and exclusion criteria for AI platforms for the data collection. This part of the DELPHI method contributes to the broad definition of component 1, complementing the in- and exclusion criteria from the literature review. Then, the questionnaire was discussed, asking about relevance of each topic and feature. According questions were formulated in a neat way, to prevent confusion or different interpretations among the questionnaire respondents. New topics, features and questions were formulated, and certain topics, features and questions were deleted or adjusted with each interview.

After the first round of interviews with all experts, the results were aggregated to construct a new version of the questionnaire. This version of the questionnaire was sent out to each expert for the second round of interviews. One representative of the AI product vendor could not attend this round of interviews. The new aggregated version of the questionnaire was discussed in the same way as the first round. The experts were already agreeing on a lot of topics, features and questions and coming to new realizations from other experts' opinions. Again, new topics, features and questions were formulated, and certain topics, features and questions were deleted or adjusted with each interview. After all the interviews of the second round, the results were aggregated to construct a third version of the questionnaire. The new version of the questionnaire was sent out to all experts again, for a third round. The third round consisted of written feedback on the questionnaire. Every expert participated in the third round. The feedback was completely based on the formulation of questions, with no feedback or disagreements on the topics and features. It is assumed sufficient consensus is achieved and no further rounds were conducted. A total of 11 interviews were conducted and 6 written feedback documents were received. The interviews were recorded and reviewed extensively after each round but were not transcribed.

3.3. Questionnaire construction

The aggregated opinions and feedback from the DELPHI method resulted in a final questionnaire, consisting of 7 topics to assess 35 features. The full questionnaire can be found in Appendix 2. All topics and a selection of important features resulted from the DELPHI method are shown in table 3. The table also indicates which stakeholders considered which features as relevant to include in the questionnaire. All features identified in the literature review are marked, to identify new features from the DELPHI method, which were not mentioned in the literature.

Table 3: The topics and features resulted from the DELPHI method. The yellow marked features indicate features that resulted from the DELPHI method and were not found in the literature review. Departments = radiology departments, i.e., IT expert and clinical physician; Platforms = representatives AI platform vendors. Products = representatives AI products vendors.

Topic	Feature	Relevant stakeholders
Platform & sales	Processing platform	All
	Customer exclusivity	Departments
	Regions clinical use	Departments
Offered solutions	First party AI products	Departments
	Third party AI products	Departments and platforms
	AI product development	Platforms
Workflow integration	PACS and EHR compliancy	Departments
	Uniform front-end	Products
	Front-end layout	Departments
	Automatic image orchestration	Departments and platforms
	Prior image retrievement	Products
AI product output	Output adjustability	Departments and products
	Vendor feedback	Products and platforms
Image processing	Server location	Products
Economic factors	Single contracting point	All
Service & support	Single support point	All

The first topic was ‘platform & sales’ and aimed to gather data on the type of platform and the customer base. The first feature was ‘processing platform’ and was included in the questionnaire for reassurance of inclusion of the AI platform. The features aimed to assess whether the AI platform offers a solution for the processing of multiple AI products. This was considered relevant by all stakeholders, since this defines an AI platform. Some AI platform vendors originated as a different product vendor, e.g., a PACS vendor, and only offers the AI platform solution for their existing customers, in this example customers that already use the vendor’s PACS. The feature ‘customer exclusivity’ assesses whether the platform is exclusively for existing customers. This feature was considered important by the experts from the radiology departments, since they might not be able to use certain AI platforms with their existing HISs. The second feature ‘regions clinical use’ assess in which regions the AI platform is sold for clinical use. This feature was also considered important by the experts from the radiology department, to know if the AI platform is sold in the region the radiology department is located. None of these features were found in literature.

The second topic was ‘offered solutions’ and aimed to gather information regarding the AI products offered for integration on the platform. The first two features, ‘first- and third party AI products’, aim to assess the number of self-developed AI products and AI products developed by other AI products vendors, offered for integration on the platform. Both features are considered important by the radiology department, since they prefer a wide selection of AI products for different use cases. The number of third party AI products are also considered important by the platforms, since certain platforms focus on offering as much AI products as possible, which is a feature they might use to promote their AI platform. The last important feature is ‘AI product development’ and aims to assess if the platform enables customers to develop their own AI products on the AI platform. This feature is considered important by the AI platform vendors, since this is feature certain AI platform vendors really promote their AI platform with. Two out of these 3 features were already identified in the literature review.

The third topic was ‘workflow integration’ and aimed to gather information regarding the integration of the AI platform into the radiologist’s workflow. The first feature was ‘PACS and EHR compliancy’ and aimed to assess which PACS and EHR systems the AI platform is integrated with. This feature was considered important by the radiology departments, since this feature defines whether their existing HISs are compatible for the use of the AI platform. The second feature was ‘uniform front-end’ and aimed to assess whether the AI platform offers a single, uniform front-end for all their customers. This feature was considered important by the

AI product vendors, since some AI products offer a unique front-end with certain options they wish to provide to their customers. If an AI platform offers a uniform front-end for all their customers, these options are most likely not available. The layout of the front-end was the third features and aimed to assess the layout of the front-end on which customers are working. This could be a dedicated web viewer, an extra application or customizable by the customers. This feature was naturally considered important by the radiology departments. The fourth feature was ‘automatic image orchestration’ and aimed to assess how the images are orchestrated to the relevant AI products and can either be organized automatically with DICOM tags or manually by the radiologist. This feature was considered important by both the radiology departments and the AI platform vendors, since it effects the workflow of the radiologists and might be a key feature for the AI platforms. The last feature was the ‘prior image retrievement’ and aimed to assess whether prior patient images where available for retrievement for the AI products vendor, conform all privacy regulations. Naturally, this feature was considered important by the AI product vendors, since they could improve their AI products with this information. Only the image orchestration feature was previously identified in the literature review.

The fourth topic was ‘AI product output’ and was aimed to gather information regarding the output of the AI products. The first feature was ‘output adjustability’ and aimed to assess whether the output of the AI products was adjustable or rejectable. This feature was considered important by all stakeholders, since every stakeholder benefits from this option in a certain way. The next feature is ‘vendor feedback’ and aims to assess if either of the vendors, AI product vendor or AI platform vendor, is given feedback on the adjusted output. Both vendors can improve their product by this feedback and thus this feature is considered important by both vendors. The feature ‘output adjustability’ was previously identified in the literature review. The fifth topic was ‘image processing’ and was aimed to gather information regarding the servers and required hardware for the AI platform. The most important feature was ‘server location’ which aimed to assess where the servers are located; on-premise, data center, or via a cloud vendor. This feature was considered important by the radiology departments, since the customer needs to know whether any on-premise servers are needed before procuring an AI platform.

The sixth topic was ‘economic factors’ and logically aimed to gather information regarding the economic factors of the AI platforms. The most important feature was the ‘single contracting point’ which aimed to assess how the contracting of AI products integrated on the platform is organized, through the platform (single contracting point) or through the individual AI product vendors (multiple contracting points). This feature was considered important by all stakeholders; the radiology departments want the easiest access to all products, the AI platform vendors want to ease the selection of new AI products, and the AI product vendors want to know how their AI products are sold. This feature was already identified in the literature review. The seventh and last topic was 'service and support' and was aimed to gather information how the support is organized. This feature was considered important by all stakeholders, for the same reasons as the previous topic. This feature was previously identified in the literature review.

After validation of the list of platform features using the DELPHI method, a questionnaire was made that comprises all features. Google Forms was used for the construction of the questionnaire, due to the planned continuity of maintaining the website by the Diagnostic Image Analysis Group (DIAG) of Radboud university medical center. The questionnaire was prefilled as much as possible for each individual platform by using public information, in order to ease participation in the questionnaire and ultimately increase the response rate. The results were analysed using Microsoft Excel and focused on showing differences and similarities of the features in table 3, to distinguish commonly recurring features from less common features.

3.4. Broad definition for AI platform inclusion and questionnaire analysis

As mentioned earlier, during the first round of interviews in the DELPHI method, a definition was discussed with each expert. Based on the aggregated results of these discussions and the features that are identified in the literature review and DELPHI method, a broad definition for AI platforms is formulated with according exclusion criteria, to finish the first step of component 1. We defined an AI platform as a technical solution that enables the deployment of third party AI products. The following exclusion criteria were in place:

- *The distributor only offers the procurement of third party AI products, without offering a platform that enables deployment of said AI products*
- *The distributor offers a platform that only enables deployment of third party research AI products*
- *The third party AI products are exclusively embedded into a medical device*
- *The distributor offers a platform that exclusively enables deployment of their own AI products*

AI platforms are a solution to manage multiple AI products for radiology in a clinical setting. When procuring AI products, the deployment of each AI product individually is the main issue. The first criterium excluded solutions that do not offer the deployment of AI products procured from other companies. The second criterium excluded platforms that exclusively enable deployment of research AI products. Research AI models may not be used for clinical use. Since the goal of this study is to guide radiology departments in the procurement of an AI platform for clinical use, the second criterium is essential. The third criterium excluded platforms that only offer AI products that are exclusively embedded into a medical device. It is unrealistic that a radiology department will procure a new medical device for each new AI product. The last criterium excluded platforms that exclusively enable deployment of their own AI products. These platforms do not offer deployment of third party AI products, so with the procurement of a new self-developed AI product, the platform has to integrate with their own AI product. The deployment issues are not present with this type of integration, so AI platforms that exclusively enable the integration of first party AI products are excluded.

Based on the analysis of the results and the recurring features, this definition and exclusion criteria are substantiated. Features that are common in all platforms, were assumed discriminatory for the definition of an AI platform. Features that are absent in all platforms, were assumed discriminatory for the exclusion of the definition of an AI platform. A distinction is made between features that are discriminatory for inclusion, discriminatory for exclusion, commonly included (but not discriminatory for the definition), and commonly excluded (but not discriminatory for the definition). Furthermore, the results of the questionnaire will results in an answer to component 3, which aims to identify features offered by available AI platforms.

3.5. Summary and deliverables

Finishing the methods will achieve each components goals; a definition is formulated for AI platforms and an up to date list of available AI platforms and their features are publicly uploaded on www.aiforradiology.com (figure 10). The platforms were linked to the products page and vice versa for a clear and transparent overview of all available platforms and their CE certified product offerings. The platforms that have not filled in the questionnaire will still be placed online, only using available information online. A source distinction is made between responded platforms and non-responded platforms on the website. By achieving the component goals, the research question is answered and the thesis goal, to guide radiology departments in the procurement of an AI platform, is achieved.

4. Results

This chapter shows and elaborates on the results of each component of the research model. This chapter will elaborate first on component 2, then component 3, and finally component 1, which is the same order the methods were executed and is the logical order. Component 2 elaborates on all reviewed potential platforms to include AI platforms. Component 3 shows the results of the questionnaire and analyses the results for common features. Component 1 defines an AI platform based on the analysis of the questionnaire responses.

4.1. Component 2: identifying available AI platforms

The list of potential AI platforms consisted of 66 potential platforms, and this took place from March 2022 until the end of May, when the result analysis started. 49 potential platforms were collected on the distribution channels of AI products on www.aiforradiology.com, 13 new potential platforms were identified through publicly acknowledged partners from the original 49 potential platforms, and 4 platforms were collected from other sources, i.e. recommendations from interviews and new launched platforms in radiology newsletters (figure 11). After reviewing the websites for in- and exclusion criteria, 19 potential AI platforms have been excluded based on available information online. The 19 excluded potential AI platforms were solely AI product, PACS or EHR developers, platforms that resell third party AI products without offering deployment of AI products, or platforms that distribute data sets for AI products to be trained with.

The remaining 47 potential platforms have been reviewed more extensively by contacting company representatives and consulting with experts, which resulted in the exclusion of 12 more potential platforms. Some of the excluded potential platforms offered a platform that exclusively included different first party AI products, which still makes them an AI product vendor and not an AI platform. Other excluded potential platform offered different third party AI products, exclusively embedded in medical devices, e.g. CT-scanner or MRI. These products are standardly sold with predetermined AI products included and the AI products automatically process each image after each scan. One of the excluded potential platforms was actually not a distributor of AI products, but a very similar website to www.aiforradiology.com. The websites lists all available FDA approved AI products for radiology with their offered features and use cases. At the time of writing, the websites lists 196 FDA approved AI products, which is very comparable to the 200 CE certified products on www.aiforradiology.com.

A remaining total of 35 platforms have been included in this thesis. Out of the 35 included AI platforms, 20 platforms have confirmed meeting the definition and not meeting the exclusion criteria. The remaining platforms (n=15) have not confirmed meeting the criteria yet and therefore have not received the questionnaire. Among the included AI platforms, already a clear distinction between different AI platforms was noticed. Some platforms that originated as a different radiology HIS vendor, e.g., PACS vendors, that now also offered an AI platform, already had a customer basis and a certain degree of maturity and corporateness. This was noticed due to the level of hierarchy when reaching out to the vendors and the confirmations needed from different teams before providing definitive answers. In general, these AI platforms offered a wider selection of AI products than other AI platforms. Other AI platforms that launched more recently and originated as an AI platform, offer a more limited selection of AI products. However, the communication process went with more ease and information was more accessible.

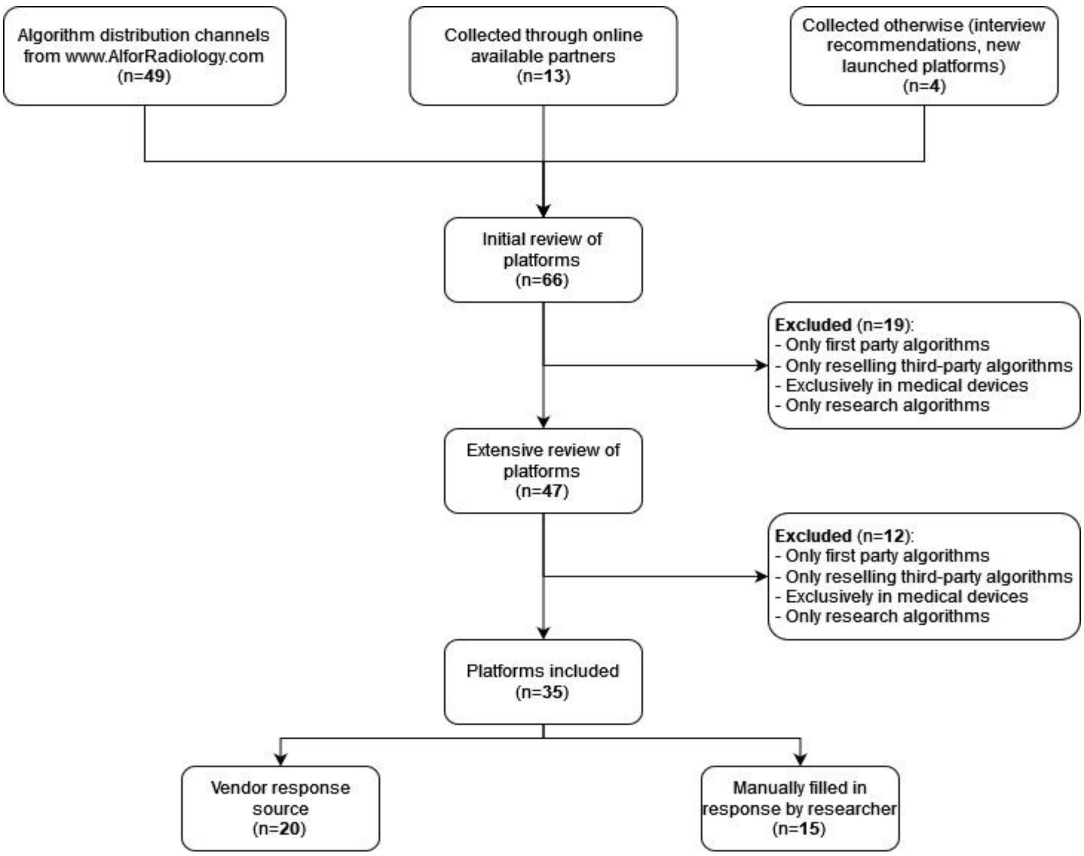

Figure 11: inclusion and exclusion of AI platforms based on the draft definition of an AI platform and corresponding exclusion criteria.

4.2. Component 3: identifying features of available AI platform

The questionnaire was sent out to all 35 included platforms and ten platform vendors have submitted a response. The remaining 25 platforms will not be included in the following analysis of the results, which will elaborate on the most important findings per topic and feature. Table 4 is a summary of the questionnaire results, showing the frequency for each feature as mentioned in table 3 in the methods. All mentioned features are further explained below the table, divided in sub sections per topic.

Table 4: summary of important features offered by included AI platforms. The features are divided in seven topics and the frequency of each feature is indicated.

Topic	***Feature***	***Frequency***
Platform & sales	Processing platform	10/10 (100%)
	Customer exclusivity	2/10 (20%)
	Regions clinical use	
	European Union	7/10 (70%)
	North America	2/10 (20%)
Offered solutions	First party AI products	3/10 (30%)
	Third party AI products	10/10 (100%)
	AI product development	8/10 (80%)
Workflow integration	PACS and EHR compliancy	
	All DICOM compliant	7/10 (70%)
	All HL7 compliant	8/10 (80%)
	Specific number of partners	2/10 (20%)
	Uniform front-end	4/10 (40%)
	Front-end layout	
	Web viewer or application	5/10 (50%)
	Directly sent to PACS	2/10 (20%)
	AI product dependent	3/10 (30%)
	Automatic image orchestration	10/10 (100%)
	Prior image retrievement	8/10 (80%)
AI product output	Output adjustability	
	Always adjustable	1/10 (10%)
	AI products dependent	9/10 (90%)

	Vendor feedback	
	None	3/10 (30%)
	AI product/customer dependent	7/10 (70%)
Image processing	Server location	
	Exclusively on cloud	2/10 (20%)
	At least 1 required on-premise	1/10 (10%)
	AI product/customer dependent	7/10 (70%)
Economic factors	Single contracting point	9/10 (90%)
Service & support	Single support point	10/10 (100%)

4.2.1. Platform & sales

All ten platforms offer a solution for the processing and deployment of multiple AI products. Two respondents offer their AI-processing platform service exclusively for existing customers of their PACS imaging software. Seven platforms are sold for clinical use in the European Union (EU), while two platforms are exclusively sold in North America and have no CE certification. One platform is currently in the certification process and is not sold for clinical use yet.

4.2.2. Offered solutions

Figure 12 shows the number of certified AI products offered on the platforms, with 12.a showing the number of first party AI products, i.e., developed by the platform vendor, and figure 12.b showing the number of third party AI products, i.e. developed by other institutions. The y-axis indicates the name of the AI platform. NOVU AI is not live yet and wishes to keep this information confidential, whether first party or third party. PAIR's response was also confidential for both features. Both platforms however confirmed offering integration and deployment of third party AI products. Visage AI Accelerator offers their own AI products and have a customer driven integration with third party certified AI products. This means that a customer can procure any AI product individually through the AI product vendor. The AI platform vendor handles the integration with the AI product on the customer's Visage AI Accelerator platform. The remaining platforms with no first party AI products offer no self-developed AI products (n=5).

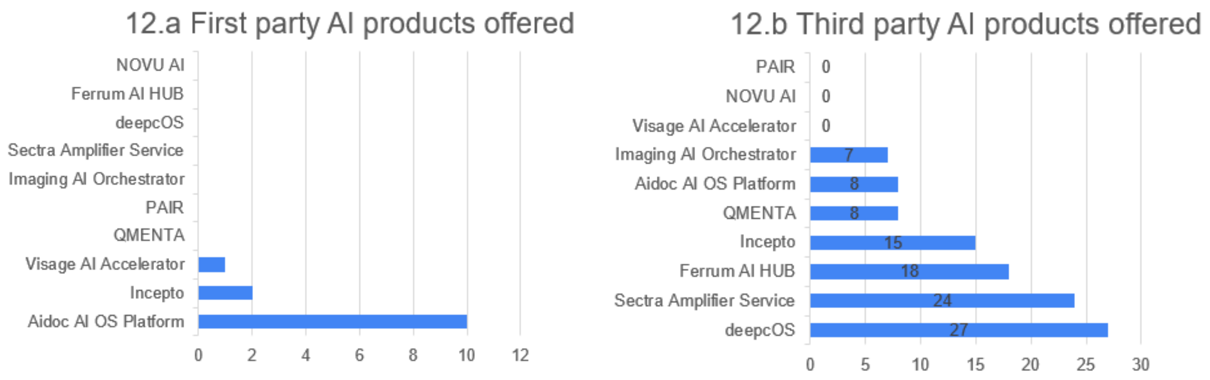

Figure 12: the number of AI products offered per platform; 12.a indicates the number of self-developed AI products and 12.b indicates the number of AI products developed elsewhere.

Furthermore, eight platforms offer their customers the option to develop AI algorithms on the platform, making AI products available for clinical use. This does not mean only the deployment of inhouse developed AI algorithms, but the actual development of AI algorithms on the platform. Two out of those eight platforms offer the option to distribute self-developed algorithms to other institutions using the platform or operate algorithms developed and offered by other institutions via the platform.

4.2.3. Workflow integration

Figure 13 shows the compliancy of the AI platform with other PACS or EHR/EMR software for integration. Most platforms offer PACS integration (n=7) and EHR/EMR integration (n=8) with all PACS and EHR/EMR software that comply with the global DICOM and HL7 standards. This suggests integration with almost all PACS and EHR/EMR software. Two platforms are limited to integration with their own PACS software, which are the same two platforms that are exclusively available to their existing PACS customers. One platform offers PACS and EHR/EMR integration with seven companies that offer both software systems. One platform offers integration with four EMR/EHR companies.

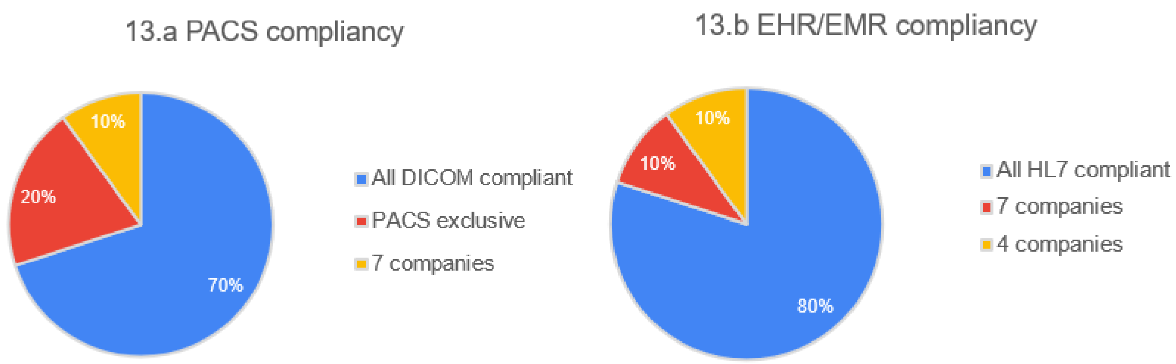

Figure 13: integration of the platforms with other PACS and EHR/EMR software.

To show the results of the AI products, four platforms enforce a standard, uniform front-end for their customers, of which three platforms use a web viewer and one platform sends the images directly to the PACS (figure 14). The other six platforms offer their customers a customizable front-end, usually shown in an extra application (n=1), a web viewer (n=1), directly sent to the PACS (n=1) or are dependent on the AI product vendors as the front-end layout (n=3).

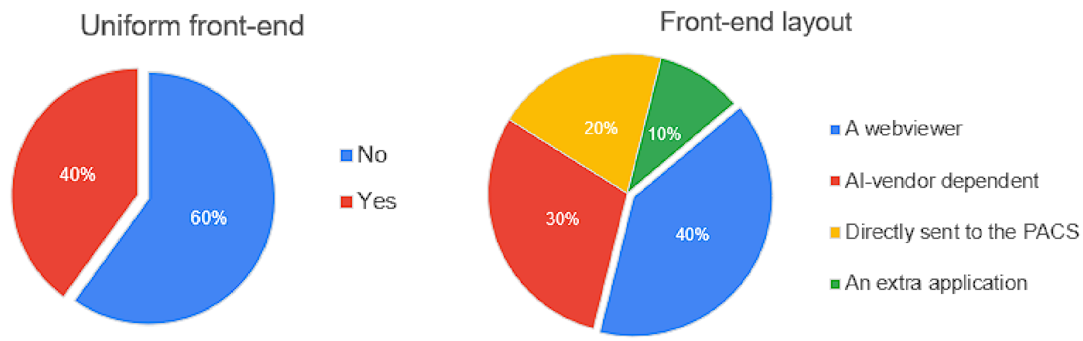

Figure 14: the front-end layout for customers to view the results of AI processed images and uniformity for all customer

To orchestrate the radiology images to relevant AI products for processing, all (n=10) respondents offer automatic, platform embedded orchestration (figure 7). Half of the respondents (n=5) offer the platform embedded orchestration standardly, while the other half offer their customers the option to customize between automatic orchestration and manual activation of AI products. In none of the cases, the image orchestration is dependent on the AI product vendor. Furthermore, as can be seen in figure 15, almost all platforms (n=9) facilitate the retrievement of prior scans (anonymized and conform all privacy regulations). Only one platform facilitates the retrievement of prior images exclusively for the AI platform vendor, which means that prior images are not retrievable for the AI product vendor, while the other platforms facilitate retrievement of scans for both the platform and the AI product vendor.

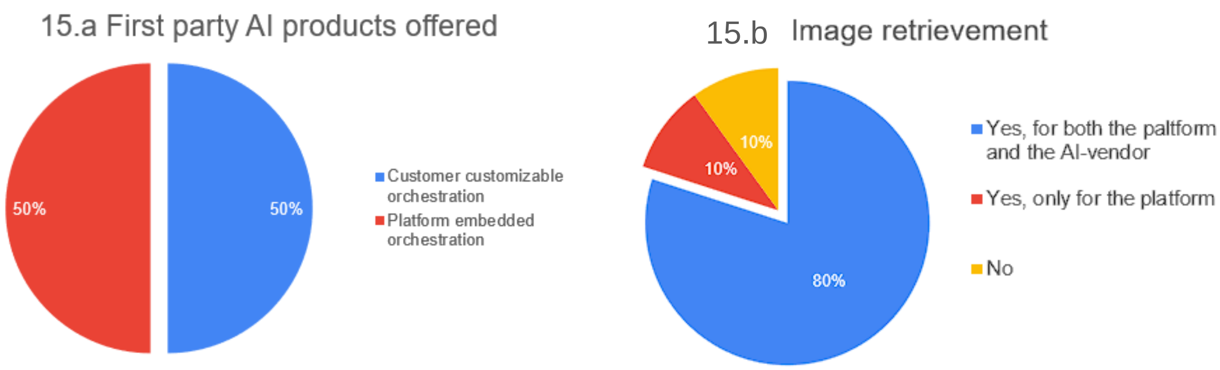

Figure 15: image orchestration to relevant AI products (15.a) and retrievement of prior scans and images (15.b).

4.2.4. AI product output

When an image is processed through an AI product, it depends on the AI product vendor whether the predictions are acceptable/rejectable and adjustable (n=9), as can be seen in figure 16. This means that for the option to accept/reject or adjust the output of an AI product, depends on the AI product itself. One platform always offers the option to accept/reject or adjust the AI product output, regardless of the AI product.

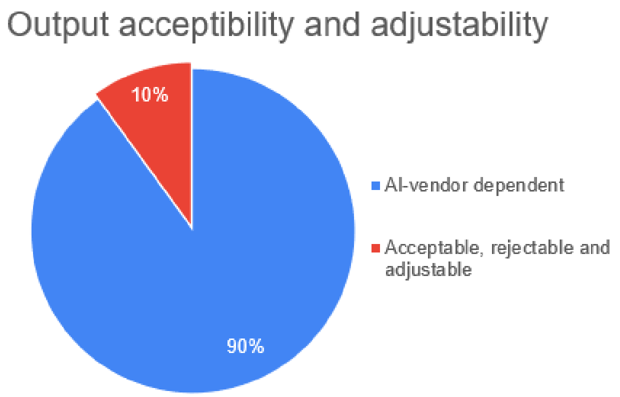

Figure 16: the ability to accept, reject and adjust the AI product output.

When the algorithm output is accepted, rejected or adjusted, one platform does not send feedback that the algorithm output is either accepted, rejected or adjusted, to the relevant AI product vendor (figure 17). This means that an AI product vendor does not receive feedback regarding the effectiveness of their AI products in clinical setting. Four platforms depend the option of providing output feedback to the AI product vendor, on the customer and the AI product vendors. Besides the two not applicable responses, the remaining three platforms completely depend the option on the customer's wishes.

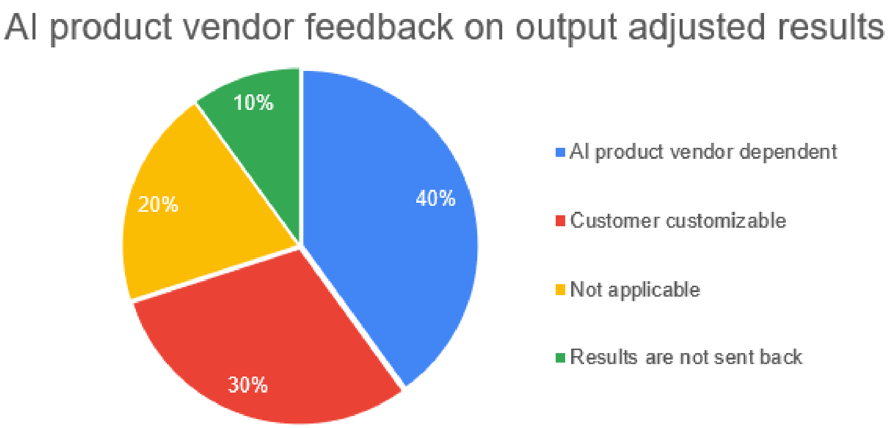

Figure 17: whenever the AI product output is accepted, reject or adjusted, the platforms do not always provide this feedback to the relevant AI vendors.

4.2.5. Image processing

To process the images with the AI products through the platform, data servers are essential. These servers can be either on premise (at the customer), via a cloud vendor, via a data centre managed by the platform vendor, or as a hybrid of any of these options. Figure 18.a shows that most platforms (n=7) depend the server options on the AI product vendors (n=2), let their customers customize the options (n=3) or a combination of both (n=2). Figure 18.b shows that out of these seven platforms, these customizable options always include a cloud vendor (n=7). Some platforms (n=5) include a hybrid option of a cloud vendor with an on premise server and a few include all hybrid options (a combination of a cloud vendor, an on premise server and/or a data centre) (n=2). As seen in figure 18.a, two platforms exclusively make use of a cloud vendor, and one platform always requires at least 1 on premise server. The size and number of the servers needed depends on the customer's daily volume and modality of images that need to be processed.

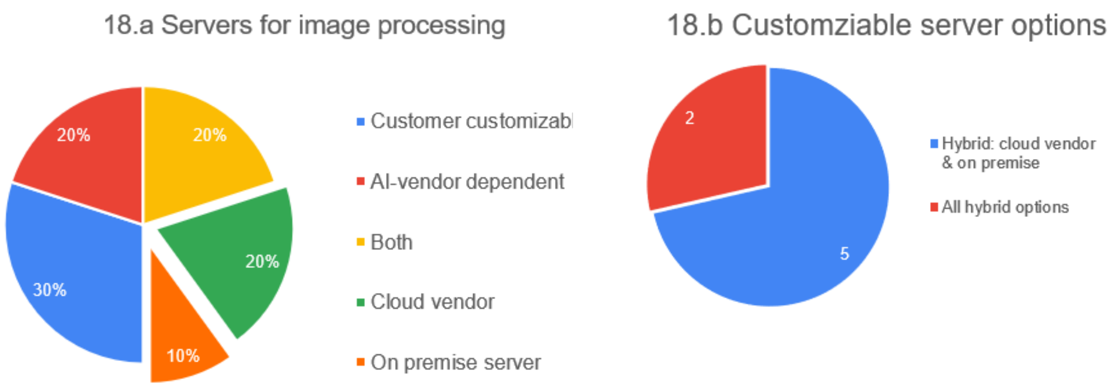

Figure 18: the type of servers that a customer needs to use the AI platform and process images.

4.2.6. Economic factors

As can be seen in figure 19.a, almost all platforms (n=8) organize the contracting of AI products through the platform vendor itself. This means that the procurement process for the customer is through a single point, namely through the platform. One platform offers their customers the option to choose how the contracting is organized, either through the AI platform (single point) or through each individual AI product vendor (multiple points). One platform always organizes the procurement of AI products through multiple points via the individual AI product vendors. Figure 19.b shows that most platforms (n=6) work with a subscription as their business model, paying a set amount each month, year or every few years. One platform specified that their subscription has multiple tiers, based on the usage of the customer, meaning the more a customer uses the platform, using the platform becomes relatively cheaper. One platform implements a pay per use business model, paying a certain amount for each time the platform to process an image. One other platform offers the customer to choose a payment model of their own wish. The remaining two platforms responded with not applicable, assuming this information is most likely confidential.

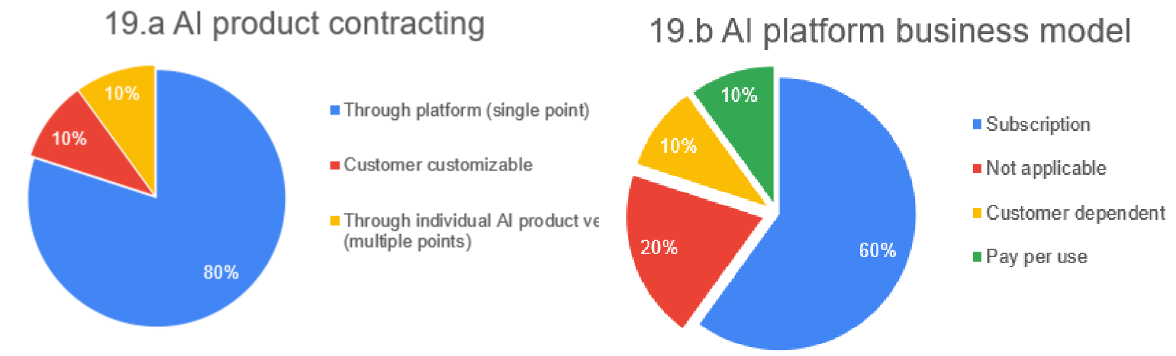

Figure 19: organization of the procurement of the integrated AI products on each platform (19.a) and the payment model of each platform (19.b).

4.2.7. Service & support

All platforms (n=10) offer service and support for both the platform and the integrated AI products on the platform (figure 20). This includes both customer support and service as technical support and service, e.g., software updates and upgrades. The complete list of features and questions in the questionnaire can be found in Appendix 2. Furthermore, the individual responses and complete features of each platform can be found on the website www.aiforradiology.com/platforms.

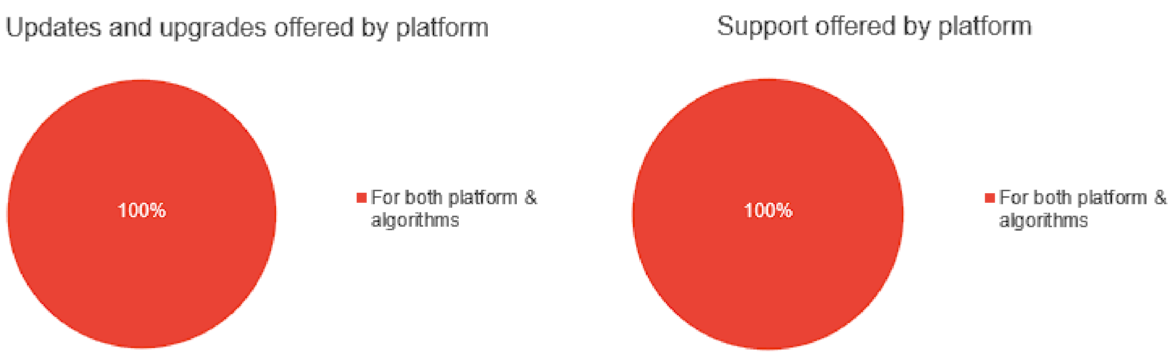

Figure 20: the customer support and technical support that is offered by the platform vendors.

4.3. Component 1: defining AI platforms

The broad definition with according exclusion criteria provided in the methods, which were used to include AI platforms in this thesis, form the basis for the specific definition of component 1. Based on the collected platform characteristics, certain features appear to be more common for AI platforms than others. The frequency of features is shown in table 4 at the beginning of the results. Multiple features are common amongst the AI platforms but are not offered on all platforms. It is assumed these features are not discriminatory for the specific definition of an AI platform. First party AI products on the platform are not very common (30%). These platforms function particularly as a processing platform for third party AI products and do not develop algorithm software themselves. Although it is very common (90%), it is not required that the procurement of third party AI products is offered through the platform vendor. Some platform vendors implement a customer driven integration of AI products, meaning the platform vendor handles the integration of any compliant AI products the customers wish into their AI platform. The AI products, however, may be procured through the AI product vendors individually.

Furthermore, 80% of the platforms offer the development of new AI algorithms through their platform. This is a common trend amongst the AI platforms, since the in-house developed algorithms are integrated into the platform and can be implemented for clinical use. This, however, cannot be assumed to be a discriminatory feature for an AI platform. With regards to PACS and EHR/EMR integration, it is common for AI platforms (70% and 80% respectively) to offer integration with all DICOM and HL7 compliant AI products. However, some AI platform vendors that also offer PACS or EHR/EMR software (20%), limit the use of their AI platform exclusively to their existing customers. Likewise, some AI platform vendors (20%) may choose to partner with specific PACS or EHR/EMR vendors to integrate with, to guarantee a certain quality or due to contractual reasons.

Some features are offered by all platforms and are assumed discriminatory for the specific definition of an AI platform for radiology, which suggests that a platform is required to meet that criterium to be considered an AI platform. These features are shown again in table 5. The table shows that all AI platform vendors offer a product that processes radiology images with AI product software through their platform. This question was included in the questionnaire as an inclusion confirmation of AI platforms, since this feature was already included in the broad definition in the methods. If any respondent submitted a different answer, the AI platform could be excluded from the results. Logically, all AI platforms also focus on integration with third party AI products, as was part of the inclusion criteria. However, the table shows that all platforms offer an automatic orchestration of images to relevant AI products embedded in the platform. This relieves the radiologist of the manual activation of relevant AI products for each image. This is a new discriminatory feature for AI platforms. In addition, all platform vendors offer support and updates for their offered AI products, which is also a new discriminatory feature for AI platforms. No features were identified that are not offered by any AI platform. Therefore, no features are considered discriminatory for the exclusion of an AI platform.

Table 5: summary of features that are offered by all included AI platforms.

Feature	***Frequency***
Processing platform for multiple AI products	10/10 (100%)
Third party AI products offered on platform	10/10 (100%)
Automatic image orchestration to relevant AI products	10/10 (100%)
Single point for customer support and updates	10/10 (100%)

Concluding, an AI platform is defined as *a technical solution that enables the deployment and orchestration of third party AI products, consolidating all service and support.* Furthermore, the same exclusion criteria are still in place. The results are summarized are broadly summarized in figure 21. *yellow mark is new features **green mark is discriminatory for specific definition ***full list of included platforms is in appendix, these are only the respondents.

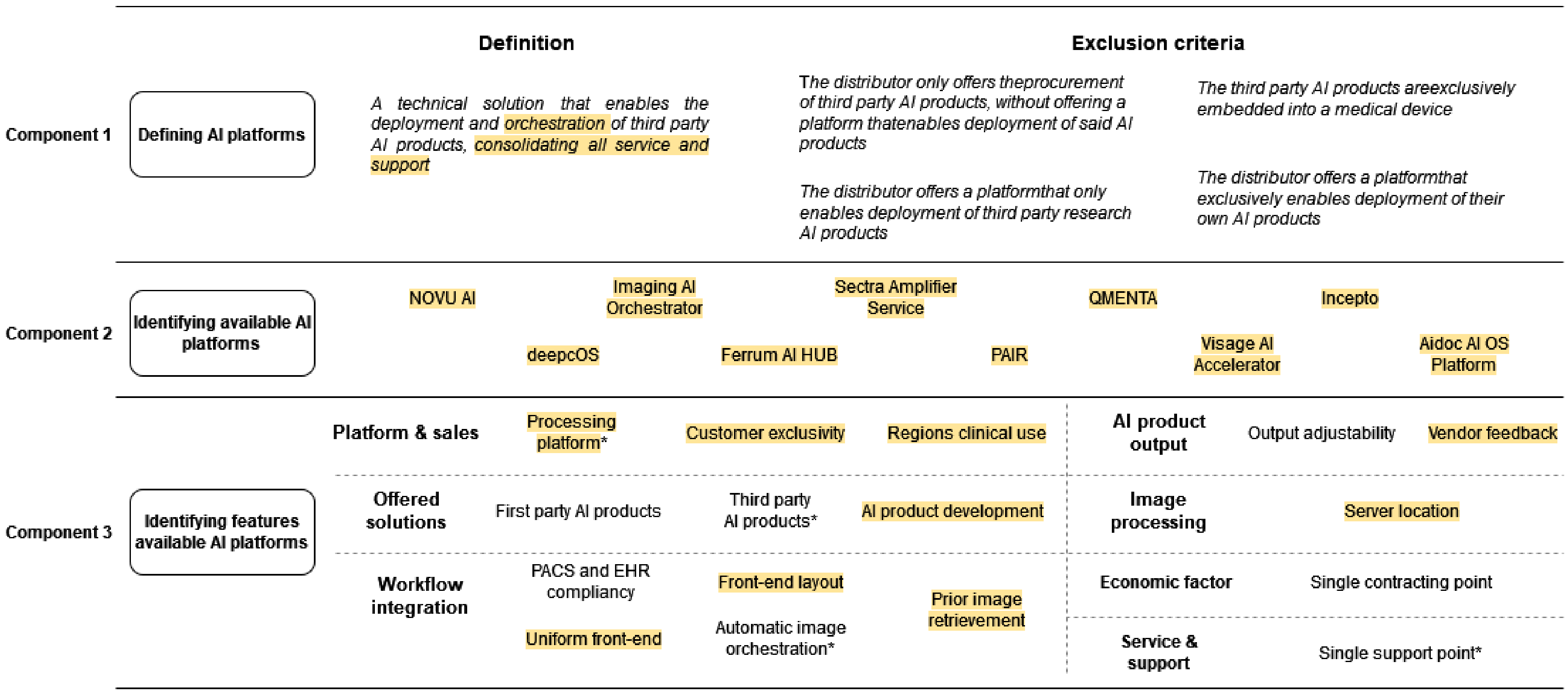

Figure 21: an overall summary of the results for all three components. All yellow marked text are new results from this thesis, that was not found in the literature review. The available AI platforms in component 2 are only the AI platforms that have responded to the questionnaire. The complete list of AI platforms can be found in the questionnaire. Features in component 3 marked with an * are features that are recurring in all respondents of the questionnaire and are discriminatory for the definition of an AI platform.

5. Discussion

This last chapter discusses the results, summarizing the most important results and interpreting them. The results are compared to the existing literature and the background. Furthermore, the biases and limitations of this thesis will be discussed, to investigate further research options. The thesis is concluded with an answer to the research question. The three contributions of this thesis were providing a definition for AI platforms, creating an overview of all available AI platforms and all offered features of available AI platforms. These contributions are achieved by the three components: (1) defining AI platforms, (2) identifying available AI platforms, and (3) identifying features of available AI platforms. The components will be discussed in the same order as the results.

5.1. Component 2: identifying available AI platforms

5.1.1. Design and biases

To identify available AI platforms, the secondary data search method was conducted to identify 66 potential AI platforms. These potential platforms were in- or excluded using the broad definition of an AI platform. Since the broad definition was not a strongly supported by research, certain potential platforms might have been unjustifiably excluded, while other AI platforms might have been unjustifiably included. With the resulted specific definition from this thesis, further research could look into an improved secondary data search. This could in turn result in an improved definition.

5.1.2. Results and comparison

Parekh's market analysis in 2019 included six AI platforms (Sanjay Parekh, 2019). Two and a half years later, 29 more AI platforms were recognized and this thesis included 35 AI platforms in total. This shows how dynamic the market is and how fast it is expanding. Together with the changing definition, this confirms the need of an updated overview of all platforms, instead of a one-time acquisition of currently available platforms. Therefore, uploading all available AI platforms with their offered features on www.aiforradiology.com is essential to maintain market transparency. Furthermore, AI platforms that were already included, but did not submit a response yet, are listed on the website with publicly available information. With the launching of the website, it is expected that these AI platforms will notice the minimal information regarding their AI platform features. This will most likely result in a follow up with the submission of their questionnaire, to update their profile page with the newest information and gain a competitive advantage.

Extra responses with more recognition of the website has already been noticed. A LinkedIn post has been made in the process, announcing the planned update of www.aiforradiology.com with AI platforms. All included platforms are tagged, differentiating between responses and non-responses. This resulted in comments for new potential AI platforms not included yet, and gained attention from representatives of non-responded, included AI platform vendors. It is recommended that further research is conducted after launching the new website. It is expected that more AI platform vendors will respond to the questionnaire and more data can be collected, preferably from all 35 included AI platforms.

In addition, with the passing of more time, more contacts can be collected. During the writing and finalisation process of this thesis, six more AI platforms that met the criteria for inclusion have received and confirmed filling out the questionnaire. Additionally, three new questionnaire responses have been submitted. It is expected that when the website has finished construction, it will gain more attention from all stakeholders. This will most likely motivate AI platforms that are not listed yet to contact the Diagnostic Imaging Group of the Radboud university medical center to be included on the website.

5.2.Component 3: identifying features of available AI platforms

5.2.1. Design and biases

To identify features of available AI platforms, the DELPHI method was used to construct a questionnaire. For the DELPHI method, 11 interviews were conducted with 6 respondents from 3 different stakeholders. To improve the results from this method, more stakeholders could have been included from different companies. However all stakeholders were evenly represented, different vendors have different visions of what is seemed as an important feature. This thesis could have used multiple hospitals instead of only Radboud university medical center. The same goes for the AI products vendors, which were both from the same company. Besides, due to a lack of time, 6 documents with written feedback was received instead of interviews. This was however experienced as a clear way of feedback in combination with interviews. The DELPHI method consisted of 3 rounds, which was deemed enough to reach consensus, since not a lot of change in opinions was noticed in the last round.

However, when analysing the results, multiple questions had differing answers, suggesting the questions were not clear enough for all questionnaire respondents. This might be due to the expert group of the DELPHI method not being diverse enough. For further research, it is recommended to look into stakeholders not only from different companies, but even from different countries. Each country or region has its own needs for AI in radiology, whether it be AI products or AI platforms.

5.2.2. Results and comparison

Looking at the results of the DELPHI method, a lot of new features have been recognized than were found in the literature review. 17 features have been used in this thesis resulting from the DELPHI method, while 7 features have been recognized in the literature review (Filice et al., 2020; Leiner et al., 2021; Sanjay Parekh, 2019). A more extensive DELPHI method with a bigger group of experts might have resulted in even more features. Besides, if one of the rounds is conducted physically or in an online meeting with the different experts, better discussion might arise resulting in a better distinction for important features.

5.3. Component 1: defining AI platforms

5.3.1. Design and biases

One of the limitations of this thesis is the response rate to the questionnaire. Out of the 35 included AI platforms, only ten platforms responded. This is in line with literature, which estimates that with a study design surveys corporate businesses with a questionnaire, a response rate of around 33% can be expected. However, during this thesis, it was challenging to reach out and get in contact with all (potential) AI platform vendors. Almost all platform vendors only mention a basic information email address, e.g. info@company.com, or can be exclusively contacted through an online contact form. Some of these companies have responded, but most of these companies resulted in a no response. For the companies that did not respond, fitting representatives of these companies have been contacted through LinkedIn. Again, this resulted in a few responses, but most of these (potential) AI platforms had not responded at the time of writing. Furthermore, some AI platforms are launched with new features in the near future. They do not want to disclose any information yet, as this is considered commercially sensitive information for now. These AI platforms will submit their questionnaire response as soon as their AI platform is launched for commercial use.

5.3.2. Results and comparison

The specific definition of an AI platform, resulting from this thesis, is a technical solution that enables the deployment *and orchestration* of third party AI products, *consolidating all service and support*. The broad definition that was based on the literature review and DELPHI method defined an AI platform as a technical solution that enables the deployment of third party AI products. We notice that the only difference is the automatic orchestration of medical images to relevant AI products, and the consolidation of all service and support by the platform. Even though this might seem as a small addition to the definition, the new, specified definition is a step further for understanding AI platforms and their features. The exclusion criteria remained the same for both the broad definition and the specific definition. This thesis did not investigate intensively enough for features that do not appear at all, that might be discriminatory for the exclusion of certain AI platforms.

Now that a definition is provided for AI platforms, it should be easier to recognize an AI platform based on essential features it should offer. Since the market is so dynamic and AI platforms keep developing, further research can be conducted to explore new bottlenecks and features, to fine tune this definition with newer insights. The fact that AI platforms keep developing new features and the offering of platforms is expanding rapidly, is supported by looking back at Parekh's similar market analysis (Sanjay Parekh, 2019). Parekh's analysis was conducted in 2019 and aimed to look at the differences of available AI platforms, which were referred to as AI marketplaces. The literature used varying terms for the solution of an AI platform, with most literature referring to it as an AI marketplace (Juluru et al., 2021; Leiner et al., 2021; Tadavarthi et al., 2020; van Leeuwen, Schalekamp, et al., 2021). This shows that with the lack of a definition, platforms are not recognized by their essential features. With the new insights from this thesis, it has become clear that the essential feature of this solution, is the deployment of multiple third party AI products and not necessarily the purchasing of AI products. If an AI platform only offers the procurement of AI products, without offering a platform to deploy these AI products, it is no different than an AI product vendor with multiple products. The deploying issues addresses by the experts in the DELPHI method and as explained in the literature review still remain (Filice et al., 2020; Leiner et al., 2021; Sanjay Parekh, 2019).

Besides, as we have seen in the results, some AI platforms offer a customer driven integration of third party AI products into the AI platform. This means that a customer procures any AI product on their own, and the AI platforms handles the deployment process for integration with the customer's platform. This shows that with the current knowledge and insights, the term 'AI marketplace' is not fitting the actual solution and the term 'AI platform' is more inclusive to the goal of the solution. In addition, one of the exclusion criteria excluded platforms that only resell third party AI products, without offering the deployment of these AI products. These solutions might better fit under the definition of 'AI marketplace', which could be explored by conducting new research.

When reviewing all potential AI platforms, it became clear that AI platforms for radiology are very similar to AI platforms for pathology. A lot of platforms offer deployment and integration of AI products for both fields. It is highly recommended to conduct a similar research as this thesis, but for AI platforms for pathology. It is also recommended to commence with a lower hierarchy level for pathology, namely starting with a research on all available AI products for pathology. All available AI products for pathology and their offered features could be uploaded to www.aiforradiology.com to complement the website and expand it with pathology products. Eventually, AI platforms for pathology can also be complemented on the website.

To conclude this thesis, an AI platform for radiology is defined as *a technical solution that enables the deployment and orchestration of third party AI products, consolidating all service and support.* For a complete overview of all AI platforms and their offered features, visit www.aiforradiology.com/platforms for more information. The combination of this new definition and the website, aims to guide radiology departments through the procurement process of a fitting AI platform.

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Appendix

Appendix 1 – list of potential platforms

Agfa Healthcare	Philips Intellispace
Aidoc	Philips HealthSuite Marketplace
Aidoc OS	Pixmeo
Ambra Health	QMENTA Trials
Arterys Marketplace	RMS Medical Devices
aycan Medical Systems	Samsung
Blackford	Sectra Amplifier Store
Canon Automation Platform	Siemens Teamplay/syngo.via/marketplace
Change Healthcare	Softway Medical
Circle Cardiovascular Imaging (CVI)	Stop TB Partnership Global Drug Facility
CorTechs Labs	StratX
Dedalus	SystemX
Edan	TELEPAXX
EDL	Terason
Esaote	Visus
Eureka Clinical AI	Volpara Health
Ferrum	Wellbeing Software
Fujifilm REiLI	Brit System
GE Edison	Candelis
Getz Healthcare	Carestream
GMP	eunity
Humanbyte	Hologic
IBM imaging AI marketplace	infinitt
iCAD inc	Merge
Incepto	Novarad
Intelerad	Ramsoft
Intrasense	Three palm
Konica Minolta	Visage imaging
Maincare	Alma HEALTH PLATFORM
Medimsight	RadPoint

Neusoft	Qure.ai
Nuance AI marketplace	Aiworx
Olea Medical	Paxera Health

Appendix 2 – questionnaire

Feature	Definition
	Platform & sales
Platform name	What is the name of your platform?
Origin company	As what type of firm did your company originate?
Way of integration	What type of integration are you offering through your platform?
Regions	In which regions is your platform sold for clinical use?
Countries	Number of countries the platform is sold for clinical use (non-research)
Live customers/installed base	Number of customers (organizations) that use the platform in clinical setting (daily users)
Algorithms per customer	What is the mean number of algorithms per customer (organization) through your platform?
Exams	What is the mean number of exams per day through your platform?
Exclusivity	Is the platform exclusively for existing customers?
	Offered solutions
First party algorithms	Which CE certified or FDA approved algorithms offered on the platform are developed by your own company?
Third party algorithms	Which third party CE certified or FDA approved algorithms are you partnered with?
Curation	What curation methods do you apply for adopting a new AI product in your platform?
Other partners	What PACS and/or EHR (Electronic Health Record) companies are you integrated with?
Research	Does the platform offer the option for customers to develop their own algorithms on the platform?
Algorithm certification	Does the platform offer research (non-certified) algorithms?
	Workflow integration
Front end compatibility	Does the platform provide a single front end for all offered AI products?

User interface	To show the AI-algorithm results, the platform adopts a user interface in the form of:
PACS back end compatibility	Does the platform provide a single form of PACS back end integration for all offered AI products?
Algorithm orchestration	How does the platform orchestrate the images to the relevant algorithms? Image routing for algorithm processing
Output export	Is the algorithm output available to necessary upstream information systems (e.g. Radiology Information Systems (RIS) and EHR/EMR)?
Prior scans	Does the platform facilitate retrievement of prior scans (conform all privacy regulations)?
Results	
Output acceptability/adjustability	The algorithm output is: …
Feedback vendor	If the platform facilitates interaction for adjustability and acceptance, are the results sent back to the AI-vendor (conform all privacy regulations)?
Triage	Does the platform influence the priority of patients on the worklist?
Image processing	
Image processing	Where are the images processed?
Number of servers	How many servers are needed for a full image process?
Hardware requirements	What are the hardware requirements for the smooth operation of an algorithm?
Inference time	What is the inference time overhead of the platform? The extra time it costs for an analysis to go through the marketplace instead of the vendor directly, in seconds
Economic factors	
Contracting	How is the customer's contracting of algorithms organized?
Platform included	Is the price of the platform included in the price of the offered products?
Business model	What does your business model look like?

Total costs	What are the total costs in euro's for the use of the platform? Please state the contents of the costs (time period, volume, included algorithms, etc)
Service & support	
Support	The platform offers support for: …
Updates and upgrades	The platform offers upgrades and updates for: …
Trial period platform	Does the platform offer a try before you buy option for the platform?
Trial period products	Does the platform offer a try before you buy option for the AI products?
General information	
Company info	Give a short summary of your platform in your own words. Max 400 characters. (non-commercial, reserve rights to delete)
Company logo	Company or platform logo suited for a white background (.png, .jpg, .tiff)
Demo logo	Provide a logo of a demo (if applicable)
Founded	When was the company founded?
Head office	Where is the head office located?
Maturity	How mature do you consider your platform with regards to reaching the company's goal?
Public mail	What is the public mail of your company?
Contact name	What is the name of the contact person of your company?
Contact mail for researcher	What is the email of the contact person we can reach out to in case of extra questions?
Comments	Are there any other comments or remarks you would like to share?

Appendix 3 – list of included AI platforms

Agfa Healthcare	iCAD inc	Siemens Teamplay/syngo.via/marketplace
Aidoc OS	Incepto	Softway Medical
Ambra Health	Intelerad	TELEPAXX
Arterys Marketplace	Intrasense	Wellbeing Software
aycan Medical Systems	Konica Minolta	Carpl.ai
Blackford	Medimsight	Deepc
Change Healthcare	Neusoft	PaxeraHealth
Eureka Clinical AI	Nuance AI marketplace	Merge
Ferrum	Philips Intellispace	Ramsoft
Fujifilm REiLI	Philips HealthSuite Marketplace	Visage imaging
GE Edison	QMENTA Trials	Alma HEALTH PLATFORM
IBM imaging AI marketplace	Sectra Amplifier Store	