AMRC ADVANCED MANUFACTURING RESEARCH CENTRE / The University Of Sheffield.

Demonstrating the integration of off-the-shelf digital technologies with a manufacturing execution system for Project RAID

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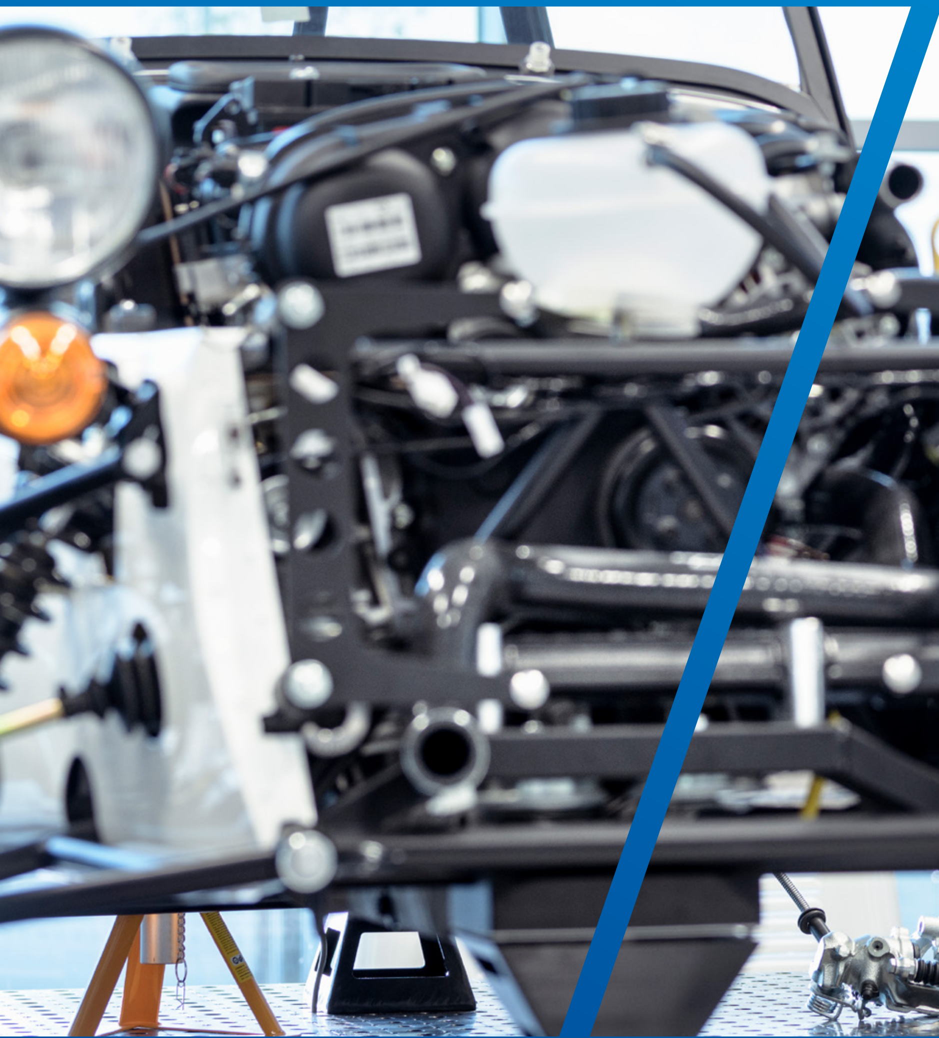

CATAPULT High Value Manufacturing
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1. INTRODUCTION

I. INTRODUCTION

PROJECT RAID (Reconfigurable Assembly Integrated Demonstrator) is the name given to a demonstration project under development within the Integrated Manufacturing Group at the Advanced Manufacturing Research Centre throughout 2017/2018, aiming to demonstrate the value and accessibility to Small to Medium Enterprises (SMEs) of digital, 'Industry 4.0' ready technologies.

The project focussed on integrating low-cost technologies together to demonstrate that valuable data can be gathered from processes and equipment without spending large sums of money. The project aimed to help accelerate the adoption of digital technologies within the 99% of UK companies made up of SMEs [8] by demonstrating their accessibility and ease of use.

The AMRC used a Caterham 270S kit sports car as the platform to demonstrate the technologies due to its relative complexity and iconic image. Although the primary aim of the project was to demonstrate the adoption of low-cost technologies for SMEs, it was identified that there would be a large benefit to also demonstrate these technologies integrating with larger shop floor software systems such as Manufacturing Execution System (MES), despite such systems being less likely to be found on the shop-floor of SMEs. The results from this work package of the project would benefit organisations already using MES in a largely manual capacity (e.g. entering data manually using Human Machine Interfaces (HMIs) or screens on the shop floor) or smaller organisations that have already adopted low-cost digital technologies and are looking to implement a system similar to MES.

2. TECHNOLOGIES & SYSTEMS

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2.1 What is a Manufacturing Execution System?: MES is the system which manages the manufacturing execution of a product from the work order all the way through to the final product [11]. Due to the system possessing considerable knowledge and information on the status of all manufacturing processes within the factory, it requires unparalleled access to shop floor devices and systems.

2.2 RFID (Radio Frequency Identification): Radio Frequency Identification (RFID) has been used for the most part of the 21st century within manufacturing and warehousing, with adopting businesses seeing improvements in operational efficiency, reduced re-work and cost savings [12]. Most passive RFID systems consist of an antenna connected to a reader, the former of which is responsible for detecting a digital tag or label encoded with data. This information is then passed to the reader, where it is decoded, processed and transmitted to an overarching system. Digital tags are relatively cheap to mass produce and are frequently used in warehousing to automate inventory control and validate manual picking tasks performed by operators. An illustrative example of the RFID architecture can be found in Figure 1.

Project RAID saw the integration of a Motorola FX9500 RFID reader with DELMIA Apriso [3], in addition to the development of a 'Kitting Cockpit' add-on for DELMIA Apriso that guides operators

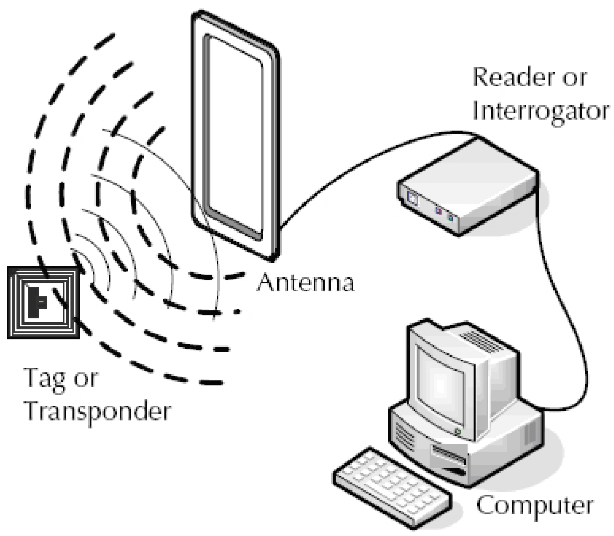


Figure 1. *Sketch of the RFID architecture, from [10]. The antenna detects the tag and reports its presence and metadata to the reader, which in turn notifies the computer or server.*

through a kitting sequence, from selecting the correct box, though kitting, to returning the box to the correct location. Each kit box had an embedded RFID tag, which was detected by an antenna and reader mounted onto the workbench where the kitting operator would be working. The system would not allow the operator to continue if they have selected the wrong box or no box at all. The RFID reader played a crucial role in the operation by enabling full traceability of box selection to be generated, and improved quality by mistakes related to incorrect box selection to be prevented in the first place. RFID was also utilised within the project to enable a mobile collaborative robot to detect the location at which it was docked to the assembly line. This, in addition to an additional antenna on a box fixture similar to that of the kitting area, allowed the robot to dynamically select the correct program for the job, based on its environment and parts in front of it.

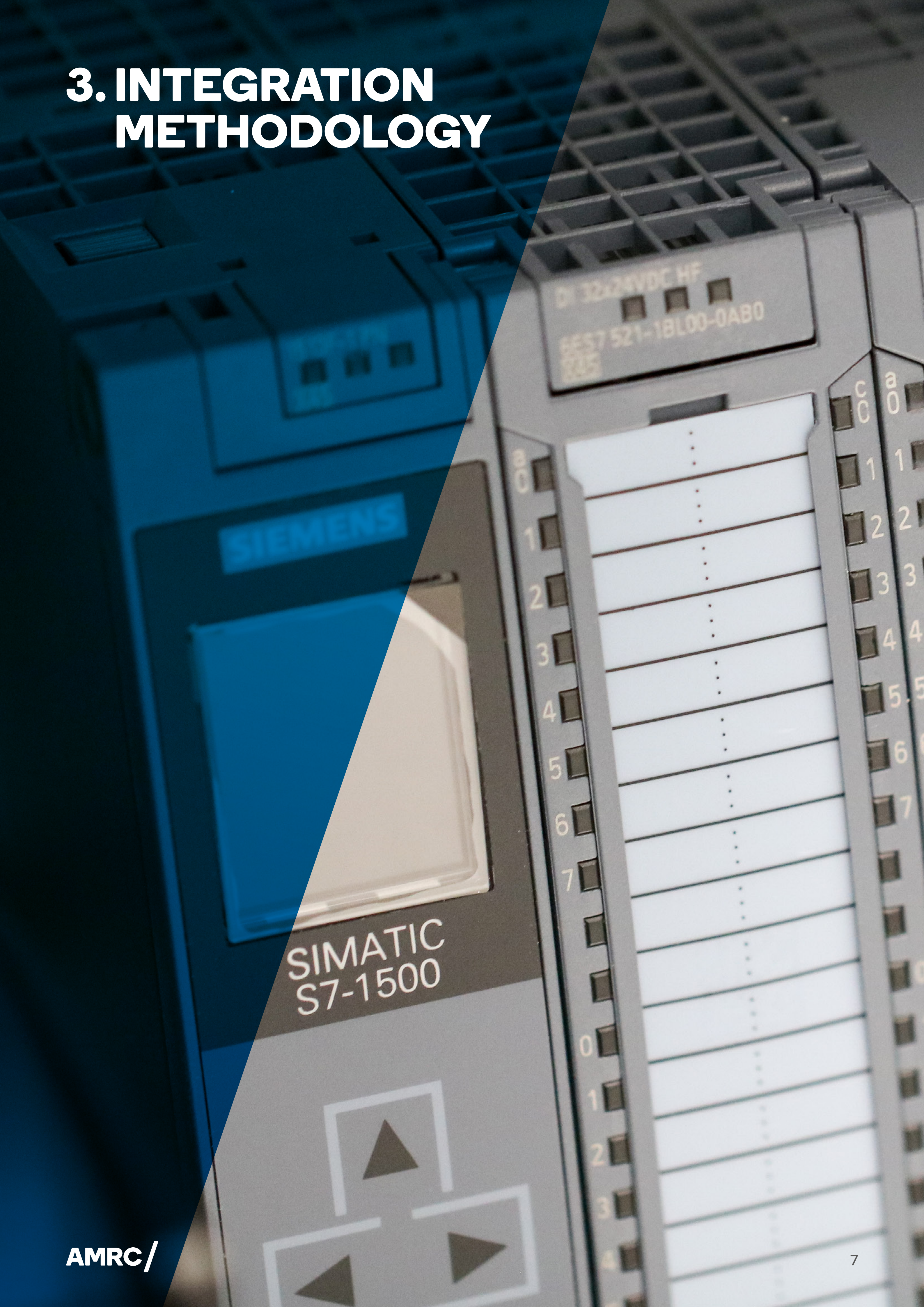
2.3 Smart Tools: 'Smart Tools' is an all-encompassing term used to describe tools with intelligent features such as wireless connectivity, dynamic program selection and in-process verification. These tools are contributing to the increasing digitalization of the manufacturing sector, helping lead us towards previously unattainable levels of traceability and control [4]. Project RAID utilised Bosch Nexo Smart DC torque wrenches [1] to perform various tightening operations on the car assembly, providing full bolt-to-bolt traceability of all operations via the DELMIA Apriso platform. The tools used for this project also possess dynamic torque profile selection, allowing the target torque profile to be selected remotely by DELMIA Apriso via Wi-Fi. This functionality reduced non-value added time related to operators changing tools whist on shift, and allowed operators to 'check-out' a tool and use the same tool for the remainder of the shift. In addition to dynamically changing program, the tool could also be dynamically disabled and enabled based on external factors such as physical location, the training level of the operator using it, or calibration status.

2.4 Industrial Cameras: Computer vision systems are commonly used in industry to perform a number of tasks, including robotic position monitoring [15], inspection [14], verification [13], Optical Character Recognition (OCR), situational monitoring, Autonomous Guided Vehicle (AGV) guidance, process monitoring, measurement, edge detection and more. Project RAID used a Cognex In-Sight [2] machine vision system within the Smart Fixturing work package to verify the correct assembly of a complex sub-assembly for the car. The Caterham

270S is available in both a wide-track and narrow-track suspension variant, which both look similar to the naked eye, greatly increasing the risk of using the wrong components. The machine vision system was integrated with the 'Smart Fixturing Cockpit' developed by the AMRC within DELMIA Apriso, which guided the operator step-by-step to assemble a sub-assembly on a reconfigurable 'smart' fixture. The fixture allowed the assembly of a variation of products and contained a variety of sensors which, when paired with the verification capability of the machine vision system, ensured that the operator assembled the correct variant of the sub-assembly each time. The operator was guided through a set of work instructions, one at a time, displayed on a HMI mounted on the workbench. Once the operator performed the task indicated, they pressed the 'next' button on the HMI. If the camera or sensors built into the fixture indicated that the step had not been completed correctly, the operator was redirected back to the previous step to re-work.

2.5 Laser Projection: Laser projection is one of many optical projection methods used in manufacturing today. Laser projection traditionally works by deflecting a single laser beam in two axes via actuated mirrors to project a shape or outline onto a 2D or 3D shape [9]. The projection system utilised in Project RAID accepted data in traditional CAD formats allowing re-use of CAD data, resulting in reduced set-up time and minimal pattern authoring. Laser projection technology has been used historically in the aerospace manufacturing sector to display templates for composite lay-up tasks [9]. A LAP CADPro [5] laser projector was used in Project RAID to supplement the digital work instructions on the Smart Fixturing Cockpit. The laser work instructions showed the operator location sensitive details in real-time related to the current step of the assembly by projecting them directly onto the fixture. This increased productivity by reducing the time the operator took to decipher the 2D work instructions on the HMI and 'map' them to the physical assembly.

3. INTEGRATION METHODOLOGY



3. INTEGRATION METHODOLOGY

3.1 Network & System Architecture: DELMIA Apriso MES is capable of communicating with devices and eqipment via a module named 'Machine Integrator'. It is via Machine Integrator that data was received and sent to devices and machines on the shop floor for use with DELMIA Apriso. Project RAID utilised Machine Integrator to communicate with the Smart Tools, RFID, Optical Projection and Industrial Cameras. Machine Integrator has the ability to communicate using the OPC UA standard. OPC is the interoperability standard for the secure and reliable exchange of data in the industrial automation space and in other industries [7], with OPC UA (Unified Architecture) being the latest version of this standard, which was released in 2008. OPC UA was chosen as the standard to transmit and store data due to its platform independence in addition to supporting 256-bit encryption, OpenSSL based authentication, message signing, and compatibility with HTTP based protocols such as SOAP-HTTPS. The RAID network architecture consisted of one server running both DELMIA Apriso and Machine Integrator, one server running KepServerEX (an OPC UA server), and one server running the Interfaces. All servers were virtualised Hyper-V instances of Windows Server 2016 running on a single physical Dell R440 server. An additional Siemens S7-1500 PLC was connected to the network to support the IOLink and GPIO used for the Smart Fixturing workbench (Figure 2). This PLC acted as an additional OPC server, which was also connected to Machine Integrator as a data source.

3.2 OPCLabs QuickOPC Integration: Each device that connected to the server running DELMIA Apriso's Machine Integrator did so via a link between the device and the OPC server called an Interface. Interfaces were bespoke services written by the AMRC, which acted as a translation layer between the device and the main OPC server. The translation layers were required in order to convert the data and commands between the native language and format of the device and the OPC server. As can be seen in Figure 3, the technologies mentioned in this report communicate to DELMIA Apriso via these services, which were were written in C# .NET due to the compatibility with the hardware APIs and OPC. OPCLabs' QuickOPC was used to enable communication between the Interface service and the OPC server. QuickOPC is a set of OPC components allowing rapid development of client OPC applications [6]. A sequence diagram showing communication between the OPC server and the Interface can be seen in Figure 4.

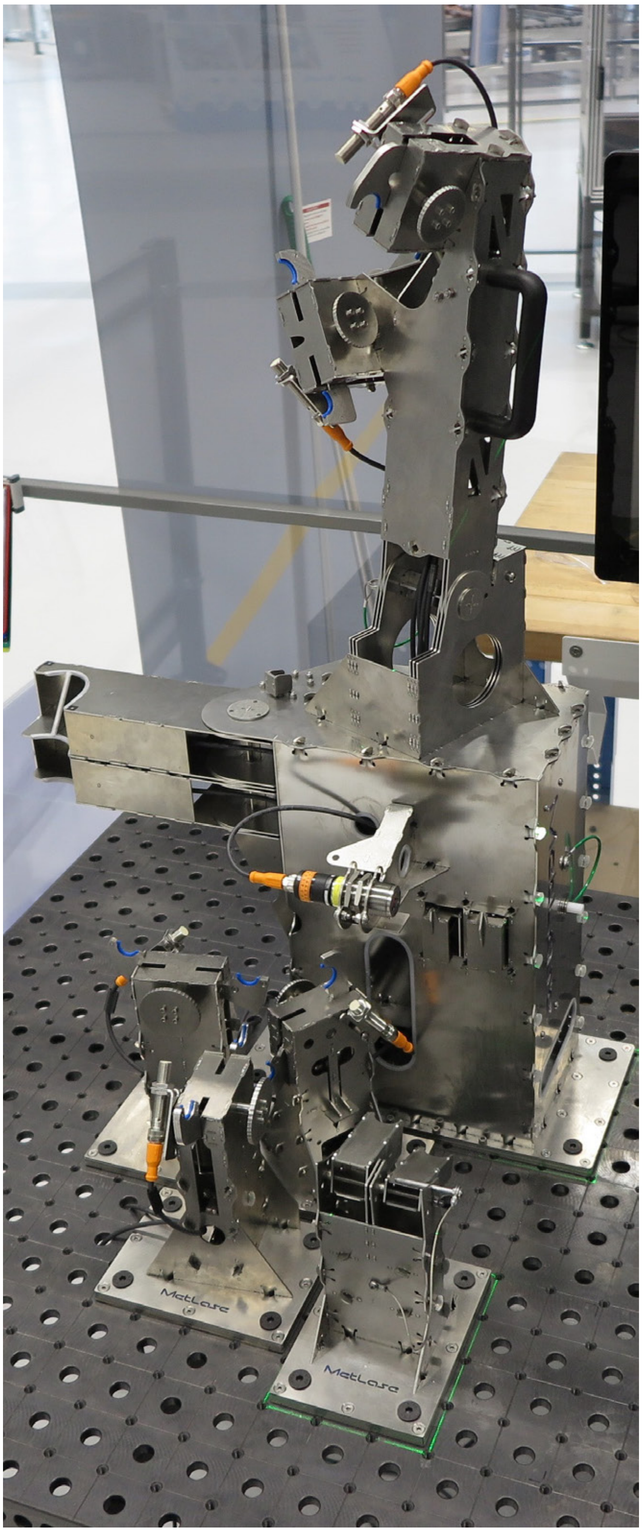


Figure 2. *Image of the Smart Fixturing. The integrated IOLink sensors can be seen protruding from the fixture in addition to the green LAP laser projection surrounding the towers, indicating where to place the towers in the first step of the sub-assembly.*

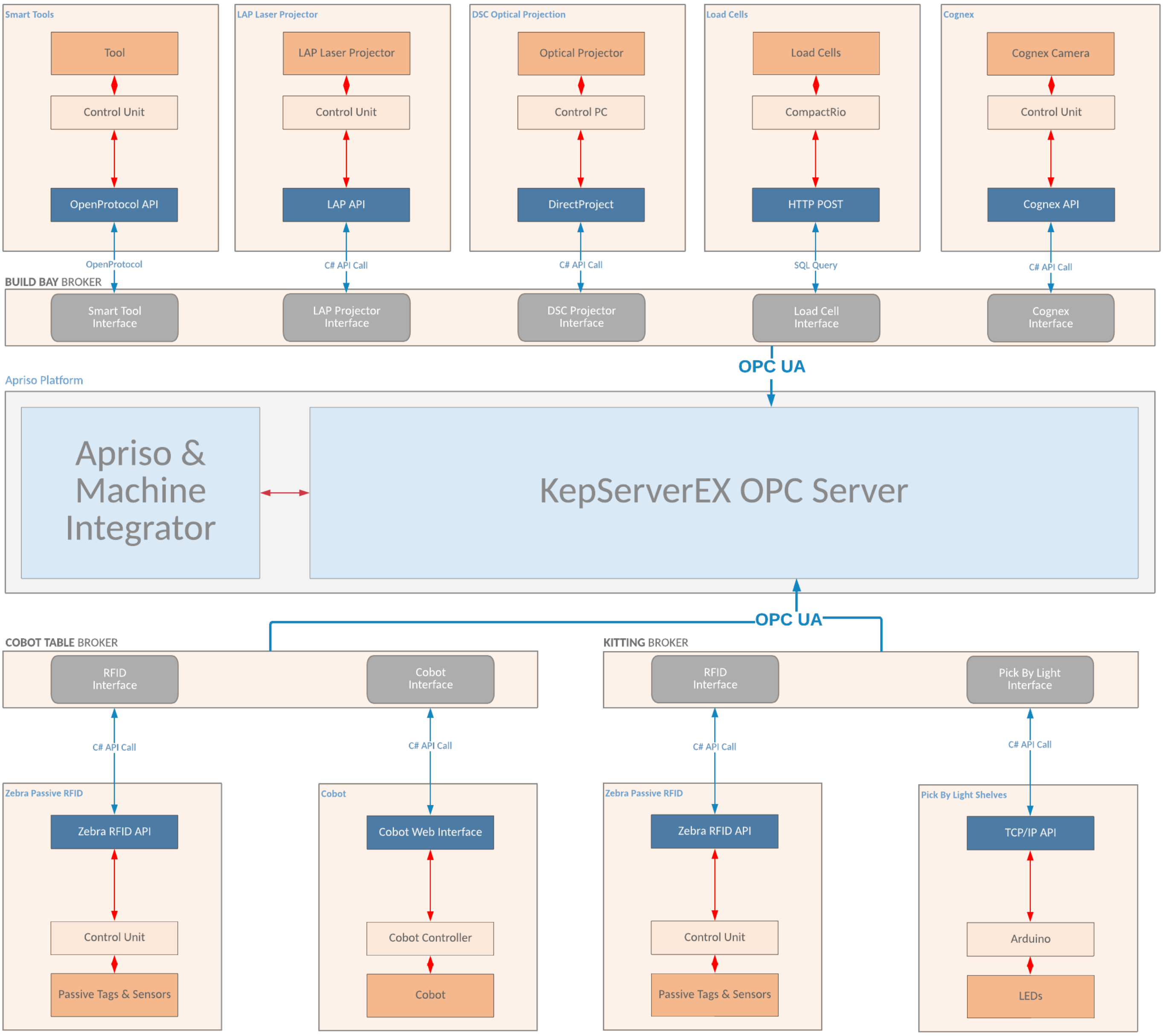


Figure 3. *RAID System Architecture*

3.3 Smart Tool Integration: The Smart Tools communicate via a protocol called OpenProtocol, which was originally developed by AtlasCopco and can communicate via either serial or Ethernet. OpenProtocol is a string-based TCP/IP messaging protocol, allowing remote configuration of the tools in addition to being able to retrieve real-time reports and results from the tool. The protocol is based on a series of communication messages called MIDs that define the command being sent, followed by parameters. The overall command string is broken into multiple sections as can be seen in Table I. For example the MID 0001 command triggers a 'Communication Start' message and is represented by the following command string.

```
00200001003 NUL
```

The Smart Tool Interface utilised the publicly available C# library for OpenProtocol in order to implement the Interface service, which monitors a tag in the OPC server for changes. Once a tag changes, the Interface issues the correct MID to the tool. Inversely, if the tool sends a MID to the Interface (such as a tightening response or error code), the message is parsed and the OPC server updated accordingly.

Message Part	Parameter	Byte	Value
	Length	1-4	0020
	MID	5-8	0001
	Revision	9-11	Range 000-004
Header	No Ack flag	12	N/A
	Station ID	13-14	N/A
	Spindle ID	15-16	N/A
	Spare	17-20	N/A
Data Field	N/A	0	N/A
Message End		21	NUL

Table 1. *Open Protocol MID Specification*

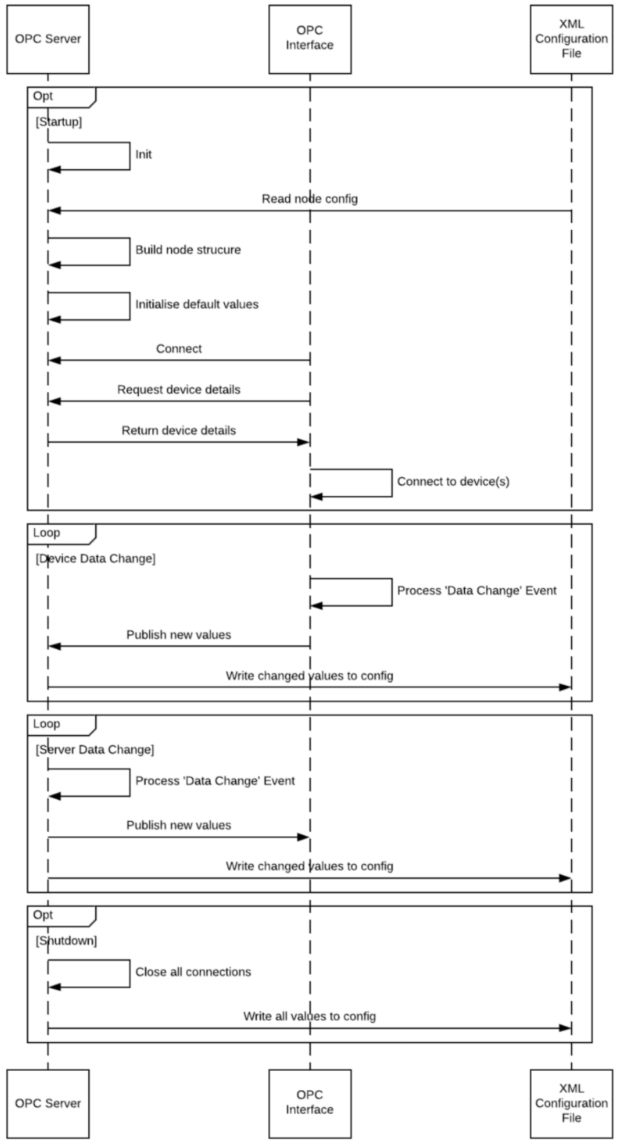


Figure 4. *Sequence diagram showing communication between the OPC server and the Inerface, via OPCLabs' QuickOPC.*

3.4 LAP Laser Integration: The LAP Laser Interface works mostly in a similar way to the other interfaces, in that the OPC-facing code is largely the same. However, in order to communicate with the Laser Projector the Interface implemented the LAP CADPro C# library. The LAP CADPro laser projector is traditionally operated by instructing the laser software to load a file, which is usually performed manually. The library allowed the Interface to instruct the laser to load a certain file automatically, dependent on the value of a tag in the OPC server. Again, the Interface monitored the value of a tag in the OPC database and instructed the laser to load a new .DXF file, with a filename matching that of the value of the changed OPC tag.

4. DELMIA APRISO MODIFICATION

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Out of the box, DELMIA Apriso is an extremely capable platform, allowing users to develop processes, screens and dashboards. The platform is the combination of a web front end, process authoring software and a back end database based on MSSQL. The integration of the hardware used in Project RAID required the modification of the stock screens and database tables that ship with DELMIA Apriso.

This section will provide an overview of the modifications required for the Smart Tool Integration. When logging into the DELMIA Apriso platform the user was given the option to log in with equipment, which allowed an operator to ’check-out’ a smart tool for use during their shift. By performing this type of login, the equipment’s ID was tied to the operator, allowing the Interface to know what tool to send the command to. Modifications to the ’front-end’ placed a ’Set Tool Program’ on the digital job card, allowing the correct program to be sent to the correct tool, reducing the probability of human error and improving operator efficiency. The correct PSet (tool program) was obtained from a column appended to the stock table containing all work instructions. Once the operator had completed the operation, the final angle, final torque and status (OK or NOT OK) were sent to the interface, which in turn populated the final angle and final torque fields of the stock database table. These values were linked to display fields on the digital job cards, giving the operator a visual representation of the status of the operation. Previously the tightening operation would have to be checked manually, signed off by a quality supervisor and entered manually into the DELMIA Apriso platform, which presents more opportunities for human error. If the result was returned by the tool to be OK, the Interface committed the value to the database, the tool was disabled to prevent any accidental additional tightening, and the job card progressed to the next operation. If the tool result was returned to be NOT OK, the operator was given the opportunity to raise a non-conformance, with key fields such as date, time, tool ID, operator information, operation number and torque curve information pre-populated.

5. MANUFACTURING COCKPITS

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Project RAID consisted of multiple demonstrations, all showing different technologies. Two of the large demonstrators within the project were 'Intelligent Kitting' and 'Smart Fixturing'. Each of these demonstrators exhibited different technologies at different price points, but both demonstrating the benefit of full traceability and the concept of 'right first time every time'. Both of these demonstrators saw bespoke applications configured within DELMIA Apriso, referred to as 'Cockpits'. This section will outline the purpose of the Cockpits and the work required to create them.

5.1 Kitting Cockpit: The Kitting Cockpit was the interface that the kitting operator uses to guide them through a kitting sequence. When an order was placed for a car, a complete set of part kits was requested in addition to the generation of the work order, which were displayed to the kitting operator on the home screen of the Kitting Cockpit (Figure 5). The Kitting Cockpit allowed the operator to select a kit and prepare it for release to lineside. This ws achieved by selecting a kit and selecing the 'Explode' button in the top right. 'Exploding' is a concept used throughout the DELMIA Apriso platform meaning to instantiate an order into its respective parts. Once the kit request had been Exploded, the same line could then be selected and the kit prepared by selecting the 'Prepare' button. The icon on the left of each row indicated the current status of each kit. Once a kit had been selected for preparation, the operator was offered the option to select the box into which the kit would be prepared. The operator then selected a box from the available options and was directed to place the box on the main

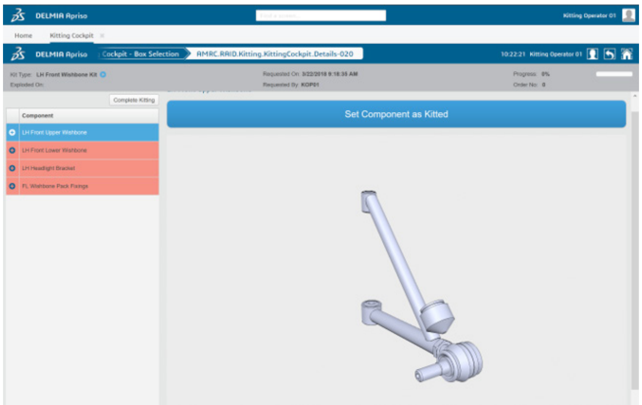
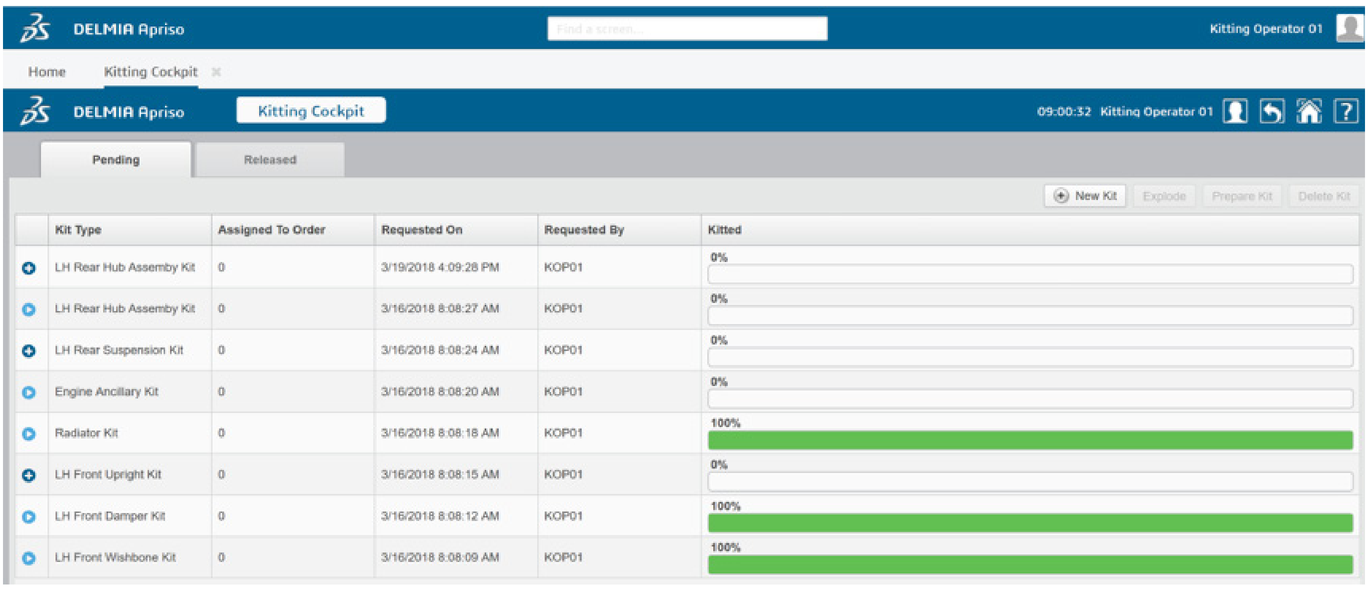


Figure 6. *Picking screen of the Kitting Cockpit*

workbench, atop an RFID antenna. Once the Kitting Cockpit had detected that the correct box had been selected, the operator was allowed to continue to the picking screen (Figure 6). The picking screen guided the operator through the picking and kitting sequence via 3D CAD and interaction with a pick-by-light system. Once the operator had picked and kitted a component, they marked it as complete on the screen and moved onto the next component. In this screen the operator could mark any non-conformances with the product in addition to adding annotations and notes to individual parts, which could then be displayed to the assembly operator inside the build cell. Once the kit had been completed, the Kitting Cockpit guided the operator through the process of placing the kitted box back into the box store at the most ergonomic location for the operator in question, guided by the pick-by-light system.



Kit Type	Assigned To Order	Requested On	Requested By	Kitted
LH Rear Hub Assemby Kit	0	3/19/2018 4:09:28 PM	KOP01	0%
LH Rear Hub Assemby Kit	0	3/16/2018 8:08:27 AM	KOP01	0%
LH Rear Suspension Kit	0	3/16/2018 8:08:24 AM	KOP01	0%
Engine Ancillary Kit	0	3/16/2018 8:08:20 AM	KOP01	0%
Radiator Kit	0	3/16/2018 8:08:18 AM	KOP01	100%
LH Front Upright Kit	0	3/16/2018 8:08:15 AM	KOP01	0%
LH Front Damper Kit	0	3/16/2018 8:08:12 AM	KOP01	100%
LH Front Wishbone Kit	0	3/16/2018 8:08:09 AM	KOP01	100%

Figure 5. *Home screen of the Kitting Cockpit*

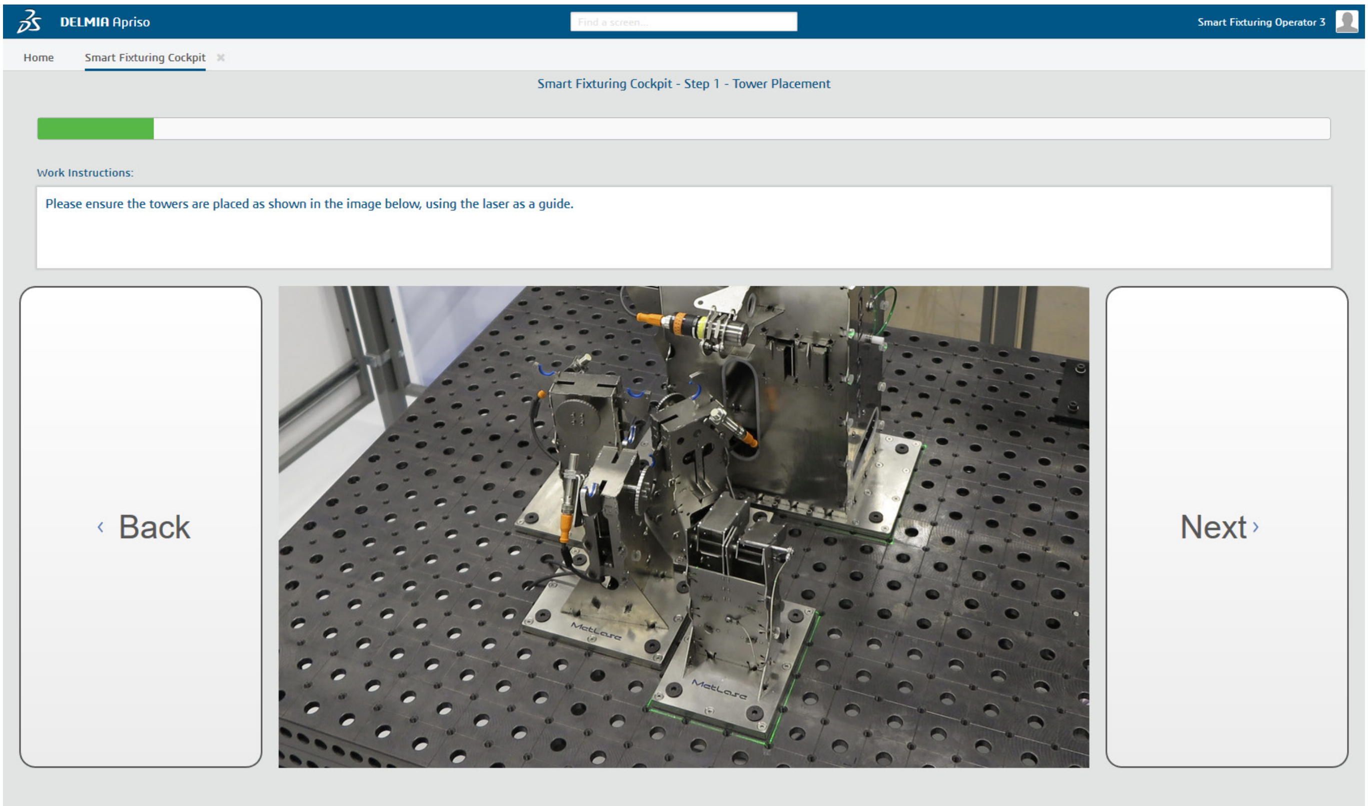


Figure 7. *Home screen of the Smart Fixturing Cockpit*

5.2 Smart Fixturing Cockpit: The Smart Fixturing Cockpit (Figure 7) is the interface used by an operator when assembling a complex sub-assembly. The Cockpit directed the operator through all steps of fixture configuration, assembly, and verification using integrated sensors, vision systems, and optical projectors resulting in full closed-loop verification and traceability. Each page of the Cockpit displayed work instructions to the operator in both text and image format, augmented by the projection from the laser. Once the operator had completed the step, they pressed the 'next' button, which instructed the DELMIA Apriso platform to perform automatic verification of the fixture via the integrated sensors and vision system. If the verification passed, the screen would advance to the next step. If the verification failed, the screen would not advance and the operator would be instructed to perform re-work. A progress bar at the top of the screen showed overall progress throughout the assembly task.

6. CONCLUSION

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The aim of Project RAID was to demonstrate the value and accessibility of digital technologies. By integrating the hardware discussed in this paper with DELMIA Apriso, the benefits of these technologies can be better realised. Benefits from investments in digital technologies such as improved productivity due to reductions in non-value-added time and re-work can be quickly justified.

Digital technologies give us the ability to visualise in unparalleled detail the events occurring on the shop floor, allowing managers to act quickly and make pro-active, informed decisions based on the newly available real-time information. Digital technologies are making our workforce more productive, improving quality and traceability, and reducing re-work. The technologies discussed in this paper have each been designed to be valuable additions to the shop floor, but by integrating them together, we are able to extract value that is greater than the sum of their individual parts.

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