Digital Transformation in Steel Inspection

Toshiba MetalSpector Customer Case Study

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CONTENTS

FIGURES

1 Overview

1.1 Introduction

Toshiba has been selling MetalSpector, a leading-edge steel inspection equipment, to several major steel companies for several decades[1]. Recently, as part of Toshiba's Digital Transformation strategy, Toshiba redesigned MetalSpector into a steel grading evaluation service, intended to reduce steel inspector's workloads while assuring the data integrity of the steel grading process. The result of this redesign uncovered a new set of services focused on how the inspection equipment is used by the customer, rather than focusing solely on improvements to how the inspection equipment works.

1.2 Digital Transformation Background

Toshiba is currently transforming from a hardware-sales business model to a subscription service model for Infrastructure Services, which is the core segment of Toshiba's business[2]. While continuing to sell hardware and infrastructure systems to our customers, we are shifting towards offering O&M (Operation and Maintenance) services as a subscription. Our immediate focus of O&M services is for Toshiba hardware, and then extending this scope to competitor hardware in the future. This is a major reason why Toshiba is prioritizing connectivity using industry standards.

The importance of this transformation is realized by a set of new managed services that are directly connected to customer value. For customers, these managed services are enabled by technology enablers such as machine learning, cloud computing, and data management tools; with these enablers, the services can adapt to evolving needs, improve the more they are used, and be updated without incurring downtime.

[1] Toshiba: Applying AI Image Processing Services to Steel Product Quality Management. [Online] 2019. *https://www.global.toshiba/ww/company/digitalsolution/articles/tsoul/31/004.html.*

[2] Toshiba: Toshiba to Reorganize Headquarters Corporate Staff toward Realization of Toshiba Next Plan. [Online] Toshiba, 2019. *https://www.global.toshiba/ww/news/corporate/2019/01/pr3101.html.*

2 METALLURGICAL INSPECTION BACKGROUND

2.1 STEEL INDUSTRY METALLURGICAL INSPECTION PROCESS

In the Quality Assurance (QA) department of a steel manufacturer, samples of the outgoing steel are extracted, and metallography is applied to assure product quality by QA inspectors using a microscope. The inspectors perform the measurement for its grade judgment based on steel industry standards and company quality requirements[3] [4].

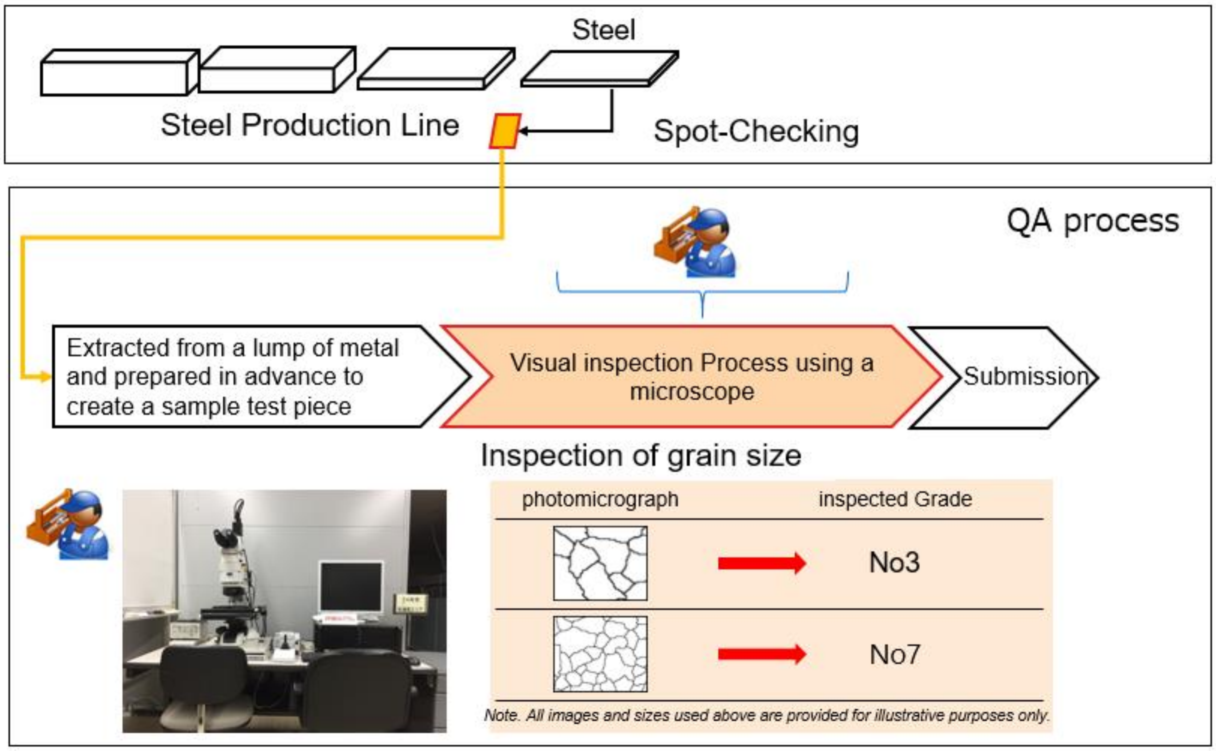

Figure 2-1 Metallurgical inspection process for grading steel samples

The non-metallic inclusion measurement system automatically measures non-metallic inclusions in steel samples by using an auto-focus optical microscope, X-Y stage, color area sensor camera, and an image processor. The sample holder with the test piece set is moved to a predetermined position on the X-Y stage, and image input is performed.

[3] ASTM: E-45, Standard Test Methods for Determining the Inclusion Content of Steel. [Online] 2018. *https://www.astm.org/Standards/E45.htm*.

[4] JIS. JIS G-0555, Microscopic testing method for the non-metallic inclusions in steel. [Online] 2020. *https://webdesk.jsa.or.jp/books/W11M0090/index/?bunsyo_id=JIS+G+0555%3A2020.*

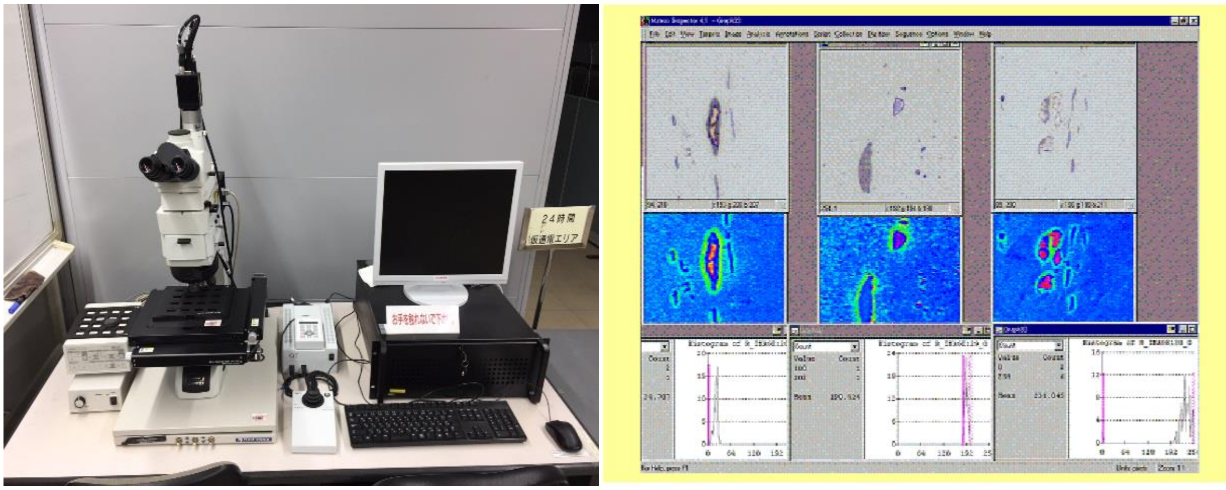

Figure 2-2 Non-metallic inclusion measurement system

Steel grade measurements take time to perform, depending on the number of inclusions found, on the order of minutes; this is because the measurements are in the sub-micrometer range and each inclusion must be measured. With this time scale in mind, decreasing the measurement time by even one minute is a substantial amount. Even with the most modern algorithms and hardware, semi-automated measurements using ASTM or JIS point calculation methods can take between 2-6 minutes to perform[5]. The measurement times can be lowered with better measurement algorithms and autofocusing functions.

While the measurement system can help identify non-metallic inclusions, it is the inspector who must make the final evaluation of the samples and grade them according to regional regulations, international standards, and customer proprietary measurement methods[6] [7]. This assessment requires considerable skill and training, so the steel manufacturer highly values their skilled inspectors.

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[5] Toshiba: Applying AI Image Processing Services to Steel Product Quality Management. [Online] 2019. *https://www.global.toshiba/ww/company/digitalsolution/articles/tsoul/31/004.html.*

[6] ASTM. ASTM E-45, Standard Test Methods for Determining the Inclusion Content of Steel. [Online] 2018. *https://www.astm.org/Standards/E45.htm*.

[7] JIS: JIS G-0555, Microscopic testing method for the non-metallic inclusions in steel. [Online] 2020. *https://webdesk.jsa.or.jp/books/W11M0090/index/?bunsyo_id=JIS+G+0555%3A2020*.

3 Customer Analysis

With increases in steel production come increases in steel quality samples, which in turns adds to the demand on inspectors (ex: longer hours and/or more inspectors). Thus, several issues arise from the existing inspection process:

Steel Inspection Process Issues	
Labor Intensive QA Process	Because the grading process requires human inspectors to grade each sample, the grading process can quickly become the largest bottleneck in the manufacturing process, especially when the number of veteran inspectors is low.
Long Inspection Hours	Steel inspection is sampled per the amount of steel produced and not by a set number of samples per day. As more steel is produced, more samples are required to be graded, which requires longer hours for inspectors.
Lack of Consistency	As inspectors are asked to work longer hours, they can become fatigued, and it becomes increasingly difficult to maintain a level of consistency in the grading process. Increasing the number of inspectors can also create a lack of consistency from one inspector to another.
Product Quality Data Fraud	As the demand for more output increases, there can be pressure to falsify records and report gradings that are not correct. In recent years, it has become public that several steel manufacturers around the world have falsified their quality records, resulting in large regulatory fines, litigation, and damage to company reputation.

3.1 Key Observations

While the inspection measurement itself is not a repetitive task, much of the initial setup work is (i.e., preparing the samples for measurement); therefore, automation can be applied to some (but not all) of the inspection processes. In the past, improvements to image acquisition and processing relied heavily on hardware improvements, so it was sensible to offer equipment upgrades. Today, however, it is not the local hardware that provides the largest improvements in image analysis; rather, it is the advancements in image processing algorithms that reduce analysis time and improve accuracy. Therefore, the idea of continuous improvements, offered as-a-service, provide greater benefits to the customer without incurring the negative impacts of hardware upgrades (i.e., the associated downtime from upgrading equipment).

As standards develop in the areas of automated inclusion measuring, the system should be designed to take further advantage of new measurement algorithms, autofocus functions, and new statistical methods (also called "clean steel measurements")[8]. By leveraging the vast amounts of metallographic structure inspection data along with these image processing technologies, advanced deep learning techniques can be developed to inspect the image samples and detect non-metallic inclusions. With experienced human inspectors to help train these AI-models, productivity should increase, so long as the inspector is able train the models with relative ease and not be burdened with understanding a new set of tools to perform the training.

Currently, national regulations require human inspection and prohibit the use of AI to perform inspection by itself. As the technology matures, and AI models are proven to be as reliable as experience human inspectors, such regulations could change. In fact, the steel industry has begun developing standards for automatic inclusion inspections[9]. However, for the present, it is not expected to eliminate human inspectors; rather, human inspectors are considered high value assets and critical to the measurement process.

[8] Toshiba: Applying AI Image Processing Services to Steel Product Quality Management. [Online] 2019. *https://www.global.toshiba/ww/company/digitalsolution/articles/tsoul/31/004.html*.

[9] ASTM: *ASTM E768 - 99(2018), Standard Guide for Preparing and Evaluating Specimens for Automatic Inclusion Assessment of Steel.* s.l. : ASTM, 2018.

4 System Development

The steel manufacturer requested improvements to the existing equipment to overcome their process issues. The key objectives were to a) reduce inspector workloads, and b) provide automatic auditing capabilities. These objectives would address the issues with higher demand for inspections and longer working hours, as well as the serious problem of false record keeping.

4.1 Updated Steel Inspection System

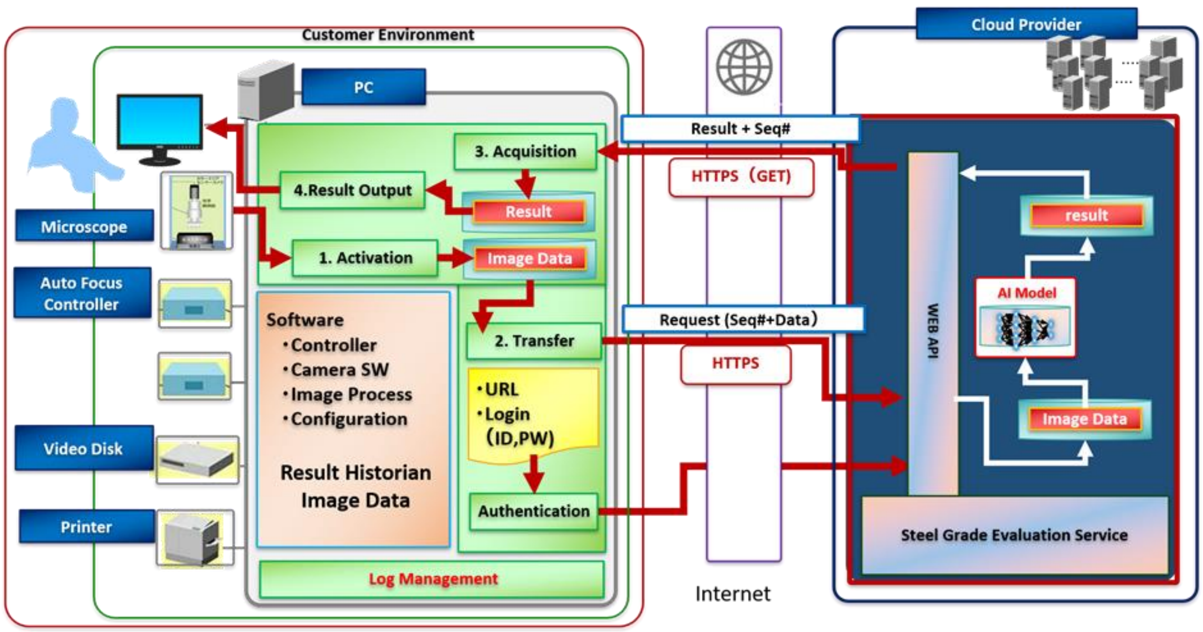

Figure 4-1 Updated steel inspection analysis

The new system (Figure 4-1) was designed with an IIoT architecture, using a combination of Edge, Platform, and Enterprise services in a 3-Tier Architecture Pattern, and implemented using containerized micro-services[10 11].

The system process flow was developed as follows:

1. Transfer steel sample's image data from microscope to image historian database
   - By using the same equipment as before, the original process remains very similar for the inspector.
2. Transfer image data with sequence number to cloud for feeding an AI model estimator

[10] Toshiba: Applying AI Image Processing Services to Steel Product Quality Management. [Online] 2019. *https://www.global.toshiba/company/digitalsolution/articles/tsoul/31/004.html*.

[11] Toshiba: Toshiba Internet Reference Architecture. [Online] 2018. *https://www.global.toshiba/company/digitalsolution/articles/tsoul/32.html.*

- By automatically recording image samples, an audit trail can be established that does not require additional workload for the inspector.

3. Store steel grade estimate from AI model and sequence number into log management database
   - Incorporation of AI estimation can improve the speed and efficiency of the grading process by recognizing routine inclusion patterns without inspector intervention. In addition, the audit trail is further maintained by pairing the AI analysis with the original image sample.
4. Inspectors determine final quality decision by referring to estimated steel grade
   - By automating the image recording and AI estimation process, the inspector can better concentrate on the steel grading process. The AI estimations aids the inspector by identifying routine inclusion patterns, allowing the inspector more time to evaluate difficult sample images.

For the auditing and steel grade evaluation services, it was important to have permission to access to the steel image sample data. The image samples must be sequenced and stored for the auditing service, and they must be and analyzed by the AI model to perform a grading estimate. Because these operations occur outside the customer’s environment, permission must be granted by the customer to allow these operations to be performed.

Because of the existing relationship with the steel manufacturer, including previous operational improvements, a high level of trust had already been established. Moreover, it was easy for them to realize the value of the auditing and AI-based evaluation services; so, allowing access to the sample data was not a concern. Nevertheless, it is always important to be aware of data ownership rules, understanding both business and legal concerns, regardless of the customer’s level of trust in the system or the supplier.

5 Digital Transformation

The redesign of the steel inspection system was initially focused on improving how the system worked. This is a typical outcome for a company that is focused on hardware sales. However, as part of the company's new focus on O&M services, the customer environment was also observed as a way of understanding how the QA inspectors used the steel inspection equipment.

5.1 New Service Offering

In partnering with the steel manufacturer and closely observing their process and product quality inspection, we were able to highlight a new process issue:

(New) Steel Inspection Process Issues	
Skills Transfer	As demand increases, there is also a demand for more inspectors to reduce the burden on existing inspectors. Because training is passed on from veteran inspector to junior inspector, manufacturers must balance the need to train new inspectors versus the more immediate need to grade steel samples. Inspector training can take years to acquire a comparable set of skills.

As a result, we developed a new training service, which was reviewed and approved by the customer. This new service takes the AI inference model for steel grade determination and uses it as a learning model to teach junior inspectors.

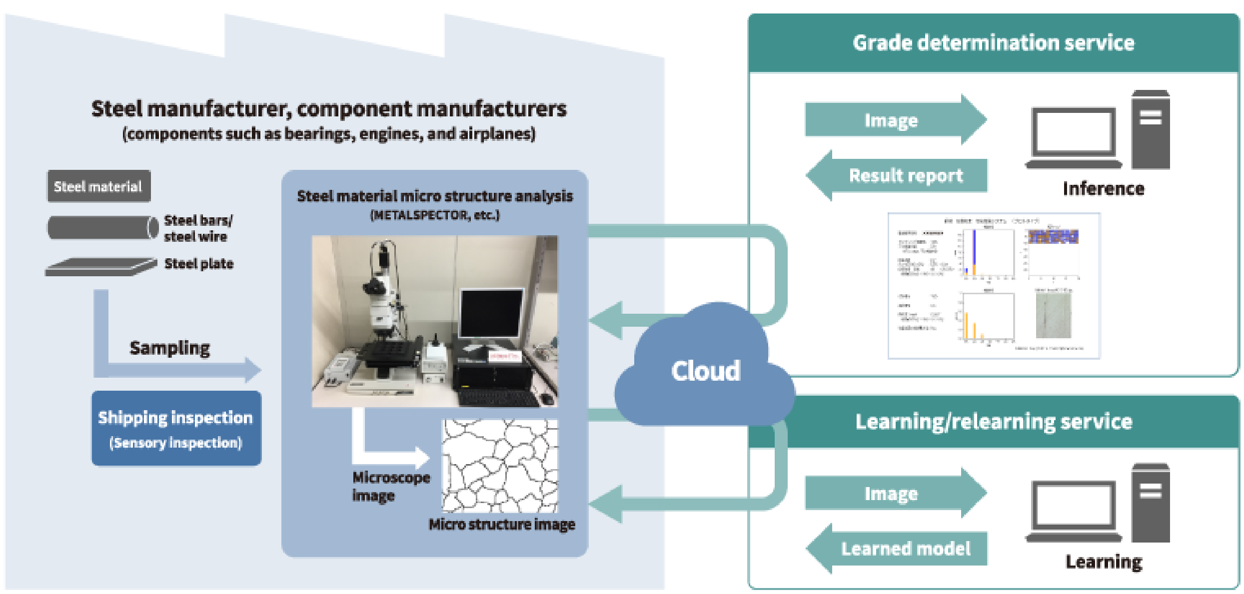

Figure 5-1 Steel inspection cloud services

As a grade determination service, that AI inference model develops its own analysis skills, automatically, with each steel sample it analyzes. It also adapts to the analysis from veteran human inspectors, who have the final judgement decision. As the human inspector performs their normal measurement analysis, they are automatically training the AI model, with no additional burden on the inspector.

As a training service, the AI model can provide real-world image samples to junior inspectors and teach them to measure for non-metallic inclusions. Since the veteran inspectors continually train the AI model, they are also providing new training material for the junior inspectors. Thus, the burden on veteran inspectors is reduced, and junior inspectors gain experience from real-world data samples.

The value of this new service offering was immediately recognized by the customer, as it reduced the number of veteran inspectors needed for training purposes, while simultaneously increasing the skill levels of junior inspectors.

5.2 Technology Enablers

The key technology enablers for the metal inspection services were as follows:

Company Perspective	
Artificial Intelligence	The Steel AI Image Processing Service can analyze steel samples, automatically determine non-metallic inclusions, and estimate grades of steel grain sizes. The AI Model can also be trained by inspectors, continually improving the model.
Cloud Computing	The Steel AI Image Processing Service runs in the cloud, so there is no need to add additional hardware on-site. The service is therefore not bound by local processing power, and updates are automatically applied with no downtime. In the case of an Internet outage, the overall system can still function without the AI Service, providing fault tolerance.
Image Recognition	The image recognition processing algorithms are applied at the imaging station (i.e., at the Edge) and are compared for speed against standard steel inspection methods (ASTM and JIS), and for accuracy against visual inspection from an electron microscope.
Data Management	All image data for the steel grading is securely stored and managed to ensure the data's integrity and consistency. The data management system allows any inspectors to read the data, but not update the data.

5.3 Transformation Achieved

Company Perspective	
Mindset Focus	Changed from Product Function oriented to Product Usage oriented
Revenue Stream	Changed from NRE and fixed purchase to As-A-Service
Solution Focus	Changed from performance-focused, hardware-oriented solutions to user-focused products and services
Business Opportunities	Changed from highly customized integrations to modular services that can be adapted to specific customer needs

From Toshiba's perspective, the use of Data Management techniques, AI for image recognition, and Cloud Computing resources allowed the key product functional concerns to be addressed.

By proving the value of the AI image estimation and data auditing, the customer became receptive to providing customer data as part of a subscription contract. This in turn allowed a new set of services, based on training the customer's inspectors, to be realized.

Because the AI imaging service found success in a real word scenario, the value of similar business opportunities was recognized. Image inspection is highly relevant to other manufacturing applications, and new image inspection services can be provided to customers with similar needs.

Customer Perspective	
Data Integrity	The data integrity is assured by storing in a secure database which eliminates data fraud.
Workload Efficiency	Inspectors can focus on the more difficult inspection samples and train junior inspectors.
Continuous Improvement	The AI Model can be improved over time, providing continuous improvement.
Skills Transfer and Training	Once the AI model training is complete, it is used for not just inspection, but also used for junior inspector education, which enables improved transfer of skills to the next generation

From the customer's perspective, the key objectives of productivity and data integrity were fully satisfied. Inspectors were able to focus more time on difficult inspections as well as training for junior inspectors. The AI modeling service can be trained over time to adapt to different types of steel samples, and newer methods of inspection. Moreover, the AI modeling estimations were shown to be useful for inspector training, providing a completely new training service to the company that further alleviates the burdens on veteran inspectors.

6 SUMMARY

From a hardware-sales business model perspective, the redesigned system solves the customer's pain points via automation, with a strategy of minimizing the human role in the process. However, this is not the customer's objective, as human inspectors are a critical resource and highly valued. The customer's objective is in fact to better enable inspectors to perform their critical role of quality assurance.

Gartner describes *digital humanism* as a means of redefining the way people's goals can be achieved. Contrasted with automation, digital humanism focuses on minimizing the complexities and difficulties a human user has when using a system. Instead of automating system processes and tasks for the purpose of eliminating human operation, the goal becomes instead to empower human users to do more with the system, potentially unveiling new uses and providing new value that was otherwise unachievable[12].

It is important to note that the AI modeling is not intended to eliminate the human inspector from the process. In fact, it is critical to retain skilled inspectors for the steel manufacturers competitive advantage. Regulations also prevent the sole use of AI to perform metallic inclusion inspection, so until such regulations are updated, human inspection is necessary. The use of AI modelling is therefore intended to offload many mundane tasks and allow the inspectors to focus on the non-repetitive analysis steps.

While automation is a key process improvement, it is not the end goal. Supporting the steel inspector's ability to identify issues with the steel production process is the end goal; this involves both machine automation as well as improved human involvement. By combining automation with digital humanism, the focus on providing customer value can be maintained[13].

The successful deployment of MetalSpector helped validate the managed services approach at the business level. Since then, new image inspection services for other manufacturing and infrastructure applications have been developed, opening new business opportunities. For example, Toshiba has created a new managed service for the pharmaceutical industry, to measure surface defects in PTP packaging sheets. Similar managed services are also being developed for the inspection of film materials, paper, and non-woven cloth. Because these use

[12] Brian Prentice: *Digital Humanism Is a Key to Digital Success.* s.l. : Gartner, 2021.

[13] IIC; Industrial Internet Reference Architecture IIRA 1.9. [Online] 2019. ***https://www.iiconsortium.org/pdf/IIRA-v1.9.pdf***

cases also involve sample inspection, many of the image analysis components developed for MetalSpector can be applied to these inspection cases, too.

The migration from hardware sales to As-A-Service sales is a challenging effort for many companies. Our fundamental change was from a reactive product development design to proactive service offerings. Digital Transformation Enablers, such as AI, allow continuous improvement to the customer's operations, without additional knowledge and effort on their part. It also helps uncovers new use cases that help solve additional problems a customer has. This can lead to the creation of new services, providing new value to customers.

7 ACKNOWLEDGEMENTS

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